

Spatial variations in access to sanitation across Tema, Ghana

Iris Ekua Mensimah Fynn^{1*} and Richard Grant²

Abstract

Inequitable access to sanitation remains a major barrier to sustainable urban development, as sanitation services are central to public health, environmental quality and economic well-being. By integrating environmental, infrastructural, and household-level indicators, the study moves beyond narrow assessments of sanitation access. This study examines spatial variations in access to sanitation across Tema in Ghana, focusing on communities 3, 12 and Newtown. Conceived as Ghana's first planned city after independence and initially connected to a unified sanitation grid, Tema now faces significant infrastructure strain as rapid urbanization, population growth and chronic municipal funding limitations have transformed its sanitation landscape. Using a multi-methods approach that integrates biophysical and urban data in the ArcGIS software, access to sanitation across Tema was mapped via a multi-criteria analysis approach, and the results were explained using qualitative data. Findings reveal significant infrastructural gaps between the legacy planned system and newer residential developments, many of which remain unconnected to the formal sanitation grid. Intra-urban disparities in sanitation provision are apparent in all residential areas with communities inhabited by more affluent residents typically receiving better-quality services, more reliable infrastructure, and greater municipal attention than low-income and marginalized neighbourhoods. The study underscores the need to align sanitation planning with biophysical and urbanization realities.

Article History: Received 20 March 2025

Accepted 17 March 2026

Keywords: Access; spatial inequalities; Tema; geospatial data; sanitation

¹ Department of Geography and Resource Development, University of Ghana, Accra, Ghana.

² College of Arts and Sciences, University of Miami, USA

***Corresponding author:** Department of Geography and Resource Development, University of Ghana, Accra, Ghana.
Email: iemfynn@ug.edu.gh

Introduction

Access to adequate sanitation remains a critical component of public health, environmental sustainability, and social well-being, yet it is an arena where disparities persist globally (WHO and UNICEF, 2019). This disparity in access to sanitation varies widely within and across regions, determined by the complex interrelationship between the socio-economic and environmental variables, including available infrastructure encompassing road network and density as well as buildings (He et al., 2018). In sub-Saharan Africa, access to safely managed sanitation remains extremely low, with only about 25–30% of the population using safely managed services and roughly half of all people lacking even basic sanitation (UNICEF, 2025). The presence or absence of sanitation infrastructure affects not only individual health outcomes but also broader socio-economic and environmental landscapes with often, dire consequences (Sorenson et al., 2011).

While recent urban geographic studies of sanitation emphasize social dynamics such as informal urbanization, marginalization, and hybrid service arrangements, this study incorporates key biophysical variables to reveal the micro-spatial patterns of sanitation access and infrastructure performance. While social analyses remain essential, they often understate the biophysical conditions that determine where sanitation systems can function, fail, or be maintained. Integrating these physical variables is therefore crucial for achieving a more complete understanding of sanitation geographies (Henriques et al., 2025). By integrating environmental, infrastructural, and household-level indicators, the study moves beyond narrow assessments of sanitation access and instead, situates sanitation systems within the broader socio-ecological conditions that shape viability, resilience, and equity.

This study examines the variations in access to sanitation by exploring how multiple physical and demographic variables, including soil type, population density, sewage lines, topography, road network, and land use type, contribute to these disparities. The primary purpose of the study is to uncover the underlying spatial and socioeconomic factors that contribute to the inequitable access to sanitation, thereby informing more inclusive and effective sanitation policies and interventions. By highlighting where and for whom sanitation infrastructure and services are lacking, the study aims to support equitable resource allocation and advocate for the realization of universal and fair access to basic sanitation.

Especially in areas with high urbanization rates stemming from global integration, the creation of overcrowded slums with inadequate access to drinkable water and sanitation facilities, might become a common phenomenon (Fotio & Ngueta, 2022). Due to the unique blend of the situation of the port, as well as industrial development that propels rapid urbanization, Tema in the Greater Accra region of Ghana, presents a unique area for studying sanitation and wastewater management. The significant population growth as a result of migration in search of job opportunities, creates pressure on existing sanitation and wastewater management infrastructure, making Tema an interesting area to study

how these systems are evolving to cope with rapid urbanization. As growth in Tema is both residential and commercial in nature, the sources of wastewater are diverse, ranging from domestic sewage to industrial effluent, and understanding how to manage such diverse wastewater streams effectively, is imperative. Compounded by the high marine traffic due to the situation of one of the busiest ports in West Africa in Tema, studying how wastewater is managed to prevent pollution of surrounding marine bodies and the perpetual adherence to global environmental standards, makes Tema a valuable case study area.

The fact that Tema is divided into several communities, with some of them, more affluent than others due to income and wealth disparities, means that some communities will be prioritized by local management authorities given their ability to afford services including waste management. Due to their inability to afford private sanitation services, residents in lower-income communities (such as Tema Newtown) are more likely to face greater challenges in accessing proper sanitation as a result of underdevelopment or inadequate maintenance of sanitation infrastructure. A key source of variation in access to sanitation in Tema stems from the difference between older and new communities. While older communities have more developed infrastructure with centralized sanitation services like piped sewage systems and connections to sewage treatment plants, newly developed or underdeveloped areas like Tema Newtown may still rely on rudimentary sanitation methods such as pit latrines, septic tanks, or even open defecation due to the lack of formal wastewater systems. It is therefore important to understand the variations in access to sanitation across Tema in order to formulate targeted policies and offer concentrated efforts to ensure equitable access to sanitation for all residents in Tema.

Tema has a population density of approximately 4,538 persons per square kilometer with an annual population change of 0.48% (Ghana Statistical Service, 2021). Densely populated areas, especially informal settlements, often struggle with limited space and financial resources for developing adequate sewage systems, which can lead to unregulated waste disposal (Munamati et al., 2017). Coupled with land use type, population density impacts sanitation needs by putting a lot of stress on existing systems (Cambaza, 2021). Also, depending on the land use type, such as whether the land is being used for residential, commercial, forest, or agricultural purposes, different waste generation and treatment needs can or cannot be accommodated.

Sanitation infrastructure, including access to sewage systems and treatment facilities, is significantly influenced by the surrounding environmental and socioeconomic conditions. For instance, soil type can determine the feasibility of traditional sanitation solutions like septic tanks, where certain soils provide better filtration and drainage capacity, enhancing the efficiency of onsite waste treatment systems and also influence the quality of groundwater that is often accessed for household consumption (Munamati et al., 2017). Additionally, soil permeability interacts with slope of the land and distance from roads, to determine the feasibility and sustainability of sanitation infrastructure. The topography of an area also impacts the distribution of sewage lines as steeper areas

may face greater infrastructural challenges needing more complex engineering solutions including more labour, as well as higher construction costs.

Another vital determinant of sanitation access is the availability and distribution of sewage lines including the locations of pulling stations where collected solid waste are disposed (Ali & Gujiba, 2024). Well-planned sewage systems, which often depend on an area's topography, can facilitate better waste management. Furthermore, a developed road network can influence access to sanitation services by improving transportation routes for waste collection and management. The type of roads in an area facilitates the maintenance and expansion of sanitation systems by improving accessibility for construction and repair work, underscoring the interdependence between transportation infrastructure and sanitation service delivery (Rajagukguk, 2021).

By providing a comprehensive analysis of different socio-economic and environmental variables, this study aims to understand how diverse factors contribute to variations in sanitation access across Tema using three strategically located communities. By examining these physical and demographic determinants, this study will shed light on how tailored approaches can better address sanitation needs in varied environments, leading to more equitable and sustainable sanitation solutions (Pullan et al., 2014).

