TOILET BOARD COALITION

IWA the international water association

Improving Public Health Through Smart Sanitation and Digital Water

How data ecosystems and wastewater epidemiology can play a larger role

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Foreword

from the International Water Association

The digital revolution is firmly embedded in our daily lives—from how we interact with each other, to how we manage our finances. The digital revolution is also having a major impact on the sanitation sector, particularly in developing countries, where we are witnessing a shift from assumption-based management to more data-driven management.

UN Sustainable Development Goal 6 ("Ensure availability and sustainable management of water and sanitation for all") has promoted a new paradigm for sanitation, which is no longer simply based on the narrow view of providing access to safe sanitation installations, but one that looks at the entire chain that follows: wastewater management, resource recovery, and preventing pollution of our aquatic ecosystems.

Rather than foist one approach everywhere on all, Sustainable Development Goal 6 promotes the entire sanitation service chain, and offers both sewered and non-sewered solutions, or hybrids of the two. The service chain can be overlaid by a value chain, indicating which are the most economically viable pathways. The sanitation targets define adequate sanitation as "a system for the collection, transport, treatment and disposal or reuse of human excreta and associated hygiene". Rather than view faecal matter as a liability that must be treated, systems thinking unlocks a perspective of beneficience, from which can be extracted and recovered valuable assets through opportunistic feedback loops. In this way, cost sinks become profit centres. For many in the developing world, there is a great anticipation that resource recovery and reuse will be the panacea, the cure, with the potential to make sanitation systems financially sustainable.

It is anticipated that the digital revolution will enable the sector to transition to the new paradigm for sanitation. It will be made possible through innovations in sensors which have enhanced data capture and can be coupled with cognitive computing facilities that provide actionable decisions in complex situations, and which feed smart devices that can implement those decisions. The digital revolution will allow for sanitation systems that value local context, work back from the problem, incorporate new technologies and, over the next 20 years, usher in a golden era for and sanitation provision—an era of systems with a smaller footprint, improved energy, and lower costs.

From its position as a global membership organisation, IWA can channel the experiences, knowledge, and willingness of water professionals to contribute to progress. This paper on smart sanitation and digital water brings together key change agendas for improved sanitation and for digitalisation of the sector, both of which are highlighted in IWA's strategic plan. The paper highlights the importance of an improved health–water–sanitation nexus for early detection and disease prevention in relation to viruses, presenting current applications and case studies using digital technologies, as well as highlighting challenges and possible solutions. The relevance of this focus for the IWA community is demonstrated, for example, by the IWA COVID-19 Task Force, established early in the pandemic to provide a member-led response to the concerns and information needs of the water sector.

At IWA, we believe that, by joining forces and sharing experiences through collective actions, our sector and our society can emerge from critical moments such as we have been facing far more resilient than we ever imagined possible.

Kalanithy Vairavamoorthy
Executive Director
International Water Association

Foreword
from Toilet Board Coalition

At the Toilet Board Coalition, we strive to uncover and build value in a system that has traditionally been considered an unaffordable public cost. In 2016 we first began looking at the potential of sanitation to become "smart"—diving into the value and power of the data and information flowing through sanitation systems daily. Many of the entrepreneurs we work with in our business accelerator programme are a last mile node into their community: they are interacting with their customers on a daily basis and reaching many who are not otherwise reached by public services. We believe this provides immense opportunities on several levels—this paper is specifically focused on the potential for preventative public health.

Digitising sanitation and wastewater systems can save lives and prevent the spread of disease. As we have seen throughout the COVID pandemic, while governments and health systems scrambled to understand the rate of infection in their populations, sanitation and wastewater-based epidemiology has emerged as one of the earliest and most accurate reflections of a city's infection rate. We advocate that disease surveillance through sanitation and wastewater systems must become a key component of future outbreak prevention and management strategies for cities, communities, and business.

Monitoring disease circulation by means of wastewater treatment plants is not new; however, its application as a generally-accepted strategy for preventative health and pandemic response is. The eye-opening work of the Massachusetts Institute of Technology (MIT)'s Alm Lab, Biobot, and the Underworlds project has shed new light on the types of information that can be drawn from sewage (e.g. 4,000 biomarkers, bacteria, and 58,003 viruses can be visualised from a 24-hour sampling of sewage (MIT, 2018)). MIT's work has also demonstrated that the closer to the user (or toilet) you sample, the more accurate, and often cheaper, the process. When diagnostic data can be combined with toilet usage and environmental data, we start to garner new and deeper insights into the health and behaviour of communities.

Sanitation economy operators are innovating their services in response to the global pandemic and are already building customer health checks, medical services, and an increased focus on hygiene into their models. Smart sanitation and digital water mindsets will be required. We have observed that digital water and smart sanitation applications are not yet widely understood by sanitation and wastewater operators, public health officials, governments, or business. So we have come together with IWA to present this new vision for a public health ecosystem that extracts new value from wastewater. We increasingly have the technologies and know-how; we now need the business models and data ecosystems to make this public health service reliable and efficient.

Alexandra Knezovich
Director of Operations
Toilet Board Coalition

Abbreviations

GIS	Geographic information system
GSMA	Global System for Mobile Communications
IWA	International Water Association
KCCA	Kampala Capital City Authority
M4D	Mobile for Development
MIT	Massachusetts Institute of Technology
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
WBE	Wastewater-based epidemiology
WHO	World Health Organization

Acknowledgements

This White Paper is the outcome of a collaborative effort between the International Water Association (IWA) and the Toilet Board Coalition (TBC). We would like to thank all those who contributed to the preparation of this white paper for their valuable inputs and insights.

The following individuals and organisations are acknowledged for their contribution to the case studies mentioned in this paper:

George Bauer, GSMA
John Peter Archer, Gather
Katya Moniz, Underworlds
Nikhil Pasari, Satsense Solutions
Ulka Sadalkar, Saraplast
Jasmine Burton, Wish for WASH
Declan Crosse, Woodco
Mayank Midha, GARV
Noriko Endo, BIOBOT
Tala de los Santos and David Boyle, PATH

IWA and TBC acknowledge the following people for providing substantial contributions to the paper:

Katharine Cross (Strategic Programmes Manager, IWA), Samuela Guida (Strategic Programmes Officer, IWA), Alexandra Knezovich (Director of Operations, TBC), Mukta Dhere (Communications Associate, TBC), and Cinthya Ramirez (Pfizer, TBC Independent Director).

Finally, the authors would like to express gratitude towards the designers, editors, reviewers, and those who have provided overall leadership in the completion of this paper.

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Executive Summary

The International Water Association (IWA) and the Toilet Board Coalition (TBC) have developed this white paper as a call to action for sanitation and water operators to embrace opportunities for their products and services to feed into a new digital public health ecosystem. The paper highlights the leadership of IWA from its digital water programme, and the TBC from its smart sanitation economy work, as well as reflections from a variety of innovative businesses around the world who are addressing water and sanitation in a new way. The text includes extracts from existing published work by contributing partners. The aim is to provide insights on innovation opportunities around essential services and public health, accelerating the adoption of digital technologies, and reinforcing the value of remote monitoring. Many of these innovations, for example around environmental surveillance, have been brought to the forefront by the COVID-19 pandemic.

