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SANITATION DISPARITIES ACROSS SOCIOECONOMIC STRATA: MICROBIAL RISKS AND HEALTH HAZARDS

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ABSTRACT

Every individual has the fundamental right to access and use proper sanitation facilities; however, significant gaps persist globally, particularly along socio-economic lines. This study emphasizes the disparities in sanitation low- and middle-income countries (LMICs) and low earning communities, which contribute to disproportionate exposure to microbial and parasitic infections and a higher burden of disease and wealthier communities benefit from modern amenities such as sewage systems, flush toilets, and advanced wastewater treatment, underprivileged populations often rely on inadequate facilities that initiate and sustain illness within these communities. To better understand the transmission pathways of microbial contamination, this review draws on recent findings from environmental microbiology and epidemiology, focusing on reservoirs such as water, soil, surfaces, food, air, waste streams, and other fomites. It also explores the growing relationship between the human microbiome and sanitation practices, particularly highlighting children who are more vulnerable to growth retardation and gastrointestinal illnesses in unsanitary environments due to a weak immune system. This study also discusses the importance of climate resilience, behavior modification, and technological innovation in addressing sanitation challenges. It highlights the crucial role of climate-adaptive systems, culturally sensitive approaches, and microbiological research in enhancing sanitation outcomes, particularly in resource-constrained and climate-vulnerable settings worldwide. To mitigate the adverse health effects of sanitation inequality, the analysis concludes by emphasizing the need for equitable infrastructure investment, effective policymaking, legislative reform, and active community engagement at both national and international levels.

Key-words: sanitation infrastructure, epidemiology, microbes, environment, community.

INTRODUCTION

Like other human rights, access to safe sanitation is also a fundamental right, yet large and significant global disparities persist across regions, especially along socioeconomic lines (Dinka and Nyika, 2024; Kryston *et al*., 2024; Ly *et al*., 2022). Women and Girls Bear Brunt of Water and Sanitation Crisis (UNICEF-WHO, 2023). Approximately 2.3 billion people worldwide lack access to primary sanitation services, with a disproportionate burden falling on the world's poorest populations. Between the elite and low-income communities, sanitation inequality remains a critical and main issue with direct implications for contamination, communicable disease burden, and human health (Boakye-Ansah *et al*. 2016; Carlton *et al*. 2012).

The population of the elite class typically enjoys the ease, comfort, and benefits of contemporary sanitation infrastructure, such as attached toilets, modern sewage networks, treatment plants for wastewater, and access to reliable, clean water (Njuguna, 2019). In contrast, low-earning communities, especially those in low and middle-income countries (LMICs), usually rely on compromised sanitation facilities, or even resort to open defecation, and

disparities reside more in underdeveloped and developing countries. These disparities lead to exposure to pathogens and hygiene-related diseases.

Contemporary advances in microbial ecology and metagenomics indicate how sanitation conditions and socioeconomic status (SES) shape the human microbiome (Mehta *et al*., 2021; Shridhar *et al*., 2024). Exposure to colonies of microorganisms due to poor sanitation quality can influence and affect the composition of gut, skin, and respiratory microbial colonies by facilitating the settlement of harmful or drug-resistant microorganisms. This new and emerging perspective bridges environmental microbiology with human health, highlighting the multifaceted consequences of sanitation inequality and injustice (Ma *et al*., 2024).

In this review, we examine sanitation inequality, evaluation of microbial abundance, contamination level among the socioeconomic strata, and explore implications for the human microbiome and outcomes of public health between high and low-income families of different communities across the world (Fig. 1). This study represents evidence (Table 1) from environmental microbiology and epidemiological studies conducted recently. It concludes with condensed policy recommendations aimed at reducing unjust inequality through infrastructure investment, community engagement, and monitoring microbial risk.