Theoretically, this study is rooted in the System Theory, which highlights the notion that the collective impact of a wide array of interconnecting factors, rather than the weakness of any singular factor, is significant for addressing inequitable access to sanitation (Valcourt et al., 2020). Hence, geospatial data, which is widely used in sanitation studies (Ntozini et al., 2015), is supported by socioeconomic data in this study, to illuminate understanding of inequitable access to sanitation in an urban area such as Tema in Ghana. This system approach includes multi-criteria decision analysis, composite scoring, and soft systems methodology (Valcourt et al., 2020). By primarily using Geographic Information Systems to analyse spatial data and identify sanitation disparities, this study combines socioeconomic data, contributing to a more participatory GIS approach to understand access to sanitation within an urban context.

The structure of this paper is organised as follows. Section 2 begins with historical description and background of the study area and then details the data collected and the research methodology used for the analysis. Section 3 combines the results of the study and discussion of the results. The study is concluded in Section 4, which includes some recommendations.

Methods

Study area

Often called "Ghana's Industrial City," Tema is located about 25 kilometres east of Accra along the Atlantic coast. Originally a small fishing village, Tema was transformed into a planned industrial city in the 1950s under Kwame Nkrumah, centred around a deep-water port, residential areas, commercial centres, road networks, and a central sanitation

grid. Planned by Sir Patrick Abercrombie, Theodore Shealtiel Clerk, and Doxiadis Associates, the city was organized into 24 numbered communities to support industrial expansion and population growth (Kirchherr, 1968).

Between the 1960s and 1970s, industries such as Tema Oil Refinery, Volta Aluminum Company, Tema Steel Company, and Ghacem accelerated Tema’s economic growth and urbanization. However, rapid population growth, overcrowding, housing shortages, traffic congestion, waste management problems, and environmental degradation placed increasing pressure on infrastructure and sanitation services. By 2020, Tema’s population exceeded 200,000, with continued growth driven by industrial and trade opportunities.

Tema is linked internally and to Accra through an extensive road network, most notably the Accra–Tema Motorway, which serves as a primary corridor for the movement of goods and commuters. These transport links are critical for accessing the port and industrial enclaves, and the city’s rail connections further integrate Tema with Accra and other regions. This connectivity also facilitates the movement of solid waste to disposal and treatment sites outside the municipality. Despite this connectivity, sanitation and waste management challenges persist, particularly in densely populated and industrial areas.

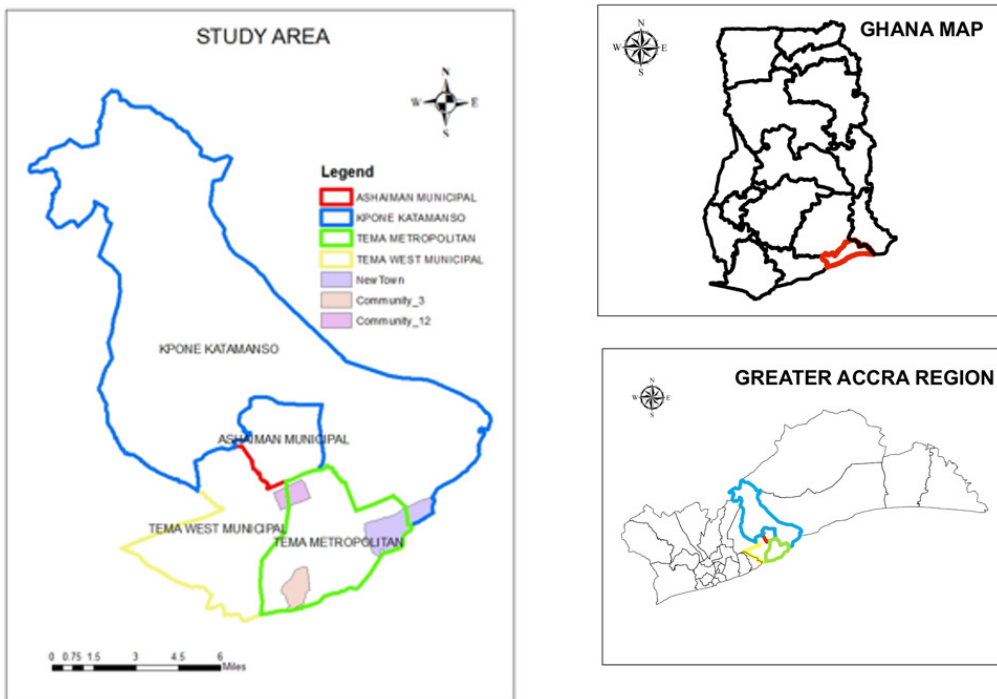


Figure 1. Map of Ghana showing the Greater Accra region and the four districts encompassing the study communities

Three communities were selected for detailed assessment because of their distinct urban typologies (Figure 1). Community 12 is a microcosm of mixed urban development, located in proximity to Ashaiman, which is a large informal settlement

with well-documented sanitation challenges, representing a residential area at the interface of formal and informal service challenges. Community 12 exhibits a diverse socio-economic landscape, combining more affluent enclaves with lower-income neighbourhoods, and featuring housing that ranges from planned middle-income estates to informal settlement areas. Some homes in Community 12 are more contemporary and benefit from approved sanitation infrastructure, while others are densely populated with poorer housing conditions. Community 12 illustrates the challenge of growth at the periphery of the planned core, as has been well documented in the peri-urban literature (Ashiagbor et al., 2019).

Community 3 is an affluent and well-established community situated near the Atlantic Ocean and located entirely within the Tema Metropolitan jurisdiction (Figure 1). Community 3 benefits more from established connections to the formal central sanitation network, such as sewerage systems and pumping stations. It is consequently predominantly comprised of middle to upper-income residents. This community serves as a reference point for how planned infrastructure performs over time.

Newtown, by contrast, was selected because its origins are entirely informal. When residents of the formerly rural village of Tema were displaced during the city's development, they were initially resettled in this area. As a result, informal housing patterns and rudimentary sanitation infrastructure have characterized Newtown since its inception (Chalfin, 2014). While some parts of Newtown have access to basic services, many areas continue to experience significant deficits, including inadequate waste disposal systems, widespread reliance on septic tanks or pit latrines, and irregular or inefficient waste collection services. This community offers insight into the persistence of informal sanitation regimes.

Data collection

To evaluate sanitation accessibility and infrastructural performance across three socio-spatially distinct communities in Tema, we assembled a multi-layered dataset integrating biophysical, infrastructural, and socio-economic variables. This mixed data approach was necessary because sanitation outcomes in rapidly urbanizing African cities are shaped not only by household characteristics but also by environmental conditions, land use patterns, and the legacy of planned versus informal development.

Biophysical and environmental data

Soil data were obtained from the Ghana Soil Research Institute (SRI), which provided information on soil classifications and permeability. This data set was used to assess how soil composition and texture affect the feasibility of different sanitation systems. Topographic data were derived from Shuttle Radar Topography Mission (SRTM) digital elevation models (DEMs) with a resolution of 30 meters. Slope and elevation metrics were extracted to assess their potential impact on sanitation infrastructure, particularly in

terms of sewage line feasibility. Hydrological data, including river and stream locations, were extracted from topographic maps and verified with local hydrological records. River density was calculated by dividing the total length of river segments by the area within each neighbourhood.

