Sanitation in the Context of Planetary Health: Opportunities and Challenges

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What is Planetary Health?

Planetary health addresses the interconnections between the processes of environmental change and their impacts on human health and well-being, at scale.

The links between environmental change and human health may be either direct (e.g. impact of air pollution on respiratory and cardiac functioning) or indirect (e.g. extreme weather events, sea level rise or desertification leading to permanent displacement). There is plausible connection, evidenced by science, between the change in natural systems and human well-being in all instances.

Planetary health operates chiefly at a transboundary/international scale, covering issues that one country cannot address in isolation. Solutions, however, may be local, national, regional or international. Planetary health is horizontal (across borders and economies) and vertical (across time, preserving and renewing Earth's natural systems for future generations).

The planetary health concept builds on the ecological framing of planetary boundaries[1] and the human development framing of the UN Sustainable Development Goals (SDGs)[2]. The work of the Rockefeller Foundation Economic Council on Planetary Health, through its Secretariat based at the Oxford Martin School at the University of Oxford, emphasizes the interconnectedness, universality and equity that emerges from the SDGs.

The Rockefeller Foundation Economic Council on Planetary Health aims to provide a policy-oriented, economic perspective to developing solutions through a report that will be published in 2019. The central economic concept to the report is that externalities (or costs and benefits to another party that are not priced, regulated or consented to) should better address planetary boundaries than at present, while remaining mindful of the SDGs. The analysis pays attention to equity and distributional issues, recognizing how different people, institutions, countries and trajectories of development are affected by both the impact of planetary health and the measures proposed to address it. This work seeks to target recommendations at global and national policy-makers.

To address externalities, three key dimensions of change (both positive and negative) are considered through which planetary health should be considered, and from which global public goods can be developed. These are:

1 Rockström, Johan, Will Steffen, Kevin Noone, Åsa Persson, F. Stuart Chapin III, Eric Lambin, Timothy M. Lenton et al. "Planetary boundaries: exploring the safe operating space for humanity." Ecology and society 14, no. 2 (2009).

2 United Nations. "Sustainable Development Goals". Accessed from *www.un.org/sustainabledevelopment/sustainable-development-goals*

1. New incentives for planetary health can be achieved through price/market and non-price/regulatory mechanisms and policies. These are instruments such as taxes, subsidies and pricing schemes, mandates and also investment in research, knowledge and information that shift behaviour.

2. New and adjusted forms of governance and institutional arrangements are needed to address the (political) challenges and trade-offs of planetary health at multiple scales. Intergovernmental mechanisms have had varied impact on enabling effective multilateral coordination, cooperation and new forms of polycentric global institutions including non-state actors, such as businesses, cities and NGOs, are emerging.

3. Existing planetary health monitoring mechanisms can be strengthened through better knowledge and stronger connections between human health and natural/environmental monitoring and measurement systems, and by drawing on new technologies to measure and manage data.

A series of background papers has been developed by the Secretariat to inform the Council Members. These aim to illustrate where solutions might be identified and applied, diagnosing planetary health issues by highlighting drivers of change, significant environmental impacts and the resulting human health impacts. Direct and indirect interlinkages between the drivers, environmental and human health impact are considered.

The full set of papers can be accessed at *www.planetaryhealth.ox.ac.uk/publications/*

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Transporting fecal sludge in Lusaka, Zambia
Credit: © WSUP/Gareth Bentley

Sanitation in the Context of Planetary Health: Purpose of this Paper

This paper is an output of the Secretariat of the Rockefeller Economic Council on Planetary Health. It is intended to inform the council and to review the relationship between sanitation, one of the key public health challenges, and planetary health.

Sustainable access to clean and adequate water, air and diets sit at the heart of the planetary health agenda. The United Nations Sustainable Development Goals, SDG 6 in particular, focus attention on the role of water and sanitation.

Sustainable Development Goal 6:
Ensure availability and sustainable management of water and sanitation for all
Target: 6.2 – By 2030, **achieve access to adequate and equitable sanitation** and hygiene for all and **end open defecation**, playing special attention to the needs of women and girls and those in vulnerable situations.

Target: 6.3 – By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, **halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally**.

Target: 6.A – By 2030, **expand international cooperation and capacity-building** support to developing countries **in water- and sanitation-related activities and programmes**, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.

Global losses associated with inadequate water supply and sanitation are estimated to be 1.5% of GDP. Poor sanitation is costing countries such as India more than 6% of GDP, while less than half the global population use a safely managed sanitation service. This paper shows investment in sanitation to be the second-best health investment globally, behind only hygiene promotion. Economic benefits are in the range of US$5-16 benefit for every US$1 spent.

Barriers to improving sanitation vary across contexts both in terms of rural and urban development and national wealth. We suggest that the application of a planetary health approach can provide new ways of valuing and addressing the challenges of sanitation, and in doing so can generate additional benefits for the environment and economic development.

In particular, by focussing on resource recovery from fecal sludge and wastewater – and its potential to generate clean energy – prudent investment in sanitation and waste management can help countries to reduce their greenhouse gas emissions, reduce the use of artificial fertilizers in agriculture, ease pressures on freshwater availability, and create jobs in the waste collection sector and in waste treatment plants.

Re-use of treated sludge produced by Kanyama Water Trust for soil conditioning, Zambia
Credit: © WSUP/Gareth Bentley

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1.0 Sanitation for Planetary Health: An Overview

Key points

- Well-managed sanitation improves health, benefits agriculture, creates clean energy and provides employment opportunities.
- However, less than half the global population (39% or 2.9 billion) use a safely managed sanitation service.
- Nearly a third (32% or 2.3 billion) of people still lack even basic sanitation.
- 892 million people still practice open defecation.
- Across Africa, less than 10% of the population is connected to a sewer system; in some regions, there is no sewer infrastructure at all.
- Poor sanitation is a factor in an estimated 80% of all environment-related deaths.
- Poor sanitation costs countries between 0.5 and 7.2% of their annual GDP.
- The World Health Organization estimated total global economic losses to be US$260 billion annually in 2012.
- Investment in sanitation returns an estimated US$5-16 for every US$1 spent.

1.1 Introduction and background

A challenge for densely populated human settlements is how to dispose of the correspondingly large quantities of human waste[1] which, if not safely managed, impact on human health, the environment and economic prosperity. In 2012, the World Health Organization (WHO) estimated total global economic losses associated with inadequate water supply and sanitation to be 1.5% of GDP (US$260 billion)[2] with poor sanitation costing countries between 0.5 and 7.2% of annual GDP[3] (7.2% of GDP in Cambodia, 6.4% in India, 6.3% in Bangladesh, 3.9% in Pakistan and 2.4% in Niger[4]), due to premature deaths, the cost of healthcare treatment, productivity time lost to sickness and seeking treatment, and productivity time lost to accessing sanitation facilities. In developing countries, at any one time as many as half of all available hospital beds can be filled with people suffering from diarrhoea.[5]

More recent studies estimate losses from sanitation alone to be US$222.9 billion in 2015, a 22% rise on World Bank Water and Sanitation Programme (WSP) figures for 2010.[6] In India – where sanitation coverage was particularly poor for the country's level of development at the time the figures were calculated – economic gains from improved sanitation were estimated at US$54 billion annually,[7] with even higher potential when benefits from wastewater reuse were factored in.[8,9] In developed settings, sanitation involves not only the removal of waste, but also its treatment, recycling and reuse into natural fertilizer, biogas and clean energy, providing additional economic benefits. Global biogas sales, for example, could be as high as US$50 billion annually by 2026.[10] Based on Disability Adjusted Life Years (DALYs) and the Global Burden of Disease (GBD), the two most commonly used health metrics, investment in sanitation would be the second-best health investment in the world, behind only hygiene promotion.[11] This is without counting the health co-benefits that would come with cleaner energy and improved fertilizer use.

This highlights that although initial capital costs of sanitation systems can be high – sanitation has to be properly funded and managed, as inappropriate sanitation can be a worse health hazard than none at all[12] – the long-term investment will pay off. However, the Millennium Development Goal (MDG) targets on sanitation were missed by nine percentage points (700 million people). Key challenges identified included difficulties in securing political buy-in for sanitation improvements; a lack of focus on the different requirements of rural and urban areas, leaving rural areas lagging behind; insufficient data – particularly at subnational levels – to provide convincing evidence to policy-makers; and too strong a focus from international agencies and NGOs on supporting small-scale household or community projects rather than larger, city-wide or national programmes.[13],[14]

This has led to an increased focus on sanitation and waste management in the Sustainable Development Goals (SDGs)[15] and a strong intention to do better in achieving the targets for the period 2015-2030. Two indicators in particular relate to sanitation: SDG 6.2 – "Percentage of the population using safely managed sanitation services (i.e. a toilet not shared with other households, for which excreta is safely disposed of in situ or treated off-site[16]), including a hand-washing facility with soap and water"; and SDG 6.3 – improved wastewater management, recycling and reuse.

