Assessment of water, sanitation, and hygiene target and theoretical modeling to determine sanitation success in sub-Saharan Africa

Ernestine Atangana1 · Paul J. Oberholster1

Received: 31 January 2022 / Accepted: 11 August 2022 / Published online: 3 September 2022
© The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract
Accessing the status of clean drinking water, sanitation, and hygiene remains a challenge in sub-Saharan Africa (SSA). The current article contributes to the progress made by the WASH initiatives in ten SSA countries in eliminating open defecation by 2030, using theoretical data from 2017 to 2019. The authors used regression trend estimation to observe that rural and urban population growth had a statistically significant detrimental influence on the elimination of open defecation by 2030. According to the predicted data model, by 2030–2035, the urban population of SSA would be 65, 25, and 10 million in all the three categories of income groups. An increase in the number of modern pit users (C1) shows no improvement at the annual rate of change. The unimproved toilets and open-pit latrines (C2 and C3) show a linear growth rate, which expanded over time. Population growth, higher unemployment, and teen pregnancies contribute to this increase. Under current conditions, the curve of modern pit latrine users will increase linearly. Nigeria has the most significant number of spread pit latrine users, which has decreased linearly from 25 to 20% since 2017. It was evident that the power-law trend in Nigeria would increase the usage of unimproved pit latrines and open-pit latrines. Ghana had the highest rate (50%) of open-pit latrine users, while the data show that this situation remained stable (2001–2017). In the Democratic Rep. Congo, annual rates increased linearly from 25 to 33% (2000–2017), while Burundi was one of the countries in the region with the lowest number of open-pit latrine users, although the annual rate has increased from 6.13 to 11.75% since 2017 to 2019.

Keywords Rural–urban population growth · Water, sanitation, and hygiene · Sanitation success · Statistical analysis · Sub-Saharan Africa · Theoretical modeling · WASH-related diseases
Introduction

Improvement of water access is generally a fundamental human right for all. Yet, many people do not have these basic needs (United Nations Children’s Fund and World Health Organization (UNICEF/WHO), 2019). The World Bank (2003) has shown that around 10000 people die per day from water, sanitation, and hygiene (WASH)-related illnesses, and more than 10000 are suffering from devastating diseases. Across the globe, around 30% of the population lack access to safe drinking water, whereas 40% lack essential services such as handwashing services (soap and water). More than 673 million people still use open-pit latrines due to poverty, inequality, mismanagement of public funds, and insufficient funding (UNICEF and WHO, 2019). The United Nations General Assembly (2015) has endorsed the 2015 Millennium Development Goals (MDGs) for clean water and hygienic sanitation, followed by the Sustainable Development Goals (SDG) for 2030. All people should have access to safe drinking water, sanitation, and hygiene, and open defecation should be prohibited. SDG 6 includes this principle, reflected in Targets 6.1, 6.2, and 6.3 (UN-Habitat, 2015; United Nations General Assembly, 2015). UN-Habitat (2015) also documented good health care and slum well-being as reflected in SDG 3, Targets 3.3 and 3.9. The 2015 MDGs disclosed that only five developing countries in the Global North met this target. In contrast, the Global South (Central Asia, Oceania, Northern Africa, and sub-Saharan Africa (SSA) did not meet the targeted goals (WHO, 2015). The SSA region achieved 20% to improve drinking water. In contrast, there was a twofold increase in the total population of the SSA from 1990 to 2017, with only a 6% increase in the sanitation and hygiene facilities (open-pit latrines) (UNICEF and WHO, 2019).

Given the growth in the rural–urban movement toward a more economically viable means of livelihood, the rural population in most nations in SSA has declined. Despite various slum rehabilitation attempts worldwide, informal settlements continue to have a pervasive negative side effect of urbanization. Informal settlements currently house more than half of the urban population in low-income countries and 863 million people globally (Acuto et al., 2018; UNSD, 2019).