Urban infrastructure and built environment data

Road network data were sourced from OpenStreetMap and verified through field surveys and municipal records. Roads were categorized based on their types (major, minor, access roads), and spatial density was calculated for each neighbourhood to examine the effects of connectivity on sanitation infrastructure accessibility. Land use data were obtained from satellite imagery and the Tema Municipal Assembly's land use records. The images were classified using supervised classification techniques to identify residential, commercial, industrial, and green spaces. The data helped to understand variations in sanitation access across different land use zones.

Data on sewage infrastructure were obtained from the Tema Development Corporation (TDC) Ghana Limited. The location, type, and density of sewage lines were mapped and calculated to understand how proximity to these networks influences sanitation access. The location of pulling stations and manholes were also mapped. While the sewer lines and manholes did not cover the entire Tema and therefore, does not span across the whole area of all three communities, they did extend outside of the study area in certain sections and therefore, represented the true state of the density of sewerage in Tema.

Socio-demographic and household level data

Population density data were acquired from the Ghana Statistical Service (GSS) based on the latest census. This data was spatially interpolated to match the resolution of other variables, providing estimates of population distribution at the neighbourhood level. As part of a larger project, random points were generated in ArcMap across the study communities, and points representing houses, selected for data collection. Selection of houses was based on the location of the randomly generated points; points that fell on houses were included in the data collection process, while points further from any residential buildings were eliminated. In the end, a total of 1592 households in communities 3 and 12, as well as Newtown, were identified for data collection using a structured questionnaire. Data collected from primarily household heads or their representatives above 18 years from these households included household size, educational background, water usage, and average income levels. This data was used to establish links between variables such as education, capacity to afford sanitation infrastructure, gender, age, and access to sanitation. The data collected also included interviews in focus groups to provide nuanced context for understanding the results.

Spatial Analysis

Collected data on the different variables were further analysed in the ArcMap software. Elevation was calculated from the DEM and visualized as a grayscale raster to show basic elevation changes across the study area. Using the Reclassify tool, three elevation zones (low, medium, and high) were mapped. The soil data was imported into ArcMap as a polygon layer with attributes for each soil type, which were then symbolized by unique colours to distinguish each soil class visually. Based on their permeability, the Reclassify tool was used to categorize the soil in the study communities.

Buffers were generated around the major roads in the study area in ArcMap using a Euclidean distance of 10m to assess the extent of areas with immediate access to road infrastructure, enabling the visualization of areas with accessibility to the road network. Again, the Reclassify tool was used to categorize the study area into three: low, medium, and high road density.

Sewage data, which included locations and types, whether main or sub lines sourced from Tema Municipal Assembly, were standardized and made compatible with other data layers and then aligned with the administrative units. Subsequently, a buffer of 10m was drawn around the sewage lines to identify areas within sewage lines to categorize the study area as either low, medium, or high sewage density. This data was enriched with the product of a buffer analysis on the locations of manholes and pulling stations in the study area, also categorized into low, medium, and high manhole density areas.

A 10m buffer was traced around existing waterbodies in the area, with areas within the 10m buffer categorized as area with high drainage density and areas between 10 and 20m categorized as medium drainage density. All areas further than 20m from the waterbodies were categorized as having low drainage density. This output was rasterized and reclassified using the Reclassify tool in ArcMap.

Using authoritative sources, including geological surveys, information on soil properties provided by the FAO, as well as satellite data, the types of soil that are dominant in the study area were classified into three groups, with 1 being the least favourable soil and 3 being the most preferred soil group. These classifications were based on soil types, textures, stability, drainage capabilities, and permeability of the soil. Random field trips were used to ascertain the accuracy of the soil classifications.

Landsat 7 ETM+ images retrieved from the United States Geological Survey (USGS) online data portal were obtained and geo-processed. The satellite images were acquired between December and February, corresponding to the country's dry season, to avoid land cover reflectance and cloud interferences. These images were projected in ArcMap using the Universal Transverse Mercator (UTM) zone 30 North projection after being radiometrically calibrated with the Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH) tool in the software package ENVI version 5.1. In ArcMap, the maximum likelihood classification algorithm, a supervised classification method, was used to group similar pixels into four classes. The classes included areas with Dense

Vegetation, Grassland, Built-up, and Water. Based on personal knowledge of the study area as well as experience with using satellite images for geospatial analysis, training samples were collected and polygons, created around features to represent specific land cover types. These polygons were randomly created but intentionally placed to reflect the spectral variability within each of the four classes. Subsequently, the accuracy of the land use map was assessed with a confusion matrix derived from a minimum of 50 Regions of Interest (ROI) from each land use class.

Each layer was converted into its raster form so that each pixel representing an area on the ground had a value attached to it. Every pixel in a raster layer represents a unique value based on specific characteristics of the location. This means that overall values of each pixel in the study area can be computed by simply adding values for each pixel for every variable or layer under consideration. The resulting map was obtained using the overlaying technique in ArcMap (Figure 2). The overlaying technique involves the combination of multiple layers and is a common technique in geographic analysis for simple categorized results (Nath et al., 2000). The Zonal Statistics tool was thereafter used to calculate the summary statistics of each of the three study communities.

Results and Discussion

The topography of the study area exhibits marked variation significantly across the three communities. While Community 3 and Newtown are characterized by predominantly gentle slopes, Community 12 exhibits a markedly more varied terrain, with medium to steep gradients that intensify toward the eastern portions of the community. These topographic differences have significant implications for sanitation infrastructure, as development is disproportionately concentrated in areas with gentler slopes where construction costs, drainage requirements, and engineering constraints are comparatively lower. This pattern aligns with findings by Shi et al. (2023), who describe a similar process as the “slope climbing” trajectory of urban expansion—where urban development progressively extends from relatively flat, accessible terrains toward steeper slopes and higher elevations as land availability in low gradient areas becomes constrained. This raises important concerns for land use planning in Community 12, particularly in the gently sloping areas that remain undeveloped. As urbanization intensifies, these low gradient zones are likely to attract accelerated residential and infrastructural expansion because they require comparatively lower construction costs, less complex engineering solutions, and fewer site stabilization interventions. As Sorensen et al. (2011) note, urban growth frequently gravitates toward terrain that minimizes development constraints, which can result in the rapid conversion of such areas—often ahead of adequate planning controls or infrastructural provisioning.

As demonstrated by Sorensen et al. (2010) and Vargova et al. (2020), the physical environment plays a critical role in shaping infrastructural development. Terrain characteristics, including slope and landforms, directly affect the design and

implementation of sanitation systems, with steeper gradients posing distinct engineering cost and maintenance challenges relative to gently sloping areas. These slope variations further indicate that no single sanitation intervention would be uniformly effective across all three study areas, despite their shared location within Tema. The distinct topographic profiles necessitate differentiated, context-specific sanitation strategies. The design of sanitation infrastructure must be responsive to the distinct slope and landscape characteristics of each community, ensuring alignment with natural drainage patterns and mitigating risks such as soil instability and erosion (Owusu Ansah, 2016). By adopting tailored approaches in each community, sanitation interventions can be designed to be more effective, resilient, and more aligned with a sustainable pathway. Such context specific strategies are better able to address distinct communal needs by accounting for local physical conditions, available resources, and the challenges present in each setting (Marshall & Khosrow, 2013).