Monitoring progress towards the targets associated with these goals is an important part of the SDG programme and is undertaken by WHO and UNICEF's Joint Monitoring Programme (JMP).[17] Improvements in sanitation could help countries achieve as many as 32 SDG targets, including reducing the burden of infectious diseases and child mortality, improving education, achieving gender equality and empowerment for all girls and women, making cities more liveable and improving food security. WHO identifies two key regions for action: smaller urban centres and rural areas of sub-Saharan Africa, and large cities with vulnerable water systems in Asia.

In addition to the human health benefits of good sanitation, the reuse of human excreta in fecal sludge and wastewater, particularly as agricultural fertilizer, offers economic opportunities. A 2009 report by India's Central Pollution Control Board[18] calculated that 93% of the value of wastewater is down to the micronutrients it contains. There are enough micronutrients in one person's excreta to grow the wheat and maize needed to feed that person for a year. Some studies[19] suggest that in countries dominated by smallholder farming, all fertilizer use could be replaced by nutrients recovered from human excreta, with its cash value making a significant impact on the annual finances of smallholder farmers and their families, particularly if reduced household spending on artificial fertilizer is factored in. Organic kitchen waste, which may be disposed of through the same systems as excreta, can also be recycled.

Poorly managed sanitation can create additional environmental challenges, however. While pit latrines can be hygienic and can count as improved sanitation for the SDG goals, they can create more than 1 tonne of CO_2eq per year due to increased methane emissions of anaerobic decomposition in the pits.[20] Connecting the latrine pit to a household-scale biogas plant, which can also process kitchen waste, reduces this by more than 80% and provides clean household energy, further reducing the carbon emissions of other fuel sources such as wood or charcoal. At a municipal scale, biogas captured from waste treatment plants can be used to power vehicles, added to energy grids, and used to power the treatment plants themselves.

Achieving the potential economic benefits may require a change in how sanitation and wastewater management are approached, however. At present, such issues are widely considered to be part of public health and increasingly as an important part of environmental protection. They are also considered to be an important part of enhancing gender equality, freeing women from water collection and caring for sick relatives, as well as protecting them from harassment in the bush and providing the privacy they need during menstruation to engage fully in school and the workplace.[21] Sanitation and waste management are not yet widely considered to be resource management tools, however, capable of generating additional economic growth and thus becoming cost neutral to their providers.

Managed safely, sanitation is financially and politically sustainable. It can deliver direct economic benefits by reducing healthcare costs associated with disease burdens, particularly with regard to diarrhoeal disease; increasing the indirect economic benefits related to improved health outcomes, such as reducing lost productivity due to sick days; and increasing the indirect economic benefits from non-health outcomes, such as making areas more attractive to businesses.[22] Tourism opportunities in particular can be adversely affected by poor sanitation infrastructure.[23] By applying a planetary health approach across the triad of public health, environmental health and economic opportunities, policy-makers and environmentalists can begin to think in terms of not only the disposal of human waste, but also of resource recovery and reuse, considering the benefits this can bring to the environment, including reduction of greenhouses gases and recovery of nutrients for agriculture, as well as reduced exposure to disease pathogens. This should encourage safer management from which human health (including the occupational safety of water treatment workers) will benefit.

1.2 Sanitation as a public good

Sanitation has to be a community-wide – if not nationwide – endeavour. Unlike with clean, piped water, there is little benefit to one household in a community installing a toilet if others do not: people will still be exposed to pathogens and their environment will still be polluted. Once toilets have been installed, a public health campaign may need to be instigated to ensure they are actually used for their intended purpose: people need to "get a toilet, use the toilet and clean the toilet".[24] This may need to be coordinated and managed for households at the community level, especially where toilets are shared.[25] Without this, toilet structures can end up being used as storage sheds or for other inappropriate uses, with little benefit to the community.

Sewer systems and waste management services, including fecal sludge management (FSM) services that collect fecal waste from tanks in regions where municipal sewers have not been installed, need to be planned, invested in and built at a community or city level. If doing so is impractical or prohibitively expensive, alternate systems – which may be financial systems as well as technological ones – that are more appropriate to the context need to be considered.

Perceptions and behavioural change around sanitation can be as important as technological innovations in driving forward changes. Frank Geels of the University of Manchester has argued that the transition from cesspools to sewer systems in Europe during the Industrial Revolution illustrates the importance of framing the relationship between environmental factors and human health in order to drive interest in improved sanitation onto political agendas.[26] Framing sanitation as a key public service enables it to be used as a cause on which to build pressure for further social reform, particularly if the issue is adopted by regime insiders. In 1947, Mahatma Gandhi advocated good sanitation for all, declaring it to be "more important than independence"[27] and the Indian government has vowed to end open defecation in the country by 2019, the 150th anniversary of his birth.[28] Political and economic support for sanitation as a public good that improves health, the environment and opportunities is needed at the international, national and community level, if the SDG targets are to be met.

Human waste, health and the environment

The evidence for investing in sanitation as a public good is strong: along with improved nutrition, better housing conditions and improvements in medical science, it has helped to improve the health of many of the world's populations over the past 200 years.[29] In 2007, readers of the *British Medical Journal* voted sanitation to be the most important medical milestone since the journal was first published in 1840.[30] Epidemiologist Abdel Omran considers it to be an important part of the second stage of humanity's epidemiological transition,[31] the "age of receding pandemics", during which the number of deaths caused by infectious disease, especially in early childhood, reduces considerably. [32,33]

The health risks from poor sanitation come from human exposure to the bacteria and viruses contained in human feces or carried by the vectors that feed and breed on it. The average person excretes approximately 130g of feces each day, and 800-2,000ml of urine, depending on age, medical condition and liquid consumption. One gram of human feces can contain up to 100 million pathogens and as many as 10,000 parasites,[34] responsible for diseases such as cholera, dysentery, Hepatitis A, polio, typhoid, schistosomiasis and trachoma. Many of these, such as *Escherichia coli* and *Salmonella spp*, and microscopic parasites including *Cryptosporidium spp*, cause diarrhoea, which was estimated to be responsible for more than 100 million DALYs worldwide in 2013[35] and nearly 1.4 million deaths in 2015.[36] More recent research suggests that these figures may be even higher when the effects of nutrition on childhood growth and development are fully factored in.[37] Of this disease burden, 92% is borne by low- and lower-middle income countries (LMICs). Of the estimated 842,000 people in LMICs who die as a result of poor hygiene each year, poor sanitation is the main cause in 280,000 cases,[38] and is responsible for one in five cases of diarrhoea.[39] Improved sanitation can reduce the rates of diarrhoeal disease by 32-37%[40] but 1.8 million people still use a water supply at risk of fecal contamination.[41]

1.3 Technologies and political support

The available evidence should provide a strong incentive for providing global access to improved sanitation. Technological solutions to poor sanitation are available: the introduction of facilities such as latrines, septic tanks, toilets and sewers that reduce contact between humans, the environment and harmful waste. But sanitation also requires financing and institutional governance in a systems approach that considers the entire waste-management cycle. A stronger focus in the SDGs on end-to-end management as well as the state of the facilities into which waste is excreted, collected and treated, led to the previous MDG category of "improved" to be restructured: it is now defined as "facilities that include flush/pour flush to piped sewer systems, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs". "Improved" now encompasses three categories – basic, limited and safely managed.

WHO/UNICEF JMP categorizes sanitation facilities as:[42]

- **Open defecation:** Open defecation onto open ground or into water courses
- **Unimproved:** Pit, bucket or hanging latrines that are not safely managed (may cause water or soil contamination)
- **Basic:** Use of improved facilities that are not shared with other households (but which may not reach the standard of "safely managed")
- **Limited:** Use of improved facilities shared between two or more households (which may or may not otherwise meet the criteria for 'safely managed')
- **Safely managed**: Use of improved facilities that are not shared with other households and where excreta are safely disposed of in situ or transported offsite

Environmental risks of poor sanitation

Poor sanitation not only affects human health: it can also damage ecosystems. Poorly managed latrines and septic tanks can leak into soil and water, and untreated wastewater released directly into the environment can pollute rivers. Anaerobic decomposition in latrine pits can release five times as much greenhouse gas to the atmosphere as in a biogas converter.[43] Coastal dead zones can result from the depletion of oxygen used to break down large quantities of organic waste, and untreated waste can also cause eutrophication – excessive plant growth due to the high concentrations of phosphates and nitrates it contains.[44] The risk is higher during extreme weather events such as storms and flooding,[45] the incidence of which is expected to increase over the coming decades[46] due to climate change. Drains and sewers need to be designed to cope with seasonal differences in carrying capacity, such as during periods of heavy rainfall or monsoons.

Poor sanitation was linked to one in 10 deaths in India in 2014. At that time, the country accounted for more than 60% of the global population without access to a toilet,[47] but India is far from being the world's poorest country, nor one of the least developed, suggesting that sanitation is not only an issue of economic development but also needs behaviour change programmes to make a difference. The Swachh Bharat Abhiyan (Clean India Mission) campaign, launched in 2014 by Indian President Narendra Modi, has constructed hundreds of thousands of household and community toilets across India, has produced more than 80 MW of clean energy and has recycled more than 150,000 tonnes of waste to compost per year from India's cities.[48]

The increasing availability and use of sanitation systems shows a strong positive correlation between a region's level of economic development and the prevalence of improved facilities, but there are also cultural and social drivers behind the reasons for more than a third of the world's population still lacking adequate sanitation. These also need to be considered when planning sanitation projects across the world.