The white paper highlights the need for a global architecture that facilitates the efficient sharing of data and information across countries, states, or territories to enhance global health surveillance. It also reiterates the idea of collaborative ecosystems, where sanitation and water operators work with municipalities and governments to map their systems and usage data. These data streams create additional value for existing systems, and can shift responses to disease outbreak from reactive to preventative.

While COVID-19 has significantly and probably irreversibly affected the economic, social, and cultural fabric of governance, those managing water and sanitation systems across the globe are rethinking their operating style and response mechanisms to adapt to the crisis. Through the global response to COVID-19, a new social contract is emerging around health and hygiene. Communities around the world are turning to environmental surveillance, and specifically wastewater-based epidemiology, as a complementary tool to prepare and respond better to the current COVID-19 pandemic and future outbreaks of disease by monitoring public health at the aggregate level.

To accelerate the pace of innovation, this paper calls upon governments, investors, sanitation and water operators, and data experts for their collaboration in building this new data infrastructure and in rethinking ways to build back better, stronger, and more resilient.

1

A new era for water and sanitation

Beyond operations and maintenance: what are the new services water and sanitation utilities can be expanding into?

Digitalisation is a tool that connects assets, allows for more situational awareness and a greater understanding of what is happening, and brings together data for informed decision-making. To cope with the increasing difficulties in managing scarce water resources, the future calls for a digital water and sanitation economy with a smart approach to design, use, application, and control.

Collaborative ecosystems

When cities and sanitation and water operators join forces

As sanitation and water systems become more digital, a distinct opportunity arises to share these data streams with municipalities for the benefit of the consumer and the city. Increasingly we are seeing sanitation and water operators work with municipalities and governments to map their systems and usage data. With emerging technologies, we can envision public health and infectious disease or vaccine monitoring layering on top of that data.

Technological advances around preventative care and precision medicine are converging and moving us to greater and more patient-centric health systems. Sanitation and water systems can provide routine data collection and health monitoring tools, all whilst creating new value for the existing system and shifting responses to disease outbreak from reactive to preventative. As evident during the COVID-19 pandemic, when it comes to disease, early detection, treatment, and community response are all vital to limiting the impact on an individual's health and preventing outbreaks within a community. Through equipping sanitation and water systems with smart sensors, they can begin to detect disease and monitor environmental and societal transmission factors quickly and autonomously. The data collected can be used to provide evidence-based decision support for those tasked with managing the spread of disease, while predictive health analytics can assist early-warning systems.

A global data architecture that facilitates the rapid and efficient sharing of data and information from countries, states, or territories is a key component of global surveillance. While the International Health Regulations stipulate the legal responsibilities to inform the World Health Organization (WHO) about the occurrence of certain public health events, there is currently no harmonised public health reporting mechanism that enables information exchange from public health institutes and agencies directly to WHO. Such a mechanism is needed to access and analyse the disaggregated data required to understand age- and sex-specific epidemiological features, risk characteristics of certain sub-groups, and distributions of cases over time and geographical areas.

The foundations of such an architecture have already been laid through the creation of the Epidemic Intelligence from Open Sources (EIOS) data platform, which allows multiple communities of users collaboratively to assess and share information about outbreak events in real-time. The future vision of the new data architecture has been articulated by the Epidemic Big Data Resource and Analytics Innovation Network (EPI-BRAIN) initiative, which harnesses cutting-edge tools for big data, crowdsourcing, and artificial intelligence. This mitigates the impact of epidemics by allowing stakeholders to merge public health data with other data sets that can provide insights into the complex factors that drive epidemics. This includes data on human and animal population movement, animal diseases, and environmental and meteorological factors. Using advances in language processing and machine learning, these data sets are used to provide a more comprehensive analysis that helps to predict outbreaks and track their spread.[1]

This paper highlights opportunities across the health–water–sanitation nexus for early detection and prevention of viruses by using digital technologies to then harness the information for better response and prevention. Governments can play a key role through collaborating with businesses and sanitation and wastewater operators to help put together the channels and elements of the data framework. On the other hand, this serves as an occasion for the businesses to apply the same system framework as micro-pilot projects in manufacturing plants and across supply chains.

A unique role for business

Global companies employ several million people. By proactively applying sanitation economy approaches, companies have the potential to break down significant barriers and positively impact the lives of millions of the world's most vulnerable. Scaling up new sanitation economy approaches within businesses will ensure sanitation access and unlock resources and data that will transform the economics of sanitation into commercially viable opportunities.

In light of the COVID-19 pandemic, WHO has recommended that workplace preventative measures are established to reduce risk, including the appropriate directives and capacities to promote and enable standard COVID-19 prevention measures in terms of physical distancing, hand washing, respiratory etiquette, and, potentially, temperature monitoring. Additionally, WHO advocates that communities must remain fully engaged in detecting and isolating all cases, that behavioural prevention measures must be maintained, and that all individuals have key roles in enabling and, in some cases, implementing new control measures.[2]

After COVID-19, we anticipate global companies taking greater interest in the health of their employees in the workplace. Already we see temperature checks, frequent testing, and other measures being rolled out across operations. Smart sanitation systems are also an opportunity for businesses to ensure a safe and healthy work environment for their employees.

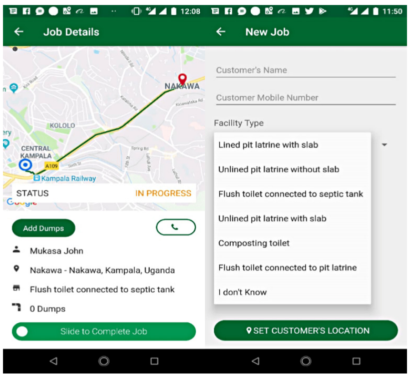


Figure 1. *Sample GIS mobile application interface courtesy of GSMA, 2020*

CASE STUDY 1: THE CASE OF KAMPALA

In Kampala, Uganda's capital, over 60% of the population lives in informal housing, while only 10–15% of the city is connected to formal sewerage. In this context, pit latrines and septic tanks are often emptied haphazardly by independent pit emptiers, who may dump waste illegally into the environment.

In response to the challenge of delivering sanitation services to Kampala's urban poor, the Kampala Capital City Authority (KCCA) launched a geographic information system (GIS)-based mobile application that links pit emptiers with customers. A grant from the Global System for Mobile Communications (GSMA) M4D Utilities Innovation Fund in 2017 was used to upgrade the pilot GIS tracking system, build capacity, and promote pit-emptying businesses. KCCA receives pit-emptying jobs from customers through its call centre, connecting customers with the nearest pit emptiers. Pit emptiers submit critical data through the app to KCCA, including customer details, the amount paid, volume emptied, and the type and location of the sanitation facility. The app and call centre serve as an "ecosystem catalyst" by connecting customers with sanitation services and helping to ensure safe disposal of faecal sludge for a cleaner and healthier city.