Soil characteristics provide a critical foundation for interpreting sanitation performance and constraints, highlighting that biophysical conditions constitute a key variable that must be incorporated into sanitation planning and infrastructural decision making. Soil type plays a critical role in mediating the extent to which contaminants infiltrate and spread through surface water systems. In Community 3, the prevailing soil type is Cambisol, which extends across much of the western portion of the area. Cambisols are generally poorly drained and exhibit low permeability, functioning similarly to clay rich soils with limited percolation capacity. As a result, they tend to retain substantial surface water, increasing the likelihood of saturation and slow infiltration. The Cambisols found in Community 3 are primarily Celtic Vertisols, a subtype characterized by prolonged water retention and notably slow percolation rates. These properties have direct implications for on-site sanitation technologies, as such soils are prone to effluent stagnation and reduced system efficiency. This implies that residents of Community 3 face an elevated risk of exposure to contaminated wastewater, as the low permeability soils cause effluent to remain stagnant on the surface for extended periods.

In contrast, Solonetz is the most abundant soil type in both Community 12 and Newtown. Within this group, ferric luvisols particularly dominate across Community 12 and Newtown. These soils exhibit comparatively high permeability, allowing water and effluent to infiltrate the surface more readily than in the low percolation Cambisols found in Community 3. Consequently, contaminated wastewater in Community 12 and Newtown is less likely to remain on the surface or come into direct contact with residents, as the more permeable soils facilitate quicker infiltration. This distinction is crucial for evaluating sanitation conditions across the study area, given that soil permeability directly affects exposure risk, effluent behaviour, and the overall performance of on-site sanitation systems.

The drainage system of the three communities in Tema illustrates a significant trend that affects sanitation growth. Community 3, like Newtown and Community 12, has more areas with low drainage density, followed by areas with medium drainage density and

then areas with high drainage density. The areas in close proximity to waterbodies have comparatively higher tendency of having more effective sanitation systems, which play significant roles in how wastewater disposal is handled and how flooding is circumvented, which consequently dictates how healthy the environment is for human population (Ali and Gujiba, 2024; Gaffan et al., 2022). With all three communities having less of these highly drained areas, there is concern about how wastewater is disposed.

Using a 20-meter distance from water bodies as a metric of drainage density takes into consideration the effect of proximity to water bodies on sanitation. Especially in areas where pipe-borne water or community accessed water is scarce, people rely on nearby waterbodies. Thus, it was important to highlight proximity to waterbodies as a metric to assess access to sanitation in Tema. Past studies show that households that are further away from waterbodies and who therefore have travel times greater than 30 minutes, progressively collect less water, consequently reducing the amount of water that is used for sanitation in the household (Sakisaka et al., 2015; Nygren et al., 2016). Thus, the variations in drainage density and the ratio of low, medium, and high drainage density areas in the three communities is important to understand the relative access to sanitation in the communities. With Newtown having comparatively more areas with high and medium drainage densities, followed by communities 3 and 12 respectively, these differences highlight variations in access to sanitation in the study area.

All three communities have more areas with low road density, followed by areas with medium road density and then, areas with high road density. As highlighted by Rajagukguk (2021), transportation infrastructure has direct impact on the management and development of sanitation systems, and areas with low road densities would present less effective waste collection and management strategies that consequently pose challenges for effective sanitation service delivery. He et al. (2018) emphasized regional differences in accessibility to infrastructure by positing that road networks act as base determinants for the accessibility of sanitation services. Compared to communities 3 and 12, Newtown has the highest road density and therefore, has more to gain when it comes to wastewater management.

Densities of manholes in the three studied communities in Tema showed a distinct pattern of distribution of sewage infrastructure. While Community 3 had the most areas with low manhole density followed by areas with medium manhole density and then a much less percentage of areas with high manhole density, the ratio of areas with high manhole densities is higher than areas with low manhole density in Community 12. Ali and Gujiba (2024) highlighted the implications of identifying suitable locations of manholes as they were relevant sanitation infrastructure whose absence have dire consequences on urban waste management, public health and environmental sustainability. This poses significant concern for waste management and generally, access to sanitation in Newtown, which does not have any constructed manholes. The spatial disparity in manhole density in the three study communities exposes the sanitation challenges in specific areas across Tema.

Spatial analysis of sewer line density in the three communities in Tema showed complex and varied patterns of distribution of sewage infrastructure. Compared to Community 12, Community 3 had the most areas with low sewage line density. In Newtown, a significant part of the area had no sewage line infrastructure at all. This spatial variation demonstrates a very big gap in municipal sewage collection across Tema. With almost similarly high population densities in all three communities, the heterogeneity of sewage infrastructure is rather disturbing, posing major obstacles in the collection and management of fecal matter, dictating the status of public health in Tema. It also highlights the discrepancy between urban planning, infrastructure and environmental wellbeing and how these work together to create healthy communities. The distribution of sewage lines and the results of their density in Tema calls for the adaptation of a targeted localized approach to sanitation infrastructural development in the municipality.

Compared to Community 12 and Newtown, Community 3 has relatively lower population density (Cobbinah et al., 2015), Amoako and Frimpong Boamah (2015), and Doan and Oduro (2012) provide relevant context and insight that explain the underlying forces that drive population density trends manifested in urban communities such as Tema. A more thorough spatial analysis of the patterns and potential underpinning factors can provide insights to further improve approaches to urban development and planning with regards to rapidly expanding human populations in urban settings. Given the fact that there are poorer sanitation situations in areas with high population density compared to areas with lower population density due to the enhanced potential for pathogens to infect new hosts through environmentally mediated and person to person transmission (Jarquin et al., 2016), the analytical addition of the population density layer and its accompanying variation, was very important.

Land use and land cover analysis of the three communities under study showed five dominant land use categories: Built-up, Dense Vegetation, Grassland, Bareland and Water. In all three communities, the most dominant land use type is Built-up with differences only seen in the second most dominant land use in each community. While the second most dominant land use type in Community 3 and Newtown is Dense Vegetation, the second most dominant land use type in Community 12 is Grassland. In all three communities, water is the least dominant land use type. Built-up being the most dominant land use type in all three communities imply high levels of urbanization and growth in Tema. Built-up areas also imply presence of high levels of impervious surfaces meaning that, there is high tendency for wastewater to simply run across land surfaces and therefore, come into contact with a lot of human beings, instead of percolating into the earth, which reduces contact with human population. Impervious surfaces tend to collect pathogens and other pollutants and also leads to the pooling of rainwater, which increases potential breeding areas for mosquitoes and other waterborne disease vectors (Gaffield et al., 2003).

Focus group deliberations

Qualitative research involving focus group discussions with management and staff of the Tema Metropolitan Assembly (TMA), Ghana Water Company Limited (GWCL), and the Tema Development Corporation (TDC) showed that management involving the collection and treatment of sewage and wastewater in Tema, is the joint responsibility of the TMA, the GWCL, and the Environmental Protection Agency (EPA). The Tema Wastewater Treatment Plant (TWWTP) is one of the primary facilities for treating both domestic and industrial wastewater before their safe release into the ocean or its reuse. A visit to the TWWTP where discussions were had with several staff members revealed that the TWWTP is designed to treat approximately 20,000 cubic meters of wastewater daily, using both primary and secondary treatment processes including the use of activated sludge technology, after the transfer of wastewater from several sewage pulling stations in Tema. While this highlights the institutional arrangement and operational capacity responsible for wastewater management in Tema, especially showing that multiple agencies share responsibility for safeguarding environmental and public health, this is inadequate. Given Tema's growing population and the mix of planned and unplanned residential developments which typically generate high and unpredictable volumes of wastewater, a treatment capacity of a 20,000 cubic meters per day is likely inadequate to treat the generated wastewater.