When reflecting on these categories, it is important to acknowledge that different contexts may favour different systems: the Western European/North American model of flush toilets and extensive sewer infrastructure may not be appropriate in regions of high water stress and/or low population density,[49] where construction materials are not easily available and where urban centres are still developing.

While there has been criticism that the WHO sets the bar for "improved" sanitation too low,[50] small steps towards improvement should not be dismissed: basic is better than unimproved, and unimproved is better than open defecation. In developing settings, safely managed FSM systems are more practical and easier to facilitate than fully plumbed municipal sewers.[51]

SDG 6.2 specifically draws attention to the needs of girls and women and those in vulnerable situations in the context of sanitation.[52] Inadequate sanitation provision for privacy, particularly during menstruation, can prevent girls and women from participating fully in education and the workplace[53],[54] while good sanitation can free their time from water collection and caring for sick family members, for schooling and for economic activities.

1.4 International support for improved sanitation

Improving sanitation is rightly recognized as a key component of planetary and global health by the WHO,[55] United Nations[56] (including the UNFCCC secretariat,[57] UN-Water[58] and UNEP[59]), World Bank,[60] UNICEF[61] and many other agencies and organizations at the national and international level, including those focussing specifically on sanitation such as WSUP – Water and Sanitation for the Urban Poor[62] and CONIWAS, the Coalition of NGOs in Water and Sanitation, in Ghana.[63] Human waste should be seen as an important part of the circular economy, enabling the economic costs of sanitation to be off-set by benefits accrued through the reuse of sewage, fecal sludge and wastewater as natural fertilizer; the creation of biogas, cooking fuel and clean energy at household, community and municipal levels; and as a driver for employment opportunities and economic development. This is in addition to increasing productivity through better health and fewer days lost to avoidable illnesses. It is also important to ensure that sanitation is seen not only as a component of the home, but also of workplaces, educational establishments and other facilities, in particular to ensure female safety, dignity and equality.[64]

WHO works with the UN Food and Agriculture Organization (FAO), International Development Research Centre (IDRC), UNHABITAT and other organizations on sustainable wastewater management, particularly in poor urban communities, where the challenges can be most acute.[65] The World Bank recognizes the economic benefits of good sanitation to include[66] lower disease burdens, improved nutrition, reduced stunting, improved quality of life, increased attendance of girls at school, healthier living environments, better environmental stewardship, increased job opportunities and wages, and improved competitiveness of cities, all of which contribute economic and social gains to society.

In 2007, the World Bank launched the Economics of Sanitation Initiative (ESI)[67], in partnership with the Water and Sanitation Programme (WSP), following a WSP report[68] that calculated the cost of poor sanitation and hygiene in five South Asian countries alone to be US$9.2 billion a year at 2005 prices. Subsequent studies were conducted in Africa and South Asia, and another is currently ongoing in Latin America. A second phase has analysed the benefits of sanitation interventions in a series of countries, including China, showing that while sanitation options that protect the environment are costlier to provide than more basic ones, their value to households, business and tourism can increase economic returns. Working with WHO,[69] ESI calculated the global economic return on investment in sanitation to be US$5.5 for every US$1 invested, with the global losses associated with inadequate water supply and sanitation to be US$260 billion annually. WHO has estimated a return of investment of between US$5.5 and US$16.6 for every US$1.00 invested in sanitation, based on lower costs of healthcare, improved worker productivity and fewer premature deaths.[70]

In 2010, the UN General Assembly recognized access to safe and clean drinking water and sanitation as a human right. In 2012, the UN Deputy-General issued a call to action, including an end to open defecation by 2025. [71] This was driven in part by the challenges of meeting the targets set by Millennium Development Goal 7.C to half the number of the world's population without sustainable access to safe drinking water and basic sanitation by 2015. In 2013, MDG 7 was recorded as being "the most lagging" MDG behind its target,[72] but despite this warning, the target was missed by nine percentage points.[73] Analysis of the failures highlighted noticeable inequalities between rural and urban areas, and between socioeconomic groups.[74]

1.5 Progress towards improved sanitation for all

Today, the World Bank records that 99% of populations across all high-income countries – and 100% of their urban populations – have access to improved sanitation but globally, this drops to 68% across all countries (while a figure of 100% is often recorded, some marginalized groups, such as the urban homeless, may lack access to improved sanitation but in numbers too small to affect a national-level reporting score). In the world's least developed countries, only 27% of the population gained improved access to sanitation during the 1990-2015 MDG period. In 2015, 70% of people without basic sanitation lived in rural areas, as did 90% of those still practicing open defecation.

Furthermore, only 39% of the global population used a sanitation service that WHO would consider to be safely managed. Of the 2.3 billion people without even basic sanitation, 892 million still defecate in the open, in bushes, street gutters or open bodies of water.[75] Gaps in access to decent, well-functioning sanitation are clear markers of inequality and disadvantage[76] and the poorest people in developing countries now face a triple burden of communicable disease due to inadequate sanitation, lack of access to healthcare services including vaccination programmes that would help to protect against some waterborne diseases, and increased risk of exposure to urban and industrial pollution, including from human waste. Challenges to improving sanitation across the world have been disappointingly persistent and must be addressed if the health, environmental and economic opportunities are to be recognized[77] and good sanitation infrastructure locked-in early to developing urban regions.

1.6 Conclusions

This introduction has sought to give an overview of the links between sanitation and planetary health, including the risks to human health, the health of the environment and economic opportunities from poor sanitation, and the benefits that will be derived from improved sanitation. As the developing nations industrialize and urbanize, the incorporation of sanitation and waste management strategies into wider environmental policies offers many advantages. It will reduce human health risks from infectious diseases, especially the bacteria and viruses that cause diarrhoea. Where contact with human waste is not sufficiently prevented by well-designed pit latrines, septic tank systems, FSM services or sewer systems, pathogens and parasitic worms can infect populations though contaminated water and soil. The young – particularly children under 5 in developing countries – bear a heavy burden.

Environmental risks from the high-nutrient content of human waste will also be reduced, preventing eutrophication caused by untreated waste released to the environment, or river and coastal dead zones caused by oxygen depletion during waste breakdown. Methane that would otherwise contribute to greenhouse gas emissions can be captured and reused.

There are clear economic benefits to be had from investment in sanitation, with an estimated return of US$5.5 to US$16 for every US$1 spent. Good waste management practices allow the nutrients in waste and wastewater to be reused as agricultural fertilizer; the biogas released from the breakdown of waste to be used as fuel, including as cooking fuel in the home and as vehicle fuel; and to generate electricity. Capturing methane emissions from human waste for biogas compared with losing them to the atmosphere could prevent a 6% annual increase in India's greenhouse gas emissions, while recovered nitrogen could meet 18% of the country's projected nitrogen demand in 2019 and nearly 5% of its phosphorus demand[78]. Using this biogas to provide clean energy to households that currently use traditional cooking stoves could potentially avoid more than 4% of India's greenhouse gas emissions, worth over US$1 billion on the international carbon market, and reduce black carbon by a third[79]. This would prevent 570,000 premature deaths annually. Recycling waste water will also ease pressures in regions of the world under water stress, though water-less sanitation systems are also a viable option.[80]

Challenges to implementing and maintaining improved sanitation vary between locations based on economic status, rural or urban settings, and cultural barriers around attitudes to defecation. All of these need to be addressed if SDG 6 is to be achieved by its 2030 deadline. The most recent reports suggest that progress is currently too slow in around 90 countries, however.[81] While the developed world is showing immense progress in collecting, treating and reusing waste, the developing world still lags behind. New solutions may need to be developed.

Open defecation: A persistent challenge

This paper focuses on sanitation, but it would be remiss not to briefly cover the issue of open defecation – urinating and defecating directly onto soil, into street gutters, or open water. Countries where open defecation is widely practiced, such as Chad (68% of population in 2015), Eritrea (76%), Niger (71%) and South Sudan (61%),[82] have high burdens of diarrhoeal disease and childhood mortality. Communities are particularly at risk from bacteria, and from worms that affect nutrient and calorie absorption.[83] This means that even if diets improve, malnourishment does not.

High rates of open defecation may be the reason for smaller average Indian body size compared with African populations living in similar environments: links between open defecation and stunting are well established.[84,85] Open defecation in India is also thought to be a factor in why higher rates of infant and child mortality have been recorded in Hindu families than in poorer Muslim ones.[86] Importantly, in communities where open defecation is practiced, individual families who install a toilet in their own home may not see the benefit, as the environment in which they live will still be polluted.[87] Encouraging the whole community away from open defecation requires concerted behavioural change campaigns.[88]

Worldwide in 2015, an estimated 892 million people were still regularly practicing open defecation. The practice is most closely correlated with extreme poverty and remote rural areas in developing countries, but poverty is not always the main barrier. Cultural taboos can prevent populations from using latrines even when they are available. Historically, this has been a particular issue in India, where religious taboos, particularly around ritual purity and human waste, hindered government efforts to introduce improved sanitation.