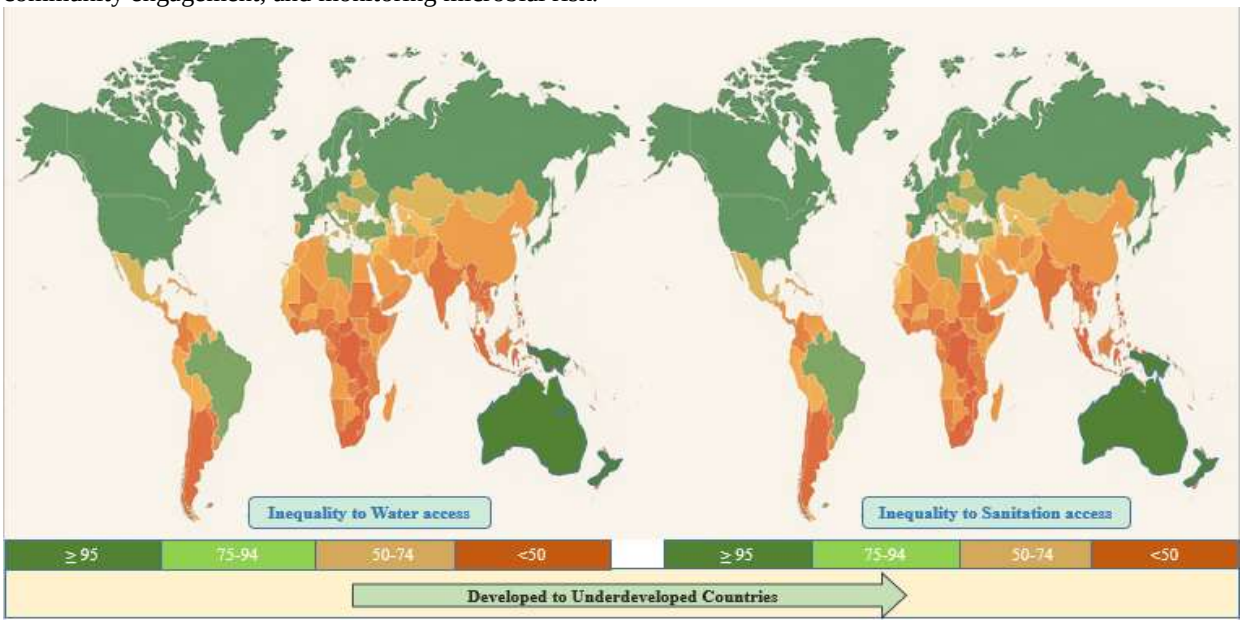

Fig. 1. Disparities increasing from left to right among the countries in access to clean water and sanitation (Bayu, Kim, and Oki 2020).

1. Sanitation access and infrastructure

Health services are significantly influenced by sanitation infrastructure, particularly when people with varying socioeconomic statuses are involved. The Joint Monitoring Programme (JMP) of the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF) has classified sanitation services into safe, basic, limited, unimproved, and open defecation (Jitu and Masud, 2025a). According to the joint monitoring programme, private restrooms linked to a sewerage system, where waste is processed correctly and disposed of, are examples of safely managed sanitation. On the other hand, bucket latrines, open defecation, and pit latrines without slabs or platforms are all considered unimproved sanitation and pose serious health consequences to the population of the areas (Jitu and Masud, 2025b).

Access to properly managed sanitation is still highly skewed by income on a global scale (Kempster and Hueso, 2018). Countries with high GDP, such as America, New Zealand, Australia, Japan, China, Canada, and European countries, have reported nearly universal coverage of safely managed sanitation systems. In contrast, more or less 40% of people in regions like South Asia and Africa (Fig. 1) have access to securely maintained facilities (Hosking *et al*., 2022). Due to a lack of readily available and reasonably priced sanitation solutions, large segments of the population defecate in an open area, mostly in rural and low-income urban, peri-urban communities in regions such as Chad, Ethiopia, Pakistan, India, and other countries of Africa and South Asia (Qamar *et al*., 2022).

Communities in urban and rural areas are often divided by disparities in sanitation and other essential facilities. Sewer networks, wastewater treatment, hospital facilities, toilets, infrastructure, and services (Fig. 2) are more

readily available to people in urban areas because they often receive more government funding and attention than rural areas (Zapasa *et al*., 2022).

Table. 1. Type of Sanitation, microbial contamination risks, and exposure.