The collection and transfer of wastewater from the pulling stations to the TWWTP involves a network system of pipes from the pulling stations designed in the 1960s with recent improvements by World Bank projects. The sparse distribution of pulling stations in the municipality underscores a critical need for spatial expansion to ensure more equitable and efficient service coverage. A pulling station is a designated facility where wastewater transported by vacuum trucks is discharged for preliminary treatment and stabilization before being conveyed to downstream treatment systems or released into the environment. Pulling stations play a critical role in conveying wastewater from low lying areas or locations where gravity flow is not feasible, enabling its transfer to higher elevations and, ultimately, to the TWWTP for treatment. A pulling station typically has a treatment plant that effectively eliminates approximately 95% of contaminants in used water, guaranteeing its safety before discharge into natural waterbodies. Given the extensive areas within Communities 3 and 12 that exhibit low pulling station densities, there is legitimate concern about how wastewater is being managed and the potential public health risks associated with inadequate disposal and longer transport distances. The discharge of large volumes of untreated wastewater into natural water bodies poses serious environmental and ecological threats, including the degradation of aquatic habitats, contamination of fisheries, and increased risks to both domestic and wild animals. Evidence from the Tema Metropolis demonstrates that untreated effluent discharged into coastal waters and lagoon systems regularly exceeds permissible pollution thresholds, contributing to eutrophication, oxygen depletion, and significant

harm to aquatic life, with cascading public health effects for nearby communities (Marfo, 2014). Thus, pulling stations are crucial for protecting the environment and ensuring the most efficient management of wastewater.

The absence of pulling stations in Newtown and the sparse distribution of such facilities in Communities 3 and 12 strongly suggests that much of the wastewater collected from households in Tema is discharged directly into natural water bodies without adequate treatment. This practice contributes to the pollution of coastal and inland aquatic ecosystems, the degradation of natural habitats, and heightened public health risks, including recurrent outbreaks of cholera and other waterborne diseases. Since the large national cholera epidemic of 2014 which severely affected the Accra–Tema metropolitan corridor, Tema has remained one of the high-risk urban centres for recurrent cholera transmission. It is also important to note that even where pulling stations exist, growing population pressures and inadequate maintenance of aging infrastructure render the system increasingly vulnerable to leakages and operational failures, resulting in significant inefficiencies in wastewater collection and treatment.

Multi-criteria spatial analysis

Analysis involving the combination of the multiple layers in all three communities in Tema, reveals large differences in access to sanitation. For instance, Community 3 is largely an area with low access to sanitation with areas of medium and high accessibility, found in patches, mainly towards the east (Figure 2). Community 12 on the other hand, has a significant portion being areas with medium access to sanitation with areas of low access to sanitation largely in the west and some patches scattered in the north and south eastern parts. Newton has a unique profile with a significant chunk of the community with medium access to sanitation. Not unlike communities 3 and 12, areas with low access to sanitation are relegated mainly to the west of the community and the few patches of areas with high access to sanitation scattered north-easternwards. Layers such as sewage line density, soil type, proximity to pulling stations, manhole density, road density and slope, which are visibly skewed westwards might explain the trend seen in the communities. This is corroborated in studies where the choice of sanitation technologies have been dependent on soil permeability and stability as well as sewage infrastructure (Moko et al., 2024).

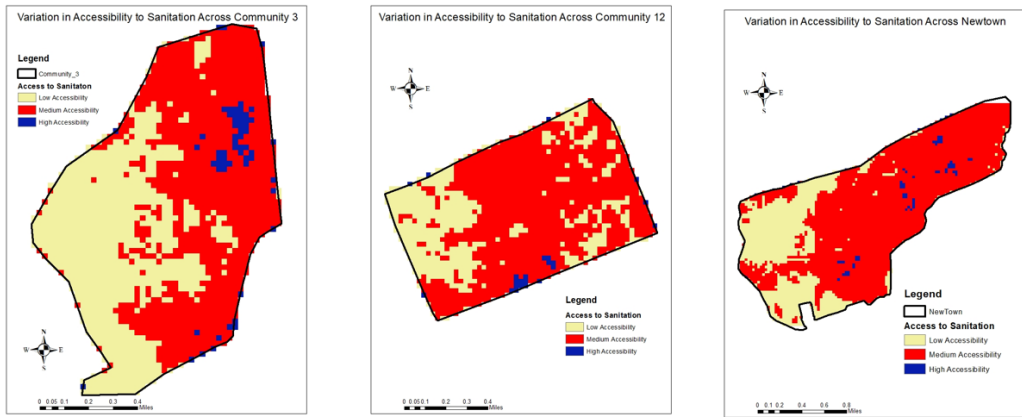


Figure 2. Map showing variations in access to sanitation across Tema

Trends presented in Table 1 depict variations in access to sanitation across the three study communities in Tema. A surprising outcome of the study was Newtown having the largest percentage of areas with medium access to sanitation given that Newtown is relatively unplanned compared to communities 3 and 12. Given that soil type and drainage density provide the most differences when Newtown is compared to communities 3 and 12, these two factors can adequately account for the results as drainage systems and soil type determine wastewater dumping, flooding and water accumulation, which dictate sanitation conditions (Ali and Gujiba, 2024).

Table 1. Variations in access to sanitation

Study area	Low access to sanitation (%)	Medium access to sanitation (%)	High access to sanitation (%)
Community 3	39	53	8
Community 12	38	58	4
Newtown	28	69	3

The results of the demographic data collected, provide good context and explain the results of the spatial analysis. The quantitative data shows that educational background and employment status of residents also have a role to play in the degree of sanitation accessible to them. Table 2 shows that approximately 20% of residents in Community 12 have a bachelor degree compared to 15% in community 3 and 14% in Newtown. When asked about water management, 52% of those involved in water management had completed secondary education, followed by those with primary education (29%). Community 12 had the highest number of respondents with secondary education at 68%, which could explain the considerably higher access to sanitation in the community as demonstrated by Khatoun et al. (2017) with the assertion that education in schools improved personal hygiene among students and their immediate families. UNICEF (2012) corroborated this with research on the provision of hygiene education by the

Ghana Health Service to school teachers and food vendors, as well as among students, and concluded that education encouraged the pursuit of healthy lifestyles not only among students, but including their immediate families which has possible implications for adhering to healthy sanitation practices.

In Community 12, the group with the highest contribution to community water resources management, earned between 1501 and 2000gh (Table 3). This trend is again visible in Community 3 with 28% and 32% of the contributors to water management, earning between 1501 and 2000gh and 1001 and 1500gh respectively. In Newtown, majority of the contributors to communal water management earn only between 501 and 1000gh. In Community 12 and Community 3, most of those involved in water management had higher incomes. For instance, only 18% of water managers from Community 12 had the lowest incomes, and only 2% of those in New Town had high incomes (2501 - 3000 GHC), compared to 5% in Community 12 and 10% in Community 3. The lowest-income earners in Community 3 were not involved in managing water, an indication that low-income households in Community 3 may have less influence in managing their community water resources compared to Newtown and Community 12. Table 3 shows that there is a statistically significant association between income groups and contribution to community water resource management (CWRM) in all three communities, especially in Newtown. Given that the investment and recurrent costs of connecting to a conventional sewer (without treatment), a sewer connection and secondary wastewater treatment, and a tertiary waste-water treatment service in an urban area such as Tema, are variable (Rosemarin et al., 2008) with the population covering over 60% of the costs (Van Minh and Nguyen-Viet, 2011), it is not surprising that Community 12, having high income earners, have lots of areas with medium access to sanitation. With both communities 3 and 12 having wealthier households and the socio-economic profile of residents, aligning with typically middle and upper-income families, residents are able to access better private sanitation options, including septic systems and personal waste management services. It is also to be expected that the local governance and public service delivery in these wealthier areas, are more robust, with better coordination and regular infrastructure maintenance (Carabine and Wilkinson, 2016) that ultimately, lead to better access to sanitation.