The platform also enables KCCA to map sanitation activities across the city, which allows them to monitor and regulate service delivery and identify locations in need of interventions. As of January 2020, 171,000 sanitation facilities, such as pit latrines, were mapped. Insights from its geodatabase and sanitation customer call centre have provided KCCA with actionable information, such as the characteristics of sanitation facilities, how frequently pits are emptied in different districts, and the distances between pits and waste treatment plants. Given that 30% of all pit latrines in Kampala's informal settlements are still emptied into the environment, KCCA aims to use this information to target and guide investment planning, allocate resources, and regulate service delivery and standards enforcement. KCCA also leads targeted advertisement campaigns to increase demand for pit emptying in districts where health outbreaks are recurrent and relate it to the reduction in disease outbreaks. According to surveyed users, there has been a reduction of 87% in illicit disposal of faecal sludge in the communities.

KCCA has also invested in supporting and empowering the pit emptiers in using digital tools, such as a mobile application. The app facilitated over 5,000 pit-emptying jobs, improving overall sanitation in the city, and building the capacity of pit-emptying entrepreneurs. Those using the app reported a 63% increase in income, with 85% of pit emptiers reporting using the app regularly.

Using digital tools to inform responses to urban sanitation in the public sector is not only important in the short run, but can also contribute to building long-term digital capacity in the public sector, which can be crucial to long-term sustainable service delivery and the city's ability to respond to sudden shocks, such as pandemics or natural disasters.

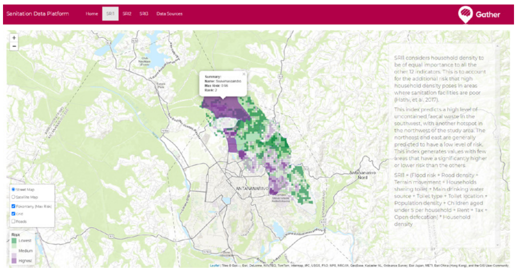


Figure 2. *Gather Benchmark Tool to improve data integrity, 2020*

CASE STUDY 2: GATHER

Gather is transforming how sanitation data are collected, shared, and used by organisations working in Antananarivo, Republic of Madagascar. Gather's approach harnesses geospatial data to help municipal decision-makers understand where and how to invest to improve sanitation infrastructure and services for vulnerable communities.

Gather's Centre for Sanitation Analytics recently completed the first assessment of the sanitation data gap in Antananarivo, to help decision-makers prioritise the collection of location data on the sanitation value chain. Gather have also led the creation of a new data standard, sanitation risk index, and sanitation data platform in partnership with Antananarivo's Commune Urbaine d'Antananarivo, Service Autonome de Maintenance de la Ville, Water and Sanitation for the Urban Poor, and Loowatt SARL. These three data tools are being refined, tested, and improved to transform how organisations collect, share, and analyse sanitation data. The aim for the geospatial visualisations is to make it easier for organisations to identify priority areas for investment for 350,000 people.

Gather have also launched a new Benchmark tool to help improve the integrity of location data collection for sanitation and development for the 50 countries at the end of the UN Human Development Index. The tool allows decision-makers to explore and compare the availability, accessibility, and accuracy of publicly-available sanitation data, including location; it encourages the global sanitation sector to sign up to eight principles to overcome some of the practical and ethical problems with how data are currently collected, shared, and used; and it invites local decision-makers to share publicly-available data so that the tool's analysis can be updated.

CASE STUDY 3: THE UNDERWORLDS PROJECT

The Underworlds project was launched in 2015 to develop a human health census by sampling the "urban gut" at multiple locations, thereby increasing the spatial and temporal resolution of sewage sampling and analysis. Pioneered by the Senseable City Lab and the Alm Lab at the Massachusetts Institute of Technology (MIT), in collaboration with other laboratories within MIT and sponsored by the Kuwait Foundation for the Advancement of Sciences, Underworlds combined automatic samplers, biochemical measurement technologies, data visualisation, and downstream computational tools and analytics.

Rather than sampling sewage downstream at the wastewater treatment plant, Underworlds focused on upstream sampling throughout the sewage network in the city to develop individual readings of neighbourhoods. The Underworlds project gave rise to continued disease-monitoring work in the Alm Lab, including typhoid and, more recently, COVID-19, and to the creation of Biobot Analytics, Inc., which spun out of the Alm Lab in 2017 to provide wastewater-based data to combat the opioid epidemic in the US, and which is currently engaged in widescale COVID-19 surveillance.

Digital water

Water and sanitation are among the most essential services a city provides and are at the foundation of economic stability. As stated in the IWA paper Digital Water: Industry Leaders Chart the Transformation Journey, "The emerging smart city initiatives are creating demand for digitalisation across industries as cities face new challenges connected to the need to optimise infrastructure, industries and services. In this context, the very nature of a water (and wastewater) utility can be used as a springboard to a 'Smart City' by increasing connectivity and better engagement of governments, citizens and businesses**.** In developed countries, water utilities touch virtually every citizen, home and business, meaning cities can exploit a digital water utility's communication network, customer base and immediate value propositions to demonstrate and communicate the overall benefits and successes of the city being an interconnected enterprise."[3]

Digitalisation in the water sector is rapidly growing in developing countries. Furthermore, as countries strive to achieve the Sustainable Development Goals in the coming decade, new markets are emerging across Asia, Africa, Latin America, and the Middle East for digital technology to meet increasing demands for the challenges in dense, urban areas and water-scarce regions[4]. Some of these challenges were reflected on by George Bauer at GSMA in a blog written for IWA and include the following:

- "**High non-revenue water**: A key constraint to more inclusive water service delivery among utilities in developing countries is non-revenue water (NRW), which is water that has been produced but 'lost' (due to leakages, faulty meters, illegal connections or non-payment) before it reaches the customer. These commercial losses alone are estimated to cost utilities in developing countries $3 billion per year.
- "**Ineffective billing collections**: The cost of cash collections for utilities in developing countries can range from 3 – 20 percent of total

revenue, severely restricting their ability to extend their reach to poorer customers and invest in network maintenance and innovation.

- "**Disconnection/Non-connection of poor households**: In sub-Saharan Africa, just under 25% of urban households have access to piped water. For those living in crowded and unplanned informal settlements, the physical layout and land tenure issues may prevent them from connecting. Another barrier is lump-sum, unpredictable bills that may come irregularly and overwhelm a poor household's ability to pay. Water utilities' economics depend on having as many paid connections as possible to pay for maintenance and keep the service affordable for all, so not connecting poor households leaves out part of their market.
- "**Insufficient investments**: Investments in urban water supply, in particular, have not kept up with urbanisation and population growth. This explains why, according to the World Bank, the proportion of urban residents with access to safely-managed drinking water in Sub-Saharan Africa has barely increased over the past 15 years."[5]

Digital tools and processes can be tailored for different areas of the water value chain, including in developing countries, for example using sensors, digital payments, and/or mobile phones. Real applications of digital tools and the solutions, as well as the benefits they provide, are outlined in Box 1.