Sanitation class	Microbial risk	Main exposure pathway	Ref
Safe Sanitation	Low pathogen risk; rarely contamination from system failure	Water contamination during infrastructure breakdown	Jitu and Masud, 2025a; Bain *et al*., 2014
Basic Sanitation	Mild to moderate risk from improper trash handling or weak maintenance; *E. coli*, *Salmonella*, *Shigella*	Contaminated water, soil, hands, or utensils from faulty sewage systems, leach pits, etc.	Mekonnen *et al*., 2024; Nizame *et al*., 2016
Limited Sanitation	High risk of pathogens such as *E. coli*, *V. cholerae*, rotavirus, and helminths	Contaminated water from nearby sewers, hand-to-mouth transmission, and surface contamination on communal restrooms	Kwiringira *et al*., 2014; Jitu*et al*., 2017
Unimproved Sanitation	Very high risk pathogen load, i.e., *Salmonella*, enteroviruses, and helminth eggs	Water runoff during rainy seasons, insect vectors, and soil contamination surrounding pits	Santamaría and Toranzos, 2003; Thoummalangsy *et al*., 2019
Open Defecation	Maximum and extreme risk of fecal pathogens: *E. coli*, *V. cholerae*, *Shigella*, protozoa, and helminths	Airborne particles, direct environmental contamination, food contamination via flies, and surface contact	Goddard *et al*., 2020; Farling *et al*., 2019
Open Drainage	High levels of *Salmonella*, *V. cholerae*, enteroviruses, and antimicrobial-resistant bacteria	Direct contact during cleaning, bioaerosols, floodwater, and irrigation water contamination	Narayan and Davis, 2023; Lee *et al*., 2016

Even in urban areas, notable differences exist in sanitation systems. Affluent areas often have access to modern plumbing and a steady water supply, whereas slums and informal settlements usually use homemade or communal restrooms without adequate waste disposal systems. For instance, research studies from Kibera settlement in Nairobi, Kenya, and slums in Dhaka, Bangladesh, reveal that shared facilities by the government are often poorly maintained and contribute to increased microbial exposure (Giné-Garriga *et al*., 2017; Gruebner *et al*., 2014; Kwiringira *et al*., 2014). The quality of sanitation infrastructure also correlates with household income at the national level. Latrines or toilets in low-income houses may be built with substandard or temporary materials, which can lead to structural collapses during severe weather conditions, contaminating nearby water sources and exposing residents to pathogens. Additionally, the poor families frequently lack access to menstrual hygiene products, soap, and maintenance supplies, which makes hygiene-related vulnerabilities more challenging (Anbesu and Asgedom, 2023; Rossouw and Ross, 2021; Sebert Kuhlmann *et al*., 2019; Singh and Singh, 2008).

Fig. 2. A: Rural life, B: Urban life, Inequalities and disparities in sanitation and other facilities across different communities in rural and urban areas.

According to data from the World Bank and the Joint Monitoring Programme, the inequalities in facilities are due to systemic differences in financial distribution, governance, and policy priorities. Compared to water services, governmental investment in sanitation remains low in many low and middle-income countries (LMICs). When infrastructure projects are funded by the government sector, wealthy, influential communities are usually given priority for development and improvements (Hutton and Chase, 2016a).

The imbalance in infrastructure and access to sanitary facilities continues to be a glaring example of income disparity worldwide, particularly in underdeveloped countries. These structural disparities influence larger cycles of

poverty, and communities encounter high levels of pathogen exposure. To identify vulnerable locations and focus actions that support equality and public health resilience, it is crucial to comprehend the distribution and caliber of sanitation systems (Calderón-Villarreal *et al*., 2022; Hutton and Chase, 2016b; Kumar *et al*., 2024).

2. Microbial Contamination Pathways

The underserved communities are disproportionately affected by contaminations (Fig. 3) linked to inappropriate sanitations, which can lead to life-threatening bacteria, viruses, and parasites via a variety of environmental pathways (Islam, 2025; Izah and Ogwu, 2025). The primary and key sources of contamination are polluted surfaces, food, soil, and drinking water, which are the primary and most important routes of pathogen transmission within humans. These all subjects can all operate as pools and reservoirs for fecal indicator bacteria and enteric pathogens. The risk is increased to many folds by poor infrastructure, restricted access to sanitary supplies, and inadequate and inappropriate wastewater treatment (Goddard *et al*., 2020; Julian, 2016; Santamaría and Toranzos, 2003).

