Flushed and Forgotten Waste Water Treatment A Dinosaur Technology 01-04-25

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FLUSHED AND FORGOTTEN

WASTE WATER TREATMENT

A 'DINOSAUR' TECHONOLOGY

ECO-DEGRADATION OR REGENERATION OUR CHOICE!

PREPRINT

THE CRUCIAL CLIMATE ROLES OF WATER, SEWAGE, AND REGENERATIVE AGRICULTURE IN THREE VOLUMES

VOL. 1.

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The book uses a lot of short referenced and italicised quotes from a wide variety of often technical publications for accuracy, to recognise their contribution to the vast diversity of interlinked technical subjects on which this book of necessity draws, and because educational material is generally dense and carefully crafted. It is thus difficult to rewrite concise points in a way that equally succinctly optimally and accurately conveys often complex relevant specialist information. It is also hoped that readers will feel inspired by the quotes to visit at least some of the publications cited. The author invites readers to visit the original documents for a broader perspective.

The author expresses gratitude and thanks to all those who have contributed to the works on which the book draws.

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A confessed 'nerd', with endless curiosity, a fascination with the emergence of humans out of the laws of the universe, a fear we will extinguish ourselves as a species, an understanding that we are the expression of our brains, thus our destiny as a species, are deeply influenced by what we eat, impacted by the quality of our food water and air, which collectively ultimately significantly determine our intellect, abstract thought capacity, empathy, and collectively the expression of our humanity.

Written in the hope that we achieve wisdom and a worthy vision for our future place in the universe, before we wittingly or unwittingly give the power to decide our destiny to A1.

DEDICATION

I dedicate this book to all those involved in dietary, regenerative agriculture, sewage, water, and environmental research. Your persistence, dedication, and humanity have provided the knowledge needed to make an argument for change, and I am deeply grateful and indebted for your contributions.

SYNOPSYS

Implementing regenerative agriculture and a new paradigm for urine and faeces collection and processing is more urgent than ever. Current agricultural practices and sewage systems have significant negative health, environmental, and climate change implications, including for the pollution and degradation of soils, oceans, water, air, and food, as well as the potential to facilitate devolution of the human species.

The subject of sewage lurks in the shadows, albeit due to pollution incidents with contaminants of concern, including pharmaceuticals, PFAS, endocrine disruptors, microplastics part of the extensive range of pollutants; the public are beginning to see through the haze, that the current sewage protocols are causing significant environmental and health issues.

There is an opportunity for a substantial rethink on sewage collection and treatment, a move to vacuum WCs, and anaerobic digestion for green biogas, with hyperthermophilic composting of the residue allowing a return of organic to the land and closing the cycle. Change will require understanding and action at a government level, or a rich disruptor seeing economic and environmental opportunities in change.

Contents

1. AN OVERVIEW

This set of books is, by its nature, an overview. It will comprise three Volumes, two near complete and one on water in progress, respectively, considering regenerative agriculture, sewage, and water. The topics are inextricably interleaved, and all factor in climate change and environmental degradation. The books have taken several years of intermittent research and input and much time to write.

- SEWAGE Volume 1 – current Victorian WC water-based "flush and forget" 'FaF' technologies for collection and remediation of human and animal sewage are polluting and wasteful of carbon, minerals and nutrients, including nitrates and phosphates; environmentally degrade both the terrestrial and oceanic environment; introduce toxins into soils and thus foods, pollute water supplies; damage human and livestock health; hence are unsustainable at many levels. Untreated discharge causes even more significant environmental and health damage.

- Yet we continue to strive to install ever larger numbers of water-demanding, intensive, wasteful and polluting, "flush and forget" 'FaF' WC sewage systems, with inadequate, and often no, water treatment, frequently primarily for the convenience of the better. In doing so, we are introducing significant quantities of contaminants, including pharmaceuticals and antibiotics, personal care products, forever chemicals, endocrine disruptors, and other pollutants, including microplastics, onto soils, into oceans and rivers, with known and as yet unforeseeable negative consequences; on life forms, including on human development in utero, intellect, and wider lifetime individual health.

- By mixing faeces and urine into the broader waste stream, we make the adequate environmentally sustainable treatment and recycling of sewage sludge almost impossible. Current treatment technologies cannot remediate many of the vast range of toxic pollutants in sewage sludge, and there is no fix – incineration is the least bad option but does not close the environmental cycle.

- Agricultural slurry is also massively wasteful and polluting, causing pollution, eutrophication, and deoxygenation of waterways and oceans and damaging soils and the wider environment.

- There are potential alternative solutions to the current Victorian FaF water-based sewage treatment system, which is fundamentally and irretrievably flawed, a dinosaur technology. An alternative viable proven, albeit nascent, technology is Vacuum WC collection, combined with hyperthermophilic anaerobic digestion, followed by hyperthermophilic composting, with washing machine microplastic filters, separation and treatment of grey water, offering better integration of the sewage management of urine and faeces into a circular sustainable economy.

- REGENERATIVE AGRICULTURE Volume 2 – It is not widely appreciated that the current dominant '**F**ertiliser-**A**grochemical-**T**illage-**B**are-soil-**A**gricultural-**S**ystem' (FATBsAS) is both unsustainable and a substantial causative component of climate change events. In addition, FATBsAS diminishes plant nutrient density, thus reducing human, pet and livestock health. Adopting sustainable, regenerative farming techniques is key to climate change management. We cannot hope to mitigate climate change unless we also address FATBsAS. These are bold claims. These Volumes do their best to explain the compelling rationale and evidence for them.

  - **FATBAS**, '**F**ertiliser-**A**grochemical-**T**illage-**B**are-soil-**A**gricultural-**S**ystem' by failing to recognise the role of soils and plants as essential elements of our planetary and climate regulatory ecosystem, is unthinkingly inevitably damaging soil biology and health, leading to, soil degradation and diminished land fertility, reduced; soil carbon, water infiltration-penetration and storage, and increased; flooding and erosion, drying crusting and heating of bare soils thus atmospheric heating, adverse weather events and drought; as well as; killing biology; adding energy to atmospheric heat domes, raising atmospheric temperatures, increasing atmospheric carbon dioxide, degrading regional hydrology, as well as contributing to and accelerating ocean acidification and deoxygenation, and more widely being a primary factor in the planetary ecosystem service degradation we call 'climate change'.

- Further, FATBAS fertiliser-and-agrochemical-based farming contributes to pollution, including eutrophication, thus causing river and ocean deoxygenation. This adds to the risk of ocean sulphidication, hydrogen sulphide emission into the atmosphere, and damage to the ozone layer, ultimately leading to a significant Anthropocene/Plasticene extinction event.

- FATBAS also reduces the nutritional density of crops, thus the nutritive value of food, contributing to human and livestock ill-health, also contributing to mental ill health, including developmental issues, including the risk of reducing human intellect, empathy, cooperation and behaviour, which, if unaddressed, will ultimately lead to species devolution, further increasing the risk of Anthropocene self-extinction.

- Soil carbon storage, through the synergistic interaction between plants and the soil biome, is part of the evolved planetary regulatory ecosystem for partitioning oxygen and carbon/carbon dioxide between the atmosphere, oceans, soil, and living organisms. James Lovelock christened the product of competitive evolution, arising out of laws of matter, the interdependent self-regulating ecosphere system that is the basis of sophisticated terrestrial life; a 'Gaian' system, after a key Greek 'Earth Goddess', the mother of all creation, one of the "*primordial elemental deities (protogenoi) born at the dawn of creation*", (Theoi Greek Mythology, n.d.). Lovelock alluded to the system having the characteristics of a 'complex living organism'.

- We humans often fail to respect the fact that terrestrial soil-based, and oceanic, photosynthetic organisms, and their wider bacterial and fungal symbionts, are central obligate enabling pillars of more complex forms of life and thus essential parts of the Gaian system. Plant-captured sunlight energy powers the oxygen-carbon-dioxide-cycle and the production of the complex carbon-dioxide-derived, carbon-based organic molecules that underlie the very existence of complex 'LIFE', including humans.

- FATBAS does not consider the obligate need for maintaining planetary ecosystem health, including the central necessity to optimise the photosynthetic light energy capture potential of plants, thus maximising soil carbon and life in the soil biome. This is essential to plant health and productivity, and hence life itself. Terrestrial surface incident diurnal sunlight energy, which powers the planetary ecosystem through photosynthetic organisms, including plants, is ultimately a finite resource that can build life or destroy life by heating bare soils.

- We humans, by taking agricultural control of billions of hectares of formerly natural green growing ecosystems and related eco-services, have substituted ourselves for crucial aspects of that evolved Gaian system without understanding the implications and consequent responsibilities this places upon us.

- Adopting regenerative agriculture, assisted by more sustainable sewage management, will help make farming more sustainable and profitable. At the same time, it is central—an arguably near-equal partner to reducing fossil fuel combustion—in addressing the environmental climate change-related and human health risks outlined above. Climate change cannot be solved without addressing how we manage billions of hectares of agricultural land.

- WATER AND HEALTH Volume 3 (In progress) 'W*ater is life*', as the Bedouin appositely observe, yet we are, at pace, polluting rivers, aquifers, and oceans globally.
  - We facilitate large-scale FaF sewage pollution of rivers, water bodies, aquifers, and oceans. Reduced groundwater means that to grow crops, we are forced to draw down natural 'fossil water', depleting aquifers, and using polluted urban and sewage water for irrigation.

  - Through FATBAS, we are changing our climate and destroying our soils. We compact and crust our soils, leave them bare of vegetation, heating the air and causing heat domes, plough and turn and destroy them, including by exposing soil life bacteria and fungi to UV, by using a variety of chemicals that kill soil life, we use artificial fertiliser that disincentives the supply of photosynthetic carbon sugar root exudates to the soil biome, discouraging and destroying soil life that otherwise ceaselessly mines minerals and creates nitrates, and creates metabolic water, delivering them to plant roots; soil life that burrows through, mixes and aerates vast volumes of soil, their destruction combined with ploughing, collectively massively reducing rain infiltration rates, from eleven and more inches an hour, to, often less than one inch an hour; thus rain is not recharging water tables, increasing the risk of water shortages and drought. The unwarranted run-off causes flooding, erosion, related downstream damage, and ocean eutrophication.

  - Through FATBAS, we are drying our climate, increasing the risk of heat domes and fires, and reducing inland ocean airflow-derived rainfall. At the same time, as temperature increases and marine air's moisture-holding capacity consequently increases, the magnitude and irregularity of rainfall events increase.

  - Regenerative agriculture, by focusing on maintaining soil health and soil biome life, conversely significantly improves water infiltration rates and regional hydrology, reduces the need for pharmaceuticals for livestock, and allows natural distributions and dispersion of livestock urine and faeces.

  - Steps such as vacuum WC systems, improved remediation, regenerative agriculture, and sponge cities are both doable and essential but require a step change in our global mindset to one committed to recognising the importance of water to life and the need to use it wisely.

The above issues, including the need for better collection, treatment, and recycling of urine and faeces; regenerative improvement of soils, including carbon sequestration; reduction in broader environmental, including marine pollution; mitigation of global warming and related issues; as well as production of higher quality foods; improving, nutrition, related societal health, including mental wellbeing: are wide-reaching, interlinked, and complex, but achievable.

These issues at their heart have relatively simple realistic solutions, namely regenerative agriculture and a move to vacuum WC sewage collection and treatment systems; but, due to their broader economic impact on existing industries and the adaptation required, will require widespread public education and understanding; as well as government and corporate acceptance of the urgent need for change, and consequent significant adjustments, including; in farming practices, degraded land recovery and regeneration, collection and treatment of faeces and urine, pollutants including plastic reduction, and water conservation and management.

1. THE BARE BONES

At the global level, for the reasons set out in this book, Flush and Forget 'FaF' mixed-waste-stream-derived water-transported sewage treatment systems, are a fundamentally flawed and completely unsustainable unfixable 'dinosaur' technology, in terms of infrastructure provision, running and capital costs; water demands; lack of effective sewage sludge disposal options; and the great difficulties in the treatment and or disposal of pollutants, in sewage discharge water and particularly sludge, including, pharmaceuticals, antibiotic-resistant material, personal care products, forever-chemicals. microplastics, and a wider range of other pollutants.

'FaF'-based, high-volume, multiple-pollutant-containing sewage collection and treatment is, at its core, a busted flush; even high-quality remediation of the accompanying polluted sewage water is challenging, very costly, and imperfect. The other residue, sewage sludge, is impossible to remediate, and incineration, whilst the least harmful option, creates its own environmental issues.

Indeed, the segment of the European Environment report, '*Beyond water quality — Sewage treatment in a circular economy*', titled, '*Rethinking 'urban waste water treatment*', implicitly acknowledges that sewage treatment plants are not fit for purpose, in that they are ultimately incapable of adequately remediating a wide range of pollutants; *"Health protection and prevention of pollution continue to be the key purpose of sewage and urban waste water treatment. Improved scientific knowledge since the 1990s has shown the presence of many pollutants in surface waters, and many of these arise from chemicals and products that we use in our homes and workplaces. Such societal and sectoral issues are beyond the capacity of water managers to resolve. . . "*. (EEA, 2022) (This authors' underline).

It is, therefore, time for an extensive, revolutionary, back-to-basics rethink of how we deal with urine and faeces and for a fresh start with a leap to new technologies. We must start, without delay, to perfect and implement integrated sustainable economic circular alternative mechanisms that facilitate the minimisation of pollutant content by external sources through collection at source, thus allowing recycling of human and livestock excreta, for example, with vacuum WC collection, combined with biogas production and hyperthermophilic composting.

1.1. THERE IS A SEWAGE SOLUTION – VACUUM WC COLLECTION

Vacuum WC collection and transport technology is a viable alternative sewage collection solution to our current Victorian flush-and-forget, 'FaF'-based urine and faeces collection and treatment system. Vacuum WC collection and transport technology, as used on many luxury cruise liners, allows the collection and transport of urine and faeces with minimal water usage and, at the same time, provides equivalent, and arguably better, user convenience.

Collection at source excludes the inclusion of wider pollutants. It reduces the liquid volume, opening up other treatment options, including the production of biogas, a potentially globally significant additional green energy source, and hyperthermophilic composting of the residue for land improvement.

Further, initial research suggests hyper-thermophilic anaerobic digestion, followed by hyper-thermophilic composting, would remediate a significant portion of the pharmaceuticals, including antibiotics in urine and faeces, possibly 80% plus, reduce greenhouse gas emissions, and create a compost product that could be returned to land projects, even perhaps agricultural use.

Institutional reluctance, as well as financial and broader structural inertial reticence, to look afresh and objectively at how we dispose of urine and faeces has led and continues to lead to investment in and creation of expensive, 'status quo', environmentally unsustainable, outmoded, outdated, and inefficient 'FaF' based sewage treatment systems and piping infrastructure, with their many irredeemable drawbacks.

The negatives of 'FaF' systems are magnified in more water and or financially stressed environments, as noted in India; *"poor financial sustainability, high energy requirements and water intensity, . . . discharge loads and inadequate final treatment which in turn becomes a vector of diseases. The ultimate disposal of the treated wastes in landfills and in water bodies only adds to the already high environmental burden and externalities*" (Simha, 2017).

1.2. UNSUSTAINABLE LEVELS OF ENVIRONMENTAL DAMAGE

Current levels of environmental damage are unsustainable. We are seeing insect die-offs, biodiversity loss, damage to marine ecosystems, species loss, and declining soil, aquatic systems, and ocean environmental health. These are just some of the long lists of negative impacts of a range of insufficiently considered human large-scale interventions in natural systems, as presciently warned against in Rachael Carson's 1962 book, '*Silent Spring'*.

If we are to maintain clean water resources, soils, a sustainable wider environment, and long-term public health and well-being on a crowded planet, we cannot continue to squander precious resources, including water, phosphates, nitrates, and organic carbon, and simultaneously significantly pollute the environment, including our soils, water sources, and oceans.

Rachael Carson's still salient thoughts included, "*In nature, nothing exists alone*." . . . "*The history of life on earth has been a history of interaction between living things and their surroundings*." . . . "*Man's attitude toward nature is today critically important simply because we have now acquired a fateful power to alter and destroy nature. But man is a part of nature, and his war against nature is inevitably a war against himself.*"

Sixty years later, we still have not viscerally understood how we unthinkingly, and 'blindly' continue, to hobble and ultimately destroy the Gaian planetary ecosystem support services, that allow our very existence, through utterly unsustainable, water-based Flush and Forget 'FaF', sewage and slurry management, and multiple other pathways, including FATBAS '**F**ertiliser-**A**grochemical-**T**illage-**B**are-soil-**A**gricultural-**S**ystem' farming, discussed in Volume 2 on regenerative agriculture.

Thus, there is a pressing need for clear and widespread public understanding that how we deal with sewage, the related issue of how we farm, and their impact on water quality, are utterly unsustainable at many levels. We need to rethink the way we collect and treat human and livestock urine and faeces, as well as how we farm and think about water; if we are ultimately to avoid environmental disaster, if not extinction of the human species, albeit irrationally, it appears we are reluctant to do so.

1.3. MENTAL HEALTH, NEUROLOGICAL FUNCTION, ANXIETY AND POLLUTION

The West is seeing significant rises in developmental and 'acquired' mental health conditions throughout the lifespan, from autism to Alzheimer's, depression, anxiety, a few of a long list, in increasing numbers of people, and the numbers of children with special educational needs are growing.

The reasons for rising developmental and 'acquired' mental health conditions are multiple and difficult to disambiguate but include degraded, overprocessed foods of declining nutritional value and environmental pollutants in the atmosphere, water, and food.

Research has documented the adverse effects of atmospheric, water, and food pollution on mental health. The degree of impact depends on dose over time, concentration, years of exposure, and, but less clearly and under-researched, the mix of toxins involved.

The FaF sewage treatment systems allow the mixing of a wide range of external pollutants with urine and faeces, which makes, remediation of sewage sludge almost impossible, and high-quality tertiary treatment of water difficult and costly, meaning those pollutants are entering our water systems, soils, and atmosphere, thus impacting our mental and wider health through the life course. Research and 'common sense', suggest that the adverse effects of pollution and poor diet, on mental health and brain development, will accumulate additively in each subsequent generation.

A human population that is less intelligent, empathetic, and capable of abstract thought, that is more anxious and angrier during times of growing environmental stress, resource conflict, and antagonism between geographic regions, is less likely to survive and prosper and, in the most extreme scenarios, is at greater risk of being the author of its own demise.

1.4. WIDER LAND AND ENVIRONMENTAL DEGRADATION – REGENERATIVE AGRICULTURE

All are interconnected. Our failure to deal with sewage flows on a more sustainable basis, and unthinking use of agricultural slurries, and sewage sludge, on agricultural land, through pollution of the land and water, and the wider environment; contributes to soil degradation and pollution, impacting crops, livestock, the food chain and human health. Sewage sludge and sewage water use on soils contributes to the negative consequences of **F**ertiliser, **A**grochemical, **T**illage, **B**are-soil **A**gricultural **S**ystems, 'FATBAS', leading to soil and crop degradation, erosion, and broader negative environmental impacts, as set out in Book 2.

While authorities recognise the issue of soil degradation and pollution globally, including in major agricultural producing areas such as Russia, Ukraine, Australia, and the USA, pollution and erosion that result from soil degradation continue on a vast unsustainable scale. Yet, the declining health of soils is still not at the forefront of the public conscience or agenda.

By way of example, in New South Wales, Australia, "*more than 70 per cent of the state is affected by at least one form of land degradation. Of this area, 29 per cent is 'severely' to 'very severely' affected by land degradation*" (Life Cycle Inventory and Life Cycle Assessment for Windrow Composting Systems, 2006). More surprisingly, "*around 45 % of the mineral soils in Europe have low or very low organic carbon content (0–2 %) and 45 % have a medium content (2–6 %)*" (EAA, 2021).

This is nothing new. As discussed in Volume 2 on regenerative agriculture, the book '*Conquest of the Land Through Seven Thousand Years*' (Lowdermilk, 1939), and other related impassioned publications, including; '*Rape of the Earth'* (Jacks, 1936), '*Behold Our Land'* (Lord, R. 1938), and '*Deserts on the March*' 1935 (Sears P, 1935), set out, in words, and strikingly depressing images, examples of the demise of historical civilisations, through desertification of many previously very fertile areas, including round the Mediterranean: all are consequences of failure to care for soils properly. However, unlike in times past, we are running out of new, fertile forest and wild prairie land to clear, farm, and degrade.

We have taken over approximately four billion (4bn) hectares of formerly natural ecological systems. We have ousted nature and, without appreciating our actions' enormity and inevitable consequences, appointed ourselves the new Gaian 'farming managers', the environmental controllers and 'responsible custodians' for those four billion hectares, as self-appointed farming environmental controllers of a good proportion of the earth's fertile land. Environmental regeneration or destruction—the choice is ours.

1.5. FaF AND FATBAS - FACTORS IN CLIMATE CHANGE

Our failure to deal with the problem of sewage more circularly is a factor in environmental degradation and change, as well as the reduction in human health. Given that air, water, and food pollution negatively impact neurological development and function at every age, our failure to better deal with sewage is likely contributing to a reduction in mental facility and wellness at population levels, including as additive, albeit as yet unquantified, risk factors, for conditions like Autism (Duque-Cartagena, 2024) and Alzheimer's.

For example, a study titled "*Association between water and sanitation, air and emission pollution and climate change and neurological disease distribution: A study based on GBD* (Global Burden of Disease) *data*" concludes, "*In conclusion, water and sanitation and their related factors are plausible factors in the distribution of neurological disease*" (Sarmadi, 2021).

Further, FaF sewage collection and treatment contribute to pollution of the atmosphere, waterways, and oceans; poisoning of soils, including with nano-microplastics, and the resultant impact on farming and food; the waste of clean water, minerals, and carbon; and failure to close the environmental cycle, all of which factor at some level, directly and indirectly, in climate change.

As discussed in more detail in the Volume on regenerative agriculture, the loss of soil biome quantity and diversity, thus fertility, is driven by FATBAS farming; fertiliser and tillage-based mono-cropping; bare land between crops; and heavy use of agrochemicals, aggravated by sewage based fertilisers, and irrigation with treated sewage water, which together degrade and kill the fungal, bacterial, and other life forms, in the soil biome, inhibiting soil biome support services to plants, and reciprocal services supplied by plants to the soil biome including the provision of root carbon sugar exudate, reducing plant health, and increasing the occurrence of;

- loss of capacity of soils to allow rainwater infiltration, with reductions from 7-10 inches to 1 inch an hour;
- loss of water retention capacity of soil at a rate which is proportional to soil carbon content depletion;
- water run-off; depletion of water tables and regional aquifers; declining river levels; flooding;
- loss of atmospheric moisture from plant respiration due to bare soils, reduced growth and related photosynthesis;
- loss of cloud seeding bacteria released by plant stoma;
- increased atmospheric heating by bare soils;
- heat domes drying and fires;
- drought by multiple mechanisms;
- increased wind and water-based soil erosion;
- loss of soil biome life due to bare soils, effect of ploughing, chemicals, soil bacteria and fungi exposure to UV, and lack of carbon sugar energy substrate provision consequent on lack of plants;

- loss of soil life, thus soil carbon, given carbon is life, which carbon is lost to and increases carbon dioxide to the atmosphere, which given the large acreages under human management is a huge amount of soil carbon, potentially billions of tons;
- eutrophication and pollution of rivers and oceans;
- pollution of soils;
- atmospheric pollution by chemicals, microplastics, and smoke toxins from stubble burn-off;
- as well as adding vast amounts of carbon dioxide to the atmosphere;

all significant factors in what is described as climate change; all due, in large part, directly to FATBAS farming practices, rather than being the direct results of higher and more uncertain rainfall and weather, consequent on raised atmospheric carbon dioxide increasing air temperatures.

2. WATER-BASED SEWAGE TRANSPORT, 'A BUSTED FLUSH', RETHINK TIME!

Our current **F**lush **a**nd **F**orget, 'FaF', water-based sewage transport and treatment technology for urine and faeces, is utterly unsustainable at very many levels, a technology that is not fit for purpose, a 'busted flush', so to speak.

Access to clean drinking water, a limited resource, is essential to human health and survival. The review "*Wastewater reuse and pharmaceutical pollution in agriculture: Uptake, transport, accumulation and metabolism of pharmaceutical pollutants within plants*" observes, "*Water scarcity is poised to emerge as one of the most significant challenges in the immediate future and according to estimates, 40% of the world's population would experience severe water scarcity by the year 2050. Worldwide, a mere 3% of the total freshwater is available for drinking and irrigation according to the European Commission*."(Mosharaf 2024)

'FaF' flush-and-forget WCs use a significant amount of water, particularly where older high-volume cisterns are used. In addition to the direct water usage, the mixing in the sewage collection network of WC flush 'black water' with wider surface water sources introduced into the sewage stream and industrial discharge into sewage flows significantly pollutes large additional volumes of water.

Downstream water supply sources are polluted, to varying extents, by the discharge of untreated sewage, sewage sludge applied to land, and treated sewage discharge water. The Mosharaf review thought-provokingly suggests, "*Approximately 80% of wastewater from industries and municipalities across the world is discharged into the environment without any treatment, which has a severe negative impact on ecosystems and human health*" (Mosharaf, 2024). The review also notes, "*Around two million tons of waste including organic pollutants, inorganic heavy metals and waste products of biological origins are discharged into the ocean on a daily basis throughout the world*" (Mosharaf, 2024)

Thus, the negative impacts of 'FaF' on water availability and quality are multilayered, pervasive, massive, self-reenforcing and circular. We continuously extract and purify drinking water to flush WCs, thus repeatedly polluting it again with faeces, urine and wider pollutants, and then, to varying extents, return that polluted water to those same water extraction supply sources so we can again repeat the process using a system, and technology, that is ultimately not fit for purpose, and more so, in an environmentally challenged world with a growing population. Effects are magnified in drought-prone areas, where sewage outflows can form a significant portion of stream and river flows; often, the sewage is untreated, exacerbating pollution of water sources, including aquifers.

A viable technological alternative solution exists: low-water-usage vacuum WC systems and separate collection. Combined with biogas production and hyperthermophilic composting treatment, these would significantly reduce water use, eliminate the need to apply sewage sludge to land and discharge treated waters and eliminate downstream pollution due to untreated discharge, as explained in later sections.

The future for urine and faeces disposal is their collection at source, using low water usage vacuum WC technology, combined with sequential hyperthermophilic anaerobic digestion of the collected urine and faeces for biogas and hyperthermophilic composting of the residue, which whilst not a perfect solution, would be a considerable improvement on the status quo, at many levels, including in terms of; energy recovery, pollutant reduction, clean water savings, wider environmental benefits, economics, sustainability and circularity.

2.1. LARGE AMOUNTS OF CLEAN DRINKING WATER TO FLUSH WCs? – UNSUSTAINABLE

Ultimately, in a world of increasing water shortages, the use of large quantities of expensive, scarce, cleaned and treated drinking water to transport smelly faeces and urine from our homes, 'out of sight – out of mind', is unsustainable, unconscionable and irrational, and particularly so, given that viable and better alternatives exist, namely vacuum WC collection related systems, that provide the same user experience and convenience, with minimal water usage; and capacity to; make energy, as well as to remediate many of the pollutants, and potentially to provide useable compost,

Many, if not billions, of people understandably still aspire to the convenience of 'Flush and Forget' 'FaF', out of sight, out of mind, sewage systems. However, in many nations, the ironic reality is that for those groups with the least access to flush and forget technology, 'here and now', drinking and washing water shortages are pressing issues. Due to water shortages, those same groups living in poverty and aspiring to a Flush and Forget WC often struggle to find or buy the water necessary for their daily survival.

It is also important to keep in mind that the ever-increasing global demand for flushing WCs, as well as exacerbating unsustainable clean water demand, results in the ever-increasing consequent downstream pollution of broader water supplies, which will inevitably further negatively impact drinking water quality and availability. The urban poor in nations with limited water sources bear the greatest cost.

On the positive side, as discussed but repeated, there is a more sustainable alternative solution that provides the same 'FaF' user convenience but uses comparatively little water and would allow urine and faeces to be recycled. The answer is Vacuum WC low-water-usage urine and faeces collection and transport technology. Vacuum collection uses very little clean water; air pressure moves the urine and faeces. The collected product can be used for hyper-thermophilic anaerobic methane production, followed by hyper-thermophilic, forced air temperature-controlled, aerobic composting.

2.2. WASTE OF RESOURCES, AS WELL AS POLLUTION AND EUTROPHICATION

Faeces and urine contain valuable resources, including a range of minerals, including phosphate, nitrates, and carbon. When low in pollutants, appropriately used and applied in the form of fungal and bacterial-rich composts to the soil, they can significantly assist soil health, fertility, and related plant growth, including for re-greening projects, with minimal runoff or eutrophication of watercourses.

Conversely, when artificial fertiliser, sewage sludge, and agricultural slurry, which contain high levels of quickly released soluble nitrates and phosphates, are applied to land, they cause the eutrophication of rivers and oceans. Sewage sludge and slurry may also contain wider pollutants, including antibiotics, other pharmaceuticals, personal care products ‘PCPs’, forever chemicals, heavy metals, nuclides, and microplastics. Fertilisers also often contain heavy metals, nuclides and other pollutants, adding to land pollution.

The level of environmental pollution is greatly increased when insufficiently treated, or worse, untreated sewage is released directly into the environment, including water courses. Therefore, it is of great concern that a huge proportion of the world’s sewage is released directly into the environment without treatment.

Faeces and urine contain a significant portion of the antibiotics we and livestock ingest, leading to antibiotic resistance development and spread. Resistant genes are spread vertically and horizontally across multiple species in marine and terrestrial environments. For example, via water and soil, they enter plants; some enter pollen, providing a potent airborne transmission route, and thus can spread widely. Antibiotic-resistant bacteria enter the food chain through plants, which can and have resulted in human antibiotic-resistant illnesses.

The vast, sometimes distant, and at times unforeseen, potential scale of impact of pollution due to fertiliser, sewage, and slurry is illustrated by the growing annual seaweed inundation seen in the Gulf of Mexico and the Caribbean, the growth of which is likely primarily driven by excess nitrates and minerals, including heavy metals, from; fertilisers, sewage, and slurry, runoff and discharge, arriving from rivers including the Mississippi, and Amazon. It is a profound irony that these beached Sargassum seaweed overgrowth inundations are suggested to be unsuitable for agricultural fertiliser because of their heavy metal content, which is not seen in Sargassum seaweeds from remote locations, so must have originated from a mix of sewage, slurry, industry and farm rock phosphate fertiliser runoff (Rodríguez-Martínez’, 2020), “*Vegetables grown in soil enriched with sargassum had higher levels of arsenic and cadmium, heavy metals that can be toxic to humans and animals. Researchers warn that sargassum should not be used to compliment animal fodder, nor used as a fertilizer for consumables until further investigated*” (Johnson J. &, Engel. S, 2022).

2.3. POLLUTANTS IN URINE, FAECES, THE WIDER SEWAGE STREAM, AND FARM SLURRY

What we ingest in food, use on our skin, and absorb ends up in urine and faeces, referred to as 'black water'. The water we put down our sinks, personal care products, washing products, and other materials is called 'grey' water.

'Sewage', arriving at sewage treatment plants or discharged directly into the environment, comprises significant cleaned, treated, expensive, sometimes scarce, drinking water used for flushing faeces and urine from WC pans; domestic grey water, again initially drinking water; to which is added much more significant amounts of surface water; and a range of wider externally added pollutants.

Into the sewage flows from our toilets, we mix the pharmaceuticals we ingest, personal care products, cleaning products, microplastics from our washing machines, and road run-off with other externally added pollutants, including from hospitals and the pharmaceutical, chemical, and textile industries. Depending on the pipework, other external pollutants may be added before discharge into the environment or transported to a sewage treatment works for onward disposal.

Adequate sewage treatment to keep the wide range of pollutants in mixed sewage flows out of the wider environment is extremely difficult because the urine and faeces are hugely diluted, mixed with a range of contaminants, and impossible to remediate once turned into sludge. In contrast, opportunities exist to treat the pollutants in urine and faeces, with onward downstream specialist treatment, provided they are collected at source, with the least possible amount of water added.

The presence of pharmaceuticals, including antibiotics, and wider contaminants of concern from personal care products and other sources in discharge water and sewage sludge damages land, streams, rivers, waterways and aquifers, oceans, and the wildlife they sustain. This damage collectively contributes to the long-term degradation of the global ecosphere regulatory systems that are utterly essential to our survival, including our sustenance, as discussed in Volume 2 on regenerative agriculture.

'Cleaned' sewage waste water, even after standard primary and secondary sewage treatment, can still contain significant amounts of pharmaceuticals, antibiotics, antibiotic-resistant material, forever chemicals, microplastics, and other soluble pollutants. Expensive and highly technical tertiary oxidative and activated carbon water treatment systems will remove a significant portion, but not all, of those pollutants. However, due to cost, such water treatment technologies currently have only minimal usage. Reverse osmosis is still better, but it is technical and expensive. The removed residues still require treatment and disposal.

The extraction and treatment of water from sewage streams arriving at treatment plants still unavoidably leaves the residual sewage sludge, which, due to its semi-solid nature, consistency, and wide range of pollutants, is practically impossible to remediate effectively and is generally disposed of; by application to agricultural land, which it pollutes; through landfill, with leakage and gaseous emissions, where the predominant part of the pollution is passed down to future generations; or incinerated, which pragmatically is the least-worst option, but does not close the cycle, giving rise to several distinct environmental consequences, as discussed later.

Livestock slurry similarly contains pharmaceuticals, antibiotics and antibiotic-resistant material, heavy metals, as well as microplastics; additionally, it is also high in soluble nitrates and phosphates, which are quickly released in rainfall water flows, polluting both agricultural soils and water sources, at multiple levels, with wider negative environmental and health consequences, as well as leading to more distant damage, including eutrophication of rivers and oceans.

As discussed in more detail, current strategies for disposing of human urine, faeces, and livestock slurry are environmentally unsustainable for multiple reasons. Already, pharmaceutical pollutants, personal care products, wider emerging contaminants of concern, and microplastics from sewage sludge and slurry, treated or directly discharged, are being found increasingly widely, including in streams, rivers, deep aquifers, oceans, soils, crops, and thus the food chain.

Some propose that pollutants of concern are legislated against and excluded at source, and less damaging alternatives are found. Given their significant public health roles, this is possible for many pollutants but practically impossible for pharmaceuticals, including antibiotics. About 70% of antibiotics pass unmetabolised into urine and faeces.

2.4. ANTIBIOTIC-RESISTANT BACTERIA SPREAD BY AGRICULTURE

Bacteria and fungi underlie life. The dangers of the excess use of antibiotics and, more widely, antimicrobials, their discharge into the environment, and the consequent development and spread of antibiotic/antimicrobial-resistant material, as well as their potential negative impact on human, animal, and soil health, are not fully understood and underappreciated by the public (Iwu, 2020).

Bacteria and fungi are symbionts essential to the function and health of many lifeforms, including humans, livestock (McGranaghan, 1999), plants and their seeds, and soils. They are also present in urine and faeces and are potential transfer vectors for antibiotic/antimicrobial-resistant material.

Whilst this book focuses mainly on antibiotic resistance, the pressing problem of the development of resistance to wider microbials, including antifungals, should not be forgotten. The article, '*The Silent Pandemic of Antifungal Resistance,*' observes, "*Drug-resistant bacteria often receive the largest share of research funding and attention, but experts warn of the growing threat of antifungal resistance*" (Gerhard, 2024).

Antifungal resistance is a serious issue given the limited number of antifungals available and the numbers with fungal conditions, "*Antifungal resistance makes invasive infections even more deadly. As a result of resistance, superficial skin and mucosal infections could take on more chronic and disabling forms, especially since the arsenal of antimycotics to which physicians have access is very limited. If one class of drug becomes ineffective due to resistance, few alternatives are available. In the event of resistance to multiple or all classes* *of drug, infections become virtually untreatable.*"(Health Council of the Netherlands, 2024). The manner of sewage treatment, the spreading of sludge on agricultural land, and the use of fungicides in agriculture are all contributory factors.

Experts state, "*The use of manure on agrarian soil used for the cultivation of food crops can potentiate the dispersal of ARB (*Antibiotic Resistant Material) *and ARGs* (Antibiotic Resistant Genes) *onto food crops intended for human or animal consumption*". (Iwu, 2020)

Indeed, "*The World Health Organization (WHO) reported that ARB* (*on the farms can contaminate vegetables and fruits as DNA fingerprinting has confirmed a link between ARB isolated from sick people and an agricultural source. Despite the importance of the agricultural ecosystem in the provision of food, scant information is available on the dissemination routes of antibiotic resistance within the complex nexus of the agro-ecosystem and eventually to humans through plant and animal foods*". (Iwu, 2020).

Further, while knowledge is growing, much remains unknown regarding the potential risks of transmission of antibiotic resistance through discharge and application of sewage or slurry to agricultural land.

2.5. FACING REALITY

The move to new sewage technologies requires humanity first to face a truth: due to the mixing of external waste streams into the sewage collection network, FaF sewage systems are incapable of creating a circular sustainable economy; consequentially, they are a fundamentally flawed and impaired technology incapable of ever closing the nutrient cycle.

Whilst vacuum WC technology, hyperthermophilic anaerobic digestion for biogas, and hyperthermophilic composting are all existing, albeit emerging, working technologies, implementation will require a global thought reset.

Further development of these processes will require a new approach to sewage collection, treatment, and disposal at all levels, including by the government, funders, researchers, industry, and the public. We must recognise and admit that we must rethink how we collect, process, and recycle faeces and urine.

3. A SOLUTION – CLOSING THE CYCLE - VACUUM TOILET TECHNOLOGIES

Vacuum WC systems use minimal amounts of water. Vacuum WC systems allow, at source, separate collection of urine and faeces, including the antibiotics and pharmaceuticals they contain, with significantly reduced water use, potentially allowing hyperthermophilic biodigestion with the collection of biogas, followed by hyperthermophilic composting, which together, evidence suggests, will remediate a significant portion of the pharmaceuticals and antibiotic-resistant material in faeces and urine, allowing selective reuse of the compost produced for, land reclamation, fertilisation of pastures, or even agriculture, depending on the level of residual pollutants.

3.1. VACUUM URINE AND FAECES COLLECTION AT SOURCE

The simple solutions to improving the negative, unsustainable and dead-end environmental impact of current FaF sewage technology include reducing usage and pollution of water, the adverse effects of sewage sludge, the pollution of soil and food, and gaining some degree of circularity, include;

- vacuum WC collection at source;
- thermophilic anaerobic, then thermophilic aerobic composting;
- use of compost for land, including desert reclamation and or agriculture;
- grey water, separation at source, local treatment and reuse;
- washing machine microplastics, filter-based or other interception;
- surface water, separate collection and use;

which are feasible, much less damaging, more sustainable, affordable, distributable, and likely cheaper in capital and running costs than 'FaF's current sewage capture, delivery, and treatment technologies; thus, realistic alternatives to close the economic and sustainability cycle.

3.2. BENEFITS OF VACUUM WC SEWAGE COLLECTION

As a better alternative to the fundamentally flawed, *Flush and Forget '*FaF' water-based sewage transport and treatment systems, vacuum WC collection and transport, followed by hyperthermophilic anaerobic, then hyperthermophilic aerobic digestion, has the following advantages, which are explained in greater detail in later sections:

- Vacuum WCs, hyperthermophilic anaerobic digestion for biogas, and hyperthermophilic composting are existing working effective technologies with massive scope for onward development;
    - vacuum WCs are used on cruise liners and more widely;
    - whilst less developed, there are working examples of both:
        - hyperthermophilic anaerobic digestion for biogas,
        - and hyperthermophilic composting, which provides good remediation of many pharmaceuticals, including antibiotics;
    - they are all, at their root, basic technologies which can be developed globally by local companies in ways that suit local resources and economic conditions;
- there are no other alternatives that I am aware of with the potential to close the environmental cycle to such an extent;
- vacuum WCs have high public user acceptability due to similarity to existing WCs;
- they meet familiarity, aesthetics and noise requirements;
- they provide better odour control and reduction in smell than a FaF installation, so reduce chemical air freshener needs;
- they reduce risks of the spread of WC use-related, flush-aerosolised bacteria and viruses found in faeces and or urine, including coronavirus and SARS, that are circulated in the unseen spray produced by FaF flushes;
- dramatically reduces the use of sometimes expensive and scarce, clean drinking water to flush toilets to half a litre for solids and minimal amounts for urine;

- with savings in the cost of infrastructure needed for water collection and treatment and or other costs, including reverse osmosis/desalination;
- by separating and collecting urine and faeces at source, with minimal water, dramatically reduces the volume of sewage outflow; facilitating onward transport for anaerobic digestion and composting specialist treatment;
- avoids mixing faeces and urine into broader wastewater streams, thus limiting pollutant content to those found in urine and faeces;
- improved opportunities for greywater collection, treatment and reuse;
- provides a substrate for local or distant, anaerobic thermophilic digestion, thus both reducing pollutants and creating significant amounts of green biogas for energy, assisting the transition to 'net zero', and provides a substrate, with the addition of plant carbon, for subsequent aerobic hyperthermophilic composting;
- hyperthermophilic composting treatment offers significant further remediation of antibiotic-resistant bacteria and pharmaceuticals;
- hyperthermophilic composting provides the opportunity to create biologically rich compost, which, subject to pollutant testing, could be used for land for regreening, pasture, or agriculture, depending on residual pollutant profile and level. (Ultimately, it may be necessary to further separate and collect urine and faeces at source, where they contain high levels of drugs (e.g. from hospitals) or particularly toxic substances such as radioactive tracers);
- potential for improvement of vacuum WC technology, including meeting cultural needs and regional climate considerations such as monsoons,
- less susceptible to flood-related pollution events as pipework is not connected, or open to, surface water systems or inundations;
- vacuum air pressure systems are not gravity flow dependent; thus, smaller pipes can be used, and without the need for constant level falls, therefore relative improved ease and greater flexibility of installation of external and internal pipe systems, with lower infrastructure costs, particularly so in existing buildings and urban landscapes, with an additional valuable benefit of reduced disruption for road systems etc.;
- reduces infrastructure requirements and costs, removing the need for large-bore, gravity-based, and pump-dependent, high-volume long-distance sewer pipe transport systems;
- does away with the FaF-related need for sewage treatment plants;
- likely capital cost savings compared to existing systems overall – (once the savings in water, plus the value of methane and compost, are factored in). There will also be savings in water infrastructure costs, as well as drinking water and sewage treatment plant capital and running costs, as sewage treatment plants will no longer be needed, as well as savings in the need for, and cost of, tertiary water treatment and sewage sludge disposal; however, there will be additional costs for bio digesting and composting plants;
- avoids mixing of microplastics from washing machines with urine and faeces, from which they cannot be removed;
- dramatically reduces the risk of downstream pollution of soils and waterways, including due to eutrophication,
- will reduce high nitrate levels in drinking water sources and animal feedstock, with positive health benefits to the environment and human and livestock health;

- allows surface water to be used for irrigation and or reintroduced into waterways and aquifers with minimum localised treatment;
- shifts responsibility and ownership for urine, faeces, grey water, and surface water onto property owners and occupiers. Public authorities could reduce sewage and related water charges as a quid pro quo.

The disadvantages of a vacuum-WC-based system are that the cost of equipment and plant of vacuum WC systems and maintenance are higher. Still, there would be multiple significant financial advantages and wider cost savings. In addition, there would be massive environmental benefits, which also have economic, health and social value.

4. POO; A COMMON OBLIGATORY OUTPUT THAT FACILITATES ALL LIFE

Excrement is a common thread that binds, underlies and facilitates all life, as very elegantly summarised by Ian Angus in a socially focused historical commentary reflecting on the history of sewage disposal in London, titled; '*Cesspools, Sewage, and Social Murder' 'Environmental Crisis and Metabolic Rift in Nineteenth-Century London*'.

The commentary starts with the Victor Hugo quote from, '*Les Misérables', "A great city is the most mighty of dung-makers" This* summary would be challenging to improve on; hence, it is quoted below:

"*All living things ingest matter from their environment, use solar energy* (it contains) *to process it, and excrete the waste products of those metabolic processes into that same environment. Over hundreds of millions of years, coevolution has produced an extraordinary range of complex cycles, in which every species' excretions are nourishment for others.* (Angus 2018)

Human beings are fully embedded in these life cycles. We inhale oxygen and exhale carbon dioxide; plants do the reverse. We eat plants and metabolize their components into materials we can't live without, and plants metabolize the leftover chemicals that we excrete. (Angus 2018)

"The links between our excrement and our food have been fundamental to human survival as long as our species has existed." (Angus, 2018) We ignore these fundamental truths at our peril.

Ultimately, water and food, and consequent expulsions of the products of their digestion, urine and faeces, are essential realities of existence and life: Water and food sustain us, and the capacity for excretion of waste, if nothing else, saves us from exploding.

4.1. THE WIDER PICTURE

My journey into the world of sewage was inspired by the work of Sir Albert Howard on compost and the result of my attempt to fathom, in a modern world, how we could recycle human urine and faeces through composting to improve soil health because a healthy and diverse fungal and bacterial soil biome is essential to; health, growth, water resilience, pest and pathogen control, the nutrient density of crops, as well as being central to human and wider environmental health. Further, recycling soil carbon, nitrates, and mineral nutrients makes excellent sense.

It soon became evident that the question of how to recycle human faeces and urine had significantly been complicated by how we collect sewage and the amounts of pharmaceuticals we use. Further, sewage sludge, livestock slurry, water availability and quality, wastewater use and disposal, and agriculture have become inextricably entwined. The question of how to best recycle urine and faeces became a part of this journey, an intertwined trilogy considering the interlinked topics of agriculture, water and sewage.

What if our passage through the choppy climate, nutrition, health, and mental well-being waters of the Anthropocene Epoch could be smoothed and improved by more intelligent management of the ubiquitous products of a process common to all life, the expulsion by defecation and urination of partially digested material, bacteria, and cellular process fluids?

What if more intelligent cyclical use of the resources in faeces and urine, 'excreta', as part of a broader move to more environmentally sustainable practices, is an essential element in mitigating important aspects of environmental damage, climate change including flooding fires and drying, degradation of human health, increased threat of global hunger, and consequent risk of resource shortage driven conflict? What if a more sustainable way of dealing with excreta, currently perceived as a problem, as implied by its derogatory common names, could be part of the environmental solution?

While this book is skewed towards the pressing problem of human faeces and urine management, it recognises that livestock produces far greater volumes of urine and faeces than humans and pets, which also needs integration into the 'circular economy'. Albeit, rotational grass-grazed livestock, during grazing, critically assisted by soil creatures such as dung beetles, spread and integrate their urine and faeces onto and into the soil, simply as part of their movement and activities.

In contrast, urine and faeces of feedlot livestock are collected in bulk, and, like that of humans, contain pharmaceuticals and heavy metals, thus requiring management, transport, storage, and disposal, and a drive to eliminate the use of heavy metals and pharmaceuticals in confined animal husbandry.

Given the vast, endless daily volumes of human and animal urine and faeces, the potential pollution consequent on the way we deal with them is a huge issue; such pollution includes eutrophication of waterways and oceans by sewage components, which, combined with a failure to recycle the soil nutrients, including the carbon and minerals they contain, is one of many significant factors in the human activity related degradation of the Gaian Ecosystem, the planetary carbon-and-oxygen-life-support-and-regulation-system, including of climate; that as well as giving us a comfortable beautiful wonderous ecosphere ultimately facilitates our existence.

Land and water pollution due to inappropriate sewage disposal and Fertiliser, Agrochemical Tillage, and Bare soil Agricultural Systems (FATBAS) continue to grow. The consequences are global. They are not confined to low-income and conflict-prone countries. They pose serious threats to all, rich and poor, needless to say, including those in stable, better-off, Westernised, more economically developed countries.

4.2. WHAT IS IN FAECES AND URINE

Faeces comprise a mix of fractions of food the gut fails to digest or finds indigestible, water, living bacteria, and the contents of dead bacteria. On average, humans produce somewhere between 0.25 and 0.5 pounds of faeces, with a mean of 128 g per capita, and around 1.4 litres of urine daily, as helpfully detailed by Rose et al. in '*The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology*' (Rose, 2015).

Faeces weights in non-Westernised groups, with higher fibre intake, maybe more than double that (Hosseini & Hosseini, n.d.). Fibre intake increases faeces weight. Livestock, dependent on species, may produce considerably more.

Of the solid quarter of solid faeces, upon diet, 84 to 93 per cent is organic material. *"Dead and living bacteria comprise approximately 25 – 54 per cent of dry solids"* . . . "*Carbon content of feces is between 44% and 55% of dried solids*" . . . "*Nitrogen can make up 5–7% of the dried solids" (Rose, 2015)*

Phosphorus in sewage is a significant potential resource; for example, "*The mean content of P in sewage sludge originating from municipal sewage sludge treatment plants in the Wielkopolska region in western Poland is estimated at 23.34 g kg−1, ranging from 4.9 to 67.5 g kg^{-1}*" ('Estimation of phosphorus bioavailability from composted organic wastes' - Jakubus, 2016).

In contrast, urine is mainly water (90 per cent), containing soluble chemicals, as well as minerals, "*The dried solids contain about 13 per cent carbon, 14 – 18 per cent nitrogen, 3.7 per cent phosphorus and 3.7 per cent potassium*" (Thomas L, n.d.).

4.3. ANIMAL WASTE INCLUDING SLURRY

The quantity of faeces and urine produced by livestock is much greater than that produced by humans. Livestock does not have the luxury of access to flushing toilets; however, it probably would consider them too much of a 'FaF', preferring to poo at will, 'in the moment', in an open green space, in the fresh air, leaving their ordure behind them, as they moved onto fresh pastures.

Despite the debate as to the relevance of cattle to climate change, before agricultural confinement, at an evolutionary level, massive numbers of seasonal cyclical migratory grazers spread saliva, urine, and faeces with ingested undigested seeds, bacteria and fungi from plants and regional soils, as well of those living in their oral and gut biome, which, with the help of small burrowing soil creatures, worked for them, in maintaining the soil biome, plant health, landscape, and the environment, thus securing their food supply.

Through confined feedlots and static fenced field livestock production, we have broken those natural cycles, introduced a range of pollutants, and concentrated animal manure in confined areas.

Consequentially, how we manage the content and disposal of livestock urine and faeces has significant health ramifications. For example, heavy metals and pharmaceuticals, including antibiotic-resistant material in slurry, sewage sludge applied to land, and recycled sewage water used for irrigation, are taken up by plants, which are in turn fed on by livestock, including cattle and humans, which retain some, and excrete the balance, of ingested pollutants, creating a feedforward cycle of increasing soil pollutants, including of antibiotic-resistant material.

5. LACK OF PUBLIC AWARENESS - FLUSH AND FORGET - ALL ABOUT CONVENIENCE

Inescapably, the consequences of planetary daily consumption of life-giving food and water are the production of large amounts of faeces and urine. Thus, if we and our livestock are to survive and prosper, the faeces and urine we produce must be carefully and sustainably woven into our social settlement rather than considered an affront to modernity.

The maintenance of a viable, minimally polluted planet, clean water, food of high nutritional quality, not contaminated with heavy metals and pharmaceuticals, including antibiotics and pollutants of concern, are crucial to ensuring future generations of optimal humans, as nutrition and pollution are factors of fundamental importance in; neurological development, optimisation of abstract thought capacity, and empathy, as well as broader health and longevity.

However, the connection between flushing a toilet, environmental damage, water pollution, the need to maintain soil quality and minimise leaching of nitrates, phosphates, and wider pollutants, the uptake of pollutants by crops, thus food, the intake of food by livestock and humans, and the impact on their health and social disposition is not on most people's horizons.

The convenience for the user makes Flush and Forget 'FaF' such a compelling technology. With no more than a push of a button or a pull of a chain or lever, excreta of both kinds and any paper paraphernalia vanish without any direct consumer responsibility for their future fate and are never seen again.

We have a mindset that excreta is a 'bad thing'; thus, maybe in our mind, there is no downside to adding more 'bad things' to it; indeed, we may muse, does it not make sense to have all the 'bad things' in one place? Thus, to the mix of faeces and urine, sometimes referred to as 'black water', is added greywater from washing machines, showers and dishwashers – including all the chemicals and plastic microfibers stripped from clothes (Weithmann, 2018) – other output from domestic homes including; pharmaceuticals, recreational drugs, personal care products, wider contaminants of concern, forever chemicals, endocrine disruptors etc.; downstream further pollutants are added to the water-waste-stream, from hospitals, farms, pharmaceutical plants and wider industry; as well as water run-off from roads, carrying winter road salt, dust from car tyres, compounds from brakes; and other pollutants.

At the point of arrival of this soup of all society's semi-solid and liquid leftovers at the sewage treatment plant, any chance of harvesting each separate component for its particular beneficial purposes has long since disappeared. Various stages of remediation separate the sewage wastewater stream arriving at treatment plants into treated sewage water discharged into waterways or used for irrigation, and sometimes purified by reverse osmosis for drinking water (in drought areas); sewage sludge (or slurry) disposed of; on agricultural land; as landfill; by incineration; and sometimes by direct discharge into rivers and oceans.

While sewage treatment processing clarifies the arriving effluent water component, removing some but not all bacteria, a portion of the chemical content in the discharge water, including chemicals, pharmaceutical products, personal care products, sweeteners, microplastics, etc., remains unremediated and, in general, ends up being discharged one way or another into the environment. Thought-provoking perspectives on the current sewage systems are included in the 2003 film by Jeff McKay, '*Crapshoot: The Gamble With Our Wastes'.*

The sewage sludge solids contain a wide range of unremediated pollutants, including pharmaceuticals, PCPs, PFAS, endocrine disruptors, other toxins, heavy metals, microplastics, tyre particles, etc. Thus, disposal options are limited. The public is largely oblivious to the broader pollution issues. However, aspects are now regularly appearing in the media. For example, in recent years, sewage overflows have featured strongly in UK news, and there are growing numbers of media reports on pollution due to the application of sewage sludge on farmland. However, the fundamental flaws and problems inherent in current 'Victorian / Edwardian' 'Flush and Forget' WC collection, transport, and treatment of faeces and urine, and their multiple wider downstream consequences, tend not to be discussed.

Despite our negative view of, and response to, faeces, millennia of evolution have yet to find an alternative to eating food and defecating or to lessen the volume we produce. Benjamin Franklin's prognosis for human life, *"In this world, nothing can be said to be certain, except death and taxes",* remains pithy and apposite. Given that excretion of faeces in a crowded world is also an inevitability, does Franklin's prognosis not warrant extension, giving us, "*In this world, nothing can be said to be certain, except death, taxes and excreta*"?

5.1. SEWAGE – HOW WE SEE IT – 'SHIT, POO, CRAP . . .'

When it comes to excreta, it seems Western 21st-century sensibilities, for most, result in an overlap between an initial gag mechanism and a desire that said faeces and urine vanish politely into the ether, not to be mentioned again.

Human visceral distaste and fear of sewage are evidenced by the lurid and vivid vocabulary around excreta, which is commonplace in daily conversations. In language, in the ways words such as; 'Shit, Poo, Crap, to Soil' are used, we again find human instinctive prejudice. Miriam Webster defines the verb 'to soil' as a "*to stain or defile morally: corrupt - to make unclean especially superficially: dirty - to blacken or taint (something, such as a person's reputation) by word or deed".* (Merriam-Webster)

Yet historically, there was also longstanding pragmatic recognition of the value of urine and faeces to societal wellbeing. Whilst the noun ‘soil’ has negative connotations, it also implicitly recognises the value of faeces and urine to agriculture; “*the upper layer of earth that may be dug or plowed and in which plants grow - the superficial unconsolidated and usually weathered part of the mantle of a planet and especially of the earth”* (Merriam Webster)

It is little wonder that ‘human waste’ has attracted unpleasant monikers and nicknames. In a modern world, where most urban populations have access to sufficient food to survive yet are entirely divorced from ecosystem realities, few are aware of the historical importance of urine and faeces as soil conditioners or the pollution and wider negative environmental consequences of how we currently deal with sewage.

Our inherent negative modern outlook on urine and, particularly, faeces is exacerbated by a fear of ‘germs’. Marketing of bactericides for use all around the home, including via the generation of fear, has magnified an insufficiently balanced outlook on microorganisms. Worryingly, the excessive use of bactericides in our immediate environment can create the danger of damaging and accelerating the evolution of microbial communities in our gut and elsewhere, which are otherwise essential to our healthy function.

However, as well as being threatened by some bacteria and fungi, we are greatly biologically influenced and supported by others, as are soils and plants. Our evolutionary symbiosis with bacteria and fungi is age-old, and they remain fundamentally important adjuncts and symbionts to human biology, including in the gut, mucal, and skin biomes. Whilst some bacteria and fungi can be harmful, others are essential to a healthy gut and function, and depending on circumstances, some can be either.

It is increasingly widely understood that bacteria in the gut assist immune function and provide essential nutrients, including otherwise scarce vitamins such as B12 and K2, as well as short-chain fats as substrates for beta-oxidation for energy in the liver. It is less widely appreciated that fungi also have a role in gut function. A Lancet paper observes, “*The gut mycobiome (fungi) is a small but crucial component of the gut microbiome in humans. Intestinal fungi regulate host homoeostasis, pathophysiological and physiological processes, and the assembly of the co-residing gut bacterial microbiome.*” (Zhang, F. 2022)

Pathogenic bacteria and fungi pose varying risks, depending on their strain, the manner of acquisition, and the health status of individuals affected. However, sensible measures such as providing clean water and washing, including hand washing, reduce—though never eliminate—the risk of transmission of infection.

With more thought, we would realise that our inherent disgust at faeces, the broader rational assessment of harms, and possible beneficial uses require separation. It is possible to be appropriately concerned about potential harm while acknowledging usefulness or value. For example, many people instinctively and pragmatically rationalise nuances of benefits and harms when weighing issues such as weapon use and chemotherapy or, more mundanely, when contemplating eating bacterial-rich foods such as yoghurts, kefir, cheeses, and fungi of various sorts.

5.2. WHY SHOULD WE CARE

One way or another, our failure to deal more' intelligently' with animal and human faeces and urine and consequent failure to collect and process it appropriately is, as outlined, causing widespread downstream environmental and human health damage at multiple levels, as considered briefly below and in more detail in the later specific sections.

It is even more concerning that we do not fully understand the long-term consequences of our actions. Microplastic pollution is an example; it was undoubtedly never foreseen that microplastics would spread widely throughout the environment and ultimately be incorporated into many human tissues, with yet-to-be-fully appreciated health consequences. Another concern, considered in more detail later, is the spread of antibiotic resistance.

The '*Scientist*' article, titled '*Garbage to Guts':* under the heading, *"The Slow-Churn of Plastic Waste*', observes, "*Humans consume up to five grams of MPs* (micro-plastics) *a week—the equivalent of five paper clips—through various routes, turning the human body into its own reservoir of MP waste. Researchers discovered MPs flowing through human blood and islands of MPs in various organs, including the liver, kidney, spleen, lungs, placenta, and stools."* (Kulbatski, 2023) (Also found in testes, brains, and breast milk).

We never foresaw the microplastic issue, and most of us are still unaware of the extent of the emerging, but as yet not quantified possible long-term health implications of microplastics, ingested from food, water and air, now being found in an extensive range of tissues, including the placenta and brain.

Similarly, we gave little thought, and there is limited research as to what effect antibiotics in sewage sludge, wastewater, and slurry may have on soil bacterial populations, including due to the exchange of antibiotic-resistant elements or the onward impact on plants. We also do not know what effect artificial sweeteners, which are slow to break down, may have on the environment, and the list of unknowns goes on.

Thus, we should be very concerned to ensure, in a monetary-blinded pursuit of profit and technological 'advancement', that we do not unthinkingly irrevocably pollute the planetary ecosystem that gives us life, optimises our health, and crucially our brain function, which underlies mental health generally; and in optimal situations, helps us to be the most; intelligent, abstract thought capable, empathetic, artistic, co-operative, humans, we are capable of being.

All these aspects of successful human survival are interdependent and rest on our maturity as a species to understand and address what matters during this particularly challenging, resource-stressed, competitive, conflicted Anthropocene/Plasticine époque of our own making. We are arguably failing in many ways to grapple with the more significant fundamental issues central to and underlying the meaning of life and our ongoing existence.

In the words of Rachael Carson, in her book '*Silent Spring*'; "*We in this generation, . . . we're challenged as mankind has never been challenged before to prove our maturity and our mastery, not of nature, but of ourselves.*"

5.3. PUBLIC UNDERSTANDING AND EDUCATION

The idea of utilising human faeces and urine to prepare compost for agricultural use is often greeted with ridicule and disgust. However, people pragmatically accept reverse-osmosis-treated sewage drinking water and sludge application to agricultural land. In contrast, historically, many civilisations appreciated the agrarian value of appropriately and safely composted livestock and human, urine and faeces.

For example, a study on contemporary attitudes to the use of sewage as fertiliser in South Africa found the practice "*is still foreign and generally not accepted", and "Human excreta is regarded as waste products, unhealthy and detrimental to humans*" (Mugivhisa, 2015).

For the public to learn to love, or at least pragmatically accept, the need to recycle sewage requires a better public understanding of the broader picture, including the available options and their comparative impacts. "*The utilisation of toilet waste is being hindered by prejudice and lack of information . . . Only by efficient information can we influence public opinion*," ('Human faeces as a resource in agriculture', Malkki, 1999).

Several studies – including the following South African one - suggest public sentiment will evolve as the issues become well understood: "*Respondents indicated that they were willing to change their attitudes if they were better informed… People should be well informed and educated about human excreta as a useful resource [and] as a threat to health if it is not done properly. More…has to be done to educate people about the importance of reuse and recycling of the human wastes for agricultural* (and wider) *purposes"* (Mugivhisa, 2015).

The presence of pharmaceuticals, including antibiotics, in urine and faeces and the subsequent introduction of a wide range of pollutants from various external sewage waste streams make wastewater treatment difficult and the safe composting of sewage sludge for agricultural or land reclamation reuse virtually impossible, thus precluding the closing of the environmental cycle.

More widely but related, it is essential that there is better public comprehension of how close to irretrievable exhaustion many millions of acres of land around the world are, due to the environmentally damaging effect of FATBAS, '**F**ertiliser-**A**grochemical-**T**illage-**B**are-soil-**A**gricultural-**S**ystem', including pollution of soils directly and indirectly via sewage and slurry related pollution, and through irrigation with treated and untreated sewage wastewater. Further, it needs to be understood how crucial both the recovery of degraded and ongoing maintenance of productive agricultural soils are to food supply and nutrient density, thus health and mental well-being, as well as the mitigation of climate change.

There needs to be widespread understanding that the 'FaF' model of sewage collection and treatment is an unsustainable Victorian dinosaur technology, which, with colossal population expansion and proliferation of chemical pollutants in our ecosphere, is no longer fit for purpose, due to the amount of water used for flushing, the vast range of contaminants now introduced into the sewage stream, and the consequential pollution of land and water sources. Whilst wastewater can be tertiary treated to a high standard, albeit costly, it is almost impossible to treat sewage sludge effectively, incineration being the least-worst option. Thus, FaF is a broken, unmendable technology, a 'busted flush'.

There is no ideal solution, but vacuum WC technology offers a much more sustainable outlook. The public needs to understand:

- how environmentally unsustainable current FaF water-based sewage collection and treatment systems are;
- the urgent need for a move to a more sustainable new model of sewage management, namely vacuum WC collection, followed by hyperthermophilic anaerobic digestion and hyperthermophilic composting,
- and the positive implications of a vacuum WC-based collection system for agriculture and the wider environment.

Fig. 1. A generic underground sewer pipe, with thanks to the Mulderphoto and Adobe Stock, a Baruch portable latrine, US Army, World War One, with thanks to Otis and Wikipedia, Outhouse with squat toilet with thanks to Meteor2017 and Wikipedia, and 3 three "Imperial" bourdaloues, with thanks to David Monniaux and Wikipedia.

6. FLUSH AND FORGET - 'FAF' - A HISTORY

The aspiration for 'convenient sanitation' is a product of humans moving beyond hunter-gathering, developing agricultural food surpluses, and, consequently, being able to set up complex hierarchical communities in one place, with time on their hands for other activities.

The desire for 'convenience' drives humans to put distance between them and their preferred comfortable place of faecal deposition and the eventual destination of said ordure. That is easy to achieve when continually on the move but far harder when your residence is fixed. Thus, the creation of human settlements inevitably requires the faecal deposit to be moved, be that by the emptying of a chamber pot out of a window into the street, provision for organised collection and transport from homes or other locations, as in privies and dunnies; or by movement by water in sewers.

For 4,000 years, at various times and places, urban elites, divorced from the needs and realities of agriculture, have been able to 'Flush and Forget'; an easy spell to fall under when food is plentiful and forests to cut and convert into new fertile land to farm, commonplace.

Fig. 2. Toilets at Ostia Antica, Italy, with many thanks to Fubar Obfusco and Wikimedia

The first European flush lavatory was on the Greek island of Crete. Four thousand years ago, the Minoans improved upon toilet technology by constructing sewers beneath the sprawling royal palace of Knossos. Faeces then, as now, were encouraged to vanish into the abyss with the assistance of water.

Similar innovations were up and running around the same time in the Indus, the site of a rich ancient civilisation covering modern-day Pakistan, eastern Afghanistan and western India. Brick-lined archaeological remains have been uncovered at the UNESCO World Heritage Site of Mohenjo-Daro, where a municipal toilet system featuring a network of domestic latrines was hooked up to sewers that deposited excreta in a cesspool, likely outside the city.

The Romans used water-based, excreta-removing, communal toilets as a public health measure and a chance for social interaction. However, by mediaeval times, the growth of European populations and cities and a lack of administrative focus meant adequate rudimentary urban sanitation was the exception. Pity the poor passer-by, who failed to heed the warning "*Gardez l'eau!*" as the chamber pot contents were hurled into the street from a window above.

In the late 16th century, eccentric poet and courtier Sir John Harrington invented a contraption we would recognise as a flushing lavatory. Although it impressed his godmother, Queen Elizabeth I, it failed to dent the wider public consciousness. Across Europe, many 19th-century houses had external toilets called privies, with a space underneath for accumulation of 'night soil', which was periodically removed by then sewage workers and sold for composting.

However, despite this, by 1858, direct and indirect sewage discharges resulted in the pollution of London's land and water reaching a critical point. In Victorian England, as set out in the fascinating and sobering article, by Ian Angus, in the publication '*Cesspools, Sewage, and Social Murder*' '*Environmental Crisis and Metabolic Rift in Nineteenth-Century London'*, he observes, "*In the 1840s, writes Stephen Marcus, the English middle class was "abruptly disturbed by the realization that millions of English men, women and children were virtually living in shit. The immediate question seems to have been whether they weren't drowning in it.*"" (Angus, 1918).

The social, economic, health and mortality consequences of failing to plan for and implement policies for the safe disposal of human ordure, once added to broader social needs, were dire. "C*ruel overcrowding and malnutrition gave respiratory and other forms of tuberculosis a grotesque predominance among the fatal infections, and enabled typhus to take a steady annual toll. Infant diseases, product of dirt, ignorance, bad-feeding, and overcrowding, swept one in two of all children born in towns out of life before the age of five.*" . . . "*From the 1820s,*" writes historian Royston Lambert, "*the towns of England began to kill off their inhabitants at an increasing pace*". . . (Angus, 1918)

The Thames sewage pollution crisis was dubbed '*The Great Stink*'. The smell from the River Thames became unbearable, even and notably, in the Houses of Parliament. When wet blankets in the windows failed to keep out the stench, those in power could no longer ignore the issue. The Government decided to invest in massive, organised, engineered, underground piped and pumped sewage transport systems, using early '*Flush and Forget*' WCs, together with gravity-based water transport systems, to export faeces and urine to more distant areas, placing it '*out of sight and out of mind*'. We continue to rely on much of that Victorian underground sewage infrastructure today.

Fig. 3. "*The Silent Highwayman*" (1858). Death Rows on the Thames, with many thanks to Punch and Wikimedia

The Victorian era saw the emergence of the sanitary design of the modern 'convenience', the FaF WC system. Thomas Crapper's flush box and Albert Gilbin's U-bend were among the innovations. Once the urban health benefits of direct sewage disposal to places outside the city became evident, water-based removal and treatment systems were expanded. Perhaps it is easy to forget just how recent these innovations are. By the end of the Second World War, less than half the population of the US was connected to a sewerage system (70 million people out of 149 million), and only 85 million had access to clean public drinking water systems.

Over time, recognition that untreated sewage could not simply be disposed of in rivers for environmental and health reasons led to the development of treatment processing plants. These plants separate sludge from water and, to various extents, allow for their remediation. However, the resultant treated water and sewage sludge products still have to be disposed of, and their treatment, particularly the sludge, is deeply flawed.

6.1. NOT ALL VICTORIANS AGREED THAT FLUSH AND FORGET WAS THE SOLUTION

Interestingly, some farsighted Victorian critics saw 'flush and forget' FaF and did not provide a long-term sustainable solution. Chemist Charles Glassford – whose wisdom was unfortunately ignored by his peers – presciently pointed out that the new London sewer system was a "*scheme which offers as yet no prospect of cash returns*". (Glassford, 1858)

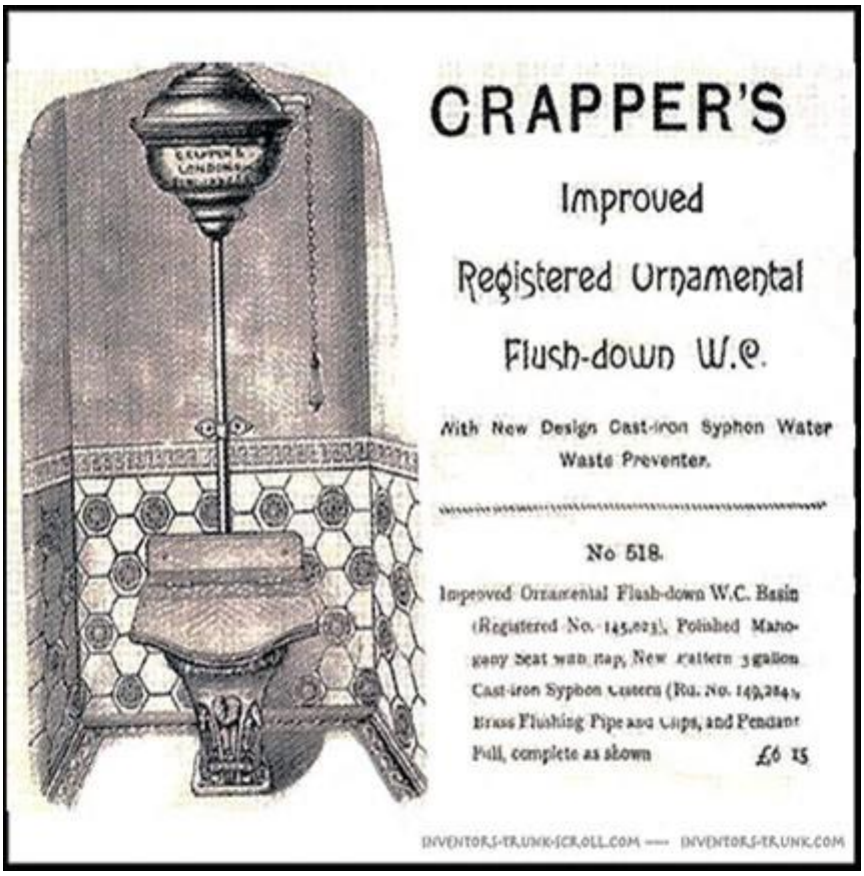

Fig. 4. An early wall mounted Crapper flush-down W.C. with many thanks to Noodleki and Wikimedia

Glassford insisted the then project was an "*absolute waste and destruction of fertilising material sufficient for the cultivation and growth of vegetable and animal matter for the sustenance of the whole population*," adding: "T*he present absurd water-carriage of excreta must be abandoned, and sewers employed for their legitimate purpose, viz.: — to carry away* (surface) *wastewater to its natural receptacle, the river*" (Glassford, 1858)

Glassford advocated using the cost of guano (the then main industrial fertiliser) as a financial yardstick. "*The money-value of the fertilising matters lost in the sewage of London has been variously estimated at from a half million to one and a half million pounds sterling per annum,*" (Glassford, 1858) he calculated. This was a considerable sum in 1850.

He concluded: "*It is for the public, now, to examine this matter carefully, and decide whether they will allow their wasted but valuable excretage to contribute still to their discomfort and dissolution, or whether it shall be economised and become a new source of wealth to the country*." (Glassford, 1858)

The Victorians recognised the advantages of collection at source and the negative consequences of mixing urine and faeces into the mixed external waste stream. They understood that sewage solids from a mixed waste stream were too polluted to be returned to the land. Farmers did not want the sludge produced by the then-treatment plants, observing that it damaged their land and produce.

However, the political convenience and immediacy of the solution of piping sewage out of sight and mind won the day, defeating the economic and common sense, the broader value of recycling urine and faeces to the land. That decision set a precedent globally.

With new emerging technologies, burgeoning populations, growing environmental pressures, and the flawed current treatment and collection system, the need, urgency, motivation, and opportunity to revisit how we deal with our urine and faeces are more pressing than ever. We need to act now rather than later.

6.2. IMPROVEMENTS IN VICTORIAN SEWAGE TECHNOLOGY

Water treatment systems date back millennia. Humans have used flocculants, sand, and other filters, as well as exposure to sunlight, to clean water for hundreds, if not thousands, of years. In contrast, bacterial treatment and clarification of sewage wastewater have only been used for about a century.

In 1913, Arden and Lockett developed the use of selected bacteria to degrade and metabolise sewage water contaminants, including carbon-rich organic residue and nitrates. At the same time, the plant settled out solids (Arden & Lockett, 1915; AED, n.d.), with the first example built in 1920.

While the treatment of sewage streams has seen some improvements over time, it is crucial to acknowledge that, in most cases, the fundamental methods have remained essentially unchanged for decades. Urban wastewater treatment plants (WWTPs) have primarily been designed to remove organic carbon, nitrogen, and phosphorus, as noted by Pistocchi (2022). However, they are not as effective in removing other pollutants that have been recently introduced, such as pharmaceuticals, personal care products, microplastics, and a range of other contaminants. This underscores the urgent need for better sewage treatment technologies.

As discussed further below in more detail, it is essential to appreciate that tertiary treatments vary in efficacy <u>and can only be used to clean wastewater</u>. It is only more recently that technological-tertiary- processes for better purification of modern sewage water have been developed that significantly degrade pharmaceutical and personal care products, aka 'contaminants of concern', but are complex, costly, and in limited usage. Basic tertiary treatment fails to degrade many pollutants in sewage wastewater adequately. Most sewage water only undergoes secondary treatment, which delivers minimal remediation capacity, with many pollutants remaining in the treated water.

In contrast, and crucial to the argument, FaF is a broken dinosaur technology because there <u>are no options for remediating the pollutants in sewage sludge. The only economic practical disposal options are incineration, landfill, or use on agricultural land, and the reality is that much is discharged directly, untreated, into the environment, 'DiE'</u>.

6.3. SEWAGE WASTE WATER PURIFICATION SYSTEMS

High-quality tertiary water purification methods include reverse osmosis, the use of oxidants such as ozone, and the use of activated carbon as a sophisticated flocculent. However, such processes are technically demanding and expensive in capital and running costs, thus impractical and likely unaffordable for many countries, particularly those with limited treatment capacity.

At enormous cost, the Swiss, who are conscious of the environmental importance of the large lakes around which many of their cities are situated, are upgrading 100 of around 700 systems. Switzerland is one of the few countries starting to install advanced sewage wastewater technology. They have selected advanced wastewater ozone/activated carbon treatment processes.

These systems are a significant improvement but still imperfect, removing around 80% or more of an identified list of micro-pollutants. Thus, pharmaceutical and other pollutants are still present in the most advanced wastewater treatments used by the Swiss to protect their lakes, albeit at much lower levels.

The potential bill for retro-fitting all treatment plants with more effective tertiary water treatment technologies – likely still with imperfect results - would be eye-watering; for example, in 2018, the UK Water Industry Research group estimated the cost of implementing the upgrades necessary to remove pharmaceuticals in Britain alone, (even if truly feasible) at £27-31 billion over 20 years (OECD workshop on Managing Contaminants of Emerging Concern in Surface Waters: Scientific developments and cost-effective policy responses, 2018). Such sums, which will ultimately have to be borne by the public in water bills or rates, will likely be baulked at in the developed world and simply unaffordable for governments and populations of emerging economies.