Moreover, the unprecedented increase in the rural–urban population in recent years was due to a need for adequate improvement drivers within the SSA regions to assimilate the developing rural population in which unemployed youths account for over 60% of the entire population (Bloch et al., 2015). According to the national statistical offices, the rural population refers to people living in rural areas (World Bank, 2019a). It was also defined as fewer than five million people living in less than 5 m². Likewise, the urban population refers to people who live in cities. This can be estimated by using the World Bank’s projections and the urban ratios of the United Nations’ world urbanization prospects. However, combining the urban and rural populations does not equal the total population (World Bank, 2019b). It has been estimated that close to one billion people living in rural and urban slums or informal settlements in the SSA are assumed to be highly affected by COVID-19 (Lopez & Moloney, 2020). Most of them lack essential water supply (an improved community water source within a 30-min round trip), basic hygiene, and sanitation (improved toilets and handwashing with soap and water) for every household (Lilford et al., 2016). Most rural slums lack adequate and secure housing with a nonexistent or short supply of water, sewerage, and waste collection (Emina et al., 2011). These people are cut off from safer water in remote rural areas where water is untreated or polluted (O’Riley et al., 2017).
According to Mara & Evans (2018) review, the Global South sanitation and hygiene target of the MDG 6, less than six billion people will require sanitation by 2030, with approximately one million requiring a transition from open-pit latrines to fixed (modern) hygienic toilets. Container-based management and safety, particularly in urban slum communities, shared sanitation coupled with safety management, is likely to be part of the suggested solution. According to the authors, WASH facilities (handwashing with soap and water) have also increased in SSA, Northern Africa, and Western Asia (Mara & Evans, 2018).

The current study aimed to determine the success rate of WASH in SSA (2015–2020) and the progress related to eliminating open defecation by 2030 by the WASH programs. The objective was to conduct a literature review to understand the theoretical base for the study and the crucial variables encountered to the success of adequate, equitable water, sanitation, and hygiene and to end the practice of open defecation by 2030.

The article discusses the current state of the source and the progress of drinking water, sanitation, and hygiene facilities. Secondly, statistical analysis and empirical modeling of the SSA countries’ growing population to determine whether water hygiene, sanitation, and open defecation will improve by 2030. Thirdly, the health and environmental implications of WASH and the path forward to providing appropriate WASH in SSA countries.

2 Background literature

Achieving SDG 6 requires an understanding of the theoretical base for the study and the crucial variables encountered to access adequate and equitable water sanitation and hygiene and end the practice of open defecation by 2030. However, some challenges exist in meeting the SDG 6 target, including population growth, the state of the source of drinking water, sanitation, and hygiene services in some SSA countries. Data were captured from the Joint Monetary Programme (UNICEF, 2015; UNICEF/WHO, 2017).

However, some challenges remain in achieving the SDG 6 target, including population growth and the state of the source used for drinking water, sanitation, and hygiene services in some selected SSA countries. Data were collected using the Joint Monetary Programme.

2.1 Population growth

The anticipated population growth in poor regions poses a challenge to safe sanitation management. Africa’s population growth rate will double by 2030–2050 (UNSD, 2019). This indicates an additional burden for the provision of essential services. The concentration of fecal coliforms, an indicator of poor sewage treatment, correlates strongly with the high population density (Milledge et al., 2018; UN-Water, 2015). In most countries in SSA, the rural population has been experiencing a decreasing rate compared to the urban population, assuming the rural–urban tendencies to search for more economically viable means of living. The urban population in low- and middle-income countries in SSA is around four billion. The rural population will increase by approximately three billion between 2016 and 2030 (United Nations Department of Economic and Social Affairs (UNDESA, 2015).
2.2 State of source of used drinking water in sub-Saharan African countries

The MDGs for water and sanitation aimed at reducing the proportion of the global population without access to safe drinking water and basic sanitation by half in 2015. The global portable water objective of 88% was met in 2010 (UNICEF, 2015). By 2015, 91% of the global population had access to improved drinking water sources, compared to 76% in 1990, the baseline year. By 2017, 660 million people were without safe drinking water globally, with 323 million (46%) living in the SSA (WHO, 2017). Even though the number of individuals in SSA who had access to better drinking water has increased, more than 40% of people in the ten nations examined used tap water at home, higher than the general population (76%). There were national and urban/rural inequalities among the nations in the SSA region and federal and selected SSA country disparities in achieving the MDG objective for water (WHO, 2017).