Fig. 3. Pathways of contamination and affecting new individuals (Zerbo, Delgado, and González 2022).

2.1 Contaminated Water

One of the main highly significant challenges in underdeveloped countries is access to clean drinking water (United Nations, 2015). A scientific and systematic review revealed that water sources classified as "improved" still showed fecal contamination in nearly 38% of samples in LMICs (Bain *et al*., 2014). In Ethiopia, studies at the household level found that more than 60% of stored water samples exceeded the WHO guidelines for fecal coliforms, especially in households with unimproved sanitation. In contrast, upper-income neighborhoods in the same regions of Ethiopia exhibited significantly lower microbial loads, which can be attributed to better water handling practices and infrastructure.

2.2 Soil and Environmental Surfaces

Microbial contamination can occur in soils very next to pit latrines, open defecation sites, or poorly managed waste areas (Thoummalangsy *et al*., 2019; Tillett, 2013). A study found high levels of bacteria, such as *E. coli* and other parasites, including helminth eggs, in soils surrounding shared latrines in low-income neighborhoods, while affluent communities showed negligible contamination. Fecal contamination was found on surfaces such as home floors, kitchen countertops, and kid-friendly play areas in Kenyan urban slums, raising the risk of ingesting pathogens and disease transmission, and keeping the population of that area at a high risk of infection.

2.3 Food and Hands

Moreover, contaminated hands of infected hosts, cutlery, food storage containers, animals, soil, and other fomites are means of transmission (Fig. 3 and 4). Most frequently, in settings where access to soap and clean water is limited, people do not wash their hands after defecating or before preparing food. Research studies from South Asia, especially Bangladesh and India, show that the hands of caregivers and ready-to-eat food in low-income

households can harbor pathogens, including viruses, Bacteria, and other parasites. On the other hand, more educated and wealthy families have access to refrigerated food storage, improved hygiene awareness, which results in lowering the risk of microbial loads in utensils, food, appliances, and other for mite samples (Nizame *et al*., 2016).

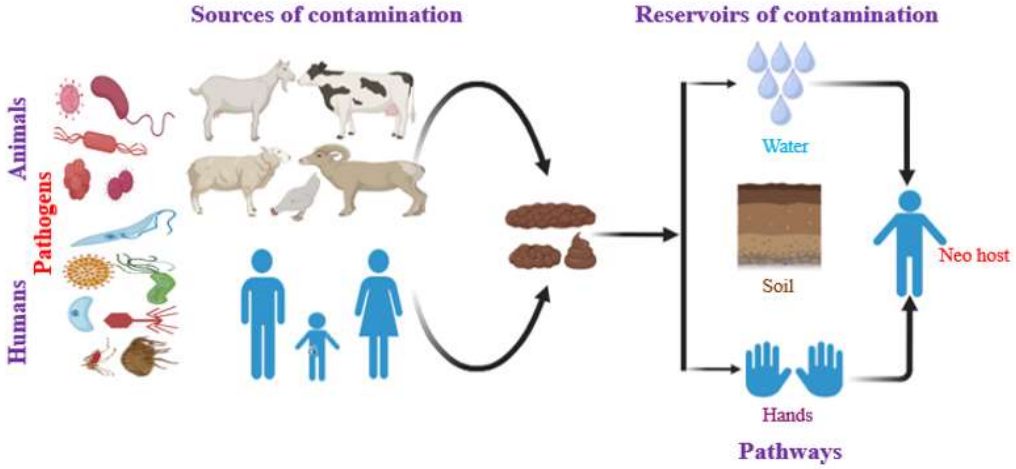

Fig. 4. General sources and reservoirs of contamination and infecting new hosts.

2.4 Wastewater and Open Drainage

Wastewater from households is commonly discharged primarily in third-world countries into adjacent freshwater bodies or runs untreated through open drains in informal urban areas, which exacerbates the situation. Numerous microbial populations, such as *Salmonella*, enteroviruses, and the pathogen *Vibrio*, as well as other parasites, are present in these open drainage networks. The rainstorms in these areas exacerbate the issue by allowing bacteria from feces to contaminate sources of drinking water. To minimize and reduce microbial burdens in foodborne samples, a multi-country investigation study showed that open drains in low-income communities were hotspots of microbial spread (Narayan and Davis, 2023).