While high-technology tertiary treatment systems capture and concentrate pollutants, that resultant concentrate has to be treated and/or safely disposed of, which is not easy and can create other issues.

For example, reverse osmosis produces drinking water to a high standard but at a high cost. The purified water also requires remineralisation. Reverse osmosis water may potentially contain significant numbers of nano-plastic particles. Further, the pollutants in the osmosis 'reject'-water are concentrated in the process of their separation by reverse osmosis from the clean water. These pollutants in the residue water do not disappear; they have to be disposed of; by further treatments; in the ocean; or into land drains; eventually ending up in the water table or wider environment. The same is true of flocculation.

The pollutant-containing osmosis by-product could be further treated with oxidative and other processes, as set out, for example, in 'Treatment of Reverse Osmosis Reject Water from Industries' (Saravanane, 2017), albeit microplastics in the filtrate would remain. Treatment of the osmosis residue adds significantly to costs, and there is still likely to be residue that must go to a landfill.

Sewage sludge disposal is a separate and distinct problem. The Swiss primarily incinerate their sewage sludge to avoid dumping it onto agricultural land. As discussed later, incineration is the least-worst option but still presents environmental issues.

The inclusion of pharmaceuticals, particularly antibiotics, from faeces and urine in a mixed external water waste stream is not just an environmental challenge but a potential human health hazard. The gravity of this situation cannot be overstated, making it imperative to find ways to prevent the inclusion and dilution of faeces and urine in such heavily polluted water waste streams.

6.4. DIRECT INTO ENVIRONMENT 'DiE' "DROWNING IN EXCRETA" 'DiE'

Untreated sewage discharge is a huge problem at many levels. There is little doubt that **D**irect **i**nto **E**nvironment 'DiE' untreated sewage discharge, leaving people metaphorically, if not literally, '*Drowning in Excreta*' (Nadkarni, 2002) (also DiE), is an environmental and human hazard in the making. Nevertheless, as discussed, the status quo is that large numbers worldwide have no access to wastewater treatment technology (Mosharaf, 2024).

This is history repeating; many poor urban conurbations lack proper piped sewage transport and treatment, little different from the situation in the 1800s previously discussed, reflected in the publication '*Cesspools, Sewage, and Social Murder*' '*Environmental Crisis and Metabolic Rift in Nineteenth-Century London',* where it was observed people were in "*danger of drowning in excreta*". (Angus, 1918)

Then as now, the unsurprising consequence in many parts of the world of a lack of planning and provision of urban sewage for whatever reason is extensive environmental pollution, with significant adverse social outcomes, including for health, which self-evidently cannot and must not persist if planetary systems are to remain capable of supporting healthy, socially content humans.

Downstream pollution due to treated 'FaF' sewage is lower but still significant, given that most countries cannot afford tertiary oxidative treatment of sewage wastewater and incineration of sewage sludge. Even where FaF sewage systems exist, many are poorly managed, overstretched, and failing to a greater or lesser extent, thus resulting in pollution.

Indeed, Narain and Nadkarni observe, for example, that in India, much of the 'FaF' sewage stream, due to treatment system failures, is piped directly into rivers, albeit massive efforts are being made to clean these rivers.

Ironically, 'Direct into Environment' 'DiE' sewage discharges– generally *"comes from the flush toilets of the rich, not the poor*", thus are *"a subsidy for the rich to excrete in convenience*" (Narain & Nadkarni, 2002; Nadkarni, 2002).

In contrast, in many deprived areas, excretion tends to be via simple pit toilet systems, emptying buckets, or open defection, sometimes directly into already heavily polluted water courses. This results in surface contamination, runoff, and related health and environmental risks. Much of this localised content from haphazard sanitation attempts will, in due course, surely wend its way into smaller streams and then larger rivers.

Meanwhile, the deceptive allure of FaF as an effective technology to 'deal with' sewage is, in reality, a failing technology that only exacerbates social tensions. Perceptions of unfair treatment and inequity in health outcomes will contribute to societal divisions and magnify the risks of societal instability.

Realistically, the water requirements and environmental cost of 'FaF' globally are too high to be practically and sustainably implemented. Thus, FaF technology is arguably a 'busted flush'.

7. 'FaF' - ECONOMICALLY AND ENVIRONMENTALLY "UTTERLY MINDLESS"

The 2002 article, '*Ecologically Mindless*' by Nadkarni and fellow environmentalist Sunita Narain, in the magazine '*Down To Earth*', states, "*the Flush and Forget mindset is increasingly destroying our water systems.*". It is, indeed, '*utterly mindless*' to continue to pursue and invest in '*Flush and Forget*' 'FaF' Victorian sewage transport, and Edwardian treatment technology for each and every terrestrial citizen because "*the more [WC] water you use, the more the investment is needed to clean it up*" (Narain & Nadkarni, 2015; Narain, 2012), particularly when there is an available alternative.

In a world of growing water shortages with falling per-capita water availability, the aspiration of '*Flush and Forget'* for all is unrealistic and unaffordable; rivers are dammed, exacerbated by the increasing amounts of water extracted for irrigation, drying, losing their flows, and thus proportionately increasingly impacted by the sewage and other waste released discharged into them. Environmentalist Nadkarni concludes: "*The price of chasing the Flush and Forget dream for all, is leading to an environmental catastrophe.*" (Nadkarni, 2002)

The irrationality of the vicious cycle we have created is that by installing ever more 'Flush and Forget' FaF technology - mixing ever larger volumes of clean drinking-quality water with our faeces and urine, and then adding industrial pollution and rain runoff from hard surfaces, we are ever increasing the demands on an already water-stressed, environmentally damaged and polluted, world.

The aspiration of 'flush and forget' FaF for all means, we pollute ever more significant amounts of the same precious drinking water supplies - then spend vast amounts of money to again clean the water we recently again 'Flushed and Forgot'. Restored to a sparklingly clean drinking-standard, we use it again to fill ever-growing numbers of WC cisterns. We thus propagate an inevitable downward vortex spiral while simultaneously creating wider environmental pollution, including ocean eutrophication.

Mixing faeces and urine, pharmaceuticals including antibiotics, into mixed external water-waste-streams containing microplastics, personal care products, and wider pollutants make the effective treatment of the vast volumes of mixed products arriving at sewage treatment plants almost impossible. Consequently, a proportion of pharmaceuticals, minerals including phosphates and nitrates, in urine and faeces, along with personal care products in washing water, and microplastics from washing machines, with exceptions, are at risk of ending up in the environment in either the sewage sludge or sewage water discharge.

Further, old treatment plants are often insufficient in size to cope with mixed inflows from multiple sources, particularly at times of high rainfall. This results in overflow discharges of raw sewage, as seen in the UK and elsewhere, exacerbated by higher and less certain rainfall events caused by global atmospheric warming.

In many less economically well-off countries, sewage is not treated and discharged 'raw' directly into the environment, partly because transport and treatment systems are unaffordable or impracticable.

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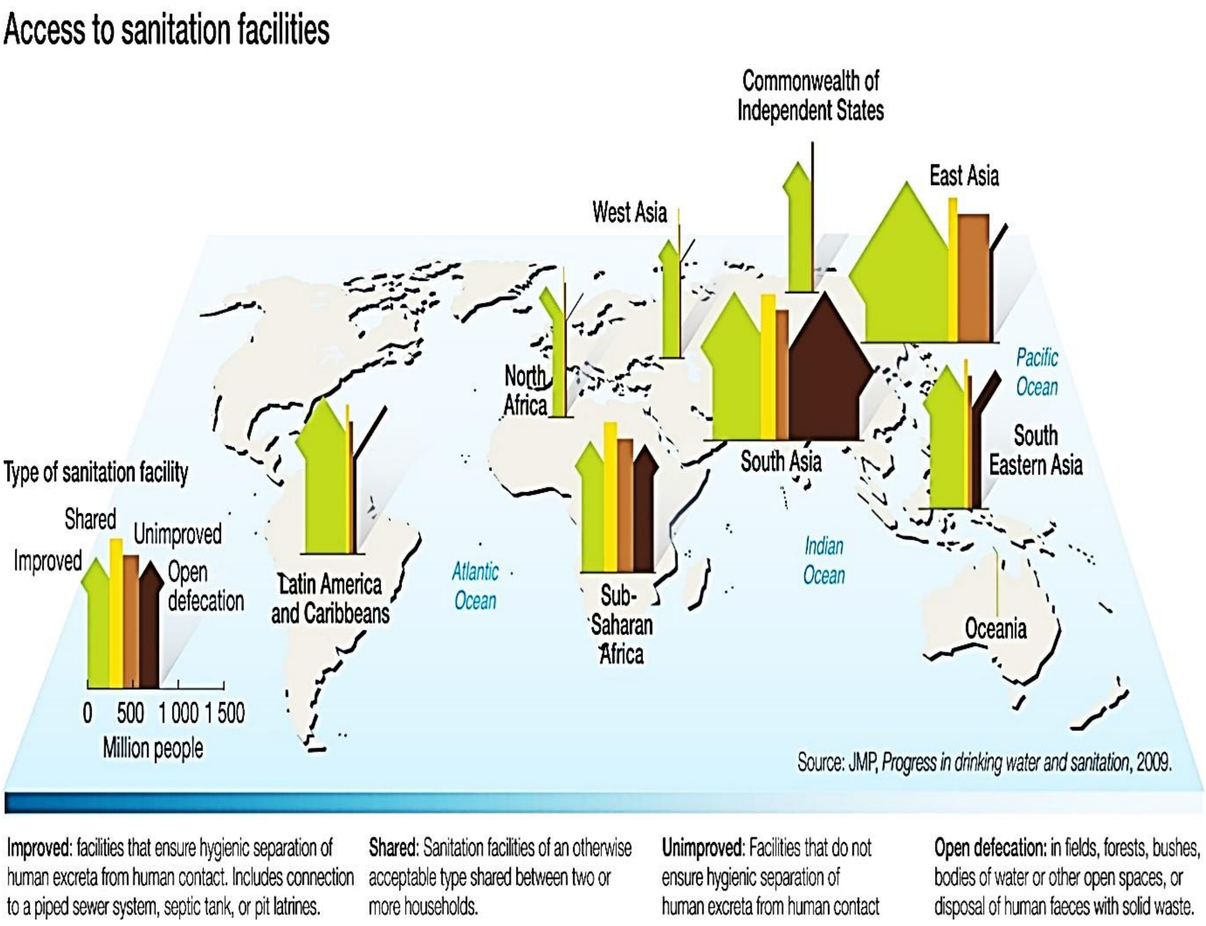


Fig. 5. '*Access to sanitation remains a pressing issue*', with many thanks to the authors of '*Sick Water*' and the UN (Corcoran, n.d.)

7.1. 'FaF' - DOOMED TO FAIL

Whoever first coined the pejorative phrase 'Flush and Forget', 'FaF', recognised with clarity the folly of 'FaF'. The truth is, 'FaF' can only ever be an aspiration doomed to fail. We may blithely 'flush' – but we can never truly 'forget', however much we wish to, because the consequences of our unthinking actions are inexorably accumulating.

Current global paradigms demand that ever more 'FaF' systems be installed—and that starts with the faeces of the well-off. The urban poor often suffers the consequential related water shortages, and many living with unsanitary conditions are often paddling in if not actually "*drowning in their own excreta.*" ('*Drowning In Human Excreta*') (Nadkarni, 2002).

The urban population surges, seen in the West during the Industrial Revolution, are currently being repeated, for example, in India, Brazil and Nigeria, though on an even larger scale, exacerbating water and infrastructure demands.

Economic and demand growth tend to use, not create, more available water. Available resources, financial and natural, will arguably never be sufficient, to install and maintain the infrastructure to supply and treat the vast amounts of water, required to install, flush and forget FaF for all of the world's population, billions of whom, one way or another, currently have no access to sanitation.

Fig. 6. "The above shanty town image is from Ezbet

Al Nakhl, in Cairo, Egypt, where garbage is sorted manually. Residential area is visible at the top of the image", with many thanks to Ventus and Wikimedia.

A finite number of often drying, overexploited streams and rivers bear the brunt, not only of clearing away treated wastewater and directly discharged faeces and urine, but at the same time are required to provide clean water for drinking, washing, cleaning, and flushing ever more WCs. As discussed, it is arguably highly irrational to cyclically sanitise water over and over again to drinking standards, to then sully it, thereby causing ever incrementally increasing environmental pollution and damage, rising costs, with the system failing a little more with each cycle.

There is no escape from the need to urinate and defecate. Neither 'FaF' nor 'DiE' makes sense because neither is sustainable. Thus, 'Flush and Forget', 'FaF' is, indeed, 'a busted flush', an irredeemable technology, and we are unknowingly 'kicking cans' down the road, piling problems for future generations.

7.2. 'INCONVENIENCE' FOR THE POOR

Whilst the opportunities for more sustainable sewage management are the same worldwide, the sewage *status quo* varies enormously according to the part of the world in which one resides.

A significant proportion of sewage in more prosperous economies is to various extents treated, but in contrast, treatment is often absent in less well-off economies; for example, in Uganda, "*only 1 per cent of the urban population is connected to sewers and 27 per cent has improved on-site facilities*" (*Guidelines on Sanitation and Health.* 2018).

More widely, the review, '*Better sewage treatment critical for human health and ecosystems'*, notes widely, "*over 80 per cent of the world's wastewater - and over 95 per cent in some least developed countries - is released to the environment without treatment; 2.4 billion people still do not have access to improved sanitation. Only 26 per cent of urban and 34 per cent of rural sanitation and wastewater services effectively prevent human contact with excreta along the entire sanitation chain and can therefore be considered safely managed*" (Lamizana, 2019).

7.3. INDIA – A CASE STUDY OF 'FaF' FAILING – A DINOSAUR TECHNOLOGY

Whilst commonplace globally, core sewage service and infrastructure dilemmas are probably easiest seen in sharper focus in India, a country with open information, a vast and booming population, and exponential industrial growth. India features stark kaleidoscopes of wealth and poverty, cities and rural outposts, industrialism and agrarianism. In India, historical events have fused enduring traditions with Western institutions and infrastructure.

In the recent past, millions in India were reported as having no access to WC facilities (Narain, 2012; What happens after you flush your toilet? n.d.). In 2011, it was reported, "*In rural areas, around 67 per cent of the population defecate in the open, a practice that poses severe risk to health and safety"* (Census of India, 2011).

However, now, open defecation is a shrinking issue in India; the government's aim and policy to eradicate open defecation is resulting in improvement at pace. Census figures now suggest open defecation no longer happens, albeit the problem is massive. '*Why India is still struggling to provide access to toilets ...*' (France 24, 2022).

However, ironically, increasing the volume of collected sewage magnifies the need for collection and treatment infrastructure. Sewage sanitation problems in India are further magnified by massive urban population growth and regional monsoons. Understandably, vast volumes of monsoon rains are associated with poor sanitation and difficulties in year-round maintenance of 'FaF' sewage collection, transport, and treatment systems.

However, people and Governments inevitably yearn for and fund, out of sight and out of mind, 'FaF' sewage collection transport and treatment technology for its self-evident convenience and here-and-now advantages. However, as discussed, 'FaF' technology is sadly badly flawed, environmentally damaging, ultimately unsustainable, and more so in water shortage regions and monsoon climates.

In India, despite the Government's admirable intentions and action, due to the monumental scale of the problem, significant amounts of WC output remain untreated and at risk of direct discharge into watercourses. Whilst things have improved, many still rely on septic tanks. The 2023 article, '*India struggles with urban sewage treatment as population surges*', comments, "*According to the United Nations, India is set to overtake China as the world's most populous country, housing almost 1.43 billion people. The urban population is set to increase by 270 million people by 2040. However, of the 72 billion litres of daily sewage currently created in the country's urban centres, a massive 45 billion litres which is enough to fill 18,000 Olympic-sized swimming pools, goes untreated, as reported by government data for 2020-2021.*

Fig. 7. Studio photograph Mohandas K Gandhi in London, 1931, with thanks to the author and Wikipedia

The nationalist icon Mahatma Gandhi in 2010, at the United Nations declared:
"Sanitation is more important than independence," "the right to safe and clean drinking water and sanitation [is] a human right that is essential for the full enjoyment of life and all human rights"

Surprisingly, the sewerage system in India serves only one-third of the urban homes across the nation, . . . many sewage treatment plants currently in use aren't up to par; 26 out of Delhi's 35 facilities fail to adhere to the standards." (Jenn, 2023).

A 2018 Durham University paper, '*Population density controls on microbial pollution across the Ganga catchment',* observes: "*We find a strong non-linear relationship between upstream population density and microbial pollution, and predict that these river systems would fail faecal coliform standards for* *irrigation waters available to 79 per cent of the catchment's 500 million inhabitants*". (Milledge, 2018)

Monsoon water flows impede effective sewage transport and treatment. "*Sewage treatment plants on the Ganga are expensive and easily overwhelmed during monsoons; 30 per cent of them were not operational in 2013, while others were utilising less than 60 per cent of the installed capacity. They are disabled by frequent power cuts and are frequently defunct due to high operational and maintenance costs*" (Lamizana, 2019). [To better understand the practical difficulties in maintaining mixed flow systems in countries subject to monsoons and silt, see '*The Monsoon and the fury of the river Ganga*'(Chatterjee, 2016)].

Even where sewage treatment plants are present, they were never designed to remediate antibiotic-resistant bacteria or toxic waste from heavy metals, pharmaceutical products, or personal care products (Lamizana, 2019). This is when growing economies also see untrammelled growth in antibiotic use due to their easy availability, especially when access to professional medical care may be unaffordable for some.

Flush and forget sewage systems demand clean water, but water shortages are a pressing issue in India, as in many other countries. The review '*Water resources development in India*' notes: "*Increasing demand for drinking water, poor management of available water resources and unreliable water supply due to both anthropogenic and climate factors cause a virtually chronic water crisis*" (Thatte, 2018).

Fig. 8. India's sacred - and most polluted - river, the Ganges, from '*Better sewage treatment critical for human health and ecosystems*'(Lamizana, 2019), with thanks to the author, and UNEP. (It is noted huge efforts are being made to reduce pollution of the Ganges)

Realistically, and ignoring the deficiencies of Flush and Forget, how can countries such as India, with significant water issues, ever rationally prioritise, or at a practical level, implement the provision of 'Flush and Forget' for all?

In areas with dense populations, poverty, water shortage pressures, and monsoon-type weather patterns, it is inevitable that aspirations to provide all with '*FaF*' facilities—however well-intentioned—will sooner or later fail due to water shortages, economic difficulties, lack of maintenance, and broader funding. These issues are compounded by problematic monsoon weather patterns, which lead to increased infrastructure difficulties and failures.

India is undergoing rapid urbanisation. In 2011, 30 per cent of the population lived in urban areas (Census of India, 2011), putting growing pressure on surface and groundwater supply. This results in the urban poor suffering water poverty and public anger manifesting on occasions in violence (Onwosi, 2017).

Indeed, in Indian urban environments, in a world of suggested water supply corruption, some, it appears, find themselves with very restricted water access, dependent on the massive provision of water by private tankers, resulting in severe rationing and high cost, as graphically highlighted in video documentaries on the topic. Water shortage reactive violence, dubbed 'water wars', in Indian 'slums', have even seen people murdered in pitched battles over supplies.

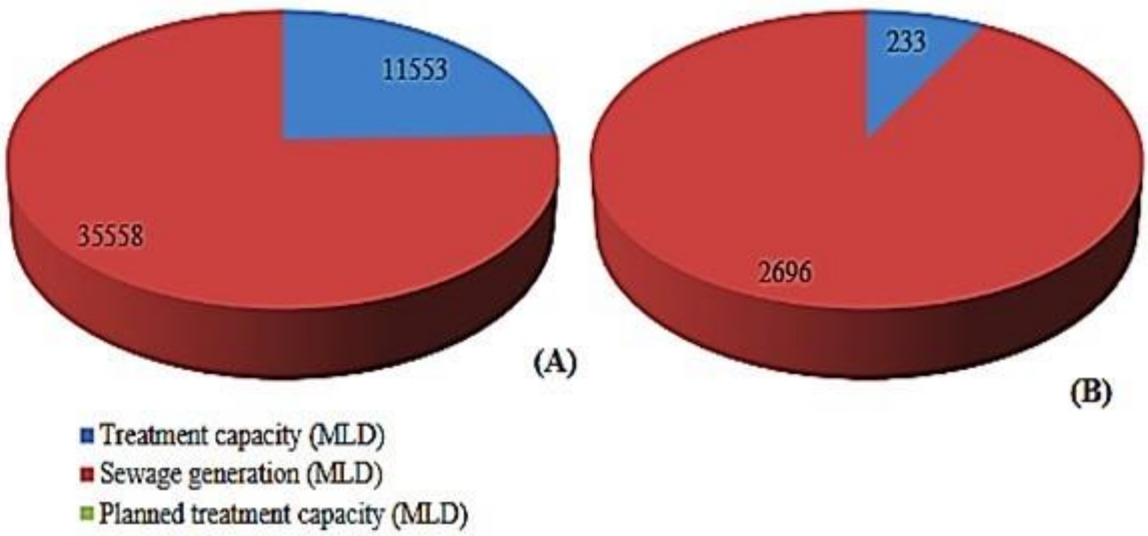


Fig. 9. Sewage generation and treatment capacity in 498 Class I cities and 410 class II towns in India. (CPCB, 2009) from '*Wastewater production, treatment and use in India*' (Kaur et al, n.d.), with many thanks to the Authors and Indian Agricultural Research Center.

In the face of water shortage and quality issues, very clearly, it is important to acknowledge increasing Government focus, action and achievement on such issues, including improving water quality in the Ganges, as reflected in the UN news item titled, '*Restoring India's holiest river*', which reports, "*This week delegates at the United Nations Water Conference, a landmark summit on the state of the world's freshwater resources, highlighted the successes* *of the Namami Gange programme. It was hailed as a case study for other countries struggling with river pollution*." (UNEP, 2023)

Given that massive infrastructure would be required to connect all people to 'FaF' sewage treatment systems, using what is arguably a dinosaur technology, surely this is the time to reassess the way sewage is dealt with, and look to a combination of vacuum urine and faeces collection; followed by combined, hyperthermophilic, anaerobic biogas production, and aerobic digestion to create compost, which option would close the cycle, and save huge amounts of clean drinking water, treatment infrastructure creation and maintenance costs, as well as reducing monsoon susceptibility, and downstream pollution.

Fig. 10. Generic water discharge pipe with thanks to toa555 and Adobe Stock

Even if a *'FaF'* for all, the pipe dream could come true, all it would achieve is the same cyclical, self-reinforcing waste of resources, only on a larger scale – and the associated environmental degradation would continue and at a larger scale.

After all, if the UK, a much smaller country with a long-developed economy and substantial 'FaF' sewage collection and treatment capacity, is failing to prevent river and wider environmental pollution, how can India be expected to do so?

For example, unauthorised discharges are a significant issue and are regularly reported as a matter of public concern in UK media, *"There are 17,684 licensed sewer overflows across England and Wales: places where water companies are allowed to discharge untreated sewage directly into the environment. Of these, 89% discharge to rivers. In addition there are 750 such places covered only by temporary licences with only very basic conditions. Data that was made available from one water company suggests that 14% of overflows are spilling* *untreated sewage into rivers more than once a week, and half are spilling more than once a month. Some are spilling hundreds of times a year."* (Blackburn, 2017)

These discharges impact UK river health. In 2017, in the UK, the WWF report '*Flushed Away*' commented, *"Yet for all their beauty and value, our rivers are in decline. I find it truly alarming to hear that just 20% of rivers in England and Wales are now classed as being in a healthy state. They face severe pressures from pollution and over-abstraction, which affect not only our wonderful wildlife but also the people who depend on rivers for their livelihoods or use them for recreation. Such impacts are creating one of the most urgent environmental crises facing the UK today."* (Blackburn, 2017)

We now know the number of discharges in the UK is higher; discharge 'spills' in the UK in 2022 numbered 301,391 (Environment Agency Event Duration Monitoring data for 2022, 2022). The problems in India are similar, it is just a matter of scale and history.

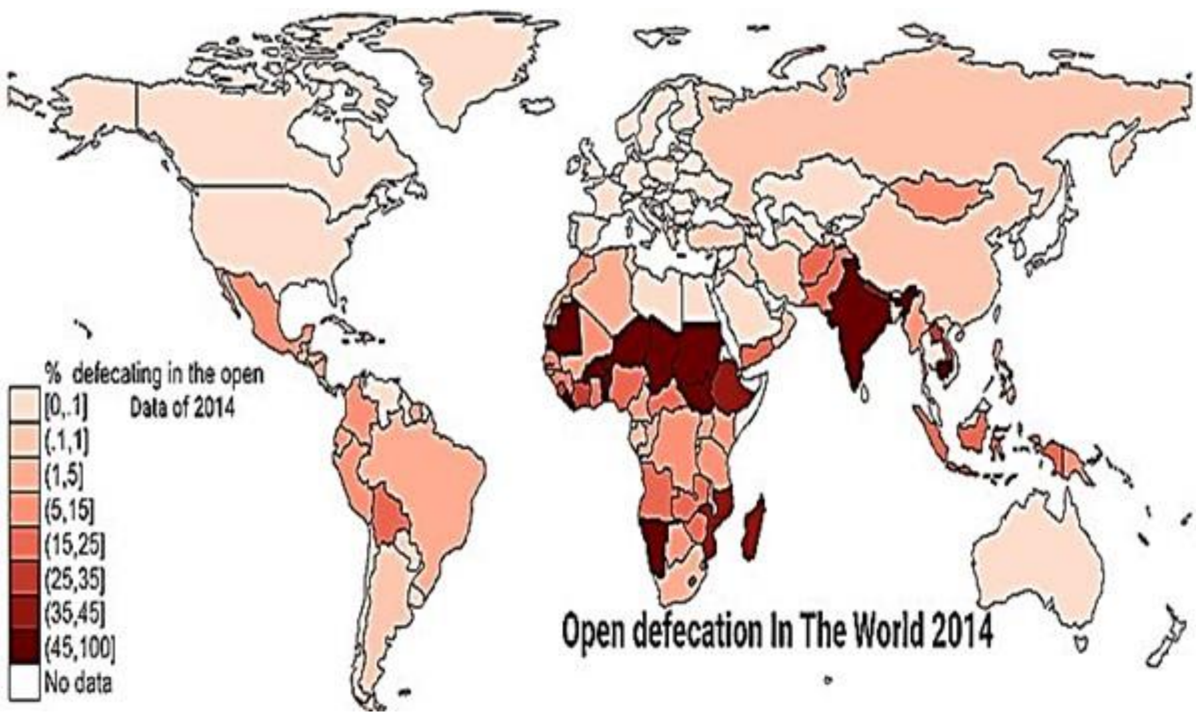


Fig. 11. With thanks to the Authors of '*Open Defecation in the World*', 2014, and the r.i.c.e. Institute.

8. FLUSH AND FORGET - A PIPE DREAM – UNSUSTAINABLE WATER DEMAND AND WASTE

Ultimately, '*Flush and Forget*', *'Out of sight and out of mind'*, WC sewage transport systems, reliant on high water use, are a "*pipe dream*" *('Drowning In Human Excreta') (Nadkarni, 2002)* the water availability burden; inability to effectively recycle sewage sludge; direct financial capital required plus ongoing running costs; and consequential concomitant cost of pollution of mixed external water streams, thus of the terrestrial and marine environment; are unaffordable for all, and particularly so for less economically prosperous countries (Bhaduri, 2012).

If pursued in the long term, the aspiration to flush and forget FaF WCs for all will ultimately become an environmental nightmare. Edwardian-style treatment plants are ineffective at significantly remediating antibiotics and pharmaceuticals. The FaF sewage plants can be updated; however, the costs are high and of more critical importance; core issues are intractable and remain unresolved, including the significant usage of clean tap water in the face of water shortages, the limited remediation of pollutants, including of contaminants of concern and antibiotic-resistant material; and in addition, the lack of capacity to effectively remediate sewage sludge remains.

A dawning realisation among some that 'FaF' 'flush and forget' technology is – to coin a phrase – a 'busted flush' comes when globally usable water is becoming a more limited resource. Supplies of water are dwindling due to a combination of unsustainable FATBAS; changing regional weather and hydrology; drawdown of underground aquifers; at the same time as rising agricultural and human water demands, including to meet increasing demand for water using FaF WCs.

As discussed in the Volume on regenerative agriculture, fertiliser chemical-intensive farming, FATBAS, which leaves ground bare for significant parts of the year, crusting the soil, making it much less permeable to rain; absorbing heat and warming the atmosphere, and failing to support, thus degrading the soil biome; including killing the water containing, and water respiring (the energy cycle) soil life, in all its diversity; thus reducing soil carbon and water content, which, inevitably will; increase irrigation needs, reduce water infiltration and retention, diminish water transpiration by life (metabolic water) in the soil, leading to; deteriorating local hydrology, reduced regional atmospheric moisture, lower bacterial rain seeding by plant bacteria, negative impacts on regional and wider weather; as well as increasing risk of heat domes, and related climate events, such as wild-fires, as discussed in Volume 2.

In consequence, water availability *per capita* is falling in many parts of the world, as discussed in the review, '*The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability*', which observes: "*The overexploitation of freshwater resources threatens food security and the overall well-being of humankind in many parts of the world. The maximum global potential for consumptive freshwater use (i.e. freshwater planetary boundary) is approaching rapidly, regardless of the estimate used. Due to increasing population pressure, changing water consumption behaviour and climate change, the challenge of keeping water consumption at sustainable levels is projected to become even more difficult in the near future*" (Kummu, 2016) [this author's underline].

"An area is experiencing water stress when annual water supplies drop below 1,700 m3 per person. When annual water supplies drop below 1,000 m3 per person, the population faces water scarcity, and below 500 cubic metres "absolute scarcity"." (UN, 2015)

"Whilst in the 1900s just over 200 million people (14 per cent of global population) lived in areas under some degree of water scarcity, this number increased to over two billion by the 1980s (42 per cent) and reached 3.8 billion people (58 per cent) by the 2000s" (Kummu, 2016) [this author's underline].

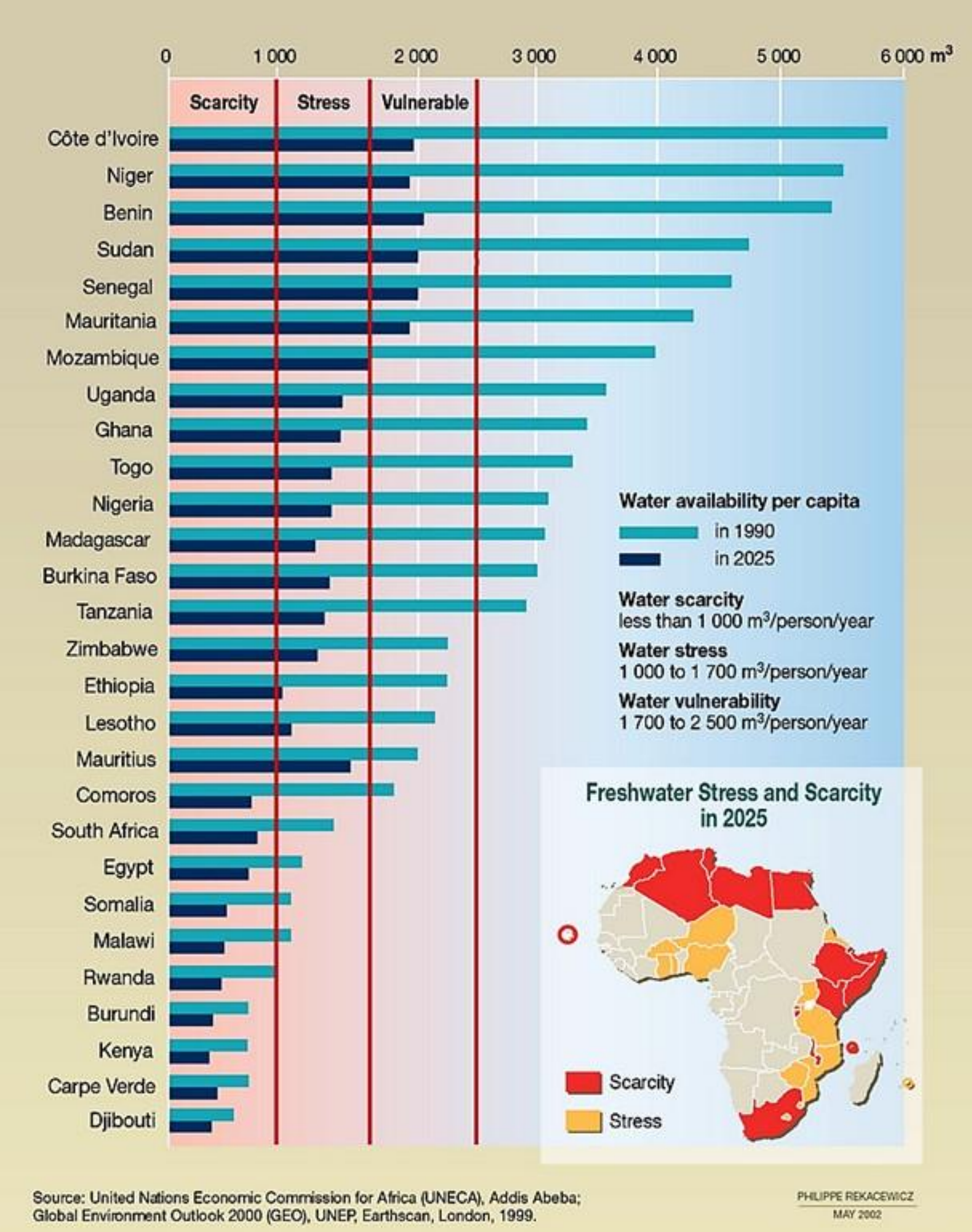


Fig. 12. Projections water scarcity/stress in Africa, from Global Environment Outlook, with thanks to United Nations Economic Commission for Africa and UNEP 2002.

Renowned Swedish hydrologist Malin Falkenmark, in her 2013 review, '*Growing water scarcity in agriculture: future challenge to global water security*', observes: "*The most populated latitudes are, in fact those in which water is at its most scarce. In these regions, agricultural water use is more dominant than in other parts of the globe.* (Falkenmark 2013)

"*In 22 countries, mostly in the Northern Africa and Western Asia region and in the Central and Southern Asia region, the water stress level is above 70 per cent, indicating the strong probability of future water scarcity*" (Overview — SDG Indicators, n.d.).

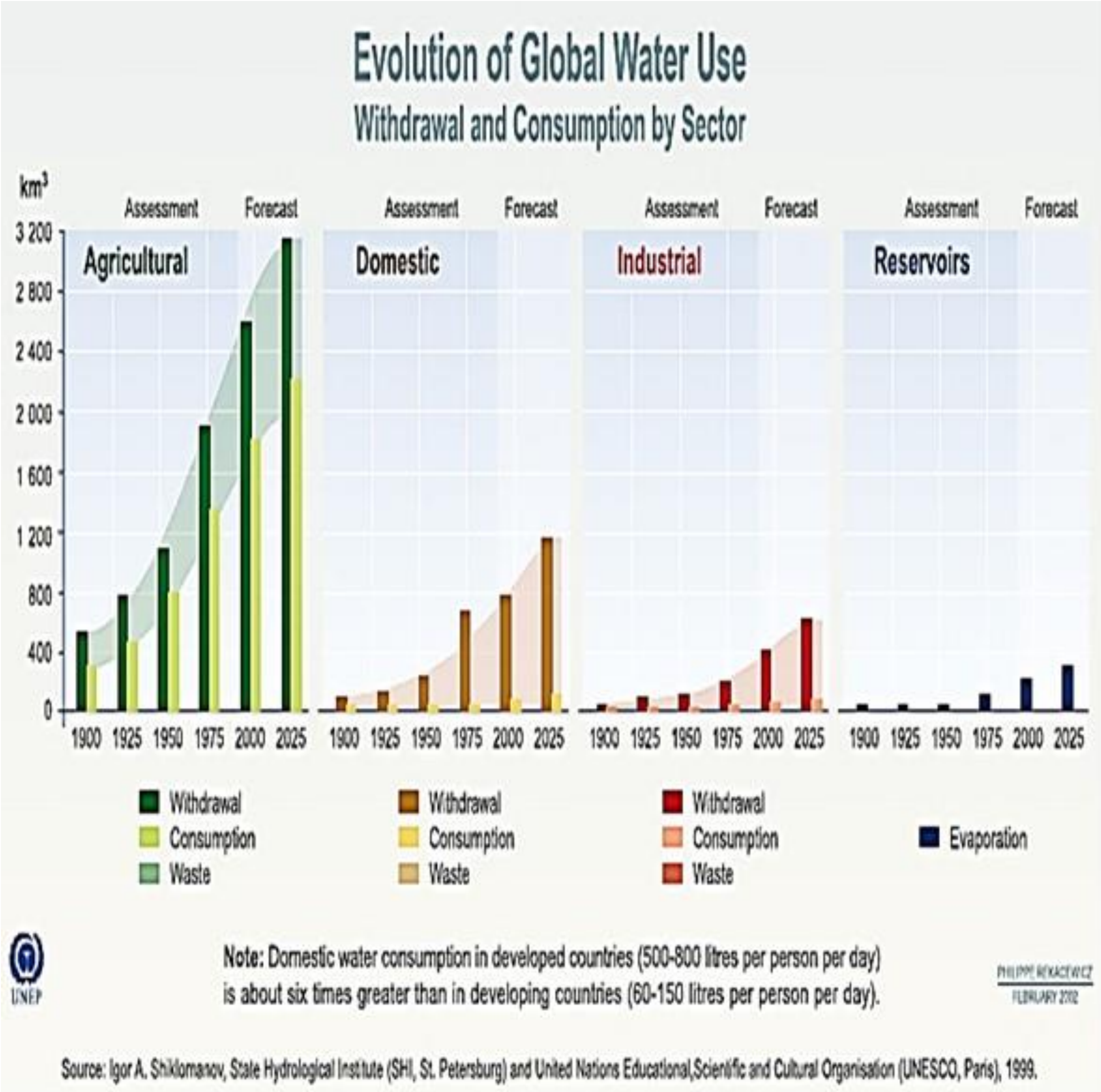


Fig. 13. Relationship between global water withdrawal, consumption, and waste, by sector, with many thanks to Sick Water, the Authors and UNESCO

8.1. WATER SUPPLIES - POOPED-OUT

Water availability per capita is falling. At the same time, better sanitation is urgently needed. However, the increasing scarcity of the water necessary for survival logically means that providing everybody with water-intensive, water-polluting, 'Flush and Forget' WC sewage systems is a non-starter, a busted flush, a pipe dream, not something any rational person should promote.

While there are undoubtedly many other significant water users, including FATBAS, the largest by a long way, we should not underestimate the direct water usage and the additional indirect downstream pollution effect on drinking water supplies due to our use of 'Flush and Forget' FaF sewage systems.

There are several billion of us on the planet. A family of five, based on about seven visits a day each and a WC flush volume of 12l, requires 150,000 litres per annum to flush away an estimated 250 kg of sewage solids and accompanying urine. Modern WC flush-box water cisterns will reduce water use for solids to around 6l, and for urine to around 3l, a reduced but still significant amount of water when considered in terms of global daily usage.

Fig. 14. A generic sewage plant with thanks to the Author and Adobe Photo Stock

Thus, to provide the water necessary to extend 'Flush and Forget' sewage technology across the developing world would require immense investment in infrastructure, such as dams and river management, including in drought-prone geographic locations where such resources are already clearly and unsustainably drying and ecologically dying.

That is just the start of the catalogue of problems which make FaF unachievable for most of the planet's population. One must also consider that because WC flush water is generally delivered to communities by the same pipe system that transports drinking and washing water, it has to be purified to the same standards, even though its initial destination never extends beyond a toilet bowl:

- This massive quantity of drinking-standard flush water, as its circular journey continues, as discussed, is then mixed with excreta, run-off and other industrial pollutants.
- Sewage wastewater negotiates a vast, extensive, expensive maze of networked pipes, sewage manholes, pumping stations and treatment plants before being discharged into rivers and aquifers, either directly and untreated or following some degree of treatment. Affordable, practical technology to remove pharmaceuticals or antibiotic-resistant bacteria from the massive volumes of sludge and wastewater produced has not yet emerged. Reverse osmosis is costly, and produces a flow of concentrated pollutant waste (Romeyn, 2016). Sewage sludge cannot be effectively further treated.

Fig. 15. Generic sewer relining with thanks to Oleksandr Bilyi and AdobeStock

- Extreme weather events leading to flooding—including during monsoon seasons in tropical regions—lead to sewage backup into domestic properties unless massive quantities are discharged untreated into waterways, leading to significant pollution. "*You've got to divert somewhere so it doesn't get backed into people's yards and homes*" (Jackie McKay, 2019).
- Significant seasonal weather events, such as cyclones and monsoons, place extra demands on infrastructure and, thus, maintenance budgets. For example, "*The sewers in Delhi have lost 80 per cent of their carrying capacity due to age and poor maintenance*" ('Drowning In Human Excreta') (Nadkarni, 2002).

By way of example, in India, as it stands, "*within cities only a minority has access to water and sewerage systems*" (Bhaduri, 2012), so one can imagine the additional pressure on a creaking urban system should hundreds of thousands more homes be connected up to it. The likelihood is that most of the existing infrastructure would have to be ripped out and replaced before fresh capacity can be added, causing costs to soar. The unending large water volumes and high flow rates, exacerbated by monsoon flows, into wastewater treatment plants would also limit remediation treatment options.

8.2. LACK OF WATER? - NOT ONLY POOR COUNTRIES

Lack of water is not simply the preserve of less economically well-off regions; it is also an issue of growing prominence for cities such as Los Angeles and San Diego in California, Sydney in Australia, and Cape Town in South Africa. In those cities, significant investment is now being made into recovering even treated sewage wastewater, which, as everywhere, would otherwise be pumped into rivers and aquifers to dilute any pollutants it contains.

Tertiary water treatment techniques such as reverse osmosis are increasingly used to turn wastewater back into potable water, allowing it to be remixed in catchment dams. For example, in Australia, Ian Wright, senior lecturer in environmental science at Western Sydney University, noted in '*The Conversation'* that *"residents in some parts of north western Sydney drink water that is partly supplied by… indirect reuse of treated sewage. The North Richmond Water Filtration Plant extracts and treats water drawn directly from the Hawkesbury-Nepean River." (Wright 2018)*

Fig. 16. Warragamba Dam –- *"Several large towns discharge treated sewage into rivers supplying Warragamba Dam, which holds 80 per cent of Sydney's water reserves*" (Wright, 2018). with many thanks to the Author Jonathan Pope from Vancouver, Canada and Wikipedia

"*A major contributor to the river flow is treated sewage discharged from upstream treatment plants . . . In the very low river flows in the recent dry summer, I estimate that treated sewage comprised almost 32 per cent of the Hawkesbury-Nepean flow in the North Richmond area for* *the first week of January. The water is highly treated at the Sydney Water-owned North Richmond plant to ensure it meets Australian drinking water guidelines*" (Wright, 2018).

"*Every year the river receives more and more treated sewage as a result of population growth. This is certain to continue.*" . . . "*Several large towns discharge treated sewage into rivers supplying Warragamba Dam, which holds 80 per cent of Sydney's water reserves*" (Wright, 2018). However, as discussed, the extent to which such water, albeit treated to varying extents, still contains micro and nano-plastics and other contaminants of concern, including pharmaceuticals, must be considered.

Similarly, Cape Town has water issues and suffered severe water restrictions in 2017/18, dramatically highlighting the long-term importance of optimising the usage of available water for activities other than 'Flush and Forget'.

Fig. 17. The Waterkloof Dam, Cape Town's largest reservoir, ran dry in 2018, with thanks to the WWF.

8.3. WATER CONFLICT

Individuals and States globally are affected by water shortages. Water shortages lead to conflict, corruption, hardship, ill health, resentment, and migration pressures at national and population levels, including due to international competition for water resources, dam building on rivers that were shared historical primary water sources, and aquifer extraction from communal resources.

The BBC article, '*How water shortages are brewing wars*', reports, "*As much as a quarter of the world's population now faces severe water scarcity at least one month out of the year . . . it is leading many to seek a more secure life in other countries. "If there is no water, people will start to move," says Kitty van der Heijden, chief of international cooperation at the Netherlands' foreign ministry and an expert in hydropolitics"* (Milne, 2021).

"Water scarcity affects roughly 40% of the world's population and, according to predictions by the United Nations and the World Bank, drought could put up to 700 million people at risk of displacement by 2030. People like van der Heijden are concerned about what that could lead to" (Milne, 2021).

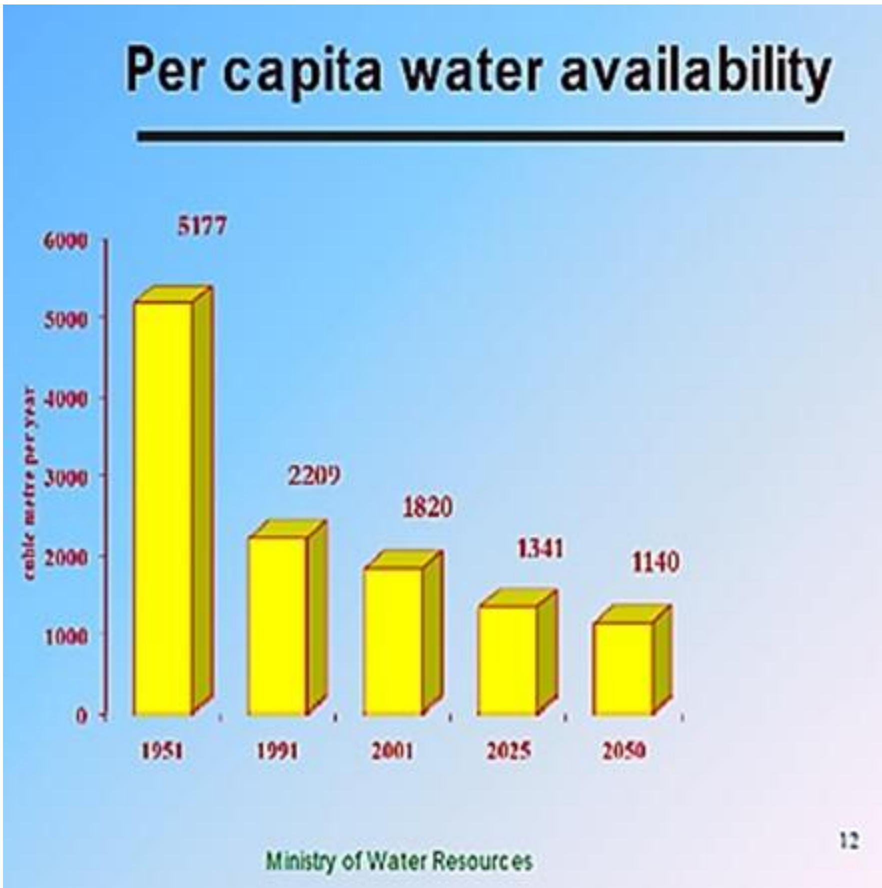


Fig. 18. '*Water Resources Development and Management in India - Overview*' Presentation, by UN Panjiar, Secretary to the Ministry of Water Resources, India. (Panjiar, n.d.), with many thanks to the Author.

The BBC article continues, "*Over the course of the 20th Century, global water use grew at more than twice the rate of population increase. Today, this dissonance is leading many cities – from Rome to Cape Town, Chennai to Lima – to ration water. Water crises have been ranked in the top five of the World Economic Forum's Global Risks by Impact list nearly every year since 2012. In 2017, severe droughts contributed to the worst humanitarian crisis since World War Two, when 20 million people across Africa and the Middle East were forced to leave their homes due to the accompanying food shortages and conflicts that erupted.*" (Milne, 2021)

In India, for example, it was reported that there have been *"a growing number of conflicts between users (agriculture, industry, domestic), intra-state and inter-state" ('Water Resources Development in India: Critical Issues and Strategic Options', generally n.d.)*.

Scott Moore, a specialist in water resource management and author of '*Subnational Hydropolitics*', notes that water shortages "*in recent years alone, have required use of the army to retake a canal seized by protesters near Delhi, forced IT firms to close in India's high-tech capital of Bangalore, and sparked riots in which politicians from neighbouring states have been burned in effigy. There is a serious risk that these internal water wars will destabilise Indian politics and hold back its rise as a regional power.*" (Moore, 2010) (See also 10 Violent Water Conflicts, Detges, 2017) ('*India's Internal Water Wars,* Moore, 2018).

In areas of water stress, water shortages and conflict globally will increase migration pressures towards safer, more stable environments, with downstream implications for more financially secure regions (Hassan, 2018).

Another example: in July 2021, clashes occurred in Khuzestan province in Iran between security forces and demonstrators protesting severe water shortages caused by prolonged drought, unseasonably hot weather, and mismanagement of dwindling resources.

A wry line from a report by the Indian Centre for Science and Environment captures the potential for simmering resentment, which water inequality breeds, when it talks of "*the political economy of defecation – investment in sewage systems mainly assists the rich to excrete in convenience*" (The political economy of defecation. 1992).

Indeed, political tensions over global water rights, including rights to build dams or abstract water from rivers that pass through several countries or regions, are becoming more common. The UN Office for the Co-ordination of Humanitarian Affairs (OCHA) lists the world's most contentious water conflict areas as the River Nile (Egypt, Sudan, Ethiopia); Yemen; Euphrates-Tigris (Turkey, Syria, Iraq); Afghanistan/Iran borderlands; the Mekong River Basin (China, Laos); Somalia; Turkey/Armenia borderlands and Bolivia. As discussed, significant amounts of clean drinking water are needed to flush WCs.

8.4. EXAMPLES OF REGENERATIVE AGRICULTURE COMBINED WITH POLICIES TO ENCOURAGE PLANT GROWTH ADDRESSING REGIONAL WATER ISSUES

The regenerative agriculture Volume explains why the reintroduction of regenerative agriculture is key to stabilising climate change, including moderating weather, preventing drought, and reducing floods through simple techniques such as regenerative agriculture practices, earth dams, water collection strategies, the reclaiming of very degraded lands, stabilising water availability, raising water tables, maintaining yields, increasing nutrient density, reducing pollution, improving lives and the environment.

9. FAECES AND URINE; AKA NIGHT SOIL - THE STARTING POINT

Faeces and urine are an obvious starting point when considering sewage. Historically, they were a wholly natural organic product containing organic matter in the form of undigested fibre and bacteria, minerals including phosphates, and nitrates.
In times past, urine and faeces were widely distributed back to and incorporated in the soil by soil denizens, vast herds of wild animals, livestock, and humans, providing substrate to fungal, bacterial and wider soil life, as well as helping to cycle and introduce rumen and saliva derived, as well as seed plant and soil, bacterial and fungal biology, thus, directly and indirectly, assisting plant germination and growth. Nutrients, as well as fungal and bacterial biology, were also recycled within oceans by marine creatures, helping maintain and define ecosystem annual cycles on which we rely for life.

The ancient historical recognition of the importance of faeces in agriculture and its capacity to help turn marginal land into productive ground in which to grow crops, is presumably why the mix of urine and faeces is also called '*soil*', and why urine and faeces collected at night from urban privies, was called '*night soil*'.

The advancement of human 'civilisation', the vast expansion of human population, the consecutive emergence of densely populated conurbations, and related human-organised livestock proliferation in confined enclosures, massively challenged and complicated the long-standing natural cycle of return of faeces and urine to the land.

9.1. BY FAR THE LARGER PORTION OF SEWAGE IS PRODUCED BY LIVESTOCK

We have replaced migrating ruminants on prairies with arable farmland and enclosed livestock production. The majority of urine and faeces production is through livestock. We have greatly exacerbated the problem of disposal and recycling of cattle urine and faeces through; stockyard and other enclosed rearing; what we feed livestock; how we keep them; and by vastly increasing their numbers.

Most of this book relates to human urine and faeces because that is the more complex issue. However, livestock urine and faeces, generally as slurry, are an equally pressing, voluminous, and impactful environmental issue.

9.2. EXCRETA AS A SOIL FERTILISER – SOURCE OF CARBON, NITROGEN, MINERALS

Historically, excreta of all sorts was highly regarded as a land conditioner. For example, Hunza children would take the trouble to gather sheep droppings from paths for inclusion in compost. Historically, Chinese families frowned on family members using the toilets of other families because the significant agricultural value of faeces was widely recognised. Composted manure played a vital role in nations' health and wealth for many generations.

Collectively, we produce a lot of faeces and urine. While there are clear and significant health caveats, pollution worries, and real-life practical issues in the industrialised world, the capacity of unadulterated human faeces and urine to support plant growth has been clearly shown.

For example, environmental engineer Antti Hannila examined the use of human waste as a fertiliser in a Zambian village, and his 2008 paper on the subject includes the startling conclusion; “*the annual amount of excrement (urine and faecal matter) from a single person contains approximately [the] same amount of nutrients that are required to grow grain for [a] single person’s annual need. Basically, this means that we all produce enough fertiliser to cover our own food requirements.*” The figures Hannila relies on are in the table below (Hannila, 2008).

The most important nutrients	*Urine (500 L)*	*Solid excrement (50 L)*	*Total*	*Nutrients required to produce 250 kg of grain*
Nitrogen (N)	*5.6 kg*	*0.09 kg*	*5.7 kg*	*5.6 kg*
Phosphorus (P)	*0.4 kg*	*0.19 kg*	*0.6 kg*	*0.7 kg*
Potassium (K)	*1.0 kg*	*0.17 kg*	*1.2 kg*	*1.2 kg*
Total	*7.0 kg*	*0.45 kg*	*7.5 kg*	*7.5 kg*

Table 1. Nutrients in Human Faeces and Urine, with thanks to the Author (Hannila, 2008)

The same conclusion was reached by Sirkka Malkki – a specialist in dry toilets and composting from Finland’s TTS Institute – who estimated: “*The annual amount of toilet waste is about 520 kg/person. This amount includes altogether 7.5 kg of nitrogen, phosphorus, and potassium, and some micro-nutrients in a form useful for plants. If the nutrients in the faeces of one person were used for grain cultivation, it would enable the production of the annual amount of grain consumed by one person (250 kg)*” (‘*Human faeces as a resource in agriculture’,* Malkki, 1999). Elsewhere, the paper ‘*Characterisation of Sewage Sludge Generated from Wastewater Treatment Plants in Swaziland in Relation to Agricultural Uses*’ (Mtshali, 2014) looked at the mineral content of sludge from various sources in Swaziland.

Mineral	**N** %	**P** %	**K** %	**Na** gr/kg	**Ca** %	**Mg** %	**Cu** mg/kg	**Organic matter %**
Sludge	1.6-3.9	1.0-2.4	0.05-0.16	0.07-0.18	0.51-1.22	0.06-0.42	208-528	20-60
Mineral	**Fe** %	**Cr** mg/kg	**Pb-** mg/kg	**B** mg/kg	**Ni** mg/kg	**Zn** mg/kg		**Carbon** %
Sludge	2.15-2.89	429-943	7-90	50-93	4-233	93-1577		10-30

Table 2. ‘*Characterisation of Sewage Sludge Generated from Wastewater Treatment Plants in Swaziland in Relation to Agricultural Uses*’ – lowest and highest average median in the range from 6 sewage treatment sites. (Mtshali, 2014)

An example of the mineral content of urine is set out in the indicative data below from the website, ‘*What Is the Chemical Composition of Urine?* (Figures vary, see also Tables 8 and 9 of the review, ‘*The Characterization of Feces and Urine: A Review of the Literature to Inform*

Advanced Treatment Technology', Rose. (2015)) *However, despite robust indicative data, historical wisdom, and common sense, in our more squeamish times, modern sewage and wastewater treatment is grounded in a philosophy that considers human excreta as inherently dangerous 'waste' rather than as a potentially valuable resource that we heavily pollute, making safe recycling very difficult.*

Inorganic content of Urine g/l (figures vary)									
Water	**Urea**	**Sodium**	**Chloride**	**Sul-phate**	**Potassium**	**Phos-phate**	**Amm-onia**	**Nitrogen**	**Magnesium**
95%	9.3-23.3	1.2-4.4	1.9-8.4	0.2-1.8	0.8-2.7	1.2	0.5	8-12	0.1

Table 3. Data from the website '*What Is the Chemical Composition of Urine?* (2020) with thanks to ThougthCo. (ThoughtCo. 2020)

Whilst not ubiquitous, un-composted human sewage sludge is, with strict usage regulation, returned to land in some countries as a soil improver. Albeit, that practice is becoming increasingly controversial due to the pollution of sewage with; heavy metals, chemicals, microplastics, and pharmaceutical products. Indeed, cattle and people have become ill where and farmland has become significantly polluted due to inopportune sludge use,

As discussed and critically, the only FaF sewage sludge disposal options are; application to agricultural land; landfill; incineration; or discharge into rivers and oceans; all of which create their own problems. Some countries are turning to incineration, but it is not only very potentially expensive but also raises its own gaseous and disposal pollution issues.

Wastewater, as against sludge solids, treated or not as the case may be, to varying extents, is discharged into aquifers, rivers, lakes, oceans and used directly to irrigate farmland, causing varying levels of pollution. The solution is root and branch reform of sewage collection and transport, focusing on minimising the pollutants it contains. Vacuum WC systems would enable the collection of human urine and faeces in a way that minimises pollutant content, allowing thermophilic biogas production and hyperthermophilic composting, which would further reduce pollutants.

9.3. FAECES – AN ADDITIONAL 'GREEN' ENERGY SOURCE

Taking an energy-centric perspective, optimising the treatment and utilisation of human and animal urine and faeces through source collection and biogas production, as well as providing a host of wider environmental benefits, could help address global energy issues.

For example, it is suggested, "*The potential to generate energy from currently available and sustainable grown/recovered major feedstocks (livestock manure, food waste, sewage, crop residues and energy crops) in the world is 10,100 to 14,000 TWh. This energy can meet 6-9 % of the world's primary energy consumption or 23-32% of the world's coal consumption. When used as electricity, it has the potential to meet 16-22% of the electricity consumed globally. If the energy is utilized as biomethane, it can substitute 993 to 1380 bcm of natural gas, equivalent to 26-37% of the current natural gas consumed globally.*" (EBA, n.d.)

Of course, there are many ways to estimate and assess environmental benefits. The above estimates include crop residues, which should be left as soil armour. Food waste and crop residues could be better used to provide additional carbon for composting. However, the scope of potential energy benefits is thought-provoking and could help close the environmental cycle.

The Finish review titled, '*LCA of anaerobic digestion: Emission allocation for energy and digestate*' took an alternative perspective and still found benefits in using faeces for biogas. (Timonen 2021)

Anaerobic digestion is considered in more detail in later sections. A combination of biogas production and composting arguably looks to offer the best of both worlds. Appropriately produced composts can provide diverse fungal and bacterial biology lacking in all but the most developed carbon-rich soils, minerals, and some organic material. The minerals and biology are arguably more crucial than the carbon content to plant and soil biome growth because, as above, 90% of soil carbon is supplied by photosynthetic sugar exudates – plant detritus only supplies about 10% - providing additional rationale for the net benefit of bio-gassing urine and faeces for energy, followed by composting that optimises biology.

9.4. A STITCH IN TIME SAVES NINE – PRE-EMPT POLLUTION

The helpful review "*Sewage sludge: Why we need to stop pollution at source*" by the Marine Conservation Society observes, "*Preventing contaminants from entering wastewater systems must be prioritised, as it is the most effective and sustainable option to reduce contaminants within sludge.*" (Marine Conservation Society 2021). To sludge as a contaminant source, one could add wastewater discharge, untreated sewage discharge, farm slurry, grey water, and the list goes on. As a pollution mitigation strategy, pre-empting pollution at source, using vacuum WC technology, makes unarguable common sense.

10. SANITATION – TREATMENT AND RECYCLING – THEN AND NOW

Until very recently, through the many millennia of the extended human story, the composted faeces and urine of animals, humans, and birds have been an important mechanism to supplement the soil's minerals, nitrates, microbial, bacterial, and mycorrhizal diversity and thus close the circle. We need to re-find a 21st-century way to similarly close the circle.

10.1. YESTERDAY'S TECHNOLOGY

Most current sewage treatment and collection systems, as discussed, have Victorian and Edwardian origins. Whilst treatment systems have improved, they have not significantly altered in underlying techniques for over a hundred years and are environmentally unsustainable because:

- The amount of water used and polluted in a drying world with growing populations is unsustainable.
- The mixing of several waste pollutant streams greatly complicates treatment and recycling.

- Whilst micropollutants in sewage wastewater can be largely remediated (as in a small proportion of plants in Switzerland at significant expense), sewage sludge cannot be significantly remediated by any available technology and contains an extensive range of organic pollutants, micro-plastics, tyre dust, and heavy metals etc.
- Burning sewage sludge, whilst potentially the least bad disposal option, is expensive in capital and running costs, beyond the budget of many countries, and produces carbon dioxide as well as atmospheric pollutants. The ash has to be disposed of in specialist landfills. Incineration also fails to close the cycle and wastes mineral and carbon resources that could be used better.
- Using sludge on agricultural land damages and pollutes soils; pollutants, including pharmaceuticals and microplastics, are taken up by crops and grasses, impacting their biology and entering the food chain. Further pollutants in sewage sludge applied to agricultural land are released by rain run-off, entering the wider environment, including via rivers, lakes and oceans. Plastic micro-particles in sewage sludge that are applied to land and dried by the sun are absorbed and picked up in the wind, incorporated in clouds, and spread globally.

There is currently no movement to root-and-branch change in urine and faeces capture and treatment. The response to overwhelmed and inadequate sewage systems is an investment in more of the same, just newer and more extensive.

For example, in the UK, with growing public appreciation and expression of concern as to the negative impacts of sewage discharge into the environment, as mentioned above, huge sums are being spent on new and old pipe systems, as in the London 'Thames' project, to collect and transport sewage to treatment plants, which plants, as discussed, have limited efficacy, thus whilst unregulated discharge is reduced, issues of disposal of treated sewage wastewater and sewage sludge, remain.

Thus, depressingly, the public is being asked to invest massive amounts, through charges or taxes, to improve what is logically yesterday's irredeemable FaF dinosaur technology. This technology uses and pollutes large amounts of clean drinking water and, by mixing waste streams, precludes effective decontamination, and recycling of resources that close the environmental cycle.

Logically, ultimately, a move away from 'Flush and Forget' WC technology is inevitable, as ongoing use of water-demanding, inefficient, wasteful, polluting current FaF systems is simply unsustainable at many environmental levels for the reasons set out.

<u>The sooner the general public widely understands that the current FaF sewage systems are unsustainable, technologically outdated, unfit for purpose, fundamentally flawed, irredeemable dinosaurs and that an alternative exists, vacuum WC collection-based systems, the sooner we can begin investing in more sustainable sewage collection and treatment, rather than wasting money on what will likely prove over time, to be expensive, redundant, outdated, fundamentally flawed, environmentally unsustainable systems, incapable of closing the resource cycle.</u>

10.2. TIMES GONE BY – THE PAST

Excreta, historically, was seen as an invaluable component of productive soil. Faeces and urine were not always waste products, costing significant amounts of 'public' money to dispose of. In English cities, before we so extensively polluted our faeces, the 'night-man', in Tudor times referred to as the 'Gong-farmer', once found brass in muck by collecting the latter to sell to the farmer for composting.

Trade in human ordure as an economically valuable commodity, with agricultural value, was entrenched for millennia in China, where, historically, sewage was always part of the circular economy. In past times, human waste was paid for in gold in China. Generations of Chinese agricultural observations on how to feed large numbers on small acreages had led to human excreta being recognised as a crucial factor in creating fertile, productive soils.

Franklin King, a distinguished American agronomist, following a one-year tour of China, Korea and Japan, produced a book in 1911 titled '*Farmers of Forty Centuries*', recording then contemporary Eastern agricultural practices and results. In his excellent book '*Farmers of Forty Centuries*', he noted that human waste was big business. "*The International Concession of the city of Shanghai, in 1908, sold to a Chinese contractor the privilege of entering residences and public places early in the morning of each day in the year and removing the night soil, receiving therefore more than $31,000 [in] gold for 78,000 tons of waste" (King, 1911).* Such was the nuanced appreciation by Chinese farmers of faeces and urine as fertiliser that those from European districts commanded a higher price.

Fig. 19. The calling card of an 18th-century London nightman - the person who emptied the privy and sold the waste for compost with many thanks to the Wellcome Collection.

King, in 1911, casting a glance back home at the then growing need of then-nascent FATBAS western intensive farmers for nitrates and phosphates, and the levels of non-organic fertiliser used, observed, *"All of this we not only throw away but expend much larger sums in doing so* [whereas the Chinese] *could not survive and tolerate such waste*" (ibid).

Interestingly, in China, King could tell how far he was from a city by the health and greenness of crops. Owners of land alongside roads would set up WC facilities, competitively trying to entice travellers to use their facilities, including by providing free cups of tea and poems to pass the time. As discussed, even in recent times, the use by a family member of another family's toilet was considered an act of disloyalty. (A more detailed history of the reuse of faeces in China – and the degree of logistical coordination behind it – is detailed in the chapter '*The Treatment of Night Soil and Waste in Modern China*' by Yu Xinzhong (Leung, 2010).

Similarly, in London, urine and faeces had value before mineralised guano fertiliser arrived, and an extensive water-based sewage disposal system was developed. *"In 1846, the City of London had been able to charge contractors £5,000 for the right to collect dung from streets and houses . . . boats and barges that carried grain and vegetables to London's markets returned laden with manure purchased at Dung Wharf . . . but five years later the City had to pay contractors £4,900 to do the same thing. The market for urban excrement had collapsed . . . . "* (Angus, 2018)

In a past era, when paper bags and grease-proofed paper were used as food packaging, composting of human faeces and urine, along with all the other organic wastes from towns, continued in the UK in municipal facilities until the 1960s. Sewage and municipal rubbish composting processes (before the widespread use of plastic bags, a throwaway society, and burgeoning pharmaceutical use) were used to effectively remediate common pathogens and bacteria to acceptable risk levels, to the point where the resultant composts in rural non-industrialised catchment areas, could be reasonably safely and usefully incorporated in cropping soils. Such fertilisers were much appreciated by farmers (*Fertility from Town Wastes* – Wylie 1955).

10.3. THE ADVENT OF ARTIFICIAL 'FERTILISER'

With the advent of a combination of growing populations, large industrialised conurbations, flush WCs and FaF technology, and the consequent flushing away of resources in urine and faeces into rivers, rather than their return in compost to soils, then emerging FATBAS farming techniques, obliged industrial societies to turn to the exploitation of natural but limited sources of; nitrates, phosphates, and other minerals, such as guano, shipped from distant continents, to secure adequate crop yields.

For example, until resources became exhausted in 1874, dried layer upon layer of compacted guano—the excreta of birds feeding on nutrient and mineral-rich marine foods—was mined from the Chincha Islands off Peru and shipped to Europe. This allowed Victorians to enjoy the benefits of foods grown on soils fertilised with bird dung conspicuously high in phosphorus, nitrogen, and likely a wide range of marine micro-minerals, as well as iodine.

This was an age when exporting, composting, and returning to the land of faeces and urine in animal waste were still valued. The combined impact of composts and nutrient-rich guano doubtless played a part in improving the quality of soils and the nutritional value of the foods grown in them, thus for the fortunate, lending a hand in better standards of essential health, including cardiac disease and, notably, potentially better neurological development and function. Yes, it is surprising, but there is evidence that essential health in relation to non-communicable disease was better before the arrival of modern FATBAS-grown highly processed food.

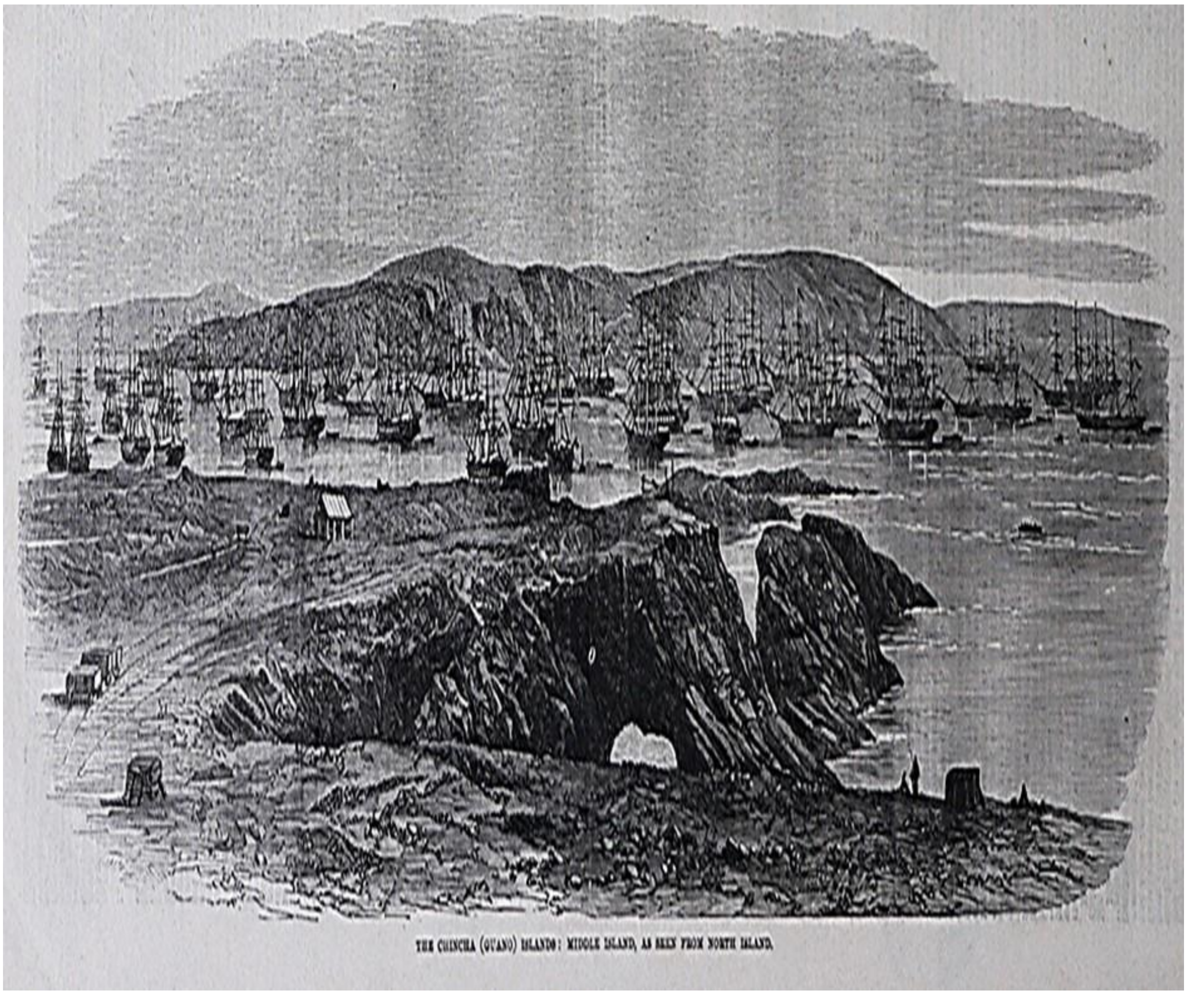


Fig. 20. Chincha Islands, where guano was found in abundance. Mining was done on-site, and ships transported it to Europe with, thanks to Wikipedia

However, guano sources were depleted over time, and other fertiliser sources were needed. As discussed later, the next fertiliser innovation was the use of rock phosphate, the extraction, treatment, and use of which creates its own environmental and biological issues.

Like guano, supplies of rock phosphate-rich ores of the right quality are ultimately finite. Replacement of rock phosphates requires adequate organic deposition and millions of years for appropriate tectonic plate movement, so it is not something that foreseeable generations can rely on. Further, producing fertiliser from phosphate rock is energy—and resource-intensive and polluting, as are artificially produced nitrates.

Importantly, equivalent yields are being achieved using regenerative agricultural techniques without artificial fertilisers. Instead, regen ag builds soil biology and relies on natural nutrient production and supply pathways, potentially making rock phosphate and artificial nitrogen fertilisers largely redundant. These issues are discussed in the Volume on regenerative agriculture.

Fig. 21. The cormorant, the most important producer of guano with many thanks to Leucocarbo and Wikipedia

Fig. 22. The nest of the Peruvian booby is made of almost pure guano with thanks to A Catenazzi and Wikipedia

11. FAILING INFRASTRUCTURE – DINOSAUR TECHNOLOGY - ECONOMIC AND SOCIAL COSTS

FAF infrastructure is costly, unaffordable for many nations, where available failing, and ultimately a fundamentally flawed dinosaur technology. Discharging untreated sewage water that flows into the environment causes significant damage worldwide. The better-appreciated environmental consequences of untreated discharge are discussed within the wider text. However, there are also significant wider social health and economic costs for those not connected to adequate sanitation.

For example, in India, “*Rural people spend at least 100 rupees (97p) each year for the treatment of water/sanitation-related diseases. According to the government of India, this adds up to 6,700 crore rupees (£650 million) annually, which is just 52 crore rupees less than the annual budget of the Union health ministry's and more than the allocation for education*” ('Drowning In Human Excreta';_Nadkarni, 2002).

11.1. FAF - A DINOSAUR TECHNOLOGY

Whilst alluded to already, it is reiterated in a separate section because it is crucial. Current FaF sewage collection, transport, treatment and disposal modalities are fundamentally flawed, irredeemable, dinosaur technologies because:

- the characteristics of sewage sludge, its texture, organic content, and wide pollutant content profile, mean there are NO effective or economic technologies, existing or foreseeable, green or otherwise, to remediate sewage sludge to a standard that allows closure of the environmental; farm, food, excreta loop;
    - incineration of sewage sludge is the current least bad option, but it is expensive, creates issues and does not close the cycle
    - application to farmland is poisoning the environment and polluting the food chain.
    - Landfill produces methane and irresponsibly passes the pollution onto a future generation.
- these FaF deficits cannot be rectified because there is no way to remediate the pollutants in sewage sludge, once faeces and urine have been hugely diluted and mixed into a large variety of wider pollutants from the external mixed source liquid sewage waste stream;
- the pollution caused by untreated sewage has significant, even unaffordable, social, environmental, and economic costs;
- high-quality tertiary sewage wastewater treatment is feasible, but plants require substantial economic investment to build and operate. Thus, they are not an option for many economies. Further, the residue of extracted pollutants requires disposal.
- Inevitably, it is ultimately the consumer that will pay, and large currently invested corporations that will profit from the status quo will be reluctant to invest in change, even if for the long-term species and planetary benefit, if it will impair their immediate income streams – such is human nature;

- the simplest and most effective solution, is to collect urine and faeces at source, avoid massive dilution and exogenous pollution of them, thus allowing processing of them to standards that would allow the recycling of the nutrients they contain.

11.2. 'STORM' BYPASS, AND DIRECT SEWAGE DISCHARGE

Even in developed nations with extensive collection and treatment systems, untreated sewage release, including in 'storm' bypass discharges, is a particular source of pollutants, including pharmaceuticals, and related antibiotic-resistant material.

By way of example of the extent and global nature of untreated discharges, in the UK, in 2022, wastewater bypass discharges 'spills' numbered 301,391 (Environment Agency Event Duration Monitoring data, 2022). In poorer countries with more challenging climates and less developed infrastructure, self-evidently, the occurrence and volume of untreated sewage discharges will be considerably greater. However, untreated discharges are an inherent problem of FaF sewage systems, and are seen in even the wealthiest, best-organised countries.