Table 2: Income groups and contribution to community water resources management

Community	Income groups	Contribution to CWRM		Total n (%)	X ²	p.-value	G	p-value
		No contribu- tion n (%)	Contributes n (%)					
Community 12	< = 500 GHC	35 (10.4)	12 (18.2)	47 (11.7)	14.35	0.0259	15.49	0.0167*
	501 – 1000 GHC	71 (21.2)	8 (12.1)	79 (19.7)				
	1001 – 1500 GHC	47 (14)	9 (13.6)	56 (14)				
	1501 – 2000 GHC	45 (13.4)	15 (22.7)	60 (15)				
	2001 – 2500 GHC	35 (10.4)	14 (21.2)	49 (12.2)				
	2501 - 3000 GHC	68 (20.3)	5 (7.6)	73 (18.2)				
	Other	34 (10.1)	3 (4.5)	37 (9.2)				
	Total	335 (100)	66 (100)	401 (100)				
Community 3	< = 500 GHC	10 (4.1)	0	10 (3.4)	12.31	0.0554	15.94	0.0141*
	501 – 1000 GHC	49 (20.3)	12 (21.1)	61 (20.5)				
	1001 – 1500 GHC	51 (21.2)	18 (31.6)	69 (23.2)				
	1501 – 2000 GHC	46 (19.1)	16 (28.1)	62 (20.8)				
	2001 – 2500 GHC	28 (11.6)	5 (8.8)	33 (11.1)				
	2501 - 3000 GHC	50 (20.7)	6 (10.5)	56 (18.8)				
	Other	7 (2.9)	0	7 (2.3)				
	Total	241 (100)	57 (100)	298 (100)				
New Town	< = 500 GHC	26 (9.3)	11 (18.3)	37 (10.9)	43.11	0.0000	44.8	0.0000
	501 – 1000 GHC	80 (28.5)	37 (61.7)	117 (34.3)				
	1001 – 1500 GHC	91 (32.4)	9 (15)	100 (29.3)				
	1501 – 2000 GHC	48 (17.1)	2 (3.3)	50 (14.7)				
	2001 – 2500 GHC	22 (7.8)	0	22 (6.5)				
	2501 - 3000 GHC	13 (4.6)	1 (1.7)	14 (4.1)				
	Other	1 (0.4)	0	1 (0.3)				
	Total	281 (100)	60 (100)	341 (100)				

Table 3: Relationship between education level and contribution to water resources management

Community	Income groups	Contribution to CWRM		Total n (%)	X ²	p-value	G	p-value
		No contribution (%)	Contributes n (%)					
Community 12	No formal education	2 (0.5)	1 (1.3)	3 (0.6)	31.26	0.000021	-15.57	0.0162*
	Basic	111 (28.8)	10 (12.8)	121 (26.1)				
	Secondary	138 (35.8)	53 (67.9)	191 (41.3)				
	Vocational training	9 (2.3)	0	10 (2.2)				
	Post Sec Diploma	25 (6.5)	2 (2.6)	27 (5.8)				
	Bachelor degree	80 (20.8)	11 (14.1)	91 (19.7)				
	Post graduate	20 (5.2)	0	20 (4.3)				
	Total	385 (100)	78 (100)	463 (100)				
Community 3	No formal education	23 (6.3)	4 (6.3)	27 (6.3)	2.31	0.8885	0.17	0.9997
	Basic	106 (29.2)	21 (33.3)	127 (29.8)				
	Secondary	156 (43)	27 (42.9)	183 (43)				
	Vocational training	7 (1.9)	0	7 (1.6)				
	Post Sec Diploma	7 (1.9)	2 (3.2)	9 (2.1)				
	Bachelor degree	55 (15.2)	8 (12.7)	63 (14.8)				
	Post graduate	9 (2.5)	1 (1.6)	10 (2.3)				
	Total	363 (100)	63 (100)	426 (100)				
New Town	No formal education	37 (9.8)	4 (6.3)	41 (9.3)	3.89	0.6919	3.37	0.0665
	Basic	153 (40.4)	29 (46)	182 (41.2)				
	Secondary	164 (43.3)	26 (41.3)	190 (43)				
	Vocational training	7 (1.8)	0	7 (1.6)				
	Post Sec Diploma	8 (2.1)	1 (1.6)	9 (2)				
	Bachelor degree	9 (2.4)	3 (4.8)	12 (2.7)				
	Post graduate	1 (0.3)	0	1 (0.2)				
	Total	379 (100)	63 (100)	442 (100)				

Newtown, as a predominantly lower-income settlement and having the most residents relying on public toilets as it is the community with the least number of houses connected to sewer lines, should typically have lots of areas with low accessibility to

sanitation as evidenced in the western part of the community. However, with most of the central and eastern sides where there is no connection to sewer lines, having high access to sanitation, it begs the question of what is contributing to the trend. A study conducted in Ghana, showed that Community-led Total Sanitation (CLTS), developed to cause collective transformation at the community level using participatory methods to incite repugnance at open defecation, is sustainable (Crocker, Saywell, & Bartram, 2017). Under CLTS, communities prevent open defecation by independently, building sanitation facilities using locally available materials. This has led to the proliferation of public toilets in Newton, as public toilets serve a dual purpose of preventing open defecation and providing income for their owners. In unsewered areas such as the central and eastern parts of Newtown, public toilets are connected to septic tank systems that are directly drained into natural waterbodies. With the high drainage density of Newtown, public toilets are highly effective for improving sanitation, which explains why the central and eastern sides of the community with no connection to sewer lines, have medium access to sanitation, even despite the low socioeconomic profile of many of its residents.

In Tema, the coexistence of the centralized treatment at the Tema Wastewater Treatment Plant and more decentralized and informal disposal systems reflects a hybrid wastewater infrastructure shaped by both planned urban layouts and expanding unplanned settlements. While institutions such as the Tema Metropolitan Assembly, Ghana Water Company Limited, and the Environmental Protection Agency (Ghana) share responsibility for wastewater management, gaps in coverage and treatment capacity have led to partial reliance on septic systems, informal drainage, or direct discharge. This hybrid system creates uncertain biophysical impacts, including potential contamination of coastal waters, groundwater, and urban soils, particularly when wastewater volumes exceed the designed capacity of formal infrastructure or when untreated effluent enters the environment. The ecological and public health implications of Tema's hybrid sanitation assemblage remain insufficiently understood, underscoring the need for systematic environmental monitoring as weak sanitation and environmental services concentrate disease burdens.

Conclusion

For cities like Tema, where rapid industrial growth, migration, and informal expansion intersect with aging planned infrastructure, integrating biophysical analysis is not optional. It is foundational for improving sanitation and advancing progress toward SDG 6; for designing equitable and technically appropriate sanitation systems; for informing land use planning; for reducing public health risks; and for ensuring that development trajectories do not exacerbate existing inequalities, particularly those already evident in sanitation access and service provision. Urban and social scientists must therefore treat biophysical determinants as integral to understanding urban variation and infrastructural fragmentation, not as background conditions but as active agents shaping the lived urban experience.