2.5 Airborne Pathogens

Since this fact is less frequently studied, respiratory exposure to pathogens may result from the aerosolization of germs from drains, latrines, or waste disposal sites. Modern research employing air sampling methods has shown that bioaerosols around unprotected or inadequately ventilated sanitary facilities contain fecal bacteria, viruses, and other microorganisms. This is especially more problematic in densely populated slum areas where people live near trash disposal sites in low-income countries (Farling *et al*. 2019; Lee *et al.,* 2016)

These parasite contamination channels collectively demonstrate how weak and poor sanitation practices, inadequate infrastructure, and other substandard facilities in developing countries pose a widespread risk of environmental hazards. In such areas, the residents have a cumulative microbial load that dramatically increases the spread of disease, particularly in children under five, who are more susceptible to growth deficits and enteric infections due to low immunity (Budge *et al*. 2019).

3. Inequalities in socio-economic groups

Geographical location, gender, and socio-economic level all have a substantial impact on access to modern sanitation facilities. Poor and inadequate sanitation services are a common problem in marginalized and overpopulated areas, which increases health hazards several-fold and social marginalization to its peak.

3.1 Urban vs rural sanitation access

Access to sanitation with better facilities is typically worse in far rural areas. For instance, just 29% of people in the rural population of sub-Saharan Africa had access to basic sanitation, whereas 55% of people in urban areas did so. Urban areas most usually receive political attention, and infrastructure development (Anonymous, 2023).

3.2 Challenges of sanitation based on gender

The burdens and sense associated with sanitation are higher for women and girls, especially regarding menstrual hygiene, privacy, and safety. In such cases, inadequate facilities result in lower school attendance and harassment.

Access to proper sanitation is also essential for the adequate health of mothers, especially in countries with low GDP (Sommer *et al*., 2016).

3.3 Informal slum settlements

Unstable and weak governments often implement uncontrolled land use and informal settlement policies, which neglect the provision of basic sanitary facilities in their countries. Residents use communal or homemade restrooms, which are often hazardous and unhygienic, increasing their risk of contracting communicable diseases on a large scale (Corburn and Hildebrand, 2015).

4. Health hazards due to poor sanitation and microbial exposure

Widespread health hazards have resulted across different regions due to contaminated sources, including food, water, environmental pollution, and poor sanitation. It dramatically raises the danger of cholera, typhoid, hepatitis, parasitic infections, and diarrheal illnesses. In these regions, children are more susceptible to malnourishment, stunted growth, cognitive impairments, and loss of life due to recurrent diseases. Every year, poor sanitation causes tens of millions of disability-adjusted life years (DALYs) and more than a million avoidable deaths globally.

4.1 Burden of waterborne diseases

More than half of rural inhabitants and 43 percent of urban dwellers were assessed, and it was found that water and sanitation conditions were terrible. *Salmonella*, *Clostridium*, *E. coli*, and *Enterobacter* were found in the drinking water. Typhoid (20%), hepatitis (13%), diarrhea (27%), skin infections (23%), stomach issues (53%), and allergies (33%), with greater incidence in rural regions, were among the health outcomes examined (Ahmed *et al*., 2020). Of the 1,427 homes, 52.2% had diarrhea, 51.1% had parasite infections, and 55.5% of the children were undernourished (Jabeen *et al*., 2011). Muddy flooring (OR=2.29), sporadic water supply (OR=2.72), and unclean toilets (OR for improved hygiene ~0.68) were also significant predictors (Freeman *et al*., 2017).