In 2015, 40% of the Indian population still defecated openly,[89] though more recently the government's Swachh Bharat Abhiyan (Clean India Mission)[90] has made significant progress on this since its launch in 2014 with nearly 8 million toilets built as of June 2018, and 17 states declared open defecation-free. All but three Indian states now report rates of Individual Household Latrines (IHHL) above 70%, and coverage is above 85% for the country as a whole (though these figures are yet to be verified by the WHO/UNICEF JMP).[91]

Such findings emphasize that public health education campaigns can be as important as technical solutions to overcoming the challenges: studies from the 1960s to the present day have covered societal taboos and concerns about human excreta and suggest that these may hamper academic study into the subject, as well as presenting barriers to the introduction of sanitation.[92]

Sanitation projects and approaches in regions of the world where open defecation behaviours are embedded need to consider incorporating behaviour change into any project rollout. It is important to acknowledge that there are three stages involved in sanitation:[93]

1. Get a toilet
2. Use the toilet
3. Clean the toilet

Behaviour change programmes to help embed this in communities can, for example, include positioning a toilet as an aspirational household item that shows dignity and encourages respect, and as something guests expect you to have; as an important possession for maintaining health around significant lifetime events such as the birth of a first child; or as a valuable tool for protecting the safety and dignity of female family members. By positioning open defecation as something others look at with disgust, and associate with animals, its practice can be discouraged. Combining public health messages around toilet use with complementary messages about handwashing and home cleaning will help to promote cleaner and more hygienic environments.

Economic messages that stress the link between poor sanitation and days lost to work due to sickness, to schooling due to worms, or the cost of diarrhoea treatments and doctors' visits, can also help to encourage households and communities to see the value of sanitation.

It is also important to emphasize links between sanitation options and greenhouse gas emissions. Untreated pit latrines produce higher greenhouse gas emissions than open defecation. During decomposition in the open air, most of the carbon in fecal matter is converted into CO_2. In latrine pits, however, anaerobic conditions result in methane production,[94] particularly when significant amounts of water are used. This is a particular issue in India, where a move from open defecation to pit latrines could see an increase in GHG emissions if this is not addressed by biogas digestors that can capture the methane and reuse it as clean energy.

Collection of waste in Kisumu, Kenya – Credit: © WSUP

2.0 Gender and Sanitation

Key points

- Private, single-sex sanitation facilities, particularly during menstruation, can remove barriers to full participation in education and the workplace.
- Household sanitation protects girls and women from harassment and violence.
- Improved sanitation can free women and girls' time for education and economic activities.
- Including women in planning and delivery will ensure their needs are addressed.

2.1 Gender and the SDGs

Gender is a cross-cutting theme of the SDGs. Target 6.2 calls for attention to be paid to the needs of girls and women, an addition from the MDG 7, and the framing of sanitation in 7.C as purely for environmental benefit.

In many developing countries, and particularly in rural regions, women and girls are responsible for household water supplies – including fetching and carrying water from wells and rivers – and care for relatives when they are sick. As such, sanitation provision can have a huge impact on them, as it can free up time to attend school or to engage in income-generating activities. When girls and women have to leave their home to defecate in the bush or in shared community toilets, they are vulnerable to harassment and violent assault. Positioning sanitation in terms of the safety it affords women can help to overcome cultural barriers to having toilets in the home, by showing that this is a greater benefit, and one that caring families who want to protect their daughters will accept.[95]

If gender issues are not considered when installing sanitation, facilities in schools can be inadequate for girls, particularly during their menstrual period, leading them to skip classes. School enrolment and retention increases where private sanitation provision for girls, separate from boys' facilities, is made.[96] In developing countries, girls may use rags as sanitary napkins which they need to wash and hang somewhere to dry after use; if there is no private place to change, and no water and soap to wash them properly, they risk infection and may drop out of school once their periods begin.[97] Women will also be more likely to engage in the workforce if female-only facilities are provided. In developed, liberal economies, however, there has recently been a kick-back against gendered toilet facilities, as they can be uncomfortable for transgender people and people who do not identify as either male or female.[98,99] Ensuring that women and girls are included in the planning of sanitation projects, in leadership and consultancy roles, can help the development of gender empowering sanitation services.

Further information on gender equality and sanitation can be found at the following links:

UN Water for Life – *http://www.un.org/waterforlifedecade/gender.shtml*
World Bank – *http://siteresources.worldbank.org/INTGENDER/Resources/watersanitation.pdf*
WSUP Gender – *https://www.wsup.com/themes/gender*

3.0 Waste Management: Fecal Sludge, Wastewater and Treatment

Key points

- An average adult's annual production of urine contains 4kg nitrogen, 0.4kg of phosphorus and 0.9kg potassium.
- Fecal sludge also contains valuable nutrients that can be used as natural fertilizer and its breakdown produces methane that can be used for biogas.
- Biogas used to fuel vehicles produces 95% less CO_2, 80% less nitrous oxide than diesel and has no particulate emissions.
- Uncaptured methane emissions from human waste contribute 7% to total global methane emissions.
- Water-based sanitation systems use 15,000 litres of water per person per year.
- 80% of wastewater generated each year is discharged untreated into the environment.
- 90% per cent of all human waste is released untreated into the environment each year in low-income countries.
- UNESCO estimates that more than 200 million tonnes of human waste each year receives no treatment at all.
- The 9.5 million m^3 of human excreta and 900 million m^3 of municipal wastewater produced every day contains enough nutrients to replace 25% of the nitrogen currently used in synthetic fertilizers and 15% of the phosphorus.

3.1 Waste as a circular economy

As well as the hygienic value of the safe management of human waste, there are considerable economic opportunities to be had from viewing it as part of the circular economy.

Human excreta consist of two main components: urine, which contains by-products of human metabolic processes, and feces, which is the remains of undigested food, dead cells and gut bacteria. These contain valuable organic compounds including phosphorus, nitrogen, potassium, iron, chlorine, boron, copper and zinc. An average adult's annual production of urine contains 4kg of nitrogen, 0.4kg of phosphorous and 0.9kg of potassium,[100] for example; these can be recovered and reused. The high phosphorus and nitrogen content in particular makes human waste an excellent natural fertilizer, and the methane released during its organic breakdown can be used as biogas. Waste can be reused untreated, by spreading it on land as natural fertilizer, or it can be treated in septic tanks and waste management facilities. The safe management of waste is an important part of the sanitation process and includes how waste is collected, transported and treated, and how the final products of any treatment are reused or released into the environment. Sanitation is best approached not in isolation, but through a systems approach – for example, as part of an integrated and harmonized water cycle that includes the provision of clean drinking water, the removal of wastewater from toilets, baths, tanks and other domestic and industrial sources, and the protection of recreational waters.[101] This is often referred to as WASH (water, sanitation and hygiene)[102] and in developing urban regions may be better arranged through decentralized sanitation systems such as fecal sludge management (FSM) services[103] than through the large municipal sewer systems common in Europe and North America.

3.2 Sewers, decentralized systems and FSM

The management of waste in developed countries is a complex, industrial process that includes a number of stages. As economies develop, sanitation moves from a "drop and store" system of latrines and cess pits where the waste may remain in situ or be periodically emptied, to "flush and discharge" systems connected to piped water and sewage infrastructure. Fecal sludge management (FSM) is an intermediate system, in which waste is collected in a private tank, or one shared between a small number of households and businesses. This is regularly collected, emptied and transported to treatment works by FSM providers who may be private operators, part of public sector municipal services, or a combination of the two. FSM services are appropriate in low-income, developing urban settings where large-scale municipal sewerage systems have not yet developed and where the ability to construct sewers is limited. Sewer systems mix human excreta with water so that it can be easily transported away through pipes, creating large amounts of wastewater – it is estimated that water-based sanitation systems typically use 15,000 litres of water per capita/year,[104] which can be challenging in regions prone to water stress.[105]

Sewer systems that receive the contents of flush toilets usually also receive wastewater from other sources, such as industrial sites and agriculture, which may also contain harmful substances, including toxic chemicals from fertilizers, dyes, detergents and pharmaceutical residues.[106] Septic tanks and latrines may also collect household waste, toilet paper and sanitary products, which need to be removed during treatment before the waste can be reused. Wastewater from healthcare facilities, that might contain higher concentrations of pathogens and high concentrations of pharmaceutical residues, pose a particular challenge. The Joint Monitoring Programme (JMP) of the WHO and UNICEF contains specific additional criteria for handling waste from healthcare facilities, including the segregation of sharps and infectious waste.[107] How waste is transported away, treated and finally disposed of has important implications for human and environmental health. As much as 80% of wastewater generated worldwide flows directly into the ecosystem (i.e. the sewer pipe opens into a lake, river or the sea) without any treatment.[108] As only 55 countries have collected full data on wastewater management, and 57 collected none at all,[109] there are large gaps in the evidence and the full extent of the issue is unknown. Only about a quarter of the global population is connected to a sewer system, though this is not necessarily a major issue: efficient, effective and hygienic waste management can be achieved by decentralized sanitation systems in which toilets empty into localized collection points that are emptied by tanker[110] at the institutional and household level.