Contemporary urban planning often pays insufficient attention to biophysical characteristics in sanitation decision making, reflecting a persistent reliance on standardized engineering models, fragmented institutional mandates, and development pressures that prioritize rapid urban expansion over environmental suitability. Too often, “one size fits all” sanitation solutions—typically centralized sewer networks or uniform on site systems—are applied across highly heterogeneous urban landscapes, despite the fact that their performance is strongly conditioned by local biophysical characteristics and implemented in contexts where urbanization pressures are dynamic and difficult to anticipate, as recent evidence from rapidly growing African cities demonstrates (Manteaw, 2020).

As a result, critical variables such as soil permeability, groundwater depth, slope, drainage patterns, and erosion risk are frequently overlooked, producing sanitation systems that are technically misaligned with local ecological conditions and prone to failure. Incorporating biophysical analysis is therefore essential for designing context appropriate, resilient, and equitable sanitation infrastructure—particularly in cities like Tema, where rapid urbanization interacts with complex environmental constraints.

Urban systems are shaped as much by their material and ecological environments as by governance, social dynamics, or planning decisions. Knowledge of biophysical conditions—such as soil type, slope, hydrology, drainage patterns, and groundwater dynamics—plays a foundational role in shaping how infrastructure is designed, delivered, maintained, and experienced. This knowledge is essential not only for formal planners but also for actors operating within hybrid infrastructure systems and informal service economies.

It is important to emphasize that urban planning must design infrastructure that works with—rather than against—the biophysical environment. In coastal and rapidly growing African cities, neglecting biophysical realities has repeatedly led to system failures, accelerated infrastructure degradation, costly retrofits, and heightened risks for future investments that are not context sensitive. Integrating environmental data into planning enables the development of context specific, climate resilient, and technically appropriate solutions, rather than relying on “one size fits all” models that consistently underperform across diverse landscapes.

This study provides valuable insights into the disparities in access to sanitation across different communities in Tema. It shows that there are variations in access to sanitation across Tema, shaped by underlying biophysical and infrastructural factors such as soil type, land use type, road density, drainage density and topography. In addition to these physical factors, socioeconomic factors that influence urban planning, infrastructural development, and governance structures, also trigger variations in access to sanitation across Tema. The results highlight that wealthier communities such as Community 3 enjoy better sanitation services due to advanced infrastructure and private investments, while areas like Community 12 face a mix of better and worse access depending on location, and lower-income areas like Tema Newtown suffer from significant sanitation challenges due to informal settlements, inadequate infrastructure, and limited governance.

The variation in sanitation access between these communities highlights the unequal distribution of resources and infrastructure within urban areas, which often leads to marginalization of poorer neighbourhoods. The findings also emphasize the critical role of urban planning and local governance in determining sanitation access. While cities like Tema have made progress in expanding sanitation services, rapid urbanization and the proliferation of informal settlements make it challenging to ensure equitable service delivery across all communities. Insufficient investment in sanitation infrastructure, coupled with a lack of coordination between local authorities, exacerbates inequalities in access to sanitation.

Finally, the study underscores the need for a more integrated and inclusive approach to urban sanitation planning. Addressing the disparities in sanitation access requires not only expanding infrastructure in underserved areas but also ensuring that governance mechanisms are in place to monitor and maintain these systems. Furthermore, public education campaigns and community engagement are essential in improving sanitation practices and fostering behavioural change among residents, particularly in informal settlements.

Addressing these disparities requires a multi-faceted approach that includes improving infrastructure in underserved areas, investing in sanitation systems such as public toilets for informal settlements, and enhancing governance structures for more effective service delivery. Moreover, urban planning must prioritize equitable access to sanitation, considering both the current needs and future growth of cities. By focusing on inclusive, sustainable development practices, cities can bridge the sanitation gap, reduce health risks, and improve the overall quality of life for all residents, regardless of their socio-economic background.

In conclusion, ensuring equitable access to sanitation across urban areas is not just a matter of expanding infrastructure; it is also about addressing systemic inequalities that disproportionately affect poorer communities. Cities must adopt holistic approaches to urban sanitation that prioritize inclusivity, sustainability, and active community participation in order to create more resilient, healthier urban environments.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Iris Ekuia Mensimah Fynn  <https://orcid.org/0000-0002-8516-9272>

Richard Grant  <https://orcid.org/0000-0002-5409-8117>

References

- Ali, A.F., & Gujiba, U.K. (2024). Household wastewater management in sub-Saharan Africa: a review. *Discov Water*, 4 (6). <https://doi.org/10.1007/s43832-024-00060-6>
- Amoako, C., & Frimpong Boamah, E. (2015). The three-dimensional causes of flooding in Accra, Ghana. *International Journal of Urban Sustainable Development*, 7(1), 109–129. <https://doi.org/10.1080/19463138.2014.984720>
- Ashiagbor, G., Amoako, C., Asabere, S. B., & Quayе-Ballard, J. A. (2019). Landscape transformations in rapidly developing peri-urban areas of Accra, Ghana: results of 30 years. *Open Geosciences*, 11 (1): 172-182. <https://doi.org/10.1515/geo-2019-0014>
- Carabine, E., & Wilkinson, E. (2016). How can local governance systems strengthen community resilience? A social-ecological systems approach. *Politics and Governance*. 4 (62). 10.17645/pag.v4i4.746
- Cambaza, E. M. (2021). Influence of population density and access to sanitation on Covid-19 in Mozambique. *Angolan Journal of Health Sciences*, 2(1), 3–8. https://doi.org/10.54283/RACSaude.2789-2832.v2n1_2021.p3-8
- Chalfin, B. (2014). Public things, excremental politics, and the infrastructure of bare life in Ghana's city of Tema. *American Ethnologist*, 41(1), 92–109. <http://www.jstor.org/stable/24027565>
- Cobbinah, P. B., Erdiaw-Kwasie, M. O., & Amoateng, P. (2015). Africa's urbanisation: Implications for sustainable development. *Cities*, 47, 62–72. <https://doi.org/10.1016/j.cities.2015.03.013>
- Crocker, J., Saywell, D., & Bartram, J. (2017). Sustainability of community-led total sanitation outcomes: Evidence from Ethiopia and Ghana. *International Journal of Hygiene and Environmental Health*, 220, 551–557. <https://doi.org/10.1016/j.ijheh.2017.02.011>
- Doan, P. L., & Oduro, C. Y. (2012). Patterns of population growth in peri-urban Accra, Ghana. *International Journal of Urban and Regional Research*, 36(6), 1306–1325. <https://doi.org/10.1111/j.1468-2427.2011.01075.x>
- Fotio, H. K., & Nguea, S. M. (2022). Access to water and sanitation in Africa: Does globalization matter? *International Economics*. 170, 79-91. <https://doi.org/10.1016/j.inteco.2022.02.005>.
- Gaffan, N., Kpozèhouen, A., Dégbey, C., Ahanhanzo, Y. G., Kakai, R. G., & Salamon, R. (2022). Household access to basic drinking water, sanitation and hygiene facilities: secondary analysis of data from the demographic and health survey V, 2017–2018. *BMC Public Health* 22, 1345. <https://doi.org/10.1186/s12889-022-13665-0>

