# Smart Sanitation

Subjects: Others
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The Toilet Board Coalition defines *Smart Sanitation* as a way to build resilience in cities, communities and sectors by utilizing Fourth Industrial Revolution technologies to improve the collection and monitoring of wastewater for both individualized and aggregate-level preventative health surveillance.

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## 1. Introduction

The health of individuals and communities is more interconnected than ever, and emergent technologies have the potential to improve public health monitoring at both the community and individual level. Biosensors are being developed for a range of uses including monitoring illicit drug usage in communities, screening for viruses and diagnosing conditions such as diabetes. Most studies were nonrandomized, small-scale pilot or lab studies. Of the sanitation-related biosensors found in the literature, 11 gathered population-level data, seven provided real-time continuous data and 14 were noted to be more cost-effective than traditional surveillance methods. The most commonly discussed strength of these technologies was their ability to conduct rapid, on-site analysis. The findings demonstrate the potential of this emerging technology and the concept of *Smart Sanitation* to enhance health monitoring at the individual level (for diagnostics) as well as at the community level (for disease surveillance).

## 2. Strengths and Weaknesses of Biosensors in Sanitation Infrastructure

This literature review shows that there is interest in continued prototyping and piloting of biosensors in sanitation infrastructure. These emerging technologies have the potential to gather preventative and behavioral health data about individuals and populations that could save time and money compared to traditional methods. From as early as 2014, mainstream publications and companies have promoted the concept of *Smart Sanitation* by predicting and provocating that sewage systems will become ‘smart’ and could include ‘lab-on-chip biosensors’ which will permit continuous data collection and real-time surveillance for viral outbreaks at the aggregate level [1]. As one of the papers in our 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 to accurately and rapidly monitor low levels of biomarkers/pathogens with minimal sample processing by unskilled personnel at the site of sample collection.” [2].

Overall, our findings demonstrate that biosensors are being developed for use in the sanitation sector and preliminary results indicate that these biosensors can collect useful health-related data. Additionally, biosensors could be used to supplement standard tests that are already in place, such as colonoscopies, surveys or blood work testing to monitor individual and population health more holistically.

However, many papers noted that despite the promising advantages that biosensor technology can bring to health systems, this is a nascent field; therefore, it requires continued rigorous research and product development to reach its potential. Additionally, the lifespan of these various biosensors from both a hardware and surveillance perspective is largely unknown since the majority of the studies were lab-based or pilot studies [3]. These systems may be less accurate when applied to complex matrices such as sewage due to the variable mix of multiple contaminants, pathogens and physical trash (such as used diapers or menstrual health products) that perhaps were beyond the scope of many of the lab-based tests [2]. Some experiments that did test real wastewater, sewage or human specimen samples in the lab tried to account for temperature and other conditions that would be encountered in the field, but these technologies would still require pilot testing to ensure they would be reliable on site.

Additionally, there were some limitations that were only mentioned in a few papers (such as data privacy and impracticalities for low-resource settings [4][5]), while some limitations were not mentioned explicitly but are feasible (such as the potentially high costs related to biosensor technology or installation [5][6]). One paper also reported that "it is uncertain whether the algorithm [that was used with the biosensor to detect 'likely defecation events'] detects child feces disposal, child latrine training and menstrual [health] management events as 'likely defecation events'," which is also a notable limitation [4]. The majority of the actual limitations reported for biosensors embedded in sanitation infrastructure are technological rather than methodological barriers; therefore, they have the potential to be improved through iterative changes in the various devices' product designs and fine-tuning their technological prowess.

Despite the current limitations of biosensors, the long-term benefits outweigh the barriers. Public health stakeholders and WASH practitioners should not be deterred from adopting biosensors into sanitation products and infrastructure and should seek to further build the evidence base to determine the true global health potential that this *Smart Sanitation* technology could have.

## 3. Population- and Individual-level Health Considerations of Smart Sanitation

Transforming sanitation infrastructure into a health diagnostic tool has implications both on the population and individual levels. At the population level, decision makers and public health practitioners could use biosensors that have been integrated into public sanitation infrastructure to mitigate and prevent infectious disease outbreaks [2]. On the individual level, there is also a demand for personal health monitoring. Similar to the biometric sensors integrated into consumer products such as the Apple Watch [7] or Fitbit [8], there appears to be a growing demand for individuals to use *Smart Sanitation* products to inform their lifestyle decisions and personal health investments. There are already at-home diagnostic methods available, such as Cologard's colon cancer screening kit where individuals can mail stool samples to be tested [9], which have potential to be improved and streamlined with the use of biosensors.

There has been an influx of *Smart Sanitation* private sector products on the market, such as TOTO's Flow Sky Toilet in 2018, a toilet that is equipped with a biosensor to capture the flow rate of the user's urine as an integrated urological medical examination [10], and Pampers' 'smart diaper' in 2019, which tracks an infant's sleep and urine patterns which is oftentimes a recommended practice from pediatricians [11]. These technologies represent the burgeoning market and demand from consumers for *Smart Sanitation*-related products for monitoring their individual health.

While there are a myriad of innovative opportunities for further research in the field, it is imperative that these products account for data privacy. Capturing data about individual-level health data, as opposed to information gathering about population-level health, must often adhere to regulatory standards such as the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule [12] in the United States of America and the General Data Protection Regulation (GDPR) [13] in the European Union. *Smart Sanitation* consumer products should be developed in such a way that is in line with these standards to safeguard individual-level health data while also fostering consumer trust as a result of transparent data protections in these products.

## 4. The Covid-19 Era: Furthering the Case for Increased Smart Sanitation Research

The need for embracing and further researching the implications of *Smart Sanitation* has been underscored by the widespread societal implications of the Novel Coronavirus (COVID-19). Recent studies have also shown SARs- CoV-2, the virus causing COVID-19, is shed in feces which means that fecal-oral contamination could be another route of transmission [14]. Biobot, a wastewater epidemiology startup, has conducted opioid and COVID-19 wastewater analytics and monitoring within the United States to create data-driven maps for community-level decision makers to see as the disease spreads in real time [15]. Researchers in Spain are now collecting samples approximately twice a week from over 250 wastewater treatment facilities for improved COVID-19 surveillance through sewage [16]. This would be an ideal place to implement biosensors in sewage systems, which would allow for this data collection to occur more quickly with less potential for exposure for field workers and lab technicians.

However, due to the nascent nature of this sector, the preventive health benefits of the S*mart Sanitation Economy* will likely not be realized quickly enough to meaningful impact the COVID-19 pandemic. Beyond current pathogenic testing, next generation *Smart Sanitation* biosensors could be made to detect a wide array of biomarkers to mitigate and monitor future epidemics.

## 5. Conclusions

The findings of this systematic review demonstrate the public health potential of biosensors as an emerging technology and how *Smart Sanitation* can be used to enhance health monitoring at the individual level as well as at the community level. Most studies were nonrandomized, small-scale pilot or lab studies and revealed that few biosensors have been used in toilet or human sewage settings outside of lab tests. Many of the biosensors provided real-time continuous data and were reported to be more cost-effective in terms both time and money when compared to traditional surveillance methods. The most commonly discussed strength of these technologies was their ability to conduct rapid, on-site analysis. The use of biosensors in sanitation is a nascent field that has the potential to promote global health security and strengthen health systems. In order to effectively develop and implement these technologies for public health surveillance and individual health monitoring at a large scale, more robust research is needed to evaluate and improve existing biosensors technologies to not only ensure the efficacy of their use but also their compliance with global data privacy and human study protocols. Additional research in this field could also identify gaps where next generation versions of the biosensor technologies can emerge.

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