3.3 The SDGs and waste treatment

One aim of the SDGs is to reduce the percentage of untreated wastewater released back into the environment. Ideally, waste – and wastewater in particular – should be treated before it is released. There are three main stages – primary treatment, secondary treatment and tertiary treatment.[111] Primary treatment includes removing grit, gravel and large solids from the wastewater and allowing the remaining, largely organic matter to settle at the bottom of a tank (which may be a large tank in a water treatment works or a simple septic tank that is not connected to a sewer system and is emptied by FSM service providers).

During secondary treatment, which can occur in septic tanks as well as larger scale systems, the residual organic matter is broken down by bacteria. The resulting "activated sludge" then passes into a sedimentation tank where the solid sludge is collected and removed; it may also be disinfected and/or treated with ultraviolet light at this stage to kill remaining bacteria. The liquid component contains many soluble compounds, such as nitrates, that may be removed by tertiary treatment. At the end of any of the three stages, water can be discharged back into water courses or reused,[112] and the remaining sludge can be used as fertilizer. Methane produced during the process can be used as biogas and to create clean energy. Globally, at least 75% of wastewater that enters a sewer system undergoes at least secondary treatment.

Breaking down the organic matter during secondary treatment is a particularly important process: although human waste would break down naturally in the environment, in high concentrations the oxygen required to do this can create oxygen-depleted dead zones that affect wildlife in rivers and coastal areas. The high phosphorus and nitrogen content of wastewater can also lead to eutrophication if not reduced, in the same way as artificial fertilizer run-off.[113] In the UK, 75% of sewage sludge is broken down before discharge or reuse.

An added advantage is that the process creates methane that can be used as biogas, a renewable energy source that can be used for heating or cooking, to generate electricity, added to the national gas grid or used as vehicle fuel.[114] According to the US Environmental Protection Agency (EPA), uncaptured methane emissions from wastewater contributed 7% of total global methane emissions in 2010. If this can be captured and used as fuel instead, the greenhouse gas emissions are lower than for many competing fuels. Used as an alternative to diesel, it could lead to 70 million tonnes CO_2 reduction annually.[115] The biogas used to fuel vehicles produces 95% less CO_2 and 80% less nitrous oxide than diesel and has no particulate emissions. As methane is a more potent greenhouse gas than CO_2, burning it in vehicle engines or capturing it at sewage works or landfill sites arguably creates a carbon reduction of more than 100%.[116]

Around 10,000 tonnes of sewage sludge produced annually at the Bromma waste water plant in Stockholm, Sweden, is treated under anaerobic conditions to produce biogas for use in vehicles and the remaining sludge is used in agriculture as a soil conditioner. The municipal sewage treatment works in Heidelberg, Germany, can generate biogas from sludge within five days. A third of the electricity generated from this is used to power the treatment plant while the rest is sold to the German national grid.[117] The UK generates 15,000 tonnes of dry sludge every year, 80% of which is used as fertilizer, 18% is incinerated, generating power, and less than 1% is sent to landfill – the least desired outcome. The level and type of treatment needed can vary depending on whether the treated wastewater is released into salt water or freshwater systems, the level and type of wildlife in the local habitat, and the proximity of human populations, particularly if there is local recreational use of water, such as for swimming in seaside areas. Globally, however, UNESCO estimates that more than 200 million tonnes of human waste each year receive no treatment at all.[118] As much as 90% of human waste is released untreated into the environment each year in low-income countries,[119] along with around 70% of that generated in low-middle income countries and 30% in high-income countries.[120],[121] Poorly managed latrine systems can increase the amount of methane created during waste breakdown,[122] adding to greenhouse gas emissions. In India, this could lead to an annual increase of 7% equivalent on current levels if not managed appropriately.[123]

3.4 Waste as an agricultural resource

Human waste that undergoes any level of treatment is usually mixed with water at some stage of the sanitation process, particularly where toilets empty into a septic tank or sewer system, but also in pit latrines, where water may be poured into the pit. Globally, an estimated 9.5 million m^3 of human excreta and 900 million m^3 of municipal wastewater is produced every day.[124] This contains enough nutrients to replace 25% of the nitrogen currently used in synthetic fertilizers for agricultural land, and 15% of the phosphorus. It also represents enough water to irrigate 15% of all the currently irrigated farmland in the world (some 40 million hectares). At the city scale, the wastewater containing excreta from a city of 10 million people contains enough recoverable plant nutrients to fertilize about 500,000 hectares of farmland, which in turn could produce about 1.5 million tonnes of crops. Management of wastewater will be an increasingly pressing issue in the coming decades as the number of urban dwellers living within arid and semi-arid areas of the global South increases. These populations are likely to present a real challenge for conventional water-based sanitation systems, which typically use 15,000 litres of water per capita/year[125,126] making the recycling of water from such systems a high priority.

The reuse of wastewater in agriculture is particularly useful as the sector is the world's largest water user, but without proper management, problems can occur. If crops are watered with untreated wastewater in which pathogens are still present, communities can be put at risk of disease, especially if the crops are not washed properly before being eaten. If wastewater is not used, however, the crops may wilt before harvest and be lost. This can create complex trade-off considerations in regions where both water and waste treatment infrastructure are scarce: children living in areas that use wastewater irrigation can have higher instances of helminth infection but better overall nutritional status than those living in areas irrigated by river water,[127] for example.

3.5 Final disposal of human waste

Despite the known advantages of using human waste as a resource, careless disposal remains a serious issue – in developed as well as developing countries. In August 2005, 600,000 tonnes of sewage were discharged into the UK's River Thames, killing fish and causing a stench reminiscent of the "Great Stink" of London, 1858;[128] subsequent inquiries revealed that Thames Water was discharging untreated sewage into the Thames around 60 times per year,[129] usually after rainfall.

The company has continued to receive criticism for its operation and was fined more than £20 million by the UK government in March 2017.[130]

New York discharges 4% of its sewage into its harbour.[131] Ocean dumping of sludge was banned in the 1990s,[132] meaning that countries must dispose of waste locally, but this is clearly not happening as efficiently and effectively as it might be and still needs to be addressed, particularly in light of the levels of greenhouse gas emissions and waterway pollution that relate to different waste management systems. Regulation and oversight of sanitation systems can be as important as the technology used.

FSM transfer station under construction in Chazanga, Zambia where waste is treated – Credit: ©WSUP

4.0 Sanitation in Rural Developing Regions

Key points

- In developing countries, up to 80% of all environment-related deaths have a link with poor sanitation and lack of clean water supply.
- Sanitation in rural developing settings is more likely to consist of pit latrines with no connection to a sewer system and no access to FSM services.
- Constructed and managed well, such latrines can be sufficiently hygienic and sanitary.
- Waste collected from latrine pits can be used as fertilizer or cooking fuel; waste can produce biogas and can be used to generate electricity, even at household level.
- However, poorly managed latrines risk contaminating soil and wells used for drinking water.

4.1 Rural regions and basic sanitation

The areas of the world that have the poorest sanitation are the rural areas of low-income countries, particularly those in sub-Saharan Africa and Asia.[133] Many of these regions are also affected by food insecurity, undernutrition, water scarcity, soil degradation and diarrhoea, which improved sanitation can help mitigate.[134] There is also considerable crossover between these regions and the areas that are predicted to urbanize rapidly over the next few decades. From an early stage, investment in sanitation, FSM and wastewater management, and treatment plants – as part of urban planning and infrastructure development – is needed to ensure this happens safely. However, this chapter focuses on low-income rural settings that are likely to remain rural. Those transitioning to more urban settings are covered in the following chapter. Nearly three times as many people (2.3 billion)[135] globally lack basic sanitation as lack access to clean drinking water (844 million).[136] In developing countries, up to 80% of all environment-related deaths have a link with poor sanitation and lack of clean water supply.[137] Across Africa, child mortality can be 10-20 times higher in areas with poor sanitation than in those with good services.

In developing rural settings, sanitation is more likely to be a "drop and store" model. The typical arrangement is a pit latrine – essentially a hole in the ground, into which urine and feces are excreted, where they may remain, or be removed periodically. In some parts of Africa, less than 10% of the population is connected to a sewer system[138] and in rural areas there may be no connection at all. If the excreta is not removed from the latrine pit, one option is to periodically cover it over with soil and reconstruct the latrine elsewhere – sometimes with a tree planted over the old pit to take advantage of the nutrient-rich buried excreta, known as an "arborloo".[139] Latrines not connected to a septic tank or sewer system can be hygienic and such systems can fit the WHO conditions of "improved sanitation", though they can produce high methane emissions which smell unpleasant, add to greenhouse gas emissions and miss opportunities to capture biogas for household use.