For example, the Swiss 2022 article titled, "*When rain overwhelms the sewers, antibiotic-resistant bacteria flood the river*", reported, "*Wastewater bypass is a major temporary point-source of antibiotic resistance genes and multi-resistance risk factors in a Swiss river*". (When rain overwhelms the sewers, antibiotic-resistant bacteria flood the river, 2022)

"During heavy rains, many other potential sources of antibiotic resistance contamination enter the river, complicating our research further. This includes surface runoff that transports soil into the river, such as from fields and meadows that may have been manured." "Using modern sequencing techniques to distinguish microbes from different sources, we disentangled these inputs. Our results show that the sewage overflow, so-called 'wastewater bypass', was clearly the major source of antibiotic resistance in the river." (When rain overwhelms the sewers, antibiotic-resistant bacteria flood the river, 2022)

As discussed elsewhere, antibiotic-resistant material is just one of multiple pollutants in raw sewage. Pharmaceutical, chemical and textile manufacturing plants and other pollutant sources, including road run-off, significantly add to pollution levels in rivers, oceans, and the wider environment. In nations with lesser economies, without extensive treatment systems, the adverse outcomes of untreated discharges, are similar, just much more significant. (Lee, 2022)

11.3. CREAKING SYSTEMS - WHO PAYS TO CLEAN UP?

Even in the well-heeled West, the traditional Victorian Flush and Forget and related Edwardian-based treatment sewage plant network is creaking at the seams. Among the headline findings of the World Wildlife Fund Report, '*Flushed Away*', it was noted, *"most of the present-day sewerage infrastructure was installed over half a century ago. Investment is not keeping pace with deterioration – at the current renewal rate, it will take 800 years to renew and replace ageing assets."* (Blackburn, 2017).

The WWF report added: *"The combined pressures of urbanisation, population growth and climate change are placing a heavy burden on a system already running at or over full capacity… It seems companies are relying on sewer overflows to compensate for under-capacity. . . Sewage pollution is a hidden problem: very little information is in the public domain, and public awareness is low"* (Blackburn, 2017): prescient indeed.

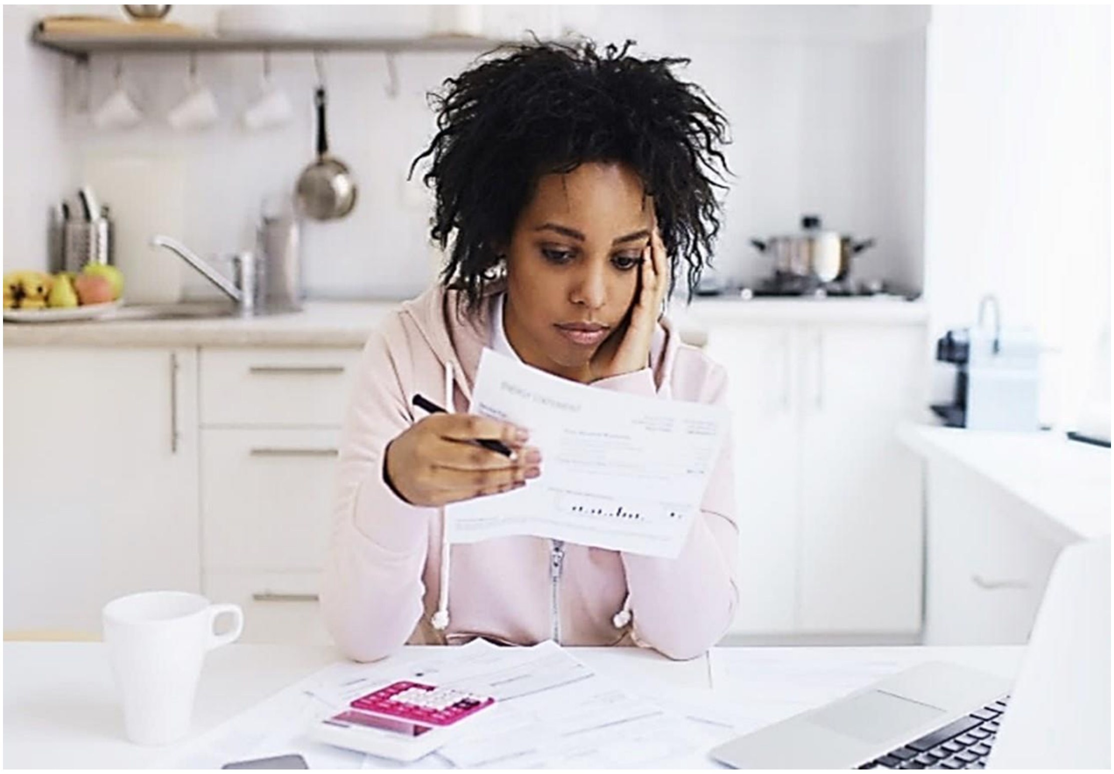


Fig. 23. Worrying about the bills with thanks to Damir Khabirov and Adobe Stock

In recent years, sewer overflows have been increasingly relied on in the UK to mitigate a lack of capacity and plant failures. As noted above, wastewater bypass discharges 'spills' in the UK in 2022 numbered 301,391 (Environment Agency Event Duration Monitoring data for 2022). As more information emerges, there is increasing public concern and disquiet at the number of sewage overflows reported.

Part of the problem is the enormous cost of connecting communities to an already often overloaded distant Victorian and Edwardian-type sewage treatment plant system, which itself is in radical need of improvement. In the privatised UK system, these capital costs will ultimately be passed onto residents, placing significant financial burdens on the less well-off.

For example, in the UK, South West Water invested £2 billion or more, into connecting the main direct ocean outflows on their section of the south coast of England into the regional network. In consequence, "*For families in the south west living in a small house or flat the water bill can easily exceed their heating bill, and water poverty is becoming an increasing concern in many areas of the UK. 23 per cent of households spend more than 3 per cent of their income on water bills and 11 per cent pay more than 5 per cent. In households that are on benefits the figures are 50 per cent and 20 per cent respectively*" (Hassell, 2012).

The 25km super-sewer-under-Thames tunnel was completed in the London region in 2024 for £5.0 billion. The development aims to connect 34 combined sewer overflow points in the capital, to reduce estimated emissions of 39 million tonnes of untreated sewage per annum into the Thames, but issues will still remain; "*London's super sewer won't solve the city's epic poop problem*" . . . *there's a general consensus in the water resources community that we cannot build ever larger and deeper sewers, that's just too impractical and costly."* (Varghese, 2018).

The sewage will be treated at the Becton Sewage plant using activated sludge processes, and sludge is being increasingly incinerated. Waste ash will have to go to landfill; a portion of it, the fly ash, is toxic and may require more specialist storage.

As discussed, on a country-wide basis, the costs of installing more sophisticated tertiary wastewater treatment, to improve discharge-water quality, solutions such as ozonation, and activated carbon, would be substantial, in the tens of billions. Yes, they do remove a significant portion of micropollutants such as pharmaceuticals and antibiotics, as much as 80% of specific identified pollutants, but as repeatedly discussed, the sewage sludge remains heavily polluted, with disposal options being; incineration, which is very expensive in capital and running costs; landfill; or use on agricultural land; all of which have their own environmental and pollution issues.

One way or another, the public will inevitably bear the treatment costs. In emerging economies with limited existing sewage infrastructure, the capital and running costs for even basic Victorian FaF transport, and Edwardian-type treatment and sludge disposal systems, are substantial - even where tempered by lower labour costs – thus even basic treatment is realistically wildly unaffordable, and represents a vast investment in what is a dinosaur technology surely destined for extinction.

11.4. GLOBAL FINANCE – ROOT AND BRANCH REASSESSMENT REQUIRED

The World Bank finances countless infrastructure projects around the world. However, sadly, its outlook on sanitation appears still to be wedded to 'Flush and Forget' dinosaur technology, with parallel investment in reverse osmosis. Thus, massive amounts are spent on 'sticking plasters' rather than facing the underlying issues.

By way of example, a 2012 Bank article titled, '*Spaceship city: drinking wastewater, and going back to the future*' (Vergara, 2012), focuses very much on the capacity to reuse water from sewage treatment plants, but without consideration of the broader implications, including; capital and running costs; the need for disposal of the pollutants extracted during reverse osmosis; or the enduring problem of disposal of sewage sludge.

The World Bank's belief in recycling sewage wastewater using reverse osmosis was demonstrated by the finance of a sewage and water project in Shimla, India (Misra, 2018). It is excellent that finance is available, but it is very depressing that the pressure is for more of the same, possibly pragmatically 'here and now' necessary but ultimately unsustainable, flawed FaF model (Shimla-Himachal Pradesh Water Supply and Sewerage Services Improvement Program, 2021).

However, perhaps change is finally in the air. The Bank's own 2019 water report recognised, that such technology may not be practical, admitting that while there is *"urgent need for greater investment in wastewater treatment plants, especially in heavily populated areas…* [we find] *that at times, investments in wastewater treatment facilities lead to little measurable improvement in water quality, representing a waste of scarce public funds'' (Damania, 2019),* indicating a recognition that current treatment systems are often not sufficiently effective.

However, it is unlikely that a root-and-branch review of sewage disposal will happen until the World Bank, UN, and other leading global organisations are convinced of the need for a review of the potential merit and environmental effectiveness of using vacuum collection and hyperthermophilic anaerobic and aerobic treatment to help reduce resource use and environmental damage and better close the environmental cycle for sewage.

12. ENERGY IMPLICATIONS – SEWAGE TRANSIT – LOST HEAT IN WATER

In summary, WC flush water savings using vacuum WC technology, savings in transport costs, better use of grey water, reduced pollution, potential for biogas and compost production, and reduced plant capital and running costs present significant financial, resource, and environmental opportunities, in addition to the benefits of more sustainable water use and closing the environmental cycle.

12.1. SEWAGE TRANSPORT – ENERGY REQUIREMENTS

It is obvious when pointed out, but rarely considered, that water has to be raised by pumps to allow gravity to drive flows across varying topographies; thus, sewage transport is energy-intensive.

The review '*Greywater reuse as a key enabler for improving urban wastewater management*', helpfully observes, "*The energy cost to transport water in centralized water management systems in the United States is estimated to be, on average, four times the energy required for the actual water treatment and is as high as 20 times in California, with treatment and transport making up 4% of the nation's total electricity consumption. An additional energy cost of 2.5 kWh m−3 has been estimated for the transport of water over a distance of 100 km with a 250 m height increase*" (Van de Walle, 2023).

Vacuum WC systems and localised grey and surface water treatment and use would significantly reduce sewage volumes, saving water transport costs to treatment plants.

12.2. GREY WATER HEAT RECOVERY

Van de Walle observes, "*Of the total household energy consumption in the European Union, 14.8% is used to heat water*" (Van de Walle, 2023), thus there is significant potential in large residential developments to recover heat from grey water, whether or not the grey water is subsequently included in the sewage flow.

13. VACUUM TECHNOLOGIES - SEPARATE FAECES AND URINE AT SOURCE

Technologies to collect urine and faeces at source before they are mixed and diluted with other pollutants include vacuum WCs, compost toilets, and urine separation. As discussed later in separate sections below, neither composting toilets nor urine separation are realistic large-scale prospects and further fail to remediate micro-pollutants, including pharmaceuticals.

13.1. SOURCE CAPTURE OF URINE AND FAECES MAKES SENSE

Allowing faeces and urine to be mixed, diluted, and further polluted in external mixed waste streams before being turned into sewage sludge is irrational. This dramatically reduces the potential to capture the resources in faeces and urine. As mentioned above, alternatives are urine capture at source and composting toilets, but they do not make practical, environmental, or economic sense, leaving vacuum WC systems as the only option.

Fig. 24. Generic sewage treatment, with thanks to the Author and Adobe Photo Stock.

Urine unquestionably contains valuable nutrients and has value as a fertiliser, but as discussed below and later, WCs that separately collect urine are impractical for several reasons. Further separate urine collection and use is not viable at scale.

Issues related to urine application to farmland include; the need for treatment and/or storage for months to reduce pathogens; smell; runoff; and consequential nitrification and pollution of waterways. Further drawbacks of separate urine collection include the practical and economic feasibility of separate urine transportation.

For example, *“For the farmer, the spreading of urine in the field makes sense only if the benefit exceeds the costs and the use causes no harm to the environment or health. The labour and* *machinery costs of urine transportation can easily exceed the value of the nutrients. Furthermore, spreading the urine at the wrong time or unevenly on the field can cause considerable crop failures*" (ibid).

Further separation of urine from faeces reduces the fertiliser value of compost. JC Wylie, in his 1955 tome '*Fertility from Town Wastes'* (a time when pharmacological pollution of urine and faeces was much more limited), observes that the mixing of faeces and urine into mixed external flows, and subsequent treatment in sewage works, will inevitably steal away at least some nutrients. "*The established methods of treating sewage used by sanitary authorities in this country are wonderfully efficient in putrefying the sewage liquor,"* he wrote. *"But [they] are defective in that they discard enormous quantities of agriculturally valuable mineral salts and organic matter which have a natural function in maintaining the humus of soils*." He adds: "*As sewage sludge is collected, conveyed to, and passes through sewage treatment plants, most of the mineral substances contained in the solid matter dissolve out, including those that are important to the nutrition of crops.*" Those dissolved nutrients will be present in the discharged treated sewage wastewater, often released into waterways and, ultimately, oceans, facilitating eutrophication.

The question of how to collect and treat urine and faeces in a circular, sustainable way is a complex, interconnected topic. However, it must be addressed because it is inevitable that once pollutants are in the sewage sludge stream, they are challenging to remediate, as discussed in '*Residuals, sludge, and biosolids: Advancements in the field*'. (Brisolara, 2020).

13.2. VACUUM WCS

Fig. 25. A vaccum WC in a stunning location with thanks to the Index Project Award 2019, and Jets (The Index Project 2019)

Many of us have already encountered vacuum technology in planes or ships. Vacuum toilets (VWC) remove excreta with a vacuum-created air-pressure-based evacuation of the pan, with only a sprinkling of water, under 1 litre for solids and almost none for urine, rather than the substantial volume of flush water used by traditional WCs. Thus, VWCs save significant amounts of clean drinking water.

13.3. VACUUM WC – USER EXPERIENCE AND AESTHETICS.

Importantly, from the user's perspective, there is no aesthetic difference in the lavatory unit itself. The system is hygienic, relatively quiet, and odourless. Crucially, but worth restating, VWCs use approximately 0.2 to 1.0 litres per flush, much less—ten to twenty times or less—water than traditional water flush toilets. Over time, as research and development kick in, one can expect the energy costs of vacuum WC systems to shrink.

13.4. VACUUM WC V FaF FLUSH – AEROSOL PLUMES - BACTERIAL SPREAD

Vacuum WCs also have the additional benefit of reducing the aerosolised spread of WC-related airborne viruses and bacteria, including coronaviruses, found in faeces and urine.

Fig. 26. Aerosol plumes from traditional flush FaF toilets can rise up to 5 feet above the bowl, and remain suspended in air, exposing people to disease vectors, with many thanks to the Authors (Crimaldi, 2022).

A '*The Conversation*' article reports, "*We found that a typical commercial toilet generates a strong upward jet of air with velocities exceeding 6.6 feet per second (2 meters per second), rapidly carrying these particles up to 5 feet (1.5 meters) above the bowl within eight seconds of the start of the flush." "Aerosol particles containing pathogens are important human disease vectors. Smaller particles that remain suspended in air for a period of time can expose people to respiratory diseases like influenza and COVID-19 through inhalation. Larger particles that settle quickly on surfaces can spread intestinal diseases like norovirus through contact with the hands and mouth.*" (Crimaldi, 2022). *"Aerosolization can continue through multiple flushes to expose subsequent toilet users. Some of the aerosols desiccate to become droplet nuclei and remain adrift in the air currents."* (Johnson, 2012) More research is required to determine the actual, as against potential, risk of transmission of disease, by toilet aerosols (Johnson, 2012).

13.5. HISTORY OF VACUUM WC SYSTEMS

Surprisingly, vacuum WC technology was actually first employed in Victorian times. The review '*Guideline: Vacuum sewer systems*' (Mohr, 2016) provides a useful history and appraisal of the advantages and disadvantages. It reveals: "*The concept of using negative pressure for sewage transport is not new. The earliest reports of vacuum sewers go back to the end of the late 19th century. It is not entirely clear who can be named the inventor. While Adrien Le Marquand proposed his wastewater collection by barometric depression in the US in 1888, the Dutch engineer Charles Liernur presented his system in Europe at around the same time. Soon it was installed to cover wastewater services in suburbs of Paris, Amsterdam and Berlin. In 1892 in Levallois-Perret, a North-Western suburb of Paris, the vacuum sewer system served 500 premises accommodating around 15,000 inhabitants. But despite excellent experiences the system somehow got forgotten. It was not until 1959 when the Swedish engineer Joel Liljendahl picked up the technology and developed new improvements which led to increased interest in the vacuum sewer technology and further developments.*" (Mohr., 2016)

Some early modern attempts to harness this technology have failed, most likely due to poor management, lack of public familiarity, or difficulty obtaining spare parts in developing economies. Examples of such troubled schemes are set out in '*Guideline: Vacuum sewer systems'* (Mohr., 2016).

However, the technology is now sufficiently mature to be, and is, increasingly widely used in buildings, including for retrofits, cruise ships and aircraft. Jets group in an older brochure (Think Smart-Save More, N.D.) state vacuum WC systems are suitable for a wide variety of uses, including:

- *"Public areas: hotels, shopping centres, office buildings, hospitals, schools, restaurants, etc.*
- *High-rise, residential buildings or part of a building that is situated at a lower level than the sewage network or sewage tank.*
- *Renovated buildings where toilets need to be relocated or the existing sewage infrastructure has deteriorated."*

By 2008, over 100,000 valves had been installed by the multinational company Airvac & Roediger. Significant-sized systems have been recently commissioned as well. For example, vacuum WCs have found favour in New Zealand, where earthquakes have badly impacted sewers. "*The experiences in Auckland convinced the public utilities in Christchurch . . . The city's infrastructure is still affected by the damages from the earthquake in 2011 and frequently experiences heavy earthquakes, such as in February and November 2016. The authorities considered the vacuum sewer to be the best solution to respond to future earthquakes and to the large damages caused by previous ones. The system which is designed to serve 2,700 households is in the final phase of construction*" (Mohr, 2016).

Vacuum WCs are commonly deployed on aircraft, trains and cruise liners, with thousands of toilets linked to the same system. Quieter versions are appearing in hotels, offices, shopping malls, universities, correctional institutions, government offices, public facilities and even prestigious residential developments, such as Palm Island in Dubai.

Other vacuum W.C. installations included "*Hotel Ivar Aasen Ørsta, Norway, Casa Daros Museumrio De Janeiro, Brazil, Arena Castelão Fortaleza, Brazil; Melbourne Water Authority Melbourne, Australia; Hareid Group Headquarters Hareid, Norway; Parque Da Cidade Community Centre/Complex São Paulo, Brazil; Water Campus Leeuwarden, The Netherlands; Uddevalla Prison Uddevalla, Sweden; Complexa JK Commercial building, Brazil*."

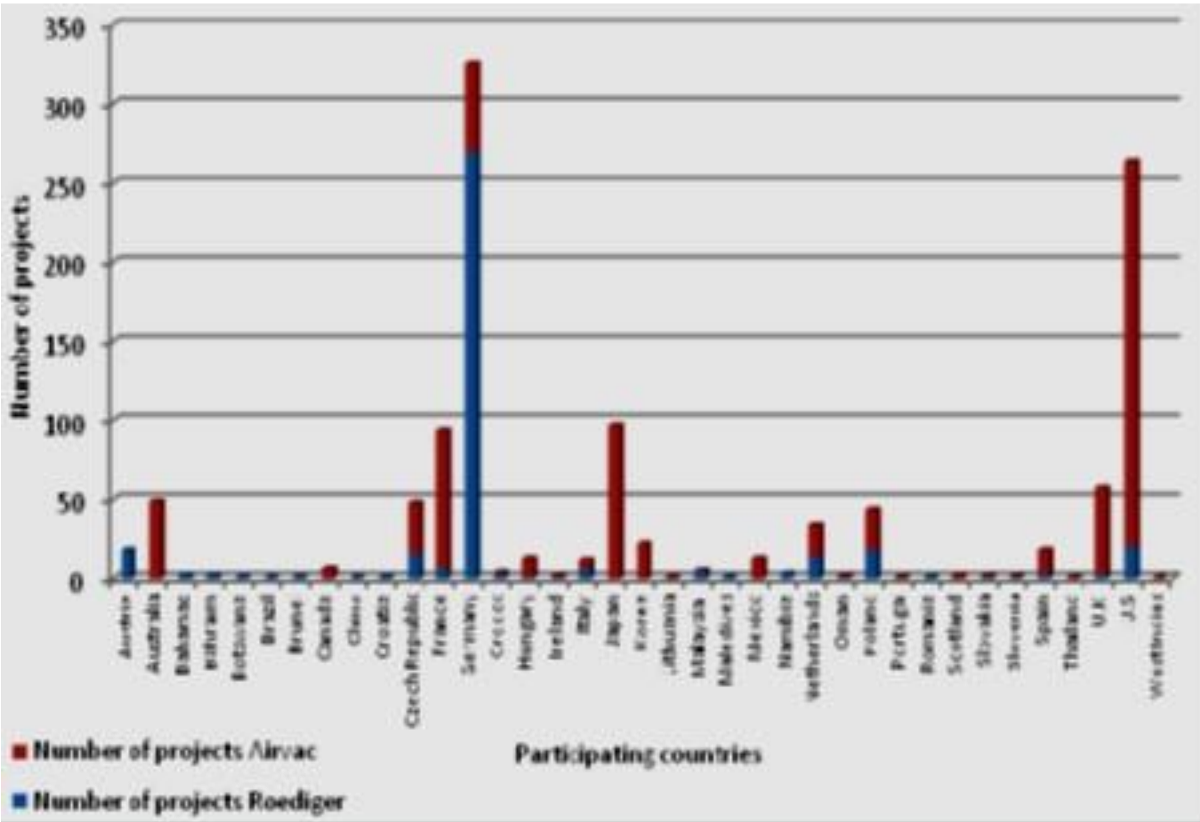


Fig. 27. The number of vacuum sewer projects implemented by Airvac & Roediger (now Aqseptence Group) between 1973 and 2008, clearly 20 plus years later, things have moved on, and the slide is no longer in their 2007 brochure, but illustrates that vacuum WCs are an established technology, with thanks to the authors (ROEVAC ® Vacuum Sewer Systems, 2007).

Examples from Roediger's historic literature include: - "*A Suburban town outside of Warsaw with 145,200 people installed a vacuum sewer system for an area of 620 square kilometers to serve 5,600 of residents outside of town.*" - "*Vacuum sewers were installed for 670 buildings along a sensitive water way along the Rhine with 2 pump stations" – "in a Formula 1 Speedway in Shanghai, China, - University Sabak Bernam, Malaysia and other installations".* (On-site sanitation case study 03: Vacuum Flush Installations in the US and Beyond. 2012). More recent information as to Roediger installations can be found on their website. https://www.roediger-vacuum.com/en/portfolio/sewer

A company called Flovac refer in their literature to a number of schemes undertaken (Flovac 2023 a), including one in Poland: "*Between 2006-2019, Imielin implemented a comprehensive vacuum sewage system as part of a multi-phase construction process. A total of 60 km of vacuum lines were built and more than 1,000 vacuum valves installed. Flovac Polska was an integral partner in the project, supplying vacuum valves, vacuum station equipment and a propriety cable monitoring system.*" (Flovac 2023 b). Multiple other examples of Flovac installations can be found on their website: https://flovac.es/en/news/ .

Several suppliers exist in the market. To maintain independence, the author, as of December 2024, has had no contact with any of them. The existence of such schemes, and the usage of vacuum WC technology in cruise liners with thousands of passengers on vacation, suggest it is a viable technology with regional and use-specific potential, particularly if combined with active monitoring and automatic status reporting by all system elements, using emerging chip sensor and related communication technologies.

13.6. VACUUM WC – ALTERNATE POWER SOURCES INCLUDING SOLAR

Yes, vacuum WCs require a power source to provide vacuums, but equally, 'FaF' systems in high-rise apartments require power to move water. Potential options to create the energy needed to maintain the necessary vacuums include simple weight systems and solar panel technology.

Fig. 28. Sign indicating a buried vacuum sewer in Germany, with thanks to C Lower and Wikipedia

In sunnier climes, solar power can already be harnessed to power the system (AirTech Vacuum, n.d.), which means that in equatorial countries, they could operate independently of the grid, a potentially important factor in lower-GDP countries. "*VOD* (Vacuum on demand) *systems are available in a solar powered version and since the vacuum only is generated when needed the energy use is low; less than 10 kWh/person/year according to one manufacturer. The VOD is suitable for use in single houses or cabins, and for installations of up to 10-15 toilets connected to one vacuum generation unit. The VOD is very flexible and more robust than earlier vacuum systems. The robustness is due to the flexibility and ease of serviceability of the smaller units and increased tolerance of air leaks*" (Jenssen., 2004).

As new markets are identified and grow, the technology will mature further. Hand- or foot-operated vacuum pumps may provide a mechanism for operating VWCs in settings with lower infrastructure availability.

13.7. BIOGAS AND HYPERTHERMOPHILIC COMPOST – THE WAY FORWARD?

Collection of urine and faeces at source, possible partial on-site or nearby treatment, including hyperthermophilic, anaerobic fermentation for methane derived energy, and remediation of the residue by hyperthermophilic composting by specialist centres, will never be perfect, but offers the potential of being considerably better than the status quo; and likely of sufficient quality, to allow reuse of compost on mycorrhizal biome rich land, or land for greening, without significant long-term risks.

Any risks of residual pollutants, on a risk-reward basis, are outweighed by the benefits of composting to soil; health, carbon content, water retention and use efficiency, and productivity, as well as the reduction in rock phosphate and artificial nitrate requirements. In addition, such systems avoid the multiple downsides of pollution and the significant capital and running costs of; sewage treatment plants, incineration, and landfills.

13.8. ONWARD TRANSPORT FOR COMPOSTING

Eventually, the vacuum WC residue in the collection tank or biogas settler must be removed, ideally to a composting hub. This will likely require the development of new long-distance vacuum sewage transport technologies, or on-site hyperthermophilic composting, as tankering from collection centres may not be practical.

Volumes of vacuum WC waste output are much lower than that of conventional FaF systems; in a study on the use of black water in a new multi-apartment block in Sweden, "ultra-low-flush vacuum toilets (0.5 litres per flush) *were assumed to be used. The number of flushes during 65 per cent of an average day that a person spends at home was estimated at 4.6. In total, about 22 m3 of black water were collected annually from the 18 persons in the house*" (Spångberg, 2014). A large sewage tanker can carry 20m^3, so just over one load a year would suffice for 18 people. On-site initial treatment could well further reduce volumes for onward transport.

Urban long-distance vacuum, or pressure-based, transport may emerge as a possible alternative, given that sub-ground infrastructure for both types of air systems is much easier and less disruptive to install for several reasons, including gravity independence, smaller diameter, and much greater route flexibility, than for traditional gravity-based sewage systems. Further, it would be possible to install the smaller vacuum lines within the existing sewage pipe network, which could still be used, where required, to transport surface water.

Ahead of tankering, vacuum or pressure-based transport of vacuum WC / biogas residue, away for composting, the water content of the residue could be further reduced on-site by, for example, using heat or vacuum technology, evaporating some of the liquid, possibly along with the use of a mix of absorbent, natural non-polluting additives, such as biochar and clays. Historically, cattle shed floors were lined with clay and the resultant blend of urine and earth was incorporated into the compost. Such additives may also help retain valuable amounts of ammonia and nitrogen in the sludge. The practicality and desirability of such treatments depend on onward transport and composting options.

13.9. VACUUM WCs - WATER SAVINGS

Vacuum WCs represent vast savings on what has gone before. Old-style toilets use around 13 litres per flush, and more modern ultra-low-flush types use a minimum of six litres for solids. In contrast, VWCs require only 0.5 litres for solids and as little as 0.1 litres for urine-only visits. Thus, switching to VWCs would reduce flush water requirements by ten to twenty times or more.

Fig. 29. 64,000-capacity Castelão Stadium in Fortaleza, with thanks to the Governo Federal Brasileiro and Wikipedia

In Brazil, a VWC system was installed as part of a refurbishment of the 64,000-capacity Castelão Stadium in Fortaleza. It is reported to have saved around 500,000 litres of water for every football match it has hosted since.

There are knock-on savings in areas of water shortage that use desalination. Producing desalinated water, including to flush FaF toilets, requires significant energy - "*seven million gallons per day could require about 50 million kWh/yr, which would be similar to the energy demands of an oil refinery or a small steel mill.*". (Cotruvo, 2005) Thus, the savings at the Castelão Stadium alone would constitute a significant electricity saving in water desalination costs per match day.

Similar infrastructure at the University of Sao Paulo cuts costs by $1,500 daily, and water consumption dropped by 1 million litres every 3 days ('Projects Vacuum Toilets Australia').

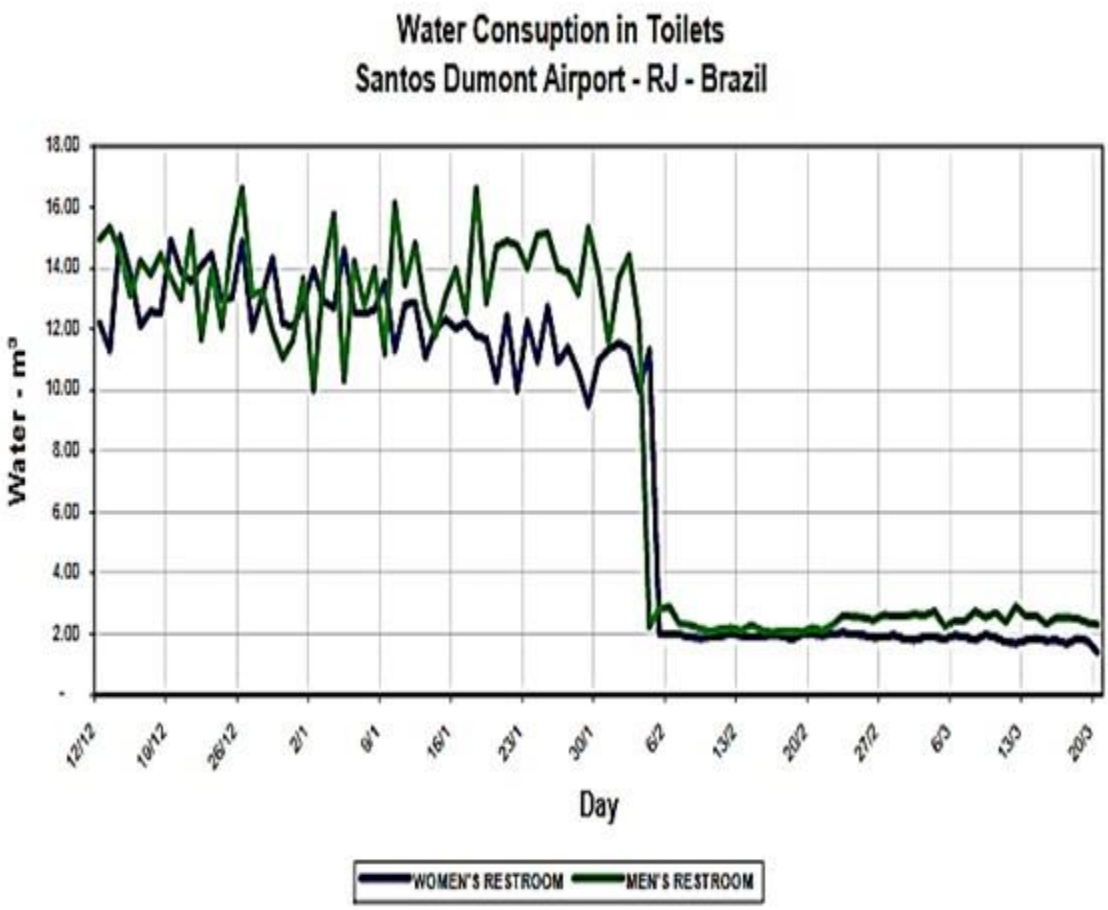


Fig. 30. '*Water consumption change with move from traditional to vacuum WC units (21 WCs) at Santos Dumont Airport, Brazil.*' During the first 55 days of the evaluation, the calculated savings in water consumption was 83 per cent. Image from '*Application of a Vacuum Water Closet System in a Brazilian Airport*', with many thanks to the authors (Oliveira Junior & Silva Neto, n.d.).

A vacuum WC system was also installed at Santos Dumont Airport, Brazil, with dramatic savings in water. The sanitary ware was similar to 'FaF', so acceptable to consumers.

13.10. VACUUM WCs - ADVANTAGES – LOW WATER - GRAVITY INDEPENDENT – SMALL BORE

The piping system of a vacuum VWC is easier to install and cheaper, as well, which goes some way to mitigating the more expensive price tag of the technology. The Inicio web page '*Sustainable Sanitation and Water Management Toolbox*' (Stauffer SSWM - Tools for sustainable sanitation and water management. n.d.) lists the advantages and disadvantages as follows:

"Advantages

- *Large water savings*
- *No deposits in the toilet, reduced use of detergents*
- *Very hygienic*
- *Flexible and convenient*
- *No deposits in the pipes*
- *Odour-free*
- *Facilitates reuse of urine and faeces*
- *Applicable in many different constructions*

Disadvantages

- *Relatively high investment cost*
- *Depended on the electric power supply*
- *Coarse materials can lead to blockage of the collection system*
- *House service connection and vacuum station have to be maintained*
- *Need for a vacuum station (house-or community based)*
- *Requires space for connection*
- *Bulky material (i.e. sanitary napkins) can lead to clogging"* (Stauffer SSWM - Tools for sustainable sanitation and water management n.d.)

Whilst capital equipment costs are higher, there are savings in installation costs and multiple other positive value streams, including savings in water, reduced downstream sewage treatment capital and running costs, and value benefits in possible downstream methane production from anaerobic digestion and aerobic compost production. In addition, there are multiple downstream environmental benefits in avoiding the pollution issues caused by conventional treatment systems.

The Roediger brochure (ROEVAC ® Vacuum Sewer Systems, 2007) lists reasons why the installation is more straightforward, including for connecting up low-rise residential units:

- *"Narrow and shallow Trench*
- *Depth of 1 - 1.2 m*
- *Small Diameter (80 - 250 mm)*
- *Plastic Pipes (PE or PVC), SDR11*
- *Simple or even no Machinery for Excavation*

- *Fast Trenching*
- *Inspection access 100m max separation, but no manhole requirement*
- *Installation less level sensitive*
- *Pumping stations not required for small negative level changes*
- *Easy to work round obstacles" (ROEVAC ® Vacuum Sewer Systems, 2007)*

Fig. 31. Palm Island in Dubai, United Arab Emirates, is a vacuum WC project by Roevac. It features 2,300 villas, approximately 40 km of vacuum sewer lines, 1,050 collection chambers, and one central vacuum station. On completion in 2008, it was the world's largest vacuum sewage installation (Mohr, 2016), thanks to NASA and Wikipedia.

Table 13 of the document '*Guideline: Vacuum sewer systems*' (Mohr., 2016) provides a more detailed summary of advantages and disadvantages, including technical installation and maintenance requirements. (11.2 critical features pages 61 and 62).

Though the potential for blockages in the system remains, VWCs are used in large cruise liners carrying several thousand passengers, which suggests that the blockage issues are manageable. Cruise line holiday clients are likely fairly demanding, and had there been significant problems, the systems would no longer be used. Further water demands and waste volumes are inevitably lower because so little water is used to flush solids and very little for urine, which are significant advantages, particularly on cruise liners.

13.11. VACUUM WCs - NOISE

Vacuum WCs are installed in cruise liners. Older systems were reported to be noisy. Newer systems are claimed to create noise levels similar to traditional water-based WCs (Evac is Quietly Flush with Success, 2009). A later model has been developed with a noise level of 66db(A). Noise levels can be reduced with appropriate insulation material. (Ouellette, 2011)

A residential vacuum WC project in Amsterdam, further reduced noise levels to 37db (a volume level between a quiet library and a whisper). However, that did not meet building by-law noise standards of 30db. It is unclear whether this could have been prevented by better design or pipe installation, but it arguably should have been possible. (Neighbourhood biorefinery for the treatment of pre-separated wastewater as a facilitator for a circular city district. 2019)

Alternatively, and pragmatically, given the noise levels we are exposed to even indoors in city environments, if necessary, noise standards should be slightly relaxed because of the broader environmental benefit and the importance of having working pilot projects.

13.12. VACUUM WC TECHNOLOGY - KEY TO A CIRCULAR SEWAGE SOLUTION?

In summary, Vacuum WC technology has massive potential. It is arguably the best option for collecting faeces and urine in the future and closing the environmental cycle as far as possible, as outlined in section 3.2 above.

Taking a broader view, one of the beauties of vacuum WCs and associated treatment is their likely ability to generate savings and income streams, including from gas production, in the long term. Possible cuts in household sewage and water charges, or related taxes, could provide further domestic incentives for changing to low-flush.

If such technology became mandatory, the benefit for urban authorities from reduced water-based sewage treatment infrastructure and maintenance costs could be considerable. It could, in part, possibly be passed back to consumers. As a short-term incentive – and as a nod to the old days of the nightman – perhaps there may even be the chance to pay the public for adopting this technology, in the same way, that the Feed-in Tariff encouraged homeowners to take up renewable energy sources such as solar and wind.

Grey water could be treated locally using ozone-based technology and reused for irrigation. There is also the opportunity to use ‘sponge city technologies’ to collect and direct run-off water into aquifers, lakes, or other water storage facilities, with a reduced need to process it first because mixing with sewage is eliminated.

13.13. VACUUM WCs - ADOPTING THE CONCEPT

On the one hand, turning around the current momentum to extend a primarily Victorian sewage system technology that is unsustainable, costly, and flawed at many levels is a Herculean task—but, on the other hand, this is a startlingly simple problem to fix, at least conceptually. Pessimists should remember that preparing the concept is the first step to solving any crisis.

Private enterprises should be encouraged to engage in the necessary research and enter the vacuum WC production and distribution markets. In addition, as discussed and importantly, the principle of vacuum collection of faeces and urine is Victorian. Hence, the principle is not patentable, albeit specific equipment is. Thus, newcomers would be free to develop Country and culture-relevant systems. Arguably, the technology is currently where Microsoft and Google were at the origins of the internet; thus, tremendous opportunities exist for innovation.

As far as I can see, the concept of replacing water-intensive 'FaF' with a combination of water-saving vacuum WC collection and subsequent hyper-thermophilic anaerobic and aerobic digestion is the only realistic, feasible, affordable, easily implementable, 'open-source' basic WC technology available to at least begin to close the environmental loop.

14. COMPOSTING TOILETS - NOT A FEASIBLE ALTERNATIVE AT SCALE

In contrast to vacuum WCs, dry composting toilets (non-flushing toilets) are unlikely to prove publicly acceptable (Nasri, Brun & Fouché, n.d.) due to hygiene concerns and the impracticability of installation in high-density housing and office units. This is for a host of reasons, including, crucially, the collection and disposal of composted material. Of fundamental practical importance, realistically and rationally, a composting WC is unlikely to add to the sales value of an upmarket apartment in a high-rise building.

'*Sustainable wastewater management in urban areas*'(Jenssen, 2004) gives reasons why composting toilets are incompatible with modern urban homes:

- *"One must accept the fact that at some time the composted waste* must *be handled.*
- *There are inherent health risks with collecting and storing human excrement.*
- *Space is required for processing the waste, which, in addition to installing ventilation shafts, may require structural changes to the home."* (Jenssen, 2004)

15. SEPARATE URINE COLLECTION - NOT REALISTIC LARGE-SCALE OPTION

Within the context of the volume of material arriving at a sewage treatment plant, urine contributes only 1 per cent to total sewage water, so "*to capitalize on the plant nutrients in urine, the liquid would need to be separated at its source rather than processed at a treatment facility*" (Brasch, Modern Farmer, 2014).

15.1. URINE - POLLUTANTS AND PATHOGENS

Further, contrary to the common belief that urine is sterile, separately collected urine would still need complete remediation treatment in the same way as faeces because urine contains pathogens, including viruses, which can in infected people include, for example, cystitis, typhoid fever, schistosomiasis and leptospirosis.

A study in South Africa assessing contaminants in urine observed: "*The most frequently detected viral pathogens were JC polyomavirus, rotavirus and human adenovirus in 100 per cent, 34 per cent and 31 per cent of samples, respectively. Aeromonas spp. and Shigella spp. were frequently detected gram-negative* [drug-resistant] *bacteria, in 94 per cent and 61 per cent of samples, respectively. The gram-positive bacterium, Clostridium perfringens, which is known to survive for extended times in urine, was found in 72 per cent of samples*" (Bischel, 2015). *Indeed, "for hygiene reasons, urine should be stored in a sealed vessel for six months before spreading"* (Human faeces as a resource in agriculture, Malkki, 1999).

Several treatments are proposed for removing pollutants from urine, including nanoparticles, specific agents, membrane technologies, carbon technologies, oxidative processes, and ammonia and phosphate removal. However, such processes are complex, costly and ineffective.

15.2. URINE COLLECTING TOILETS

Fig. 32. Urine diverting toilet in Sweden with many thanks to the author EvM-Susana and Wikipedia

Ergonomically, it is undoubtedly possible to collect urine separately within a single WC, but as stated above, urine separation and collection in toilet systems have several disadvantages. From a user's perspective, combined collection WC pans are more challenging to keep clean and in working order, so they may achieve lower public acceptance. Domestic and municipal installation and maintenance costs will be significantly higher due to the need for dual pipe systems. Further, urine pipework can clog due to mineral deposition and build-up, requiring specialised chemical-based cleaning and extra maintenance costs.

15.3. URINE AS A SOIL CONDITIONER

Whilst *"solid waste has the lion's share of organic material such as carbon, fibre and beneficial microorganisms… urine contains many of the chemical elements plants need"* (Brasch, Modern Farmer, 2014). Several studies, including *'Source Separation: Will We See a Paradigm Shift in Wastewater Handling?'* (Larsen, 2009), recommend its use as a soil conditioner.

Its effect on plant growth has generally been positive, reducing requirements for artificial fertilisers. A urine fertiliser study in Zambia noted: "*The growth of cabbage and maize was equally good with urine-fertilised crops than artificially-fertilised crops*" (Hannila, 2008).

Research from Finland and Sweden has shown positive outcomes in crops such as cucumber, beet, pumpkin and tomatoes (Heinonen-Tanski, Pradhan & Karinen, 2010). Rice productivity and soil quality were improved in Nigeria (Njoku, 2017), and a study in Ethiopia found benefits for beet and tomato compared to no fertilisation (Egigu, 2014).

As discussed in the biochar section, urine has also shown potential as a growth enhancer when combined with biochar. However, the issues of pollutants in the urine and a urine/ biochar mix remain.

15.4. URINE AS A FERTILISER – CONCLUSION

Over the years, there has been an active debate about whether urine could or should be collected separately from faeces for use as an agricultural fertiliser. Urine is a source of nutrients and potential pollutants, including pharmaceuticals, antibiotics and wider contaminants. If applied to soils, the unbound phosphates and nitrates it contains could leach, causing eutrophication. It also has a high volume and thus is expensive to transport in proportion to its nutrient content. Further, urine itself needs treatment, as, contrary to common opinion, urine contains pathogens and pollutants, including pharmaceuticals and related products.

Thus, while WCs have been developed that separately collect urine and faeces, the technology has not achieved much purchase due to several inherent problems with urine as a fertiliser, including economics, remediation, storage, transport, and risk of runoff, as well as practical downsides to urine-separating toilets.

16. SEWAGE SLUDGE AND WASTEWATER – AN INSOLUBLE PROBLEM?

Sewage, wastewater, and sludge have different pollutant profiles. Both sludge and wastewater will contain a range of potential contaminants:

- Sewage wastewater is the water component of the sewage arriving at a treatment plant after settling out of the sludge and further secondary and sometimes tertiary treatment of various formats.
- Sewage sludge is a processed aggregation of all precipitated solids extracted from the combined water flows arriving at a sewage treatment plant.

Water-soluble pollutants will generally end up in the wastewater, while less soluble elements, including fats, will be associated with solids and thus become part of the sewage sludge.

Sewage sludge has a chequered environmental reputation, and for good reason. Along with polluting elements from faeces, urine, and households, sewage sludge inevitably contains and concentrates products that are solid or bind to solids. Whilst, due to better regulation, modern sewage sludge in Europe is less polluted than it used to be, nonetheless, it can contain hundreds of chemical products and residues, including pharmaceuticals, personal care products, PFAS, hospital and industrial waste, debrided tyre particulates and wider motoring related pollutants, and micro-plastics.

Heavy metals, pharmaceuticals, nano- and microplastics, and many other chemical pollutants in sewage sludge are extremely difficult to remediate or remove. The volumes of sewage involved magnify this problem, and sewage sludge's semi-solid texture and high organic content further complicate the situation. Pollutants in sewage can be very long-lasting and accumulate in soils. Disposal options for sewage sludge are considered in later sections.

Some of the more complex processes used in sewage sludge and waste-water treatment are helpfully detailed in the table below, from '*TABLE 11. of The Characterization of Faeces and Urine: A Review of the Literature to Inform Advanced Treatment Technology*' (Rose, 2015), with additional commentary in the RHS column, in bold, by this author:

Process	Example	Resource recovered	**Challenges**
Biological	*Anaerobic digestion*	*Biogas*	**Issues of residue disposal, pharma, antibiotic resistance, heavy metal, and other pollutants. Toxicants in water used to transport sewage are very difficult to treat due to the volumes involved. Residual pollutants reduce the feasibility of a safe return to agricultural land.**
	Decoupled HRT (hydraulic retention time) and SRT (solid retention time)	*Digestate/Biosolids/liquid fraction*	**As above.**
	UASB (upflow anaerobic sludge blanket)	*Biofuel production*	**As above.**
	Wet and dry composting	*Compost fertiliser*	**As mentioned above, urine and faeces are not separated at the source.**
Thermal processes	*Pyrolysis/gasification*	*Energy/Char*	**As the above issues remain with the water fraction, incineration produces varying amounts of gaseous pollutants, and ashes require disposal.**
	Incineration	*Energy/Ash*	**As above.**

Separation	*Biofiltration*	*Pathogen free water*	**Filtration does not remove soluble toxic residues, including pharma products.**
	Membrane pervaporation	*Pyrolysis*	**As mentioned above, issues with the water fraction, gaseous pollutants remain, and ashes require disposal.**
Chemical processes	*Electrochemical disinfection*	*Pathogen-free products*	**Disinfection does not remove soluble toxic residues, including pharma products.**
	Ammonia disinfection	*NPK irrigation water/fertiliser*	**As above.**
	Struvite	*Phosphorus*	**Extracts phosphates, but issues with water compartment and residues remain.**
	Ammonia stripping	*Fertiliser*	**As above.**

Table 4. Classifications of broad treatment pathways in wastewater treatment (Derived from 'Table 11. of *The Characterization of Faeces and Urine: A Review of the Literature to Inform Advanced Treatment Technology'* (Rose et al, 2015), with additional bold commentary with many thanks to the authors.

Where wastewater plants exist, there are several basic, established, if inefficient, primary and secondary treatment processes for sewage water effluent (Topare, 2011). Most existing standard primary and secondary treatment options cannot treat many of the broad mix of pollutants, in addition to those in faeces and urine, arriving at sewage plants.

Advanced tertiary wastewater treatments, such as ozone and activated carbon, are not feasible for sewage sludge, and the only options for disposal of sludge or residue after biogas production remain to spread on land, landfill or incineration.

16.1. SEWAGE WASTE WATER – TREATMENT AND REUSE - OPTIONS

There are three water treatment levels for outflows from WCs, combined with other inflow sources, in the sewage streams that arrive at sewage plants, known as primary, secondary and tertiary treatment:

- primary includes sedimentation and filtration,
- secondary is usually some form of aerobic and or anaerobic bacterial water treatment to reduce organic matter and provide limited treatment of pollutants,
- tertiary treatment is a broad term encompassing a range of water treatments of wildly varying efficacy, having in common the minimum aim of removing all (California standard) or most (WHO standard) bacteria so sewage water can be used without restriction for agriculture, as set out in the review '*Wastewater tertiary treatment options to match reuse standards in agriculture'* (Licciardello, 2018). (Effective 'tertiary' further remedial treatment of the separated sludge component

is not practically possible). Tertiary water treatments vary significantly in cost and efficacy. More than one technology can be combined to achieve the desired outcome.

Wider pollutants in sewage water, if not removed, directly or indirectly reused for drinking and or irrigation (excluding reverse osmosis treated water), may include pharmaceuticals/antibiotics, personal care products, endocrine disruptors, heavy metals and a raft of other emerging contaminants of concern including PFAS, which contaminants, viewed in the long term, as discussed in more detail in later sections, pose significant, often under-considered, potential risks, for; the soil biome, plants, food and feedstock, livestock, humans, and the wider environment.

The review *'Wastewater reuse and pharmaceutical pollution in agriculture: Uptake, transport, accumulation and metabolism of pharmaceutical pollutants within plants'* is recommended reading, and notes, *"In dry regions, using treated sewage for crop irrigation is the major solution to sustain agriculture . . . 1.6–6.3% of the world's treated sewage is used for irrigating agricultural land . . . Globally, around 15 million m³ of reclaimed water is used daily for agricultural irrigation . . . 10% of the global population consumes food irrigated with wastewater. . . by adopting wastewater reuse for agriculture, Israel has increased its production by 1600%, becoming a global benchmark. Wastewater reuse in agriculture as irrigation water has been reported to be ranging from 22 to 77 % in different countries"* (Mosharaf, 2024).

Thus, it is clear that the potential for using treated sewage wastewater for irrigation, and more widely, including for drinking water, is a globally significant issue, and more so in dry regions.

Sadly and concerningly, we have not sufficiently considered or grappled with the cumulative combined downstream environmental and health consequences of the long-term application of a mix of a wide range of unremediated pollutants onto agricultural land, their intake through food, or direct in drinking water, for the long-term development, and health including mental health over the life course. However, we have clear evidence that air, water, and food pollutants can impact mental health and development.

16.2. SEWAGE WATER DISPOSAL / REUSE OPTIONS

Options for sewage water disposal/reuse include:

- reverse osmosis, remineralisation, and inclusion in drinking or industrial process water streams, but the process byproduct polluted residue water still has to be disposed of or treated;
- other forms of tertiary treatment are considered in the section below;
- discharge into rivers and aquifers;
- discharge into marine environments;
- agricultural irrigation using treated or, in some instances, untreated water.

16.3. SEWAGE WATER TERTIARY TREATMENT OPTIONS

Top-end tertiary water treatment techniques, such as reverse osmosis, will remove most pollutants. Less technical and costly tertiary treatment solutions prescribed by authorities for agricultural irrigation water, such as those proposed by WHO and California; for example, "*in order to reach an effluent quality suitable for irrigation, the California guideline proposed conventional biological treatments in combination with tertiary treatment, filtration and chlorine disinfection, while the WHO suggested a series of stabilization ponds*" (Licciardello, 2018), which will remove some, or all bacteria and pathogens; however water treated to these standards will still contain a wide range of pretreatment pollutants, of uncertain concentration, and chlorine by-products including EDCs, (Endocrine-Disrupting Chemicals).

The long-term impacts on human and livestock health of the accumulation of such pollutants in plants and their movement up the food chain are as yet unclear. However, it is clear that such pollutants, when present in sufficient quantities over extended time frames, can and do impact human health, development, and mental health.

Fig. 33. Generic sewage treatment, with thanks to the Author and Adobe Photo Stock.

A variety of tertiary-water-treatment technologies exist (Rodríguez-Hernández, 2022; Werkneh, 2023); the more effective ones are generally technical, expensive, and require the treatment and disposal of residues, including:

- reverse osmosis. (very effective);
- oxidation treatments including with ozone (effective in combination ~ 80-90%);
- flocculation with activated carbon (effective in combination ~ 80-90%).

Less technical, less effective, tertiary-water-treatment processes exist, which each have their remediation fortes, but none of which are capable of remediating the basket of pollutants described, thus are flawed in terms of protecting the environment and health include:

- electro-chemical treatment;
- ultraviolet – which, appropriately deployed, will kill bacteria but has limited efficacy in terms of broader pollutant reduction;
- chlorine – which, appropriately deployed, will oxidatively kill bacteria but has limited efficacy in terms of pollutant reduction and has the disadvantage of creating a range of EDCs (Endocrine-Disrupting Chemicals);
- membrane bioreactors;
- phytoremediation, including the use of wetlands, has limited remediation capacity.
    - "*Horizontal sub-surface constructed wetland system, biological pond, storage reservoir, sand and disk filters*" (Licciardello, 2018);
    - "*Horizontal sub-surface constructed wetland system, sand and disk filters, ultraviolet (UV) system*" (Licciardello, 2018);

Highly technical tertiary water treatment options, which are the subject of ongoing research, include:

- engineered microbes;
- electrochemical;
- solar photo-Fenton;
- membrane including graphene filters, nano-filters, and ultrafiltration,

Heavy metal tertiary wastewater treatment techniques include;

- *"adsorption-, membrane-, chemical-, electric-, and photocatalytic-based treatments"* assessed as to "*cost-effective, technical maturity, environment friendly, and automaticity*" in '*Removal of heavy metal ions from wastewater: a comprehensive and critic review*' (Qasem, 2021).

Biological solutions and disinfection of sewage-wastewater, while removing bacteria and pathogens to varying extents and designated 'zero' or 'low risk', will still only partially remediate contaminants of concern with differing efficiency. Similarly, heavy metals are removed with varying efficiency, depending on the process used. All face the significant post-processing issue of dealing with the pollutants generated and/or collected and concentrated as part of the treatment processes.

As discussed, if not removed, an extensive range of contaminants of concern, including antibiotics and ARGs, PFAS, heavy metals, and microplastics, once discharged into the environment, including via agricultural irrigation, will move through the environment and, via uptake by plants, enter the food chain, with upstream adverse health, as well as wider environmental consequences, including for humans and livestock.

There is an emerging recognition of the potential health consequences of wider contaminants entering the environment and food chain, as evidenced by the European Union Agricultural Waters and Food Safety Regulation EU 2020/741 (Dongo, 2021). However, such concerns do not appear to have manifested significantly in the agricultural, food and feedstock industries or the public conscience.

16.4. SEWAGE WATER REUSE– LARGELY, PARTIALLY, OR UNTREATED - CONSEQUENCES

As noted above, sewage water can be untreated, partially treated, or treated in WWTP, with a portion, after initial cleaning, treated in tertiary systems of varying efficacy, including reverse osmosis.

The water streams can be disposed of or used in various ways;

- Discharged into rivers, aquifers and groundwater. Where the discharge volume represents a significant part of the river flow, the risk of pollution of subsequently abstracted water is significantly increased.
- Untreated or partially treated for agricultural irrigation.
- Inclusion in drinking or industrial process water streams.
- Untreated, partially treated, or untreated discharge into marine environments.

The second Volume about water considers reverse osmosis, including the consequent need for remineralisation to prevent mineral deficiencies in humans and livestock, the risk of residual pollutants, and the need to dispose of the residue water, which accumulates and concentrates the removed pollutants.

This volume further considers the environmental health consequences, including to humans and livestock, and the broader implications, including on agriculture, of discharge of treated and untreated sewage water into rivers and the marine environment. They are also considered in Volume 2 on regenerative agriculture and Volume 3 on water.

Pollutants in wastewater also impact the soil biome and plants. They accumulate and concentrate over time, further moving into plants and thus up the food chain with potentially adverse health consequences.

Limited knowledge exists about the movement of single pollutants. Further, the effect of a basket of such contaminants on soil biomes, plants, livestock, humans, and the wider environment is currently unknown.

The use of secondary treated wastewater for agriculture is extensive and growing, and official Global bodies, including the United Nations, recommend it. However, it is uncertain if they have thoroughly considered the likely long-term consequences on soil, crops, livestock, humans, and broader environmental health.

There is a temptation to believe that sewage remediation can perhaps be done on a domestic basis, enabling citizens "to do their bit" in the same way that they might install a small wind turbine in their back garden or solar panels on their roof. Some small-scale technologies allow individual households to treat their waste, including bioreactors, septic tanks, and drainage fields, which dispose of 'treated' water in the water table.

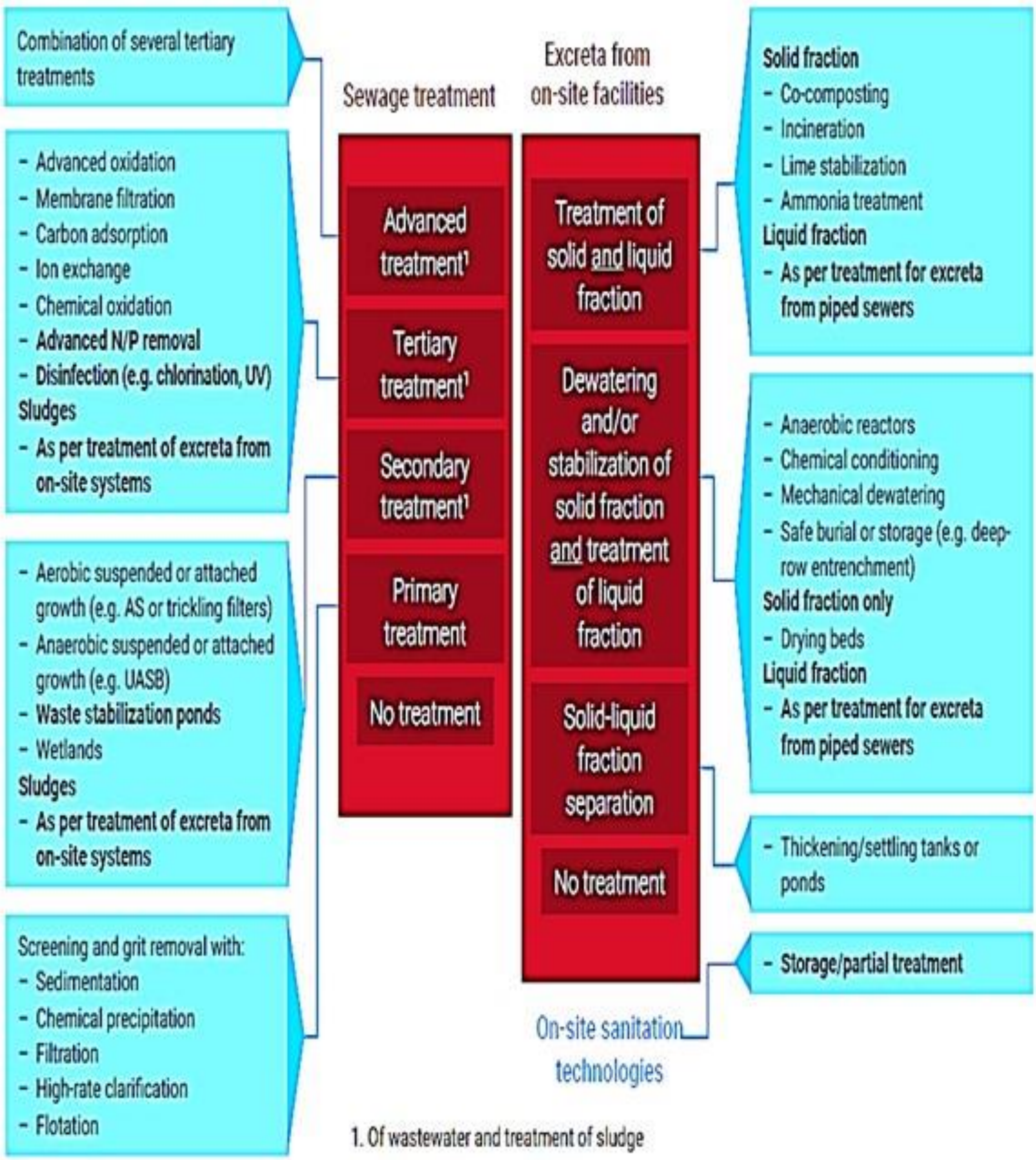


Fig. 34. The United Nations paper 'Progress on Safe Treatment and Use of Wastewater (Guidelines on Sanitation and Health IGO, 2018)' describes wastewater treatment types—many thanks to the authors. Notably, treatment is not considered in terms of the need to close the nutrient cycle. Further composting and other alternatives for return to land and recovery of nutrients are not included as options.

Decentralised domestic sewage treatment is growing due to water pressures and costs. Superficially, this is an attractive idea as it reduces public infrastructure costs (Kautz, 2016). However, domestic sewage treatment systems cannot remediate a wide range of contaminants of concern and pharmaceuticals, including antibiotics.

16.5. SEWAGE WATER TREATMENT – ONGOING RESEARCH

Ongoing research explores possible new methods (Rajasulochana, 2016) to remediate sludge and discharge water. However, many are expensive, involve complex technology, present practical problems, and have limited capacity to deal with the huge volumes involved. The latest progress in this field has been with advances in the use of membranes, including graphene filters, chemical disinfection, and coagulation (Milman, 2015). However, many are likely impractical for all but specialist applications.

Engineered microbes, formerly used for cleaning up oil spills and bioremediation of sites contaminated with heavy metals (Dixit, 2015), are now used in sewage treatment research (Singh, 2003). Microbes also appear capable of transforming minerals into biofilms, and *"recent demonstrations of the removal and immobilisation of inorganic contaminants by microbial transformations, sorption and mineralisation show the potential of both natural and engineered microbes as bioremedial tools*" (Barkay & Schaefer, 2001). This suggests they potentially could be used to capture inorganic pollutants, such as metals, from wastewater and may assist in sludge treatment. However, residues still need to be recovered or disposed of.

However, the use of microbes is difficult to control; there is the inherent risk of them developing antibiotic resistance from drug residues in sewage and of genetic mutation through the transference of plasmid DNA with pathogens. Also, while such "*new technologies have shown promise, [they] may be cost-prohibitive on a large scale*" (Taylor-Smith, 2015).

Intermediate solutions exist for treating sewage wastewater as against sludge, as discussed, including oxidative and activated carbon technologies, such as those used by the Swiss, but residues remain.

UV disinfection of wastewater, a cheaper option, has a role, but UV fails to sufficiently remediate pharmacological products, antibiotic-resistant bacteria, and genetic material (Guo & Kong, 2019). Further, some pollutants, such as heavy metals, cannot be remediated by UV. Obvious but fundamental oxidative, carbon, and UV light treatments cannot be used on non-transparent semi-solids, including sewage sludge.

Additionally, it is not inconceivable that DNA damage caused by the imperfect use of UVC may speed up the evolution of new strains of bacteria by increasing the rate of evolutionary change.

It is important not to lose sight of the fact that vacuum WC systems use very little water; thus, waste sewage water would no longer be an issue. Grey water would continue to be produced and contain pollutants, including PCPs, that require treatment. However, the levels of pharmaceuticals, related products, and solids it contains would be much lower, making treatment technically easier.

16.6. SEWAGE SLUDGE DISPOSAL OPTIONS

Options for treated or untreated sewage disposal/reuse, all of which pose a variety of consequential environmental issues, include:

- landfill;
- agricultural land;
- incineration;
- composting – traditional or hyper-thermophilic - and use on land;
- biochar via controlled combustions;
- anaerobic traditional or hyper-thermophilic fermentation followed by any of the above;
- discharge into rivers or marine environments.

16.7. SMALL SCALE ON-SITE DOMESTIC SEWAGE TREATMENT

Fig. 35. A drainfield being installed, with many thanks to the author Nonztp and Wikipedia.

The quality and effectiveness, remediation, and monitoring of granular domestic sewage treatment systems are well below that of existing sewage treatment plants. They also inevitably fail to address the crucial issues of pharmaceuticals, antibiotic resistance, and broader pollution, consequent on discharges into the water table.

16.8. WASTEWATER – CLOSING CYCLE – MINIMISE USAGE AND SOURCE POLLUTION

Most tertiary water treatment protocols, including disinfection, UV, and wetland filtration, have limited and varied capacity to remove the long list of wider contaminants of concern, including pharmaceuticals, antibiotics, ARGs, PCBs, PAHs, PFAS, etc., to a limited but variable extent. To the extent removed, the concentrated pollutants, in whatever form or medium they have been trapped in, themselves have to be remediated and/or disposed of.

Reverse osmosis is an exception, but it is expensive; it will remove almost all pollutants; however, the water requires remineralisation, and the residue in which the contaminants are concentrated must be disposed of. Reverse osmosis is used for water purification of drinking water for cities and sometimes used at scale for agriculture, but due to cost and other considerations is the exception, WHO or California-type tertiary-treatment standards are more widely used, particularly for agricultural irrigation.

The growing need for focus on the issue of contaminants in wastewater is illustrated by Israel, which reportedly recycles a remarkable and inspirational 90% of its water, *"Today, nearly 90 percent of Israel's treated wastewater is reused for irrigation purposes"* (WRAP 2023), but what proportion of the tertiary treatment of wastewater is treated by the more effective reverse osmosis, as against filtration and disinfection, is not known by this author. Thus, much irrigation water will likely contain a range of concentrations of a wide variety of contaminants, which to varying extents will be taken up by plants and thus enter the food chain.

Whilst the presence of individual contaminants in food may generally be low, consideration of the combined effects of multiple pollutants over the long term is unknown, and evidence of the potential harm of using sewage-related products on land is mounting, as discussed elsewhere.

These potential risks are more significant in countries highly reliant on such water. For example, Israel, a global leader in water reuse, supplied approximately 29% of its national water, including for irrigation, with recovered "effluent" water in 2020 (See Fig.2 in WRAP, 2023).

There is an available alternative. Moving to vacuum WC sewage collection and related treatment, digestion, and composting technologies would prevent the pollution of such large volumes of water and directly save considerable amounts of FaF water. This promising solution offers hope and motivation for change at multiple economic, population health, and environmental levels.

17. ANTIBIOTICS AND PHARMACEUTICALS IN SEWAGE AND SLURRY

Many pharmaceutical products and antibiotics we and our livestock ingest are excreted unchanged. Thus, pharmaceuticals, including antibiotics, are present in untreated sewage, treated sewage, wastewater, sewage sludge, and animal slurry.

In the absence of top-tier tertiary water treatment and incineration of sewage sludge, a situation currently the exception, untreated sewage poses a significant environmental risk. Bioactive pharmaceuticals, antibiotics, and antibiotic-resistant material enter the environment, creating a substantial risk of the spread of antibiotic resistance. This can damage soil, plant seed, root, phyllosphere, fungal and bacterial biomes, as well as impacting the gut and wider biomes of higher life forms and our capacity to combat several unpleasant, sometimes fatal diseases.

Annually, humans and their livestock jointly consume hundreds of thousands of tons of pharmaceutical products globally, of which between 70 and 90 per cent are excreted. Medical and broader pollutants include; "*hormones, cytostatic drugs, antipyretics and analgesics, beta blockers, psychotropic medications, nonsteroidal anti-inflammatory drugs (NSAIDs), X-ray contrast media, herbicides, pesticides, and veterinary medications*" (Gautam, 2024). *"Common reported hormones are the natural estrogens, estrone and 17b-estradiol, as well as the contraceptive 17a-ethinylestradiol. Among cosmetic ingredients, the polycyclic musk fragrances, galaxolide, tonalide and celestolide, are ubiquitous*" (Suárez, 2008).

The review '*A critical evaluation of comparative regulatory strategies for monitoring pharmaceuticals in recycled wastewater*' notes that there are "*over 4000 pharmaceutical products available worldwide for medicinal and veterinary purposes, resulting in annual production exceeding 100,000 tons of pharmacologically active compounds*" (Miarov, 2019).

An article observes, "*Even after processing in a wastewater treatment plant, non-disinfected wastewaters contain orders of magnitude more antibiotic-resistant bacteria and antibiotic resistance genes than is naturally found in rivers and lakes. Raw sewage contains yet again*

Fig. 36. Slurry application with thanks to the USA FDA

much higher levels, and thus discharge of untreated sewage can be expected to contaminate the environment even more severely. One way this can happen, even in countries with otherwise excellent sanitation infrastructure, is when heavy rain leads to sewage volumes that exceed the capacities of sewer systems or wastewater treatment plants. A mixture of excess rainwater and sewage is then discharged into receiving water bodies, bypassing conventional treatment processes." (When rain overwhelms the sewers, antibiotic-resistant bacteria flood the river, 2022)

"*Regardless of the wastewater treatment process, sewage sludge contains antibiotics, antibiotic-resistant bacteria and antibiotic resistance genes, which can be released into the environment through its land application. Such a practice may even boost the dissemination and further development of antibiotic resistance phenomenon – already a global problem challenging modern medicine.*" (Bondarczuk, 2016; Chen, 2016)

The risk of the emergence of widespread antibiotic-resistant disease strains provides further reasons for collecting faeces and urine at the source with minimal water addition. Further and of significance, diseases our forbearers could not treat, such as tuberculosis and syphilis, could and are on the edge of again becoming untreatable due to antibiotic-resistant strains.

Collection of faeces and urine at source, with hyperthermophilic, anaerobic, and then aerobic digestion (Liao., 2018), logically offers the only likely affordable, practical, and effective solution to sustainably close the sewage cycle, including significant remediation of pharmacological products and antibiotic-resistant bacteria in faeces and urine.

17.1. WIDESPREAD, LONG-LASTING, AND DAMAGING TO AQUATIC AND PLANT SYSTEMS

The review, '*Harnessing Activated Hydrochars: A Novel Approach for Pharmaceutical Contaminant Removal*' (Gautam, 2024), powerfully, elegantly, and succinctly summarises why pharmaceutical pollution is such a significant environmental issue, including in relation to aquatic spread. As a consequence, a long quote is included.

Fig. 37. Generic selection of pharmaceutical tablets, with thanks to the Authors and Adobe Photo Stock

The review observes, "*What sets pharmaceutical contaminants apart is their exceptional persistence and mobility in aquatic ecosystems. They traverse substantial distances, affecting surface water, groundwater, and even potable water supplies, necessitating urgent measures* *to control and mitigate their presence. Effective disposal, advanced wastewater treatment, and rigorous monitoring are essential to tackle this multifaceted issue."* (Gautam, 2024)

"The escalated usage of pharmaceuticals, coupled with advances in detection methods and increased awareness of the associated risks, underlines the gravity of pharmaceutical contaminants as a distinct challenge. These contaminants are introduced into water bodies via numerous routes, leading to their prolonged presence and substantial threats to both public health and the environment." (Gautam, 2024)

"They disrupt aquatic life, causing population declines and accumulating in organisms, which can result in biomagnification and altered growth and development. Furthermore, the presence of antibiotic-resistant bacteria in aquatic environments contributes to antibiotic resistance, while toxicological effects lead to increased mortality rates and decreased biodiversity. Algal blooms triggered by pharmaceutical contaminants further disrupt aquatic ecosystems and produce harmful toxins. For humans, the risks include drinking water contamination, chronic exposure, direct health effects, and potential drug interactions." (Gautam, 2024)

As discussed, antibiotic pollution and antibiotic-resistant genetic material (ARG) are also widespread in the terrestrial, in addition to the aquatic environment, and impact the soil biome. Plants can incorporate antibiotic-resistant genetic material in their tissues and various mycorrhizal, phyllosphere, endophyte, and seed biomes. ARGs can even become incorporated in pollen, thus potentially impacting plant reproductive pathways: "*microbial taxa carrying ARGs in pollen can be transmitted to other organs of the plants such as ovule and the seed through vertical or horizontal transmission*" (Chen, 2023).

ARGs in plants can feed up through the food chain, impacting humans. For example, *"Abundant ARGs, . . . have been found in endophytes and phyllosphere microorganisms of livestock manure-amended vegetables at harvest*."

A substantial human health consequence is that "a considerable proportion of ARGs are multidrug-resistant*, which can undoubtedly increase the difficulty of clinical treatment*" (Chen P. 2023). Thought provokingly, "*Multiple ARGs, including resistance to ampicillin, bacitracin, colistin, cotrimoxazole, cephotaxime and carbenicillin, have been widely found in foods such as cooked rice, goat meat, milk, semi-processed foods, spices and pulses.*" (Chen P. 2023)

We have a minimal understanding of the broader consequences of the massive amounts of antibiotics we unwittingly and liberally distribute in treated and untreated sewage and agricultural slurries into our waterways and onto our soils. We know very little about how pharmaceuticals and antibiotics, including ARGs, biologically impact plant biomes, soil biomes, gut biomes, and broader bacterial activity.

The significant spread of ARGs, their potential impact on the environment, and increases in the number of antibiotic-resistant strains of bacteria are potent arguments for the separation and collection of urine and faeces at source using vacuum WC technology, thus avoiding the mixing of them, and the pharmaceuticals including antibiotic pollutants they contain, into the more expansive grey water and surface water streams, hence the wider environment.

17.2. PHARMACEUTICAL AND ANTIBIOTIC HALF-LIVES IN THE ENVIRONMENT

Half-lives of pharmaceuticals in the environment vary from days to years. Thus, over time, some, but not all, are quickly, often significantly, broken down in soils and aquatic systems. However, it is important to remember, due to repeated ongoing day-to-day medical use, that as fast or faster than they are broken down, they are constantly resupplied by human activity, at increasing annual rates, to the environment, thus even where they degrade relatively rapidly, are repeatedly replaced. Consequently, the environment is under constant ecological and, in some cases, growing pressure from antibiotics, wider pharmaceuticals, and a range of other pollutants (Bendz, 2005).

17.3. ANTIBIOTIC RESISTANCE - LIVESTOCK MANAGEMENT – A GLOBAL ISSUE

The spread of antibiotic resistance due to antibiotic use in livestock into the wider environment, rivers, oceans, and soils, and ultimately into lifeforms, including humans, is a significant issue for many reasons, both known and unknown.

‘*Antibiotic Residues in Animal Waste: Occurrence and Degradation in Conventional Agricultural Waste, Management Practices*” (Van Epps & Blaney, 2016) is a comprehensive and highly thought-provoking review. It discusses the level of antibiotics used in animal husbandry and the environmental risk posed by resistance to these drugs. Given the enormous quantities of pharmaceuticals in human and livestock urine and faeces, we must reduce usage and develop strategies to mitigate antibiotic resistance.

The paper ‘*Insights on the effects of antimicrobial and heavy metal usage on the antimicrobial resistance profiles of pigs’* notes, “*Antimicrobial resistance (AMR) is one of the great global concerns of the twenty-first century. The prevalence of AMR in primary production systems such as livestock production is of great concern due to the recognition of the interconnections between human, animal, and environmental health, also termed the “One Health principle*” (Ekhlas, 2023).