BOX 1

Examples of applications and advantages of digitalisation

Some examples provided by George Bauer at GSMA from his IWA blog include the following:

- "**Digitalisation of utility processes**: Digitizing processes, such as meter reading, billing, payments, and complaint management systems, have shown a clear reduction in NRW for many utilities. For instance, Wonderkid,[6] a Kenyan company offering Integrated Mobile Utility Management software systems to water utilities supported by the M4D Utilities Innovation Fund[7], developed a digitalised complaint management system for water utilities in Kenya. By fostering transparency, traceability, and accountability, IMUM makes water utilities more accountable to their customers, which in turn increases their willingness to pay.
- "**Pay-as-you-go water**: For low-income customers, it is easier to pay for what they consume in smaller amounts rather than a lump sum at the end of a billing cycle, especially for a service that may not necessarily have provided a steady, timely and safe supply of water. Using mobile payments also saves customers time and money by providing a secure channel to pay for water at a fair and set price without the need to travel to a local utility office. In September 2015, the GSMA M4D Utilities Innovation Fund awarded CityTaps a grant to launch smart prepaid water meters in Niamey, Niger, in partnership with the local water utility, Société d'Exploitation des Eaux du Niger (SEEN) and Orange Niger. Following the grant, customers reported savings of up to 95% of their spending on water from \$3.37 per m^3 to \$0.21 per m^3, and a reduction of 86 minutes spent collecting water on a daily basis (from over 90 minutes to under five minutes).[8] Driving digital payment options among customers can have important benefits for water utilities and their customer base. Digital payments can reduce operational expenses and streamline service delivery. GSMA surveyed 25 water service providers (both centralized utilities and decentralized water service providers), and identified the following benefits associated with introducing digital payments for water services:
  - Digital payments reduce collection costs by 57-95 percent;
  - Digital payments increase revenues (between 15 and 37 percent) and enable new business models; and
  - Digital payments increase customer reach by allowing utility service providers to operate at a greater scale and lower cost per customer.[9]

"Though it is encouraging that there are more and more utilities scaling and piloting digital payment solutions, there is still tremendous scope for growth. Combining with smart meters which record customer water usage can provide a clear picture of water consumption and convey data to both consumer and utility, allowing for improved water management, water savings and reduced costs."

An additional example extracted from Digital Water: Industry Leaders Chart the Transformation Journey, focuses on sensors:

- "**Sensors for real-time data**: Sensors are a key component of digitalization of water utilities as they can provide near real-time data on water quality, flows, pressures, and water levels, among other parameters. A variety of sensors, both fixed and mobile, can be dispersed throughout systems to aid daily operations by optimizing resource use (e.g., chemical use for water treatment), detect, diagnose and proactively prevent detrimental events (e.g., pipe bursts, water discoloration events, sewer collapses/blockages, etc.), and provide useful information for preventative maintenance and improved long term planning for water utilities (e.g., by helping to prioritize repairs and replacements for aging infrastructure). Sensors can also provide evidence for pipe corrosion and alert homeowners and utilities when water quality standards are not being met."[10]

The why and how of digitalisation: the five-stage digital water adoption curve[11] lays down a process that ranges from immature digital development phase to sophisticated use of technologies (not-developed, basic, opportunistic, systematic, transformational.)

As stressed by the IWA network, the question of why the digitalisation of water utilities is critically needed is clear: the value of lowering operational expenses and, in turn, revenue requirements, has been proved for most industries. The more important question is how to implement and execute digitalisation in the water industry. This process is especially difficult in the water sector, which in most countries is regulated, and involves multiple different stakeholders and their underlying interests. For utilities operating in developing countries in Africa and Asia, it is even more complex as losses from operational inefficiencies are greater and resources to invest in digitalisation sparser.

The digitalisation process raises several questions; the first is, "where to start?". A utility must decide which departments or processes to prioritise for digitalisation. To understand the level of digital maturity in the water sector, using insights from 40 utilities worldwide[12] the IWA white paper "Digital Water: Industry Leaders Chart the Transformation Journey" presented a five-phase "digital water adoption curve", which is both an assessment tool and a roadmap to guide utilities in their digital adoption journey. It begins with utilities that are in an immature digital development phase and need actions such as a strong push from top management to recognise digitalisation as a priority and pilot projects to explore opportunities to move forwards. As utilities move along the adoption curve, they must increasingly align themselves with data-driven goals and ensure that their processes evolve with changing technology requirements. Introducing digital tools and embedding these in the culture and strategy enables progress towards a "transformational" stage of adoption.

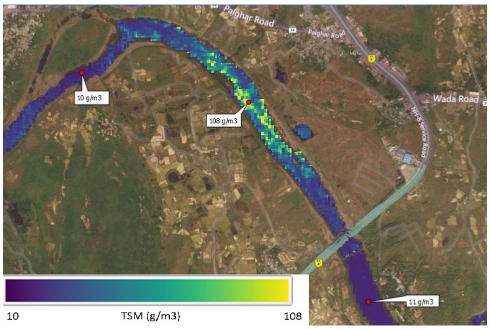


Figure 3. *Satsense Solutions Vaitarna River, 2020*

CASE STUDY 4: SATSENSE SOLUTIONS

Satsense Solutions uses satellite remote sensing and geospatial analytics to provide business and governance solutions. In a project co-funded by the European Space Agency and supported by the Toilet Board Coalition, Satsense Solutions used satellite remote sensing and artificial intelligence to develop a service to monitor effluence and water quality parameters in surface waters. This service has been used successfully by water utilities and water managers in the water, sanitation, and hygiene sector to assess the condition of water bodies and identify the source and intensity of pollutants in surface waters. The prevalence of untreated sewage and pollutants in surface waters could be correlated with risks of water-borne diseases.

Once wastewater-based epidemiology (WBE) processes detect the presence of pathogens in a community through sewage surveillance, geospatial analytics may be used to trace the extent and reach of the sewer system and highlight the affected community on a map. This may then be demarcated as a high-risk area and adequate measures can be taken by public health officials to address infections in the community.

Additionally, satellite remote sensing data might be used to estimate risks of infections within communities, on the basis of connectivity (such as road and rail connectivity, shared water resources, etc.), contamination pathways (water, human contact, etc.), population density (common healthcare facilities, schools, etc.), and transmission dynamics (vector-borne, human transmission, etc.). Such methods have been researched and used previously by NASA (the National Aeronautics and Space Administration) in estimating the risk of vector-borne disease and respiratory infections in communities using satellite data. This includes the risk of mosquito-borne diseases such as malaria and dengue, and water-borne diseases such as cholera. These methods and tools could play an important role in highlighting the risks of diseases and providing an impetus for improving sanitation in these communities.

The sanitation economy

Sanitation is one of the most pervasive yet overlooked development challenges facing us in the 21st century. An estimated 2.3 billion people around the world still lack access to basic sanitation, and 4.5 billion people – more than half the world's population – still lack access to safely-managed sanitation along the entire service chain. Increasing urbanisation is aggravating sanitation issues, environmental degradation, and public health.