Low-water and non-waterborne options[140] are appropriate in settings where there is no sewerage infrastructure, where the construction of such infrastructure is impractical due to lack of easy access to construction materials, low population density and distance from urban systems, and/or where water is scarce.[141]

4.2 Progress and challenges

Latrines confer considerable health benefits compared with open defecation,[142,143,144] particularly if they are safely managed to prevent environmental contamination and to capture methane emissions in a biogas digester.[145] Latrines also provide privacy and safety to vulnerable members of the community. Private family latrines, or community latrines closer to buildings, protect girls and women from needing to go into the bush, particularly at night,[146] where they are vulnerable to sexual harassment and attack. Private and single-sex latrines, with provision of adequate menstrual hygiene management materials, can prevent girls from skipping school during menstruation.[147]

There can be problems if latrines are poorly designed; however, WHO provides guidelines on recommended construction of pit latrines, including safe distances from living quarters to balance convenient and safe access with hygiene.[148] First, if feces are not covered by a latrine lid or soil, they will attract disease vectors such as flies and mosquitos, which can spread the pathogens they contain back to humans. Latrines can also provide mosquitos with attractive breeding grounds,[149] though this can be prevented by design features and by ventilating the latrine.[150]

Second, if the latrine pit is not adequately lined, which is the case in most areas, excreta that leaks into the surrounding area can contaminate soil and water. This can be a particular problem where groundwater quality is affected,[151] and where this may contaminate wells. In countries where pit latrines are prevalent, people often depend on groundwater wells for their primary drinking water supply.[152] Discharges can contain microbial contaminants and, where chemicals are used, nitrates that can inhibit oxygen take-up in the blood, and in high doses may cause cancer.[153] Such contamination can be worse during wet and monsoon seasons.[154]

Third, as has been covered elsewhere, latrine pits can increase methane emissions when not managed properly. Biogas digesters at the household, farmstead or community level can capture this, though if not well managed, leakage will occur and there can also be issues if production outstrips demand[155] requiring strong oversight and regulation of use.

4.3 Opportunities and barriers

Well-managed, hygienic latrine systems can offer decent sanitation to people and communities for whom connection to more centralized sanitation systems and infrastructure may be difficult. Sewage management appears to be less often considered a responsibility of the government than the provision of piped drinking water, inhibiting the development of a public service monopoly that will drive down price and subsidize poorer or more remote areas,[156] an issue that the development of decentralized systems (coved in more depth in the following chapter) is now addressing. Construction of sanitation systems is often more complicated and expensive than systems that provide clean drinking water, and people – including policy-makers – do not always understand the benefits as easily. In addition, in many parts of Africa, steel and cement would need to be imported in order to install large-scale sewerage infrastructure, adding to the economic costs and making decentralized and FSM systems, in which storage tanks are emptied by professional sanitation workers and the waste removed to treatment plants, a more viable option.

Helping people to see sanitation as a value chain, in which excreta can be sold for profit or reused as compost or biofuel,[157] is one option for improving investment in sanitation systems at an individual household or community level in rural regions. At a household level, for example, toilets can be designed to convert waste into fertilizer, biogas and energy that can power the toilet and provide additional electricity for charging mobile phones.[158] Waste can also be converted into char briquettes for use in heating and cooking.[159] The phosphorus, nitrogen and micronutrients including potassium, iron, copper and zinc in one person's excreta is sufficient to grow enough wheat and maize to feed them for a year. One study[160] has suggested that in some smallholder farming communities, all fertilizer use could be replaced by nutrients recovered from human excreta. As sludge has a monetary value, its use could make a significant impact on annual finances of smallholder farmers, particularly if off-set against the cost of buying artificial fertilizer. Animal manure and organic kitchen waste, as well as human excreta, can be recycled in this way.

4.4 Addressing cultural barriers and taboos

Introducing latrines and improved sanitation into communities is not always straightforward: financial, cultural and religious barriers can exist. In Zambia, men are often reluctant to use latrines that are also used by their in-laws and female relatives due to cultural taboos,[161] while in India, even members of households that have or could easily afford latrines[162] sometimes prefer open defecation due to cultural attitudes around social status and religious rules regarding the handling of human waste. This prevents higher castes from being willing to empty their own latrine, while Indians of all castes are unwilling to take on work emptying others' latrines as doing so contravenes religious rules for most castes and reinforces the low social status of those from "untouchable" castes, who aspire to better,[163] requiring extensive behavioural change campaigns to alter behaviour.

While the number of people using improved sanitation has increased since the introduction of the Millennium Development Goals, there is still a lot of work to be done in order to meet the targets of SDG 6.[164] Recently, the JMP has stressed that a focus on achieving "basic" sanitation in the most challenging areas may be a more realistic aim than achieving "safely managed" and should be seen as a stepping stone on the path to achieving fully improved sanitation.[165]

4.5 Female safety and dignity

An important factor in rural sanitation is the safety and dignity of women and girls. The sanitation goals of SDG 6 – which includes adequate and equitable hygiene and sanitation for all and an end to open defecation by 2030 – includes paying special attention to the needs of women and girls, and those in vulnerable situations.

Technology for rural environments

For rural communities that are remote from urban centres, largescale sanitation infrastructure may not be feasible due to lack of materials for construction, distance from waste management plants, and low density of population, but this does not mean that sanitation cannot be hygienic, nor that resources cannot be recovered from waste. Technology can be more sophisticated than simple arborloos; affordable toilets can be practical to install, avoid issues of wastewater and pathogen seepage into ground courses from unlined or poorly maintained latrine pits, and capture valuable resources for reuse. Biogas digesters can prevent methane from untreated waste being released into the atmosphere, and see it reused as household or community biogas, thus helping to reduce greenhouse gas emissions.

In 2011, The Bill and Melinda Gates Foundation launched the Reinvent the Toilet Challenge[166] to encourage the development of toilets that can capture and process human waste without piped, clean water, sewer or electrical connections, and transform human waste into useful resources such as water and energy, at an affordable price. Subsequent projects unique to China were launched in 2012 and to India in 2014, the latter alongside President Modi's launch of Swachh Bharat Abhiyan (Clean India Mission). Such toilets are able to deliver safe and sustainable sanitation to the 2.5 billion people currently using unimproved sanitation services.

Technology developed under the call has included a mobile, solar powered toilet that generates electricity and hydrogen,[167] and clean wastewater suitable for most uses other than drinking; a toilet that turns human waste into biological char, minerals and clean water[168] using hydrothermal carbonization, which produces less odorous char with enhanced heating value; and a toilet that sanitizes feces and urine and recovers resources and waste water[169] by mixing waste with sand, rather than water, and then smouldering it to kill pathogens and produce bio-oil. Such toilets are suitable for use in hospitals and schools, as well as peri-urban households.

Girls and women who have to go into the bush, away from their home at night to defecate, are at risk of sexual violence and harassment. The further away and more remote the toilet is, the greater the risk. In a study of reasons given for building latrines in India, between 50% to 69% of respondents listed improved security for women and children,[170] showing that positioned correctly, the benefits of sanitation can overcome ingrained cultural attitudes around human waste. Toilets in the home can also make a huge difference to elderly, disabled, menstruating and pregnant family members and free women from lengthy trips to collect water. In India, encouraging families to refuse to let their daughters marry into families that practice open defecation has been part of a social marketing campaign that has successfully increased latrine ownership.[171]

5.0 Sanitation in Developing Urban Regions

Key points

- Sanitation in developing urban settings is often provided by decentralized systems in which household toilets and community waste tanks are emptied by waste management workers.
- Open waterways in developing urban areas can be an issue, particularly during rainy seasons.
- Areas that are rapidly urbanizing need to ensure that sanitation infrastructure grows alongside urban population increase.
- In 2012, cities in India generated 38,354 million litres per day of sewage, but had a sewage treatment capacity of only 11,786 million litres per day.
- The percentage of urban residents in Africa increased from 31% in 1990 to 40% in 2014, but the percentage with access to improved sanitation fell over the same period.
- Decentralized sanitation services incorporating fecal sludge management and smaller, distributed sewerage treatment plants offer viable local alternatives to widescale sewer infrastructure.

5.1 Sanitation in transition

As regions transition from rural low-income to urban lower-middle and higher-middle income economies, sanitation moves towards more complex systems. The removal and treatment of industrial waste, as well as household waste, also becomes an issue. While in theory, modernization should bring with it improvements in hygiene and health, in practice the introduction of sanitation infrastructure can lag behind urban expansion[172,173] with negative health outcomes.