‘*Antibiotic Residues in Animal Waste: Occurrence and Degradation in Conventional Agricultural Waste, Management Practices*” (Van Epps & Blaney, 2016) contains, amongst much important information, the following highly thought-provoking observations, which have been quoted due to their succinct nature, profound importance, out of respect to the Author, and so as not to dilute their authority by paraphrasing. Readers are advised to refer to the original paper, which contains much additional key information, and to read more widely for the full context:

- “*The foreword of the 2014 WHO* [World Health Organisation] *report, ‘Antimicrobial Resistance: Global Report on Surveillance’, indicates that a post-antibiotic era is a real possibility in the 21st century due to the alarming rate of development and spread of antibiotic resistance*”
- “*Effective treatment of antibiotics in agricultural waste treatment systems is paramount.*”
- “*Like humans, animals do not fully metabolise antibiotics: . . . 75 - 80 per cent of tetracyclines, 60 per cent of lincosamides and 50 - 90 per cent of macrolides are excreted unchanged.*”

- *"Many of the antibiotics* **[used in livestock production are designated]** ***<u>'critically important antimicrobials' by WHO.</u> This classification involves meeting two criteria:***
    - ***Criterion 1 - An antimicrobial agent, which is the sole (or one of limited) available therapy, to treat serious human disease.***
    - ***Criterion 2 - An antimicrobial agent that is used to treat diseases caused by either: (1) organisms that may be transmitted to humans from non-human sources, or (2) human diseases caused by organisms that may acquire resistance genes from non-human sources."***

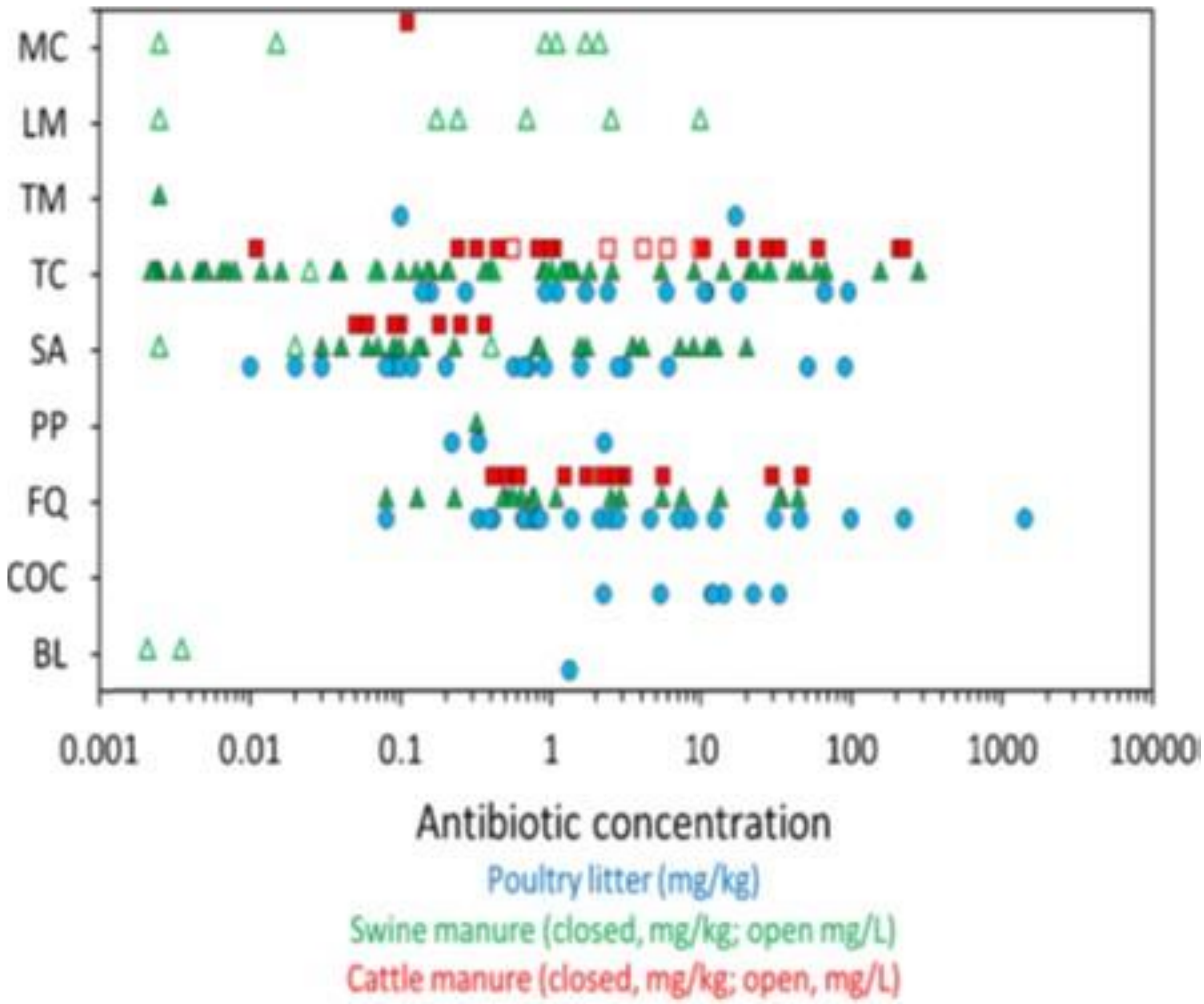


Fig. 38. "*Antibiotic concentrations detected in poultry, swine, and beef cattle manure. Data was aggregated from available reports. Antibiotic class codes on the y-axis are as follows: MC macrolide, LM lincosamide, TM trimethoprim, TC tetracycline, SA sulfonamide, PP polypeptide, FQ fluoroquinolone, COC coccidiostat, BL beta-lactam. For clarity, only the minimum and maximum antibiotic concentrations from individual studies were included here. This list is not exhaustive but is meant to convey the relative antibiotic detection and concentration ranges in animal manures*". Taken from the paper '*Antibiotic Residues in Animal Waste: Occurrence and Degradation in Conventional Agricultural Waste Management Practices*' (Van Epps & Blaney, 2016), with thanks to the authors.

- *"The widespread utilisation of human-use antibiotics in animal feeding operations may contribute to increased rates of resistance development in human pathogens."*

- *"A US Department of Agriculture study from 1999 found that 83 per cent of cattle feedlots administered subtherapeutic levels of at least one antibiotic to cattle. Using data from 710 farms and 3,328 animal feeds, Dewey found that 699 feeds used antimicrobial additives incorrectly."*
- *"Tetracycline resistance [in poultry litter] is common; however, tetracyclines are still widely used in human medicine and listed as critically important."*
- *"The diversity of antimicrobials detected in US swine manure includes the following: penicillin G, lincomycin, erythromycin, tylosin, bacitracin, sulfadimethoxine, sulfamethazine, sulfamethoxazole, chlortetracycline, oxytetracycline and trimethoprim. This diversity is concerning as the complex mixture of antimicrobials in swine manure/lagoons may more readily lead to the development of multidrug-resistant pathogens."*
- *"Antimicrobial use in the USA rose from 12.6 million kg in 2009 to 15.4 million kg in 2014."*
- *"Critical knowledge gaps remain with respect to the impact of treatment processes on inactivation of resistant bacteria and destruction of antimicrobial resistance genes."* (Van Epps & Blaney, 2016)

The graph above, taken from the paper '*Antibiotic Residues in Animal Waste: Occurrence and Degradation in Conventional Agricultural Waste Management Practices*' (Van Epps & Blaney, 2016), indicates some of the antibiotic products used, their importance to human health, and the wide range of concentrations found in manure.

On a more positive note, as mentioned above, attitudes towards antibiotic use are beginning to change. Some food companies have made significant efforts to reduce 'non-medical' livestock antibiotic usage since 2016. Selected products have been banned in some countries. Large US food corporations—including Perdue, Panera, McDonald's, Tyson, and Chipotle—have stated intentions of reducing or removing antibiotics in their livestock supply chains, but wider usage may still be increasing.

There is another option: livestock rotationally grazed on regenerative pastures remains healthy and productive with minimal pharmaceutical intervention, thus saving farmers costs and removing significant pollutants from the manure they produce, as discussed in Volume 2 on regenerative agriculture.

17.4. PHARMACEUTICALS AND ANTIBIOTICS IN DRINKING WATER

The issues of antibiotics in wastewater, rivers, oceans, and the general environment are considered in greater depth in Volume 3 on water. However, by way of background as to the extent of the issue, the National Geographic Magazine article, '*First global look finds most rivers awash with antibiotics*', recently reported the findings of a University of York study, which examined 72 rivers across six continents, and concluded, "*almost two-thirds contained enough antibiotics to contribute to the growing problem of antibiotic-resistant bacteria".* In places, researchers found *"antibiotic levels 300 times higher than is considered safe for the environment*". (Borunda, 2019)

Whilst reviews suggested that the pollutant levels of drinking water and crops in high-income economies pose little risk, drinking water, to varying degrees, is not free from contamination. However, concerns are beginning to emerge, as seen over PFAS. The basket of such pollutants is called '*Contaminants of emerging Concern*', and volumes are written on the subject, as referenced in the WHO report titled '*International Decade for Action 'Water for Life' 2005-2015*' (WHO, n.d.).

In the intervening years, evidence has accumulated and continues to accumulate that such pollutants will prove to be significant environmental and human health concerns. Further and an additive concern, much remains unknown, as reflected in the quotes below.

The WHO document, '*Pharmaceuticals in Drinking Water*', notes, "*Concern has been raised, because exposure to pharmaceuticals through drinking water is an unintended and involuntary exposure over potentially long periods of time. Moreover, there are few scientific risk assessments of exposure to low levels of pharmaceuticals, both as individual species or as mixtures, in drinking water*" (WHO, 2012).

Aana Taylor-Smith, in '*Pharmaceutical Compounds In Land-Applied Sludge And Plant Uptake: A Review*', observes: *"Although research into these compounds has accelerated in recent years, the behaviour and effects of pharmaceuticals in the environment is not well understood. . . . Because pharmaceutical compounds' potential for chronic toxicity at low, repeated doses is unknown, chronic human health effects cannot be fully assessed at this time. . . Without fail, all of the research papers reviewed in this study recommended further investigation into the environmental fate and impacts of pharmaceutical compounds."*. (Taylor-Smith 2015) [link to PDF broken].

While 'Flush and Forget' has a hand in creating this potent antibiotic 'superbug' brew, so does the direct discharge of agricultural urine and faeces; thus, the threat is just as pressing in countries with little access to modern slurry facilities or sewage treatment. After all, the same mixing process can play out with direct discharge into the environment thanks to the greater use of drugs and the ready availability of raw sewage and slurry. In short, the risks are global and common; they only differ in degree and mix.

17.5. HEALTH AND ENVIRONMENTAL RISKS - ANTIBIOTICS AND PHARMACEUTICALS, INCLUDING HORMONES AND PSYCHOACTIVES

The wide range of pharmaceuticals released into the environment poses health issues for humans, livestock, wildlife, plants, bacteria, and wider biomes. The review '*A critical evaluation of comparative regulatory strategies for monitoring pharmaceuticals in recycled wastewater*' sets out examples of their widespread impact, including;

- antibiotics - "*Consuming water or food containing antibiotic residues may lead to various adverse effects on human health, such as allergic hypersensitivity reactions, toxic effects, hepatotoxicity, nephropathy, mutagenicity, carcinogenicity, and antibiotic resistance*";
- hormones - "*Treatment of plants with steroid estrogen hormones or their precursors can affect root and shoot development, flowering, and germination';*

- histamines - *Studies evaluating the adverse effects of antihistamines in aquatic organisms have tested soil bacteria, worms, fish, invertebrates, biofilm and many more media, confirming several adverse effects";*
- anti-cancer – "*Residuals from anticancer drugs interfere directly or indirectly with the structure and functions of DNA, which also affect non-target cells and tissues of exposed organisms.";*
- psychoactives – *"Several studies indicate that psychiatric pharmaceuticals can affect physiological systems at very low concentrations.* (Miarov, 2019) . . . "*A number of other studies on Fluoxetine, Diazepam, Prozac, Sertraline, Paroxetine, along with other pharmacologically active compounds clearly showed significant adverse effects of antidepressants and anxiolytics on living organisms of aquatic matrices"* (Miarov, 2019). Another study demonstrated that '*Mianserin*', a tetracyclic antidepressant, has estrogenic activity and produces endocrine disruption in zebrafish. (Van Der Ven. (2006).

The potential economic costs of antibiotic resistance are significant. The Food and Agricultural Organisation of the United Nations (FAO) warns: "*The health consequences and economic costs of anti-microbial resistance are respectively estimated at 10 million human fatalities a year and a 2 to 3.5 per cent decrease in global Gross Domestic Product, amounting to US$ 100 trillion by 2050. However, the full impact remains hard to estimate*". (EU Action on Antimicrobial Resistance, n.d)

In 2023, the EU issued recommendations on antimicrobial resistance, yet despite the significant relevance of sewage treatment and disposal, their mention in the documents is limited.

17.6. SERIOUS KNOWLEDGE GAPS

Despite increasing awareness of the potential health and environmental consequences of contaminants of concern, including antibiotics, as discussed, worryingly, much is still unknown about the effect and fate of most of the extensive range of pollutants in sewage, particularly the combined impact of exposure to multiple contaminants over extended time frames.

For example, in considering antibiotics, the review, '*Towards a research agenda for water, sanitation and antimicrobial resistance',* observes, "*with respect to treatment, there are serious knowledge gaps around fate (persistence and survival), interactions, and treatment efficiency (removal, log reductions) of antibiotic compounds, metabolites, antimicrobial-resistant [AMR] bacteria, and AMR genes in water and wastewater technologies*" (Wuijts, 2017).

However, we do know that human mortality is predicted to rise significantly as the numbers of antibiotic-resistant medical conditions grow. The same National Geographic article continues: "***A 2016 report found that each year around 700,000 people worldwide die of infections that are resistant to the antibiotics we have today***" (Borunda, A. 2019) (this author's bold), and food factored in a significant number of the deaths by acting as a vector for antibiotic resistance. Given the uncertainties, should we not take a precautionary approach?

17.7. ANTIBIOTICS – IMPACT ON PLANT AND SOIL BIOLOGY AND FUNCTION

"Most antibiotics enter soil through animal excretions, irrigation, and manure- or sewage sludge-based fertilization" (Bloor, 2021). Antibiotics are transferred from soils into the wider environment, as well as through plants to livestock, pets and humans, thus spread through agricultural systems, and have been "*detected in soil and aquatic environments, such as agricultural soils, urban green space, forestland, surface water, groundwater and seawater.* (Jia 2023)

The emergence and interactions of antibiotic-resistant genes are incredibly complex, as set out in the review '*Antibiotics in the Soil Environment - Degradation and Their Impact on Microbial Activity and Diversity*' (Cycoń, 2019), which presents data on concentration ranges, persistence times, and soil population shifts between fungi and bacteria. At the extremes, antibiotics can reduce yields and cause plant death. (Bloor, 2021)

"*Scientists quickly discovered that antibiotics affect the composition of soil microbiota and tamper with plant biomass production. But the most concerning finding was the movement of antibiotics through agroecosystems, which can lead to the emergence of antibiotic-resistant microorganisms that pose a risk to human health."* (Bloor, 2021)

The half-lives of antibiotics range from days to years. Their fate and rate of degradation are dependent on a range of factors, including the levels of organic matter and biology in soils; *"The fate of antibiotics in the environment mainly includes adsorption and degradation, and is regulated jointly by their physicochemical properties and environmental factors."* (Jia, 2023)

Effects are complicated and can be magnified by the co-action of several pollutants, including heavy metals. Much remains unknown about the impact of antibiotics and antibiotic resistance on soil-plant systems (Chen, P. 2023) and plants, including their seed biomes. Concerningly, some have seen adverse effects of soil antibiotics on germination.

Adopting regenerative agriculture and ending the use of sludge and unremediated slurry on soils would significantly reduce antibiotic impacts on agricultural soils, with positive benefits for the environment, soils, livestock and humans.

18. NANO-MICROPLASTICS IN SEWAGE SLUDGE AND WASTEWATER

Nano-microplastics enter the environment through multiple pathways. It is underappreciated that FaF sewage water and sludge treatment and disposal is a significant source of nano-microplastics in rivers, oceans and the wider environment through multiple downstream pathways (Kay, 2018).

Nano-microplastics, in addition to being taken into plant human and broader tissues where the particles directly impact biological pathways, effectively adsorb a range of pollutants from their environment, which they will carry with them to and through tissues and other mediums as events move them. These nano-microplastic adsorbed pollutants will have additive negative physiological impacts on the tissue of bacteria, fungi, animals and plants, impacting all living things from humans to soil biomes.

Microfibres and nano-microplastics are abraded and rinsed from fabrics containing artificial fibres and discharged into the domestic sewage waste stream, including by washing machines. FaF sewage treatment systems have no significant capacity to isolate and collect nano-microplastics or prevent them from entering the environment, either through treated sewage wastewater or sewage sludge. Even filtration in tertiary water systems is very difficult due to their capacity to break down into ever smaller particles. Further, plastic filtration membranes themselves can shed nanoplastics.

Wider microplastic sources include rubbish inappropriately disposed of, fabric and carpet sources in the home, debrided tyres and multiple other materials. Nano-microplastics also enter the environment through wind pick-up, including from dried sewage sludge applied on agricultural land, consequent atmospheric transport, and redistribution in the rain (Rezaei, 2019).

Other sewage-related micro and nano-plastic dispersal mechanisms include recycling and further breakdown through inclusion in natural food chains, water filtration systems including membranes, bottled waters in some instances, and human, livestock, and wider species, nano-microplastic ingestion and excretion.

Nano-microplastics are reported as a significant factor in soil, marine, and broader, including atmospheric pollution. They are present in tap and bottled water. They are widely found in the environment, including plant livestock and human tissues, and many other life forms, including fungi and bacteria. They are present in soils and seas, where they are mistaken for food. Thus, they are an accumulating pervasive pollutant, with planetary=level consequential effects that are only beginning to be appreciated and understood for human and wider species' health and development.

18.1. NANO-MICRO-PLASTICS IMPACT BACTERIA AND FUNGI WITH EXISTENTIAL IMPLICATIONS FOR BIOLOGICAL SYSTEMS THUS LIFE

At the most fundamental level, nano-microplastics have been found within and impact the biology of bacteria and fungi. Bacteria and fungi are essential to the core, far-reaching, and complex pathways underlying life. They are central to the soil biome, a foundation stone of the Gaian ecosystem that provides us with a habitable environment and nourishment. A study reports, "*several studies have reported disturbances in soil balance and negative impacts on geochemical cycles*" (Grande-Tovar, 2022).

Nanoplastics are entering the food chain. They have been observed to be taken up by fungi, bacteria, other soil life forms, and plants. Indeed, it appears mycorrhizal fungi may collect microplastics and deliver them to plant roots, "*Using a root organ-fungus axenic growth system treated with fluorescence-labeled NPs* (nanoplastic)*, we subsequently revealed that the hyphae captured NPs and further delivered them to roots. NPs were observed at the hyphal cell walls, membranes, and spore walls*" (Li, H, 2024). They are found in bottled and tap water.

They can cross the gut lining, be taken into living cells, including the brain, placenta, and testes, and are found in breast milk. In early studies in rodents, microplastics in tissues are associated with adverse health outcomes, including impacting essential pathways, such as cardiovascular health and reproduction. The biological consequences on human health and function are only in the early stages of research. However, should we not find ways to address nano-microplastic pollution, initial results give a glimpse of a Pandora's Box of dystopian possibilities.

As well as impacting the host's cells, micro-nanoplastics will impact their integral symbiotic biomes. Plants, seeds, soils, insects and other species, including humans, have several biomes, including the gut, skin, oral, and reproductive systems. The capacity of nanoplastics to enter cells means they will also impact all bacterial/fungal biomes. Biomes, singly and jointly, affect the biological function of all living things.

In bacteria, nanoplastics can impact function and cell membrane integrity and facilitate the development of antimicrobial resistance (Liu, 2023). For example, in a study on Escherichia coli, polystyrene nanoparticles of 60nm were "*observed to enter the cells as well as accumulate on their surfaces and enhanced ROS generation of the cells*"(Kim, 2022). They have also been observed to impact gut and related immune function adversely.

Micro-nanoplastics also impact the function and behaviour of fungi; the review, '*Microplastics accumulate fungal pathogens in terrestrial ecosystems*' observes, "*Metagenomic and microscopic findings provided complementary evidence that the terrestrial plastisphere is a suitable ecological niche for a variety of fungal organisms, including important animal and plant pathogens, which formed the plastisphere core mycobiome* . . . *Therefore, MP must be regarded a persistent reservoir and potential vector for fungal pathogens in soil environments. Given the increasing amount of plastic waste in terrestrial ecosystems worldwide, this interrelation may have severe consequences for the trans-kingdom and multi-organismal epidemiology of fungal infections on a global scale"* (Gkoutselis, 2021).

Thus, nano-plastic conglomerates could provide ecospheres within living systems sheltered from the immune system and pharmaceutical agents. To these thought-provoking and saddening complexities, the potential for disrupting the interactions between fungi and bacteria can be added; one is probably rarely present without the other, as in the soil biome and human gut, and the unknown implications thereof.

There is some possible good news in that studies have found many fungi and bacteria that may have some capacity to degrade some plastics, "*to date, 436 species of fungi and bacteria have been found to degrade plastic*" (Kew, 2023). Separately and interestingly, hyperthermophilic composting has been shown to potentially have some capacity to break down plastics – is this a result of the action of fungi and or bacteria? If the case, this would be a further reason for urgent research and development of hyperthermophilic composting, with attention to the potential of hyperthermophilic fungi and bacteria to break down plastics.

Much is unknown and remains to be researched. However, initial outcomes suggest that nano-microplastics will have adverse functional effects, including on fungi and bacteria and more so on their more sophisticated plant, livestock, and human symbionts; the long-term environmental consequences of nano-microplastic pollution are unknown, but initial indications are worrying.

18.2. NANO AND MICROPLASTICS – IMPACT ON GUT MICROBIA

Recent research shows that nano and microplastics (MNPs) impact bacteria and fungi, so it is logical that they will impact gut health and function, including the broader roles of the gut, such as regulation of immune and neurological function (Sofield, 2024).

In 2016, little was known; a review observed, "*There is a lack of knowledge about the local effects of microplastics in the GI tract, including microbiota. Toxicological data on the effects of microplastics as such, are essentially lacking for human risk assessment.*" (Statement on the presence of microplastics and nanoplastics in food, with a particular focus on seafood, 2016).

However, the landscape is changing as research results are beginning to emerge, and they are indeed concerning. For instance, the 2020 review 'Immunotoxicity and intestinal effects of nano- and microplastics: a review of the literature' noted, "Numerous animal studies have shown that exposure to nano- and microplastics leads to impairments in oxidative and inflammatory intestinal balance and disruption of the gut's epithelial permeability. Other notable effects of nano- and microplastic exposure include dysbiosis (changes in the gut microbiota) and immune cell toxicity. Moreover, microplastics contain additives, adsorb contaminants, and may promote the growth of bacterial pathogens on their surfaces: they are potential carriers of intestinal toxicants and pathogens that can potentially lead to further adverse effects" (Hirt, 2020).

The review '*Micro(nano)plastics and Their Potential Impact on Human Gut Health: A Narrative Review*' notes that "*studies indicate that the accumulation of MNPs in mammalian models and human cells may result in adverse consequences, in terms of epithelial toxicity, immune toxicity, and the disruption of the gut microbiota*" (Covello, 2024).

18.3. MICRO AND NANO PLASTICS IN FISH - OCEANS, MARINE ORGANISMS

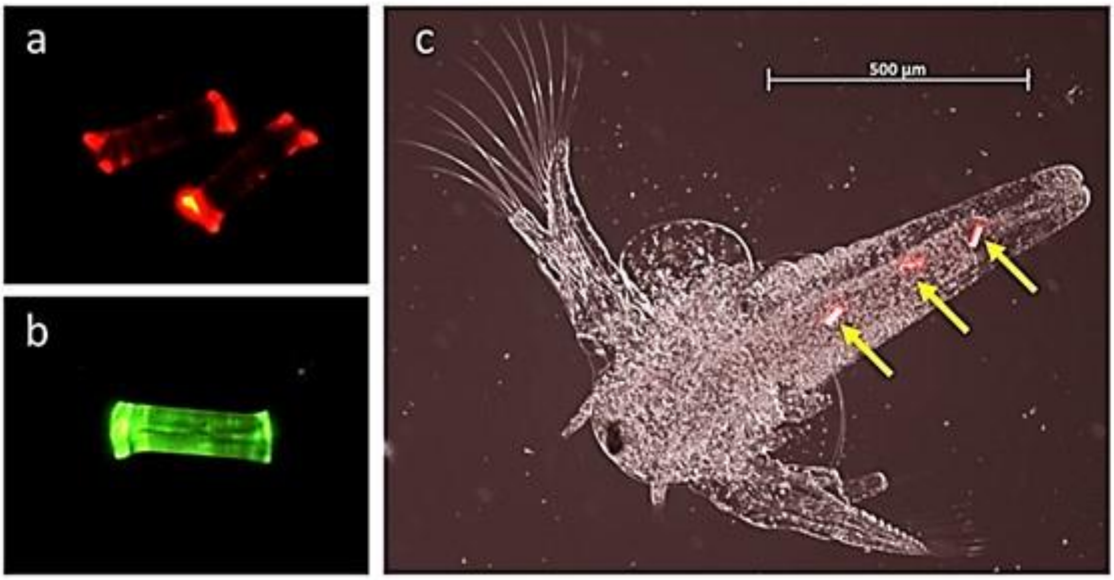
Many micro-nanoplastics released from washing machines will, over time, end up in the oceans, where, to tiny creatures, they look like food. They are, in turn, eaten by larger creatures such as mussels, oysters, and fish, and we ultimately consume those microplastics.

Studies increasingly witness the incorporation of micro and nano plastics in living marine tissues. "*In 2015, the estimated amount of plastics being released into the ocean was between 4.8 and 12.7 million tons, with a steady increase [forecast for] the coming years*" (Mattsson, 2017). The quantity of micro and nano-plastics in the oceans will likely rise and accumulate. It is suggested that "*By 2025, there will be 1 ton of plastic for every 3 tons of fish in the oceans, and by 2050 the weight of plastic will overtake that of fish*." (Mermaid Consortium, 2017).

The oceanographic magazine reported the number of microplastics of 0.03 millimetres to 4.6 millimetres per cubic meter of water found near various countries was South Africa 26,334, English Channel/France 17,184, South Africa 14,976, Balearic Sea 14,970, North Sea offshore

Denmark (14,457), with an average of 4,789. 71% were polyester-related fibres released from washing clothes, shedding directly from fabrics and litter, including fishing nets. Had the smaller nanoplastics also been counter, the figures would have been much higher. (Hutchins, 2024)

From: A novel method for preparing microplastic fibers



Micrographs: (a) fluorescent PET MFs (23 × 100 µm) at 515–560 nm excitation; (b) fluorescent PP MF (28 × 100 µm) at 450–490 nm excitation; (c) fluorescent Nylon MFs (10 × 40 µm; yellow arrows) in the intestinal tract of a 50 h.p.f. brine shrimp (*Artemia* sp.), with 515–560 nm fluorescent excitation. Images taken at x25–200 magnification (Zeiss Observer Z1; AxioVision LE). Photographed by Dr Matthew Cole.

Fig. 39. A proof-of-principle feeding experiment, in which it was shown that brine shrimps would ingest microfibres, with many thanks to the authors (Cole, 2016)

Since marine creatures likely perceive small coloured particles in the oceans as food, the explosion in the quantity of marine micro-nanoplastics is genuinely worrying. Nothing in their evolutionary past has prepared marine creatures for such a scenario. Microplastic ingestion could have significant, unforeseen consequences on the marine and, thus, terrestrial ecosphere.

The paper *'Plastic microfibre ingestion by deep-sea organisms'*, observes "*Laboratory studies suggest that corals, copepods, zooplankton, crabs, molluscs, sea cucumbers, scallops, barnacles, oyster, lugworms and polychaetes will ingest microplastics if they are introduced under experimental conditions. The effects across this range of organisms included reductions in fecundity, lower feeding rates, enhanced susceptibility to oxidative stress, reduced ability to remove pathogenic bacteria, reduced feeding activities, reduced energy reserves and balance, and decreased lysome stability"* (Taylor, 2016).

The Mermaid Consortium report noted, "*Sixteen out of 64 fish from the Californian fish market (25%) were polluted. Most of the pollution (80%) consisted of fibers*"; "*Multiple types of microplastics, including fibers, fragments and pellets, occurred in the tissue of all bivalves. The number of total microplastics varied from 2.1 to 10.5 items/g and from 4.3 to 57.2*

items/individual for bivalves. Fibers were the most common microplastics and accounted for more than half of the total microplastics" (Mermaid Consortium, 2017).
The European Foods Safety Assessment (EFSA, 2016), titled, '*Statement on the* p*resence of microplastics and nanoplastics in food, with particular focus on seafood*' highlights that there are many areas of potential concern, observing inter alia; "*Nanoparticles can interact with a wide range of molecules, such as proteins, lipids, carbohydrates, nucleic acids, ions, and water present in the GI tract" . . . "Once nanoparticles have been absorbed, whole body distribution has been shown. For example, after intravenous injection of various sized gold nanoparticles (10–250 nm) in rats, the smallest particles appeared to be widespread and were found in the liver, spleen, heart, lungs, thymus, reproductive organs, kidney, and even in the brain (i.e. crossed the blood–brain barrier). The largest particles were mainly found in the liver and spleen)* ("Statement on the presence of microplastics and nanoplastics in food, with particular focus on seafood," 2016*)*.

Such widespread absorption and migration of nano-microplastics in life forms has worrying implications at many levels for the health and function of the Gaian, including the ocean and ecosystem on which we rely.

18.4. MICRO AND NANOPLASTICS IN SOILS – IMPACT LIFEFORMS

In addition to impacting marine life forms, nano and microplastics impact soil life forms' biological function and health. Whilst research is limited, it is clear they can both transfer up and across the soil and related trophic chains as might be logically expected; those in bacteria and fungi will move into their predators, thus to nematodes and worms, and large creatures such as hedgehogs and moles, continuing up the food chain (Wang Q, 2021).

The publication '*Interactions between microplastics and soil fauna: A critical review*' observes, "*MPs can cause negative impacts on the growth, reproduction, lifespan, and survival of soil fauna, via diverse toxicity mechanisms such as ingestion and bioaccumulation, histopathological damage, oxidative stress, DNA damage, genotoxicity, reproductive toxicity, neurotoxicity, metabolic disorders, and gut microbiota dysbiosis"* (Wang Q, 2021).

18.5. NANO PLASTICS TAKE UP BY PLANTS – FOOD CHAIN IMPLICATIONS

Depressingly, micro (MPs) and nano-plastics (NPs) are also present in soils, from where they are taken up and incorporated into plants, creating a food chain pathway for their incorporation into livestock, pets, and humans. The presence of microplastics in plants raises concerns about the potential health risks associated with their consumption, highlighting the need for further research in this area.

The review, '*Uptake and Accumulation of Nano/Microplastics in Plants: A Critical Review',* commented, "*According to Li.'s findings, plastic particles enter the epidermal tissue of wheat's primary and secondary roots and are stimulated through the pericycle and moved into the xylem. Inside the central cylinder, these particles, through the xylem, can move to the aerial part of the plant" . . . "Plastic particles were transferred from root to shoot by the vascular system via the transpiration stream. Confocal images confirmed that plastic luminescence signals were traced mainly in the vascular system of the stem. MPs and NPs can travel in* *microscopic extracellular channels and reach the vasculature accountable for water transportation. Water transportation system supporting NPs can quickly transfer to the stem, leaves, and possibly fruits.*" (Azeem, 2021)

Though provokingly, germination may also be transiently impacted by microplastics; a paper observed, "*Significant differences in root growth were observed after 24 h, but not after 48 or 72 h of exposure. Impacts on germination are likely due to physical blockage of the pores in the seed capsule by microplastics, as shown by confocal microscopy of fluorescent microplastics. In later stages, the microplastics particularly accumulated on the root hairs.*" (Bosker, 2019)

Plants' nano and microplastic uptake creates a range of concerns and unknowns. There are further issues, such as microplastics attaching themselves in water hollows formed by the leaves of plants (Fogašová., 2022); thus, the potential list of future unknowns grows.

18.6. NANO PLASTICS IN MILK AND MEAT PRODUCTS

The "*New Study Finds Microplastics In Meat, Milk, and Animal Blood*" notes that a recent pilot study found microplastics in beef, pork, and the blood of farm animals. They have also been found in milk taken directly from cattle. The article cites the '*Plastic Soup Foundation*', which said, "*With microplastics present in livestock feed, it is not surprising that a clear majority of the meat and dairy products tested contained microplastics,"* (Ettinger, 2022).

Further, Maria Westerbos at the Plastic Soup Foundation said in a statement, *"We urgently need to rid the world of plastic in animal feed to protect the health of livestock and humans.*" (Ettinger, 2022). That would indeed seem desirable and logical.

18.7. SOURCES OF NANO AND MICROPLASTICS IN WATER - REVERSE OSMOSIS?

As might logically be expected, micro-nano-particles have been found in tap waters. Of significant potential concern, one source suggests that 94 per cent of tap water contains plastic contaminants. However, the WHO document, '*Microplastics in drinking water*' (WHO, 2019), considered that the risks at that time from the presence of microplastics in good quality supplies were low, but recognised, as do others, that more research is required, and since then concerns as to their long-term impact on health have, and continue to, grow.

In addition to those found in tap water, nano-microplastics could originate from membrane filtration systems in bottled water treatment facilities. The various plastic-containing water treatment and purification filters (NIH, 2024), including polyamide filters (Freger, 2021) used in reverse osmosis, could be potential sources of microplastics.

Of concern, given the rising intake of bottled waters, <u>micro</u>plastic levels appear to be much higher in bottled than tap water; a study found, "*an average of 10.4 <u>micro</u>-plastic particles >100 um in size per liter of bottled water processed*" (Mason, 2018; Gambino, 2022). The higher levels of microplastics in bottled water raise concerns about the potential health risks associated with their consumption, highlighting the need for further research.

An article considering the smaller nanoplastics, titled, '*In-depth Analysis: Nanoplastic Contamination in Bottled Water in Malta*', referring to the Qian study (Qian, 2024), notes, "*It is suggested that many of the plastic particles come from the bottles themselves and the reverse osmosis membrane filters used in the bottling process*", observing, "*The study found that there are approximately 110,000 to 400,000 nanoplastic particles per litre in bottled water, with an average of around 240,000*" (Tapp water Malta). More research is required. Not all bottled waters are produced by reverse osmosis. The topic of reverse osmosis of waste water is considered in greater detail in the water Volume.

Further, micro and nanoplastics in drinking water contribute to the broader environmental burden because the micro and nano plastics in our drinking water, excluding those we retain in our gut microbes and broader body tissues, will end up in sewage discharge water and sludge.

18.8. MICRO AND NANO PLASTICS - UNFORESEEN HEALTH CONSEQUENCES

Micro and nanoplastics are emerging as potentially much greater human and wider environmental health issues than ever anticipated. The review '*Plastic and Human Health: A Micro Issue?*' concludes, "*Although microplastics and human health is an emerging field, complementary existing fields indicate potential particle, chemical and microbial hazards. If inhaled or ingested, microplastics may accumulate and exert localized particle toxicity by inducing or enhancing an immune response. Chemical toxicity could occur due to the localized leaching of component monomers, endogenous additives, and adsorbed environmental pollutants. Chronic exposure is anticipated to be of greater concern due to the accumulative effect that could occur. This is expected to be dose-dependent, and a robust evidence-base of exposure levels is currently lacking.*" (Wright, 2017).

Concerning research continues to emerge, including the presence of microplastics in the; "*liver, blood, heart, placenta, breast milk, sputum, semen, testis, and urine*" (Enyoh, 2023), brain, placenta (Garcia, 2024) and blood.

The study titled '*Microplastic exposure disturbs sleep structure, reduces lifespan, and decreases ovary size in Drosophila melanogaster*' found microplastics, fed to fruit flies in quantities found in the most polluted water used by humans, had significant negative health impacts, including on reproduction, sleep and lifespan (Yan, 2024).

Other concerning observations as to microplastics include;

- *"fish may be drawn to eating plastics by the smell,*
- *ten percent of all plastic ends up in the oceans where samples indicate that 5 trillion pieces of plastic lurk,*
- *94% of tap water samples have microplastic contamination, and*
- *fish near wastewater treatment plant outflows suffer kidney damage and feminization."* (Lepisto. 2018).

18.9. NANOPLASTICS – BRAIN – NEURAL FUNCTION AND ADVERSE BEHAVIOURAL OUTCOMES – WIDER SURVIVAL IMPLICATIONS

Micro-nano plastics can enter the brain and have been associated with behavioural disorders in fish and mice; they are likely to occur in humans. The Rhode Island University report '*Microplastics infiltrate all systems of body, cause behavioral changes*' on the study '*Acute Exposure to Microplastics Induced Changes in Behavior and Inflammation in Young and Old Mice*' (Gaspar, 2023) observed, "*They found that microplastic exposure induces both behavioral changes and alterations in immune markers in liver and brain tissues. The study mice began to move and behave peculiarly, exhibiting behaviors akin to dementia in humans. The results were even more profound in older animals*" (Rhody Today, 2023). Studies on other pollutants found in sewage sludge and water also suggest their presence is associated with developmental and behavioural change risks.

Global degradation of human neural capacity, function, and behaviour of both the living and future generations, including through in utero and early years effects on neural development including IQ, abstract thought capacity and empathy, combined with an increased consequent manifestation of anxiety and abnormal social behaviours, which increases the risk of conflict and creates increased consequential failure as a species to sufficiently focus on pollution, including degraded food and related developmental consequences, with their broader existential risks; instead being driven by heightened anxiety and tendencies to abnormal social behaviours, to put our focus and resources into wars.

Studies have reported equivalent pollution-related adverse developmental, neural, and behavioural effects in animal models; thus, these concerns are not dystopian fantasies but are based on observed reality in other species.

The paper '*Brain damage and behavioural disorders in fish induced by plastic nanoparticles delivered through the food chain*' (Mattsson., 2017) observes, "*Here we demonstrate that plastic nanoparticles reduce survival of aquatic zooplankton and <u>penetrate the blood-to-brain barrier in fish and cause behavioural disorders</u>. Hence, for the first time, we uncover direct interactions between plastic nanoparticles and brain tissue, which is the likely mechanism behind the observed behavioural disorders in the top consumer. In a broader perspective, our findings demonstrate that plastic nanoparticles are transferred up through a food chain, <u>enter the brain of the top consumer and affect its behaviour</u>, thereby severely disrupting the function of natural ecosystems*" . . . "*<u>behavioural disorders depended on the size of the nanoparticles</u> and analyses by hyperspectral microscopy showed that the plastic nanoparticles were present in the fish brains*." (This author's underlines) (Mattsson., 2017)

There is also growing evidence that microplastics, as do other pollutants in food and water, result in a risk of increased anxiety; for example, the study, *'Polystyrene micro- and nanoparticles exposure induced anxiety-like behaviors, gut microbiota dysbiosis and metabolism disorder in adult mice'* observed, *"Behavioral tests showed PS-NPs* (polystyrene-nanoplastics) *and PS-MPs* (polystyrene-microplastics) *treatment remarkedly induced anxiety-like behaviors compared with the control group."* (Chen X, 2023).

Micro-nanoplastics also appear to impact neurodevelopment pathways in the offspring of exposed mothers, with negative behavioural consequences in offspring, including increased anxiety. The study '*Exposure to polystyrene particles causes anxiety-, depression-like behavior and abnormal social behavior in mice*' observed, "*Additionally, offspring of PS-Ps* (polystyrene particle) *-treated dams exhibited signs of anxiety- and depression-like behavior, and abnormal social behavior. We propose that PS-Ps accumulation in the brain disrupts brain development and behavior in mice. This study provides novel information regarding PS-Ps toxicity and its harmful effects on neural development and behavior in mammals.*" (Shin, 2023).

18.10. SYNTHETIC TEXTILES – A SIGNIFICANT SOURCE OF MICROPLASTICS

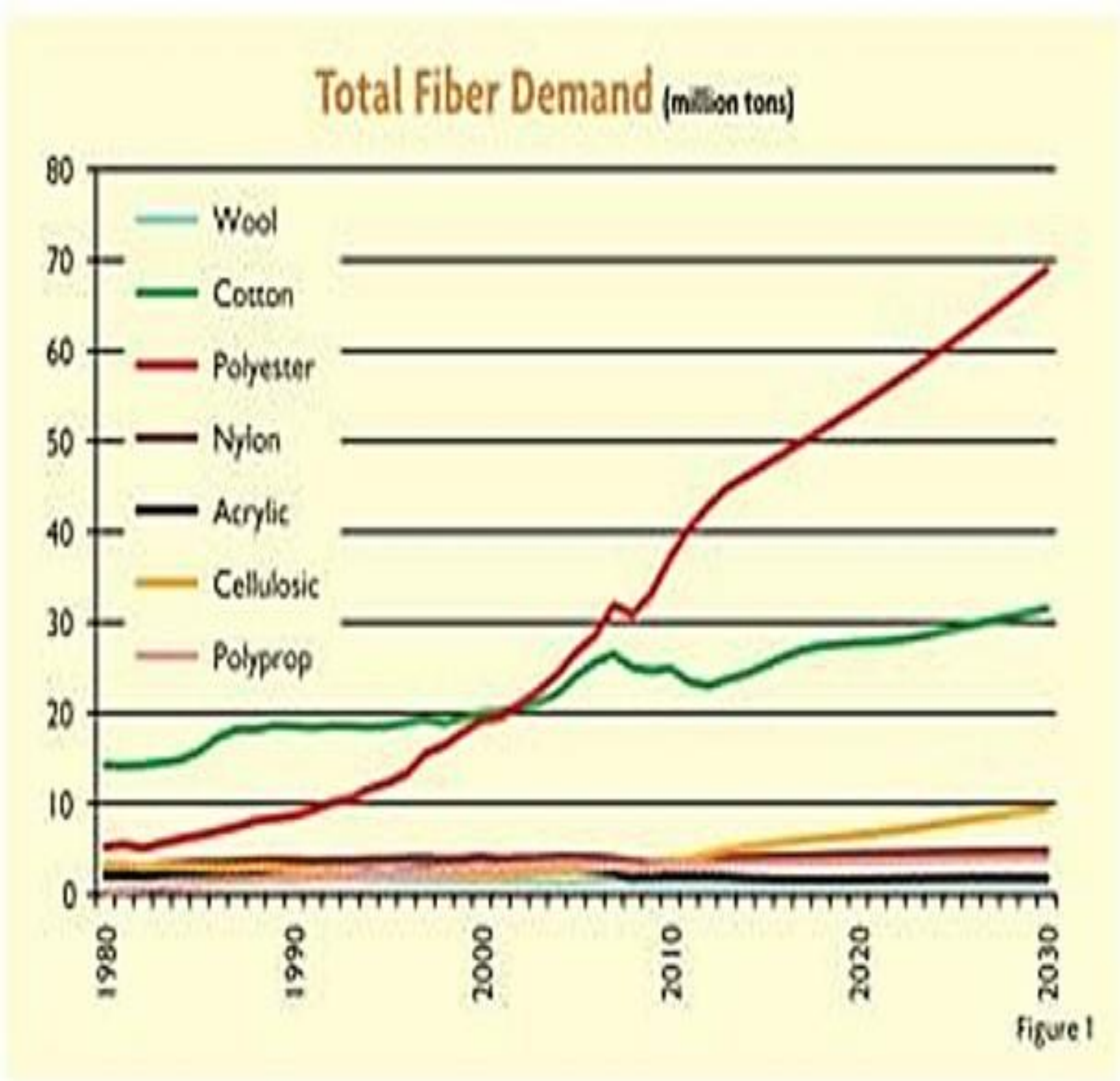


Fig. 40. "*The graph illustrates fibre demand between the years 1980 to 2030. It depicts that the demand of fibre has been rising sharply*" from '*Analysis of microfibres in wastewater from washing machines*', (Lamichhane, 2018), with many thanks to the author.

Thought-provokingly, a review suggests, "*More than 60 per cent of global textiles are now produced from synthetic fibres*" (Henry, 2018). Microplastics and nanoplastics from textiles, particularly those from washing machines, are proving to be another issue with the potential for significant environmental improvements. However, there appears to be a lack of understanding or willingness to grasp the issues. For example, microplastic filters on washing machines would significantly reduce microplastic pollution of land, rivers and seas. However, there appears to be little appetite for government programs to mandate filters on washing machines.

Micro and nano-plastic fibres from washing machines discharged into sewage systems attach to sewage sludge and are present in wastewater discharges, even those that have been treated. As a result, they are found in watercourses upstream and downstream of treatment plants (Long, 2009), in oceans, and in soil where sewage slurry is applied. The impact of microfibers will be higher in emerging economies with greater use of direct discharge.

While a return to more sustainable fashion, including natural fibre use, is gaining support, and calls for reducing the demand for 'throw-away' fashion are increasing, pragmatically, the use of artificial fibres will continue. Most countries are now consuming twice as many artificial fibres as natural ones. Demand for polyester garments soared tenfold between 1980 and 2017 (Lamichhane, 2018).

18.11. ADSORPTION OF POLLUTANTS BY NANO-MICROPLASTICS

Microfibers also adsorb various pollutants, including heavy metals, during processing in wastewater treatment plants (Bayo, 2016). Some microfibers are metal coated, for example, with steel, copper, or silver, for various specialist uses, including as antimicrobial materials. Metal coating, or adsorption of metals and organic molecules, to the microfibers, by potentially making them more recognisable to organic processes and membrane transporters, will increase the likelihood of interaction with bacteria and tissue membranes, including in humans. Nano-microplastic will also gain access to tissues through solute drag and piggybacking recognised molecules.

Adsorption of various chemicals magnifies the range of their potential biological effects. The paper '*Microplastic pollution from textiles - A literature review*' states, "*Chemical impacts may also be enhanced since the larger surface area of fibres potentially allows greater sorption of harmful compounds and a higher retention in the gut allows more time for leakage of plastic additives. Organic contaminants of concern include polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, petroleum hydrocarbons, organochlorine pesticides, polybrominated diphenyl ethers alkylphenols and bisphenol A".* (Henry, 2018).

Fig. 41. Microplastics on a beach, many thanks to the Author and Adobe Photo Stock

The exact proportions of environmental microfibers coming from different sources are difficult to determine, but it is believed that laundry is a significant contributor. "*Most of the micro plastics will be in greywater including as a consequence of washing microfibre garments. . . . Close to two-thirds (63.1%) of the on average 3.2 million tons per year that is released as primary microplastics into the environment is due to the laundry of synthetic textiles (34.8%)*" (Mermaid Consortium, 2017).

"Without intervention the amount of fibers that is released via the sewer into our waterways will increase significantly in the near future: 30% of the world population is already doing the laundry with a washing machine." (Mermaid Consortium, 2017); surely, the remaining 70% of the world will buy one as soon as they can.

18.12. WASHING MACHINES – A MAJOR MICROPLASTIC SOURCE

Fig. 42. Washing machines are a significant source of microfibers in river oceans and on soils with thanks to the Author and Adobe Photo Stock

Each wash produces approximately two grams of these particularly modern particles, and given the boom in throwaway fashion, the total volumes released can only grow. Adding microplastics makes cleaning greywater, sewage wastewater, and sludge a more complex challenge than a decade ago.

Importantly, microfibers from washing machines are not the only micropollutant in sewage and broader water flows; just over a quarter of the contaminants are believed to be derived from "*the erosion of tyres while driving (28.3 per cent)*" (Mermaid Consortium, 2017).

18.13. WASHING MACHINE MICROPLASTIC FILTERS – A SIMPLE WIN

Microplastic filters for washing machines are appearing on the market, as evidenced by the Swedish Environmental Protection Agency report, '*Filters for washing machines - Mitigation of microplastic pollution*'. The report concludes, "*There are filters on the market that can be installed in washing machines or adjacent to washing machines, and which may remove microplastic fibres and larger plastic fibres from laundry water. The washing trials support that filters can remove microplastics from the water. To elucidate exactly how efficient those filters are at removing microplastic fibres would require more comprehensive laboratory work.*" (Brodin., 2018) Gels that accumulate microplastics are also being trialled (Lepisto, 2017).

Fig. 43. Plastic pollution with thanks to the Author and Adobe Photo Stock

Affordable disposable filters fitted to washing machines could be a simple and relatively inexpensive technology for removing a significant amount of microplastic pollution at source. However, whilst some are already starting to develop a market for washing machine filters (albeit some of the filters are very expensive in relative terms), there appears to be little momentum for affordable filters on washing machines to be mandated at the governmental level. Is it not time to fit washing machine filters for microplastics, thus reducing a significant source of microplastics in the environment?

18.14. BACTERIAL AND FUNGAL DEGRADATION OF MICROPLASTICS

Bacteria and fungi have and are being found that can remediate some plastics (Wilkes. 2024). The review '*Insights into the mechanisms involved in the fungal degradation of plastics*' observes, "*Fungi are considered among the most efficient microbial degraders of plastics, as they produce salient enzymes and can survive on recalcitrant compounds with limited nutrients.*" As discussed in a later section, significant remediation of microplastics was observed during hyperthermophilic composting; there is an urgent need for further research into the role of hyperthermophilic in the remediation of plastics.

19. WIDER POLLUTANTS AND PATHOGENS - SLUDGE AND WASTEWATER

Potential pollutants are referred to as 'Environmental Contaminants of Concern ECs'. The EC list grows, and more are continually added as science and detection advances. Sewage water and sludge contain various pollutants, 'contaminants of concern', aka 'CECs', in varying proportions.

Pollutants include microplastics, pharmaceuticals, antibiotics, personal care products, flame retardants, pesticides, artificial sweeteners, caffeine, organic products oxidised including during chlorine water treatment, endocrine disruptors, industrial chemicals including PFAS, and tyre dust with the host of chemicals that leach from it. To varying extents, a wide range of those pollutants will be present in both the treated wastewater and sludge in different proportions, retention being determined in part by their polarity and solubility.

Wastewater can be further treated to remove residual pollutants, including pharmaceuticals. However, such treatment is costly, and whilst the best treatment dramatically improves water quality, even the best treatment systems have environmental issues. Sewage sludge, as discussed, is difficult to treat, and consequently, incineration is currently considered the least-worse environmental option, albeit incineration is far from ideal for several reasons.

19.1. POOR CONTAMINANT REMOVAL IN STANDARD AEROBIC SEWAGE PLANT SYSTEMS

Contaminants of concern are variously, variably, and only partially remediated by sewage plant digestion. The review, '*How are pharmaceutical and personal care products (PPCPs) removed from urban wastewaters?"* notes that digestion of the type used in wastewater plants fails to remove the majority of pollutants; "***Most existing plants are not an effective barrier for some of these substances***, *which are thus being continuously discharged in the environment mainly through STP* [Sewage treatment plant] *effluents*" (Suárez, 2008).

Another paper, "*Fate of pharmaceutical and personal care products (PPCPs) during anaerobic digestion of sewage sludge*," examined 13 varied products and observed varying levels of remediation (Carballa, 2007).

Removal is essential because many chemicals have biological effects at low concentrations that can bio-accumulate, interact with, and become more potent in the presence of other substances. Some are small enough to evade capture by bio-membranes.

As discussed, many 'add-on treatments' for better purification of wastewater are expensive for use in bulk processing, *"Post-treatment techniques, such as ozonation, membrane filtration and sorption on activated carbon maybe effective for completing the removal of the most recalcitrant PPCPs, although it would be also costly to implement, with estimated costs in the range of 0.01–0.04 € m^{-3} for ozonation and one order of magnitude higher for the other two techniques*" (Suárez, 2008) and thus their use is limited to wealthier countries.

Fig. 44. Generic personal care products with thanks to the Author and Adobe Photo Stock

As discussed, the Swiss are implementing oxidative peroxide and carbon flocculation technology at limited wastewater treatment sites. To avoid doubt, such processes are only meaningfully applicable to wastewater. Consistent with this, the Swiss and others are increasingly incinerating sludge.

Treatments vary in efficacy. Some suggest that the concentration of some products may even occur during treatments (Boix., 2016). More complex but expensive, multifaceted systems can remediate material from more concentrated pharmacological sources, such as pharmaceutical plants and hospitals (Shi, 2017).

19.2. IDENTIFIED POLLUTANTS ARE NUMEROUS AND MORE EXIST

It is inevitable, a matter of physics and chemistry, that small particulate material, heavy metals, lipophilic substances, and items of low solubility concentrate in sewage sludge as part of the treatment processes, and it is almost, if not impossible, to practically and economically remove them from sludge.

Identified pollutants are numerous, and the actual number is likely far higher. Technical papers on the topic note, "*Sludge can contain (its exact composition varies and is not knowable) any of the 80,000 synthetic chemicals used by industry; new chemicals created from combining two or more of those 80,000; bacteria and viruses; hospital waste; run-off from roads; pharmaceuticals and over-the-counter drugs; detergents and chemicals that are put down drains in residences; and, of course, urine and faeces flushed down toilets*" (Orlando, 2017).

Thus, sewage sludge "*contains impurities from a host of organic pollutants"; some* are persistent, an alphabet soup, including PCBs, PAHs, PCDD/F, PFAS, dioxins and pesticides, as well as synthetic hormones, "*the most harmful being polychlorinated dibenzodioxins/furans*

(PCDD/F), halogen compounds and organic tin compounds. . . All of these various organic substances often stem from numerous household products including household detergents and cleaners, as well as body care products. Other sources attributable to human activity include DIY products such as wood protection agents, as well as pharmaceutical products." (Wiechmann, 2013). Some are endocrine disruptors and move up the food chain; thus, they are pollutants of significant concern. (Part, n.d.)

Sludge also contains bromide, flame retardants, and other compounds, including; "*a wide number of compounds largely consumed in modern societies, including drugs (antibiotics, tranquillizers, anti-epileptics, etc.), hormones (natural and synthetic), X-ray contrast media, musk fragrances, etc., which, until recently, have not been of major concern with regard to their environmental effects.*" (Suárez, 2008).

A systemic review of sewage sludge in China observed 749 pollutants in 35 categories, many of which were CECs (Contaminants of Environmental Concern) (Feng. 2023). A European-wide study of WWTP effluent identified 366 contaminants of concern (Finckh. 2022).

Further, pollutants are found in sewage sludge in quantities sufficient to have environmental impacts. For example, **"***Over 80 pharmaceutical compounds have been found over the level of microgrammes per litre in sewage effluent, surface waters and groundwater*" (Spångberg, 2014).

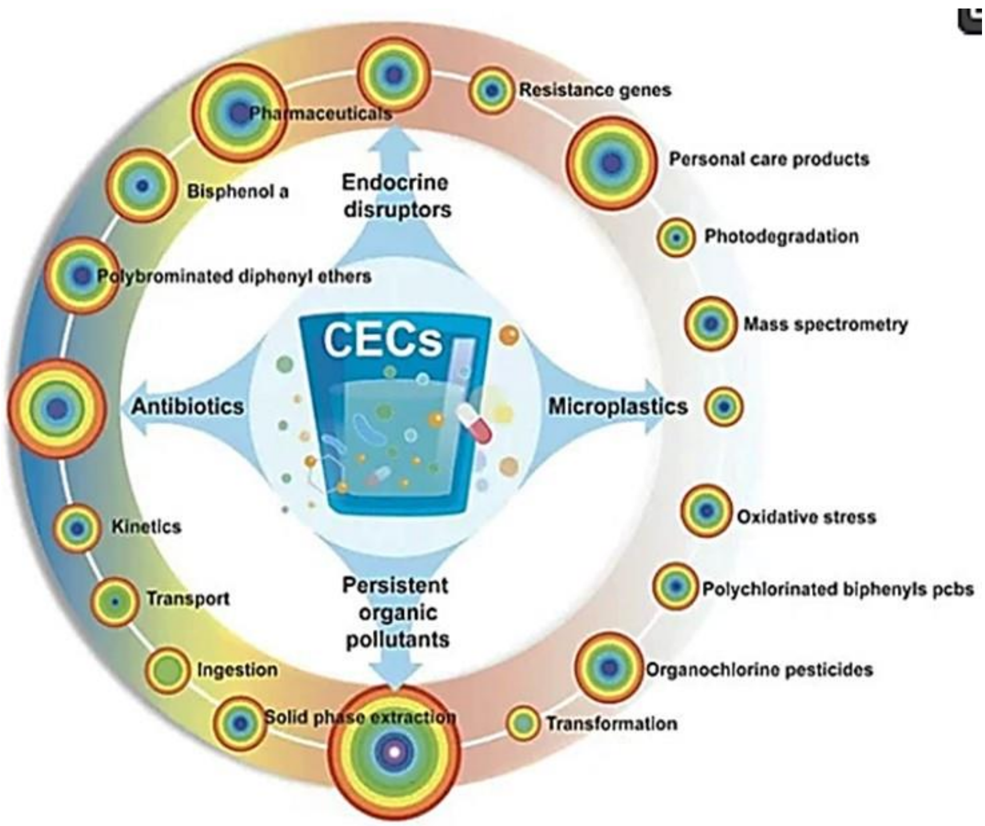


Fig. 45 "*Various CECs in the Yellow River Basin's agriculture-linked surface water and sediments.*" with many thanks to the Authors. (Feng. 2023)

19.3. DIOXINS

Dioxins are a significant pollutant in sewage, much of which originates in greywater, particularly from washing machines. "*dioxins present in household wastewater and laundry wastewater are similar to those found in the sediments of sewer collecting systems and sewage sludge. A mass balance indicates that between two and seven times more dioxins in sewage sludge originate from households than from urban run-off. Washing machine effluent is a major source of dioxins in household wastewater*. (NZWWA, 2003; Thornton, 2001). Their source in washing machine water may include "*pentachlorophenol-treated cotton from overseas, chloranil-based dyes in the fabric, fabric bleaching, soil and human skin*" (' EPA, 2017. Dioxins in San Francisco Bay | Region 9: Water', US EPA, n.d.).

Current sewage systems fail to remove dioxins effectively. A review observes, "*the occurrence of PCDDs/PCDFs* [dioxins] *and PCBs in inflowing wastewater causes considerable problems for WWTPs because conventional biological and chemical processes are insufficient for removing them*" (Urbaniak & Wyrwicka, 2017).

Given the presence of dioxins in grey water, remediation of greywater collected separately from the broader external sewage stream requires technical solutions, such as oxidative and/or activated carbon treatment. However, the technology for the *in-situ* collection and treatment of greywater is in its infancy.

Thus, the presence of dioxins in greywater adds to arguments for collecting urine and faeces at the source and separate collection and localised treatment of greywater. The obvious place to trial innovations is in large domestic, residential, or commercial building developments. However, translating such technologies to the mainstream will require a mix of legislation and financial and social incentives.

Treatment options are generally technical and, at least currently, impractical for single domestic applications. The difficulties in treatment lend weight to arguments in favour of legislation to remove such products from washing machine detergents, fabric treatments, and new clothes, putting the onus on manufacturers.

19.4. PFAS AND RELATED FLUORO PRODUCTS

PFAS are another increasingly ubiquitous ingredient of the toxic alphabet sewage pollutant soup. This exemplifies how the initially unknown, potentially adverse, negative health effects of under-researched chemical additions to our lives are becoming evident over time; indeed, a cautionary tale in the making.

PFAS are persistent and potentially damaging to health in multiple ways; "*PFAS came into use after the invention of Teflon in 1938 to make fluoropolymer coatings and products that resist heat, oil, stains, grease, and water. They are now used in products including waterproof fabric such as Nylon, yoga pants, carpets, shampoo, feminine hygiene products, mobile phone screens, wall paint, furniture, adhesives, food packaging, heat-resistant non-stick cooking surfaces such as Teflon, firefighting foam, and the insulation of electrical wire. PFAS are also* *used by the cosmetic industry in most cosmetics and personal care products, including lipstick, eye liner, mascara, foundation, concealer, lip balm, blush, and nail polish.*" (Wikipedia. 2024 b).

Concerningly, like many pollutants, "*The research conducted to date reveals possible links between human exposures to PFAS and adverse health outcomes. These health effects include altered metabolism, and body weight regulation, and risk of childhood obesity, increased risk of some cancers and reduced ability of the immune system to fight infections.*" (NIH, n.d). As well as being absorbed by other mechanisms, PFAS are taken up by plants, meaning they have become part of the food chain (Adu, 2023). Research into the environmental impact and fate of PFAS, as well as mitigation possibilities, is ongoing. (Coker, 2020).

The European Environment Agency EEA in the article, '*Emerging chemical risks in Europe — PFAS*'' section '*Why are PFAS a concern*', observes, "*PFAS either are, or degrade to, persistent chemicals that accumulate in humans, animals and the environment . . . Of the relatively few well-studied PFAS, most are considered moderately to highly toxic, particularly for children's development.*" (EEA, 2019).

Other wider per- and polyfluoroalkyl substances are also of concern; "*PFOS, PFOA, and PFNA have caught the attention of regulatory agencies because of their persistence, toxicity, and widespread occurrence in the blood of general populations and wildlife*" (Wikipedia, 2023; NIH, 2023).

19.5. PATHOGENS, INCLUDING BACTERIA, IN SLUDGE AND WASTEWATER

Sewage sludge and wastewater contain antibiotic-resistant bacteria, wider pathogens (Ajonina, 2015), viruses (Osuolale, 2017), and protozoa. The amounts of bacteria present after basic wastewater treatment will vary and may be bacteria or bacterial spores.

The principal human pathogenic bacteria in municipal wastewater and sewage sludge, as listed in the Arthurson review (Arthursun, 2008), are:

Salmonella spp.	*Salmonellosis, typhoid*
Shigella spp.	*Bacillary dysentery*
Escherichia coli (enteropathogenic strains)	*Gastroenteritis*
Pseudomonas aeruginosa	*Otitis externa, skin infections (opportunistic)*
Yersinia enterocolitica	*Acute gastroenteritis*
	Gastroenteritis (food poisoning)
Clostridium perfringens	
Clostridium botulinum	*Botulism*
Bacillus anthracis	*Anthrax*
Listeria monocytogenes	*Listeriosis*
Vibrio cholera	*Cholera*
Mycobacterium spp.	*Leprosy, tuberculosis*
Leptospira spp.	*Leptospirosis*

Campylobacter spp.	*Gastroenteritis*
Staphylococcus	*Impetigo, wound infections, food poisoning*
Streptococcus	*Sore throat, necrotizing fasciitis, scarlet fever*

Some bacteria, particularly spores, once applied in sewage sludge to soils are long-lived, some living several months; for example, some "*reportedly survived up to 16 months on grass treated with sludge in Switzerland*". Further, "*Bacteria in the spore form present in sludge are extremely difficult to destroy using conventional sanitization procedures due to their resistance to heat and desiccation <u>and persist in the environment for several years</u>*". They can then transfer up the food chain, including "*to cows and eventually to milk via silage fertilized by digested residues*" (Arthursun, 2008) as also noted in *'Sewage Sludge Management in Germany'; "If such sludge is used as fertilizer, the pathogens in it can enter the human and animal food chain, thus endangering the health of both.*" (Wiechmann, 2013).

19.6. ENDOCRINE DISRUPTORS

Some pollutants are of particular concern because they can disrupt hormone pathways with a wide potential range of adverse effects. "*There are many CECs and PPCPs that act as so-called endocrine disruptors (EDCs). EDCs are compounds that alter the normal functions of hormones resulting in a variety of health effects. EDCs can alter hormone levels leading to reproductive effects in aquatic organisms, and evaluating these effects may require testing methodologies not typically available along with endpoints not previously evaluated using current guidelines.*" (EPA n.d)

The review, "*Removal of endocrine disrupters from the contaminated environment: public health concerns, treatment strategies and future perspectives*", observes, "*<u>Human exposure to EDCs in the environment is a life-threatening concern with unknown long-term consequences</u>, particularly when EDC-laden sludge has been used as a fertilizer or effluent reused in agricultural practices. In addition, the principal source of these contaminants in the environment is through wastewater treatment plants (WWTP)*" (Werkneh. 2022).

The American Government Environmental Protection Agency's document, "*Contaminants of Emerging Concern including Pharmaceuticals and Personal Care Products*", states, "*The emerging contaminants may also demonstrate low acute toxicity but cause significant reproductive effects at very low levels of exposure. In addition, the effects of exposure to aquatic organisms during the early stages of life may not be observed until adulthood. Therefore, traditional toxicity test endpoints may not be sufficiently comprehensive for criteria derivation for these chemicals and the chemicals may also have specific modes of action that may affect only certain types of aquatic animals (e.g., vertebrates such as fish).*" (EPA n.d.).

19.7. PCPs – PERSONAL CARE PRODUCTS –

Meanwhile, personal care products (PCPs) are another growing modern source of environmental contaminants (ECs). Soap, shampoo, perfume, and toothpaste are not new. However, over the past few decades, we have seen a boom in the consumption of products such as sunscreen, deodorants, hair care products, moisturisers, fake tan, and male and female grooming products, many of which may contain synthetic chemical compounds.

The table below, 'Table 1 of *Sustainable Treatment Techniques for Emerging Pollutants—The Case of Personal Hygiene Products'* (Dueñas-Muñoz, 2022), helpfully lists examples of personal care products and pharmaceuticals (PPCPs) and their impact.

The study*, 'Sustainable Treatment Techniques for Emerging Pollutants' — The Case of Personal Hygiene Products',* observes, *"PPCPs have recently been identified as a group of ECs with persistent and bioaccumulative characteristics that are used with increasing frequency, making their presence in the environment ubiquitous",* further noting, "*ECs are present in parts per billion or less in aquatic matrices, forming* (more) *than a thousand toxic compounds to date.* (Dueñas-Muñoz, 2022)

"The compounds discarded by the use of PCPs are not legislated or regulated since very little is known about their effects on the environment. . . However, several studies have demonstrated that the main source through which PPCP contaminants are transported in the environment are wastewater treatment plants (WWTPs) since they are <u>not designed to completely remove these compounds during treatment</u>" (Dueñas-Muñoz, 2022)

PCPs	Toxic Components	Environmental Impact
Feminine Sanitary Napkins	Aldehydes, Alkanes, Halohydrocarbons, Terpenes, Ketones, PAHs	They generate toxic and mutagenic waste, produce cancer at the time of postuse exposure [80].
Deodorants	Heavy metals	They are bioaccumulative, cause several diseases [81].
Disposable Masks	Microplastics	When receiving UV rays, they release chemical substances that cause adverse effects on the marine ecosystem [82].
Condoms	Parabens (Methylparaben, Propylparaben and Octylparaben)	Endocrine disturbances. Both estrogenic and antiandrogenic effects [83].
Fragrances	Musk Xylene, Musk Ketone, Galaxolide	Musk causes endocrine disruption in aquatic biota and galaxolide is bioaccumulative [84,85].
Soap, shampoo, detergent, toothpaste, sunscreen and deodorant	Triclosan (TCS, 5-chloro-2-(2,4-dichlorophenoxy)phenol)	Alters the composition of benthic bacteria. Toxic for algae species, it presents endocrine disruption in fish [86].
Sunscreen	Octocrylene Oxybenzone	Benzophenones cause DNA alteration, bleaching and death of corals and reefs [86].
Hair dyes	Triclosan (TCS, 5-chloro-2-(2,4-dichlorophenoxy)phenol)	Dye residues accumulate on the seafloor, entering the food chain [86].

Table 5. With many thanks to the author from '*Table 1 Sustainable Treatment Techniques for Emerging Pollutants—The Case of Personal Hygiene Products*' (Dueñas-Muñoz, 2022)

It is clear that in common with pharmaceuticals and microplastics, PCPs persist through non-specialist wastewater treatment processing; then, via aqueous discharges and sewage sludge, they find their way into the marine environment. Their presence has also been detected in soils irrigated with treated greywater.

The ultimate health and broader environmental risks posed by PCPs, including their uptake through the food chain, are, as yet, unknown and debated. However, the risks are unquestionable; for example, a small, more exhaustive study on sheep grazed on pastures treated with sewage sludge, titled, '*Long-term exposure to chemicals in sewage sludge fertilizer alters liver lipid content in females and cancer marker expression in males*', noted, "*Our results demonstrate that chronic exposure to ECs (Environmental contaminates) causes major physiological changes in the liver, likely to affect multiple systems in the body and which may predispose individuals to increased disease risks."* (Filis, 2019)

19.8. HEAVY METAL TOXICANTS FROM MINERAL FERTILISERS AND ANIMAL FEED

Many are unaware that mineral rock phosphate-based fertiliser and animal mineral rock phosphate-derived supplements can also be significant sources of heavy metal pollution, including toxic cadmium (cd) in soils; however, fertiliser's heavy metal content can vary significantly between phosphate sources.

Some heavy metals—including copper and zinc—are essential to the function of key enzymes (and so life itself) but toxic in excess; others are toxic at almost any level (Arif, 2016). For example, lead, mercury, and cadmium can also interact with the same enzymes as the lighter metals in the same family but inhibit or degrade their function, making them toxic at relatively low intakes.

When applied to the land, pollutants in the human and livestock food chain, excreted in sewage sludge and slurry, create an additive feedback cycle. Whilst uptake and behaviour of heavy metals in the soils and accumulation by crops is complex, governments have recognised the potential dangers and legislated to reduce them; "*Because fertilization increases the risk of Cd transfer to the food chain, some governments have imposed limits restricting the Cd content of P fertilizers.*" (Roberts, 2014).

Analysis of phosphate fertilisers sold in the UK, Italy, the US, India, Australia and New Zealand found they all contained significant but varying amounts of heavy metals (Chibueze, 2012). For example, research looking at metals in phosphate rock (PR) found the following ranges (expressed in mg/kg of PR): "*Cd (5–47), Co (6–104), Cu (5–41), Cr (18–331), Li (2–9), Mn (11–6553), Ni (1–61), Pb (7–43), Rb (3–18) and Zn (54–576). The corresponding values of the non-trace metals expressed in g/kg were: Al (1.7–20.0), Ba (0–4.4), Ca (211–330), Fe (1.4–45.7), K (0.3–10.9), Mg (0.6–16.9), Na (1.0- 22 .8), and Sr (0.3–6.7). At the detection limit of 5 ng/mL, no caesium (Cs) was found in the PR analysed*" (Kpomblekou-A & Tabatabai, 1994).

Further, some toxic heavy metals were historically used as livestock growth enhancers to reduce fungal and bacterial issues. Some pesticides historically, and still to some extent (possibly 10%), currently rely on heavy metals.

19.9. HEAVY METAL POLLUTANTS IN SLUDGE AND SLURRY

Substance	Unit of measure	Value range according to DWA
pH value	–	7.7*
Dry solids (DS)	wt %	30.5*
Loss on ignition (LOI)	%	45–80**
Water	wt %	65–75
Volatile matter	wt %	30
Net calorific value (NCV)	MJ/kg DM	10–12
Carbon (C)	%	33–50
Oxygen (O_2)	%	10–20
Hydrogen (H_2)	%	3–4
Nitrogen (N_2)	%	2–6
Sulphur (S)	%	0.5–1.5
Fluorine (F_2)	wt %	<0.01
Chlorine (Cl_2)	%	0.05–0.5
Phosphorous (P)	g/kg	2–55
Antimony (Sb)	mg/kg DS	5–30
Arsenic (As)	mg/kg DS	4–30
Lead (Pb)	mg/kg DS	70–100
Cadmium (Cd)	mg/kg DS	1.5–4.5
Chrome (Cr)	mg/kg DS	50–80
Copper (Cu)	mg/kg DS	300–350
Manganese (Mn)	mg/kg DS	600–1,500
Nickel (Ni)	mg/kg DS	30–35
Selenium (Se)	mg/kg TS	1–5
Thallium (Th)	mg/kg TS	0.2–0.5
Vanadium (V)	mg/kg TS	10–100
Mercury (Hg)	mg/kg TS	0.3–2.5
Zinc (Zn)	mg/kg TS	100–300
Tin (Sn)	mg/kg TS	30–80
AOX	mg/kg TS	350
PCDD/F	mg/kg TS	0.000035
Molybdenum (Mo)	g/kg TS	3.9*
Cobalt (Co)	g/kg TS	6.53*
Calcium (Ca)	g/kg TS	71*
Potassium (K)	g/kg TS	2.63*
Magnesium (Mg)	g/kg TS	9.17*

* Werte stammen aus [Oliva et. al.]: Median
** Werte stammen aus [Oliva et. al.]

Fig. 46. Mineral content of sewage sludge taken from '*Sewage Sludge Management in Germany*' (Wiechmann, 2013) with many thanks to the Authors and Umweltbundesamt (German EPA)

Heavy metal pollutants in fertiliser, feed, and mineral supplements, directly and through the food chain via sewage sludge and slurry applied to land, will end up in soils, where they are recycled back into crops and livestock. In addition, they form part of 'run-off', dissolved in water, or attached to soil particles lost as part of soil erosion.

Interestingly, the 2008 review '*Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment*' noted, *"KEMI, the Swedish Chemical Agency, recommends a limit of 12mg cadmium per kg phosphorus added to soil to keep safe levels (KEMI, 2008), but analyses of chemical fertilisers sold in Europe show median concentrations of 87mg per kg phosphorus (2008)",* (Spångberg, 2014).

That said, tremendous efforts have been made since 2008 to sift out heavy metals from waste streams. In Europe, the combination of a decline in heavy industry and regulations around artificial fertilisers has significantly reduced their presence in sludge. Thus, as illustrated by the chart below, it is not all bad news; toxic metals in sludge in Europe have significantly reduced.

mg/kg of dry solids	1977	1982	1986–1990	1998	2001	2002	2003	2004	2005	2006	Change between 1977 (=100%) and 2006	Change between 2001 (=100%) and 2006
Lead	220	190	113	63	53	50	48	44.3	40.4	37.2	-83.09	-29.81
Cadmi-um	21	4.1	2.5	1.4	1.2	1.1	1.1	1.02	0.97	0.96	-95.43	-20.00
Chrome	630	80	62	49	45	45	42	40.7	37.1	36.7	-94.17	-18.44
Copper	378	370	322	289	304	306	305	306.3	306.4	300.4	-20.53	-1.18
Nickel	131	48	34	27	27	27	27	25.8	25.2	24.9	-80.99	-7.78
Mercury	4.8	2.3	2.3	1	0.8	0.7	0.7	0.62	0.59	0.59	-87.71	-26.25
Zinc	2,140	1,480	1,045	835	794	750	746	756.7	738.2	713.5	-66.66	-10.14
Total nitrogen	n/a	n/a	n/a	n/a	39,357	38,846	40,328	42,025	42,457	43,943	ns	+11.65
Total phos-phorous	n/a	n/a	n/a	n/a	27,337	22,019	22,559	23,581	24,312	24,531	ns	-10.26

Fig. 47. Sludge concentrations of selected heavy metals and nitrogen and phosphorus between 1977 and 2006, taken from '*Sewage Sludge Management in Germany*' (Wiechmann, 2013), with many thanks to the authors.

Similarly, in Sweden, *“the quality of sewage in terms of heavy metal content has greatly improved over the past 20 years. Concentrations in sewage sludge of the six metals discussed have decreased by on an average 85 per cent, showing that environmental policies followed by measures to control metal emissions in Swedish society have been very effective*” (Kirchmann, 2017). However, there is no certainty that the same trends are seen globally.

However, despite such efforts, using sewage sludge from mixed waste streams on farmland adds to the accumulation of heavy metals and other toxicants in soils. *“Soils are the major sink for heavy metals released into the environment by anthropogenic activities and unlike organic contaminants which are oxidized to carbon (IV) oxide by microbial action, most metals do not undergo microbial or chemical degradation, and their total concentration in soils persists for a long time after their introduction. The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants”.* (Wuana & Okieimen, 2011)

19.10. OTHER SOURCES OF HEAVY METALS

In addition to sewage sludge and fertiliser, other sources of heavy metals include atmospheric emissions from coal plants (Wikipedia, 2019g), brick kilns, sewage incineration, military operations, river and harbour silt, and municipal waste disposal, including dumping and landfill (Shakoor, 2013).

Further heavy metal sources include animal feed, household products, leaching of pipes and plumbing fittings, including due to the action of demineralised recycled water on metal pipework and fittings, road run-off, and historically deposited lead from the combustion of petrol additive.

Fig. 48. Coal-fired power station in Tuticorin, Tamil Nadu, India with many thanks to the NLC India Ltd. and Wikipedia.

Another review observes, *"Bioaccumulation of metal toxins in the food chain poses disastrous effects on human health. Plants accumulate some non-essential heavy metals having no contribution in biological functions these heavy metals cause serious risks to plants, animals and human health*." "*An increased accumulation of heavy metals can have lethal effects on soil fertility, ecosystem functions and poses a health to human beings and animals*" (Shakoor., 2013) (Author's underline].

The topic is complex. The mineral content of sewage sludge and disposal methodologies vary significantly globally. However, the review, '*Occurrence, geochemical fractionation, and environmental risk assessment of major and trace elements in sewage sludge*', looks in detail at the issue in China (Nkinahamira, 2019), again bringing us back to the proposition that FaF is a busted flush; thus, we need to move to vacuum collection of faeces and urine, therefore, separation at source.

On the positive side, the introduction of regenerative agricultural practices, as discussed in Volume 2, by significantly reducing, if not eliminating, fertiliser and agrochemical use, will logically create a positive feed-forward reduction cycle, lowering levels of heavy metals in soils, crops, livestock, faeces, and urine.

Where crops are naturally fertilised, research suggests they will contain higher protein and essential mineral nutrient content, and interestingly, may include lower amounts of toxic heavy metals (it appears that healthy soil biomes, working in cooperation with plants, may select against uptake of harmful heavy metals); thus livestock fed on such feeds from healthy soils, will have lower intakes; and consequentially their faeces and urine will contain falling amounts of toxic heavy metals.

Fig. 49. Landfill with many thanks to the Author and Adobe Stock

Overall, heavy metal soil contamination is a much more serious issue globally than generally realised. The review, "*Heavy metal pollution, a global problem and its remediation by chemically enhanced phytoremediation*", observes, "*The world's heavily effected areas from heavy metal pollution have been proving as health risks to more than 10 million people in various countries. In Linfen in China people faced extreme loads of pollution, In Haina of Dominican Republic, people suffered from a huge amount of lead poisoning, in Ranipet a city of India about 3.5 million people are being affected by tannery waste.* (Shakoor, 2013)

19.11. BROMIDES IN WASTEWATER AND SLUDGE

Bromide may be released in industrial water discharges, including from flue gas scrubbing. Other bromide sources include "*fossil fuel extraction activities, including oil and gas development and coal mining [and] coal-fired power generation. Discharges from these sources are associated with elevated bromide concentrations in rivers*" (Good & Van Briesen, 2019). Where industrial bromide discharge is upstream of drinking water abstraction, it can create health risks. Bromide used in foods can also be transferred to land through sludge and wastewater irrigation, and thus crops.