Sanitation as a business is growing and has the potential to unleash innovation, economic growth, and development with speed and scale. The Business and Sustainable Development Commission's "Better Business, Better World" report[13] (2017) places water and sanitation infrastructure in cities among the 60 biggest market opportunities related to delivering the Global Goals. Furthermore, its value could be worth at least US$12 trillion a year in market opportunities and generate up to 380 million new jobs by 2030, with more than half this value in developing countries.

Sanitation is no longer a sector associated with the 'yuck' factor; instead, it is seen as a crucial opportunity for development projects and an opportunity for businesses to transform behaviours. The sanitation economy is a robust marketplace of products and services, renewable resource flows, data, and information that could transform future cities, communities, and businesses.

Smart sanitation in cities

Digital technologies and data are opening new ways to re-think sanitation services in cities. A key underlying principle of the sanitation economy is that sanitation is not a system apart, but an integral and visible part of the wider infrastructure, services, and resource flows. Many cities lack reliable information about public and community toilet usage, the quality of wastewater and sewage running through the system, and the spread of infectious disease. Sanitation can be included in the architecture of smart cities through data monitoring of public and community toilets. Technology can provide unique opportunities for municipal authorities to retain regulatory oversight of their cities' sanitation services while collaborating with business and investment to build, refurbish, operate, and maintain the system. Monitoring and analysing this data will provide more efficient and effective public sanitation services in the world's growing cities.

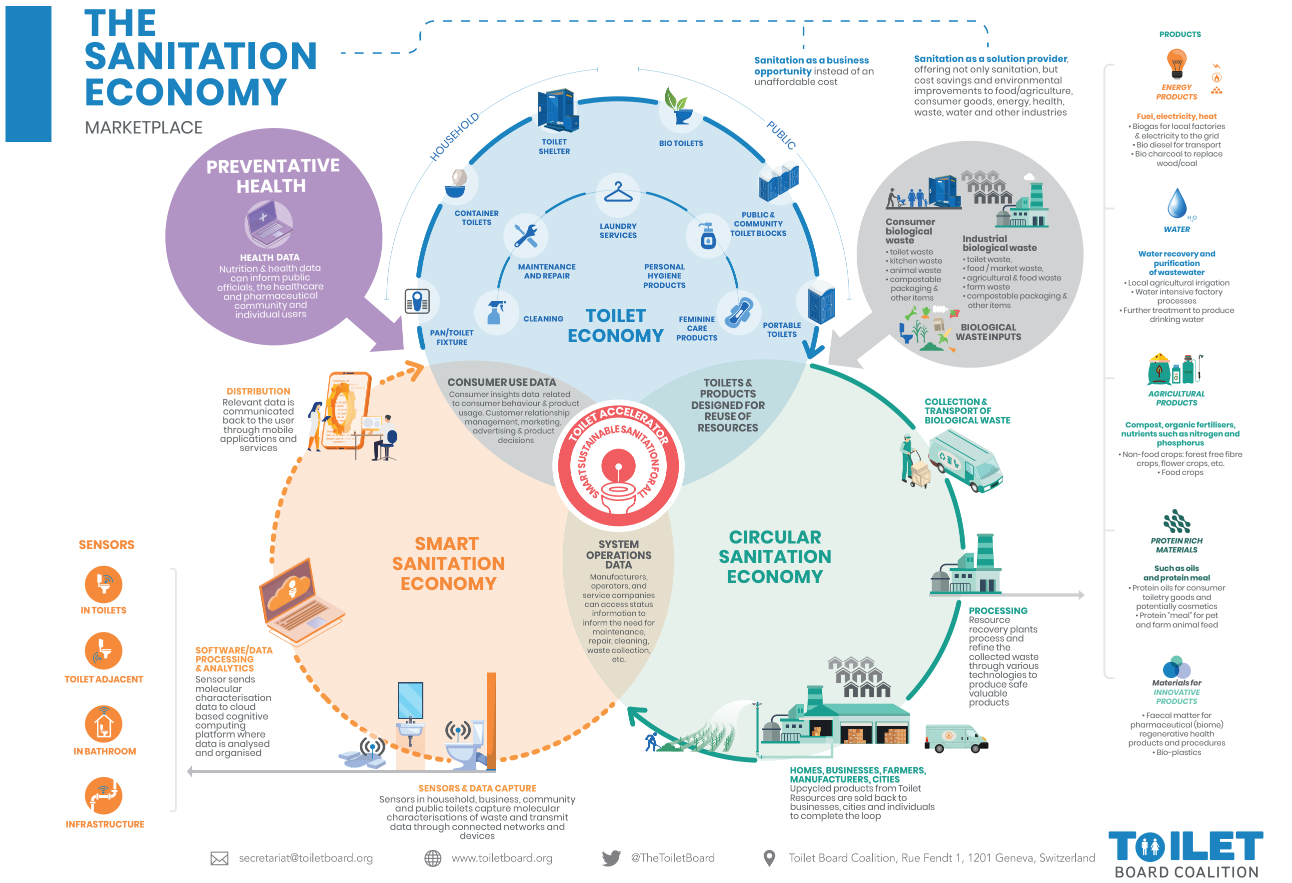


Figure 4. *Sanitation Economy Infographic, Toilet Board Coalition, 2020*

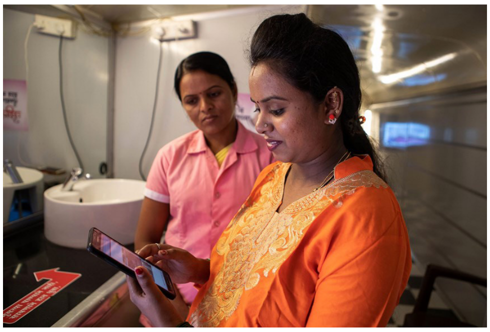
Mapping and monitoring toilets, waste treatment, and health through control centres in smart cities creates new sanitation intelligence and a new lens through which to translate citizen and city sanitation needs into targeted solutions and new value creation. The sanitation intelligence produced from a sanitation economy approach within a city enables more efficient and informed decision-making, leading to vital cost savings for the city, better services for citizens, and innovative revenue-generating opportunities in partnership with the private sector.

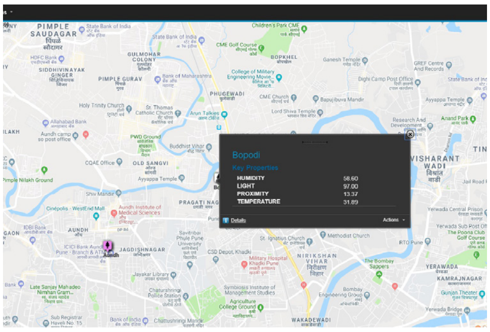
New digital technologies available today – including smart sensors – can be placed throughout sanitation systems in a city to provide real-time user, resource, and health information that will save the city money and create new revenue opportunities for business. Using data captured throughout the system, stakeholders can monitor, manage, and respond in real-time. In addition, the power of Earth observation, including satellite imagery and geospatial data, can unlock insights that were once invisible. Making sensor and Earth observation data available and transparent enables an open innovation platform for businesses and innovators to provide new solutions that will improve the lives of billions of citizens in cities.