- Gaffield, S. J., Goo, R. L., Richards, L. A., & Jackson, R. J. (2003). Public health effects of inadequately managed stormwater runoff. *American Journal of Public Health*, 93(9), 1527-1533. <https://doi.org/10.2105/ajph.93.9.1527>
- Ghana Statistical Service. (2021). 2021 Population and Housing Census: General report. Ghana Statistical Service. <https://census2021.statsghana.gov.gh/>
- He, W. J., Lai, Y. S., Karmacharya, B. M., Dai, B. F., Hao, Y. T., & Xu, D. R. (2018). Geographical heterogeneity and inequality of access to improved drinking water supply and sanitation in Nepal. *International Journal of Equity Health*, 17, 40
- Henriques, C. D., Ferreira, V. and Cavaco, C. (2025). Urban dynamics in Africa: measuring, monitoring and shaping change through multiple lenses. *African Geographical Review*, 44(6), 535-542. <https://doi.org/10.1080/19376812.2025.252949>
- Jarquín, C., Arnold, B. F., Muñoz, F., Lopez, B., Cuéllar, V. M., Thornton, A., Patel, J., Reyes, L., Roy, S. L., Bryan, J. P., McCracken, J. P., & Colford, J. M. (2016). Population Density, Poor Sanitation, and Enteric Infections in Nueva Santa Rosa, Guatemala. *The American Journal of Tropical Medicine and Hygiene*, 94(4), 912-919.
- Khatoon, R., Sachan, B., Khan, M., and Srivastava, J. (2017). Impact of school health education program on personal hygiene among school children of Lucknow district. *Journal of Family Medicine and Primary Care*, 6(1), 97. <https://doi.org/10.4103/2249-4863.214973>
- Kirchherr, E. C. (1968). Tema 1951-1962: The evolution of a planned city in West Africa. *Urban Studies*, 5(2), 207-217. <http://www.jstor.org/stable/43191797>
- Manteaw, B. O. (2020). Sanitation dilemmas and Africa's urban futures: foregrounding environmental public health in contemporary urban planning. *Academic Journal of Interdisciplinary Studies*, 9(5), <https://doi.org/10.36941/ajis-2020-0096>
- Marfo, A. A. (2014). Environmental effects of sewage pollution and wastewater effluent quality assessment: A case study of Tema Metropolis, Ghana (Master's thesis, University of Ghana). University of Ghana Institutional Repository. <https://ugspace.ug.edu.gh/items/e2b6b433-bbf3-468e-927c-a8e2b2ef5f22>
- Marshall, R. E., & Farahbakhsh, K. (2013). Systems approaches to integrated solid waste management in developing countries. *Waste Management*, 33(4), 988-1003. <https://doi.org/10.1016/j.wasman.2012.12.023>
- Moko, J., Mwanzo, I., & Nyang'echi, E. (2024). Physical and environmental factors influencing accessibility to sanitation and hygiene services among people living with disabilities in Kitui County, Kenya. *International Journal of Current Aspects*, 8, 49-69. 10.35942/53ry6e63.

- Munamati, M., Nhapi, I., & Misi, S. N. (2017). Types and distribution of improved sanitation technologies in Sub-Saharan Africa. *Journal of Water, Sanitation and Hygiene for Development*, 7(2), 260-271. <https://doi.org/10.2166/washdev.2017.123>.
- Nath, S. S., Bolte, J. P., Ross, L. G., & Aguilar-Manjarrez, J. (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural Engineering*, 23(1-3), 233-278. [https://doi.org/10.1016/S0144-8609\(00\)00051-0](https://doi.org/10.1016/S0144-8609(00)00051-0)
- Ntozini, R., Marks, S. J., Mangwadu, G., Mbuya, M. N., Gerema, G., Mutasa, B., Julian, T. R., Schwab, K. J., Humphrey, J. H., & Zungu, L. I. (2015). Sanitation Hygiene Infant Nutrition Efficacy (SHINE) Trial Team using Geographic Information Systems and spatial analysis methods to assess household water access and sanitation coverage in the SHINE trial. *Clinical Infectious Diseases*, 61, 7. <https://pmc.ncbi.nlm.nih.gov/articles/PMC4657592/#s2>
- Nygren, B. L., O'Reilly, C. E., Rajasingham, A., Omore R, Ombok M, Awuor AO, Jaron P, Moke F, Vulule J, Laserson K, Farag TH, Nasrin D, Nataro JP, Kotloff KL, Levine MM, Derado G, Ayers TL, Lash RR, Breiman RF, & Mintz E. D. (2016). The relationship between distance to water source and moderate-to-severe diarrhea in the global enterics multi-center study in Kenya, 2008-2011. *The American Journal of Tropical Medicine and Hygiene*, 94(5), 1143-1149. <https://doi.org/10.4269/ajtmh.15-0393>
- Owusu-Ansah, J. K. and Atta-Boateng, F. (2016). The spatial expression of physical development controls in a fast growing Ghanaian city. *Land Use Policy*, 54, 147-157. <https://doi.org/10.1016/j.landusepol.2016.02.012>
- Pullan, R. L., Freeman, M. C., Gething, P. W., & Brooker, S. J. (2014). Geographical inequalities in use of improved drinking water supply and sanitation across Sub-Saharan Africa: mapping and spatial analysis of cross-sectional survey data. *PLoS Medicine*, 11: e1001626.
- Rajagukguk, W. (2021). Transportation, access to safe sanitation, and number of midwives and economic growth in districts in Indonesia. *E3S Web of Conferences* 244, 10022. <https://doi.org/10.1051/e3sconf/202124410022>
- Rosemarin, A., Ekane, N., Caldwell, I., Kvarnstrom, E., McConville, J., Ruben, C., & Fogde, M. (2008). *Pathways for Sustainable Sanitation*. IWA Publishing.
- Sakisaka, K., Chadeka, E. A, Nagi, S., Mwandembo, D. S., & Jimba, M. (2015). Introduction of a community water supply in rural western Kenya: impact on community wellbeing and child health. *International Health*, 7(3), 204 – 211.

- Shi, K., Yu, B., Ma, J., Cao, W., & Cui, Y. (2023). Impacts of slope climbing of urban expansion on global sustainable development. *Innovation (Camb)*. <https://doi.org/10.1016/j.xinn.2023.100529>.
- Sorenson, S. B., Morssink, C. & Campos, P. A. (2011). Safe access to safe water in low income countries: water fetching in current times. *Social Science and Medicine*, 72, 1522–1526.
- UNICEF. 2012. Water, sanitation and hygiene (WASH) in schools: A companion to the child friendly schools manual.
- United Nations Children’s Fund (UNICEF) & World Health Organization (WHO). (2025). Progress on household drinking water, sanitation and hygiene 2000–2024: Special focus on inequalities. WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene. <https://data.unicef.org/resources/jmp-report-2025/>
- Valcourt, N., Javernick-Will, A., Walters, J., & Linden, K. (2020). System Approaches to Water, Sanitation, and Hygiene: A Systematic Literature Review. *International Journal of Environmental Research and Public Health*, 17(3), 702. <https://doi.org/10.3390/ijerph17030702>
- Van Minh, H., & Nguyen-Viet, H. (2011). Economic aspects of sanitation in developing countries. *Environ Health Insights*. 2011, (5)63-70. <https://doi.org/10.4137/EHI.S8199>.
- Vargová, M., Veszelits Laktičová, K., Hromada, R., Cimboláková, I., Uher, I., Papajová, I., & Peter, K. (2020). Sanitation and the Environment. *IntechOpen*. doi: <https://doi.org/10.5772/intechopen.93106>
- WHO. (2019). WHO/Unicef Joint Monitoring Programme For Water Supply, S., Hygiene (JMP). Estimate Progress in Water, Sanitation and Hygiene: 2019 Update and SDG Baselines. World Health Organization (WHO) and United Nation’s Children’s Fund (UNICEF), Geneva (2019)