Bromine is a halogen, a biological iodine competitor and can, for example, impact the thyroid and broader function, particularly where iodine intake is insufficient. Insufficiency of iodine intake is a widespread problem globally, including in some high-income countries. Concerningly, excess bromide intake has been associated with developmental and neurological issues.

19.12. URGENT CONCERNS: FLUORIDES IN SEWAGE AND FERTILISER - DENTAL AND SKELETAL FLUOROSIS – IMPAIRED NEUROLOGICAL DEVELOPMENT

Excess mineral fluoride intake is another health issue, particularly for infants and children. While low levels of fluoride administration in public water supplies, or direct application to teeth, are used for strengthening dental enamel and can help prevent tooth enamel decay, excess or inappropriate fluoride intake is a serious health issue. It can lead to a condition called fluorosis, caused by excessive fluoride consumption; conditions include sub-optimal neurological development and the occurrence of skeletal, dental, and wider fluorosis. The effects of high fluoride intake are magnified by insufficient iodine intake, which is common in many Western countries, as discussed below.

Fluorides in sewage sludge and wastewater can be relatively high due to human fluoride ingestion from various sources, including toothpaste, pesticide contamination, tea, and fluoridated water.

Fluorides are present in sewage sludge, rock phosphate-based fertiliser, and industrial atmospheric emissions (Ramteke., 2018) and will move up the food and water supply chain. As a result, some in the world are exposed to excess fluoride in food and water; for example, "i*ncreased levels of fluoride in drinking water wells have been associated to high use of phosphate fertilisers, for example in intensive agriculture areas in West Bengal, India*" (Tirado & Allsopp, 2012"), "*in India, the incremental load of fluoride in agricultural fields was* *estimated to be 127,650 ± 14,550 (*Metric Tonnes y−1*) based on the grand average fluoride content of 0.851 ± 0.097% (w/w).*" (Ramteke., 2018)

Industrial plants may also emit fluoride into the atmosphere, from where it precipitates onto farmland, including grazing pasture. Sometimes, this causes fluorosis in livestock and indeed feeds into food, livestock feed, and water sources, thus entering the faeces cycle.

High levels of fluoride in sludge applied to ryegrass grazing increased "*the concentration of fluoride in ryegrass of 18 mg/kg dm at cut 1, 8 mg/kg at cut 2 and 5 mg/kg at cut 3*" which levels can lead to fluorosis in livestock (Davis, 1980).

Fig. 50. Skeletal Fluorosis "*Fluoride can have disastrous impacts on health*" with thanks to NDTV '*Every Life Counts*', funded by Bill and Melinda Gates.

Fluoride uptake by plants increases with soil content. Crops impacted include brinjal, tomato, mung, mustard, ladies' finger, chilli, maize, and rice. Thus, fluoride moves up the feed food chain into the diet. Excess fluoride, within ranges between 10-220 ppm, may also negatively impact plant growth, decreasing net primary productivity in all crops (Mishra, 2014).

Fluoride, as well as impacting cellular function in mammals, can influence bacterial function, including in the gut biome. Fluoride also impacts industrial digestion processes, including treating organic waste and biogas production, which involves various metabolic steps by multiple microorganisms.

19.13. FLUORIDE: THE GUT BIOME UNDER THREAT?

Inhibition by fluoride of bacterial function could also be relevant to the gut biome, and animal studies suggest it is. A review observed, "*Animal studies generally examined acute fluoride toxicity following ingestion of fluoridated food and water and conclude that fluoride exposure can detrimentally perturb the normal microbiome . . . Unfortunately, none of the studies retrieved examined the effects of ingested fluoridated water on the human microbiome.*" (Moran, 2023). Although one study looked at the impact of fluoride on stool biology and determined that high dosages of fluoride might be harmful to gut function, concluding, "*more attention should be paid to toxicity of fluoride with high dosage to gut microbiota.*" (Chen, G. 2020). However, concerningly, there appears to be little or no research into its impact on human gut function.

Fluoride in groundwater is rising in some locations. It is a concern that increasing amounts are reported in some areas, for example, in India (Singh, V. 1999); "*more than 200 million people worldwide are thought to be drinking water with fluoride in excess of the WHO guideline value*". (Edmunds, n.d.) These are likely of geological, fertiliser, or industrial origin, but a contribution from human sewage-related sources is also likely.

High fluoride leads to dental and wider fluorosis. Fluoride urinary levels are related to severe dental fluorosis (Del Carmen, Javier, & Aline, 2016). Dental fluorosis is a particular problem in India (Verma, Shetty, Guddattu, Chourasia, & Pundir, 2017), and dental fluorosis has also increased in other parts of the world, including in the USA (Beltrán-Aguilar, Barker, & Dye, 2010). Dental fluorosis is also rising in the UK and potentially in Europe (Pretty., 2016; Whelton, 2004).

An article in the British Dental Journal titled '*Are there good reasons for fluoride labelling of food and drink*?' observes "*Several reports from western countries have shown an increase in the prevalence of mostly very mild to mild dental fluorosis including a relatively recent UK study, in children aged 11–13 years, which indicated a dental fluorosis prevalence (at any severity level) of 55% in fluoridated areas and 27% in non-fluoridated areas*." (Zohoori, 2018).

Dietary sources, including baby formula and water, are significant sources of fluoride in young infants up to 1-year-old. "*Although toothbrushing with a fluoridated toothpaste is a major source of fluoride intake for children, data from fluoride intake studies in the UK have shown diet to be the sole source of fluoride intake for the majority of infants (up to 6 months of age) with a fluoride intake of up to 0.18 mg/kg BW/d. Similarly, in the US, the Iowa Fluoride Study reported that during the first 12 months of age, up to 96% of total fluoride intake can be from diet, which then decreases to 53% at age 24 months*" (Zohoori, 2018).

Thus, the level of fluoride intake in infants is a significant concern. Studies suggest fluoride can impact early neurological formation, including in utero. A mechanism for this may be that excess fluoride exacerbates the adverse effects of iodine insufficiency on early neurological development (Connett, 2015; Fa-Fu, 1991; Ren, 1989; J. Wang, 2004). Iodine has essential roles in neurological development and function. For example, iodine is crucial for optimal neuronal migration, which, in humans, starts as early as week seven.

Indeed, fluoride significantly negatively impacted the structure of rats' brains. The authors found that adverse developmental effects occurred most notably in the early stages of development, from day 0 to 20. The changes were connected with increased oxidative stress (Ge, 2005).

Thought-provokingly, the study also noted, "*In agreement with this view, Li reported a lower IQ in children living in fluoride-endemic areas and suggested that the effects of exposure to HiF intelligence probably occurs at an early stage of embryo and infant development, when differentiation of brain cells is occurring and development is most rapid.*" (Ge, 2005).

Consistent with this, "*In a meta-analysis, researchers from Harvard School of Public Health (HSPH) and China Medical University in Shenyang for the first time combined 27 studies and found strong indications that fluoride may adversely affect cognitive development in children. Based on the findings, the authors say that this risk should not be ignored, and that more research on fluoride's impact on the developing brain is warranted.*" (Dwyer, 2012)

Similarly, in Mexico, "*higher prenatal fluoride exposure, in the general range of exposures reported for other general population samples of pregnant women and nonpregnant adults, was associated with lower scores on tests of cognitive function in the offspring at age 4 and 6–12 year."* (Bashash, 2017)

Consistent with fluoride in formula baby milk being a potential matter of concern, particularly when elevated, the study *'Fluoride Exposure from Infant Formula and Child IQ in a Canadian Birth Cohort'* noted, *"Exposure to increasing levels of fluoride in tap water was associated with diminished non-verbal intellectual abilities; the effect was more pronounced among formula-fed children.*" (Till, 2019)

Interestingly, very little fluoride is found in breast milk (Ekstrand, 1981). Therefore, it is likely important that mothers do not use high-fluoride water to prepare formula, which can already contain biologically significant amounts of fluoride ("Top 5 Ways to Reduce Fluoride Exposure from Infant Formula," 2012).

Increased fluoride in feedstock and grazing will increase levels in milk, thus logically also in formula derived from milk. Fluoride in sewage, fertiliser, and from powerplant emissions will also increase uptake by crops, including soy, creating risks of higher fluoride in soy milk formula derived from soy, "*soy-based formula reconstituted with distilled water has more fluoride (0.24–0.30 mg/L depending on whether it is ready-to-feed or concentrated) than milk-based powdered formulas (0.12–0.17 mg/L)*" (Till, 2019). High fluoride levels in formula baby milk may have developmental implications, for example, on neurological pathways, and may also increase the risk of mild dental fluorosis.

The addition of fluoride by humans into the water table and soils, thus the food chain, by a wide range of mechanisms, is a phenomenon outside natural cycles. Therefore, consideration should be given to further research into how to mitigate potential sources of excess fluoride in the diet, including water, baby formula and foodstuff, ingestion via toothpaste, mouthwashes, fluoride-containing fertilisers, fluoride in soils and water from sewage sludge

(Ochoa-Herrera., 2009), and atmospheric pollution. When greywater usage is considered, the potential for fluoride contamination should also be kept in mind.

Monitoring fluoride intake through food suggests that fluoride levels are rising, albeit most foods are relatively low in fluoride. Tea can be a significant source of fluoride, depending on tea type and intake. Levels in sewage, fertilisers and atmospheric pollutants contribute to those rises.

Iodine, like fluoride, is a halogen and will 'compete' with fluoride in biological pathways; interactions are complex, but as a generality, increased iodine will help mitigate the impacts of higher fluoride intake, including in relation to neurological development and dental fluorosis (Goodman, 2022). Those at most significant risk appear subject to high fluoride and insufficient iodine intake. High levels of iodine insufficiency in many Western populations would magnify the effects of high fluoride intakes. More research is required, but ensuring that populations are not insufficient for iodine would seem a sensible public health strategy.

However, given rising levels of dental fluorosis in several populations and the negative neurological development implications of excess fluoride in utero and infants, there should be a greater focus on collecting long-term data trends on fluoride intakes through food, water, toothpaste, and other products, including baby formula.

Fig. 51. Dental fluorosis – with thanks to the Author and Adobe Photo Stock

However, it is essential to remember that fluoride metabolism is complex, and insufficiencies of other minerals, including calcium and potentially iodine, may result in greater uptake of ingested dietary fluoride from the gut.

19.14. FLAME RETARDANTS

Flame retardants have been found in sewage sludge. They are the subject of debate. Concerns have been raised as to their toxicity and presence in the environment. Retardants and/or firefighting foams include brominated compounds (Xiong. 2019), PFAS, and organophosphates (Bruchajzer, 2015). The subject is complex. Collection of faeces and urine at the source may reduce their presence and provide opportunities to monitor and research any mitigation impact of anaerobic digestion and specialist composting.

19.15. CAFFEINE

It is not widely appreciated that caffeine, in urine and faeces, when discharged into the environment, is an environmental pollutant of concern, including in the marine environment. Research has shown it can impact the biology of a wide range of aquatic life, including; *"microalgae, corals, bivalves, sponges, marine worms, and fish"* (Mongabay. 2022). However, as with many pollutants, science is only beginning to unravel caffeine pollution's broader environmental impact.

For example, the review, '*Caffeine as a contaminant of concern: A review on concentrations and impacts in marine coastal systems*', notes, "*Caffeine has been found in tissues from coastal and marine biota including microalgae, coral reefs, bivalves and fish due to bioaccumulation after chronic, long-term exposures in a contaminated environment. Additionally, caffeine residues had been demonstrated to have adverse impacts on aquatic organisms, at environmentally realistic concentrations, inducing oxidative stress and lipid peroxidation, neurotoxicity, changing energy reserves and metabolic activity, affecting reproduction and development and, in some cases, causing mortality.*" (Vieira, 2022)

In the words of the Mongabay 2022 review, titled, '*Caffeine: Emerging contaminant of global rivers and coastal waters*', *"Caffeine is the most consumed psychostimulant in the world, . . . Partially excreted in urine, it is now ubiquitous in rivers and coastal waters."*

Caffeine is present in coffee, chocolate, energy drinks and pharmaceuticals, "*from 1002 mg/L to 1353 mg/L in concentrated caffeine supplements, 267–340 mg/L in energy drinks, 36–804 mg/L in coffee, 41–132 mg/L in cola, 13–68 mg/L in ice tea and 17–551 mg/L in chocolates*" (Raj, 2021).

A portion is excreted in urine, enters, and is replenished in the environment every day throughout the year, year in and year out. Further caffeine intake is increasing, worsening the situation with time.

Given the presence of caffeine in urine, sewage is a significant source of caffeine in the environment via both sewage sludge and treated wastewater (Tawfik, 2024). Whilst some high-end treatment plants with add-on tertiary water treatment can significantly remove caffeine "*in the range of 64%–100%*", most cannot, removing only around 10% (Raj, 2021).

Adopting vacuum WC collection at source would ensure that caffeine in urine is not diluted into the external broader FaF sewage waste stream. It would be collected with the faeces for processing. It is not clear how anaerobic digestion, aerobic composting, or their hyperthermophilic variants would impact the caffeine content of urine and faeces. However, the possibility warrants research, given that composting (Hanc, 2024) and vermicomposting (Hanc, 2021) have been shown to reduce the caffeine content of coffee grounds.

19.16. WIDESPREAD MOVEMENT OF SEWAGE-RELATED POLLUTANTS

Such are the complexities of natural systems that many pollutants, including microplastics, once in the environment, are transported in ways, to extents, and in places we never dreamed of. As a sobering example, microplastics are found in various fundamental human tissues.

PFAS provide another surprising example as to the capacity of pollutants to travel: PFAS *"are significantly transferred from water to air when waves break on land, and are a significant source of air pollution, and eventually get into the rain. The researchers concluded that pollution "may impact large areas"* (Wikipedia, 2023).

Similarly, as previously discussed, nano-plastics, antibiotics, and ARGs, through airborne pollen, enter the atmosphere. We need to attentively take heed of these pollutant-related 'cautionary tales' sooner rather than later.

19.17. CEC POLLUTANT FOOD CHAIN UPTAKE BY PLANTS AND LIVESTOCK

In addition to the CECs in sewage sludge, animal manure applied to agricultural land will contain relevant but different equivalent animal medications and husbandry products, as well as heavy metals, which pollutants will be taken up by plants, entering the food chain, including that of livestock, creating feed-forward concentrating cycles.

The review, '*Chemicals/materials of emerging concern in farmlands: sources, crop uptake and potential human health risks*', notes, "*Thus, there is a continuous flow of CECs from farmlands to agricultural produce, causing a serious threat to the terrestrial food chain. Consequently, CECs find their way to the human body directly through CEC-laden plant produce or indirectly via the meat of grazing animals. Thus, human health could be at the most critical risk since several CECs have been shown to cause cancers, disruption of endocrine and cognitive systems, maternal–foetal transfer, neurotoxicity, and genotoxicity." (Maddela, 2022)*

Albeit a Californian study concluded: "*Although previous studies under laboratory or greenhouse conditions showed that plants could substantially accumulate various kinds of PPCPs [pharmaceutical and personal care products] from nutrient solutions or soils, [our] results suggested that the accumulation of 19 frequently occurring PPCPs in 8 common vegetables irrigated with <u>tertiary-treated</u> wastewater was limited under field conditions and that human exposure to PPCPs through daily consumption of these PPCP-contaminated vegetables was likely to be small*" (Wu, 2014) [this author's underline].

The above conclusion was in relation to ***tertiary treated*** *water*; levels and efficacy of tertiary treatments vary considerably, and ultimately, the cumulative effect of multiple pollutants, even if in small amounts, is unknown, and examples of harm due to the use of waste products on agricultural land, are growing. Secondary treated sewage wastewater treatment discharges are sometimes used for crop irrigation. Also, in some situations, minimally treated water is used for plant irrigation.

Crucially, much remains unknown about the long-term effects of using wastewater treatment outflow for irrigation, and the precautionary principle should surely be the standard adopted.

19.18. INTERGENERATIONAL CUMULATIVE EFFECTS ON HUMAN HEALTH AND MENTAL CAPACITY AND BEHAVIOUR, AND THE ENVIRONMENT

Many environmental pollutants are long-lived and will accumulate over time. Some may degrade relatively quickly. However, we repeatedly add, evermore, an increasing diversity of short- and long-lived pollutants to our environment daily. Constant exposure to them will have a cumulative negative impact on our physiology that will worsen over generations, some through direct impacts, others through reproductive-pathway epigenetic effects. These topics are complex, under-researched, and difficult to research. However, such effects are clearly seen in animal models and increasingly reported in humans.

There is no question that the air we breathe, the water we drink, and the plants and livestock we eat take up pollutants, including through the way we collect, treat and dispose of sewage; the question is at what levels, over what time scales, and in what combinations do human harms occur, and how do we measure them? In the meantime, until we know the answers to these questions, it surely will be simpler and easier to keep them out of our air and water and off our fields, in the first place, by adopting vacuum WC collection, hyperthermophilic biogas production combined with hyperthermophilic composting.

The appearance of microplastics in human tissue reminds us how those introducing new technologies often fail to consider broader perspectives. Humans consistently underestimate or choose to put blinkers on as to the potential for the unforeseen. We fail to recognise the need for prudence and broader, more vigorous evaluation at the outset of new technologies that have the potential to reach deep into human and wide biological pathways.

These limited examples are strident reminders that if we wish to maintain the health and general mental well-being of the human species, the environment, and the related global ecosystem that supports us, we need to take seriously the way we collect and process urine and faeces and the issue of pollutants in sewage.

In the words of ‘T*he Stockholm Resilience Centre’, "humanity’s actions in the release of novel chemical entities into the environment, is threatening Earth’s “safe operating space.”* (Mowbray, 2022)

20. SEWAGE SLUDGE DISPOSAL – ALTERNATIVES – AGRICULTURE, INCINERATION, LANDFILL OR DISCHARGE INTO THE ENVIRONMENT

As discussed, options to dispose of sewage sludge are limited because it is virtually impossible at a practical level to separate the contents and thus remove and treat the wide range of pollutants sewage sludge contains, including:

- pharmaceuticals, including antibiotics;
- personal care products;
- micro and nano-plastics;
- road run-off, including tyre 'dust';
- a long list of wider pollutants, including Industrial additions;
- hospital-related contrast and radioactive agents;
- heavy metals from a variety of sources;
- pathogens and bacteria.

Current disposal methods include:

- agricultural use, including composting, use for biogas, and direct application to land;
- forestry;
- landfill;
- incineration;
- in some instances, dumping into rivers and oceans.

20.1. AGRICULTURAL DISPOSAL OF SEWAGE SLUDGE

The inability of treatment plants to effectively remediate the wide range of pollutants in sewage sludge, thus the risk of soil pollution, runoff and leaching after application, makes it increasingly difficult to justify the use of sewage sludge, or derivative fertiliser products, on soils, even though it returns some organic carbon and minerals to fields. Wastewater treatment also tends to concentrate heavy metals in the sludge, but some soluble heavy metals will remain in the wastewater component after treatment. Thus, for numerous reasons, including the wide range of pollutants it contains, disposal of sludge on agricultural land is ultimately not a practical option.

Further, as discussed, pathogens and their spores in sewage sludge can remain in soils for long periods and be taken up by plants and livestock. A Swedish study noted *"the unsuitability of sewage sludge produced in Swedish treatment plants for arable land due to its relatively high pathogenic bacterial content, irrespective of prior stabilisation procedures, including thermophilic/mesophilic anaerobic digestion, composting, and sedimentation"* (Arthurson, 2008). *"These results are consistent with those reported by Jepsen, who concluded that aerobic stabilisation does not reduce the pathogens and indicator organisms to levels that are acceptable for the unrestricted use of sludge in agriculture"* (ibid).

The inability of thermophilic anaerobic digestion to adequately remediate pathogens provides another reason to move to hyperthermophilic anaerobic digestion and hyperthermophilic composting, a dual process with higher process temperatures that will significantly reduce the chances of pathogens surviving.

The degree of soil contamination by sewage sludge, including pathogens, will vary according to source. Still, even if it is low, it will accumulate over time, be taken up by plants and thus into the food chain, and have unpredictable consequences on the health and function of soil fungi, bacteria, and broader life.

Consequently, some countries have banned the application of sewage sludge to agricultural land. Even where it is still permitted, it is heavily regulated. Nonetheless, even in economically better-off countries with oversight, such as the USA, evidence of significant pollution of farmland by sewage sludge and sludge-derived fertiliser products is emerging, as outlined in the following section. In many developing countries, oversight may be limited or virtually non-existent, giving rise to significant long-term pollution and health risks where sludge is used.

Notwithstanding pollution issues, sewage sludge is still used on agricultural land and in forest management by direct application via biogas digestate or composting. In many less-wealthy countries, farmland remains the primary destination for slurry and sludge "*since it is the most economical outlet compared to incineration and landfilling*" (Haiba, 2016).

However, as discussed, this is not desirable or sustainable and will eventually manifest long-term pollution consequences, with degraded food quality and a negative impact on livestock, human, and environmental health. For the reasons explained, all sewage sludge products contain a wide range of pollutants, although mixtures and concentrations will vary.

20.2. SEWAGE SLUDGE CAUSED SIGNIFICANT POLLUTION TO AGRICULTURAL LAND?

The application of sewage sludge to farmland has, on occasion, caused significant pollution. The Guardian newspaper, in an article titled, '*Legal action could end use of toxic sewage sludge on US crops as fertilizer*', reported, "*The action comes as sludge has contaminated farmland across the country, sickening farmers, killing livestock, polluting drinking water, contaminating meat sold to the public, tainting crops and destroying farmers' livelihoods*" (Perkins, 2024). Campaigners are suing the Federal Authorities, asking that sewage sludge application be stopped on agricultural land on the grounds of illegal pollution.

Historically, a legal case was won in the USA for reparations due to sewage sludge application to farmland, causing consequent contamination of dairy milk. Interestingly, the USA State of Maine has banned sludge applications and set up a compensation fund. Other US States are becoming concerned and taking pragmatic steps to address the emerging harm, including those from PFAS.

The paper '*Proper Sanitisation of Sewage Sludge: a Critical Issue for a Sustainable Society*' concludes: "*Stabilised sludge intended for arable land use needs to be rigorously assessed for quality due to the high content of metals (cadmium, arsenic, copper, lead, mercury and zinc), persistent organic pollutants (the organochlorines aldrin, dieldrin, heptachlor, dichlorodiphenyltrichloroethane and lindane) and pathogenic microorganisms (bacteria, viruses, protozoa and helminths) to ensure no transmission of harmful elements to humans through entry into the food chain via crops or grazing animals*" (Arthurson, 2008).

It adds: "*The majority of the standard stabilisation procedures… provide unsatisfactory results in terms of the reduction of the concentrations of human pathogenic bacteria for the safe use of sewage sludge as an appropriate crop fertiliser*" (Arthurson, 2008).

Thus, "*The use of sewage sludge in agriculture is one of the major causes of environmental pollution*" (Haiba, 2016), and in consequence, "*Although sewage sludge and its compost offer an opportunity to recycle plant nutrients and organic matter to soil for crop production stimulating biological activity, its usage as a fertiliser is limited due to a large number of toxic pollutants found in this matter"* (Haiba, 2016).

In addition, the chemical and biological composition of sewage sludge means that once applied to farmland, it is inevitable that both soluble nutrients, including nitrates and phosphates, and pollutants both move up the food chain and leach out, causing eutrophication of waterways and marine environments, with additional damage due to release of toxic material and are damaging human health and development. Less soluble pollutants will accumulate additively over time.

20.3. NO NET AGRICULTURAL BENEFIT LONG-TERM SEWAGE SLUDGE POLLUTION

The adverse effects of long-term sewage sludge application to farmland soils, including soil pollution, eutrophication, and inhibition of soil biome function, outweigh the benefits; sewage sludge – whilst being "*rich in organic matter and nutrients, mostly nitrogen and phosphorus* [albeit] . . . (is) *rather poor in other macro-nutrients*", also contains minerals that assist plant growth (Malkki, 1999), but in excess are toxic, and may include outright toxic heavy metals, such as cadmium (Bellinger, n.d), as discussed below.

Increased organic matter will promote field production capacity, nutrient storage and turnover, air circulation and resistance to erosion. (Mtshali., 2014). Thus, the use of sewage sludge on agricultural and forest land (Abreu-Junior, 2019) can bring some limited benefits, increasing humus content, porosity and water retention, thus soil fertility, "*the low plant availability of nutrients results in small yield increases even after many years of repeated sludge addition*" (Kirchmann, 2017).

However, the limited benefits are far outweighed by the inevitable negatives, including the accumulation of pollutants in soils, contamination of the food chain, and the additive effect of runoff due to unbound phosphates, nitrates, heavy metals, microplastics, and other pollutants, including pharmaceuticals, antibiotics, and ARGs, causing eutrophication and broader environmental damage to rivers, lakes, and seas.

For example, high levels of heavy metals have been recorded in the Sargassum seaweed inundating coasts in the Mexican Gulf. The excessive growth and heavy metal pollution of the seaweed is likely partly due to sewage discharge and the use of fertilisers, sewage sludge, and slurry on agricultural land, leading to pollution of rivers that outflow into the Gulf region. By way of corroborative evidence, high levels of heavy metals are not seen in samples of Sargassum seaweed from remote ocean regions.

20.4. LANDFILL DISPOSAL

Disposal in landfills passes the pollution issue onto future generations, with the additional risks of leakage, water table pollution, anaerobic fermentation, methane production, and other noxious gases.

20.5. INCINERATION

Whilst incineration may be the least bad option, it is far from ideal and fails the circularity test. Incineration produces toxic ash and releases some toxic incineration gases into the atmosphere, as well as carbon dioxide if not captured, even where flue gases are well 'scrubbed'. Further, recovering the minerals in the ash is complex, and the residue is toxic.

Switzerland and Sweden are among those looking to totally or partially ban the application of sludge to farmland, instead favouring a move towards incineration, combined with phosphorus recovery, as the least bad option (Roskosch, n.d.). Phosphates can be extracted from sewage sludge ash; "*Inorganic fertiliser (e.g. mono-ammonium phosphate fertiliser) can be produced from metal-contaminated sewage sludge ash in a process whereby the metals are removed*" (Kirchmann, 2017).

Fig. 52. The Spittelau incineration plant in Vienna, Austria, designed by Friedensriech Hundertwasser. With thanks to Gralo and Wikipedia.

When sludge is disposed of in cement plants, coal-fired power stations, and waste incineration plants, the ash can be incorporated into construction materials, rendering it immobile in the short term.

In a study of 18 sewage sludge mono-incineration plants across Germany, in one year, 91KT (kilotonnes) of ash was subsequently sent to landfill; 54 KT was used for mine sealing; 49 KT in asphalt and copper refineries and, 8.5 KT for farming (Wiechmann, 2013).

How much cleaner is the sewage sludge incineration once the broader perspective is taken? (Van Praagh, 2018) performed an environmental risk assessment for recycled bottom ash from a Swedish incineration facility. They detected the metals Pb, Hg, V, Cr, Mo, Co, Ni, Cu, Zn, and Cd, along with metalloids Sb and As, and polycyclic aromatic hydrocarbons (PAHs), which are mutagens and possibly carcinogens too. From there, they established potential routes to environmental and human exposure. Risks were evident in the emission and deposition of dust, leaching of residues to aquifers, thus polluting groundwater, lakes, and streams, inhalation and ingestion of dust, intake by plants exposed to dust and exposure of skin to dust.

While chimney gas scrubbers may moderate some of the gaseous pollutants from combustion, some toxins will escape and inevitably, deposited by rain, end up in soils—many such pollutants are long-lived (Park, 2009; Murphy, 2017).

However, incineration, whilst the least detrimental option among the available alternatives when balancing the environmental scales for sewage sludge disposal, is far from optimal because it fails to close the cycle. It is also expensive, thus likely unaffordable for lower-income societies. Incineration also entails high capital and operating costs and requires highly skilled operating and maintenance staff (Marchioretto, 2003).

Incineration, pragmatically, may remain a logical and necessary way to dispose of some highly polluted specialist sewage waste, such as that from hospitals or that fails to meet prescribed standards after composting. However, incineration is not a truly effective solution . . . the review '*The transformation of PAHs in the sewage sludge incineration treatment*' observes, "*How to avoid the pollutant releasing into environment during the treatment is a knotty problem… This study indicates that PAHs release regularly according to temperature changes in the process of sewage sludge incineration*" (Zhang, 2016).

Further, high-technology incineration of broader waste produces toxic ash and gases. "*The Dioxin, PCBs and Waste WG of IPEN report demonstrates that waste incineration residues represent a serious threat to both local and global environment as they contain high quantities of unintentionally produced persistent organic pollutants (U-POPs) listed under Annex C of the Stockholm Convention (dioxins, PCBs and hexachlorobenzene).*", and other pollutants. (IPEN, 2005).

Thus, whilst incineration of sewage sludge is a better option than using it on agricultural land or for landfill, the conceptual difficulty with incineration is that it does not provide a sustainable full-circle solution and is, in one way or another, a source of atmospheric and ash pollution.

Some are suggesting pyrolysis to create biochar, which, dependent on the method of preparation, may return phosphate into soils (Glaser & Lehr, 2019). However, it has environmental issues, including heavy metals and potentially toxic combustion products and gases.

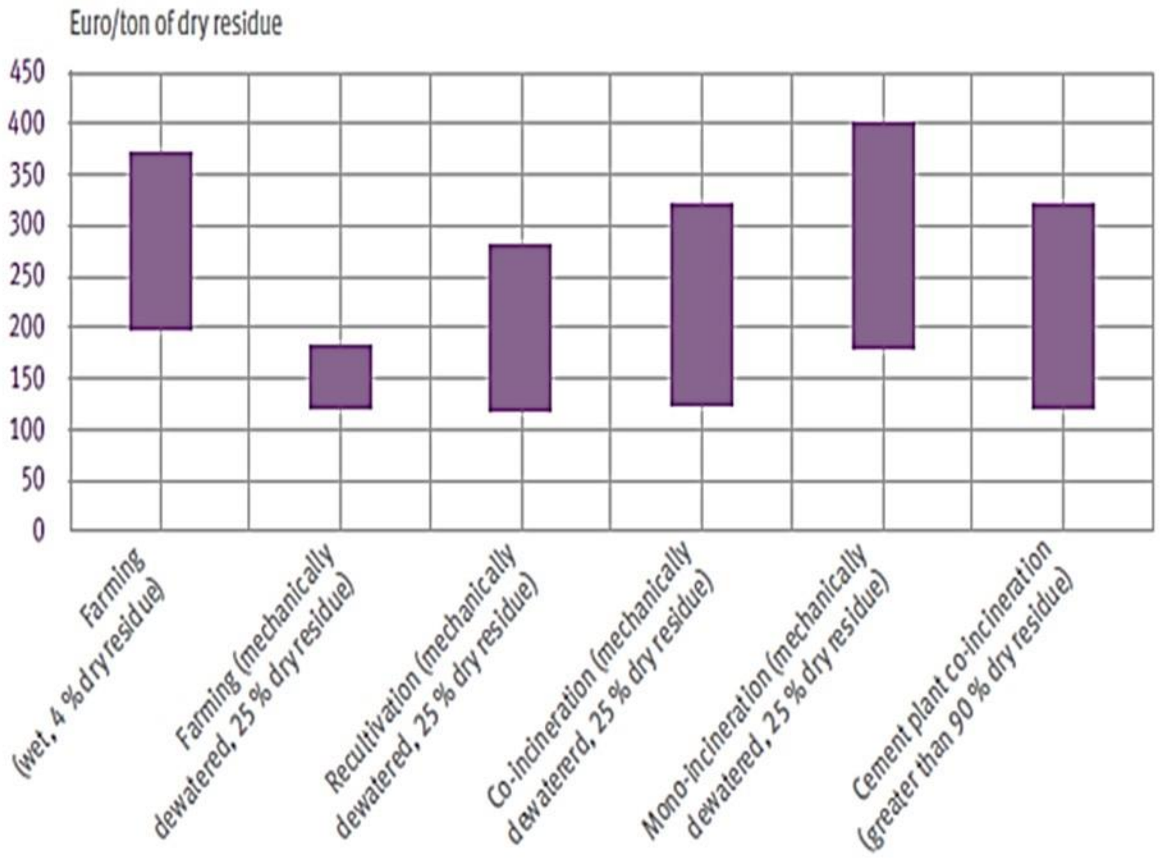


Fig. 53. Indicative sewage sludge treatment costs taken from '*Sewage Sludge Management in Germany*' (Wiechmann, 2013), with many thanks to the Authors and Umweltbundesamt (German EPA)

Whilst products of incineration of sewage sludge and opinions will vary, taking the broad view, incineration is unsustainable in the long term, particularly given that other alternatives such as hyperthermophilic, anaerobic digestion and composting exist.

20.6. FUNGAL TREATMENT OF SLUDGES

A solid-phase fungal treatment of sewage sludge was reported to significantly reduce the presence of various pharmaceuticals, providing research opportunities for add-on treatment options to hyper-thermophilic composting. (Rodríguez-Rodríguez, 2011)

20.7. DIRECT RELEASE ENVIRONMENTALLY UNSUSTAINABLE

Directly releasing treated and or untreated sewage into oceans and lakes is unacceptable. However, it continues even in more prosperous, advanced economies, as evidenced by current and historic UK reports (WWF, n.d.).

20.8. DISTRIBUTION OF SEWAGE SLUDGE DISPOSAL METHODS

Below are charts showing sludge disposal mechanisms and proportions, for example, in the USA and Germany. These illustrate how approaches vary and suggest that most sewage sludge is still disposed of by spreading on agricultural land. Incineration is a growing disposal method, but as discussed, it presents its problems. Germany and Switzerland are leaders in incineration.

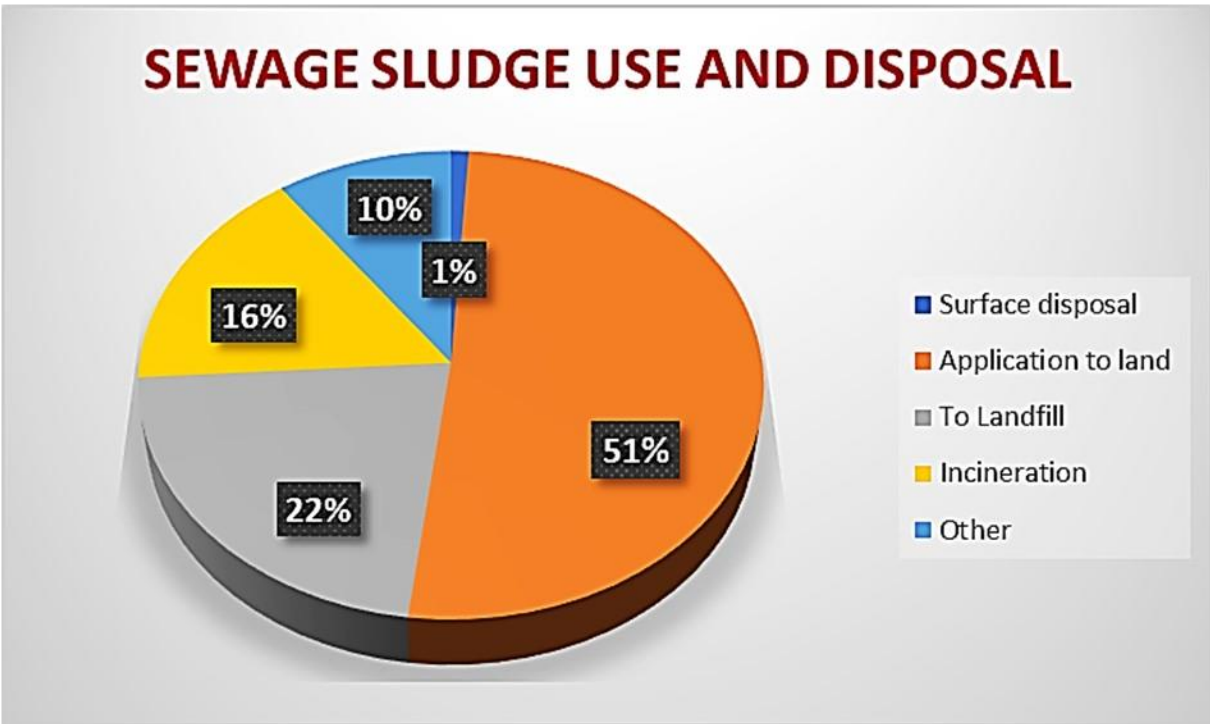


Fig. 54. Disposal profile for sewage sludge in the USA - '*PFAS in Sewage Sludge, Industrial Wastewater Targeted for Rules*' with many thanks to the EPA for the data and Authors for context. (Rizzuto, 2022)

The paper "*Sludge treatment and resource recovery towards carbon neutrality in China: current status and future perspective"* sets out its assessment of the carbon emissions profiles of the four most common treatment regimens:

- anaerobic digestion and land use;
- aerobic composting and land use;
- dry incineration plus ash landfill;
- dewatering and landfill;

furthermore, it is concluded that anaerobic, followed by aerobic, has the lowest carbon emissions footprints.

As previously suggested, both hyperthermophilic anaerobic digestion and aerobic hyperthermophilic composting should be used in sequence to minimise pollutants, extract maximum economic and broader environmental value, and, in so far as pragmatically possible, close the environmental food-sewage-land cycle.

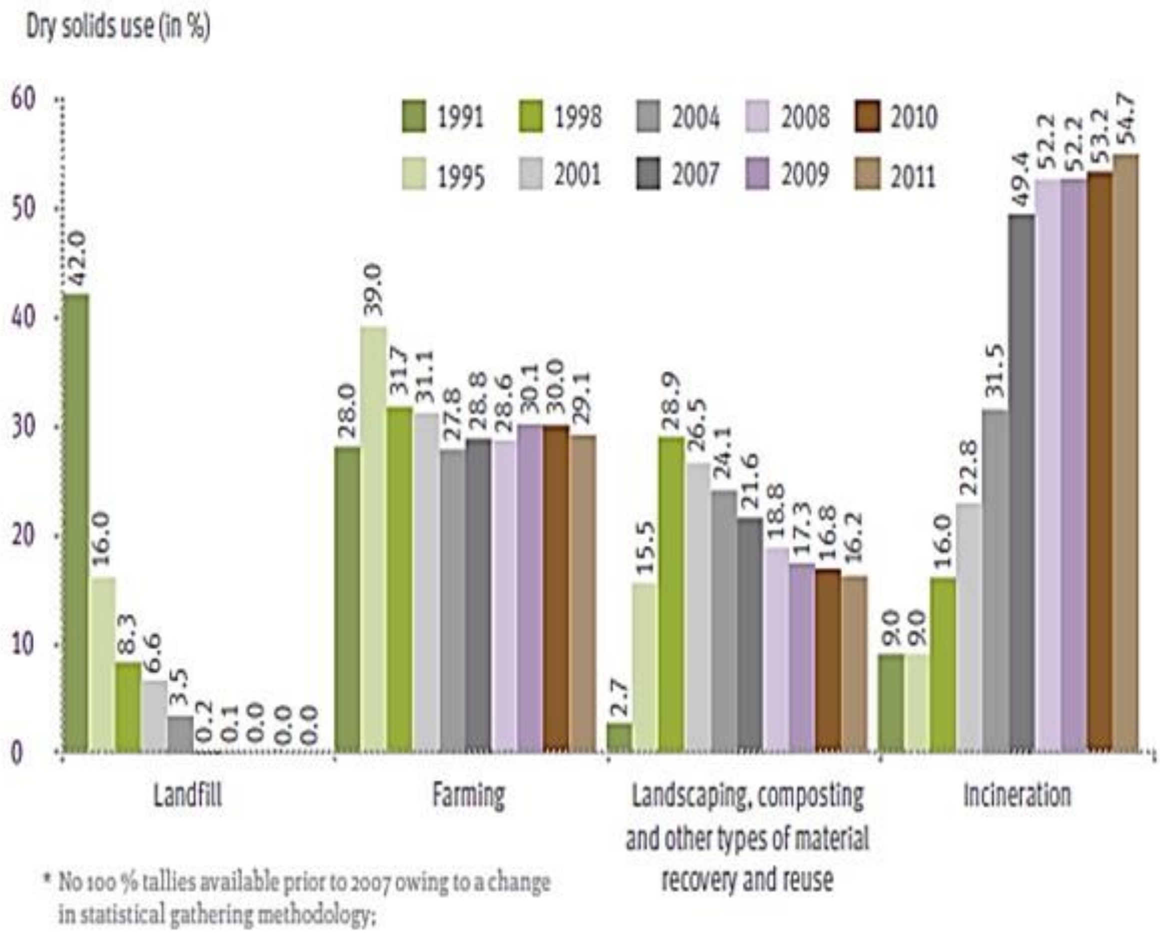


Fig. 55 '*Sewage sludge management in Germany 1991–2010*', (Wiechmann, 2013), with many thanks to the Authors and Umweltbundesamt (German EPA)

20.9. SEWAGE SLUDGE - DISPOSAL OPTIONS

The review '*Sewage Sludge Management in Germany*' (Wiechmann, 2013) takes a detailed look at sewage and examines sewage sludge uses in agriculture, the impact of contaminants, and the need for safe disposal.

Tarpani, in the review '*Life cycle sustainability assessment of advanced treatment techniques for urban wastewater reuse and sewage sludge resource recovery'*, does its best in the face of innumerable complexities to assess options for sewage sludge disposal that, in reality, are not sustainable, such as the use of sludge on agricultural land, concluding, as should be self-evident, that "*more sustainable wastewater treatment could be achieved by a circular use of water, energy and nutrients contained in urban wastewaters.*" (Tarpani, 2023).

However, taking into account the views in the Bloomberg article, "*PFAS in Sewage Sludge, Industrial Wastewater Targeted for Rules*" (Rizzuto, 2022), it is suggested that the increasing levels of pollutants in sewage sludge, combined with the lack of any sustainable way to dispose of them, yet relentless human contributions to the daily arrival of yet more 'crap' in the form of sewage sludge to be disposed of, is a "*tremendous challenge*"; indeed providing a host of unarguable reasons why FaF is a busted flush.

20.10. SLUDGE DISPOSAL: CARBON EMISSIONS FOOTPRINT – ANAEROBIC AND AEROBIC-DIGESTION BEST OPTIONS

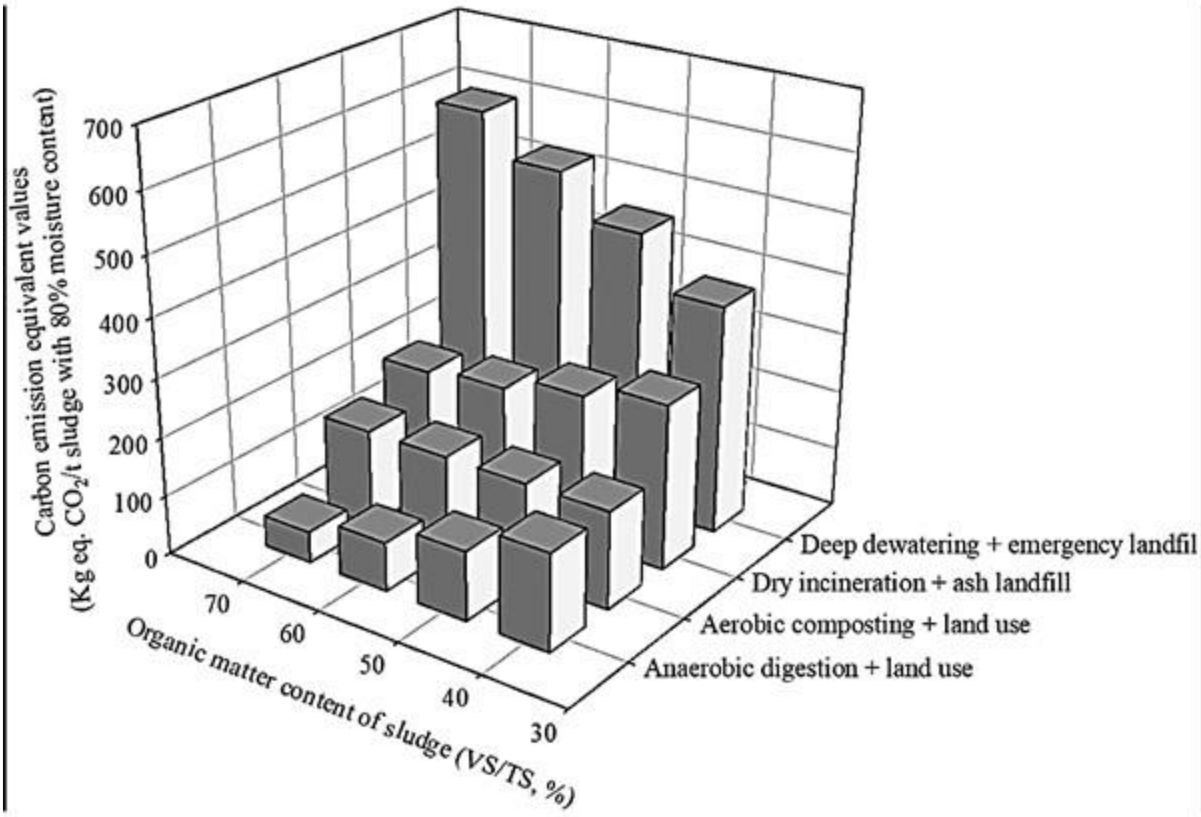


Fig. 56. From the paper, '*Sludge treatment and resource recovery towards carbon neutrality in China: current status and future perspective*', titled, "*Carbon emission equivalent values of sludge with various organic matter content and process routes: calculations are based on the accounting methods specified in the IPCC guidelines (IPCC, 2006) (VS, volatile solid; TS, total solid).*" with many thanks to the Authors (Xu Y., 2021)

In contrast, vacuum collection of faeces and urine at source, biodigestion, and subsequent hyper-thermophilic composting, logically offer more sustainable circular possibilities to cycle both faeces and urine. Vacuum collection offers significant upstream savings of clean drinking water while hugely reducing urine and faeces volumes, allowing their direct use in biogas plants. The combination of water volume reduction with gravity-independent, vacuum collection and transport technology, biogas production, and use of the residue for hyperthermophilic composting would remove the need for the current sewage processing plants and related gravity and pump, based water dependent sewage pipe transport infrastructure, which are costly in energy, capital and running cost terms.

Aside from the broader economic and environmental advantages, the capital and running costs of composting and biogas facilities could be substantially offset by income streams from biogas and compost. This potential cost-effectiveness makes them a viable and economically favourable option compared to the capital and running costs of FaF sewage disposal.

Grey water and surface water would need collection and remediation. Yes, significant rethinks would be required, but local treatment of grey water and basic filtration of surface water at local levels should be feasible.

Importantly, hyper-thermophilic composting, possibly combined with hyper-thermophilic anaerobic digestion for biogas, appears to be much more efficient at remediating pollutants than alternatives and subject to further research and development, once perfected, could prove to be the missing segment in the virtuous circle, producing quality compost for crops, turning troublesome human faeces and urine into life assets, rather than long term liabilities.

21. GREYWATER

The topic of greywater is more complex than it would at first appear. The review, "*Treatment of Gray Water for Reusing in Non-potable Purpose to Conserve Water in India*" (Manna, 2018), and '*Greywater reuse as a key enabler for improving urban wastewater management*' (Van de Walle, 2023). provide useful summaries of the complex issues involved in greywater treatment, including energy and wider resource savings.

Greywater refers to all non-industrial water flows from households and offices, including bathing, hand-washing, cooking, laundry, dishwashing, and cleaning, free of faecal contamination. As detailed below and elsewhere, greywater can contain a wide range of contaminants including "*food residues, oil and fats, soap, shampoo, hair, bleach, various body care products, toothpaste shaving waste, detergent*" (Manna, 2018), as well as, faecal bacteria from washing including of; clothes, hands, and uncooked meat; biocides, surfactants, minerals including salt, organic detritus; microplastics; PCPs; skin; wider medications, and a wide range of sundry pollutants poured down sinks including, for example, DIY products etc. (Van de Walle, 2023)

Basic greywater treatment processes include; "*screening, sedimentation, filtration, biological treatment, chemical coagulation, disinfection etc*" (Manna, 2018). As discussed below, current systems involving basic screening, sedimentation and filtration will potentially leave significant pollutants in place. Yet, many in the world of necessity even use completely untreated greywater for irrigation.

Indeed, some promoting greywater reuse offer a somewhat rose-tinted perspective, taking the view that users will, or are able, to avoid pollution of greywater by restricting the use of polluting household products (Greywateraction.org, n.d.), which the author suggests in the absence of legislation, and favourable industry participation, is for the busy majority, absent industry change, wishful thinking.

The amount of grey water produced is significant. For example, total domestic water consumption in India is around "*135 liters/capita/day*", of which "*70 – 90 liters*" is grey water (Manna, 2018), which when considered on a national basis, is a substantial amount.

Grey water comes in various shades, from light to dark, depending on the pollution level and source. Bathwater is termed light grey water; sink, dishwasher, and laundry water is termed dark grey. Thus, there are several options for subdivision, processing, and usage.

However, even once vacuum WC technology becomes widespread, given that minimal clean or grey water is required for toilet flushing, a good deal of organisation and infrastructure would be needed to find appropriate treatments, safe uses, as well as storage for large amounts of grey water in many urban environments, and particularly so where irrigation of public spaces and gardens is not a primary water user. It may be necessary for treated greywater to be pragmatically included with surface water outflows that are returned to streams, rivers and aquifers; hence, assessment of relative risk in relation to the level of treatment is essential.

In the Western world, the current design and plumbing of 'Flush and Forget' sewage systems and/or direct discharge ensure that most greywater gets mixed into the wider external sewage-water flows along with faeces and urine, making it impossible to separate or remediate.

Options for raw untreated greywater reuse include:

- return untreated to the water table, with all the negative pollution implications;
- use untreated for agricultural or garden irrigation, with significant pollution implications;
- partial treatment including one or more of fat removal, screening and filtration, and chemical disinfection/bacterial treatment, and use for agriculture or garden irrigation;
- treatment in wetlands, with a return to a water course or use for irrigation;
- treatment with a membrane bioreactor (a mix of biological treatment and membrane filtration - membrane bioreactors for domestic use have relatively high capital and running costs, as well as potential high maintenance requirements) (Makisha,2018);
- higher level oxidative or other disinfection / bacterial treatment to as far as possible remove organic pollutants and bacteria, etc., for reuse in domestic settings, for example, for flushing of WCs, or in agriculture for irrigation;
- reverse osmosis.

Effective and practical grey (and industrial) water treatment is essential to closing the environmental cycle. We need to rethink how urban and rural greywater can be best managed, including mandatory minimisation of the pollutants in our personal care products and related public education.

Greywater reclamation is an emerging technological field with various pollution implications. As discussed, only reverse osmosis and the technical oxidative tertiary treatment will remove all or a significant proportion of wider pollutants.

Thus, greywater treatment systems require further development and significant care in planning implementation and installation; irrespective of project size, "*many greywater treatment-and-use projects failed where planning, design and implementation were based mainly on technical aspects without adequate examination of the economic or socio-cultural issues*". (Abu-Madi, n.d.; Zomer , 2017)

21.1. GREY WATER CONTAMINANTS

Greywater may contain a range of pollutants, bacteria and other potential pathogens, according to its source, as outlined in the table below. In a modern world, it will also likely contain a range of other emerging contaminants of concern, including personal care products, medical products, insecticides from new clothes, micro-nanoplastics from washing machines, contaminants in wider household detergents, dissolved material from washed surfaces, and random pollutants from things washed in, and disposed of in sinks and basins, such as paints etc.

However, little research exists in this field, and more is required to better define the scope and number of wider pollutants of concern in grey water. Grey water derived from kitchen sinks, washing machines, and dishwashers arguably poses the most significant problems because it contains a wide range of pollutants, including fats, organic material, and microplastics. However, these can be partially addressed using basic localised treatments such as grease traps and filters.

Greywater source	**Possible contaminants**
Washing machine	*Organic material and suspended solids (from food), bacteria, increased salinity and pH, fat, oil and grease, detergent bathtub and shower bacteria, hair, organic material and suspended solids (skin, particles, lint), oil and grease, soap and detergent residue (and microplastics)*
Dishwasher	*Suspended solids (dirt, lint), organic material, oil and grease, sodium, nitrates and phosphates (from detergent), increased salinity and pH, bleach (and microplastics)*
Sinks	*Bacteria, organic matter and suspended solids (food particles), fat, oil and grease, soap and detergent residue*

Table 6. Classification of greywater contaminants according to their sources, from '*Table 3 of Encouraging the Use of Treated Greywater in Palestine*', with many thanks to the Author. (Hansen, 2012)

The '*Independent review of the costs and benefits of rainwater harvesting and grey water recycling options in the UK*' (Waterwise, 2020), considers some of the issues in greywater collection and non-potable reuse, and provides cost-benefit analyses for various options, from individual households to sizable developments. The report recognises that greywater separation provides benefits in reduced capital infrastructure costs for sewage treatment plants due to the reduced volumes of sewage.

21.2. GREYWATER – RECYCLING

Greywater, after basic treatment, can be returned to water flows, although it will contain varying levels of pollutants. Depending on the treatment level, contaminants will likely be less than the output of domestic sewage treatment systems, but this would be far from ideal.

However, when separately collected, greywater can be treated on a local scale and appropriately used. Our failure to grapple with the separate recovery of greywater is a wasted opportunity that is not sustainable in the long term. It is prudent to develop new small—and larger-scale technology, based on existing water cleaning technology, for greywater reuse, even if not proposed at present, as retrofitting is costly and often very difficult.

Whilst schemes reusing grey water in various ways are running, they require public acceptance and understanding that care needs to be taken when using grey water, and the level of care depends on the sophistication of treatment technologies. The public's perception of the value of grey water will depend on water availability, cost, and scarcity.

A mix of public education about greywater, greater focus by manufacturers on avoiding non-biodegradable and toxic components, and localised appropriate small-scale treatment plants could make an enormous difference.

Fig. 57. Left: Greywater sample from an office building. Right: Same grey water after treatment in membrane bioreactor, with thanks to the SuSanA

21.3. GREY WATER – AGRICULTURAL USE – UNTREATED AND PARTIALLY TREATED

In some countries, such as Australia, large quantities of greywater are recycled for irrigation; however, it is generally not treated before application. In other regions, such as Palestine, partial treatment systems were developed. There has been limited research into the impact of un-remediated and partially remediated greywater on plants and the wider environment. Problems have been encountered with the use of un-remediated grey water. Reuse within a domestic environment, particularly where water storage is involved, for example, for flushing WCs, will require higher treatment.

A study in Palestine recognised the risks of using greywater in agriculture: "*The use of untreated greywater leads to serious degradation as the soil becomes polluted with organic matter and pathogens. The treatment process of greywater treatment systems adequately reduces the concentrations of pollutants to within the WHO's acceptable guidelines and is thereby able to restore soil integrity*" (Hansen, 2012). However, there is now recognition of the wide range of potential contaminants in grey water.

The review, '*Comparative socioeconomic study of greywater and cesspit systems in Ramallah' (Abu-Madi, M., Al-Sa`ed, R., (n.d)),* also considered issues surrounding greywater use in Palestine. Palestine faces several water-related difficulties and pragmatically has sought low-tech, low-capital, low-cost greywater treatment systems with economic benefits over a cesspit capable of servicing the needs of between 6 and 25 people. It developed a filtration method featuring anaerobic and aerobic treatment, known as the '*Burnat up-flow system*'. In trials, its performance received widespread local approval; "*The issue on which the entire greywater enterprise stands or falls is that of socio-cultural acceptability".* (Hansen, 2012).

In contrast, the study notes that "*where the use of untreated greywater for crop irrigation arose spontaneously and without planning, negative environmental outcomes proliferated; citizens of Qebia suffered from offensive odours, explosions in the population of pests such as flies and mosquitoes, clogged soil, and the growth of algae and fungi among other ecological problems*". (Hansen, 2012)

Fig. 58. Grey water "towers" are used to treat and reuse grey water in Arba Minch with thanks to Wikipedia and SuSanA secretariat

The gradual increase in salinity of the soil was also an issue. The paper suggests that "*controlling household salt inputs from detergents, water softeners etc., or installing saline water filtration*" should be essential considerations. The study concludes that "*the net benefit of reusing nutrient-rich treated greywater for irrigating crops is positive, as the alternative cesspit systems are the leading source of groundwater pollution today. Ultimately, recovering and reusing the 80 per cent of household wastewater which greywater comprises, reduces pressure on the overloaded and over-polluted environment in Palestine and helps to maintain the integrity of its precious fresh-water resources*". (Hansen, 2012).

A three-year Israeli study which compared grey to fresh water was less optimistic and concluded: "*We demonstrated that using raw* greywater *(GW) for irrigation of arid loess soil with greywater may result in accumulation of salts, surfactants and boron in the soil, causing changes in soil properties and toxicity to plants*" (Gross, 2005). Although the study did not look at toxicity, it did indicate that some plants experienced growing problems.

Whilst treated greywater may promote plant growth, a more detailed investigation of pollutants in treated greywater, micro and nano plastics, including from washing machines, and their long-term impact on soils, crops, livestock, humans, and the wider environment is required to better determine the long-term risks.

In many countries where untreated grey water is used directly on food crops, toxic materials, infective agents, and micro and nano plastics risk being incorporated into plants and passed up the food chain, with potential health and environmental issues. Given that plants take up pollutants, risks exist for all greywater agricultural usage, particularly where advanced, including oxidative treatment technologies, are not used.

21.4. GREYWATER PUBLIC PERCEPTION AND KNOWLEDGE

A study on public perception and knowledge about greywater was carried out in Sydney, Western Australia, where water supply is a prominent issue. Of the sample group, 84% knew about water shortage issues, 43% were affected by scarcity, 50% reused greywater, and 36% of all participants were unaware of potential health risks.

The study concluded, "*The cost of plumbing and health risks to people, plants and soil are the two most important issues that need attention. Overall, people are environmentally conscious and are interested in saving water provided there is proper encouragement given by government, local councils and other authorities that regulate water supplies and reuse. The study indicated that for widespread reuse of greywater, homeowners need some reliable and practical information for its safe and sustainable reuse. The study also pointed out that financial incentives from the state and federal governments may help more reuse of greywater.*" (Pinto & Maheshwari, n.d.) Significant government input, legislation, discussion, technical development, and education are required (Van de Walle, 2023).

21.5. GREY WATER – POLICY, EDUCATION AND LEGISLATION TO REDUCE PCPS.

Further, producers and the public should be made more aware of the environmental impact of personal care, cleaning products, and pharmacological products and the opportunities for replacing them with more environmentally friendly alternatives.

Arguably, the risk of persistence in the environment of pharmacological skin and personal care products, including sun creams, should also receive greater attention during their formulation. It will be much easier to exclude pollutants from products than treat them. This may require a mix of legislation and discussion with manufacturers to reduce contaminants in PCPs and cleaning products, combined with broader public education.

22. RAINWATER SEPARATION AND COLLECTION

Opportunities exist to better separate and collect rainwater from hard surfaces - including rainwater that gathers on the roofs of larger building complexes. Israel, in particular, focuses on the conservation and reclamation of water. It significantly recycles water and is looking further at the decentralised processing of grey and run-off water. Pollution of surface water with urban contaminants is a common problem. One study found that run-off contained surprisingly high levels of mineral pollutants, particularly after periods of drought (Ben-Neriah, 2017). Considering how best greywater and urban run-offs could be recycled and reused in an urban environment makes sense.

23. INDIVISIBLE – FAECES AND URINE, FERTILISER, COMPOST, NITROGEN CYCLE, SOIL PLANT AND HUMAN HEALTH

Nitrates, phosphates, and wider pollutants in sewage streams are significant factors in sewage management, water pollution, and eutrophication. They are also central to agriculture because water, nitrates, phosphates, minerals, and pollutants are transported to plants and move up the food chain.

Thus, it was difficult to decide whether to include details on nitrates, phosphates, artificial fertiliser, and, importantly, compost in the regenerative agriculture book or the sewage Volume because they are central to both topics. However, as they and compost are key to a circular system for recycling urine and faeces, the subject ended up included in the Volume of sewage.

23.1. SOIL BIOME MYCORRHIZAL SYSTEMS

Mycorrhizal systems are experts at mining minerals, have a much wider reach than plant roots, and by physical interaction with the roots, can transport minerals, nitrates (Wang, 2020), nutrients generally, as well as a wide range of pollutants, directly from and into plants, in exchange for photosynthetically produced plant root carbon sugar and lipid exudates.

For example, the publication '*Advances in Agronomy – Microbial Associations*' observes, "*Mycorrhizal colonization of roots increases root surface areas to enhance root exploration of large soil volumes compared to uninfected roots and increases mineral nutrient uptake and* *plant tolerance to soil chemical constraints (acidity, alkalinity, salinity), toxic elements, and drought. Mycorrhizal fungi and/or mycorrhizal roots have particularly increased acquisition of Cu, Fe, Mn, and Zn in plants grown under deficiency conditions (usually in alkaline soils) and decreased B, Fe, and Mn in plants grown under conditions where these minerals are excessive (usually in acidic soils). Mycorrhizae are also involved in the biological control of root pathogens and in nutrient cycling (solubilization, mineralization)"* (Fageria, 2002).

Further, through symbiotic relationships and systems such as rhizophagy, plants uptake bacteria within the root system, strip-extract nutrients from them, and return the slimmed-down bacteria to the soil to repeat the cycle, optimising plant and soil biome health.

23.2. ARTIFICIAL FERTILISER – LARGELY UNSUSTAINABLE AND UNNECESSARY

As explained in Volume 2, regenerative agriculture can produce similar yields with higher nutrient density at lower cost. A central premise of Volume 2 is that Fertiliser, Agrochemical, and Tillage Bare-soil Agricultural Systems (FATBAS) are unsustainable and significant contributors to climate change.

As discussed in Volume 2, the use of nitrate and phosphate-based fertilisers, in the context of FATBAS, in the long-term, will reduce soil biome diversity, volume, function, health, soil carbon, water retention capacity, metabolic water production, plant health and yields, crop nutrient density, and contribute to; soil impermeability to rain, soil water loss, soil drying, regional droughts, flooding, soil heating of atmosphere, fires, erosion and run-off.

In addition, minable mineral deposits of rock phosphates are a limited resource. Phosphate extraction and production processes from mined phosphate-rich rock are environmentally damaging due to high energy production requirements and varied downstream pollution effects.

Further, soluble mineral rock-phosphate-derived fertilisers may contain detrimental amounts of heavy metals, radioactive isotopes, and other pollutants, leading to soil contamination, runoff, and eutrophication of rivers, lakes, and oceans.

23.3. ARTIFICIAL FERTILISER – LARGELY UNNECESSARY

A healthy, diverse, mature soil biome, maximising photosynthetic capacity, and diverse cover crops will provide adequate nitrates and minerals for cash crop growth. In return for sunlight energy-driven photosynthetic carbon sugar root exudate, which provides the energy that runs the soil biome, minerals are mined, nitrates made, and transported and supplied to plant roots over broad areas and sometimes long distances by mycorrhizal fungal as well as bacterial systems. In addition, nitrates are provided to plant roots during tissue breakdown, through cycles of death, and in life by excretion by soil biome lifeforms. Conversely, plant carbon sugar exudates are transported by mycorrhiza from plant roots to the widespread soil biome.

23.4. FERTILISERS - DETRIMENTAL TO SOIL BIOLOGY

For the vast majority of soils, for plants given access to healthy, carbon-rich, biologically diverse soils, the use of manufactured rock-phosphate and nitrate-based fertilisers is unnecessary, unsustainable, and detrimental at multiple levels, as discussed in depth in Volume 2 on regenerative agriculture.

Fertiliser supply to plants disrupts the evolutionary mutual symbiotic support 'trading system' between plants and the soil biome, namely the exchange of plant photosynthetic sugar energy for biome-mined/supplied minerals and nitrates.

Crucially, the readily available minerals and nitrates in manufactured fertilisers, and likely slurries as well, disincentivise the production by plants of photosynthetic sugars and created fats for exchange trade with the soil biome, thus reciprocally disincentivising the soil biome from supplying nitrates and minerals, including phosphates, to plants. Hence, artificial fertilisers are detrimental to the soil biome, volume, health and biodiversity, water infiltration and retention, carbon content, and diversity, inhibiting optimal soil biome function; and in extremis, over time, severely degrading and compromising the existence of the plant soil biosphere – resulting in highly degraded soils.

Further, when nitrates and phosphates are supplied as artificial fertilisers to plants, including in the form of soluble nitrate-rich sewage sludges and slurries, there is a significant risk of runoff, including phosphates, nitrates, and heavy metals, which causes environmental damage, including river and marine eutrophication.

23.5. SOIL BIOME NITRATES NATURAL SOURCES

Mycorrhiza and bacteria interact in harmony. (Sagwan, 2022) Complex soil biome systems do this more efficiently. Soil biome systems function best when photosynthetic plant carbon sugar exudate supply is optimal. In the absence of a supply of carbon sugar root exudates and lipids for its sustenance, the soil biome has to draw down on soil carbon stores embodied in the residual life in the soil, in effect cannibalising itself.

With long-term self-cannibalisation of the soil biome, for carbon for energy, once the soil has lost most of its organic matter, devoid of carbon, and consequently drying, unable to retain water, the soil biome eventually becomes a non-viable ecosystem, thus effectively dying, and the soil becomes desert-like.

To revitalise 'dead', depleted soil devoid of organic material requires <u>both</u> water <u>and</u> the reintroduction of diverse soil biology using mature composts, as well as germinating growing photosynthesising plants to supply root exudate carbon to soils. Thus, the soil biome will be sustained and grown, supporting improved plant growth by providing minerals, nitrates, and metabolic water.

Studies have shown that multi-species cover-crop plant mixes and the use of mature biologically diverse compost extracts on poor soils will result in improved soil biome systems, increased availability of bacterially produced plant-available nitrates to plants (Sui, 2024), enhanced mineral supply, and greater water availability, including during dry spells.

The Physorg article titled '*Cover crops as living mulch boost soil health and nutrient cycling, study finds'* observed concerning the Sui paper "*The study highlighted the potential of cover crops as a "living mulch" technique to improve soil health. . . . This method could help address soil degradation challenges, such as declining fertility and erosion, which threaten food security.*" (Na, Physorg, 2024)

24. NITROGEN CYCLE - AN ESSENTIAL BUILDING BLOCK OF LIFE

Nitrogen is an essential building block of life, extracted from the atmosphere and converted to usable nitrate forms. The nitrogen cycle and its supporting role in terrestrial life are much more complex, interconnected, nuanced, and plant-soil biome interaction-dependent than generally portrayed. In its way, the nitrogen cycle is just as fundamental to the existence of life as the oxygen cycle.

Plants require nitrates for growth and, like humans, cannot make their own. The health of the nitrate cycle, including efficient and sufficient natural nitrate production, is very much dependent on functional, healthy living vital, diverse soil biomes and the obligate complementary presence of above-ground, healthy, photosynthesising, root sugar exudate-providing soil biome plant symbionts.

The evolutionary emergence of plants, with the essential holobiont support of the soil microbiome, as a food source of organic and inorganic nutrients for higher life, including nitrogen-containing, amino acid and protein building blocks, lipids and plant antioxidants, as well as minerals in absorbable form, in turn, facilitated the emergence and existence of more sophisticated life forms, including humans.

The soil biome/plant holobiont system (Lyu, 2021) is immensely sophisticated, self-supporting, interdependent, interactive, interlinked, and mutually interactively adjusting to optimise the collection and supply of variably available mineral and other resources according to the soil type and growing conditions.

It is important not to lose sight of that:

- holobiont plants and subsoil biomes, self-sustaining nature-based evolved and evolving ecosystems, prospered in a variety of forms for billions of years, including in the carboniferous époque, sequestering from the then atmospheric carbon dioxide, the vast amounts of carbon, that now form coal oil and gas deposits;
- these natural evolutionary-driven systems sourced and cycled the nitrogen derivatives and minerals they required for growth and existence without any requirement for human-made, artificial, nitrogen-containing agricultural fertilisers;
- humans, seeking to create and exploit technological inventions and markets, ingeniously developed techniques to make artificial soluble nitrates, which were then

provided to soils by humans in concentrations and forms not seen in nature, with positive initial outcomes.

- in soils recently converted to agriculture from savannas and forests, not yet depleted of soil carbon and related soil biomes, nitrates were observed to enhance plant growth but, largely unappreciated at that time, provision of concentrated soluble nitrates to plants, disturbs soil biome and ecology;
- provision of soluble nitrates and phosphates negatively impacts soil ecosystem plant interactions, regulation, and balance, disincentivising, thus reducing the provision of photosynthetic carbon by plants to soils, and in consequence, reducing the reciprocal provision of nitrates and minerals by soil systems to their symbiont plants; nitrates are dominant over phosphates; indeed a study titled '*Phosphorus and Nitrogen Regulate Arbuscular Mycorrhizal Symbiosis in Petunia hybrida*' nitrate insufficiency promoted plant mycorrhizal associations even when exogenous phosphate was supplied; high exogenous phosphates were also associated with lower plant mineral density (Nouri, 1999),
- over time, falling soil carbon levels impact soil biology diversity and function, thus degrading soil biomes and their capacity for provision of a range of eco-services, including nitrogen production, and in dry spells of metabolic water, in turn negatively impacted plant growth and health;
- significant soil application of slurries and sewage sludges provide soluble nitrates to plants in amounts that, by similar mechanisms to artificial fertilisers, disincentivise and inhibit the supply of nitrates, minerals, and other plant services by the soil biome.

24.1. NATURAL NITRATE SOURCES – BACTERIA, LIGHTNING, SOIL LIFE AND EXCRETA

Nitrates originate from atmospheric nitrogen, representing approximately 78% of all atmospheric molecules. Lightning, solar flares, and biological fixation by bacterial enzymes can convert atmospheric nitrogen to nitrates; biological fixation is the dominant nitrate source that underlies life.

In contrast, while other soil and terrestrial surface lifeforms contain nitrates as part of their structure and functional metabolites, they cannot make nitrates. However, felicitously and remarkably, given the right conditions, specialist bacterial enzymes can break the powerful bond holding nitrogen gas together, thus facilitating the nitrate production that underlies the existence of life.

Bacterial families, known as diazotrophs, make nitrates, both in association with plant root nodules as in brassicas and independently in other low oxygen environments, and for the avoidance of doubt, that ability is very much not restricted to those diazotrophs that associate with legumes.

Bacterial-produced nitrates move up and sideways through the food chain, including through plants, thus facilitating the production of a range of biological products, including amino acids, that are essential enabling components of more sophisticated life, including humans.

All nitrate-containing life, including humans, ruminants, plants, and soil denizens, in one way or another, eat and excrete and, in turn, die. Their nitrogen components are degraded and recycled in soils, forming key and significant parts of the nitrogen cycle. Nitrates are also likely stripped from bacteria by plant roots through rhizophagy (White, 2018).

Over time, one way or another, the nitrogen in lifeforms is ultimately recycled back to the atmosphere, in "*a repeating cycle of processes during which nitrogen moves in changing forms through both living and non-living things: the atmosphere, soil, water, plants, animals and bacteria*" (Aczel, 2019.).

24.2. NITROGEN PRODUCING BACTERIA - DIAZOTROPHS

Diazotrophs exist in a range of forms in both terrestrial and marine environments. Generally, they can only produce nitrates in spaces where oxygen levels are low, including low-oxygen root nodules, the growing root tips of plants where the metabolism is high and oxygen levels are low, anaerobic soil, and other environments.

The review, '*Diversity and importance of diazotrophic bacteria to agricultural sustainability in the tropics*', observes, "*Overall, BNF* (Biological Nitrogen Fixation) *contributes 65% of the total input of N in Earth, or 96% of the N input derived from natural processes; accordingly, it is considered to be the second major contributor to life after photosynthesis*" (Kaschuk, 2017).

The review continues, "*The N2-fixing (diazotrophic) bacteria reduce atmospheric nitrogen (N2) into NH3 with the enzymic complex nitrogenase and proliferate in several different environments with different life strategies. Considering their strategies in agricultural systems, diazotrophic bacteria are classified into four groups:*

- *soil free-living,*
- *rhizospheric associative,*
- *endophytic,*
- *and symbiotic nodule-former"* (Kaschuk, 2017).

The review further notes, "*The N2-fixing (diazotrophic) bacteria include heterotrophic, phototrophic-sulfur, actinomycetes, proteobacteria, cyanobacteria and methanogenic species inhabiting soil, water, animal gut, and in association with plants in varied relationships ranging from colonization of the rhizosphere to complete symbioses.*" (Kaschuk, 2017).

Many leguminous plants, 90%, can form associations with nitrate-forming bacteria. Legume species are widespread and diverse, "*Numerous species belonging to the family Leguminosae are also abundant in natural ecosystems, such as the forests of tropical regions*". (Rascio, 2013).

However, whilst symbiotic diazotrophic plant associations, including rhizospheric, endophytic, and symbiotic nodule-formation, account for "*an estimated 60% of BNF in terrestrial ecosystems", "non-symbiotic diazotrophs in soils have also been shown to be important contributors to the N budgets in a number of ecosystems*" (Han, 2019).

Diazotrophs are disincentivised from producing nitrates, where supplied by other sources, including humans, and by the presence of oxygen; "***Fixation is shut off when other sources of nitrogen are available****, and, for many species, when oxygen is at high partial pressure."* Wikipedia lists a range of free-living and symbiotic diazotrophic bacteria of various sorts, including photosynthetic cyanobacteria (Wikipedia, 2024 a). (author's underline and bold)

In contrast to inorganic fertiliser, nitrogen-producing bacteria also provide other assistive synergistic biological services to improve soil and plant function and health, including "*genomic potential for several other plant-soil functions, such as phosphate solubilization and phytohormone production*," biological control, and "*synergistic diazotrophic bacteria and mycorrhizal symbioses*" (Kaschuk, 2017).

The review '*Plant Growth-Promoting Effects of Diazotrophs in the Rhizosphere*' highlights other symbiotic mechanisms, observing, "*Apart from fixing N2, diazotrophs can affect plant growth directly by the synthesis of phytohormones and vitamins, inhibition of plant ethylene synthesis, improved nutrient uptake, enhanced stress resistance, solubilization of inorganic phosphate and mineralization of organic phosphate*". (Dobbelairie, 2002)

Thus, given the opportunity and support, nature 'does it better' than human artifice. It synergistically enhances plant root and above-ground growth, increasing photosynthesis rates and consequential root sugar exudate production, improving soil biome growth and function. This will also cyclically benefit diazotrophs by, in turn, supporting their growth and multiplication in a virtuous feedforward cycle.

25. NITRATE POLLUTION BY FERTILISERS, SEWAGE SLUDGE, AND SLURRY

Excess-free nitrates in the land, water, and marine environment lead to environmental degradation and health issues for humans, livestock, and likely other species and contribute to global warming through atmospheric ammonia-derived nitrogen-related emissions. Nitrates also enter the human and livestock food chain, causing problems when present in excess and contaminating water supplies.

Dr Christine Jones, in '*Farming Profitably Within Environmental Limits*' (Jones, 2017), observes, "*Globally, over $100 billion of inorganic nitrogen fertilisers are applied to crops and pastures every year. Between 10% and 40% of the applied N is taken up by plants. Much of the remaining 60% to 90% is returned to the atmosphere as ammonia or nitrous oxide - or leached to aquatic ecosystems as nitrate.*" (Jones, 2017).

Sewage sludge and slurry disposal onto farmlands or through direct discharge into the environment significantly increase the environmental nitrate load from fertiliser-based runoff and atmospheric pollution.

The publication '*A review of emerging adsorbents for nitrate removal from water*' observes, "*Nitrate, due to its high water solubility, is possibly the most widespread groundwater contaminant in the world, imposing a serious threat to drinking water supplies and promoting eutrophication*", globally (Bhatnagar, 2011).