New sanitation intelligence such as increasing use of smart sensors, the power of Earth observation, satellite imagery, and geospatial data unlocks significant cost savings and new revenue potential for cities and businesses in toilets, treatment, and health.

Smart cities around the world are applying smart sensor technologies to understand traffic and pollution patterns to improve services. From 2017 to 2019, the city of Pune, India, in partnership with the Toilet Board Coalition, provided an open innovation laboratory in the city to test available digital technologies that could be applied to public toilets and treatment centres. This has led to the testing of new business models and a first attempt to understand the market potential for smart sanitation approaches.

As the world embarks on a massive digital transformation, our ability to capitalise fully on emerging digital technologies and data for sanitation will be one of the leading drivers of sustainable and resilient sanitation systems for the future.





CASE STUDY 5: TOILET INTEGRATION BUSES

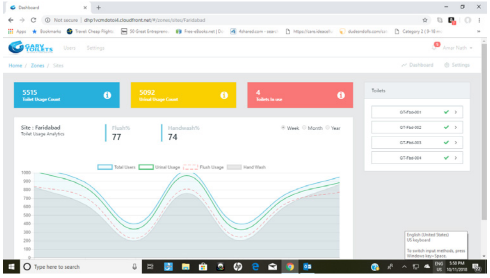
Toilet integration (Ti): Toilets for Her is a new, connected hygiene centre business model introduced by the Pune Municipal Corporation with the help of Saraplast to provide public toilets for women throughout Pune. The Ti bus is a converted out-of-service city bus that provides a clean and safe pay-per-use facility for women in public areas. The Ti business model generates revenue through additional services at the public toilet such as a laundry and café, as well as selling goods such as sanitary pads and products that provide health information. The buses have integrated digital technology to provide an insightful new base for consumer research, informing potential new product and service innovation.

Sensors in the buses give information about the footfall, the ventilation, and the humidity of the toilet; TV screens display educational communications to promote behavioural change; feedback monitors obtain comments and suggestions about the toilet use; solar panels electrify the buses; and Wi-Fi is used to count the number of people around the bus to understand the frequency and peak hours of use. A mobile application called *Soch-O-Mat* (meaning: don't hesitate) allows the users to locate and navigate to the nearest possible portable toilets. The Ti toilets aim to extend the use of digital technologies for obtaining data related to the public health of the users, and from the wastewater and toilet resources generated; however, the expansion of such decentralisation will need continued support and political will from Pune city.

Figure 5. *Ti Bus Mobile Application, 2020*

Figure 6. *Ti Bus Girl Washing Hands, 2020*

Figure 7. *Ti Bus Data in Pune Smart City Operations Control Centre*



CASE STUDY 6: GARV

Smart toilets, in terms of self-cleaning, have become popular throughout India. Located in Delhi, GARV Toilets are stainless steel, portable, smart, public bio-toilets equipped with an RFID-IoT (Radio-Frequency IDentification-Internet of Things)-powered mobile application that can tell how many people have used a toilet, the amount of water available, and how often the toilet has been cleaned. It is equipped with smart technologies such as sensor-based flushing systems, which clean the toilet floor and lavatory pan, depending on requirements after every use. Digital sensors installed inside the toilet also provide information such as the percentage of users flushing the toilets, the amount of water used, the number of people using soap dispensers, and help monitor the number of male and female users in the toilets.

Along with the use of radio-frequency identification technologies, GARV is piloting mobile solutions for pay-for-use, geo-locating, and mobile market surveys, as well as advertising on the toilets by the maintenance agency. The radio-frequency identification dashboard is mobile-friendly as well. Through this, the implementing agency will be able to monitor real-time data (health, hygiene, asset related) on any mobile device through the Internet of Things. The new scientific advancements have enabled marked real-time biosensing of wastewater sources.

GARV is currently working on developing biosensors to enhance wastewater monitoring and improve preventative response measures for outbreaks such as COVID-19.

Figure 8. *GARV Digital Dashboard, 2020*

Figure 9. *GARV Toilet Interior, 2020*

Figure 10. *GARV Toilet Exterior, 2020*

CASE STUDY 7: WISH FOR WASH

Wish for WASH published, in June 2020, a systematic literature review on the use of biosensors in sanitation infrastructure, including toilets, sewage pipes and septic tanks. The findings from both peer-reviewed and grey literature included sensors measuring a variety of individual and population health outcomes.

At the individual level, these sensors ranged from gathering data about specific health outcomes, such as quantifying drug consumption or screening for infectious diseases, to monitoring individual health-related behaviours, such as tracking latrine and toilet usage. Additionally, various technology types were represented among the results, including DNA biosensors that could detect both cancer markers and pathogens, disposable carbon electrode sensors to detect pathogenic bacteria and smart toilets that quantify CO^2 as a proxy measure for gut microbiome health.

These emerging, Fourth Industrial Revolution technologies also have the potential to gather data about the health conditions and behaviors of communities. For example, “smart” technologies, including biosensors, could more efficiently monitor disease outbreaks in a population. As one of the papers included in the literature review stated:

“Infectious diseases require rapid or even real-time detection to assess whether there is a need for the containment of the disease carriers to certain areas and prevent the development of an epidemic. To this end, there is a need to develop novel analytical tools that are able accurately and rapidly to monitor low levels of biomarkers/pathogens with minimal sample processing by unskilled personnel at the site of sample collection.”

Additionally, biosensors could be used to supplement standard methods that are already in place, such as colonoscopies, surveys or blood work testing to monitor individual and population health more holistically and with greater user acceptability.

The literature review showed that biosensors could save time and money compared to traditional data collection methods. There is interest from both academia and the private sectors in prototyping and piloting of biosensors in sanitation infrastructure. The Wish for WASH authors noted that “by predicting and provoking, sewage systems will become ‘smart’ and could include ‘lab-on-chip biosensors’ which would permit continuous data collection and real-time surveillance for viral outbreaks at the aggregate level”.

Overall, the Wish for WASH team’s findings demonstrate that biosensors are being developed for use in the sanitation sector and could collect useful health-related data. In order to develop and implement effectively these technologies for public health surveillance and individual health monitoring at a large scale, more robust research and product development is needed to evaluate and improve existing biosensor technologies to ensure their efficacy as well as adherence to global data privacy and human study protocols. Additional research in this field could also identify gaps where next generation versions of the Smart Sanitation biosensor technologies can emerge because, as the Wish for WASH team says, #everybodypoops.

Source: https://www.mdpi.com/1660-4601/17/14/5146/htm

2

A new era for public health

A more reflective way to monitor communities' health

What is Wastewater Epidemiology?