Historically, poorly planned urban expansion contributed to what was known as the "urban penalty". In pre-industrial Europe, life expectancy was lower, and child mortality higher, in cities than in rural areas[174,175] and in 19th century England, urban child mortality was 2.5 times higher than for rural children. Echoes of the urban penalty are still seen in the developing world: children under five in urban areas of Gaza with poorly constructed sewers have been shown to be four times more likely to be infected with the parasite Ascaris[176] during winter flooding than those in areas without sewers, though conflicting evidence has been observed from studies focussing on other areas[177]. However, the systems introduced in Europe and North America during the late 19th and early 20th centuries may not always be appropriate for developing urban contexts today, particularly in regions where water is scarce and construction materials such as concrete and steel are not readily available. Setting-appropriate decentralized and FSM systems – such as hygienic in situ storage of household waste with regular emptying by a waste management service – also need to be considered.[178]

Well planned, well-managed and well-maintained investment in sanitation can then bring health and economic benefits. In El Salvador, expansion of urban sewer networks reduced prevalence of diarrhoea amongst children by 21%, for example[179] and in India, economic savings available from good sanitation are estimated to be as high as US$54 billion annually.[180]

5.2 Progress and challenges

An estimated 87% of the Chinese urban population had access to improved sanitation in 2015 and many low and middle income countries (LMICs), including Costa Rica, Cuba, Egypt, Iran, Sri Lanka and Venezuela, had above 95%, but the figure was only 20% in Ghana and the Republic of Congo and 16% in South Sudan.[181] What this sanitation looks like also varies widely, from to pit latrines, through FSM services to integrated WASH systems with plumbed toilets linked to a sewer system that takes waste directly to treatment plants. Systems may include a flush toilet connected to a shared tank into which many toilets discharge,[182] or a chemical toilet that stores the waste at the household level, both of which are emptied regularly by waste management workers.[183] Of the 2.8 billion people who use improved sanitation globally, those using sewer systems and those using septic tanks are split evenly – approximately 38% for both systems.[184]

In developing urban settings, toilets may be shared rather than private to individual households (in WHO terminology, shared facilities are "limited sanitation", even if the same system would be considered "improved" if private). The likelihood of sharing facilities with other households varies from country to country, as does whether sharing is more prevalent in rural or urban areas. In Nigeria, for example, sharing is more common in urban areas than in rural ones. Studies show conflicting evidence for whether or not sharing facilities confers a health disadvantage.[185] Sharing amongst a small number of households – "limited sharing" – may be as good as private facilities.[186]

Waste collected from latrines and septic tanks by FSM providers is a good solution in countries where the introduction of sewer systems is impractical at present but must be overseen by strong regulation and support from municipal authorities.[187,188] Poorly regulated services can present an occupational hazard to workers, particularly in countries with poor health and safety regulation:[189] unprotected workers emptying latrines in China are twice as likely to be infected with Hepatitis A as family and friends not engaged in latrine emptying. As in rural settings, poorly maintained urban latrines, septic tanks and biogas digesters can leak into the environment and contaminate ground water and water systems, including drinking water, and smell unpleasant. Open waterways – often common in peri-urban settlements – and clogged drains can help mosquitoes to breed, spreading dengue, malaria and chikungunya,[190,191] and this can also be an issue in poor urban districts of developed nations.[192] In LMICs, wastewater flowing into sewer systems is often discharged untreated into landfills, waterways or storm drains, polluting rivers, lakes and the sea.

A particular issue in developing urban regions is industrial pollution entering waterways – either directly, untreated, or via inadequate sewerage systems and treatment works. WHO South-East Asia has identified issues with, amongst others: heavy metal pollution from tanneries; toxic chemicals and microfibers from textile factories; toxic chemicals from automobile repair shops; and pharmaceutical residues, including antibiotics that can exacerbate antimicrobial resistance, radionuclides and endocrine disrupting chemicals from pharmaceutical factories, hospitals and healthcare centres.[193] A second issue with poorly designed sewerage systems is capacity during seasonal variations, such as rainy or monsoon seasons.[194] Sewer systems need to be designed to cope with such variations.

5.3 Opportunities and barriers

The installation of a private bathroom in a household is generally financed by the household itself; sanitation systems that include sewers and large-scale treatment plants are more likely to be state-scale projects that require financing and political support from stable governments. The introduction of most municipal sewer systems in Europe were financed by the wealth of the Industrial Revolution and not all countries have the luxury of such public or private wealth. Places of work, educational facilities and other facilities also need to have good sanitation, as well as just households; the lack of single-sex toilets can discourage girls and women from participating in education and employment.

It may be inevitable that sewer systems are more likely to be introduced in business districts and wealthier residential areas first, but initiatives such as the Water and Sanitation for the Urban Poor (see box, page 32) are working hard to ensure that less wealthy urban areas are not left behind. Poorer urban regions often rely on local private sanitation providers to empty tanks and manage fecal sludge. This can incur relatively high costs but can also provide opportunities for empowerment through the community management of decentralized systems.[195,196]

Support to incentivize private companies to enter the sanitation sector may be needed, including for investment in capital outlays such as tankers in which to transport collected waste and to build waste management facilities, as well as municipal and national-level support for regulation of such industries, including the development of standards.[197] The example of the Devanahalli Fecal Sludge Treatment Plant (FSTP) in Karnataka, India, shows how smaller-scale treatment plants can create economic benefits in developing countries.[198] Sanitation development can be particularly effective when combined with policy development on national targets for sanitation coverage[199] or when combined with other policies around urban development, such as transport policies on the development of new road networks.[200]

The septic tanks, container-based sanitation systems, and FSM systems common in developing urban settings, are transitioning technologies between rural pit latrines and fully-plumbed urban bathrooms connected to sewer infrastructure. They may not be ideal long-term sanitation solutions[201]. A particular area of concern is that "hybrid" or transitioning settlements, often on the fringes of urban areas, fall between neat categorization into urban or rural. Such settlements may not be well-served by any form of sanitation system, as technologies and policies tend to focus on providing for either rural or fully urbanized[202], though they are clearly better than nothing. In many settings, they may be the only practical option, especially in the short term.

5.4 The Pace of Urbanization

There is serious concern that sanitation provision will not keep pace with the rapid rate of urbanization: in 2012, cities in India generated an estimated 38,354 million litres per day of sewage but had a sewage treatment capacity of only 11,786 million litres per day.[203] The percentage of urban residents in Africa increased from 31% in 1990 to 40% in 2014,[204] but the percentage with access to improved sanitation fell in some middle-income African countries, such as Ghana, Namibia, Nigeria and Zambia, over the same period.[205] In the short-term, decentralized sanitation systems and FSM offer a workable alternative.

Introducing widespread sanitation requires political buy-in at the national level, but can be very successful when it has this. Uzbekistan, a lower-middle income country, has 100% improved sanitation. At the turn of the 21st century, its newly independent government saw provision of state services as part of the "spiritual renovation and well-being of society"[206] following the breakdown of the Soviet Union. In India, a political drive to accelerate the improvement of sanitation throughout the country since 1999, relaunched in 2014,[207] has seen access to improved sanitation increase considerably, with more than 85% of the population having a household toilet in mid-2018; President Modi has set a target to end open defecation in India by 2019, 150 years since Gandhi's birth.

Even where political will does not extend to financing sanitation systems from public funds, government involvement in the regulation of a privatized sanitation sector, including setting standards, providing low interest set-up loans and monitoring operations can be beneficial. At the international level, supporting knowledge transfer and helping to build capacity in developing settings will all help countries to improve sanitation and meet their SDG targets.

SWEEP vacuum tanker in Dhaka, Bangladesh - enabling the private sector to provide fecal sludge management services – Credit: © WSUP

Decentralized sanitation services and FSM

A significant change from the water and sanitation goals of the Millennium Development Goals to those of the Sustainable Development Goals was a recognition that sanitation needs to be enacted at community- and city-wide levels to be effective. There is limited value in focussing on household sanitation only, particularly if there is little thought as to where the waste will go. For sanitation to be effective at larger than household scale, the public and private sectors need to be engaged to: enact policy; develop financial investments for capital projects such as sewer infrastructure (where appropriate), waste collection and management (including septic tanks, trucks and waste management plants); train waste management workers; and develop regulation around decentralized sanitation services to ensure consistent and high-quality operations. Investment in treatment plants is as important as investment in toilets.

Water and Sanitation for the Urban Poor (WSUP)

WSUP is a partnership between NGOs (including WaterAid[208] and CARE International[209]) and the private sector (including Thames Water[210] and Unilever[211]) who work with local partners to identify and deliver sustainable services providing safe water and basic sanitation in low-income and peri-urban communities.[212] It began operations in 2005, and works in six core countries: Bangladesh, Ghana, Kenya, Madagascar, Mozambique and Zambia. Local level partners (including municipal governments, public and private utility providers and the private sector) are supported to develop services, build infrastructure and attract funding that will benefit low-income communities that might otherwise be left behind. WSUP advises governments and regulators on how to develop sanitation services as a business that can succeed.

Case study: Bangladesh

WSUP works in Bangladesh to develop sanitation infrastructure in Dhaka and Chittagong. Only around 60% of the population uses any kind of sanitation service; there is no sewer system in Chittagong and very little in Dhaka, which has 16 million inhabitants of whom 3.5 million live in 4,000 informal and sometimes illegal settlements where pit latrines and septic tanks are the norm.

Since 2007, WSUP has worked with Dhaka's city utility and city authority to support local service providers and develop low-cost local sewer systems in poorer areas, including safe fecal sludge emptying services and waste collection. In 2015, SWEEP[213] was introduced, a public sector-owned brand under which private vacuum tanker companies can operate. The equipment required is owned by the public sector, but leased by the private sector and has a variable pricing structure that ensures the lowest income households are subsidized while the company still makes sufficient profit for the enterprise to be attractive. The model also allows a number of small-scale public-private partnership ventures to operate simultaneously under regulation, standardized operating procedures, and service level agreements.

At the end of its two-year pilot in March 2017, SWEEP had served more than 120,000 people in Dhaka and emptied more than 4,000m^3 of sludge. Lessons identified from its experience include the value of servicing both institutional and household customers, particularly during the start-up phase, and ensuring that a strong enabling environment for sanitation services is developed in advance of service roll-out. SWEEP will now roll-out and scale up across Dhaka and other cities in Bangladesh over the coming years.