The review, '*Quality Unknown: The Invisible Water Crisis*', observes, "*Nitrates are the most common chemical contaminant found in groundwater aquifers. This is most evident in India, where…nitrate levels exceed permissible levels in more than 50 per cent of the districts spanning 19 states... In areas with hard rock aquifers, nitrate contamination is found at staggering depths of more than 350 metres, showing that even deep groundwater is not safe from contamination*" - '*Quality Unknown: The Invisible Water Crisis*' (Damania, 2019). For the avoidance of doubt, nitrate pollution is primarily a consequence of artificial fertiliser usage, and current sewage protocols.

25.1. NITRATES – SLUDGE, SLURRY, FERTILISER, EXCESS, RUN-OFF AND EUTROPHICATION

Environmental and health consequences of the excess exogenous supply of nitrates in fertiliser, sludge and slurry include:

- environmental damage; atmospheric warming; "*accumulation of NO2 and NO3*" - "*Nitrogen emissions (e.g., ammonia, nitrogen oxide, nitrous oxide) play an important role in global climate change and contribute to particulate matter and acid rain causing respiratory problems, cancers, and damage to forests and buildings. Nitrous oxide (N2O) is a potent greenhouse gas, over 300 times more effective in trapping heat than carbon dioxide, and remains in the atmosphere for ≈114 years*" (Imran, 2021);
- runoff leads to eutrophication of fresh and marine waters, including toxic blooms that negatively impact ecosystem life; a review reported, "*In spite of ascending efforts in eutrophication control, upward trends of algal blooms in both fresh and coastal waters have been observed for the past two decades*" (Gao & Zhang, 2010; Fumagalli, Perego & Acutis, 2013);
- the enormous amounts of sargassum seaweed blanketing Mexican beaches are likely a consequence of excess nitrate and phosphate runoff into the Gulf of Mexico and from the Amazon. Eventually, as blooms of organic matter decay, the breakdown of the excess algae causes the water to be starved of oxygen, as seen annually in the Gulf of Mexico, resulting in the death of other oxygen-dependent species and consequent environmental damage.

25.2. NITRIFICATION – WATER; FEEDSTOCK; FOOD - HEALTH CONSEQUENCES AND COSTS

Nitrates in rivers, irrigation water, and other sources pollute water supplies, including finding their way into groundwater and water storage aquifers. In addition to causing environmental damage, nitrification of water poses significant health issues globally, as set out in more detail below.

Nitrates and nitrites are also taken up by pastures and crops, including vegetables, and incorporated into livestock. They are present in derived products, such as animal and plant milk and upstream foods, and when present in excess, they can result in overconsumption and harm.

The review, '*Risk assessment of nitrate and nitrite in feed'*, observes, "*high-level consumers of vegetables grown under unfavourable local production conditions may exceed the ADI* (Acceptable Daily Intake) *approximately twofold."* (EFSA Panel on Contaminants in the Food Chain, 2020).

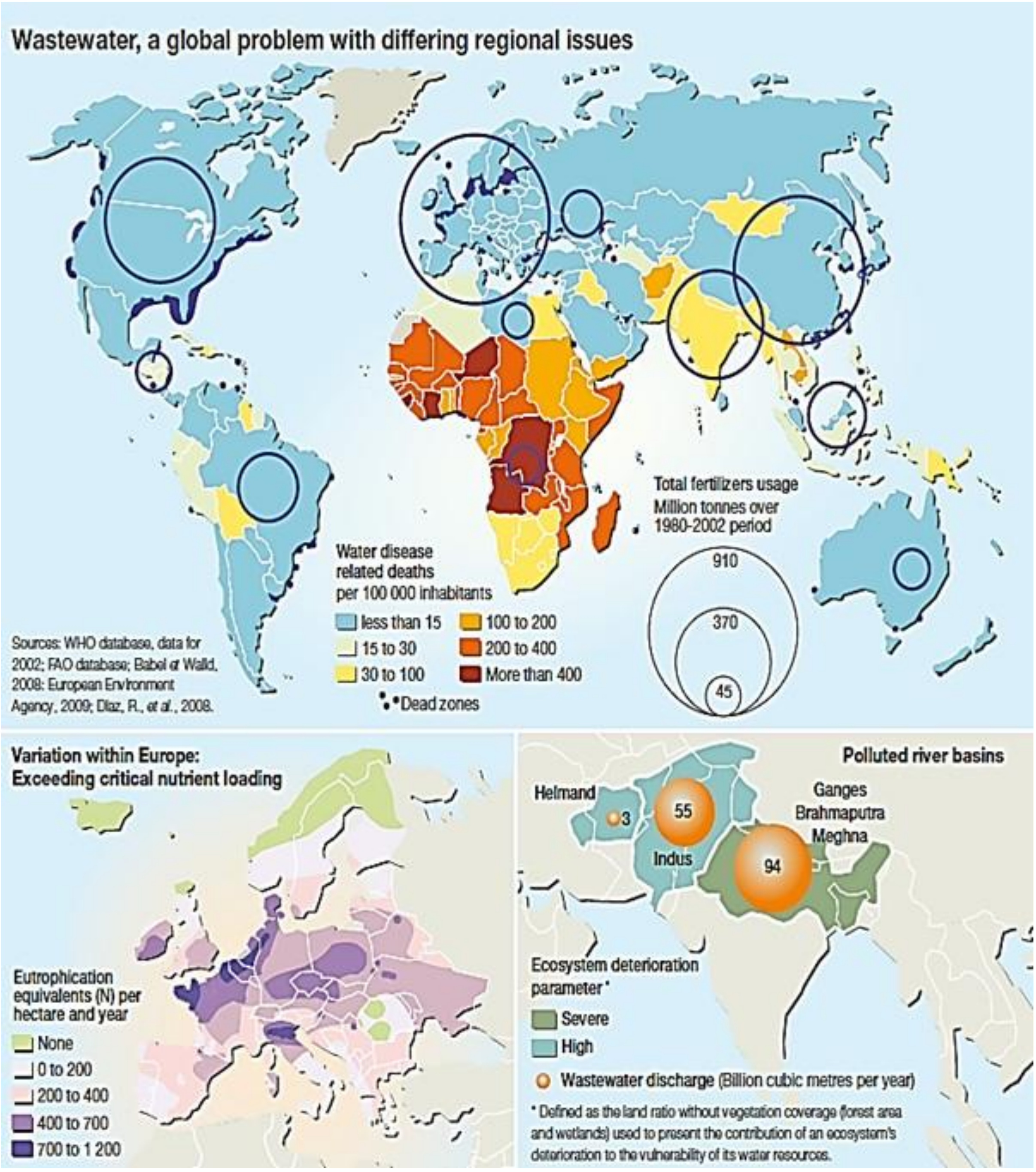
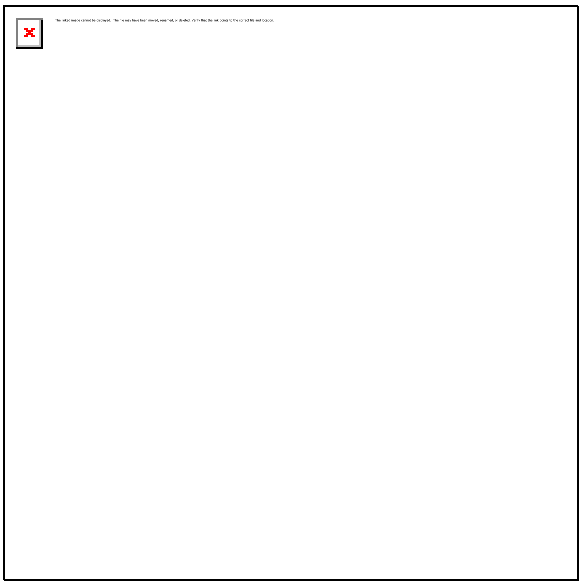


Fig. 59. '*Wastewater a global problem with differing regional issues*', with many thanks to the authors of '*Sick Water?*' and the UN (Corcoran, n.d.).



High levels of nitrates and nitrites have been found in both animal and plant-based milk products, including formula, as set out in '*Investigation into the Concentrations and Sources of Nitrates and Nitrites in Milk and Plant-Based Powders*'. (Genualdi, 2020).

Whilst gut biome-derived products of ingested nitrates have critical biological functions and are essential to health, excess intake of nitrates and nitrites has a mix of confirmed and suspected negative health consequences, including:

- excess nitrification, through pollution, of drinking water causes methemoglobinemia (blue baby syndrome) and other adverse health outcomes;
- The review, '*Dietary Nitrates, Nitrites, and Food Safety: Risks Versus Benefits*', reports, "*nitrates have been viewed negatively because they chemically form carcinogenic nitrosamines in acidic environments, e.g. stomach, purportedly leading to gastric cancer as well as neoplasia of the intestine, brain, pancreas, and contributing to Non-Hodgkin's lymphoma* (Martin, 2021);
- *other reports indicate associations with hyperthyroidism and diabetes mellitus* (Martin, 2021);
- excess nitrates may also increase risks of "*serious health concerns related to respiratory ailment, cardiac arrest, and several vector-borne diseases like malaria and cholera in cattle and humans*" (Imran, 2021);
- excess nitrates and nitrites in pasture and feedstock impact cattle health (Bhatnagar, 2011), may result in relatively rapid death, and likely impact other livestock, including horses;
- it is reported *that "several effects of nitrate and nitrite in farmed and companion animals, such as increase in oxidative stress, the depression of thyroid function and the decrease in blood pressure. The MoA (Mode of Action) underlying other effects (vitamins A and E depletion, abortion and effects on fertility) are still to be unravelled."* (EFSA Panel on Contaminants in the Food Chain, 2020). This highlights the ongoing need for research in this field.
- allergies, nitrates - "*may increase allergenic pollen production in plants*" (Imran, 2021)

25.3. NITRATES - PLANT AND SOIL BIOME FUNCTIONAL AND GROWTH INHIBITION

Biological consequences of the excess supply of nitrates on plants and the soil biome include:

- switching down the supply of plant carbon sugar exudate by plant roots to the soil biome;
- switching down soil biome production of nitrates by diazotrophs.
- plant growth disruption, including reduction of nutritional value - "*disrupts the growth and development of agronomic plants, especially affecting the phenolic, flavonoid, oil, and sugar contents in oil crops (Sesamum indicum) as well as antioxidant activity*" (Imran, 2021);
- increasing the metabolic rates of the soil biome;
- acceleration of decline in soil; carbon, life, metabolism, water retention and production capacity.

25.4. EXCRETA AND WIDER DOMESTIC ACTIVITIES AS A SOURCE OF NITRATES

At this point, it is worth considering how much nitrogen there is coursing through the average household daily and where it goes. For example, in a house with a private septic tank treatment system, "*A typical family of four using a conventional septic system can be expected to generate 20 to 50 pounds of nitrogen per year. Ten to thirty per cent of this nitrogen is trapped in the septic tank as part of the sludge/scum accumulation in the tank. The nitrogen remaining in the liquid waste is transformed to nitrate when the wastewater leaves the anaerobic conditions of the septic tank and percolates through the aerobic environment of the soil portions of the drainfield*" (Nitrogen reducing Technologies for Onsite Wastewater Treatment Systems, 2005).

These statistics, albeit estimates, and for a septic tank system, again emphasise the importance of proper remediation of human and livestock faeces and urine and their return to the land to close the circle of 'agriculture – food – excreta – soil' in a more environmentally sustainable way.

25.5. WATER DENITRIFICATION DIFFICULTIES AND COSTS

The scope of the nitrate problem, due to leaching into the environment, primarily from fertilisers, slurries and sewage, is highlighted by the impact of nitrates on groundwater, including in countries with more developed economies and extensive sewage infrastructure, such as the UK, where; "*Groundwater is a major source of drinking water supply and nearly 30% of groundwater used for that purpose in England must now be blended, treated, or replaced in order to meet tap water nitrate standards*" (Environment Agency, 2019).

Even where sewage is treated, nitrates remain in the sewage discharge water and sludge. "*Conventional primary and secondary treatment at sewage works removes 20-30% of the nitrogen in raw sewage*" (Environment Agency, 2019).

Natural systems are complex, and nitrate leaching does not happen instantaneously. Despite efforts to reduce nitrates in the environment, the problem appears to have been growing. For example, in the UK, "from 1945 to 1996, the average nitrate trend for 13 of the major aquifers was an increase of 0.4 mg/l/yr" (Environment Agency, 2019). This complexity underscores the need for comprehensive and long-term solutions.

Techniques for removal of nitrates from wastewater before discharge, as set out in *'A review of emerging adsorbents for nitrate removal from water'*, include "*chemical denitrification using zero-valent iron (Fe0), zero-valent magnesium (Mg0), ion exchange (IX), reverse osmosis (RO), electrodialysis (ED), catalytic denitrification and biological denitrification.*" (Bhatnagar, 2011). Each technique has its advantages and disadvantages.

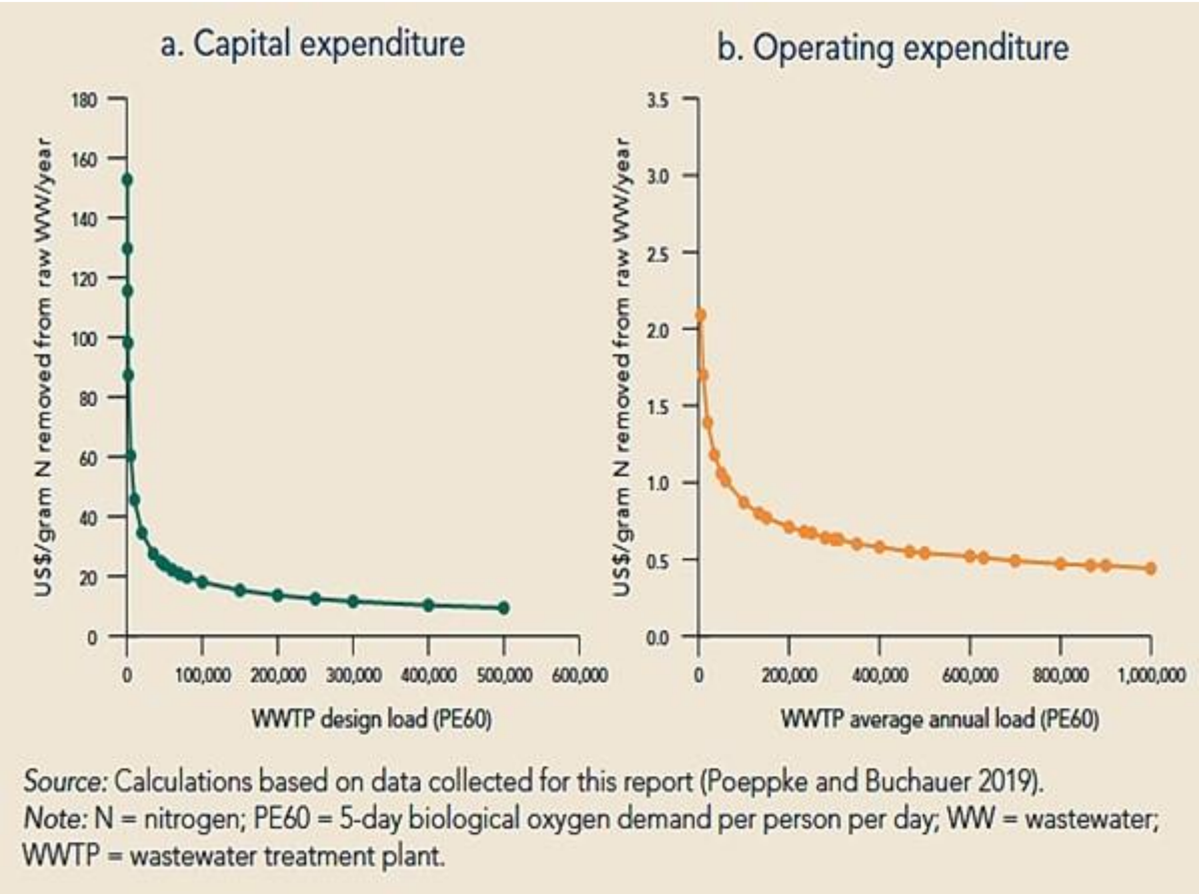


Fig. 60, "*Global average costs of treating wastewater*" from The World Bank report '*Quality Unknown: The Invisible Water Crisis' chapter 6 'Polices to tame a wicked problem*' (Damania ., 2019)

Some processes whilst removing pollutants, including nitrates from the main water steam, transfer them to a secondary concentrated wastewater stream. "*these traditional technologies do not solve the problem related to the excess of NO3− in the environment; i. . . they generate NO3− concentrated waste streams that pose a disposal problem due to the high saline content . . . creating downstream issues*" (Bhatnagar, 2011).

Denitrification of sewage water before discharge is also expensive. The World Bank report '*Quality Unknown: The Invisible Water Crisis*' (Damania, 2019) brings together global data on the cost of wastewater treatment plant operation (expressed in terms of the cost of denitrification), which ranged between US$ 18.06 and US$ 34.55, per gram of nitrogen (Box 6.4 page 100 - Damania, 2019), which is sobering given the above data, suggests that the average western family may generate approximately 9 – 23 kilos of nitrates in sewage a year.

Figures are difficult to assess, but there is a standard view that nitrate removal is expensive. For example, the UK Environment Agency report, titled, '*2021 River Basin Management Plan*', observed, "*A new nitrate removal plant for groundwater can cost some £8m for example, with annual running costs of some £250k*." (Environment Agency. 2019)

The authors acknowledge that data is sparse and uncertainties are significant but point out that the capital component is the most crucial part and, thus, needs to be factored into comparative costing. Further, nitrogen recovery technologies, including aerobic/anaerobic cycling, are still relatively new and variable in efficiency (Irvine, n.d.; Nourmohammadi, 2013).

Whilst there are considerable uncertainties, prevention clearly would be much cheaper than water nitrate removal. It would be better in health and environmental terms, to keep nitrates out of the rivers, lakes, aquifers, and oceans, in the first place, by collection of faeces and urine at the source, hyperthermophilic, anaerobic digestion for energy, and then hyperthermophilic composting, thus abstracting energy, and further mineralising nitrogen for return to soils, at the same time providing biologically rich compost, supporting regenerative soil-centric-farming, hence optimising the potential of mycorrhiza, supported by multispecies cover crops, in meeting the nitrogen needs of plants, without the need for artificial fertilisers.

26. PHOSPHATES BIOLOGY IN PLANTS AND SOIL

Phosphorus is central to many biological processes, including energy production. It is obligatory for adequate plant growth and yield and is key to nitrogen fixation. It is a component of core molecules such as "nucleic acids, ATP and phospholipids" (Campos, 2018). Alongside calcium and other minerals, phosphorus is essential in producing skeletal bone in humans and livestock.

While plants positively concentrate phosphorus, and as a result, the most abundant macronutrient in biomass after nitrogen, phosphorus is one of the scarcest elements of all in the lithosphere (crust and upper mantle - 0.1 per cent of the total). Consequentially, absent the assistance of the soil biome, plant roots have limited access to phosphorous, which is compounded by the limited physical 'reach' of their roots. (Campos, 2018).

The review '*Phosphorous Acquisition Efficiency Related to Root Traits: Is Mycorrhizal Symbiosis a Key Factor to Wheat and Barley Cropping?*' notes, "*P* (Phosphorous) *has a low availability and poor mobility in the soil, being one of the most inaccessible elements for plants. Concentrations of available P in the soil solution are extremely low, being generally lower than 10 µM, whereas in wheat leaves and stems concentrations of over 100 µM can be achieved. Therefore, as plants normally take up P faster than it is supplied by diffusion a depletion zone around the root system is quickly created, inducing P deprivation.*" This is why, absent a healthy soil biome, artificial fertilisers are needed because they provide high concentrations of phosphates in soluble form around plant roots. (Campos, 2018). On the positive side, the low mobility of insoluble phosphates means soils will tend to retain the limited phosphorus they contain.

As discussed above and in Volume 2, mycorrhizal systems are crucial to our biosphere. They are highly efficient at mining phosphorus and delivering it directly to plant roots in exchange for photosynthetic carbon sugar exudates made from carbon dioxide and powered by sunshine. Thus, plants can be healthy even in soils containing very low phosphate levels, provided the soils are rich and diverse in biology. It is worth remembering that for billions of years, plant systems flourished without human application of fertiliser.

26.1. ARTIFICIAL FERTILISER MISDIRECTION – TREATMENT SYMPTOM NOT CAUSE

As discussed in Volume 2, life is predominantly composed of carbon and water, uses carbon for energy, and respires water. Thus, the amount of carbon and water in the soils strongly indicates the levels of soil life, including bacteria and mycorrhiza, and soil water holding capacity.

Of crucial importance, soil biome life lives in the dark and thus has no energy source other than green-growing plant-produced photosynthetic root exudate sugars. Thus, to exist, the soil biome must have photosynthesising plants above and be in symbiotic contact with them.

Reciprocally, the soil biome partners and symbiotes, plants, cannot flourish without a supply of nitrates and minerals, including phosphates and water supplies during dry spells. Thus, in a survival quid pro quo, the soil biome, which needs root sugar exudates to stay alive, is strongly motivated to keep the plants above it alive by supplying the necessary nitrates and minerals, metabolic water in drought, and other services.

Too often, modern farming has treated the symptom rather than the cause, treating plant root-accessible soluble nitrogen and phosphate deficiency with fertiliser instead of creating healthier soils rich in carbon-based organic matter that better retain and respire water and promote plant growth, including through bacterially produced nitrates and mined minerals supplied by the soil biome systems to plants via their roots.

The advent of artificial fertilisers invited us, once soils were depleted of soil life and carbon, to douse the earth with even more NPK fertiliser to shore up the yield of the next harvest; a vicious cycle was set in motion, driving ever-downward, soil quality, soil life, water, carbon content, and fertility; chipping away at harvest yields, over time demanding ever-increasing fertiliser and agrochemical application to try and maintain yields, yet perversely instead, research suggests, driving downward spirals of declines, in soil quality, soil life, water, carbon and fertility, while at the same time increasing atmospheric carbon dioxide.

Importantly, and not to be forgotten, many of the world's farmers do not have enough purchasing power to afford phosphorus-based fertiliser, which means FATBAS farming is no longer economically productive for them. In addition, increasing demand and ultimately limited supply will likely raise fertiliser costs.

26.2. ROCK PHOSPHATES USAGES

In addition to being used for agriculture, phosphate has several other uses. These include detergents, lithium batteries, as well as; "*orthophosphate, pyrophosphate, and polyphosphate specialty products used in the dental market (toothpaste and other products), industrial and institutional cleaning products, oil drilling, mining, metal treatment, leather processing, construction, ceramics, and paints and coatings*." "*These phosphate additives provide many unique functions, such as abrasion, water softening, precipitation, pH buffering, rheology control, surface wetting, pigment dispersion, retardation, cure, corrosion resistance, fire protection, adhesion, and pigment suspension, as well as eliminating foam and stabilizing silicate-based paint formulations.*" (What is phosphate, 2022)
Natural minable stocks of rock phosphate—the primary source of phosphorus—are set to become increasingly scarce. Thus, not using them where they are not needed in agriculture will significantly extend the life of phosphate mines.

26.3. ROCK PHOSPHATES – LOW AVAILABILITY OF SOURCES

It is widely accepted that long-term phosphate supplies are limited, given the current industrial and agricultural demand levels. The only matters for debate are the degree and timescales of depletion, although uncertainties exist regarding future global supply sources.

Geologist Steven J Van Kauwenbergh - principal scientist behind the 2010 review, '*World Phosphate Rock Reserves and Resources: an extensive examination of the issue*' - states: "*There is limited current information on world phosphate rock reserves and resources available in the conventional scientific literature. Some information can be found on websites, in trade magazines, papers presented at conferences and in papers or reports that have limited distribution.*" (Kauwenbergh, 2010)

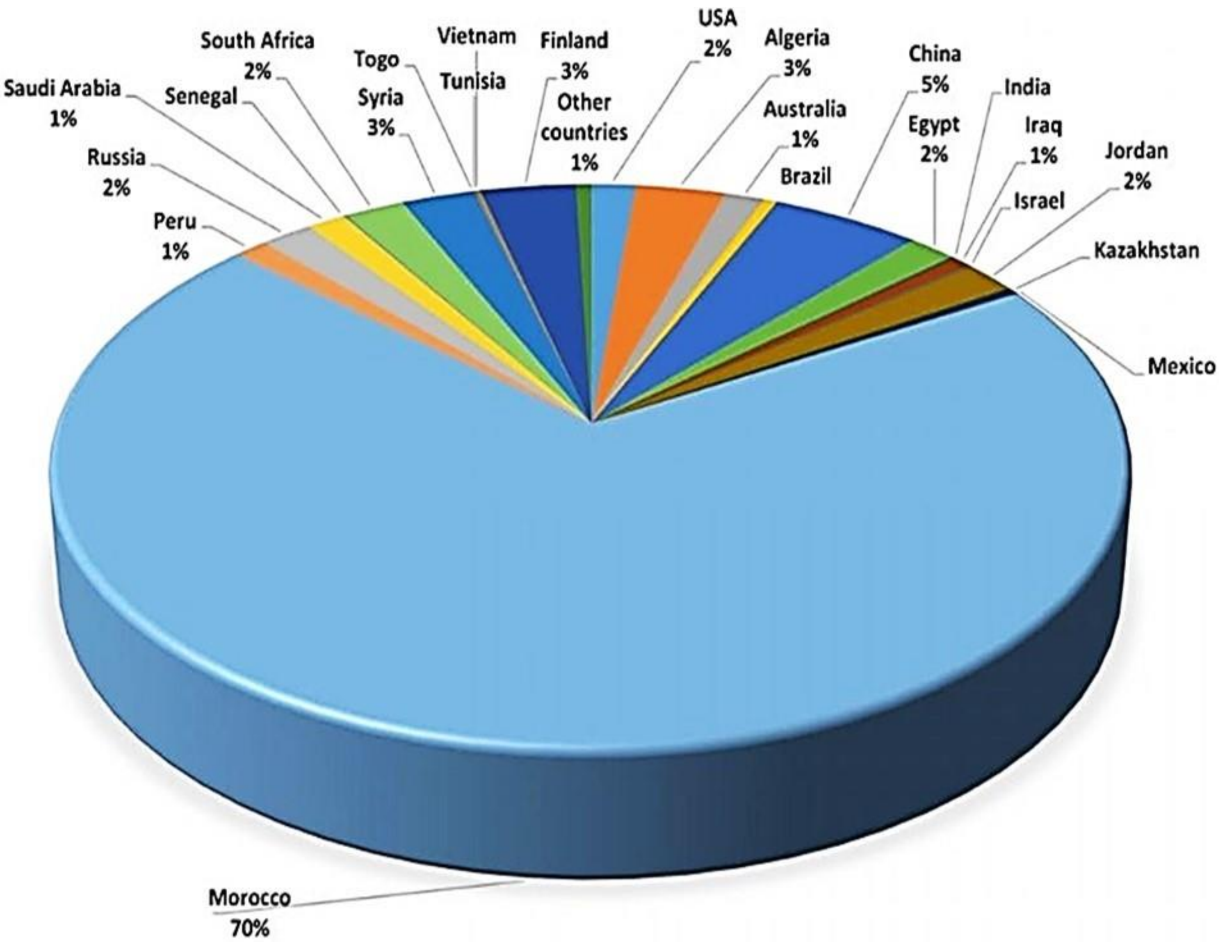


Fig. 61. Global distribution of rock phosphate reserves – indicational only – with thanks to the author ('Global Distribution of Phosphate Rock Reserves: Morocco', n.d.) and Wikimedia.

There is, however, consensus that the significant deposits are "*concentrated in a handful of countries, notably Morocco and China*", as observed in the report, '*The future distribution and production of global phosphate rock reserves resources, conservation and recycling*' (Cooper. 2017), there is a real risk of rock phosphate resource depletion in the not-too-distant future. *"[Around] 70 per cent of global production is currently produced from reserves which will be depleted within 100 years and combining this with increasing demand will result in a significant global production deficit, which by 2070 will be larger than current production. Morocco, with nearly 77 per cent of global reserves, will need to increase production by around 700 per cent by 2075 in order to meet most of this deficit. If this is possible, Morocco will obtain a much greater share of worldwide production, from around 15 per cent in 2010 to around 80 per cent by 2100, which implies more control over market prices*" (Cooper. 2017). Global demand continues to rise - particularly in China and India - despite dipping in Europe.

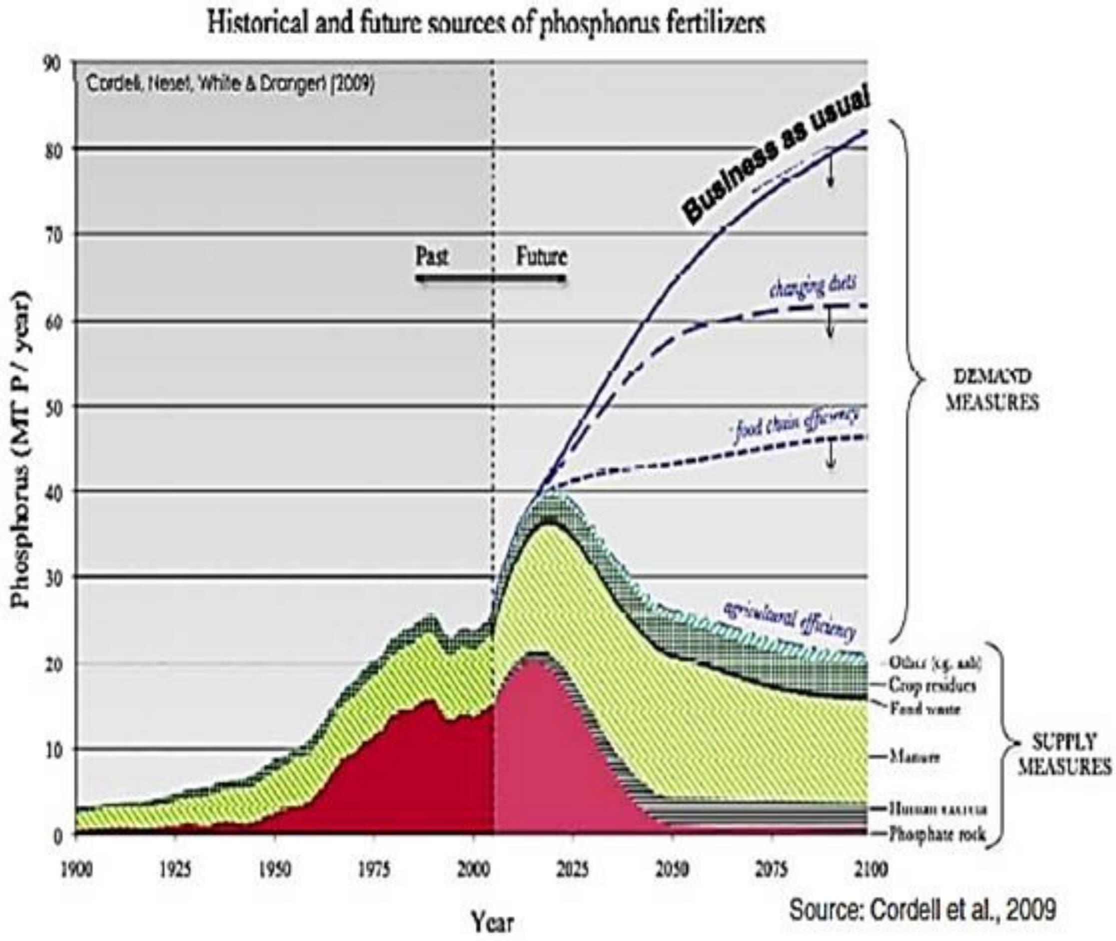


Fig. 62. '*Actual (1900 – 2010) and anticipated global demand and supply of phosphorus, from 'Phosphorus – a Limited Resource that could be made Limitless*' with many thanks to the author (Drangert, 2012) and ResearchGate.

However, shortages could manifest even earlier, "*As a non-renewable resource, rock phosphate, as well as other non-renewable resources such as oil and coal, is expected to become scarce near the 2030s, or more optimistically within two to three centuries. The market and countries are already responding to this scenario, which is reflected in the fact that both USA and China (the biggest P producer in the world) have stopped exporting this resource"* (Campos, 2018). "P*atchy geographic distribution and early signs of resource scarcity have begun to produce socio-political complexities*" (Childers D, 2011).

Further and ironically, a substantial portion of the phosphate mined is wasted by various mechanisms. *"Each year 220 million tonnes of phosphate rocks are mined, but only a negligible amount makes it back into the soil. Crops are transported to cities and the waste is not returned to the fields but to the sewage system, which mainly ends up in the sea. A cycle has become a linear process."* It adds, *"We could reinvent a modern phosphorus cycle simply by dramatically reducing our consumption. After all, less than a third of the phosphorus in fertilisers is actually taken up by plants; the rest accumulates in the soil or is washed away."*

(Faradji, 2012) The Sargassum seaweed inundations are an effect of the leaching of phosphates and nitrates, including from fertilisers, into rivers and eventually the sea.

Moving away from FATBAS agricultural systems to regenerative agriculture would substantially reduce the need for phosphate fertilisers, resulting in considerably lower long-term demand, thus maximising future reserves (Ren, 1989).

Conversely, failure to move to regenerative agriculture could exacerbate climate change issues and magnify food shortage risks. '*How the great phosphorus shortage could leave us all hungry'* observes: *"These days, the cycle is broken" (Faradji & de Boer, 2012).*

26.4. PHOSPHATE FERTILISER – ENERGY AND RESOURCE-DEMANDING

The mining of rock phosphates is not a clean process; it is energy-intensive and produces significant amounts of waste, "*to generate 1 metric ton (MT) of phosphoric acid* [the main phosphatic ingredient of NPK fertiliser]*, the wet acid process requires more than 3 MT of phosphate rock, 1.4 MT of sulfuric acid, and 11 cubic metres of water, and produces 5.4 MT of phosphogypsum as a by-product"* (Childers 2011). *"The process also requires substantial inputs of fossil-fuel energy (as does the mining process itself)*" (Childers, 2011). Energy is a significant cost component. Thus, phosphorus extraction from rock phosphate creates environmental issues and, crucially, cumulatively adds to the pollution of soils by heavy metals, fluorides, perchlorates and radioactive materials.

26.5. FERTILISER PHOSPHATE INCORPORATED AS INSOLUBLE PHOSPHATE IN SOILS

Somewhere between 35 and 75 per cent of phosphorus in manure, compost, and artificial fertiliser phosphate are annually applied and become bound in the soils. The commentary piece, '*How the great phosphorus shortage could leave us all hungry*', reveals: *"Less than a third of the phosphorus in fertilisers is actually taken up by plants; the rest accumulates in the soil or is washed away. To take one example, in the Netherlands there is enough phosphorus in the soil today to supply the country with fertiliser for the next 40 years."* (Faradji & de Boer, 2012)

Thus, insoluble soil stored historic human-supplied phosphate may factor in the good yields being enjoyed by numerous farmers using regenerative agriculture techniques—such as multispecies cover crops and no-till—where mycorrhiza flourish and abstract bound phosphate supplies soluble phosphate to plants in return for plant sugars (processes explored in greater depth in Volume 2 on regenerative agriculture).

Only in the long term, following the introduction of regenerative agriculture, which does not currently require phosphate application to soils, will we know what effect soil-stored historic phosphate fertiliser application has on yields and better understand to what extent natural weathering, including volcanic dust deposition and the breakdown of underlying rocks, replenishes phosphates in soils sufficiently to meet agricultural requirements.

26.6. EXCRETA AS A SOURCE OF PHOSPHORUS – CLOSING THE CIRCLE

The review, '*Global potential of phosphorus recovery from human urine and faeces*', observes: "*The phosphorus available from urine is approximately 1.68 million metric tons (with similar mass available from faeces). If collected, [this] could account for 22 per cent of the total global phosphorus demand*" (Mihelcic, 2011), which is thought-provoking.

A study of Swedish discharges into the Baltic Sea notes: "*The nutrient content, before losses, in urine and faeces excreted by the Swedish population corresponds to 28 per cent of the total nitrogen and 44 per cent of the total phosphorus in chemical fertilisers sold in Sweden 2010/11*" (Spångberg, 2014).

Substance flow	Estimated recoverable phosphorous, expressed in tons per year
Municipal sewage	*54,000
Industrial sewage	15,000
Municipal sewage sludge	*50,000
Sewage sludge ash	*66,000
Manure	444,000
Animal byproducts: (classes 1 through 3, excluding animal fat) (up to 6 % phosphorous)	20,000
Estimated phosphorous demand in Germany	170.000

* These potentials do not lend themselves to tallying, as they represent various competing recovery paths within the sewage treatment cycle.

Fig. 63. Estimated phosphorus recycling potential for various substance flows in Germany, taken from '*Sewage Sludge Management in Germany*' (Wiechmann, 2013), with many thanks to the Authors and Umweltbundesamt (German EPA)

Some countries import vast amounts of grain for livestock feed. The minerals, including phosphates in their feed, will end up in animals, humans, urine, and faeces. If net importers and consumers of crops, for human and livestock consumption, composted and returned, all human and livestock excreta to the land in the importing country, an overload of minerals could build up – with an inevitable deficit elsewhere in the world, exacerbating supply imbalances.

Consistent with this, the review, '*Phosphorus in agriculture Problems and solutions*', observes, "*Global studies of phosphorus imbalances found that phosphorus deficits covered 29 per cent of the global cropland area and 71 per cent had overall phosphorus surpluses*" (Tirado & Allsopp, 2012).

The report, '*Sewage Sludge Management in Germany'*, provides an example of a national phosphate imbalance. The report calculated that 170,000 tons of phosphate are required annually by the agricultural industry in Germany – yet 649,000 tons are potentially available from human and livestock, urine and faeces, 444,000 tons of it (68 per cent) from manure (Wiechmann, 2013), an indication of the size of the import-export imbalances of phosphates, including in imported crop-based animal feedstock and raising the issue as to how, long-term, such trade import/export, phosphate imbalances, should be addressed.

Whilst great care would need to be taken in creating standards for pollutant and pathogen content, the phosphorus, nitrates, and wider minerals in sewage and slurry, once incorporated in compost, could and should become the basis of a viable export industry.

27. PHOSPHATE POLLUTION - HEAVY METALS, RADIOACTIVE ISOTOPES, PERCHLORATES

Fertiliser is not free of pollutants. Phosphate-based fertilisers may contain variable traces of heavy metals and or radioactive elements that remain after processing and are applied to and incorporated into soils, leading to "*accumulation of heavy metals (e.g., lead, chromium, and cadmium), radionuclides, and carcinogenic compounds*", which then both, feed via soils through the food chain, and through run-off pollute waterways (Imran 2021).

For example, concerning heavy metals, the Greenpeace review, '*Phosphorus in agriculture: Problems and solutions*' states: "*In Western countries, 54 – 58 per cent of the cadmium found in the environment comes from the application of mineral phosphate fertilisers to agricultural land*", and cadmium "*may accumulate in arable soils as a result of the addition of rock phosphate"* (Tirado & Allsopp, 2012).

Uranium and polonium, and other pollutants commonly found in fertilisers, are taken up by the plants grown on soils so 'nourished'. The potential for uptake by tobacco of radioactive material is a particular concern because any radioactive material incorporated in cigarettes, electronic cigarettes, and vape smoke has very intimate and long-term contact with the lungs.

One review paper even suggests: "*Cigarette packs should carry a radiation-exposure warning label*" (Muggli, 2008). An article in the Journal of the Royal Society of Medicine added: "*Uranium has a very long half-life and will accumulate in the soil with repeated applications of fertiliser. As a result, modern cigarettes may contain higher levels of Po-210 than those measured 40 years ago. Smokers are killed by alpha-radiation, whatever its origin. Arguably, a significant part of this mortality is a result of Po-210 in tobacco*" ('*The big idea: polonium, radon and cigarettes*', (Tidd, 2008).
If present in tobacco, why should radio nucleotides not pose a degree of risk in edible plants, too, albeit long-term lung contact presents much more significant risks than the digestion of polonium mixed in food and subsequent rapid excretion? The hazard scale will depend on complex factors, including soil concentrations, the type of isotope and radiation emitted, the nature of foods consumed, and gut transit times. This area has had limited research (Khater & Al-Sewaidan, 2008). Still, logically, such factors should be part of the cost-benefit analysis of using compost as against artificial fertiliser.

Phosphor-gypsum, a by-product of fertiliser production, is also a concern because the production residue concentrates heavy metals and radioactive nucleotides, such as 226Ra, 210Pb, 238U, 232Th, and 40K, by a factor of up to 60 times (El-Didamony, 2012) (Sahu, 2014).

Manufacturing gypsum products for building materials requires the removal of such contaminants as far as possible, but long-term storage of the consequent waste can harm the environment (Paridaens, 2008). Phospho-gypsum is sometimes used to alkalise soils, which will inevitably add to agricultural land's heavy metal and radioactive content.

Fig. 64. Phosphogypsum stack located near Fort Meade, Florida, with many thanks to the (1.19 MB) MakeChooChooGoNow and Wikipedia.

Perchlorates are also present in fertilisers and pose significant pollution risks, "*Perchlorate salts are present in some naturally mined nitrate and phosphate fertilizers, particularly rock fertilizers from Chile*" (Oregon Department of Human Services, 2004); they are also found in rocket fuel. Given the widespread nature of perchlorate contamination across the USA (Pearson, 2005; Rice, 2007), rock-based fertiliser, rather than rocket fuel, is, on the balance of probabilities, the most significant source of land pollution in most areas. It is also found in road runoff, so it enters water supplies.

Perchlorate is applied to land in fertilisers, accumulates in plants, and can transfer up the food chain into cattle milk (Kirk, 2003; Shi, 2007) and breast milk. The paper '*Predicting Perchlorate Exposure in Milk from Concentrations in Dairy Feed*' observed: "*41.9 per cent of the perchlorate came from corn silage, 22.9 per cent came from alfalfa hay and 11.7 per cent was supplied by sudan grass*" (Rice, 2007). Perchlorate in food will also feed into faeces and urine and has, for example, been found in sewage sludge in China (Shi, 2007).

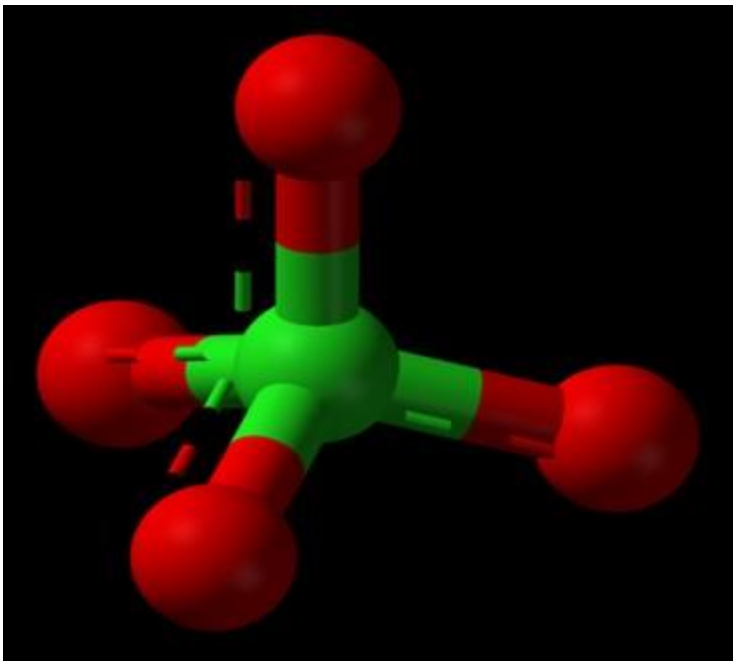


Fig. 65. Perchlorate, 3 oxygen, and 1 chlorine, use as rocket propellant when purified, sources include rock nitrate sources, with many thanks to Benjah-bmm27 and Wikipedia.

An article in Nature on perchlorate observes: "*Perchlorate, a toxic chemical in rocket fuel, is contaminating breast and dairy milk across the United States at levels that could harm human health. This situation may be mirrored elsewhere in the world, say researchers. They recommend increasing people's daily intake of iodine to combat the effects of the toxin*" (Pearson, 2005). Perchlorates may negatively impact iodide uptake by the thyroid and thus may amplify the health effects of low iodine and high fluoride intakes.

As discussed, perchlorate may negatively impact iodine metabolism. Low iodine negatively impacts neurological development. Perchlorate, like other pollutants, has been associated with impaired brain development. "*Babies are thought to be at particular risk from the chemical. Perchlorate in high doses can cause mental retardation in foetuses and young children by interfering with production of the necessary thyroid hormones*" (Pearson, 2005). There is very little data on the combined risk of pollutants.

27.1. PHOSPHATE EUTROPHICATION

Phosphate is present in fertilisers, sewage, and slurries, and release into the environment is a factor in eutrophication in waterways and oceans. Impacts include blooms of Sargasso seaweed. Algal blooms can cause significantly wider environmental damage, such as anoxia, which results in regional die-offs, including in life on the ocean floor, and promotion of other species that cope better in low oxygen environments, such as jellyfish. Long-term regional ocean anoxia can facilitate takeover and domination by jellyfish of marine habitats not previously occupied by jellyfish, with significant adverse environmental consequences.

28. LIVESTOCK MANURE AND SLURRY

The global quantities of faeces produced annually by livestock are enormous, several billion tons, many times the amount produced by humans. In more industrialised countries, a good part of this slurry is excreted in confined production systems and includes significant amounts of antibiotics and heavy metals from feedstock.

Importantly, confined stock rearing is becoming more common globally. The increased use of CAFOs (confined animal feeding operations) heightens the need for mechanisms for the safe processing and return of the nutrients in livestock faeces and urine to the land and minimising the impact of pharmaceuticals, heavy metals, and other pollutants.

Self-evidently, a better option is to, as far as possible, exclude pharmaceuticals, heavy metals, and other pollutants from livestock urine and faeces waste streams in the first place, including through improved animal management and nutrition. In addition, we should be adopting rotational regenerative grazing and recovering and regreening marginal agricultural landscapes, improving watersheds, as well as giving livestock a better quality of life, and at the same time, eat less and ensure that we adopt a nose-to-tail principle, making better use of those livestock we choose to rear.

Where livestock are raised in ways that concentrate their urine and faces in selected locations, in addition to reducing the pollutants in the resultant slurry as above, we should adopt hyperthermophilic biogas production from them, followed by hyperthermophilic compost production for return to the land.

28.1. METHANE – CLIMATE GAS - CATTLE SLURRY AND WIDER SOURCES

Methane is produced by the action of bacteria methanogens on organic matter. Methane is both a climate change gas and a significant potential fuel source. Methane gas, for energy, is obtained from historic methane deposits found in natural gas fields and by anaerobic digestion.

Methane is a climate-warming gas. Atmospheric methane levels are increasing (NOAA, 2024). The StanfordReport states, "*Atmospheric concentrations of methane are now more than 2.6 times higher than in pre-industrial times – the highest they've been in at least 800,000 years.*" (StanfordReport, 2024)

Rising atmospheric methane is likely a factor in a year-on-year rise in global air temperatures. Methane from feedlot ruminant production contributes to rising atmospheric methane. Feedlot ruminant and other livestock production is more resource-intensive than plant foods and rotationally grazed livestock. Vegetarians hold passionate views. However, the topic is much more complex than generally acknowledged.

Decay of organic matter in anoxic environments that favour methanogens (bacterial methane producers), including thawing permafrost and wetlands, rice field soils, slurry pits and manure management (9%), and landfills (16%), releases methane. Other sources of methane are methanogens in ruminant digestive systems, predominately cattle (25%), and petroleum and gas industry flaring of historically accumulated methane stored in rock strata(28%). The figures are estimated USA methane emissions (EPA. n.d. Overview of Greenhouse Gases). Figures vary significantly globally and, hence, are only given as indicative.

The global atmospheric methane cycle is not yet fully understood. For example, seasonal variations differ in unexpected ways between the northern and southern hemispheres, with falls in the summer in the northern hemisphere (East, 2924; NOAA, 2024). Methanotrophs (bacterial methane consumers) consume methane mainly in oxic environments and, at the same time, contribute to soil carbon. They also regulate atmospheric methane. Does seasonal plant growth, related increased soil biome activity, and the presence of methanotrophs in soils play a part in those variations?

Very early research suggests that soils rich in biological diversity and good condition contain more active methanotrophs and thus contribute more efficiently to methane removal from the atmosphere and related carbon sequestration in soils.

Using regenerative agricultural principles, including rotational grazing, creates soils with more methanotroph activity (Lim, 2024). However, it is unknown how regenerative agriculture-related rotational grazing-related net global methane emissions, after accounting for the methanotroph reductions consequent of the soil-enhancing activity of rotationally grazed ruminants, would compare to feedlot ruminants.

Increased methanotrophic activity also appears to have positive effects on crop health efficiency and productivity; a study titled, '*Exploring the Potential of Methanotrophs for Plant Growth Promotion in Rice Agriculture*', applying a variety of methanotroph species to rice crops, observes "*Nine out of twelve (seven single* (methanotroph) *strains and two consortia) showed positive effects on grain yield (6–38%) . . . In all the pot experiments, minimal quantities of nitrogen fertilizer were used with no additional organic fertilizer inputs. The present study demonstrated the possibility of developing methanotrophs as bio-inoculants for rice agriculture*" (Mohite, 2023). Traditional rice production is a significant methane source.

Very little work has been done on this topic. However, given the billions of hectares under cultivation, even minor improvements in soil methane drawdown and metabolism could have a significant impact. We urgently need more research into the impact and potential of methanotrophs in agriculture and the role of methanotrophs in agricultural soils in helping to regulate global atmospheric methane levels.

28.2. METHANE – RUMINANT PRODUCTION – FEEDSTOCK TYPE – FEEDSTOCK ADDITIVES INCLUDING SEAWEED – BACTERIA - GENES

Ruminant digestive systems produce significant methane (Smith, P. 2022). Estimating how the volume of methane produced by cattle in feed lots compares with preindustrial emissions by wild ruminant herds is difficult, as is estimating the amount of methane emitted by natural diets compared to a feedstock grass/grain-based diet.

However, a review titled 'Methane efflux from an American bison herd' observed, "*Enteric CH4 emissions from wild ruminants in the United States in the pre-settlement period comprised nearly 90 % of current CH4*" (Story 2021). Thus, whilst self-evidently ruminants emit methane, it is less clear to what extent farmed livestock are responsible for recent rises in atmospheric methane. This is not to suggest we should not try to minimise those methane emissions; it is just that the actuality is more complex than is often portrayed, and it is essential to ensure that strategies to reduce methane are fairly accurately and comprehensively targeted at the sources and sinks and that scapegoating is avoided.

Numerous factors, including genetics, feedstock type and quality, and lipid content, alter the quantity of methane produced. The review '*Methane sources, quantification, and mitigation in grazing beef systems*' observes, "*Due to the myriad of factors influencing enteric CH4 production, energy losses in the form of CH4 can range from 2 to 12% of GE intake.*"{Thompson, 2020).

Dietary supplements for cattle that inhibit enteric methane production have been developed, including chemical and natural products. Interestingly, seaweeds appear to reduce enteric methane production; for example, "*Red seaweeds from the Asparagopsis genus, which contain the compound bromoform, have been shown to reduce methane production in cattle by up to 97% when they make up around 1% of a cow's diet.*" (Swift, 2024). Seaweed also contains a range of nutrients and microminerals, including importantly iodine, that could potentially improve cattle health and milk quality, subjects for further research.

Of nutritional relevance, North Ronaldsay sheep in the Orkney Islands subsist almost entirely on seaweed, quickly adapting to a seaweed diet. Free-ranging cattle on the Scottish Isles also choose seaweed from beaches as part of their diet (Aiken, 2018).

In relation to biogas production, methane inhibitors in cattle feed do not appear to significantly impact the capacity to compost their slurry (Owens, 2020) or soil health (Owens, 2021). I have found no data on methane production by biodigestion using slurry from cattle fed with methane inhibitors, which is an important question.

28.3. RUMINANT NUMBERS PRE-HUMAN INTERVENTION

Ruminants are a source of methane. For hundreds of thousands of years, before human proliferation and the development of agriculture, there were vast herds of ruminants of immense variety and innumerable small creatures, all of necessity flatulently defecating regularly, yet the climate was 'stable'.

Does this not suggest that human ruminant management, rather than the ruminants, is the problem? Of course, we should seek to reduce methane emissions, but those decisions must be rationally and factually driven.

Unlike 'stockyard' livestock, wild ruminant herds spread their urine faeces and slimes widely in an environment where there was an extensive chain of soil-biome life forms, including dung beetles (Holter, 2016), and worms, '*ecosystem engineers*' (Boze, 2012), that one way or another; process, transport and spread, and incorporate, aerating and fertilising, vast tonnages of urine and faeces, thus recycling them into the soil-biome, in ways that support, rather than degrade, evolved ecosystems, therefore improving soils. At the same time, they save farmers considerable expenses, such as tillage, spreading, transport, equipment, related labour, and fuel costs.

As discussed, the distribution of urine and faeces by range-pastured livestock using regenerative agricultural livestock management principles, including rotational grazing, where pharmaceuticals, deworming agents, and mineral blocks are more rarely used, is environmentally beneficial because it helps mimic natural cycles and reduce pollutants.

28.4. LIVESTOCK AND HUMAN URINE AND FAECES ARE FUNDAMENTALLY SIMILAR

It would be easy to consider animal manure as a separate issue from human urine and faeces. However, whilst volumes and textures differ, both are composed of faeces and urine and contain indigestible organic matter, bacteria and viruses, nitrates, phosphates and wider minerals, and a range of introduced pollutants.

Ultimately, whilst differently constituted, feedlot livestock and human manure have broadly similar properties and treatment requirements. Thus, the same range of treatment options, including hyperthermophilic anaerobic digestion and hyperthermophilic aerobic composting, are relevant to both.

In terms of treatment options, the main differences between agricultural feedlot and human waste are:

- agricultural urine and faeces are not mixed in with other waste streams, thus contain a narrower range of pollutants;
- shovels, diggers, tractors, and pumps, rather than flush and forget, are used to transport animal-feedlot waste;
- It has long been perceived that agricultural manure and slurry can be safely put back on agricultural land untreated, but with the advent of nitrate and phosphate excesses in the environment, pharmaceuticals, antibiotics, and heavy metals in feed and fertilisers, that is no longer the case. Furthermore, we now better understand the function of the soil biome.

28.5. MANURE AS A SOURCE OF SOIL NUTRIENTS

The review, '*Global Assessment of Manure Management Policies and Practices*', notes that a substantial portion of nutrients in animal feed is excreted; "***Between 60 per cent and 95 per cent of the animal's nutrient intake via feed is excreted via dung and urine containing undigested carbon and nutrients***" (Teenstra, 2014). Thus, animal manure is a significant potential carbon source for biogas production and soil nutrients, including N, P and K (Pozdnyakova, 2012).

Appropriately applied, as happens with migratory herbivores in the natural environment with biologically rich soils or with regenerative rotationally grazed livestock, where mineral supplement and pharmaceutical, including worming agent, usage is minimal, "*manure is a valuable source of nutrients, organic matter . . . naturally improving fertility"* (Teenstra, 2014).

However, stockyard manure from cattle given pharmaceuticals, restricted diets, and rock phosphate-derived mineral blocks, when applied as a concentrated slurry at a single point in time, pollutes soils and the wider environment, both by direct accumulation and runoff into rivers, lakes, and oceans.

We need to improve the environmental value of slurry as far as possible by

- improving cattle health, thus diminishing the need for pharmaceuticals;
- reducing heavy metal-containing mineral-block usage;
- reducing the use of artificial fertiliser and sewage sludge on land;
- implementing regenerative agriculture, including rotational grazing;
- using the resultant slurry for hyperthermophilic, biogas and compost production, further reducing the pharmaceutical and antibiotic burden, creating a product that can be returned to land for reclamation, or possibly pasture, depending on the residual pollutant profile.
- Compost would not be free of pollutants, but biodiverse soils would provide further remediation, and it would be a much better solution than current slurry collection and disposal.

In a cycle of benefits, besides providing better-quality slurry, these actions will improve feedstock quality, reduce pollutants and improve livestock health, generate green energy and usable compost, help close the environmental loop, and provide additional income streams.

28.6. QUANTITIES OF LIVESTOCK FAECES AND URINE

The amount of animal manure produced on pastures and feed lots globally is enormous. In the USA, "*The majority of meat and animal products in the United States are produced by large confined animal feeding operations (CAFOs), where livestock and poultry annually generate a substantial quantity of manure*" (He, 2014). In the USA, it is estimated that more than a billion tonnes of manure is produced annually, including approximately 87 million cattle and 500 million poultry in 2023.

Yes, such figures change over time and will differ between sources. These figures are now outdated, as this book has been written over several years, but the point of their inclusion is that amounts are unquestionably large, and the issues are global; for example, in the USA, a review reported," *in 2012, livestock and poultry on the largest concentrated animal feeding operations produced 369 million tons of manure: this was almost 13 times more waste than that of the entire US population of 312 million*" (FoodPrint' n.d. - 'What Happens to Animal Waste?), and of course, the USA is far from the only source.

The report, '*Inventory of Manure Processing Activities in Europe*', observes, "*The entire [annual] manure production in the EU that potentially is available for manure processing, distributed on Member States, is estimated to be 1.4 billion tons"*, produced by 153,226,384 pigs; 88,493,237 cattle and 1,284,963,000 chickens (2009 figures) (Foged, 2012).

Fig. 66. Generic stockyard with thanks to Author and Adobe Photo Stock

In Sweden alone, "*27,410,000 tons of animal manure (cow: 24,190,000 tons, pig: 2,750,000 tons) were spread annually on agricultural land in Sweden in 2012/13*" (Risberg, 2017) to which can be added 1,360,000 tons of digestate.

China is also a significant producer of increasing levels of livestock and, thus, animal waste. "*Agricultural development in countries like China is generating substantial amounts of organic waste. By the year 2010, the annual wastes of straw and manure generated were up to 0.8 and 2.12 billion tons, respectively*. (Yang, 2018); and in addition, "*4.9 million tons of fish processing waste, 180 to 270 million tons of rice straw, and 97.72 million tons of food waste are produced annually" (Wang, 2021). Thus, livestock faeces and urine output present huge problems and great opportunities.*

28.7. LIVESTOCK NITROGEN PRODUCTION, SOURCES AND LAND APPLICATION

The FAO report '*Nitrogen inputs to agricultural soils from livestock manure, New statistics*' (FAO, 2018) provides data and charts that visually highlight nitrogen sources and applications to land in Europe, the USA, and Africa.

Fig. 67. Chicken farm stock with thanks to the Author and Adobe Photo Stock

Globally, cattle, due to their need to obtain adequate nutrients from fibre-rich and relatively low-nutrient-density pastures, are the most significant natural concentrators of nitrogen in the form of faeces and urine, more than sheep, goats, buffaloes, and chickens put together.

By daily weight of faeces, a cow produces 25-50 kg (liquid), compared to 4.5 kg (liquid) for a swine, of which 13-15 per cent is solids. Approximately 40-60 per cent of manure is excreted in sheds, barns, stables or corrals (Rosati, 2005). Much of that will end up as slurries then applied to farmland, with all the associated long-term sustainability issues discussed. Graphed FAO data from '*Cumulative global nitrogen input from livestock manure and synthetic fertilisers 1961-2014*', reproduced with thanks, helpfully gives a visual indication of nitrogen sources in different global regions.

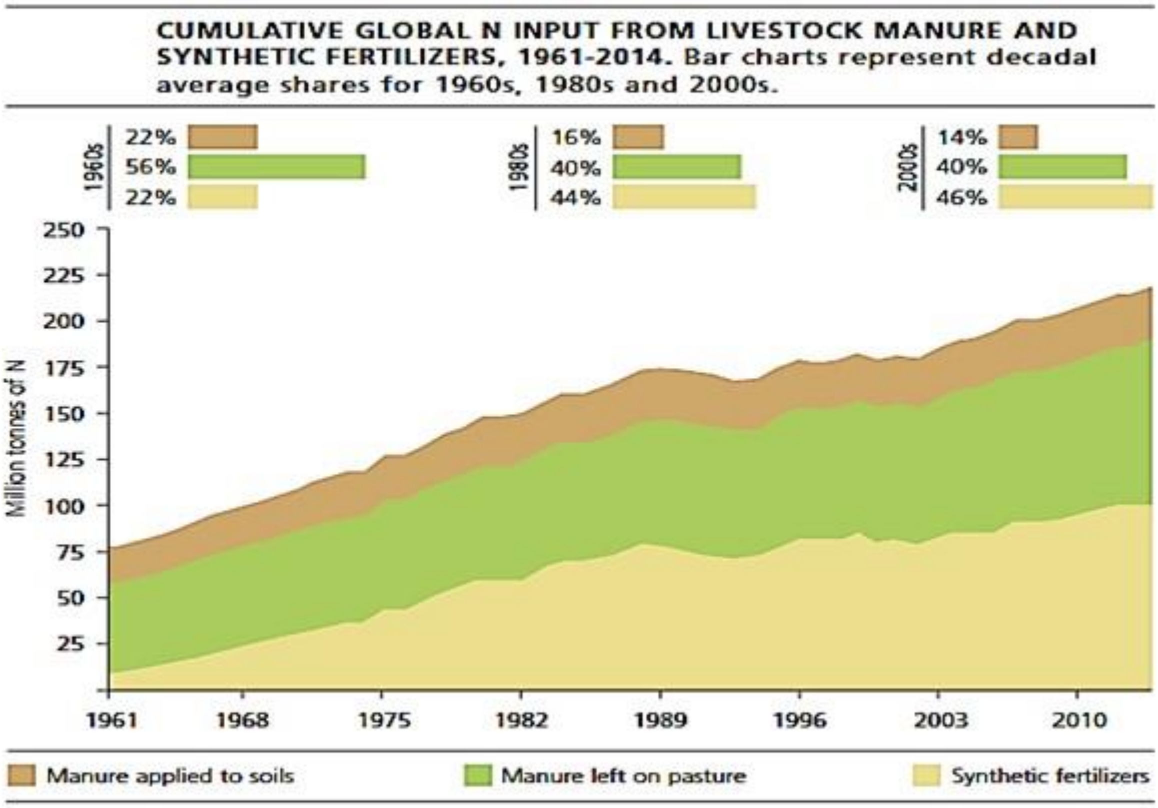


Fig. 68. '*Cumulative global nitrogen input from livestock manure and synthetic fertilisers 1961-2014*' from '*Nitrogen Inputs to agricultural soils from livestock manure*' (FAO, 2018), with many thanks to the Authors and FAO.

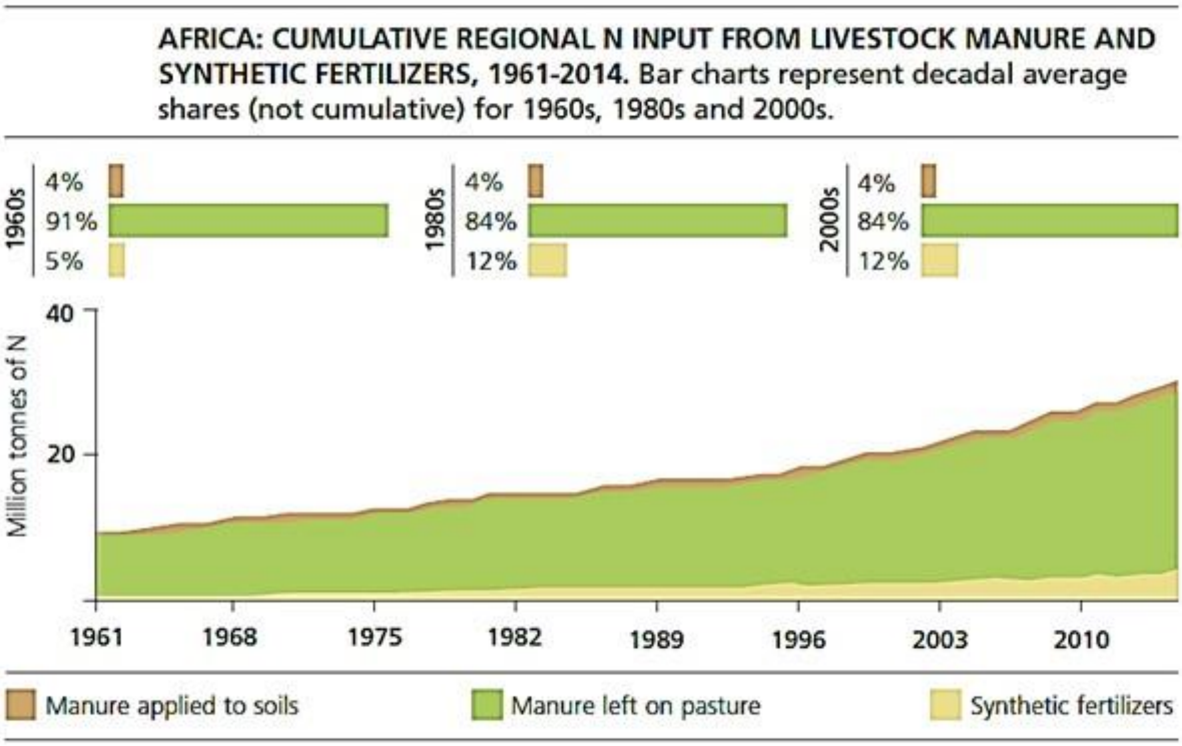


Fig. 69. '*Africa: Cumulative regional N input from livestock manure and synthetic fertilizers, 1961-2014*' (FAO, 2018) with many thanks to the Authors and FAO.

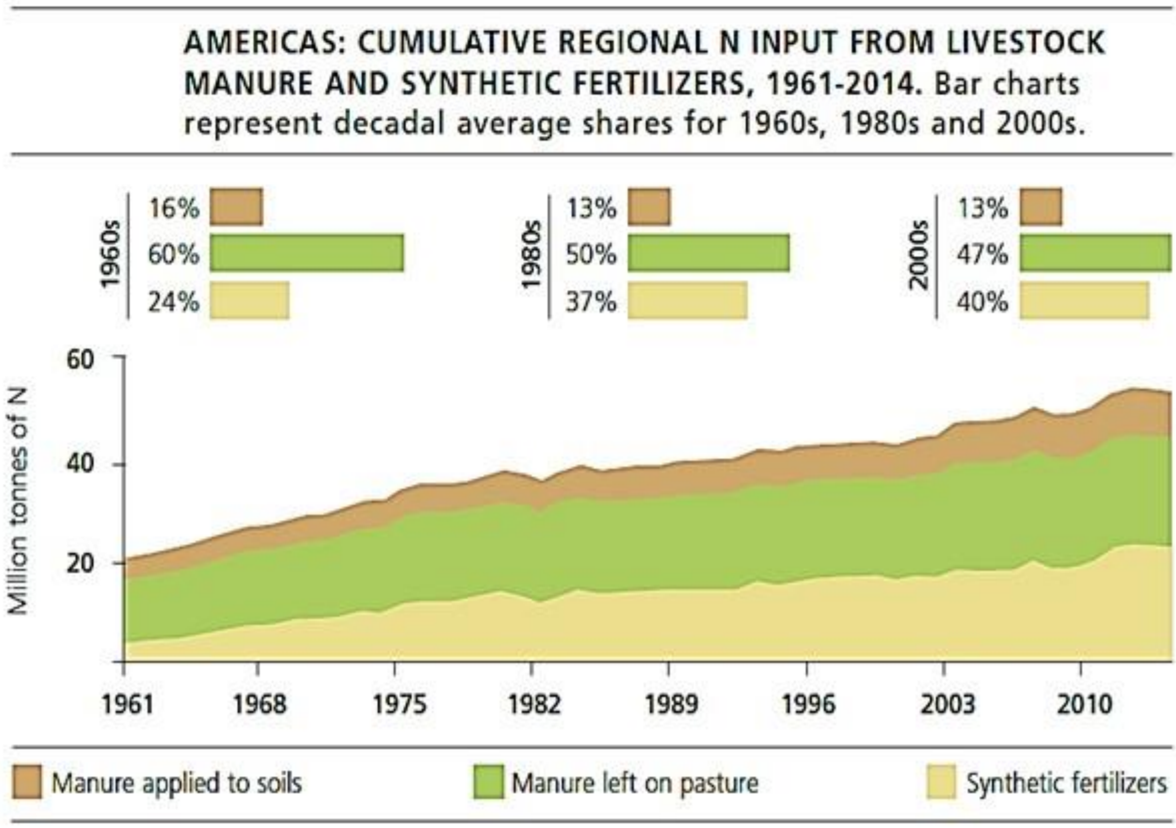


Fig. 70. *'Americas: Cumulative regional N input from livestock manure and synthetic fertilizers, 1961-2014'* (FAO,2018) with many thanks to the Authors and FAO.

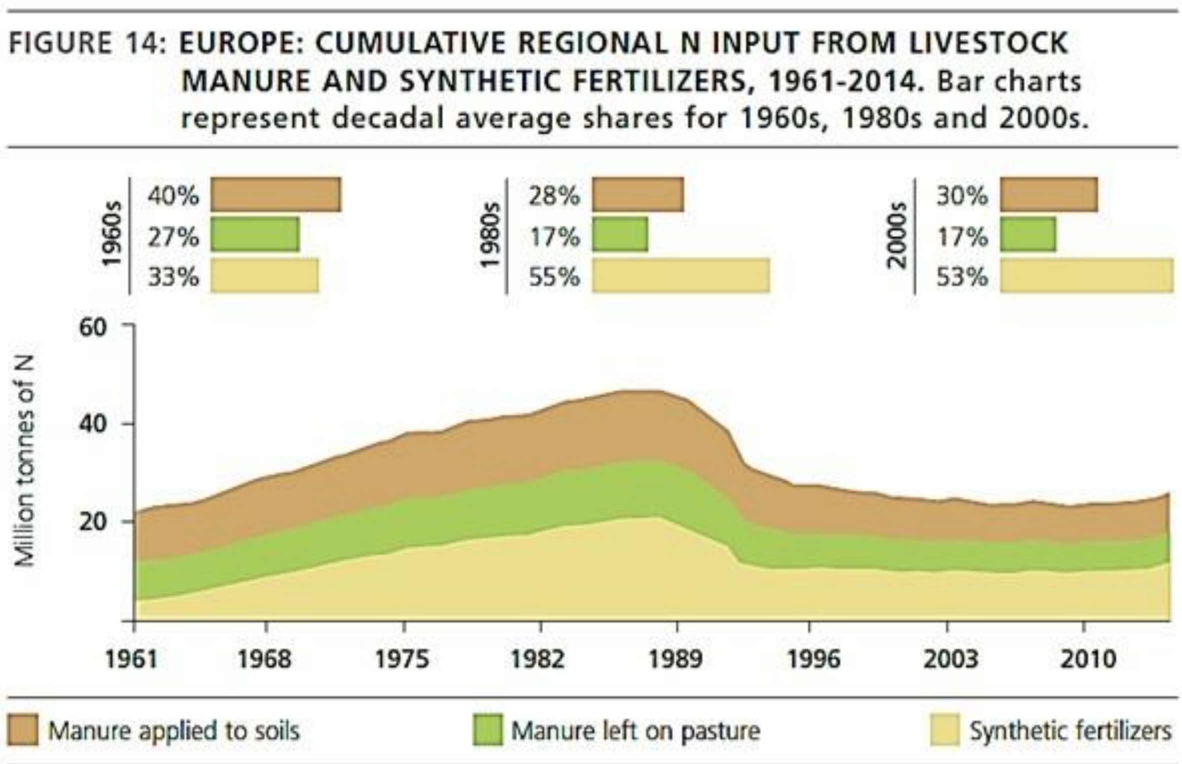


Fig. 71. *'Europe: Cumulative regional N input from livestock manure and synthetic fertilizers, 1961-2014'* (FAO, 2018).

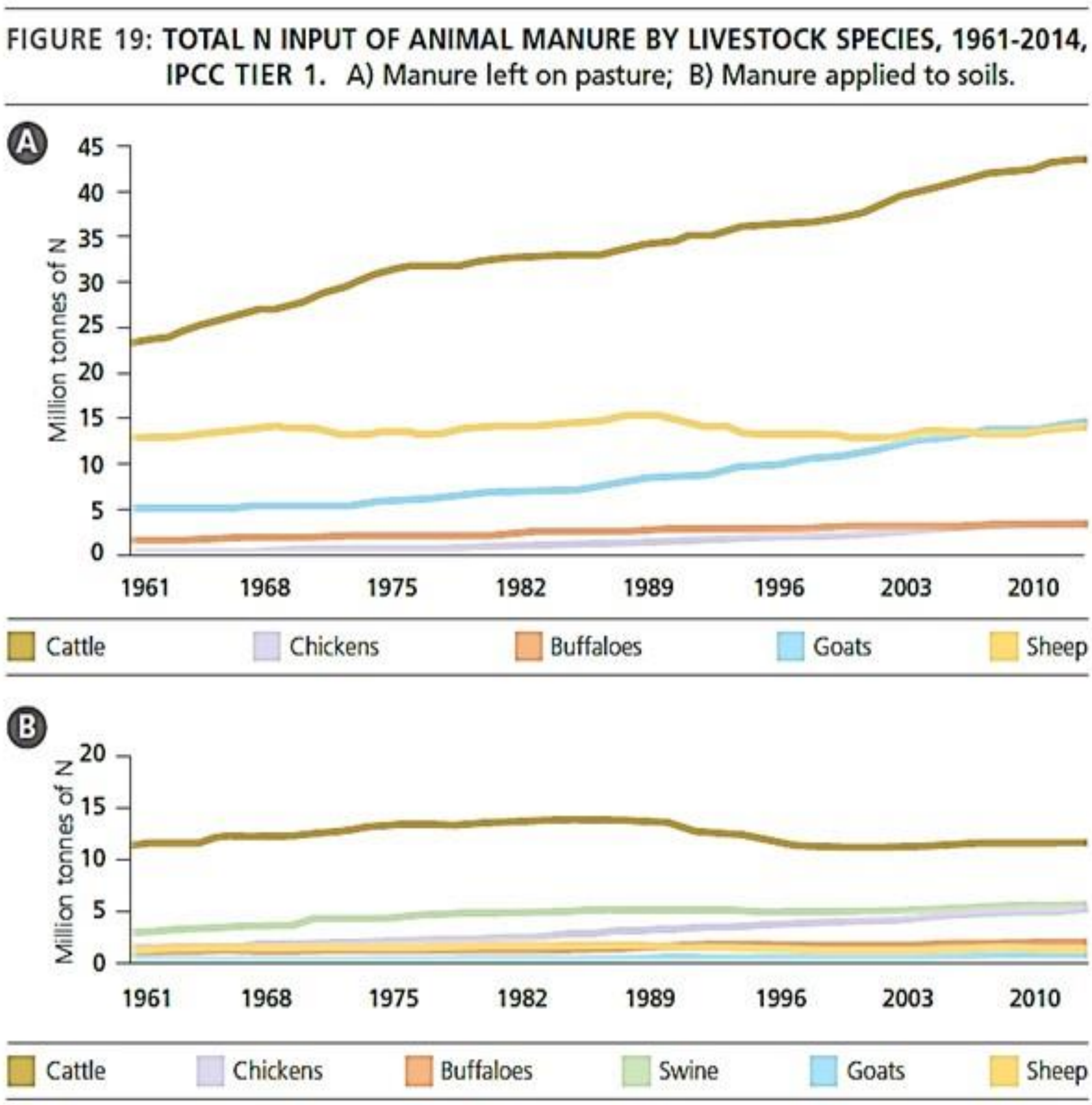


Fig. 72. '*Total N input of animal manure by livestock species, 1961-2014*' (FAO, 2018) with many thanks to the Authors and FAO.

Multiple factors, including feed, gut microbiota, and breed, will change the amounts of nitrogen in cattle urine and faeces. For example, in relation to breed differences, "*Intake, fecal, and urinary N were reduced by 29, 33, and 24%, respectively, in Jersey cows compared with Holstein cows.*" (Knowlton, 2010) and further, in respect of gut flora; "*specific bacterial families may be correlated with feed efficiency of steers*" (Welch, 2021).

Agriculture has significantly changed since Sir Albert Howard's time. Still, it remains clear that there needs to be a considerable focus on the potential value of mature, well-made composts in accelerating soil biology development, thus crop health quality and yield, and getting livestock back onto range-fed, regenerative, rotational grazing systems.