Environmental surveillance – the process of sampling and analysing environmental samples such as water, air, or surfaces – can provide key information about the presence and dynamics of pathogens, such as polio, typhoid, and SARS-CoV-2. Particularly in the framework of wastewater surveillance, WBE refers to the chemical analysis of pollutants and biomarkers in raw wastewater to obtain qualitative and quantitative data on the activity of inhabitants of a given region[14,15]. WBE has the double role of providing information about the health and habits of the population as well as clarifying the anthropogenic impact on the wastewater. Over the past two decades, WBE has established itself as a valuable tool to track certain societal behaviours and the impact of everyday life on human health.

Currently, WBE is used to monitor the exposure of communities to organic and inorganic pollutants, carcinogens[16], as well as the abuse of legal substances (caffeine, nicotine, alcohol) and illegal drugs (cannabis, cocaine, amphetamine, opiates, etc.)[17,18]. Additionally, the WBE approach has been used to help identify the presence of diseases (hepatitis, poliovirus, and norovirus) and as a tool for testing vulnerable communities. For example, wastewater surveillance has successfully been used as a sentinel system for polio in Israel, triggering a widespread vaccination campaign to prevent further spread.[19]

While the novel coronavirus has destroyed the economic, social, and cultural fabric of governance, systems all around the world are rethinking their operation styles and response mechanisms to adapt to the crisis. Through the global response to COVID-19, we have seen a new social contract emerging around health and hygiene. We have seen communities around the world turning to environmental surveillance, specifically WBE, as a method to prepare and respond better to the current and future outbreaks of COVID-19 by monitoring public health at the aggregate level. As a result of the COVID-19 pandemic, the crucial role of WBE in identifying hot spots as well as being a tool for surveillance and early warning in future outbreaks has become evident. The ability to detect silently circulating pathogens, as well as to gain unbiased insights into community-wide pathogen levels and dynamics, can help guide public health interventions such as vaccination campaigns[20] or local shutdowns.

WBE can help detect and estimate the prevalence of pathogens in communities independently of clinical surveillance and therefore without the biases introduced by the availability of clinical testing. WBE is particularly valuable for diseases with long incubation periods and/or high rates of asymptomatic carriers, and it can therefore serve as a population-level early-warning system, as well to evaluate the efficacy of public health interventions in real-time. WBE has been used for the early detection and direct mitigation of disease outbreaks in Israel, Egypt, and Sweden.[21]

Wastewater surveillance through WBE can provide a vital supplement to clinical surveillance for informing public health decision-making as it offers a relatively inexpensive, efficient means to monitor public health at the aggregate level. WBE can detect and estimate the prevalence of pathogens in communities; it can also serve as a population-level early-warning system, as well as a means to evaluate the efficacy of public health interventions in real-time.

Scientific research has shown the possibility and potential of using these techniques, but their translation from scientific studies to applying the results to advise health authorities is an ongoing challenge. This gap in the current epidemiological landscape points to the lack of a reliable, concrete framework in place through which health-related data can be obtained, processed, and transmitted. This lays the groundwork for a potential and promising new ecosystem and data architecture around public health, integrating the data streams available through the sanitation economy.

For sanitation and water operators, this presents a prime moment of opportunity to re-imagine their products and services for hyper-relevance in a post-COVID-19 world. The digitalisation of systems, monitoring, and consumer interfaces, and the embracing of developing health-sensoring technologies, will generate new and greater value and relevance to already essential services.

BOX 2

COVID-19 is a prime candidate for wastewater surveillance as a complement to clinical testing, because it has a relatively long incubation period, high rates of asymptomatic and subclinical infections, and the widespread lack of capacity for adequate clinical testing.

In the global response to COVID-19, several groups have demonstrated that SARS-CoV-2 can be detected in wastewater in the early stages of local outbreaks[22], and that viral dynamics in wastewater mirror COVID-19 cases in those regions[23],[24],[25]. Research and commercial laboratories have now gathered valuable experience in the handling of sewage samples and analysis of the virus. The relatively long incubation period of COVID-19, combined with its high rates of asymptomatic and subclinical infections, and the widespread lack of capacity for adequate clinical testing make it a prime candidate for wastewater surveillance as a complement to clinical testing. Wastewater-based monitoring of SARS-CoV-2, both at larger population scales (e.g. at wastewater treatment facilities) and at smaller neighbourhood scales, can help public health officials identify emerging areas of concern and implement appropriate policies to mitigate its further spread, diminishing future strain on healthcare facilities and saving lives.[26] High-resolution (i.e. neighbourhood- or city-level) wastewater surveillance may also enable local governments to deliver "precision public health", introducing interventions only in affected localities, and mitigating the economic impact of broad, untargeted policies.

The global response to COVID-19 needs to have the capacity to access the epidemiological surveillance information at national, regional, and local levels, through multiple channels, with the ability to monitor real-time data and daily situation reports. To leverage fully the investments and capacities for data collection and analysis for risk assessment, a new global public health data architecture will be required.

Continuing, comprehensive and verified global surveillance data about COVID-19 is crucial for response at global, national, and local levels. Epidemiological surveillance information must be collected from all countries, territories, and areas and made accessible through multiple channels, including a dynamic dashboard and a daily situation report, as well as downloadable data extracts.[27]

CASE STUDY 8: MIT/BIOBOT AND COVID

As the COVID-19 pandemic began to unfold in the United States, Professor Eric J. Alm at the Massachusetts Institute of Technology (MIT) teamed up with Biobot Analytics – a wastewater surveillance company in Cambridge, Massachusetts – to monitor the outbreak. Collecting wastewater samples from the Deer Island wastewater treatment facility, which serves approximately 2.3 million residents in eastern Massachusetts, as well as from upstream sampling points (manholes) representing smaller communities, Professor Alm's research group and Biobot tracked the emergence and rise of SARS-CoV-2 in the greater Boston area. They were able to detect SARS-CoV-2 in Deer Island wastewater as early as 2 March 2020, when there were only two clinically confirmed cases in Massachusetts.

Key findings of this work included that SARS-CoV-2 dynamics in wastewater anticipated the dynamics of new clinical cases by an estimated 4–5 days. The strong correspondence between wastewater-based and clinical dynamics allowed researchers from Alm's laboratory to infer individual viral shedding dynamics early in infection, probably before people would have developed major symptoms and sought clinical care. Analysis of upstream catchments revealed strong disparities in viral loads, with increased viral concentrations being found in communities with lower median incomes—consistent with findings that COVID-19 has disproportionately affected socioeconomically disadvantaged communities.

The sensitivity of wastewater-based SARS-CoV-2 surveillance, combined with its anticipation of clinical trends – a critical benefit when dealing with an exponentially spreading disease – emphasises the potential of wastewater surveillance as an early-warning system that is unbiased by limited clinical testing capacity. The ability to use wastewater surveillance to infer information about individual disease course that cannot be obtained in the clinic further highlights the power of this approach. The Alm lab is now extending this work with a COVID surveillance pilot project on the MIT campus that monitors SARS-CoV-2 in the wastewater of individual residential buildings. Sampling occurs inside each building, via sampling ports installed in sewage exit pipes, with results available within 24 hours. Taken together, the Alm Lab and Biobot's work demonstrates the diverse scales at which wastewater-based epidemiology can be implemented, from populations of tens or hundreds of building residents, all the way up to millions of inhabitants in a region.