6.0 Sanitation in Developed Regions

Key points

- There is almost 100% improved sanitation in urban and rural regions.
- The most frequent system is flush toilets connected to mains sewers and water treatment facilities.
- Main challenges include water resources management, treatment and disposal of wastewater and sludge.
- Sound management can save resources for agricultural fertilizer, biogas and clean energy.
- Pharmaceutical residues can be an issue in societies with advanced healthcare systems.
- Local residents may have concerns about health impacts of facilities located close to residential areas.

6.1 Infrastructure maintenance and complex waste

As countries and regions develop, so too do sanitation systems for the disposal of human waste. It is tempting to think that in high-income countries, sanitation issues are a thing of the past, but this is not always the case. Challenges arise from ageing and poorly maintained infrastructure, chemical residues in wastewater and discrepancies between socio-economic areas. Household wastewater can contain hundreds of chemical compounds, including microscopic plastic, additives and pharmaceutical residues,[214] though health risks are much smaller than those posed by pathogens.

6.2 Progress and challenges

In 2015, on average, 99% of the population across all high-income countries had access to improved sanitation by WHO standards (100% reported in urban areas; 99% in rural), compared with just 28% in low-income countries (40% urban; 23% rural) and 65% in middle-income countries (79% urban; 51% rural).[215] Twenty-three countries* had 100% improved sanitation in both urban and rural areas. Of these, 22 were high-income (the exception is Uzbekistan – see previous chapter).

Sanitation systems in high-income settings are advanced, and service wide areas. Most consist of fully plumbed, flushing toilets that immediately remove waste from the point of excretion via a vast network of sewer pipes. The waste, now carried in water (and usually mixed with wastewater from domestic baths, showers, washing machines and kitchen sinks), is transported, collected and ideally treated before it is released back into the environment on a huge scale. The UK, for example, has approximately 625,000km of sewers and collects 11 billion litres of wastewater each day.[216] Conventional water-based sanitation systems typically use 15,000 litres of water per capita/year.[217] However, around 30% of wastewater is still released untreated to the environment,

* Andorra, Australia, Austria, Belgium, Cyprus, Denmark, Greenland, Israel, Italy, Japan, Kuwait, Malta, Monaco, New Caledonia, Palau, Portugal, Saudi Arabia, Singapore, South Korea, Spain, Switzerland, Uzbekistan, United States

most into rivers or coastal waters.[218] The sewer systems transporting domestic wastewater to treatment plants also collect from industrial sources and restaurants, as well as receiving rainwater run-off from roads and roofs.

In the UK in 2012, 96% of the population were served by main sewers, while the remaining 4% – mostly in remote rural properties – relied on septic tanks, cesspits and other in situ treatments. Septic tank systems are still common in many rural areas of developing countries, including the US, but insufficient maintenance can result in eutrophication if water leaks into local water systems.[219] As in developing environments, however, there is no reason why a sanitation system not connected to mains sewers should not be hygienic. In Sweden, composting toilets are becoming popular as eco-friendly sanitation and waste management systems in holiday cottages.[220]

Governments and municipal agencies in developed countries have a number of options for waste management and disposal that can reduce the risk of direct health impacts, such as exposure to pathogens or carcinogens, or indirect health impacts such as damage to the environment that might contribute to global warming, loss of biodiversity and depletion of non-renewable resources.[221] In 2012, the UK produced approximately 1.5 million tonnes of dry sludge, of which 1.2 million tonnes (79%) was reused as soil fertilizer, 260,000 tonnes was incinerated (18%) and just 9,000 tonnes was dumped in landfill (0.7%).

The management and disposal of wastewater and sludge is often highly regulated – under Urban Waste Water Treatment Directive 91/271/EEC in Europe, for example. In the UK, this is governed by the Department for Food and Rural Affairs, with the Environment Agency setting standards and parameters for, and monitoring, water quality and discharges from treatment plants.[222] In addition, EU Directive 1999/31/EC,[223] which seeks to reduce the amount of waste sent to landfill, has stimulated the diversion of organic matter to composting in many EU countries, including the Netherlands, Sweden, Denmark and Austria.[224]

Wastewater and human excrement in high-income settings pose some unique challenges. In countries with modern healthcare systems, it often contains pharmaceutical residues, including radionuclides used in cancer treatments, oestrogen-affecting chemicals from contraceptives and antibiotic residues that can drive antibiotic resistance and affect soil microbiomes.[225,226] Wastewater also tends to contain phosphates from detergents, which can cause eutrophication.[227] Fats, oils and grease in wastewater from restaurants and pubs sticks to sewer pipes and can solidify and block sewers if it is not removed.[228] Rainwater may leech pollutants from contaminated toxic soils at brownfield sites – former industrial sites – and run-off from roads can contain petrol, oil, grease and metals from vehicles. Run-off from agricultural land can contain fertilizer residue and pathogens from livestock, all of which need to be removed from the wastewater at treatment plants.[229]

6.3 Opportunities and barriers

Wastewater treatment produces considerable amounts of sewage sludge – biosolids (remains of feces) and residual organic matter (such as food scraps) that can be spread on agricultural land due to its high nutrient content. There are political and economic imperatives for reusing sludge as natural fertilizer – in the US, environmental groups joined the EPA in promoting sewage sludge as farmland and garden fertilizer as a more

organic alternative to chemical fertilizers. It is attractive to industry as a cheap form of waste disposal that saves money on artificial fertilizers.[230]

However, there are some concerns about the use of sludge and wastewater as agricultural fertilizers, due to short-term pathogen survival and long-term pollutants, such as heavy metals including mercury and cadmium that can accumulate in plants.[231],[232] Agricultural sludge has also been found to contain large numbers of pathogens such as *Salmonella*, *Campylobacter*, *Escherichia coli*, *Giardia* and *Cyptosporidium*;[233] a number of studies have reported outbreaks of food poisoning linked to wastewater applied to agricultural soil.[234,235] In the UK, a voluntary agreement within the agricultural industry ensures that sludge is not used on crops likely to be eaten without being washed, such as salad vegetables. A Canadian government study found no evidence of adverse health impacts from landspreading sewage sludge in its territories,[236] but this is likely to be linked to strong food safety practices and household piped water. Crops grown in sludge-treated soil are not a problem if they are washed before being eaten, but this may not always be possible in less developed settings.

There can be challenges in developed countries around low public acceptance of the location of treatment facilities, due to concerns about adverse effects on the environment and human health, including the effect on house prices.[237] Plans for the construction of a new treatment plant can meet fierce opposition from the local community. There are various ways people living near to treatment plants can come in contact with pollutants from waste facilities, including by inhalation of fumes generated by the facility, by ingesting food or water contaminated by effluence released by it, or by fire or explosion should the plant suffer an industrial accident – as has happened at treatment plants in the US,[238] Belgium[239] and Canada[240] and other high-income countries in the past.

While composting facilities have been shown to give off bioaerosols containing bacteria such as *Clostridium botulinum*, endotoxin-producing gram negative bacteria and/or fungal spores such as *Aspergillus fumigatus*, and other studies have found convincing evidence for gastrointestinal problems associated with ingestion of sewage-contaminated recreational waters close to such plants,[241] it can be hard to link specific health outcomes to proximity to treatment facilities, as the people living close to them can be exposed to range of hazards[242,243] linked to socioeconomic status. At least one study has suggested socioeconomic status decreasing with proximity to waste treatment facilities.[244] Adverse health outcomes for the population living near landfill sites, incinerators and composting is usually insufficient and inconclusive, though there is more convincing evidence of gastrointestinal problems associated with pathogens originating at sewage treatment plants.

There is some evidence – thought not conclusive – for adverse health outcomes for treatment plant workers.[245] Workers at waste facilities may be more likely to harbour a number of pathogens and suffer more bouts of illness than other members of the population, including respiratory conditions. A systematic review of studies on the occupational disease burden of sewage treatment plant workers has showed exposure to bacteria, bacterial endotoxins, hydrogen sulphide, and organic solvents and increased incidence of hepatitis, legionella, leptospirosis, gastroenteritis, reproductive outcomes and mortality in general, though no increased incidence of cancer. Results differ from region to region; one study found no increase in adverse health outcomes in the US, but an increased likelihood of 2.2 in France for some conditions.[246]

6.4 Regulation and environmental protection

In general, the more developed countries are leading with the way with "cleaning up" the back-end of the sanitation system and promoting the reuse and recycling of sanitation by-products such as sludge and wastewater. This is, to some extent, driven by regulation and restrictions on more harmful options. Implementation of regulation, such as EU Directives 91/271/EEC on wastewater and 86/298/EEC on sewer sludge in EU member states, along with requirements for regular reporting,[247] are driving investment and research into agricultural application, biogas generation and development of biofuel. In the US, the EPA sets standards for waste management and provides guidance on reuse and recycling,[248] including providing assurances that air quality is not degraded around agricultural sites on which natural fertilizer is used. (Specific benefits derived from the outputs of waste treatment works were covered in Chapter 2 and are not repeated here.)

Wastewater treatment plant

Further Reading

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Relevant links

Joint Monitoring Programme
washdata.org

Water and Sanitation Programme
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Water and Sanitation for the Urban Poor
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