In addition, for the remaining feedlot operations, significant resources need to be put into developing hyperthermophilic anaerobic biogas production from slurry, combined with subsequent hyperthermophilic composting to biologically rich substrates and appropriate return to suitable land or, when above acceptable pollution content, incineration.

28.8. PROBLEMS WITH APPLICATION OF SLURRIES TO AGRICULTURAL LAND

As discussed above, feedlot slurry contains large amounts of soluble nitrates and phosphates, as well as organic matter, thus may provide short-term growing benefits, but at the cost of more significant damage due to runoff of soluble nitrates and phosphates; further pollution by; the heavy metals, radioactive nuclides, pharmaceuticals, and antibiotic-resistant material, that slurry can contain; and reduction of soil biome activity as plants are disincentivised by provision of external nitrates and phosphates, from providing carbon sugar root exudates to the soil biome.

The high levels of soluble nitrates and phosphates in slurries and manures logically have a similar effect to the application of artificial fertilisers in that the high immediate availability of nitrates and phosphates to plants will switch down their production of photosynthetic sugar carbon root exudates, which in turn reduces the supply via plant root systems, of the photosynthetic, plant provided, carbon, necessary to, the maintenance, of life, and reproduction, in the soil biome. Indeed, the limited data available suggests that long-term heavy manure and slurry application is associated with falling soil carbon. (Joona, 2024)

Plant root exudate is the primary source of the external carbon supply to soil. Carbon is essential for the structure and capacity to make energy that underlies bacterial fungal and wider lifeforms in the lightless soil biome. Thus, it is existential to the existence and function of the life that constitutes soil biomes. The consequence of a reduced supply of photosynthetic carbon-plant-root-exudates is that the extent of soil biome life per unit volume must be reduced.

Falling carbon root exudate equates to both a lower supply of carbon for the organic structural substrate used to create the inhabitants of the soil biome, and for the carbon sugar they need to fuel the energy production that enables soil life to function, thus reducing the capacity to maintain soil life, including of the fungal-hyphal-systems, which through interaction with root systems, transport much of that plant-supplied photosynthetic carbon root exudate to the extensive biome.

In return and exchange for carbon sugar root exudate, fungal systems transport nitrates from bacteria, dead soil life, and their secretions and excretions, along with mined minerals, including phosphates, to their plant symbionts every day.

Thus, with a reduced supply of carbon sugar root exudate, the mass of soil biome life per unit volume is reciprocally reduced, along with its proportional capacity to supply nitrates and minerals to its plant symbionts, including through biome life cycles, within which, both excreta, and the death and recycling of the nutrients within, bacteria, mycorrhizal fungi, and other soil life of every form, is an integral and crucial part of the nutrient supply and broader soil biome symbiont plant support system.

In summary, human FATBAS provision of soluble nitrate and phosphate above natural physiological levels in fertilisers, sludges and slurries drives a reduction in plant supply of photosynthetic carbon sugars through roots to the soil biome, which over time consequentially and inevitably reduces the soil carbon supply, thus in turn reduction of the volume and extent of soil life, which in turn reciprocally cannot but limit: plant fertility and growth; water retention; water infiltration; drought resilience; and plant health; for the reasons set out in Volume 2 on regenerative agriculture.

28.9. SLURRY STORAGE AND SMELL

Leaching and smell during slurry storage and spreading on agricultural land are also problems that must be addressed. *"While human waste is treated in municipal sewer systems and subject to strict regulation, animal waste is stored in open ponds (called lagoons) or pits and is applied untreated as fertiliser to farm fields. The mixture in lagoons consists of animal excrement, bedding waste, antibiotic residues, cleaning solutions and other chemicals, and sometimes dead animals." This information is sourced from 'FoodPrint ', a reputable platform that provides insights into the environmental impact of food production. "Most lagoons are lined only with clay and can leak, allowing the waste to seep into groundwater*" ('FoodPrint' n.d - 'What Happens to Industrial Agriculture's Animal Waste?).

Weather fluctuations, including rainfall and winter snow, exacerbate lagoons' inherent problems. These problems impact storage security, capacity for safe return to land, and wash-out risks.

Some countries regulate the storage of manure and sewage sludge (*'Design Guidelines For Sewage Works: Sludge Storage and Disposal'* 2019). Smell from slurry, sewage sludge, and field spreading is a common complaint among those living nearby. In contrast, unlike slurry and sewage sludge, compost does not smell offensive when produced under appropriate conditions and applied to agricultural land.

28.10. GASEOUS 'CLIMATE-CHANGE' EMISSIONS - LIVESTOCK MANURES AND SLURRIES

Storage of slurry gives rise to greenhouse gases. "*Many methods of manure storage emit large amounts of methane (CH4) and nitrous oxide (N2O), especially liquid manure storage*" (Teenstra, 2014). Thus, gaseous emissions from livestock manure storage and application are growing.

"*Gaseous losses from ruminant livestock in the form of manure management were responsible for 15.2 per cent of agricultural emissions (USEPA, 2015). In addition, GHG [greenhouse gas] emissions from dairy manure management increased by 53 per cent from 1990 to 2012 and are expected to continue to rise; therefore, <u>it is critical to recommend efficient manure management mitigation strategies to dairy producers to abate overall agricultural GHG emissions</u>*" (Holly, 2017) [This author's underline].

There is ongoing research into how to minimise slurry emissions, for example as in '*Mitigating ammonia and greenhouse gas emissions from stored cattle slurry using agricultural waste, commercially available products and a chemical acidifier*' (Kavanagh, 2021)

28.11. GLOBAL CAPACITY TO REDUCE GREENHOUSE GASES AND CONTRIBUTE SIGNIFICANTLY TO GREEN BIOGAS PRODUCTION

As an integrated part of a manure and sewage recycling protocol, anaerobic digestion 'AD' of manures has considerable potential to reduce greenhouse gasses and contribute to green energy, "*AD has the potential to reduce GHG emissions by 3,290 to 4,360 Mt CO2 eq., which is equivalent to 10-13% of the world's current greenhouse gas emissions.", "Despite the 50 million micro-digesters, 132,000 small, medium and large-scale digesters and 700 upgrading plants operating globally, according to the world biogas association, we are tapping into just 1.6 – 2.2% of the global potential of AD"* (EBA, n.d.)

Controlled containerised hyperthermophilic anaerobic digestion of agricultural slurry, followed by aerobic composting, would further reduce pollutants, including antibiotics and accompanying ARGs; facilitate biogas capture; reduce greenhouse gas emissions; and allow the return of mineral and carbon resources to soils in the form of biological rich composts.

28.12. ANIMAL AND HUMAN, URINE AND FAECES–RELATED, PROCESSING ISSUES

The Faf approach to processing human urine, faeces, and animal 'manure' is fractured, failing to bring together issues with many commonalities. Pharmaceuticals and antibiotic-resistant bacteria increasingly pollute both human and livestock excreta and cause similar broader environmental damage, including heavy metal pollution, soluble nitrate and phosphate release, the spread of wider pollutants, including pharmaceuticals, eutrophication of rivers, lakes, and oceans, and climate gas emission issues.

Use of both slurry and human vacuum WC collected urine and faeces for biogas, with subsequent hyperthermophilic composting, would help close the circle by returning minerals, some carbon, and bacterial and mycorrhizal biology to the soils, as well as diminishing long-term storage issues, emissions of methane and other climate gasses, pollution of agricultural land, and downstream eutrophication due to slurry and sludge spreading on agricultural land.

Research would be required to optimise processes, including hyperthermophilic, anaerobic digestion, and composting, and to minimise the emission of 'greenhouse' warming gases, storage, smell issues, and pollutants, including pharmaceuticals.

28.13. INTEGRATION INTO CIRCULAR ECONOMY

As with human faeces and urine, livestock manure must be effectively incorporated into a circular, sustainable economy. There were considerable advances in composting in the 1930s-1950s, including mechanised turning and gravity systems. However, things have moved on;

volumes have significantly increased, enclosed rearing systems are used more, and additional pollution from sources such as heavy metals, and pharmaceuticals, have increased.

Further, the broader appreciation of compost's relevance and beneficial impact with diverse biology built up in the 1930s-1950s has declined as historical farming knowledge has faded.

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Fig. 73. Dung cakes being prepared for fuel on the Ile de Brehaut, Brittany, France, c.1900, with many thanks to Wikipedia.

Indeed, it is time for greater focus on developing technologies and facilities common to human and animal urine and faeces, including anaerobic hyper-thermophilic digestion and hyperthermophilic aerobic composting systems. This includes considering how to meet the needs for the green carboniferous material required for successful composting, thus closing the soil-food-excreta environmental cycle.

28.14. DUNG AS FUEL AND BIOGAS

In some parts of the world, dung has long been used as a fuel and continues to be a heating and cooking energy source. For small-scale usage, it could be considered a green fuel. Post-incineration, the ash would be returned to the land. However, smoke from such fires in confined spaces raises health issues and, when considered at scale, would be a source of atmospheric pollutants.

29. FOOD WASTE

Food waste is not just a topical subject but a pressing issue that demands our immediate attention. Shockingly, forty per cent of what is grown is ‘wasted’, according to the 2021 WWF report *‘Driven To Waste’.* (WWF, 2021).

The UN Environment Programme's Food Waste Index (Forbes, Quested & O'Connor, 2021) reports that the planet binned 931 million tonnes of food in 2019. Of that, 61 per cent was thrown away by households, 26 per cent by service providers, and the remainder by retailers.

Fig. 74. Fruit and vegetables in a dumpster, with thanks to Wikipedia and the OpenIDUser2

The WWF report also notes, *"As agricultural resource use expands around the world, 4.4 million km2 of agricultural land and 760km3 of water are used to produce the 1.2 billion tonnes of food that are lost before, during and after harvest, or diverted to other uses such as animal feed and biofuel. This equates to a landmass larger than the Indian subcontinent and water volume equivalent to 304 million Olympic swimming pools - and this doesn't even include the additional resources used to produce food, that is wasted further down the supply chain."* (WWF, 2021) The figures are much more prominent; once waste on farms and elsewhere is added in, the annual total amount of food uneaten is a staggering 2.5 billion tons, albeit estimates vary.

The problem of waste is exacerbated in hot climates, particularly where there is little access to refrigeration, which ironically often overlaps with those countries most likely to suffer food shortages. "*Around 150 million tons of vegetables and fruits are produced annually in India, out of which 50 million tons of waste is being produced and is becoming a source of nuisance in municipal landfills, causing major environmental pollution problems*" (Varma, 2014). In comparative terms, Western Asia, sub-Saharan Africa and Southern Europe waste more food per household (110 kg, 108 kg and 90 kg per year, respectively) than Eastern Europe, Eastern Asia, and Western Europe (61 kg, 64 kg and 65 kg).

Municipal recycling of food waste is becoming a feature in many countries. Efforts are being made to reduce what is thrown away by corporate retail structures by making supply chains more cooperative so that, for example, so-called ugly veg is used to produce ready meals instead of being thrown away. Supermarkets are putting more effort into making food available to voluntary organisations, including food banks.

However, as noted elsewhere, corporations can focus on unwanted food as a carbon source to facilitate anaerobic digestion for biogas. Such payments can divert edible food from charitable food chain providers.

In addition to moves towards minimising food waste, advances in collection and composting food waste will help return nutrients to the soil, but only if they are part of a broader strategy that recognises the need for and value of composting.

30. ANAEROBIC BIODIGESTION – VACCUM WCS

Research has shown that vacuum-WC-collected black water (BW) can be directly used for green biogas without the need to separate solids from liquid; "*Vacuum collection by ultra-low flush volume vacuum toilets, resulting in a concentrated BW stream, makes the stream suitable for energy and nutrient recovery (NPK) through (hyper)thermophilic AD*" (Moerland, 2020}. As discussed, hyperthermophilic digestion and composting occur at much higher temperatures than usually used.

Using a vacuum WC to collect urine and faeces hugely reduces the volume compared to a FaF water-based collection system. Thus, the entire WC output, liquids and solids, can be subject to anaerobic remediation, including potentially hyperthermophilic remediation.

Interest and production of anaerobic digestion plants has consistently increased over recent years. Several variants exist, processing requires specific conditions to function optimally, including as to feedstock mix, temperature, microbiology, Ph, containers and processing criteria. These are system-specific and well-covered in related research and documentation, and discussion is outside the scope of this volume (Zieliński, 2023). The plant is costly but provides an economic and environmental return and is relatively compact; storage of liquids pre and post-processing needs adequate consideration.

Vacuum WC collection combined with hyperthermophilic and hyperthermophilic composting would be the best option for closing the soil-farm-food-faeces-soil cycle.

Anaerobic digestion has the following advantages:

- biodigestion produces green methane;
- both the soil and liquid fraction of the digestate contain soil nutrients;
- there is some mineralisation of phosphates, reducing runoff risks;
- there is some remediation of pollutants increasing with rising temperature;
- it can be used for human and livestock faeces and other organic feedstocks
- it reduces the volume of organic solids;
- carbon, minerals, nitrates, and phosphates can be returned to land.

However, it is important to acknowledge the challenges that come with anaerobic digestion:

- the nutrient density is low, meaning that transport and application are expensive;
- there can be smell issues;
- produced digestate can be used for fertiliser subject to pollutant content
- organic pollutant remediation using both mesophilic and thermophilic is limited;
- specialist application, including injection, is required to mitigate the risk of runoff
- stirred biodigestion requires dilution of digestate with sometimes scarce water, albeit alternative technologies can be used, such as plug and flow, where less water is used;
- levels of phosphates and nitrates in digestates can be too high for optimal return to land, and the ammonia content is at risk of entering the atmosphere

Hyperthermophilic anaerobic digestion has the following advantages, but more research is required:

- is faster,
- provides much better remediation of organic pollutants, which opens opportunities for using solids for hyperthermophilic composting and return to the land. It also opens up wider opportunities to use or recycle the liquid digestate,
- examples are limited, and more research is required.

30.1. CLOSING THE CYCLE - SOIL CARBON IMPLICATIONS – NOT A DEAL-BREAKER

While anaerobic digestion, by creating methane biogas, reduces the amount of carbon available for return to soils, that is less important than it might be because degraded plant matter only provides a minor proportion of soil biome carbon; the vast majority is created and supplied by photosynthesis in the form of sugar and lipid root exudates, which growing plants continuously provide daily.

Providing organic matter to soils, including surface plant detritus, is an important part of the biological soil cycle, for example, for the bioturbation functions of earthworms. Bioturbation includes significant digestive remodelling by worms of fungal and bacterial species, for example, removing some in introduced faeces whilst enhancing others that are essential to mycorrhizal soil function and plant associations, as discussed in the bioremediation section (Dominguez, 2021).

Greater accretion of soil carbon by weight can be achieved by promoting healthy, diverse soil biomes, thus plant growth-and-photosynthesis-related provision of carbon sugar root exudate, than by directly adding carbon in compost to soils. Therefore, the use of photosynthetic-derived, plant-based carbon in slurry and sewage for processing by biodigestion to produce methane, rather than return to soils, is not such a central issue as may first appear, given the core reason for the positive impact of compost on soil health and plant growth, is primarily the fungal and bacterial biology it provides; the accompanying carbon and minerals are necessary to host and support the compost biology, but only assistive, as against core, in terms of their support to plants particularly during germination and early growth.

The successful deployment of plant hydroponic growing systems strikingly illustrates this point: where adequate nutrients are always and immediately hydroponically available to the plant roots, carbon supply is not required for plant growth; in contrast, in soil where nutrients are not consistently available to plants over time, as the immediate root zone is rapidly depleted of nutrients by a growing plant, root exudate carbon-sugar powered assistance to the soil biome to make nutrients available, is essential to optimal plant growth. Thus, from an agricultural and broader environmental perspective, cattle slurry and human ordure can sensibly be used for biogas, provided the issues of pollutants in digestate are adequately addressed.

The helpful review '*Management strategies for anaerobic digestate of organic fraction of municipal solid waste: Current status and future prospects*' warns, "*Presently, the focus of optimization of the anaerobic digestion process is directed only towards enhancing biogas yield, ignoring the quality of digestate produced. A paradigm shift is needed in the approach from 'biogas optimization' to 'integrated biogas–digestate optimization.*"

Arguably, the solution is

- a shift to hyperthermophilic anaerobic digestion, combined with hyperthermophilic diverse fungal and bacterial compost creation from the separated digestate solids;
- together with alternative strategies to deal with the liquid fraction digestate, in so far as hyperthermophilic anaerobic treatment did not provide digestate of an acceptable standard;
- accompanied by implementing a regenerative farming strategy, boosting soil biome health and thus plant production of root carbon sugar exudate, with the secondary benefit of additional remediation by diverse healthy soil microbia.

30.2. BIOGAS FROM HUMAN AND LIVESTOCK URINE AND FAECES - A POTENTIAL SIGNIFICANT GLOBAL GREEN ENERGY SOURCE

Unlike aerobic composting, anaerobic digestion produces and allows methane collection, a marketable and crucially green energy source. A wide range of organic materials can be used as substrates for anaerobic digestion, including sewage sludge once separated from wastewater, farm slurry, discarded food, food processing waste, and other materials.

The biogas produced by the biodigestion of urine and faeces is a beneficial and significant potential additive green energy source. The biogas industry has the potential for massive expansion, but even current outputs, albeit a fraction of the possible production, are thought-provoking. For example, "*according to EurObservER, about 13. 4 million tonnes oil equivalent (mtoe) of biogas primary energy were produced during 2013,*" an increase on that produced in 2012 (EurObservER, 2014). Meanwhile, in the same year in Sweden, production was 1.5 TwH, with 54 per cent used for vehicle fuel, 31 per cent for heat, and 3 per cent used for electricity. At the simplest level, it is suggested that biodigesters are 'net zero' because they are, in effect, recycling processes.

30.3. MESOPHILIC DIGESTATE - POLLUTANT REMEDIATION CEC/ PHARMACEUTICAL/ ANTIBIOTIC/ ARG CONTENT

Mesophilic standard-temperature anaerobic digestion has limitations as to its remediation potential and, of importance, exhibits poor remediation of some antibiotics and ARGs. As discussed in later sections, thermophilic and particularly hyperthermophilic techniques demonstrate significantly better remediation of pathogens and other pollutants, including antibiotics and ARGs.

Notwithstanding, mesophilic digestion can be more effective than many alternative remediation treatments, for example, the paper "*Pharmaceutical residues in sewage sludge: Effect of sanitization and anaerobic digestion*"[)] (Malmborg, 2015), observes standard temperature anaerobic digestion, was more effective for sludge than other sanitisation technologies, including pasteurisation, thermal hydrolysis, advanced oxidation processes using Fenton's reaction, ammonia treatment, and thermophilic dry digestion, but with only "*on average 30% reduction*" in organic pollutants (Malmborg, 2015) the pollutant reduction is generally insufficient to allow the safe return of digestate products to soils.

Thus, many anaerobic digestates can be a source of antibiotic bacterial and related genetic elements (ARGs), which, on discharge or application to soils, are transferred into the environment. Where the digestate is split into solid and liquid fractions, the pollutants will be split between the two.

For example, the paper "*Transferable antibiotic resistance plasmids from biogas plant digestates often belong to the IncP-1ε subgroup*", looking at the issue of potential bacterial resistance in Germany, observed, "*Manure is known to contain residues of antibiotics administered to farm animals as well as bacteria carrying antibiotic resistance genes.*" "*BGP* (Biogas Plant) *digestates are a potential source of transferable antibiotic resistance plasmids, and in particular the broad host range IncP-1ε plasmids might contribute to the spread of ARGs when digestates are used as fertilizer.*" (Wolters, 2015)

The paper further noted, "*Consistently, in multiple studies piggery manure was reported as a reservoir of bacteria carrying antibiotic resistance genes and genes conferring resistance to all major classes of antibiotics have been detected in total community (TC-) DNA of pig manures and slurries. In addition, ARGs* (Antibiotic Resistant Genetic Elements) *from manure bacteria were shown to be often located on mobile genetic elements (MGEs) such as plasmid*" (Wolters, 2015).

Other expressed reservations about the long-term ill effects of repeated applications with digestate, include, *"opinions suggesting that anaerobic digestor sludge (ADS) contains only recalcitrant stuffs such as lignocellulose and its nutrition quality is poor. Prolonged application of ADS might concentrate hazardous secondary metabolites along with heavy metals that are otherwise harmful for soil microbes and rhizosphere environment. The AD sludge can also release unpleasant odour containing corrosive and noxious gases such as* H_2S *and* NH_3" (Dutta, 2016).

Further, there are gaps in the research around digestate types, including how they interact with different soils and their effect on plant growth, yields, and disease resistance. If ways to deal with them cannot be found, digestate's usefulness as a fertiliser may be limited. As discussed, hyperthermophilic composting of the solids offers a route to better remediation.

Some of the separated liquid digestates could potentially be used instead of clean water to moisten the compost during preparation, with the additional advantage of providing nitrogen to the process.

Another complication is that antibiotics, other biocides in the waste stream, and natural products, such as limonene in citrus peels, can inhibit fermentation. This can lead to operational problems in digesters.

Given the problems with standard digestate, the way forward is the development of combined hyperthermophilic anaerobic digestion, followed by hyperthermophilic composting, which should provide much better remediation.

30.4. NUTRIENT CONTENT - ANAEROBIC DIGESTATE AS A FERTILISER

"*Digestate can be used as a fertiliser in agriculture and has been shown to support crop yields equivalent to mineral fertilisers*"(von Midden, 2023).

"*Anaerobic digestion of animal manure before use as a fertilizer is generally considered positive, since the digestate obtained has higher proportions of mineralized plant-available nutrients than the untreated manure and since digestion results in a significant odour reduction*" (Risberg, 2017).

Anaerobic digestate is composed of a mix of solids and liquids, which can be and sometimes are separated into solid and liquid components, using techniques such as screw presses or taking a different approach using evaporative techniques, including for the collection of volatiles such as ammonia, which can be used in fertiliser manufacture. The solid and liquid components have different soil nutrient profiles.

The review by Logan provides indications of the split of nitrogen and phosphorous between the soil and liquid portions, "*It is estimated that liquid digestate contains 70% to 80% of the total NH_4^+-N while the remaining 20% to 30% of the total NH_4^+-N are distributed in solid fraction* (Logan, 2019). The ammonia is rapidly available to plants, which may reduce the supply of carbon sugar exudate to the soil biome. Further, ammonia can be readily released into the atmosphere or wider environment when it could contribute to eutrophication (Zilio, 2022). "*NH3 emission mainly happens after field application of liquid manure and fermentation residues (Amon et al., 2006). After field applications, over 70% of nitrogen can be lost*" (Bauer, 2009).

The phosphorus is found mainly in the digestate solids, *"However, 55% to 65% of the total phosphorus remains in solid fraction after separation while the remaining total phosphorus (35% to 45%) is found in the liquid*" (Logan, 2019), Interestingly, "*70–80 % of the potassium remains in the liquid fraction",(Van Midden, 2024)*

Carbon is found mainly in the solid fraction; "60-70 % of the carbon remains in the solid fraction" (Van Midden, 2024). It represents a useful addition of organic matter to soils in a form that is taken up by soil life.

The digestate also contains a range of other organic matter that may improve growth, "*digestates contain bioactive substances such as phytohormones, nucleic acids, monosaccharides, free amino acids, vitamins and fulvic acid, etc., that promote plant growth and increase the tolerance to biotic and abiotic stress*" (Logan, 2019).

However, the changes to the soil biology may also have negative consequences on growth, including germination, "*However, a residual phytotoxicity level was detected by a standardized test showing a germination index of about 50%*." (Di Maria, 2013) *"earthworms, springtails and nematodes dwelling in the soil surface layer can be negatively affected by digestate application due to toxicity when compounds such as ammonia are present in high concentrations"* (von Midden, 2023)

While results are mixed and more research is required, mitigating techniques such as injection and mixing with carbon sources have been trialled. Some suggest processes to reduce the soluble nitrate content. They considered separating the more liquid digestate component using presses, splitting it into fluid and semi-solid components.

The liquid portion, which is richer and nitrates, on an experimental basis, has been combined with carbon and mineral-containing, bacterial and fungal growth supporting, carbon-rich sources, such as straw or wood chip, to facilitate uptake of nitrogen by increasing microbial populations, thus reducing soluble nitrogen immediately available to plants (Van Midden, 2024), albeit the nitrogen will be released over time through a variety of biological process.

Mineralised nitrates, as against soluble plant-available nitrates, which are unavailable to plants, logically will not switch down carbon exudate supply to the roots, as the plant still requires soil services to release the mineralised nitrates and phosphates.

The use of anaerobic digestate as an agricultural amendment needs careful analysis, including the source, pollutant content, biology, and degree of mineralisation, as considered in more detail below. Using digestate with additional plant carbon sources as a feedstock for compost makes sense due to the extra benefits of combining the techniques.

Hyperthermophilic composting of the solids will reduce many of the issues outlined, including reducing organic pollutants. It will largely mineralise the nitrogen and, of crucial importance, has the potential to provide a wide range of plant growth, assisting bacterial and mycorrhizal biology to soil biomes. This promotes plant growth and health, with a raft of other synergistic benefits, as set out in Volume 2.

30.5. WET AND DRY DIGESTATE PROCESSES

Digestate is the product of wet or dry anaerobic digestion. "*The differences in wet anaerobic digestion and dry anaerobic digestion are that in wet AD, the feedstock is pumped, heated and stirred (5-15% solids) and in dry AD it can be stacked (over 15% solids), with leachate* *sprayed over the top of it which percolates through the material, breaking it down over a longer retention time.*" (What is wet Anaerobic Digestion? 2018)

"*Most of the biogas plants worldwide are built based on liquid-type anaerobic digestion (AD), wherein biomass (usually animal dung) and water are mixed in equal amounts to form a slurry in which the content of total solids is about 10-15% (TS – total solids, DM – dry matter). While this model is suitable for small-scale biogas plants, it becomes a challenge in large commercial plants where it necessitates the use of large quantities of water every day, often in water-scare areas*."

Wet anaerobic digestion is quicker and more flexible. It produces more gas but is more water-demanding and produces a more liquid residue, which complicates onward treatment and disposal, making the process more prone to problems and challenging to manage (Regeneron, n.d.).

Other anaerobic digestion techniques exist, including plug-and-flow reactors (Gomez, 2019), have been developed and marketed. However, more research is required to optimise remediation, gas production, and compost quality, including techniques for hyperthermophilic anaerobic digestion and subsequent hyperthermophilic composting.

30.6. DIGESTATE – VALUE AS FERTILISER

The review, '*The impact of anaerobic digestate on soil life*', states, "*Generalized understanding of the effect by digestates on soil biota is made difficult by differences in digestate properties caused by varying feedstock and production methods and the inherent heterogeneity of soil. There is a lack of research investigating the impact of repeated digestate application on soil biota and subsequently soil health.*" (von Midden, 2023) Measurement of soil health parameters is difficult given the complexities, as set out in 'Monitoring Soil Quality of Arable Land: Microbiological Indicators' (Stenburg, 1999).

31. HYPERTHERMOPHILIC; ANAEROBIC DIGESTION

Both hyperthermophilic anaerobic digestion (HTAD) and hyperthermophilic aerobic composting (HTC) are technologies proven in principle. HTAD, thermophilic anaerobic digestion, may, like HTC, offer advantages, including improved speed and degradation of organic matter, pollutants, and pathogens, as well as greater environmental sustainability compared to traditional anaerobic digestion (Sing, R. 2023).

31.1. HYPERTHERMOPHILIC ANAEROBIC DIGESTION REMEDIATION OF POLLUTANTS

Hyperthermophilic anaerobic digestion, shows greater potential capacity to remediate antibiotics ARGs and other pollutants, as discussed in the subsequent section. Hyperthermophilic composting similarly exhibits relatively good remediation of pharmaceuticals and ARGs, thus the combination of hyperthermophilic anaerobic digestion and hyperthermophilic composting may provide a route to making anaerobic digestion for biogas, a realistic part of a sewage treatment protocol, that creates a viable soil - food – faeces – fuel – soil environmental cycle.

By way of an example of improved remediation with increased temperature, *"Salmonella enterica, serovar Typhimurium and Mycobacterium paratuberculosis are inactivated within 24 hours in a thermophilic anaerobic digester, but the process takes weeks and months in its mesophilic counterpart*" (Arthurson, 2008).

Compared to mesophilic anaerobic treatment, HTAD provided better potential remediation of pharmaceuticals; "*thermophilic (55–60 °C) and hyperthermophilic (70 °C) anaerobic treatments had higher (antibiotic-resistant) culturable pathogen indicators removal than mesophilic anaerobic treatment.*" (Moerland, 2020, Wu, L; 2020).

31.2. HYPERTHERMOPHILIC ANAEROBIC DIGESTATE METHANE PRODUCTION

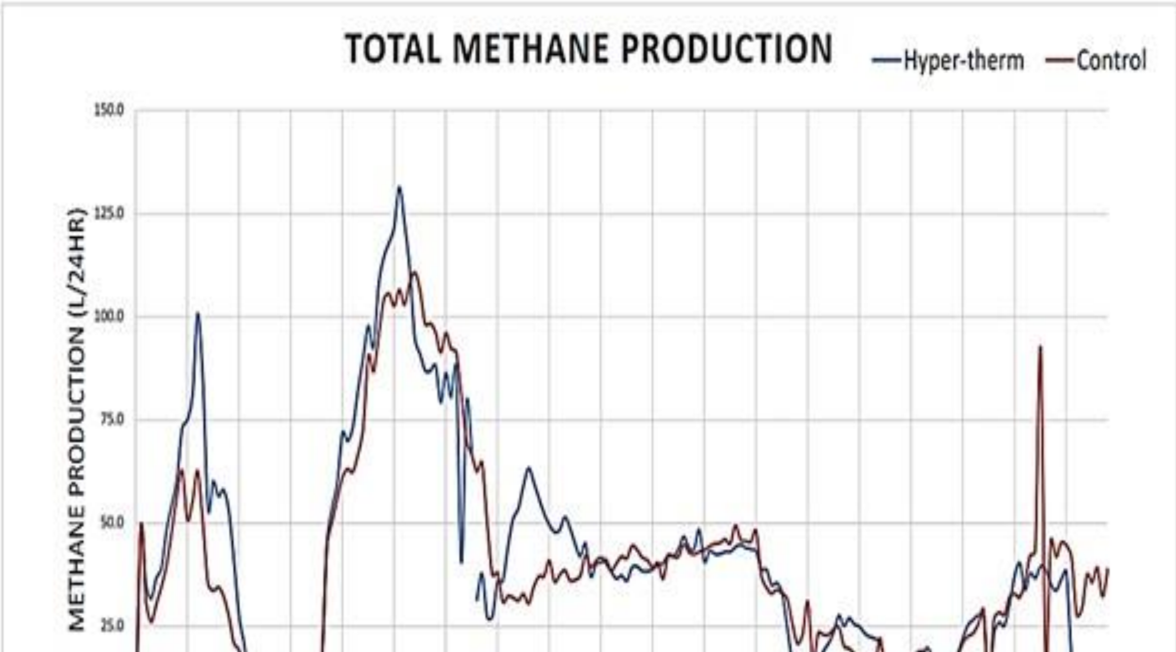

Fig. 75. From the Thesis, '*Effect of Hyper-Thermophilic Anaerobic Digestion on Microbial Health and Biogas Viability*' (Christie, 2023) with many thanks to the Authors.

Whilst more research is required, HTAD may produce equivalent or greater quantities of methane (Christie, 2023; Singh, 2023). The pilot study used "*Caldicellulosiruptor bescii (C. bescii) . . . a hyperthermophilic anaerobic bacterium capable of hydrolyzing cellulosic and other recalcitrant biomass, such as waste activated sludge"*. They postulated a 25 per cent increase in performance, and a consequent equivalent reduction in biosolids, may be possible; "*The results show the potential for EHH (enzymatic hyperthermophilic hydrolysis) to* *increase the performance of the anaerobic digestion system from an average volatile solids reduction (VSR) of 60% to a VSR of greater than 75%: a 25% improvement in performance*", with increased hydrogen production (Enica Wastewater Authority, 2022).

The efficiency of methane extraction for hyperthermophilic and thermophilic digestion of sewage varied in different studies, as illustrated by the graph above from *Effect of Hyper-Thermophilic Anaerobic Digestion on Microbial Health and Biogas Viability (Christie, 2023),* albeit another HTAD study reported a much lower output (38%). However, HTAD looks promising overall, particularly given its better remediation capacity. The combination of HTAD followed by HTC, as well as offering methane and compost production, may, in combination, result in better remediation of pollutants, providing opportunities to close the agriculture food sewage agriculture cycle. More research is required.

32. REGENERATIVE SOIL HUSBANDRY - A LONG HISTORY

Thomas Jefferson, as well as being a President of the USA, was a 'prophet', and a then leader, in agricultural development. "*Jefferson's Monticello garden was a Revolutionary American garden*" (Hatch, 2010)

He used regenerative agricultural principles, such as composting, mixed species cropping, growing material in the ground all year, ploughing in cover crops, and integrating cattle, 300 years before the term regenerative agriculture was commonly used (Callis, n.d.).

The educational article "*Jefferson: The Agronomist*" by Thomas Jewett, notes *"Jefferson was one of the first Americans to propound crop rotation as a way of renewing the soil. He devised an extensive seven-year plan for his land, as follows:*

- *Wheat, followed the same year by turnips, to be fed to the sheep.*
- *Corn and potatoes mixed, and in autumn the vetch to be used as fodder in the spring if wanted, or to be turned in as a dressing.*
- *Peas or potatoes, or both according to the quality of the fields.*
- *Rye and clover sown on it in the spring. Wheat may be substituted here for rye.*
- *Clover, and in autumn turn it in and sow the vetch.*
- *Turn in the vetch in the spring, then sow buckwheat and turn that in, having hurled off the poorest spots for cowpenning, (so these spots could be improved by the manure).*

He used this rotation system with legumes and grasses in an attempt to bind the soil against washing out, to improve his hard-used land, and to arrive at the best fit between the environment and plant." (Jewett n.d.)

Steve Callis in "*Another Short History of Composting*", notes, "*He and George Washington* (President) *frequently corresponded about farming matters. Jefferson noticed that newly cleared land didn't require fertilization due to its natural fertility. Initially, it was cheaper to obtain and clear new land but, after years of intensive cultivation, fertilizing became a necessity. Jefferson also practiced putting cattle in his fields to take advantage of their manure in restoring the fertility of his fields*" (Callis, n.d.)

Other exponents of the importance of soil care and circular agriculture include George Washington Carver, an early environmentalist (‘*the most prominent black scientist of the early 20th century*’), born a slave, the first person of colour at Iowa State University, later becoming the Head of the Agricultural Department at Tuskegee. He championed the use of crop rotation, set up a mobile education facility nicknamed the ‘*Jesup Wagon*’ after the funder of it, and was admired for his work by President Theodore Roosevelt), (Wikipedia, 2023a)

Why we are so slow to consider and learn from the wisdom of our forbearers is puzzling, ‘Illogical’ as Dr Spock of Star Trek might observe. Other prescient Sages include Charles Darwin on the importance of worms; Sir Albert Howard on the importance of compost; Robert McCarrison and William Albrecht on the relevance of growing conditions to the nutritional content of food and human health; and many others, including Rudolph Steiner, and Eve Balfour.

They all recognised the importance of soil biology and the relevance of compost. The ‘*Journey to Forever*’ ‘*Small Farms*’ website has many classic free open-access publications on soil-centric farming, including books now out of copyright, on farming, compost and related topics. Volume 2 considers the importance of regenerative agriculture in creating a more cyclical economy, in which the need to recycle urine and faeces is an important element.

33. GREENING AND BETTER WATER CATCHMENT POLICIES

Unquestionably, better environmental management of natural resources makes sense. “*More than 4 billion people live in parts of the world where freshwater scarcity directly threatens human water security or river biodiversity. Threats to human water security can be overcome by building centralized infrastructure that harvests, stores, treats, and transports water for agricultural, industrial, and municipal uses.*” (Grant, 2012)

For example, soil health was a component of a US scheme to keep water supplies cleaner at source. In 1990, New York City authorities - faced with an enormous bill for a new treatment plant as its water quality declined, in part due to growing urban-based pollution - thought laterally. Instead of building costly infrastructure, including more advanced water treatment systems, they chose to invest in the improvement of a water catchment area in the nearby Catskill Mountains. Farmers were paid to prevent run-off, improve soil health, and practise sustainable techniques such as continuous ground cover. The results were cleaner, cheaper water, and healthier, more sustainable land management,

This process was recorded in the review, ‘*The Water-Sustainable City: Science, Policy and Practice*’, which observed, "*When agriculture and residential developments threatened surface-water quality, the city considered building an $8 billion water treatment plant, but instead opted to spend $1billion buying land and restoring habitat in the water supply catchment. This approach obviated the need for a treatment plant, saved the city billions of dollars in capital and ongoing operations and maintenance costs, and preserved a critical ecosystem*”. (Feldman 2017)

34. COMPOST – BIOLOGICAL VALUE IN ASSISTING CROP HEALTH

Composting is the managed thermophilic aerobic bacterial decomposition of organic solid wastes to create a humus-like material. This material provides carbon, diverse fungal and bacterial biology, and slow-release nitrates and phosphates, which benefit soil biome and plant biology, health, and yield. Fungal and bacterial species diversity in compost depends on the aerobic techniques used, the access of multiple bacterial and fungal species to the process by deliberate integration, accidental atmospheric and other inclusion, and the maturity of the compost.

Compost's crucial and underappreciated benefit is its capacity to supply a wide diversity of fungal and bacterial biology to the soil around newly planted seeds. The soil biome, in all its diversity, has been highly motivated by evolutionary experiences to use all available strategies, including wide fungal and bacterial soil life diversity, to assist and maintain growing optimally photosynthesising plants above them whenever conditions make that possible because if you are a denizen of the soil biome, no growing plants above means 'no food' – no carbon energy substrate supply – which ultimately results in death.

34.1. ASSISTIVE SOURCE OF DIVERSE BACTERIAL AND FUNGAL GERMINATION BIOLOGY

The bacterial and fungal spores in compost, by assisting and complementing the internal and external seed biome, can help trigger and support seed germination (Sugiharto, 2022), early development of the root mycorrhizal sheath and generally enhance the speed and extent of plant soil biome synergistic interactions and development. (Chahtane, 2018; Samreen, 2021; Johnstone-Monge, 2021). Both fungal and bacterial plant holobionts are important. However, fungi have particular relevance because they provide the primary mechanism for the bidirectional transport of nutrients between the plant and soil biome.

Indeed, "*abundant literature reports the capacity of fungal endophytes to promote plant growth and to improve their tolerance towards abiotic and biotic stresses, in exchange of nutriment supply and shelter*" (Rentif, 2023). As discussed, fungi infiltrate, interconnect, and interact with plant root systems and thus are key and central to the distribution of photosynthetic carbon sugars produced by the plant to the soil biome.

The soil biome systems are absolutely dependent on carbon sugar and lipid root exudates for energy. In return for those life-giving plant photosynthetic carbon sugar root exudates, the soil biome provides, and the mycorrhizal system transports, minerals, nitrates, and other support services relating to plant health and function.

Notably, the diverse life forms of the soil biome, as a by-product of their own energy production, create metabolic water (as do all life forms), which will be proportional in volume to the amount of respiring living life in the soil. During dry periods of low rainfall, the soil biome uses that metabolic water to keep its environment moist and provide water to keep their plant symbionts alive and photosynthesising, producing carbon sugars, the soil biome's 'breakfast lunch and supper', explaining why regenerative soils and crops are more drought resistant and entirely consistent with a strategy by the soil biome to optimise its own survival prospects.

Seed biology is much more sophisticated than generally realised; for example, it can even halt germination when exposed to infectious bacteria, thus reducing the risk of infection. The sensing by seeds in coordination with their own internal and external fungal and bacterial biomes and their biological reaction to the presence of soil bacteria and mycorrhiza is likely part of their evolutionary response and adaptation to growing conditions, including the fecundity of the environment, allowing them to optimise germination processes to the regional and temporal conditions in which they find themselves, thus maximising their chances of survival and reproduction.

Clearly, bare soils do not contain plants. A bare soil means the supply of carbon sugar exudate to the soil biome is physically impossible. The absence of a supply of carbon sugar root exudate obliges the soil biome, which must have access to energy to survive, to metabolise soil stored carbon, in effect, as the primary source of carbon in soils, cannibalising itself, driving down soil life, reducing diversity, soil carbon, retained water and metabolic water production capacity, and reducing soil carbon, and future capacity to assist seed germination and mycorrhizal development.

34.2. SOIL FUNGAL 'INTERNET' / RESOURCE DELIVERY, COMMUNICATION SYSTEMS

As well as impacting plant and soil biome biology in numerous ways, soil biomes, including bacteria, fungi, and microorganisms, are by various mechanisms, the bidirectional internet delivery logistics communication network, and related bi-directional physical transport infrastructure between plant roots and the soil world, facilitating the exchange of products, including plant sugars, for soil-biome provided nitrates, minerals and metabolic water.

Increased microbial and fungal complexity improves capacity for;

- bacterial nitrate production;
- greater activity, volume, variety and turnover of soil biome life, thus plant available nutrients in soils;
- efficient mineral abstraction by mycorrhizal and bacterial systems for supply to plants, including through rhizophagy;
- better plant health, nutrient density, and antioxidant production through improved nutrient supply by the soil biome;
- increased plant capacity to photosynthesise carbon sugar exudates, both for supply to the soil biome and to support their own growth;
- better signalling and information exchange between plants and the soil biome;
- improved soil biome production and supply of plant health-protective, metabolic regulation and adaption, substrates,
- more extensive and more diverse plant soil biome exchange of bacteria and fungi, including some with antibiotic properties;
- higher plant nutrient, including mineral and antioxidant content;
- higher water retention and capacity for metabolic water production.

Increased diversity, including soil biome complexity, allows greater and more sophisticated biome interaction, allowing for more complex and extensive symbiotic networks of relationships with plants of the same and different species.

34.3. SEED BIOMES – SYMBIONT INTERNAL AND EXTERNAL BACTERIA AND FUNGAL SPORES ASSIST GERMINATION AND GROWTH.

Evolutionary natural selection has ensured that seeds, at the point of germination, have access to an assistive bacterial and fungal, internal endogenous endosphere biome, external exogenous exosphere seed shell biome, and diverse fungal and bacterial soil biome.

Several mechanisms determine how fungal and bacterial biology, seed internal and external, and soil, bacterial and fungal biomes are incorporated, utilised, and transmitted to future generations of seeds and soil biomes, thus optimising plant survival in the environments in which they find themselves. (Johnston-Monje, 2021; Mitter, 2017; Nelson, 2018).

34.4. FUNGI IN SEED BIOME - KEY TO GERMINATION AND GROWTH

A study in raspberries suggests that fungal species present in plants may change during the germination, growth, and maturation phases. It also suggests that fungal species may not always be present in a seed biome (Wysoczański, 2021), thus making the presence of a diverse fungal biome in soils particularly important.

A study on oaks suggests acorns may contain fungal biology derived from the environment of the parent plant (U'Ren, 2021). Similarly, a wheat study indicates that the seed's fungal content is influenced by its environment (Sharon, 2023).

In species and or seeds that do not carry fungi or carry limited fungal species in the seed's internal and external shell biome, the presence of fungi in the soil surrounding the seed at the point of germination assumes particular importance in early growth, not least because of the role of mycorrhizal fungi in the transport of nutrients to and from plants.

Indeed, the availability of relevant fungal bacteria from the soil biome to the seed during germination may be a critical factor in optimal growth and development of the rhizosheath, and more so given current practices of applying biocide, fungicide, and other treatments to seeds, which may kill external seed biome elements.

The provision of fungal biology by quality composts might help explain the growth-enhancing and supporting role of compost as seen in its use by the Haggertys in Western Australia and Albert Howard in India because compost supplies diverse fungal biology at germination that may not otherwise be present.

34.5. HERBIVORY – TRANSFER OF GUT AND ORAL FUNGI / BACTERIA TO SOIL AND PLANTS

A wide range of bacteria and fungi, from the soils and plants with which herbivores have had contact during grazing, as well as their own endogenous bacteria and fungi, can be transferred by herbivores to seeds during mastication, within the gut, and on excretion, adding to the diversity of the seed surface (epiphytic) and soil biome.

The potential importance of the role of ruminants in defining seed microbiome diversity is highlighted in the review, '*Insights into the seed microbiome and its ecological significance in plant life*', which observes, "*Interestingly, bacteria belonging to Bifidobacterium, Faecalibacterium, Lactobacillus, Clostridium, and Streptococcus which are common animal gut residents are abundant members of the epiphytic seed microbiome. The fact that seed surfaces harbour many of these taxa is indicative of the importance of dispersal processes in defining the epiphytic microbial diversity of seeds*" (War, 2023).

This fundamental biological communality and linkage between the animal gut and seed biomes may be one of the factors explaining the observed benefits of regenerative cyclical grazing to land health, stocking capacity, and livestock health, as well as the assistive value of livestock grazing, in transitioning land to broader regenerative arable farming practices.

These biological commonalities and interactions help explain the value of composts made from a diverse range of substrates, including human and regeneratively raised livestock, and wider species, faeces and urine, in providing biology, including fungi, that are key to fecund plant germination and growth. These symbiotic systems underline that we underestimate the importance and sophistication of evolved integrated biological systems, including life-plant interactions, at our peril.

34.6. FUNGI AND BACTERIA IN COMPOST POWERFULLY ASSIST PLANT GROWTH -

Sir Albert Howard and others achieved remarkable improvements in plant health and growth with application to soil of a quarter of an inch, approximately half a centimetre covering of compost. Indeed, others have shown that the modest application of mature, biologically diverse, unsterilised compost extract as a seed treatment, by injection, application to the seed, drip and spray, or soil application indeed boosts seed germination and growth, as discussed and referenced in Volume 2 on regenerative agriculture.

Cleary the amount of organic matter and other nutrients in such a small amount of compost, in relation to soil volumes, is limited, which begs the question, and reason to wonder, if substantial benefits to crops, reported by Howard and others, were exaggerated, or if indeed accurately reported, why compost is so effective at promoting germination and onward growth.

However, it appears the reports were not exaggerated, as David Johnson and others replicated them in the last few years, again as set out in Volume 2 on regenerative agriculture. Johnson's research supports Howard's posits that the 'secret' ingredient of quality composts is their diverse fungal and bacterial biology, which helps provide seeds with easy and immediate access to the progenitors of fungal and bacterial soil biology they need but are lacking, or in addition to, those in their internal and external epiphyte, endogenous seed biomes, needed to; form optimal mycorrhizal sheaths, create nitrates, mine minerals, and access the other services provided by the soil biome.

Whilst the seed, as mentioned, has its own external and internal biome, improvements in growth with the application of compost teas to seed suggest it is expecting or benefiting from both bacterial and, particularly, fungal diversity in soil biomes and has evolved to interact with a soil biome to achieve optimal growth.

In degraded soils, which most are, the necessary biology may not otherwise be present and available to the germinating and developing plant. Giving the plant access, at germination, to the biologic symbionts it needs to make its own optimal bacterial and fungal root garden allows it to flourish in its preferred, individual conditions-dependent, diverse mycorrhizal ecosphere without artificial fertilisers and agrochemicals.

34.7. IMPACT OF COMPOSTING PRODUCTION TECHNIQUE ON BIOLOGICAL DIVERSITY AND ASSISTIVE VALUE

The use of well-made compost extract, or potentially more specific industrial bacterial/fungal mineral supported bio-fertilisers, offer crucial opportunities to significantly accelerate the transition to regenerative agriculture and reduce, even negate, the need for agrochemicals and NPK artificial fertilisers, close the organic waste cycle; and set a path to increased profitability; and at the same time greatly enhance environmental sustainability.

However, much still remains to be learnt; whilst compost use is a technology of great age, which we cannot afford to ignore, we are only beginning to appreciate the technical and biological details. Like all biological processes, composting and its broader related aspects are multifaceted and complex. Different composting techniques can, inter alia, impact composting times, diversity of bacterial and fungal species, solubility, thus availability of nutrients, capacity to facilitate plant growth, greenhouse gas emission, initial carbon/nitrogen ratio requirements, risk of odours, remediation of pollutants, and other factors.

For example, composting methods can impact phosphorus solubility, thus availability and release. "*Different types of organic wastes composted, and the methods of composting, may directly affect the P availability to plants*. *During [a] bioreactor composting of sewage sludge, a stronger humification and stabilisation of organic compounds was observed, including bound-phosphorus, which reduced its bioavailability for plants.*

The review '*Estimation of phosphorus bioavailability from composted organic wastes*' observes, "*Much greater practical importance should be attributed to the identification of chemical forms of elements in composts and facilitating an assessment of the degree of their solubility, and thus their bioavailability*", (Jakubus, 2016). A further benefit of composting is the slow release of nutrients, reducing runoff risks and eutrophication.

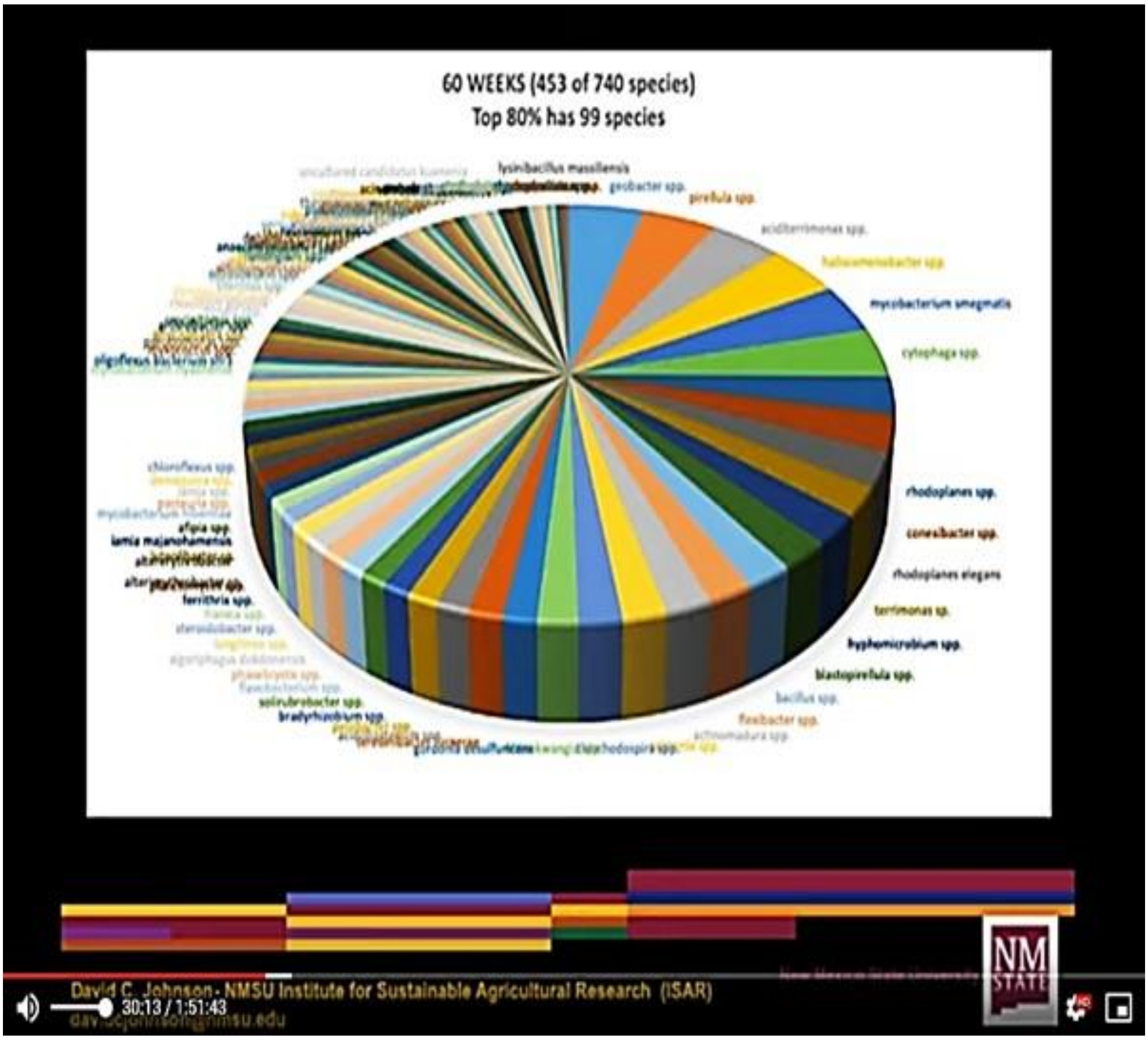

Fig. 76. Dr David and Hui Chun Su Composting with many thanks to the authors and UTube (Johnson & Su, 2019),

Compost maturation time may also be an important factor in compost quality, including fungal and bacterial species diversity, as illustrated by an analysis of 60-week-old compost, summarised in the pie chart above. David Johnson reports that biological diversity increases with compost ageing.

Diversity allows plants to select fungi and bacteria to meet their needs according to the soil and growing conditions, including weather conditions in their specific location. Creating regionally relevant diverse composts and allowing the plant to choose would seem to be a better strategy than trying to create products with specific limited fungal and bacterial populations.

Hyperthermophilic composts mature in much shorter timeframes and result in changes in bacterial populations, and research is required to better determine their bacterial and fungal profiles. Post hyperthermophilic composting, it might be possible and necessary to accelerate the evolution of fungal and bacterial composts to optimally support plant growth, with appropriate seeding of complex, high-diversity mature composts. Research into such matters is urgently required.

34.8. NITROGEN AND MINERALS IN COMPOSTS

As discussed, the amount of easily soluble nitrogen in compost tends to be lower than in sewage sludge (Bousselhaj, 2004), suggesting that the latter may be more effective in reducing the risk of run-off.

Providing limited soluble nitrates and phosphates, minerals, and carbon in compost to soils is synergistically helpful, but it is not the most important aspect of compost application. As discussed, compost's most significant and crucial impact is the provision of diverse fungal and bacterial biology to germinating seeds.

Compost, or compost extract, provides key nutrients necessary for initial germination. However, the nutrients present are not sufficient in quantity to support later growth, instead giving the germinating plant all it needs to develop a mycorrhizal sheath that efficiently interacts with the soil biome in a symbiotic process that ensures it receives all the nutrients it needs to grow efficiently, which in turn optimises the ability of the nascent plant supply of carbon sugar exudates to the soil biome. In addition, compost supplies organic detritus to soil creatures that use it in various ways.

34.9. ACCELERANT FOR TRANSITION TO REGENERATIVE AGRICULTURE IN POOR SOILS

Composts can significantly accelerate the transition from FATBAS to regenerative agriculture. As discussed, mature compost, as well as returning minerals, carbon and nitrates to the soil, interestingly and importantly, contains bacterial and mycorrhizal progenitors, including spores and dormant bacteria, capable of facilitating early seed activation and accelerating development during germination and early growth, of a healthy root encasing biologically diverse mycorrhizal sheath, supporting nitrate production, mineral mining and supply, and bacterial root interactions.

Given that seed biomes are richer in bacteria than fungi, might compost have an important under-recognised role in providing access to fungal species that, in turn, mine minerals and provide other services?

Growers that coat and/or inject seeded soils with compost extract at planting and later use foliar drips and sprays report excellent growth, yield and drought resistance, even in degraded soils. (Christine Jones; the Haggertys, David Johnson, etc. see Volume 2, on regenerative agriculture)

Experiences and observations discussed in Volume 2 suggest that mature compost extract can be further improved with a marine amendment, likely containing a mix of microminerals, including iodine. Provision of micro minerals to the seed in the germination zone in soluble form by ensuring the seedling's access to the minerals it needs during germination overcomes the real possibility that in the area of the root zone, a degraded sandy soil does not contain the necessary minerals in accessible form.

The capacity to facilitate germination in soils almost devoid of biological life will speed the development of soil life and diversity, thus accelerating the regreening of degraded landscapes, including deserts, through regenerative agriculture.

35. COMPOSTING HISTORY AND TECHNIQUES

As a technology, composting is supported by modern science and age-old knowledge and experience. Many generations have observed the power of quality compost to improve massively soil organic matter and diversity, crop yields and quality. Humans have been composting waste for agricultural use for millennia. Composting, at its simplest, is cheap, achievable, and capable of widespread implementation globally, including at the local level, both in developed and developing economies.

35.1. HISTORY

In the review, *'Another Short History of Composting',* Steve Callis records that 5000 years ago, Scots were planting crops in rotting manure. He also points out several references to composting in the Middle East, including in the Bible and Talmud. For example, he notes, *"Researchers have found clay tablets from the Akkadian Empire, around 2350 BC, which are the first to speak of "making" compost for agricultural use. The Akkadian Empire was in the Mesopotamian Valley, present day Iraq."* (Callis, n.d.)

Ancient Chinese and Hindu texts also refer to composts. Native Americans widely used compost. Cleopatra declared worms sacred. The Romans used compost; Cato the Elder wrote on the subject. The long-lived Hunza composted everything they could, including human faeces and urine.

As discussed in Volume 2 on regenerative agriculture, King, in his book *'Farmers of Forty Centuries: Organic Farming in China, Korea, and Japan'*, written in the early 1900s, recorded then Chinese farming practices, observing in detail that compost-making and use, including of human excrement, was a significant element in traditional Chinese farming.

In India in the 1930s, Howard, the noted agronomist often called the father of organic farming, developed the 'Indore' composting technique and reported remarkable success in improving crop quality, product shelf-life thus logically nutrient, including antioxidant density, yields, plant health; control of diseases common in commercial crops; reclamation of salinised soils; as well as livestock health.

35.2. COMPOSTING OF FAECES AND URINE

As discussed, animal and human waste was traditionally collected, composted and returned to the land. However, modern industrial farming practices have generally not chosen to go down that route, instead choosing application of fertiliser, untreated slurry, and or sewage sludge to land, which is wasteful and polluting.

Sludge is only partially remediated and contains a significant range of pollutants, including pharmaceuticals, PFAS and PCPs. In slurry, the pharmaceuticals are wholly unremediated, as are pathogens and viruses. Slurry and sludge also contain high levels of soluble phosphates and nitrates; *"These large amounts of wastes are under-utilised and thereby causing a serious threat to the environment (Yang, 2018).* They are released in high rain events, along with large amounts of organic matter, causing eutrophication in rivers, lakes and oceans.

In contrast, Yang et al. observe, *"Composting of organic solid wastes is an effective strategy for organic waste recycling and beneficial practice for soil restoration. Compost application not only provided an important source of nutrients, but also improved soil structure, enhanced crop yield, and suppressed soil-borne pathogens. Compost amendments therefore maintain and enhance the fertility and productivity of agricultural soils*" (Yang, 2018).

In China and Japan, virtually all organic matter was historically composted and returned to the land, as discussed in Volume 2 on regenerative agriculture. Modern Japan recognised the value of composted manure by enacting legislation for the composting of cattle manure in 2004. As a result, most of the dung produced by the nation's cattle—around 25 million tons a year—is composted.

35.3. CATTLE MANURE COMPOSTING IN JAPAN IS MANDATORY AND EXTENSIVE

Japan, by setting standards and creating established pathways in statute, helps ensure manure is handled efficiently with minimal environmental damage or nuisance and creates an expectation of *"community-scale use of compost in farms"* ('*Current livestock-related environmental issues and responses'*, Ministry of Agriculture, Forestry and Fisheries, 2018).

"Passively aerated composting is the major process used to treat Japanese dairy manure. About 68.7 per cent of dairy manure was treated by this process in 2009, and the mature compost is used as organic fertiliser for crop production or grassland application" (Maeda, 2013). Japan's example provides large-scale proof of principle that, given appropriate legislative and incentive measures, widespread composting of at least cattle manure can be introduced globally.

However, Japan is an exception. In many countries, a slurry of mixed livestock urine and faeces is returned directly to agricultural land, *"Manure management is often poor . . . The value of manure is often not recognised by farmers and policy-makers, especially in the case of liquid manure and urine. . . . [Often], the main drivers for manure policy are focused on energy production and the need to address environmental or public health problems. Often the fertiliser value of manure is not a driver for policy. . . . Technologies for and knowledge of integrated manure management are available, however, implementation is often challenged by:*

(1) a lack of awareness of manure's potential;
(2) a lack of knowledge and a supporting knowledge infrastructure;
(3) ineffective policies;
(4) dispersed expertise;
(5) a lack of resources and investments" (Teenstra, 2014).

35.4. COMPONENTS OF COMPOST

Traditionally made compost from non-polluted materials contains various components, the composition of which will depend on the original compost material, the composting techniques, and the degree of maturity of the compost.

The Food and Agriculture Organisation of the United Nations publication manual on compost, "*Soil management compost production and use in tropical and subtropical environments*" (FAO Soil Bulletin, n.d.), observes:

"*The produce left in the compost heap at the end of the breakdown stage consists of:*

i. *the more resistant parts of the original wastes, particularly the lignin or woody materials;*
ii. *intermediate products formed during the process;*
iii. *the bodies of dead micro-organisms;*
iv. *humus, the complex and stable material formed by complicated chemical interactions between materials i, ii and iii;*
v. *living micro-organisms and small soil animals;*
vi. *mineral matter (ash)* (including phosphates) *brought in with the original organic wastes as soil on plants roots or road sweepings in refuse;*
vii. *water still present, mainly absorbed in the organic matter*."

Composting creates a friable, easily handleable material, free of unpleasant smell, a valuable, rich, diverse biome and plant nutrient resource, including bacteria and fungi, small creatures, carbon, nitrogen, and mineral content, including phosphates, that can be easily stored and applied, or used to make compost extract. The processing of compost and heat generated in the process inactivates many common pathogens. Composting, including of human excreta, is a proven natural process, leant on by humankind for millennia (Callis, n.d.).

35.5. REDUCTION GREENHOUSE GASES VIA MATERIALS AND BACTERIAL SELECTION

Gases, including greenhouse gases carbon dioxide, methane, and nitrous oxide, are produced during composting. Some will be recycled out of the air by plants in the next growing season, leaving a net change; such is the nature of the cycle of life. Controlled anaerobic and hyperthermophilic aerobic composting presents opportunities to reduce emissions.

The doctorate paper, '*Greenhouse Gas Emissions from Food and Garden Waste Composting*' (Ermolaev, 2015), observes: "*During composting, different gases are emitted to the atmosphere, primarily H_2O, CO_2, NH_3, CH_4, VOCs and N_2O. Excluding H_2O, the major gas emitted during aerobic composting is CO_2, while the proportions of other gases can vary depending on process conditions and process stage, as well as compost mixture properties*" (Ermolaev, 2015; Hao, Chang, & Larney, 2004; Savage, n.d.)

The choice of composting substrates, carbon content, maturation time, and temperatures may be key factors in developing even more efficient techniques. Opportunities clearly exist to tailor the composting process to meet end-goal requirements, including speed, amount of remediation, and reduction of greenhouse gas production.

Factors that impact composting outcomes include substrate composition, humidity, temperature, oxygen flow, and nitrate content. For example, one Japanese study found that adding 400kg of grass to 4 tons of excrement reduced greenhouse gases, illustrating how greenhouse gas content and mix can be substantially altered (Maeda, 2013).

Composting in enclosed spaces would allow the capture of greenhouse gasses, including carbon dioxide, if economically and environmentally worthwhile. Enclosed, controlled airflow, with bacterial enhancement, anaerobic and aerobic composting, combined with other technologies, including bacterial species selection, may potentially reduce related emissions of greenhouse gases, including nitrous oxide, by up to 90 per cent "*by regulating N_2O-related functional genes*" (Cui, 2019). Nitrous oxide is also a factor in global warming, reportedly more potent than carbon dioxide (EPA, n.d.).

Further, as discussed in '*Archaeal Community during Cattle Manure Composting Process in Field-scale Facility*', alteration in bacterial communities, including from exogenous sources, may improve nitrification and reduce ammonia emissions (Yamamato, 2011).
More widely, the thesis '*Greenhouse Gas Emissions from Food and Garden Waste Composting*' concludes: "*Composting is a viable waste treatment alternative that can help mitigate GHG emissions… In order to maintain low GHG emissions from food and garden waste composting, it is important…that the compost is used as a soil improver and to replace mineral fertiliser".* (Ermolaev, 2015)

	CO_2-C, % initial C	Emissions in kg CO_2-eq. ton^{-1} initial WW			
		CO_2	CH_4	N_2O	Total
Home composting (Paper I)[1]	4 - 65	16-266	0.776-12.51	7.37-119	8.14-131
Covered windrows (Paper II)	21	144	17.7	1.19	18.9
Laboratory reactor (Paper III, 16% O_2)	32 - 67	173-297	0-0.982	0.094-2.35	0.094-3.33
Laboratory reactor (Paper III, 1% O_2)	28	188	3.09	0.153	3.24
Laboratory reactor (Paper IV, Run 1-5)	45 - 50	294-368	0.329-28.8	1.13-4.89	1.46-33.7
Laboratory reactor (Paper IV, Run 6)	40	213	227	4.42	231

[1]The estimates for minimal and maximal degradation are based on VS from finished compost samples. VS samples which gave negative degradation were excluded. Average degradation in home composting was 18 CO_2-C, as % initial C and the average total GHG was 33 kg CO_2-eq. ton^{-1} initial WW.

Table 7. The table above from the Thesis, '*Table 12 Greenhouse Gas Emissions from Food and Garden Waste Composting*' (Ermolaev, 2015), illustrates how greenhouse gas content and mix can be substantially altered by factors including humidity, temperature, oxygen flow and nitrate content, with many thanks to the Author.

35.6. ADSORBENTS

Urine-impregnated adsorbents (clays, biochars, etc.) may have roles to play. Sir Albert Howard, in India, used clay as a flooring material for cattle sheds and incorporated it and the urine it contained in his then much respected and copied 'Indore' composting system.

35.7. TRADITIONAL COMPOSTING, PHARMACEUTICALS AND PATHOGEN REMEDIATION

As far back as the 1940s, it was demonstrated that traditional controlled composting generated temperatures sufficient to remediate most of the then-known pathogens (Biester, 2002). Indeed, the review, '*Proper Sanitisation of Sewage Sludge: A Critical Issue for a Sustainable Society*', confirms, "*It appears that composting is a fairly effective sanitization procedure, provided the temperature reaches the desired level, is maintained for a sufficient period of time, and remains consistently high throughout the entire compost pile.*" (Arthurson, 2008).

However, modern sewage contains a much wider range of pollutants, and the detection of pathogens and viruses has improved, so this now only holds partially true. Further, more advanced analysis techniques have found that care needs to be taken in monitoring and controlling the composting processes, as pathogens often can remain.

In addition, as discussed, 'modern' faeces and urine, now in addition to pharmaceuticals, contain antibiotic-resistant material, PCPs, PFAS, other pollutants, and microplastics, which are all poorly or minimally remediated by traditional composting.

The review, '*Composting technology in waste stabilisation: On the methods, challenges and future prospects*', observes, "*The effectiveness… is influenced by factors such as temperature, oxygen supply, moisture content, pH, particle size and degree of compaction*" (Onwosi, 2017). Composting is an aerobic process, thus requiring adequate oxygen to be present. However, it also relies on various actors, including bacteria – both actino and non-actino - fungi, mould, yeast, protozoa, rotifers and earthworms.

The biology of compost changes with temperature; thus, composting at different temperatures will produce different outcomes. Hyperthermophilic composting takes place at much higher temperatures. In non-containerised composting, decomposition happens initially at low temperatures by mesophilic microbes operating at 30 to 38 °C (86 to 100 °F) (Arthurson, 2008). However, the process then enters the thermophilic stage when the heat reaches 50 to 60 °C (122 to 140 °F). These temperatures and related bacterial species present tackle pathogens and start to break down pollutants, thus remediating organic chemical structures. Hyperthermophilic composting occurs at much higher temperatures, as discussed in later sections.

35.8. PESTICIDES DEGRADATION - TRADITIONAL AEROBIC COMPOSTING -

Pesticides in urban organic waste may be derived from sources such as foods and flowers. "*Dominant pesticides in the organic fraction of municipal solid waste were: Thiabendazole, Dicofol, Endosulfan, Dodemorph, Methiocarb, Captan, Chlorothanoline and Methidathion.*

Most of those compounds are used to protect vegetable, fruit or decorating flowers during transportation. Other pesticides are 'standard' agricultural and horticultural crop protection products" (Pšenička, 2011).

Traditional aerobic composting reduces some pesticides; as discussed, hyperthermophilic composting provides greater capacity for remediation. The review '*Persistence and Degradation of Pesticides in Composting*' (Singer & Crohn, 2002) summarises why composting should assist in degrading these toxic organic compounds.

Fig. 77. A Lite-Trac four wheeled self-propelled crop sprayer, putting pesticide on a field, with many thanks to Wikipedia and the Author.

It states: "*Compost is well suited for pesticide degradation because:*

> *• The elevated or thermophilic temperatures achieved during composting permit faster biochemical reactions than possible under ambient temperatures, accelerating pesticide degradation. The high temperatures can also make pesticides more bioavailable, increasing the chance of microbial degradation.*
>
> *• Some micro-organisms may co-metabolise pesticides, where the microbes rely on the feedstock for food and energy while breaking down an adjacent pesticide. Co-metabolism means that the micro-organism does not receive any energy or potential food from the secondary reaction (in this case, from breaking down the pesticide). The many different organic matter structures in compost help to promote co-metabolism of numerous objectionable compounds, even recalcitrant xenobiotics such as DDT, PCB and TCE.*

> • *Compost feedstock contains numerous and diverse active micro-organisms, all with their own characteristics and capabilities. This diversity means a greater chance that a pesticide will encounter a microbe that can degrade it.*" (Author's underline) (Singer & Crohn, 2002)

One composting study, '*Dissipation of pesticides during composting and anaerobic digestion of source-separated organic waste in full-scale plants',* found that, after nearly four months, significant remediation of 271 pesticides had occurred, but 28 were still detectable. "*More than two third of all pesticides detected in the input materials showed dissipation rates higher than 50 per cent during composting. Many of them - 218 - were not detectable any more after 112 days*", (Kupper, 2008). Others may have escaped detection. While the levels of pesticides discovered in this study were comparatively low, the authors added: "*The occurrence of contaminants raises some concern since recycling products of high quality are expected to be free of hazardous compounds"* (ibid*).*

Notably, some pollutants are toxic even at very low levels. As a result, growers have occasionally found that pesticides in compost inhibit germination or plant growth. For example, "*as little as 10 parts per billion of clopyralid can be toxic to legumes, potatoes, sunflowers and tomatoes*" (Singer, 2002; Varma, 2014). Clearly, with these most persistent compounds, the best way to address the problem would be to ban the use of persistent pesticides and related toxins that are not readily biodegradable.

Farmers using regenerative agricultural principles find they rarely, if ever, need to resort to agrochemicals, as plants are healthier and predators and prey rebalance. Regenerative farmers find that treatments are not economical or worthwhile given the limited value of crop losses compared to the financial costs, including loss of regenerative/organic premiums and cost of products and their application, as discussed in Volume 2 on regenerative agriculture.

35.9. COMPOSTING AND ODOUR

Contrary to public perception, compost is actually relatively odourless when produced efficiently. However, compaction and a lack of aeration may lead to anaerobic pockets, resulting in excessive methane production, foul smells and lower temperatures. Smell has been a major public issue for a number of composting plants.

However, composting proponents claim that using the correct substrate ratios and oxygenation through regular turning or forced aeration reduces odour risk. Aeration is key. For example, the small-scale 'Johnson-Su' composting bioreactor for plant material (Johnson, 2017), promoted as an easy-to-build DIY domestic option, is claimed to be entirely odour-free.

BioCycle – billed as an "organics recycling authority" – lists some of the most effective compost management practices in its article, 'Controlling Composting Odours'. Among them are "*the right nutrient balance between carbon and nitrogen (at least 25 parts of carbon for each part of nitrogen, on a weight basis), adequate moisture to form and maintain the biofilm (around 50 – 55 per cent) and enough structural porosity to ensure a free air space of at least 40 per cent to keep oxygen levels above an 8 to 10 per cent minimum*" (Coker, 2016).

Interestingly, a "*microbial-mineral litter additive consisting of 20 per cent of bacteria powder (six strains of heterotrophic bacteria) and 80 per cent of mineral carrier (perlite-bentonite*)", added to manure, reduced gas outputs by between 9 and 96 per cent, depending on the method and ratio involved ('*Odour-reducing microbial-mineral additive for poultry manure treatment*', Kalus, 2017).

Research is finding other ways to optimise oxygenation through system design. It is also worth remembering that in winter, in northern climates, composting may require heating to initiate bacterial activity.

Forced air-containerised hyperthermophilic composting in tightly controlled environments would increase opportunities to capture or filter gas outputs and reduce opportunities for activity by the anaerobic bacteria that cause odour issues. As above and below, more research is urgently needed to optimise composting technologies.

35.10. IMPACT OF TEMPERATURE ON COMPOST BIOLOGY

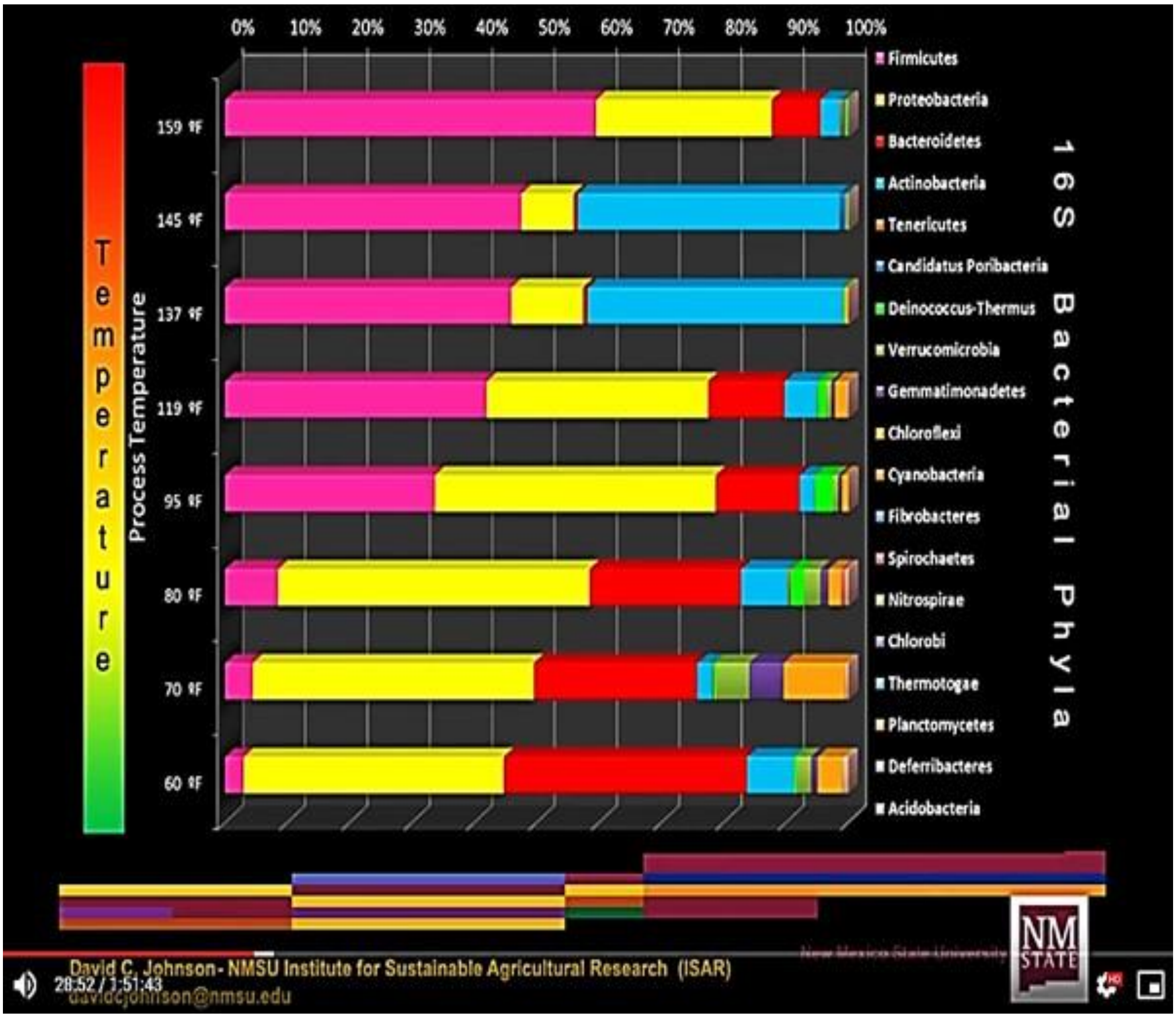

Fig. 78. Illustration of the changing microbial population balance of composts with temperature, from the YouTube lecture '*Dr David and Hui Chun Su Composting*' (Johnson & Su, 2019), with many thanks to the Authors and YouTube.