4.2 Impact of antimicrobial resistance and sanitation on child growth

Approximately 49% of water samples from over 425 schools examined contained E. coli contamination, 54% had Salmonella, 63% had Shigella, and V. cholerae was also commonly found. The elevated risk of infection with rotavirus and other infections (up to 22.6%). Sanitation greatly reduces trachoma, schistosomiasis, diarrhea, and soil-transmitted helminths, and improves child growth. The connected fecal pollution is reported to have caused up to 151 million cases of childhood stunting and 534,000 diarrheal deaths. The Fecal exposure is cited as the cause of 62% of diarrhea and malnutrition. Approximately 1.4 million avoidable deaths and 74 million disability-adjusted life years (DALYs) were caused by unsafe water, sanitation, and hygiene worldwide, with approximately 1 million deaths from diarrhea and 55 million due to DALYs (Mekonnen *et al*., 2024).

4.3 Psychosocial and mental health

Psychosocial, physical, and mental health suffer significantly as a result of poor sanitation, especially in women, children, students, nomads, and displaced people. Due to societal criticism, privacy concerns, environmental limitations, and fear of sexual abuse, women in Odisha, India, describe sanitation practices such as carrying water, open defecation, and menstruation hygiene as stressful. Students in Nigerian urban schools who were exposed to overcrowded, dirty, or non-existent restrooms experienced higher anxiety, toilet phobia, lengthier retention periods, and a rise in absenteeism from schools. Common mental illnesses like anxiety, anger, and depression are closely associated with water and sanitation insecurity. A meta-analysis of 23,103 participants in 16 countries found that poor sanitation has a significant impact on mental distress, with a standardized mean difference (SMD = 5.36) (Wada *et al*., 2022; Kimutai *et al*., 2023)

5. Change of behavior

Changes in sanitation and hygiene practices are crucial for improving public health outcomes, especially in environments with limited resources. The spread of infectious diseases can be considerably reduced by promoting regular behaviors, such as using soap during hand washing, practicing safe toilet usage, and disposing of waste properly. Culturally relevant message, education, and community involvement are frequently valid for successful community behavior change interventions. In addition to infrastructure, long-term gains also rely on changing personal habits and societal norms through consistent encouragement and support from every level.

5.1 Community-Led Total Sanitation (CLTS) approaches

By establishing a sense of pride and shame through participatory triggering events, such as community awareness and discussions, the removal of trash, and improved sanitary practices, the Community-Led Total Sanitation (CLTS) enables communities to collectively end open defecation, resulting in self-mobilization and the construction of latrines without outside assistance. According to a study conducted in Northern Ghana in 2024, socio-demographic characteristics such as district, income, and religion substantially impacted knowledge, attitudes, and CLTS-related activities, which improved due to community participatory events. This underscores the necessity of customizing interventions to local contexts to maintain behavior change, which ultimately upgrades the sanitation problems (Muktar *et al*., 2024; Venkataramanan *et al*., 2018).

5.2 Education and awareness

By providing communities with information and inspiration, education and awareness act as potent catalysts for changing sanitation and hygiene practices. Students in schools with Water, Sanitation, and Hygiene (WASH) awareness programs demonstrated significantly improved hygiene knowledge, attitudes, and practices in a mixed-methods study conducted in Gujarat, India, in 2025, involving 566 adolescents. This finding highlights the effectiveness of school-based education in promoting healthy behaviors. Another study conducted in Ujjain, India in 2021, revealed that school-based WASH training nearly tripled students' knowledge of managing and preventing diarrhea by decreasing intensity from 72% to 28% ($P < 0.001$) (Mushota *et al.*, 2021; Patel *et al.*, 2025).

5.3 Cultural Beliefs

Frequently, cultural values take precedence over the availability of infrastructure when determining sanitation practices. In Odisha, India, for instance, people often utilize canal banks as places for social gatherings as well as for defecation because they believe they are more culturally acceptable than private restrooms. Some people in peri-urban areas of Andhra Pradesh, India, avoid using restrooms close to places of worship because they think they are dirty or ritually polluting, which leads to ongoing open defecation even when they have access to them. In rural Ghana, open-air behaviors are encouraged by the idea that utilizing restrooms draws evil spirits or lowers social standing. Additionally, latrines are designated as "impure" areas in Odisha due to caste-based traditions, particularly for upper castes, which forces households to continue open defecation to maintain spiritual and domestic purity. These findings highlight the need for sanitation interventions to target taboos, religious ideas of purity, caste standards, and societal traditions to change deeply ingrained habits (Adjibolosoo *et al*., 2020; Routray *et al*., 2015).