Figure 11. *PATH, 2020*

Figure 12. *PATH, 2020*

CASE STUDY 9: PATH AND BAG-MEDIATED FILTRATION SYSTEM

PATH and the University of Washington have developed, validated, and commercialised a new environmental surveillance tool to assist in the global eradication of poliovirus.[28] The bag-mediated filtration system (BMFS) collects wastewater in a bag, and then passes it, by gravity, through a simple filter that binds the poliovirus. The BMFS can sample volumes of up to 6 litres of wastewater. It offers higher sensitivity as it samples a large volume, and the small filters are easier to ship from remote and challenging environments than liquid samples. The use of preservatives on the filter reduces the need for immediate processing when the filters are received at a reference laboratory.[29] Furthermore, a method using skimmed milk flocculation can concentrate the 6 litres into a single pellet that can be resuspended into a liquid for testing.[30]

PATH selected Scientific Methods Incorporated (www.scientificmethods.com/) as the commercial partner to supply kits at acceptable pricing to low- and middle-income countries, especially those where poliovirus remains active.[31]

Tools such as the BMFS can also support monitoring for other enteric viruses, with similar advantages for biosafety, sampling volume, and ease of use.[32] A new field of critical interest includes the implementation of the BMFS for SARS-CoV-2 virus detection to assess its persistence and distribution within communities to inform on asymptomatic reservoirs as transmission risks, especially for areas where in-person testing is highly limited or absent.[33]

CASE STUDY 10: WOODCO

Woodco "Space for Sanitation" Project

Woodco Renewable Energy Ltd. (Woodco) has developed a faecal sludge treatment solution customised to treat human waste. The solution can be operated completely off-grid, treating sludge from communities, reducing waste volume, and neutralising odours and pathogens. Woodco uses a combination of technologies to recover valuable resources from biogenic "waste" materials such as biochar—a safe, reusable, sustainable product that is beneficial for human health and the environment.

Under a "Space for Sanitation" project supported by the European Space Agency, Woodco is currently developing a smart sanitation management platform that harnesses the latest in Internet of Things and artificial intelligence technologies, and that incorporates space-based technologies that deliver Earth observation, satellite communications, and global navigation satellite system capabilities. The platform supports the collection and analysis of contextually complementary data modalities relating to toilet-user behaviour and health, sanitation management processes, and broader external environmental factors.

The main goal of the “Space for Sanitation” project is to provide an early-warning system for likely outbreaks of disease. By combining the data streams from a wide variety of terrestrial and space-based sensing technologies, the platform will deliver actionable insights, including new ones not readily available from any single modality. As an example, the system can monitor the impact of illegal dumping of faecal sludge in water courses, the flow of waste and its interaction with the local environment and local populations.

The integration of satellite communications, coupled with the existing sludge treatment solution’s off-grid performance capability, supports the deployment of the overall sanitation solution, even in remote locations where there may be little or no terrestrial infrastructure.

Woodco artificial intelligence Kick-Start: Artificial Intelligence for Sanitation-Related Disease Prediction, Prevention and Management

Woodco is currently engaged in an artificial intelligence Kick-Start project, supported by the European Space Agency, that is exploring the feasibility of developing an edge-compute device for real-time pathogen detection in waterways. Wastewater analysis can significantly contribute to our understanding of the incidence and risk of disease in populations, caused by bacteria, viruses, and other pathogens related to human sanitation. Woodco envisages that a real-time pathogen detection capability will play a critical role in predicting new outbreaks of diseases such as COVID-19, and in tracking the evolution of an outbreak, as part of its broader sanitation management solutions.

3
Call to action

At the time of writing (October 2020), the technologies and business models to realise this vision are still in prototype or piloting. However, as with most technology-focused work, innovation comes fast and the regulatory and non-technology sectors struggle to keep pace. We give below recommendations around the roles we see different stakeholders playing as this new marketplace emerges.

1. Governments: These data flows could revolutionise the health of your constituents and shift more of your public health response from reactive to preventative. Take a leadership role in protecting the health and data security of your constituents while providing a vibrant space for innovation. Investments will be needed to build the software integrations between operators and smart city systems. The power of political will to facilitate this development, particularly on a country level, cannot be overestimated.

2. Investors: Investment will play a key role in the transformation of the sector. Digital technologies will enable new business models and ultimately prove cost reducing and revenue generating, but up-front investment will be needed to realise this potential. An innovative mechanism that provides access to resources for entrepreneurs and municipalities ready to embrace this opportunity could prove a game-changer in the time it takes for our population to achieve Sustainable Development Goal 6.2.

3. Sanitation and Water Operators: Wherever possible, welcome and embrace these technologies and the innovators developing them. Run pilot projects, and be open to evolving your business model to consider your products or services as a vehicle for public health monitoring.

4. Health Community: Come to the table, work with organisations in this space to bring your know-how and help us to understand the priorities of the health community.

5. Sensor and Data Management Innovators and Experts: You may not have thought of sanitation or water as a promising space to explore. We beg to differ. Sanitation and water systems are going through a rapid transformation. These are products and services that touch every human on the planet every day—the potential is enormous.

Next steps

As the WHO and UN work to build the data architecture to process this sort of information on a global level, we call on local and municipal governments, small and medium-sized enterprises working in the water and sanitation space, and technology companies to demonstrate the value and efficacy of this system. As the parties come together, we will gain a better understanding of the data privacy policies and standardisation protocols that are needed to accompany a system such as this.

A system as powerful and far-reaching as is scoped will require unprecedented co-operation and collaboration between global and local stakeholders. Multilateral organisations, banks and the international community must clearly integrate these approaches into their programmes for pandemic response in the future.

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About the
Toilet Board Coalition

Established in 2015, the Toilet Board Coalition (TBC) is a business-led partnership platform with the goal to accelerate the transition to the sanitation economy. Our ambition is to transform sanitation systems from unaffordable public costs into robust marketplaces of sustainable business value.

The TBC is facilitating private sector engagement; large-small company partnerships and public-private collaboration to contribute to the achievement of Sustainable Development Goal 6 - universal access to water and sanitation.

We run accelerator programmes and implement strategic projects dedicated to growing sanitation economy business solutions that are smart, circular and resilient to address the unmet sanitation needs of the world's most vulnerable.

The members of the Toilet Board Coalition believe that accelerating the sanitation economy will deliver significant benefits to business and society.

Learn more at toiletboard.org

Figure 13. *Toilet Board Coalition 2020 Members*

About the
International Water Association

The International Water Association (IWA) is a network and an international global knowledge hub open to all water professionals and anyone committed to the future of water. With its legacy of over seventy years, it connects water professionals around the world to find solutions to global water challenges as part of a broader sustainability agenda. As a non-profit organisation and with a membership in more than 140 countries, the IWA connects scientists with professionals and communities so that pioneering research offers sustainable solutions. In addition, the association promotes and supports technological innovation and best practices through international frameworks and standards.

For more information, please visit www.iwa-network.org

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