Of significance, as discussed, is that the biology of compost will change with temperature, as heat also causes changes in species prevalence; thus, different techniques will tend to produce different compost biology and composting times.

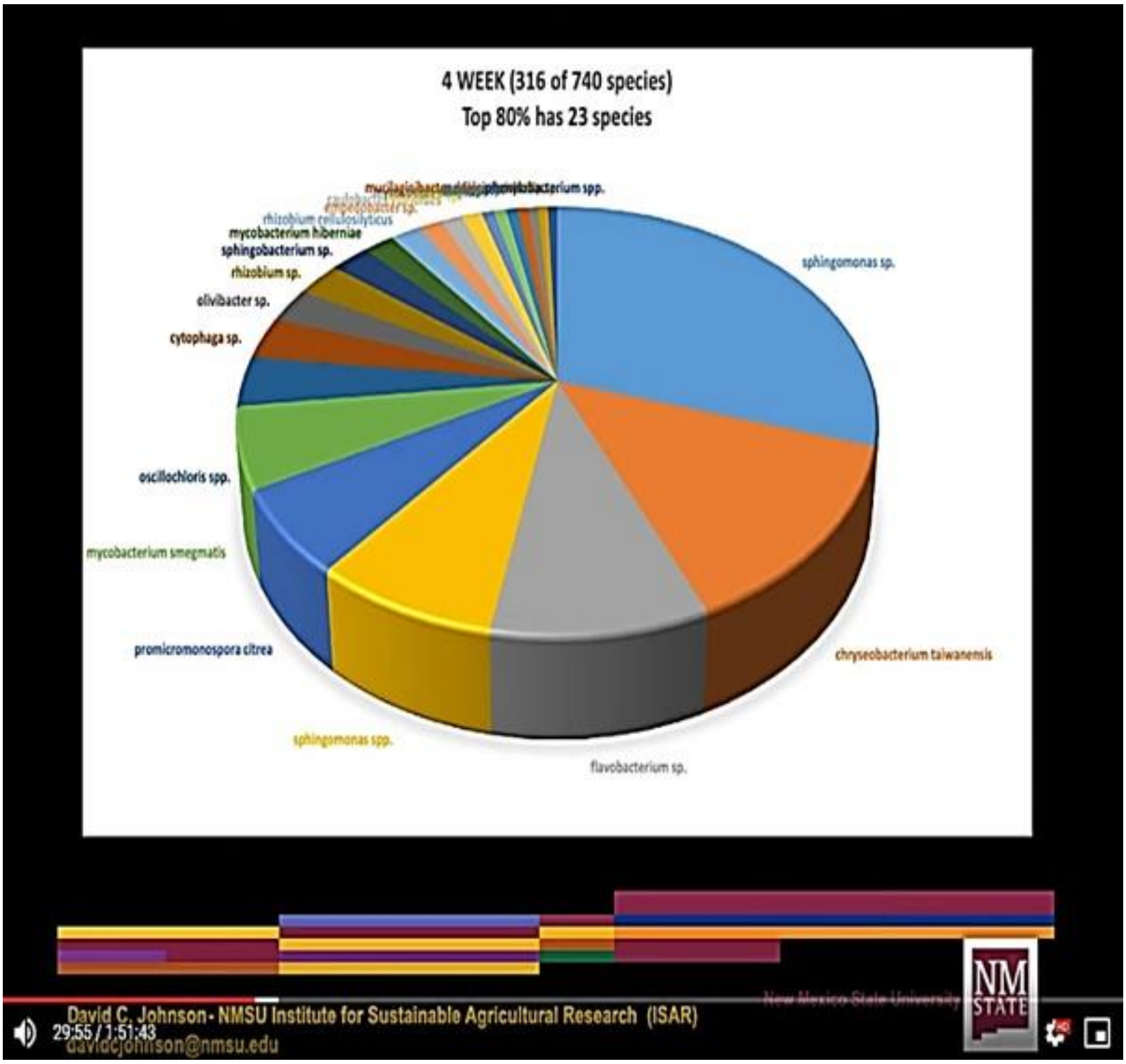

Fig. 79. An illustration of the increase in complexity with time of the microbial populations of composts is shown in slides from the YouTube lecture 'Dr David and Hui Chun Su Composting' (Johnson & Su, 2019), with many thanks to the Authors.

Hyperthermophilic composting tends to be adequately achieved in much shorter time frames, resulting in significant changes in bacterial biology. The biology will also change with the ageing of the compost, becoming more complex over time, providing another variable for optimisation. More complex biology may provide additional benefits for plant germination and growth. Biology will also change nitrogen dynamics.

Whilst knowledge is slowly growing, and more studies are slowly appearing, much about composting and its impact on plant germination and growth, including optimising the biology available to the nascent seed, remains to be discovered.

We only partially understand the impact of aerobic processes on the changes between the original substrates and the final compost. However, we are beginning to understand that nitrogen content and dynamics can be controlled to some extent (Nayak, 2014).

35.11. OTHER SPECIALIST COMPOSTING TREATMENTS WITH REMEDIATION POTENTIAL

As discussed, a large portion of pharmaceuticals ingested, including antibiotics, are excreted unaltered; thus, finding better remediation processes is important. Interestingly, Estonian researchers studying sewage sludge, found that pharmaceuticals can be significantly removed through specialist composting – but it takes time: "*During [the] 12 months composting period the concentrations of all the studied pharmaceuticals diminished for 99.9 per cent*" (Haiba, 2016).

The downside to such techniques is the time taken. There is little point in pretending that time does not matter. Long composting times present economic and practical issues. Time has a value and a cost, especially to farmers. It is thus important, both economically and practically, to shorten the time required to produce compost. However, there is a balance between composting time and the quality of the end product, which will vary with the technique employed; for example, "*Immature compost can have harmful effects on plants and soil ecosystems, particularly if the compost is applied before sowing, or if it is used as a growth substrate*" (Malkki, 1999).

Bulking agent (% from dry matter)		**SMX**	**SDM**	**NOR**	**NOR**	**OFL**
1	Peat (50)	83	77	90	92	100
2	Sawdust (33)	100	99	96	95	100
3	Sawdust + oil shale ash (29+14)	100	96	82	94	99
4	Sawdust + wood chips (total 43)	100	99	91	98	86
5	Straw (50)	99	98	79	90	74
CIP – ciprofloxacin; NOR – norfloxacin; OFL – ofloxacin; SDM – sulfadimethoxine; SMX – Sulfamethoxazole						

Table 8. Degradation of pharmaceuticals in sewage sludge compost mixtures during a 4-months composting period (%) abstracted from '*Table 3 Sewage sludge composting and fate of pharmaceutical residues –studies in Estonia*' (Haiba, 2016), with thanks to the authors.

Long composting time requirements limit commercial opportunities, but the studies indicate that hyperthermophilic composting can achieve much faster composting and better pharmaceutical remediation.

35.12. COMPOST QUALITY AND TESTING

Testing regimes exist for compost and have been used in Europe. Interestingly, the results were good. "*The pan-European investigation of contamination by organic contaminants showed generally good quality of the composts, the majority of which were in compliance with conservative limits applied in some countries. Results demonstrate performance and added value of rapid, inexpensive, effect-based monitoring, and points out the need to derive* *corresponding effect-based trigger values for the risk assessment of complex contaminated matrices such as composts*.". (Benišek, 2015). While such testing is a very positive and welcome move forward, it may be necessary to look at a broader range of parameters if composting human urine and faeces is to become the standard process.

35.13. COMPOSTING IN LOW TECH ENVIRONMENTS

Where vacuum toilet collection systems are not viable or affordable, separate collection of faeces and urine is still possible using various low-tech mechanisms. The products can then be transported for treatment.

A low-technology thermophilic composting system set up in Haiti (Jenkins, 2012) illustrates the potential of simple composting and public acceptance of it. Cooperation and a degree of success can be achieved, even where the existing composting techniques do not adequately deal with pharmacological products or antibiotic-resistant bacteria. Such cooperative systems invite the development of low-tech enclosed forced airflow hyperthermophilic composting systems built out of available, affordable materials.

Fig. 80. Soil Poopmobile delivers buckets of waste to the soil composting facility in Port-au-Prince, with thanks to Author Ricardo Venegas and Wikipedia.

Low-tech locally made enclosed-closed-forced-airflow-hyperthermophilic-composting may prove less efficient than high-tech monitored and enclosed industrial units. However, they could be affordable, 'doable', practical options in developing economies, including in rural areas. They would also likely represent a significant improvement on existing composting systems and a great improvement over the disposal of untreated sewage or septic tanks.

Thus, research is urgently needed to develop better low-tech and high-tech bio-digestion and composting techniques (likely hyperthermophilic) for optimising the remediation of pollutants, including pharmaceutical products, the production of energy, the creation of compost, with consequent benefits to the broader community.

35.14. COLLECTION OF WASTE STREAMS AT SOURCE

Separation of streams at source, including human faeces and urine, through vacuum WC technology and hyperthermophilic digestion followed by composting, with appropriate testing, arguably offers the best prospect for reducing downstream pollution and closing the cycle. Each stage has additive and different advantages; for example, dioxins were considerably lower in digestates from manure and source-separated biowaste than municipal compost (Benišek, 2015).

35.15. HEAT ENERGY FROM COMPOST

Composting produces heat. The heat from composting for agricultural gain may have been used in China more than 2,000 years ago for hotbeds. There has been increasing interest and experimentation in this field, as limited studies have demonstrated varying degrees of commercial viability.

The review, '*Heat Recovery from Composting: A Comprehensive Review of System Design, Recovery Rate, and Utilization*', observes a heat reclamation system …*"was constructed by digging a 1 m trench, filling it with manure and covering it with a layer of topsoil for crop production*" . . . "*Extracting heat from compost was further refined in France, starting in the 1600s, where hectares of glass-enclosed hotbeds were utilised for winter cultivation and season extension*" (Smith, Aber & Rynk, 2017).

Other studies, including '*Energy from Waste: Reuse of Compost Heat as a Source of Renewable Energy*' (Irvine, 2010; Collins Powder Hill Farm Compost Heat Recovery Case Study, 2019), also examined the issue of energy recovery. The development of insulated enclosed hyperthermophilic composting may provide opportunities for creating usable heat, including recycling and storage of heat, to maintain composting system efficiency in colder climates during winter.

35.16. MINERALS IN SOILS – NATURAL RECYCLING AND REPLENISHMENT COMPOST

There is a growing understanding that, left to their own devices over millennia, many natural factors play a part in recycling and redistributing soil minerals: they include the breakdown of rock substrate by the soil biome, volcanic activity, windborne ash in smoke and fires, erosion, wind-blown dust and glacial action, and spread in urine and dung of ruminants and other species.

However, the extraction and export of minerals in crops, FATBAS-bare-soil erosion, repeated quick-fire cropping of productive landscapes, sewage cycle-related discharge into watercourses, or incineration and mine storage of ash are outside any natural process cycles and, by definition, unsustainable.

Thus, there are unquantifiable risks in the very long term that regionally and subsoil rock strata-dependent levels of scarcer minerals in soils, like selenium and phosphates, might become suboptimal for plant growth, subject to replenishment by natural pathways, unless they are topped up over time.

The risks of long-term soil mineral insufficiency are largely unknown and poorly understood. However, they self-evidently should be minimised as far as possible and safely by closing the extraction return cycle through appropriate composting of human and livestock faeces and urine and by optimising the potential for the provision of minor minerals, by foliar application, possibly derived from the residue of sea salt extraction (a topic covered in more depth in the Volume on regenerative agriculture).

36. HYPERTHERMOPHILIC AEROBIC COMPOSTING

Hyperthermophilic aerobic composting of various feed-stocks, including sewage and cattle manure, is relatively new but has been trialled, developed to include real-world working examples; and with a changing bacterial biology, reaches high temperatures; is fast and efficient; will work with low carbon ratios, produces low odour, may reduce and or allow capture of greenhouse gasses; and shows relatively good remediation of pharmaceuticals and ARGs.

The review, '*Hyperthermophilic Composting Technology for Organic Solid Waste Treatment: Recent Research Advances and Trends*' observes 'HTC' techniques offer:

- better remediation,
- reduced nitrous oxide (a global warming gas) production,
- may reduce ammonia emission and improve nitrification (Yamada, 2007),
- use of enclosed vessels allows capture and even use of gasses,
- speed, composting taking 18-25 days, thus offering significant time savings,
- lower carbon nitrogen feedstock ratios (important in relation to anaerobic digestate),
- lower operational costs,
- a more significant portion of the soluble heavy metals are converted to insoluble forms,
- good remediation of antibiotics and related ARG, possibly 80-90%,
- increased controllability (Wang, S. 2021),
- high temperatures, potentially 90^0C+
- low odour,
- evidence of remediation of some microplastics, 30-40% in one study,
- production of usable compost,
- an opportunity to help better close the environmental cycle.

Wang summarises, “***HTC shows remarkable advantages over conventional technologies for organic solid waste treatment, including easy operation, resource recycling, little residue and odor emission, and a short processing period****. In particular****, HTC can effectively decrease GHG emission, in situ degrade MPs, remediate Cu(II)/Pb(II)-polluted soils, and remove antibiotic* **residues and ARGs*”*** (Wang, 2021) (This author’s bold).

Characteristic	HTC	TC
Maximum temperature (°C)	>80	50–70
Average temperature (°C)	70	40
Thermophilic period (d)	≥80 °C, 5–7 d	≥50 °C, 5–7 d
Composting period (d)	15–25	30–50
Low C/N (<10) for start-up	Easy	Hard
Compost maturity	GI [a] ≥ 95%	GI ≥ 65%
Pathogens inactivation rate	High	Low
Waste weight reduction (%)	52.4	45.9
Moisture loss (%)	58.9	53.4
Organic matter loss (%)	66.8	63.8
Nitrogen loss (%)	26.2 26.1	31.0 44.2
Odor	NH_3, less	NH_3, H_2S, SO_2, more
Operation cost	Low	High

[a] Germination index.

Table 9. A comparison of the characteristics of hyperthermophilic composting to traditional composting from (*Table 1 of ‘Hyperthermophilic Composting Technology for Organic Solid Waste Treatment: Recent Research Advances and Trends*’ with many thanks to the authors. (Wang, 2021)

Wang goes on to list areas where more research is required. Thus, overall, HTC looks promising, particularly if it could be combined with hyperthermophilic anaerobic digestion for biogas collection.

36.1. HYPERTHERMOPHILIC AEROBIC COMPOSTING – EXAMPLES AND RESEARCH

HTC potentially offers a range of benefits, as set out in ‘*Hyperthermophilic Composting Technology for Organic Solid Waste Treatment: Recent Research Advances and Trends*’, which observes, “*Compared with the TC process, the shorter composting period and higher temperature and treatment efficiency, as well as more desirable compost quality, can be achieved during HTC by inoculating the waste with hyperthermophilic microbes. Additionally, HTC can reduce greenhouse gas emission, increase the removal rate of microplastics and antibiotic residues, and achieve in-situ remediation of heavy metal-polluted soils, which greatly improve its application potential for organic solid waste treatment.*” (Wang, 2021).

The commentary, '*The distinctive microbial community improves composting efficiency in a full-scale hyperthermophilic composting plant*', helpfully notes, *"Obviously, the temperature of HTC process is 20–30 °C higher than that in conventional composting, which would increase the bioconversion efficiency. It would be superior in quality and efficiency of composting by enhancing compost maturity and shortening composting period. Our recent research also found that HTC could significantly improve the removal of antibiotic resistance genes (ARGs) and mobile genetic elements (MGEs) because the removal of ARG and MGE could depend on composting temperature"* (Yu, 2018).

In one study, during fermentation without exogenous heating, using forced aeration supplied by two UPVC tubes, temperatures reached 90^{o}C within 24 hours. "*The temperature of the hyperthermophilic treatment rapidly increased to about 90 °C after 24 h of fermentation, while in the conventional composting, the temperature raised with a much slower rate and reached a maximum temperature of 60 °C after 18 days of fermentation.*" (Liao., 2018) Higher temperatures still were reported by Oshima and Maoriya; the highest temperature exceeded 90 or possibly even 100 °C (Oshima, 2008)

36.2. CHANGED MICROBIAL POPULATIONS WITH HYPERTHERMOPHILIC TEMPERATURES

Hyperthermophilic composting also changes the balance of the microbial population species as temperature changes (Yamada., 2008; Yu., 2018), altering the physiology of the compost. More research will be required to determine if the compost produced better assists germination or if the compost produced will need the post-or-end-of-treatment addition of other bacterial and mycorrhizal seeding material from known assessed mature composts to create optimal biofertiliser. Over time, techniques and knowledge will be developed to optimise the bacterial and fungal species in the compost produced for specific uses.

36.3. ENCOURAGING HYPERTHERMOPHILIC MITIGATION OF ANTIBIOTIC-RESISTANT MATERIAL

Usefully, thermophilic composting also appears to remediate antibiotic residues in relative terms, reasonably well, and much better than traditional composting; "*in thermophilic composting most antibiotics degrade very rapidly (t1/2 = 0.9−9 days) according to previous studies.*" (Liao., 2018), and might be a relatively effective method of remediation of other pharmacological products.

Consistent with this, the paper '*Hyperthermophilic Composting Accelerates the Removal of Antibiotic Resistance Genes and Mobile Genetic Elements in Sewage Sludge*' (Liao., 2018) observed, "***Hyperthermophilic composting is more effective at reducing ARG and MGE abundances compared to conventional composting***." "***After 21 days of composting, the removal rates of total ARGs and MGEs in hyperthermophilic composting (91% and 88%) were much higher compared to those of conventional composting (39% and 51%, P < 0.05)***." (Liao., 2018) (this author's bold)

Similarly, and confirming these are solid observations, Wang noted, “*The results showed that the removal rate of ARGs and MGEs during HTC (High Temperature Composting) was 89%, which was much higher than that during TC (49%). The mechanism analysis indicated that the stability of ARGs and MGEs were negatively affected by the extremely high temperature, and MGE reduction played a vital role in ARG removal in HTC.” (Wang, 2021)*

36.4. TIME TO MATURITY – HYPERTHERMOPHILIC COMPOSTING (HTC) FASTER

With high bioconversion efficiency, hyperthermophilic reduced composting times from 45 to 25 days. “***Hyperthermophilic composting takes normally 25 days according to the experience of the compost factory. In contrast, conventional composting takes around 45 days.***” (Liao., 2018; Yu, 2018) (Author’s bold).

Importantly, remediation of pharmaceuticals also took place in that faster 25-day composting time frame, “*after 21 days of composting, the removal rates of total ARGs and MGEs in hyperthermophilic composting (91 per cent and 88 per cent) were much higher compared to those of conventional composting (39 per cent and 51 per cent, $P < 0.05$)*” (Liao., 2018).

As previously discussed, hyperthermophilic composting cannot remove all the pathogens and modern contaminants in sludge. However, a combination of techniques, including prior hyperthermophilic anaerobic digestion, can be forged to find a pragmatic equilibrium, balancing remediation efficiency with cost.

Thus, research is uncovering faster improved composting techniques with greater capacity to remediate pollutants, notably pharmaceuticals and antibiotic-resistant elements. The above studies suggest considerable scope and potential benefit for research in this area. Forced air variations may open up further interesting composting avenues, as might changing other parameters.

36.5. MICROPLASTICS REDUCED 43% IN HYPERTHERMOPHILIC COMPOSTING STUDY

HTC also shows greater capacity than traditional composting to remediate microplastics (Wang. S 2021). Chen made the remarkable, and if widely validated, fundamentally important observation in their study titled*, ‘Enhanced in situ biodegradation of microplastics in sewage sludge using hyperthermophilic composting technology’,* observed, *‘Land spreading of sewage sludge is a major source of environmental microplastics (MPs) contamination.’,* and that, *“conventional sludge treatments are inefficient at removing sludge-based MPs. Herein, hyperthermophilic composting (hTC) technology is proposed and demonstrated in full-scale (200 t) for in situ biodegradation of sludge-based MPs. After **45 days of hTC treatment, 43.7% of the MPs was removed from the sewage sludge**, which is the highest value ever reported for MPs biodegradation.”* (Chen, Z. 2020) (This author’s bold and underline). The addition of iron to thermophilic composting also achieved significant remediation of microplastics, approximately 36% (Xing, 2023), adding to reasons for urgent research in the field.

36.6. HYPERTHERMOPHILIC COMPOSTING REDUCES GREENHOUSE GASES

Hyperthermophilic composting also shows potential for mitigation of greenhouse gases, and as conducted in an enclosed space, also creates the potential for gas capture. The study '*Hyperthermophilic composting significantly decreases N_2O emissions by regulating N_2O-related functional genes*' states, "*This study reported for the first time that hyperthermophilic composting (HTC) could mitigate 90% of the cumulative amount of N_2O emissions compared to traditional composting (TC) in a full-scale experiment.*" (Cui., 2019)

36.7. HYPERTHERMOPHILIC COMPOSTING 'BASIC' WIDELY IMPLEMENTABLE TECHNOLOGY

An advantage of both anaerobic and aerobic, hyper-thermophilic, or other 'technical' digestion and composting is that at their most basic level, they are relatively simple technologies, achievable using basic materials, with vessels potentially made from concrete, brick or cement.

Forced air flows can enhance processes and regulate temperature. Rotating mechanisms could help ensure that all the contents reach the necessary temperatures quickly and evenly (Yamada, 2008).
There are further potential uses for heat energy as a by-product, such as heating greenhouses. Carbon dioxide and other gases can also be captured from closed vessels. Carbon dioxide can be used in greenhouses to enhance growth rates, subject to any adverse effect on plant nutrient density.

37. COMBINED AEROBIC DIGESTION AND ANAEROBIC COMPOSTING

To sustainably close the cycle and minimise pollution, suitable techniques must be found for treating faeces, urine, and other organic waste and cyclically returning nutrients and carbon to the soil.

As discussed, the optimal solution may be the vacuum WC collection of faeces and urine, followed by hyperthermophilic digestion and subsequent hyperthermophilic composting. Emerging research suggests the combination and integration of anaerobic digestion and aerobic composting of organic 'waste' may provide the most environmentally effective remediation process, in that energy is recovered in biogas, and the circle is closed so far as compost is returned to soils. Further, hyperthermophilic composting may remediate pathogens from urine and faeces more effectively and is additive to remediation by hyperthermophilic anaerobic digestion (Nasr, 1997).

Interestingly, and potentially importantly, albeit real-life results have not always been positive, the article, '*Integrating Anaerobic Digestion With Composting*' (Kraemer, 2014), asks, "*Which is better for managing source separated organics, anaerobic digestion or aerobic composting?,* and concludes, *"It's not an either-or proposition,*" going on to explain, the combination of anaerobic digestion and composting has several advantages, and thought-provokingly, would at least on paper, be economically more viable than either alone (Kraemer, 2014). They describe a number of then-functioning mixed anaerobic digestion and aerobic composting plants in the USA and Europe. However, two in the USA dealing with urban waste appear to have failed. Single-type waste streams with defined additive carbon sources may be more suitable and sustainable.

In 2006, the article, *'The Magic of Combined Anaerobic Digestion with Composting of Municipal Solid Waste',* observed, "*when all things are considered, combined anaerobic digestion and composting can not only be very significantly cheaper than composting alone, but the mass of the residue sent to landfill in the end will also be reduced, and global warming emissions are also minimised*" (Last, 2006)

A combination of anaerobic and traditional aerobic digestion would allow the use of high methane production potential sources, such as faeces and food, for biogas production and less methane-productive, bulkier greenery waste for subsequent composting operations. This would achieve better overall value, more space and smell-efficient processing, and better remediation of contaminants (Li, 2021).

For example, the report '*Sustainable Treatment Techniques for Emerging Pollutants—The Case of Personal Hygiene Products*', which considers possible benefits of combined anaerobic and aerobic digestion, including in single dual purpose reactors, observes, "*The results of these combined reactors presented a removal of the contaminant of 87.9 ± 0.4% and 86.8 ± 0.5% and, in turn, used 69.2% and 62.5% less energy than the use of a single process, regardless of whether it was anaerobic or aerobic*" (Duenas-Munoz, D. 2022).

The review, "*Integrating anaerobic digestion and composting* (IADC) *to boost energy and material recovery from organic wastes in the Circular Economy framework in Europe*", concluded, "*Overall, IADC appears as a promising process that needs to be further implemented due to its reduced environmental impact (i.e., reduced GHGs emission, removal of organic contaminants) and to the potential production of high-value products (i.e., biogas, biomethane, compost). By allowing their sustainable recycling and reducing dependence from fossil-fuels and synthetic fertilizers, IADC enhances circularity of organic wastes, meeting the principles of circular economy and achieving SDGs.*" (Cucina, 2023)

However, with respect to the remediation of FaF sewage sludge, the wider waste stream additive pollutants, including heavy metals, pharmaceuticals, antibiotics, PCPs, microplastics, tyre and wider road runoff, and other pollutants, create a barrier to their safe composting, and difficulties in dealing with digestate residue.

The obvious answer is, as discussed, the collection of urine and faeces at source using vacuum WC technology, with grey water and surface water being treated as separate streams. This leaves pharmaceuticals, including antibiotics, as the primary pollutants. Combined anaerobic digestion and aerobic composting already show reasonable remediation of pharmaceuticals, and limited research suggests remediation would be significantly improved by moving to integrated hyperthermophilic anaerobic digestion and hyperthermophilic aerobic composting.

Differing technologies may offer differing advantages. For example, biodigesters may better remediate dioxins from traffic emissions, burning straw combustion, asphalt abrasion and other sources (Pšenička, 2011). Thus, combining anaerobic and aerobic digestion may be the optimal way forward.

The technologies are equally applicable to the faeces and urine of livestock, including cattle, swine, and chicken, as those of humans. Indeed, where possible, combining remediation systems in regional locations could create plant and process treatment benefits.

Both HTAD and HTC require further research and commercial development, particularly looking at their use in tandem and with a focus on optimising methane production, remediation of pollutants, production of composts with diverse biology suitable for use as biological fertilisers, and potential technologies to close the soil food urine faeces cycle.

Separation and collection of urine and faeces at source, with minimal water addition using vacuum WC technology, followed by a combination of hyperthermophilic anaerobic digestion and containerised, forced air-flow, 'hyperthermophilic' composting, as discussed, seems to offer the best potential. Notably, it is relatively low technology at a basal level, so it could be applied globally, including in lower-income countries.

It is probably the only sustainable option to close the grow, eat, defecate, cycle whilst at the same time reducing environmental pollution, as well as producing biogas for energy, saving water and resources, returning minerals including valuable and scarce, phosphates; nitrates; and carbon; in addition providing compost containing essential bacterial and fungal biology, to soils, particularly those with depleted biology and nutrient resources, thus helping substantially close the sustainability circle (Liao, 2018).

38. REPLACEMENT OF TRADITIONAL WATER-BASED SEWAGE TRANSPORT AND TREATMENT TECHNOLOGIES

If vacuum WC technology, bio-digestion, dewatering and composting, hyperthermophilic or otherwise, were widely adopted, it would essentially eliminate the need for traditional water-based sewage treatment plants and the massive, extensive and very costly related sewer pipe infrastructures, significantly reducing capital and running costs. There would also be significant environmental gains at multiple levels.

More research is required to determine where such systems can be used, develop technologies, and iron out difficulties. However, arguably, we have no option but to develop such systems, given that the 'FaF' system is an irredeemable dinosaur technology. There are currently no apparent alternatives for sustainable recycling of urine and faeces.

39. ECO-REMEDIATION

In addition to anaerobic digestion and aerobic composting, several options exist for eco-remediation, including wetlands and biologically diverse soils. Eco-remediation is probably best viewed as an additive or partial remedial process because, while providing valuable services as part of broader management, basic eco-remediation has limited effectiveness for anything but low-level pollution sources.

39.1. WORMS – SUBSTANTIALLY CHANGE BACTERIAL AND FUNGAL COMPOSITION OF SEWAGE SLUDGE

Worms synergistically adapt soil biome fungal and bacterial biology to meet their needs and those of their host biome, killing some and introducing others. Vermicomposting can be used to process sewage sludge. The remarkable results of changes in the bacterial biology of sewage by earthworms suggest that much greater focus should be put on the use of earthworms in sewage sludge remediation as part of composting or post-hyperthermophilic composting bacterial and fungal species amelioration of soil fertilisers.

The paper '*Earthworms drastically change fungal and bacterial communities during vermicomposting of sewage sludge*' observes, "*Bacterial and fungal communities of earthworm casts were mainly composed of microbial taxa not found in the sewage sludge; thus most of the bacterial (96%) and fungal (91%) taxa in the sewage sludge were eliminated during vermicomposting,*" (Dominguez, 2021).

The paper continues "*Large changes in bacterial community composition were found after transit of the sewage sludge through the gut of the earthworms (GAP), with significant decreases in the abundance of Campilobacterota, Firmicutes and Bacteroidota, and significant increases in the abundance of Verrucomicrobiota, Proteobacteria and Bacteroidota*" as part of a DNA based very detailed analysis of the changes in phyla (Dominguez, 2021).

Worms similarly moderate fungal populations. The paper '*The Effects of Earthworms on Fungal Diversity and Community Structure in Farmland Soil With Returned Straw*' observed "*reduced the soil fungal populations by eating, dispersing, and killing soil fungal spores and hyphae. Fungal spores can be killed by passage through the earthworm intestinal tract*", whilst their secretions favour other species (Song, 2020).

More generally, worms and other soil fauna have diverse and important roles in soil biology and health, as helpfully set out in "*Conceptualizing soil fauna effects on labile and stabilized soil organic matter*", which observes, "*Soil fauna affects various soil biophysiochemical properties, including microbial diversity, soil structure/texture, and soil nutrients, via ingesting and transforming organic matter into more or less decomposable forms, mixing this organic matter with mineral soil, and grazing on microorganisms6–10. These processes are essential in driving biogeochemical cycles and may substantially affect soil organic matter dynamics*" (Angst, 2924)

39.2. PHYTOREMEDIATION

Phytoremediation is a mechanism for pollutant extraction from toxin-containing soils, utilising the capacity and propensity of plants to uptake toxic products. For impoverished communities and countries, this may present a cheap and sustainable process for the removal of pollutants, for example, phytoremediation by water hyacinth in sewage treatment plants (Lakshmi, 2017) and other treatment facilities (Kulkarni, n.d), but the problem of how to deal with the resultant pollutants concentrated in the plants, and then harvested, remains.

A paper titled 'Phytoremediation of sewage sludge contaminated by trace elements and organic compounds' (Guidi Nissim, 2018) observes, '*Most plants proposed for this technique have high nutrient demands, and fertilisation is often required to maintain soil fertility and nutrient balance while remediating the substrate. In this context, municipal sewage sludge could be a valuable source of nutrients (especially N and P) and water for plant growth*'). . . . '*At the end of the trial, some TEs* (Trace elements) *(i.e. Cr, Pb and Zn), n-alkanes and PCBs showed a significant concentration decrease in the sludge for all tested species. The highest Cr decrease was observed in pots with eucalyptus (57.4 per cent) and sunflower (53.4 per cent), whereas sunflower showed the highest Cu decrease (44.2 per cent), followed by eucalyptus (41.2 per cent), poplar (16.2 per cent) and willow (14 per cent). A significant decrease (41.1 per cent) of Pb in the eucalyptus was observed. Zn showed a high decrease rate with sunflower (59.5 per cent) and poplar (52 per cent) and to a lesser degree with willow (35.3 per cent) and eucalyptus (25.4 per cent). The highest decrease in n-alkanes concentration in the sludge was found in willow (98.3 per cent) and sunflower (97.3 per cent), whereas eucalyptus has the lowest PCBs concentration (91.8 per cent) in the sludge compared to the beginning of the trial*' (Guidi Nissim, 2018).

Following absorption, plants can achieve some phytodegradation of organic components and sequestration of metals into their structure (UNEP, 2002 International Environmental Technology Centre, US Environmental Protection Agency & Environment Canada). Once the process is completed, the plants and the pollutants they have taken up and concentrated must be disposed of sustainably. Options include incineration, though this is not problem-free, as previously discussed.

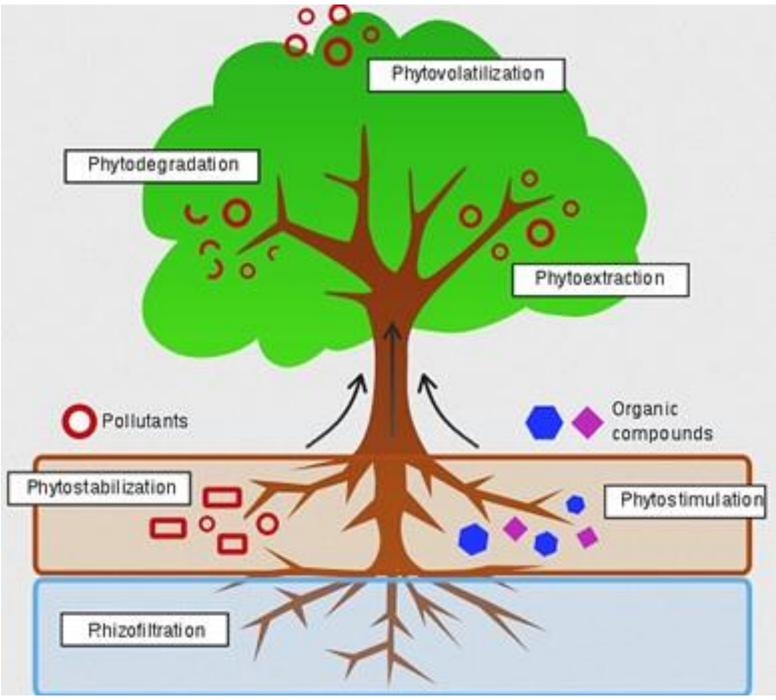

Fig. 81. Phytoremediation, with many thanks to Wikipedia and the Author

39.3. 'NATURAL' REMEDIATION BY SOIL BIOME

Bacterial and fungal remedial biodegradation by a diverse soil biome can diminish many pollutants, including antibiotics, as illustrated in the table below. Using biodiverse compost will improve soil biology, diversity, organic matter and carbon content, water infiltration and retention, soil health, and yields. Healthier, more biologically diverse, carbon-rich soils, in turn, will improve the capacity for toxin remediation by bacteria, fungi, and soil biome processes generally, as well as the biological immobilisation in the soil of residual contaminants.

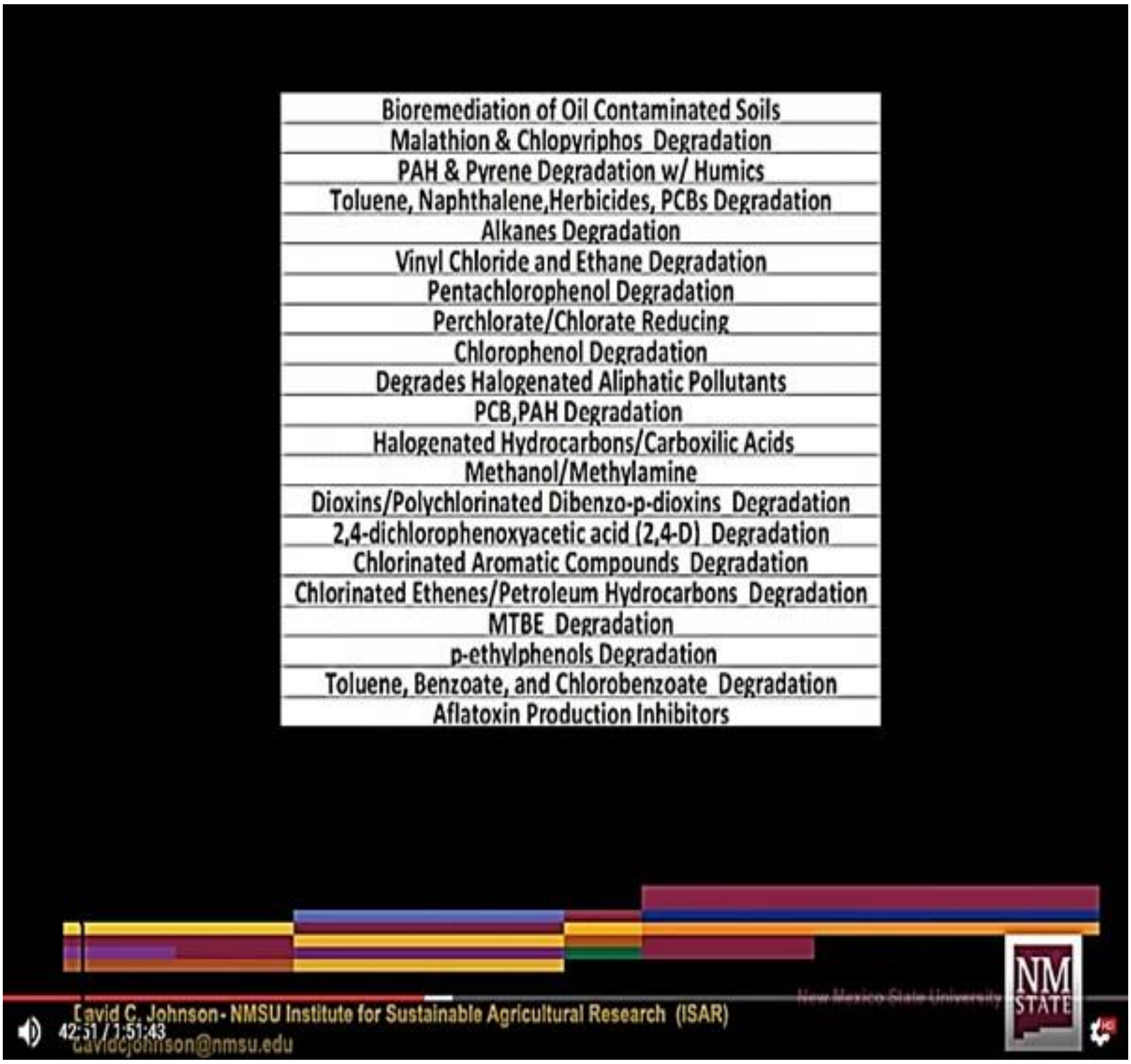

Fig. 82. A list of contaminants remediated to some degree by soil microbes, as set out by Dr Johnson and Hui Su in the YouTube lecture *'Dr David and Hui Chun Su Composting*' (Johnson & Su, 2019), with many thanks to YouTube and the Authors.

For example, soil fungi are effective bioremediators of *"different toxic and recalcitrant compounds; persistent organic pollutants, textile dyes, effluents from textile, bleached kraft pulp, leather tanning industries, petroleum, polyaromatic hydrocarbons, pharmaceuticals and personal care products, and pesticides*" (Deshmukh, 2016). Furthermore, "*investigations into* *the microbial bioconversion of PAHs has shown that wood- and litter-decay fungi are efficient degraders of these organo-pollutants*" (Pozdnyakova, 2012).

Conversely, due to their persistence, pharmacological pollutants in sewage products applied to soils may reduce mycorrhizal bacterial activity, which would otherwise help to degrade them. This magnifies the importance of developing composting techniques that optimise the treatment of pharmaceuticals, including antibiotics, antifungals, biocides, and other pollutants, thus facilitating the return of human and cattle urine and faeces to the land.

This adds weight to environmental arguments in favour of both, minimising as far as possible pollutants added to soils and focusing, using regenerative agriculture, on creating healthy biologically rich soils, which logically will be better placed to remediate and, in the short term, retain residual organic pollutants, reducing their migration into the wider environment, including, via rivers, and lakes, into oceans.

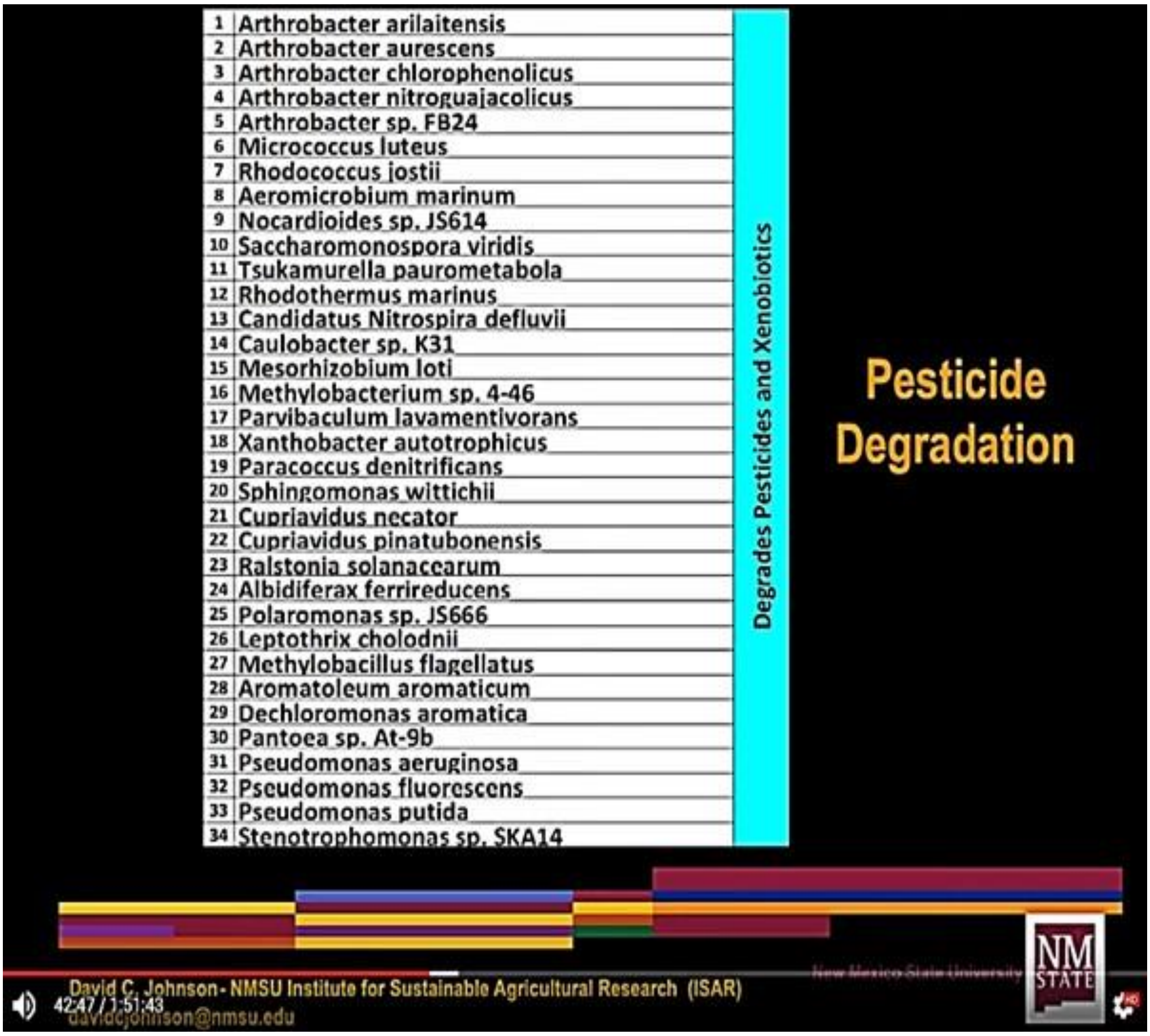

Fig. 83. Dr Johnson and Hui Su set out a list of some soil microbes that can, to varying extents, degrade pesticides, antibiotics and other pollutants in the YouTube lecture '*Dr David and Hui Chun Su Composting*' with many thanks to YouTube and the Authors. (Johnson & Su, 2019)

39.4. WETLANDS

Wetland ecosystems are used in sewage outflow treatment because they absorb nitrates and phosphates and clarify water. In relative terms, they are cheap and low-tech; thus, they would have a role in less developed economies as a partial solution. Further, plants can take up pollutants and, to some extent, store them, as discussed in the section below.

In short-term studies, wetland systems have shown significant potential to 'remediate' (14-100%) pharmaceuticals, personal care products, and antibiotic-resistant material (Chen, 2022). However, wetland results are inconsistent, changing seasonally throughout the year, and the amount of pollutants accumulated in wetland plants and organically related deposits is unclear.

A review titled '*Performance of full scale constructed wetlands in removing antibiotics and antibiotic resistance genes*', whilst recognising the potential, observes, "*A full scale CW* (Constructed Wetlands) *may or may not show efficient in reducing antibiotics and ARGs due to a variety of factors, including age of the wetland, seasonality, and plants*". (Sabri, 2021)

There is the attendant danger that wetlands and the plants they contain can also act as reservoirs facilitating antibiotic gene exchange. "*Rhizosphere processes of plants can also promote the storage of more ARGs, and the presence of more microorganisms in the rhizosphere creates space for the existence of more ARGs.*" (BAI, 2022)

Thus, wetlands, as a relatively cheap, low-tech, hence accessible, complementary technique for pollutant remediation, show significant potential, particularly so in terms of aqueous products from treatment plants and anaerobic digestion, but as generally the case in this field, more research is urgently required, because remediation of, pharmaceuticals, antibiotic-resistant material, and other pollutants, will evidence suggests be insufficient, efficiency will likely vary significantly between seasons, and pollutants may build up in the remediation wetland.

39.5. ENZYMES

Microbial enzymes - such as oxidoreductases, hydrolases, oxygenases, laccases, peroxidases, lipases, cellulases and proteases - have been shown to play an effective role in biodegrading toxic organic pollutants (Karigar, 2011; Pandey, 2017). Efficiency varies; these are technical and generally relatively expensive technologies that only provide partial solutions.

39.6. MAGGOTS AND INSECTS

Maggots and other insectivores present interesting commercial opportunities and are now used to digest waste, including sewage, to create feedstuffs for livestock. However, given that insects - like humans - are what they eat, the presence of heavy metals, pharmaceuticals, antibiotic-resistant bacteria, and related genetic material in sewage sludge and or food residues could give rise to unforeseen issues.

It is suggested that some heavy metals in faeces and urine are not significantly concentrated by maggots; nonetheless, "*the levels of Cd, Se, Pb and Cu in chicken faeces increased significantly when more maggots were used for chicken feeding*" (Wang, W. 2017). Thus, more research is required.

39.7. ALGAE

Algae has been suggested as another option for remediating contaminants. For example, the review, '*Wastewater production, treatment and use in India*', states: *"The advantage is that one can reduce the organic and inorganic loads, increase dissolved oxygen levels, mitigate CO2 pollution and generate valuable biomass by sequential use of heterotrophic and autotrophic algal species . . . As documented in studies on eutrophication, algae are known to thrive under very high concentrations of inorganic nitrates and phosphates that are otherwise toxic to other organisms. This particular aspect of algae can help remediate highly polluted wastewaters.*" (Kaur, n.d.)

The potential role of algae in remediation is confirmed in other papers, *"[*Algae has*] been shown to be highly effective in uptake of nutrients like N and P and as accumulators and degraders of different kinds of environmental pollutants, including xenobiotic compounds*" (Singh & Dhar, 2010) . . . *"Current researches suggest that algae and algae-bacteria consortia have great potentials in PCP removal but more works are required before algae-based technologies can be implemented in large scales*" (Wang, Y. 2017).

However, as with wetlands and maggots, algae, living organisms, may take up and concentrate some or a significant amount of the wide range of pollutants in reclaimed sewage water and become polluted themselves, thus having to be safely disposed of. Potential pollution in such products, also dramatically reduces the scope for their onward usage as feed or fertiliser.

39.8. BIOCHAR

Biochar presents a potential intermediate option to combustion, which both remediates organic pollutants and returns some minerals and carbon to soils. Biochar is produced from a wide variety of feedstocks, including "*wood waste, agricultural crop residues, forestry residues, municipal solid waste (MSW) and animal manure*" through a range of processes with differing outcomes. The review, '*Performance analysis of sustainable technologies for biochar production: A comprehensive review*', observes, "*Its yield, and properties vary vastly with the type of feedstock, technology and operating parameters applied, which also affect potential applications.*" (Safarian, 2023).

Typical biochar yields from the pyrolysis *pro*cess are only 35%, but depending on feedstock and process type, yields from 25-50% and up to 70% at best have been achieved (Safarian, 2023).

Other biochar production processes primarily focus on producing high levels of synthetic gas or oil, which will clearly have a lower value as a mechanism for creating biochar for carbon sequestration.

Further, the level of tar condensate products, heavy metals, and other pollutants in the biochar, once incorporated into soils, will influence plant growth in complex ways. Thus, detailed and process-specific research is required to determine the optimal process for agricultural biochar production to ensure that both carbon sequestration and plant growth are optimised.

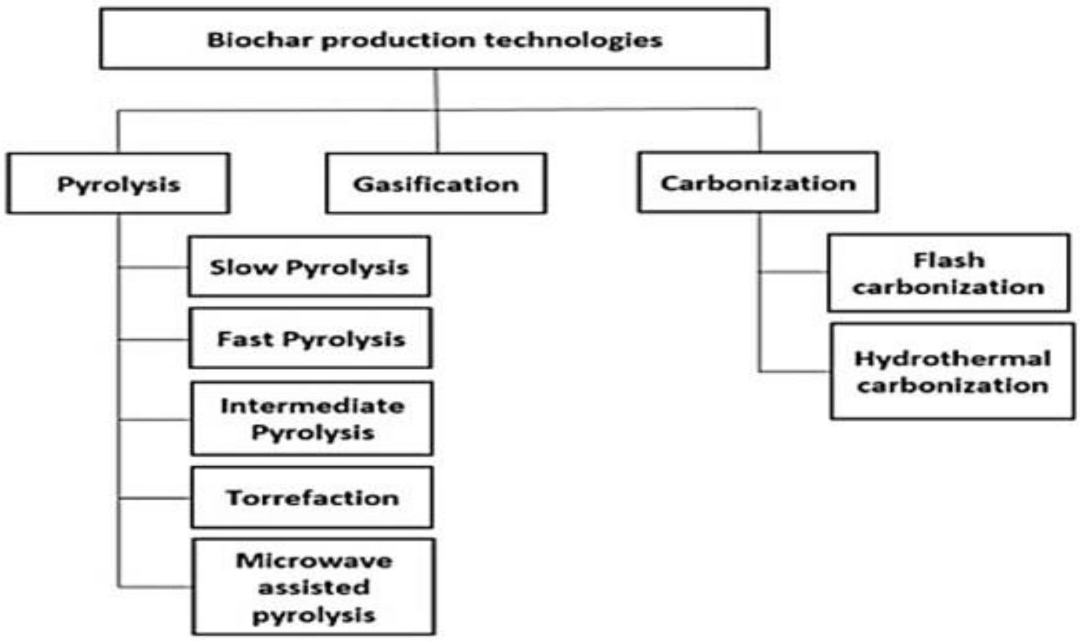

Fig. 84. Methodologies for bio-char production from '*Performance analysis of sustainable technologies for biochar production: A comprehensive review*', with many thanks to the Authors. (Safarian, 2023)

The capacity of biochar for long-term carbon storage in soils will be related to its carbon content. As mentioned above, there are a variety of production technologies, each with its own nuances. For example, slow pyrolysis tends to produce higher carbon content; however, carbon content will also be dependent on a range of factors, as set out in Safarian, 2023, including particularly the feedstock type; for example:

Slow pyrolysis – Material	**% Carbon**
Wheat straw	50.3
Corn stalks	92.8
Olive mill waste	84.7
Rice husk	46.0
Red cedar sapwood	85.8
Woody bamboo	82.1
Pinewood	54.1

Biochar production-related flue gases, including "*hydrogen, carbon monoxide, carbon dioxide, light hydrocarbons and steam*" (Safarian, 2023), create potential environmental issues. Other bi-products include bio-oil, used as a fuel, and syngas, which must undergo further processing before it can be similarly utilised.

Thus, biochar's capacity to return carbon to soils is partial. Although once in the soil, biochar has longevity and provides interstitial spaces for fungal and bacterial colonisation, in theory assisting plant growth. However, it may retain some pollutants, and the results of biochar studies on the impact on plant growth are mixed.

Biochar's other advantage – which it shares with wood ash (Malakootian, 2008) - is that it 'passivates' or binds to heavy metals (Li, 2017; Hou, 2014) found in animal or human, urine and faeces, making them less available to plants. The heavy metal content of biochar (Cang, 2012) is not considered sufficiently high to be detrimental but depends on the biochar source substrate content.

These properties make biochar a potential candidate for adding to bio-digestion and or hyperthermophilic processes. Biochar as a urine adsorption and delivery mechanism shows significant agricultural benefits. However, given possible pollutants in urine, including antibiotics, further research in varied soils is required.

39.9. BIOCHAR AND URINE

Studies enriching biochar with urine noted that it provided greater nutrient retention and positive effects on plant growth (Panigrahi, 2013; Zenrainman, n.d.), including, for example, a *"fourfold increase in pumpkin yield"* and "*plant growth stimulation of Chenopodium quinoa of 305 per cent versus 61 per cent with untreated biochar compared with the unamended control*" (Schmidt, H. 2015).

Fig. 85. Biochar, with thanks to the Author and Adobe Photo Stock

Another urine biochar combination study from Nepal saw much better growth with urine incorporation. It concluded, "*21 field trials robustly revealed that low-dosage root zone application of organic biochar-based fertilisers caused substantial yield increases in rather fertile silt loam soils compared with traditional organic fertilisation and to mineral NPK or NPK-biochar fertilisation. This can be explained by the nutrient carrier effect of biochar, causing a slow nutrient release behaviour, more balanced nutrient fluxes and reduced nutrient losses, especially when liquid organic nutrients are used for the biochar enrichment*." (Schmidt, 2017).

However, as stated above, we do not yet fully understand the potential risks or the extent of unremediated pollutants in urine, including pharmaceuticals, bacteria, and viruses, and how biochar impacts them.

39.10. HYDRO-CHARS

There is increasing research into the relatively new technology of hydro-chars, which uses high temperature and pressure in a sealed vessel containing water and the feedstock to be hydrothermally carbonised "into a carbon-rich substance under conditions of 180–250 °C and 2–20 MPa pressure in the presence of water."

Hydro-char processing is more suited for low-water substrates like waste wood or straw. It is not a solution to the remediation of sludge because of the high moisture content of sludge, which results in the release of large amounts of water, around 80%, limited hydrochar 10%, and mixed gases 10%.

The resultant hydrochar formed from sludge (Wilk, 2023) contains many toxic substances that need processing. Further, based on research, the hydrochar created from sewage is prone to 'clagging' during combustion.

40. COSTS DIRECT AND INDIRECT- 'FaF' IS AN UNSUSTAINABLE DINOSAUR

Sewage authority charges are increasing. The environmental, running, infrastructure requirements and related costs of conventional FaF sewage systems are high and include clean water provision to facilitate flush and forget and associated infrastructure costs, subterranean gravity and pump-based sewage piping and pumping stations, sewage treatment plants, additional tertiary water treatment costs, nitrate removal where needed, and sewage sludge transport and disposal; to which can be added a host of; health, environmental, including; river, ocean, and terrestrial pollution, related costs.

Those costs, one way or another, directly or indirectly, are borne by us all, be that by governments through taxes or by the individual citizen, and are becoming increasingly unaffordable for those on low incomes.

40.1. WATER COSTS - 'FaF' FLUSH AND FORGET SYSTEMS

Water used for '*flush and forget*' WCs represents "*20 - 40 per cent of the water consumption in sewered cities*" (Jenssen, 2007). We pay for that clean drinking water:

- The broader costs of providing the clean drinking water necessary for the current and expanding flush-and-forget sewage systems to function will include new capital and infrastructure to capture, store, and transport rain or groundwater.
- All drinking water requires costly filtration, treatment, testing and transport.
- In drought and water-stressed regions, we will have to spend even more money to clean a proportion of sewage and/or polluted water sources to drinking water standards.
- Recovery of potable water from treated sewage water will need costly reverse osmosis or similar, plus the necessary remineralisation of water. Failure to remineralise osmosis water has negative health consequences (Kozisek, 2005). As discussed, more research is required, as reports suggest plastic filters, including osmosis membranes, may shed large numbers of nano-plastics into the drinking water produced.
- Other costs include added notional opportunity-cost value of land for new reservoirs and diminishing groundwater assets, including aquifers.

We then use this clean, expensive drinking water to flush the toilet, mixing it with faeces, urine, grey water, pharmaceuticals including antibiotic-resistant material, microplastics, PFAS, personal care and household products, and downstream pollutants, including industrial waste and road runoff, in the knowledge that the polluted liquid mix will be costly to clean up, but not realising FaF is a dinosaur technology, a busted flush, pushing problems into the future, incapable in reality of effectively remediating the toxic semiliquid soup we have had a hand in creating.

40.2. POLLUTANTS IN DRINKING AND IRRIGATION WATER

An alphabet soup of pollutants, including PCPs, PCBs, PAHs, PFAS, microplastics, heavy metals, and other personal care, domestic, and industrial pollutants, are being introduced into our water. We have no idea what the impact of many of these pollutants is. We are told years after the introduction of some as a wonder product that they are harmful, as happened with PFAS, "*part of a class of more than 12,000 substances known collectively as PFAS, short for per- and polyfluoroalkyl substances*", which have suddenly been designated as an issue. However, evidence is emerging that it has been known since the 1960s that they were likely toxic ('*Companies Knew the Dangers of PFAS 'Forever Chemicals'—and Kept Them Secret'* Time Magazine 2023).

National water quality regulation is often aspirational but 'fuzzy', as is evident from the document "A Global Overview of National Regulations and Standards for drinking-water Quality" (WHO, 2018). Whilst basic tests are conducted, many countries do not assay water for a range of accepted pollutants, and the pollutant lists in the document only contain a fraction of the pollutants we are putting into the environment. A search of the WEB for a list of, for example, endocrine disruptors, PCBs, PFAS, etc., will quickly illustrate the extent of the issues.

We are where we are, but reducing the amount of drinking water we flush down our WCs, thereby avoiding directly polluting that water with a host of downstream toxic additions, would surely be a sensible start.

40.3. DIRECT FINANCIAL COSTS OF 'FaF' SEWAGE COLLECTION TREATMENT AND DISPOSAL

- Sewage collection, treatment, and disposal, capital and running costs, include:
  - **Pipework Infrastructure** - Capital and maintenance costs of pipe infrastructure for sewage transport to treatment plants.
  - **Transport energy** – Water-based sewage transport requires pumping stations to maintain gravitational flow, which can have a significant energy cost.
  - **Treatment Plant** - Capital maintenance and running costs of plants are high.
  - **Nitrate Removal** – Water may require nitrate or other specialist sewage-related pollutant removal, which is costly.
  - **Tertiary treatment** - Capital and maintenance of more sophisticated tertiary wastewater treatment technologies is very costly.
  - **Monitoring** - Cost of monitoring; river health, wastewater outflows and direct overflow discharges.
  - **Disposal** - Cost of disposal of sewage sludge to;
    - Landfill,
    - Incineration,
    - Transport to and application on farmland.

40.4. ENVIRONMENTAL AND ECONOMIC COSTS OF 'FaF' FLUSH AND FORGET SEWAGE AND SEWAGE WATER DISPOSAL

- Environmental and broader costs of disposal of the sewage sludge and sewage water products of FaF systems include:
  - **Landfill** - risk of pollution, including from leachate containing a wide range of contaminants, and release of methane and other gaseous emissions from organic materials, including sewage sludge put into landfills. "*Organic matter accounts for one third of the input to landfills in industrialized countries and as much as two thirds in developing countries*" (Jenssen, 2007);
  - **Incineration** - atmospheric pollution by multiple contaminants and release of carbon dioxide; the need to dispose of toxic ash from sewage sludge combustion (Wilk, 2023); and high energy costs, including due to the cost of drying sewage to less than 25% water content; additional costs for combustion gas scrubbers where installed; plant capital and other running costs.
  - **Agricultural land** – Disposal of sludge on agricultural land leads to pollution of the environment, farmland, waterways, and marine environments with antibiotics, other pharmaceuticals, antibiotic-resistant bacteria, wider contaminants of concern, as well as microplastics, heavy metals, nitrates and phosphates. Some microplastics spread in sludge onto farmland and end up in the atmosphere, thus ultimately in the oceans. Crops take up pollutants. Some agricultural land treated with sludge or fertilisers derived from sludge resulted in significant pollution of

crops and/or livestock, consequent ill-health or death of livestock, exposing humans to health and mental health risks in utero through the life course.

- **Direct discharge of untreated sewage** – Direct discharge of untreated sewage into waterways or oceans has a host of widespread, often interlinked, downstream negative environmental cost impacts, including pollution and eutrophication of rivers, lakes and oceans, damage to wildlife systems, and contributes to deoxygenation of fresh, intermediate saline, and oceanic systems, with global ecosphere implications.
- **Discharge of treated wastewater into waterways, aquifers, and irrigation use -** As discussed, secondary and most tertiary treated wastewater contains a wide range of potential contaminants, some of which will accumulate over time in waterways, lakes and aquifers
- **Wastewater used for irrigation –** residual pollutants in wastewater used for irrigation may be taken up by plants, thus entering the food chain, negatively impacting livestock and human health.
- **Tertiary Water Treatment** – Reverse osmosis (RO) is the best tertiary water treatment. However, it is costly in terms of capital resources and running costs and is demanding in technical terms. Thus, it is unlikely to be taken up except by the wealthiest, most motivated, environmentally aware nations. The RO residue water contains pollutants and has to be disposed of. Most other tertiary water treatments are intended to remove pathogens, but do not remove a large proportion of the other contaminants. Secondary treatment is unable to remove many pollutants.

40.5. ‘FaF’ ENVIRONMENTAL COSTS ‘DiE’ - DIRECT AND TREATED DISCHARGE

- Environmental costs of direct discharge of sewage water and untreated sewage into the environment, ‘DiE’:
  - The negative environmental and health, known and as yet unknown, effects and costs of untreated discharge are not easily calculable but very significant.
  - Negative health costs, known and as yet unknown, are likely significant.

40.6. LIVESTOCK SLURRY – ENVIRONMENTAL COSTS

- Environmental costs of slurry disposal and leakage:
  - Pollution from slurry leakage or application to farmland includes eutrophication due to large amounts of soluble nitrate and phosphate runoff.
  - Where applied to soils, pollutes soils directly and through run-off, including by pharmaceuticals, unremediated antibiotics and antibiotic-resistant material, wider contaminants of concern, including heavy metals and radioactive nuclides, via rock phosphate-based mineral supplements and fertiliser application; a wide range of contaminants including pharmaceuticals; and microplastics.
  - Emission of climate warming gases from slurry storage.

40.7. FATBAS FARMING INCLUDING FERTILISERS AND SEWAGE SLUDGE

- FATBAS farming significantly contributes to climate change issues, as in Volume 2 on regenerative agriculture. FATBAS-based farming also interlinks with sewage and slurry through the topics of agrochemical, nitrate and phosphate runoff, related downstream pollution and eutrophication; sewage sludge application to land, wastewater for irrigation, as well as the impact of sewage-related pollutants on the food chain and water supply, thus human health; and more widely through climate change and need to close the cycle;

  Pharmaceuticals, including antibiotics, an alphabet soup of pollutants, including PCPs, PCBs, PAHs, PFAS, microplastics, as well as heavy metals, are endlessly, repeatedly, daily, cumulatively, added, and cycled back to the land via slurries and sludge. Sewage sludge, sewage sludge-derived fertilisers, and reused sewage water pollute water supplies, soils, crops and livestock products, and, more widely, oceans. Whilst natural remediation of some pollutants can be quite fast, levels cannot fall when resupplied as quickly as they are degraded.

  Further, the pollution of crops, thus animal feed, reduces the health of livestock, so increasing the need for pharmaceuticals, including antibiotics, in a feed-forward cycle. The same issues, feeding forward into the environment through FaF, impact the human food chain and water quality, degrading human health, including development in utero and early years, as well as mental function, including behaviour and outlook, for example, through increased anxiety, with broader societal and geopolitical implications.

  Negative agricultural impacts of FATBAS include:
    - Waste of resources that should be better used; "*Theoretically speaking, the nutrients in wastewater and organic waste are nearly sufficient to fertilise crops to feed the world population*" (Jenssen, 2007);
    - Soluble runoff from sewage sludges, slurries, fertiliser and agrochemical applications, including phosphates, nitrates, heavy metals, pesticides, fungicides, herbicides, pharmaceuticals and antibiotic-resistant material, and other pollutants, causing damage to water systems, including to marine biology through pollution and eutrophication, and crucially increasing long term risk of oceans going sulphidic.
    - Reduced soil quality due to loss of soil carbon and diminished and disturbed diversity of mycorrhizal biome fecundity and biology, including due to antibiotic-resistant genetic elements ARGs entering plant and seed biomes and on pollen.
    - Reduced water retention and use efficiency due to reduced soil carbon and related life in the soil biome, with related and consequential reduced metabolic water production capacity during drought.
    - Erosion; carbon soil loss; crusting; tillage-based damage to water, moisture, and air conveying micro-tubular pathways, reduced infiltration per hour; increasing run-off; degraded regional water retention in aquifers; and diminished replenishment of soil incident rainwater over time into rivers, increasing; drought, downstream flooding risks, as set out in more detail in Volume 2 on regenerative agriculture;
    - Increased erosion of topsoil due to bare ground, runoff and flooding;

- Failure to maximise photosynthesis due to not keeping land green and covered as long as possible;
- Lost agricultural production capacity, in part due to loss of mycorrhizal and bacterial soil biome function and diminished consequent symbiotic soil biome support for plants, including natural supply of water, nitrates and minerals;
- Loss of soil biome support to plants, including minerals and nitrate supply, leading to lower protein, mineral, and antioxidant content in crops, feedstocks, and foods, resulting in poorer livestock and human health and lower crop prices;
- Lower crop feedstock nutrient value, including mineral density, means an increased need to add rock-phosphate-based minerals to feed-stock, which, through faeces and urine, feeds back to the soil, causing mineral excesses imbalances and year-on-year accumulation of soil toxic metal loads;
- Direct accumulating annual introduction of toxic metals and radioactive material into soils from rock phosphate-derived fertiliser, which plants take up;
- Increased nitrogen content in feedstock crops, food crops, livestock and milk, with adverse health consequences;
- Increased agricultural and veterinary costs;
- Lower livestock carrying capacity;
- Reduced short-term profitability, long-term viability and resilience;
- Crop quality diminution, with impacts on human and animal food chain, including:
    - Loss of nutrient value;
    - Uptake by crops destined for human and animal consumption of pollutants, including pharmaceuticals, ARGs, and microplastics;
- Climate effects include:
    - lower rain infiltration and higher runoff resulting in erosion and flooding;
    - reduced soil water retention;
    - lower atmospheric moisture level in the dry season due to loss of moisture respiring plant cover and required photosynthesis;
    - diminished bacterial atmospheric moisture seeding emissions by plants;
    - lower respiration metabolic water production due to reduced soil biome volume;
    - heating of the atmosphere due to bare soils absorbing ultraviolet and retransmitting as infra-red and infra-red absorbance and re-emission, causing atmospheric heating, and at the extreme triggering heat domes, thus blocking movement of marine moisture inland, with greater risk of excess temperatures and fires, and disturbed rainfall patterns;

together resulting in reduced water infiltration, impaired regional hydrology, more significant irrigation requirements, reduced drought resistance, crop yield loss, increased heat domes, reduced plant transpiration and air moisture, and reduced rain, floods, fire and erosion, many of the factors we label as due to climate change, but which in reality, are not directly caused by atmospheric temperature rises, but consequences of our choice of farming techniques.

40.8. HEALTH COSTS

As detailed in earlier sections, pollution due to FaF sewage collection and disposal and farm slurry management has implications for livestock, pet, human, and broader environmental health and well-being, including developmental and mental health costs, via a wide range of emerging impacts, including from; nitrates, microplastics, and long-term exposures to a mix of low-level toxic pollutants, sometimes long-lived, in air, food, and water. When considering the broader costs of 'Flush and Forget' FaF sewage collection and treatment systems, the inescapable conclusion is that root-and-branch change is required.

41. CONCLUSION

It is no easy task to try and weave together the ever-evolving array of research and literature around the environmental, health, developmental and life-course, including health and mental well-being; agricultural including livestock and food degradation; environmental pollution, economic and climate change, implications, of Flush and Forget FaF sewage collection and treatment. It is a journey that has taken much time over several years.

The current situation is not new. In 'Farmers of Forty Centuries' – China 1911 - Franklin King opined in terms which still fit perfectly in our recklessly profligate times: *"Man is the most extravagant accelerator of waste the world has ever endured. His withering blight has fallen upon every living thing within his reach, himself not excepted; and his besom of destruction in the uncontrolled hands of a generation has swept into the sea soil fertility which only centuries of life could accumulate, and yet this fertility is the substratum of all that is living"* (King, 1911). At the end of the Victorian era, had vacuum WC technology been chosen instead of flush and forget, we may be in a very different situation today, but such are the vagaries of history.

At this crucial point in human evolutionary history, as we sit on the verge of creating AI 'life', we seem unable to recognise and address many of the fundamental climate issues on which our future depends. If we do not address FATBAS and FaF, we will not stabilise the climate or moderate pollution issues that threaten our health and mental well-being. We will face increasingly severe climate change effects, including drought, atmospheric heating, fire, flooding, erosion, widespread pollution, and ocean eutrophication, all of which, at some level, are consequences of FaF and FATBAS.

It is also inevitable, and confirmed in broad outline by many diverse studies and observations, that the effects of degraded food, water, and air pollution include potentially significant developmental and life-course impairment of human health, including mental status, with consequent increasing anxiety and related anger, combined with loss of IQ and higher human function, including consequential loss of capacity for empathy and abstract thought.

A holistic approach is clearly urgently needed. Moving to regenerative agriculture, vacuum WC urine and faeces collection, and hyperthermophilic anaerobic and aerobic composting of sewage and slurries are changes that could realistically be made without significant lifestyle or financial sacrifices.

The United Nations Environmental Programme (UNEP) has usefully pointed out that the need for '*Better sewage treatment critical for human health and ecosystems*' is urgent and compelling (Lamizana, 2019); at the same time, they recognise that current methods and infrastructure were never designed to deal with modern contaminants including pharmaceutical products.

The UN WHO paper, '*Progress on Safe Treatment and Use of Wastewater Piloting the monitoring methodology and initial findings for Sustainable Development Goal 6 (SDG 6),* observes: "*Water is the lifeblood of ecosystems, vital to human health and well-being and a precondition for economic prosperity; the availability and sustainable management of water and sanitation for all is at the very core of the 2030 Agenda for Sustainable Development.*" (Guidelines on Sanitation and Health. 2018) (This author's underline)

However, tellingly, the UN proposed expansion, improvement, and add-ons to what is a fundamentally flawed, environmentally unsustainable, 'busted', flush-and-forget FaF sewage treatment system, an unredeemable dinosaur technology.

We are failing for various reasons to 'look outside the box'. For all the reasons cited, flush and forget is arguably no solution. Expanding flush and forget FaF magnifies existing issues, including water demand. The mixing of urine and faeces into the broader polluted waste stream results in highly polluted sewage sludge, which is then impossible to effectively remediate, requiring its incineration and the expensive technical tertiary treatment of sewage wastewater, which are flawed, unsustainable and irredeemable solutions, making it impossible to close the environmental cycle.

Vacuum WC collection at the source and deployment of the collected material to specialist hyperthermophilic anaerobic digestion and composting treatment facilities, as well as producing economically valuable green methane for energy and compost for return to agricultural land, would help unlock the potential to recycle greywater and reduce environmental pollution at multiple levels.

"*In earlier times and even today, engineers and politicians nearly always use a simple cost/benefit analysis when choosing a wastewater system*" (Jenssen, 2007). Arguably, a cost-benefit analysis would favour a move to vacuum WC-based sewage systems.

There would be substantial financial savings and environmental benefits, as 'Flush and Forget' infrastructure would no longer need to be replaced or built afresh. There is also significant economic value in the consequential improvement in public health and well-being due to improved water quality and reduced pollution, including in early-year development, the value of which is incalculable.

Implementing regenerative agriculture and improved sewage management would bring us closer to closing the environmental cycle, as well as massively reduce demand for artificial phosphates and nitrates, reduce eutrophication, improve the nutrient density of crops and food security, reduce soil and water pollution, ameliorate soil water retention and thus regional hydrologies, reduce irrigation needs, and protect river flows, stabilise weather, reduce atmospheric heating and heat domes, improve the carbon sequestration potential of the land at the same time drawing down atmospheric carbon dioxide helping mitigate 'climate change', improve the drought resistance of soil, and more. These factors would cooperatively help mitigate farming-related climate change effects and produce healthier soils, plants, livestock and, ultimately, humans.

The above underlines the need for joined-up thinking; however, responsibilities and decision-making processes often are not sufficiently cohesive. For example, "*National responsibilities for monitoring domestic and industrial wastewater treatment often fall to line ministries (i.e. public services and industry) and are reported through different reporting mechanisms.*" (Nippon Koei Co., Ltd. 2019).

Sewage management, at all levels, including water, pollution prevention, and resource recycling, must be given a more significant profile, cohesion, and a higher priority, including at the government level. Ministerial and departmental cooperation is required across multiple portfolios, including health, finance, agriculture, environment, fisheries, cities, energy, transport and climate change. of

Governments could significantly change the direction and focus of sewage collection and disposal by developing innovative policies and introducing legally enforceable targets. In return, there could be considerable economic opportunities at multiple levels and cost savings for the public purse.

To kick-start a complete overhaul and rethink of the way we collect, treat, and recycle urine and faeces, we need open minds, an acceptance of the urgent need for change, and a willingness to go back to basics. This observation is not a rejection of technological advancements; quite the opposite. The necessary change will entail harnessing innovation, with a central focus on closing the cycle, thus restoring harmony between human beings and nature as far as pragmatically possible.

Similar treatment strategies could be adopted for the treatment of livestock urine and faeces, combined with volume minimisation through reduced and less wasteful 'nose to tail' livestock product consumption, reduction in feedlot livestock production, and a move back to range-based mixed farming, including rotational grazing.

For us, here and now, our starting point must be to close the environmental loop and, so far as pragmatically possible, to optimise the environmental sustainability of the soil-plant-food-soil loop. Food and excreta: there cannot be one without the other. Both are nutrients, albeit for different life forms. They are both equally fundamentally essential parts of the evolved Gaian ecosphere that support us and all wider planetary life in all its various guises. Sunlight, water, food, air and an unpolluted environment are key to life.

We must not lose sight of fundamental evolutionary imperatives that support healthy humans and are equally applicable to all life forms. To fulfil our optimal human potential, we absolutely need contaminant-free air, water, and nutrient-dense food. Adequate nutrient intake, sunlight, clean air and water are obligatory for optimal cellular function, including cerebral function, consequent mental health and optimal behavioural outcomes, including minimisation of predisposition to anxiety and aggression.

Current sewage FaF, collection, transport, treatment and disposal, are unsustainable at many levels, including as to; water supplies, pollution of water and land, with; pharmaceuticals including antibiotics, PCPs, PFAS, hundreds if not thousands of industrial and domestic pollutants, heavy metals, microplastics, nitrates and phosphates; consequent pollution, eutrophication and environmental degradation, of, rivers, lakes and oceans, and resultant degradation; of food, human health and behaviour, and ecological sustainability.

Change to a new sewage model that potentially closes the cycle is possible, **if** the will and understanding are there, for the necessary crucial strategic decisions to be made globally to move away from FaF and DiE to vacuum WC collection of faeces and urine at source, combined with likely hyperthermophilic anaerobic digestion for biogas, with subsequent hyperthermophilic aerobic, composting, with the return of the compost where possible to the land.

I hope this publication provides a meaningful overview and cogent argument that flush and forget FaF technology is indeed a busted flush, a dinosaur technology, unsustainable at many environmental levels, that requires a refreshed mindset and implementation of new technologies as a matter of urgency before vast sums are flushed away, in supporting the renewal and expansion of the current FaF irredeemable dinosaur Victorian technology, which is structurally incapable of ever closing the soil-plant–food-eat-defecate-soil ecosphere, cycle. As contributors and beneficiaries, environmental scientists, policymakers, public health officials, and citizens, your role in addressing this issue is crucial.

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