6. Technologies and innovations in sanitation

Sanitation innovations are progressively enhancing affordability, intelligence, and localization systems. Hundreds of houses now have low-cost alternatives, such as the Sato pan, an inexpensive plastic toilet with a counterweighted trapdoor that effectively serves millions in low-income areas by preventing odors and requiring less than one liter per flush. Regarding smart toilets, Internet of things (IoT) enabled versions now have sensor-controlled flushing, air-quality monitoring, leak detection, and even health biomarker analysis through urine and stool. This allows for early illness identification, resource savings, and real-time hygiene management. Decentralized wastewater treatment technologies (DEWATS), which include systems like microbial fuel cells, constructed wetlands, vermi-filters, and anaerobic baffled reactors, provide powerful pollutant removal, energy recovery potential, and cost-effective on-site wastewater purification that is appropriate for small communities without centralized sewers (Sangamnere *et al*., 2023).

7. Policy, Governance, and International Frameworks

Achieving widespread access to clean sanitation in underdeveloped countries requires international frameworks, good governance, and standard policy. International programs, such as Sustainable Development Goal 6 (SDG 6), the World Health Organization (WHO), the United Nations International Children's Emergency Fund (UNICEF), and the Joint Monitoring Program (JMP), set goals to evaluate progress in sanitation. However, due to inadequate national policies, a lack of sufficient budget, and implementation gaps, many nations struggle to implement these aspirations, especially in poor countries. Closing the sanitation gap and advancing equity across regions requires strengthening governance, ensuring accountability, and coordinating national initiatives with international frameworks in areas that face sanitation challenges.

7.1 Global sanitation targets and national policies

One of the most critical international programs responsible for monitoring WASH progress, particularly in relation to Sustainable Development Goal 6 (SDG 6), is the Joint Monitoring Program (JMP). The JMP came into

being in 1990 and provides standardized data to monitor and evaluate access to safely managed sanitation facilities services in various poor countries. Gathering information on the differences between urban and rural areas, socio-economic categories, and regions plays a crucial role in informing foreign aid, assistance, and policy decisions. Although research studies highlight how the framework of JMP has increased global accountability and openness, they also point out that nations must enhance data collection and employ evidence-based planning to achieve greater results and reduce disparities in sanitation (Cronk *et al.*, 2015).

8. Climate Change

Because floods, droughts, and other extreme weather events are occurring more frequently due to global warming and climate change, sanitation systems are greatly impacted by these events. These disasters can taint water supplies properly and cause severe damage to infrastructure. Additionally, as temperatures rise due to climate change, waterborne illnesses spread more rapidly, further impacting public health. Considering the environmental unpredictability, safe waste management requires resilient and climate-adaptive sanitation technologies to lessen the effects of these events.

8.1 Flooding and drought

Drought and flooding pose a significant threat to sanitary infrastructure, with dire consequences for ecosystem resilience and human health. Heavy rains, floods, rising temperature, pollution, etc., frequently result in structural collapse, damage latrines, and cause communities to resort to open defecation, weakening the steps taken for proper advances made in sanitation, hindering flush and pour-flush systems the people use less ideal sanitation options, increasing the risk of fecal exposure and groundwater pollution (Iyer and Kohlitz, 2024).

8.2 Climate-resilient sanitation systems

For safe human waste management, climate-resilient sanitation systems are designed to withstand and adapt to climate-related pressures, including floods, droughts, storms, and rising temperatures. The piped sewerage and septic systems exhibit noticeably more flood resilience than rudimentary latrines, as noted in a resilience framework used in informal settlements in Kenya. This is due to their more robust physical construction and proactive administration. Solutions, including lined pits, high raised latrine platforms, and flood-proofing techniques, have successfully safeguarded sanitation facilities in countries such as Bangladesh and Pakistan during intense rainfall, preserving their usefulness and preventing contamination. Nature-based treatment and artificial, man-made wetlands offer the dual benefits of flood control and waste processing. The experimental systems have demonstrated an 86% reduction in peak flow during catastrophic storms and other weather-aggressive conditions (Masoud *et al*., 2022; Lebu *et al*., 2024).

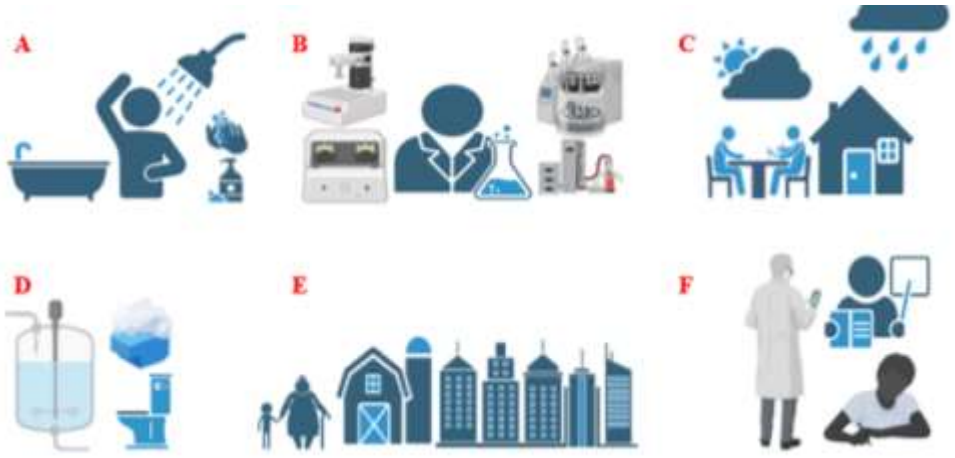

Fig. 5. Sanitation problems can be avoided through: A: Proper sanitation and soapy hands, B: Future directions and research gap, C: Community-led total sanitation, D: Innovation and technologies in sanitation, E: Community disparities and inequalities, F: Climate change strategies.

9. Future Directions and Research Gaps

Recent scientific studies have highlighted several crucial avenues for expanding our scientific understanding of the microbiological aspects of sanitation (Fig. 5). First, wastewater treatment research, including microbial ecology,

has recommended that studies can demonstrate how microbial populations influence pathogen survival, biodegradation, and system efficiency. Second, as demonstrated by a recent study conducted in Bangladesh that lasted more than 2.5 years, longitudinal and multidisciplinary studies that combine environmental sampling, social science, socio-economic, and health indicators are essential for tracking the effects of sanitation interventions on microbial hazard dynamics over a period. Lastly, modern metagenomics and microbiome technologies, such as shotgun sequencing, meta-transcriptomics, culturomics, and functional omics, offer previously unexplored opportunities to characterize intricate communities of microbes in sanitary systems and identify functional pathways essential for pathogen control and resilience (Daims *et al.*, 2006; Yang *et al*., 2025).

Conclusion

Due to larger socio-economic divides, enormous inequality and disparity in sanitation can be observed, which influences exposure to environmental hazards and general public health consequences. This study reveals that inadequate and weak infrastructure, combined with limited access to hygiene, are the primary causes of several microbial transmission channels in low-income areas, including polluted and contaminated drinking water and surfaces, as well as airborne infections. Vulnerable communities are disproportionately affected by these unjust disorders, especially children, who are more susceptible to malnourishment, diarrheal illness, and intestinal infections, having a weak immune system. Access to sanitation facilities is connected to social justice, the safety of individuals, and dignity within a population, in addition to physical health. Multi-sectoral strategies are needed to address these problems, including policy-level funding for sanitation infrastructure, focused advanced interventions in rural and informal settlements, hygiene education, and ongoing microbiological risk monitoring. To further support inclusive and resilient public health planning, future scientific studies must continue to bridge the gap between environmental microbiology, epidemiology, and social science. Enhancing and advancing sanitation and hygiene standards is essential for improving public health, particularly in underprivileged areas that are vulnerable to the effects of climate change. Beyond infrastructure, sustainable growth requires cultural sensitivity, modern technologies, behavioral change, and efficient policy implementation at both national and international levels. To guarantee fair, effective, and long-lasting sanitation solutions, science-based research and international frameworks must be combined with community involvement, education, awareness, and climate-resilient systems. Achieving the objective and aim of universal sanitation will require adopting multidisciplinary methods and closing implementation gaps between upper and lower communities.

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