Ghana and Malawi met the drinking water target, whereas the Central African Republic, Burundi, DRC, Kenya, and Rwanda did not. According to these findings (UNICEF/WHO, 2017), only South Africa had the highest percentage of improved drinking water sources in urban and rural areas (91% and 47%, respectively) (UNICEF/WHO, 2017).

Rwanda and Nigeria’s unimproved urban and rural potable water populations had the highest > 7% and > 15%, respectively. The majority of the region’s unimproved portable water sources were in rural areas. Water inequalities between urban and rural areas demonstrate that certain countries in SSA had a higher percentage of improved drinking water sources in urban areas than in rural areas. Only South Africa, Ghana, and Malawi populations had upgraded more than half of their cities’ portable water sources. On the other hand, Rwanda and Nigeria had the highest percentage of unimproved urban portable water sources (> 5%). This helps to explain why metropolitan areas have the most significant number of individuals with improved drinking water. Improved portable water sources are used by a higher percentage of individuals in urban areas (UNICEF/WHO, 2017).

2.3 State and source of sanitation and hygiene facilities in sub-Saharan African countries

In 2015, both the global and SSA MDG sanitation targets were not met. The worldwide sanitation aim was for 77% of the world’s population, with a 62% objective for SSA. Unfortunately, the gains in improved portable water sources could not be replicated since only 68% of the world’s population had access to improved sanitation, resulting in a nine-percentage point difference. In SSA, the situation was much worse than the global picture, with only 30% of the population having access to sufficient sanitation facilities and 32% missing the sanitation target by 2015 (WHO/UNICEF, 2015). Globally, 2.0 billion people lacked access to better sanitation, with 673 million (21%) living in SSA.

Similarly, 627 million people shared sanitation facilities. Furthermore, 23% of the people in SSA still used open defecation, compared to a world average of 13% in 2015 (UNICEF/WHO, 2017). Inequalities in sanitary services, as well as drinking water sources, occurred in the region. For example, in 2017, all countries revealed that metropolitan areas had a higher percentage of urban sanitation services than rural areas. Rwanda, for example, had the most significant percentage of its entire population (80%) using improved sanitation facilities in both rural and urban areas (UNICEF/WHO, 2017).
In contrast, DRC (62%) and Malawi (58%) had rural populations with unimproved sanitation (UNICEF/WHO, 2017). In urban areas, 85% of the population used improved sanitation facilities. In contrast, in rural areas, 73% of the population (7 out of 10 people) lacked improved sanitation facilities, and 76% (7.6 out of 10 people) still defecated in the open (UNICEF/WHO, 2017). Regarding persons who practiced open defecation because they lacked access to sanitation, the highest percentages were observed in Ghana and Nigeria (31% in rural areas and 7–9% in urban areas) (UNICEF/WHO, 2017).

Out of the ten nations surveyed by the JMP (WHO/UNICEF 2015), fewer than 95% of the population had access to handwashing facilities at home with soap and water. The country population with the highest percentage was Burundi (95% and 79%). Rural and urban areas have limited services without water or soap and less than 20% of no hygiene facilities at home. On the other hand, the lowest hygiene washing facilities were in Cameroon and Rwanda (5–10%) in their rural and urban areas with limited services with soap and water and no hygiene facilities at home. Because the availability of a handwashing station with soap and water was introduced as a proxy for excellent hygiene, it suggests that hygiene is low in poor, moderately poor, and absolutely poor populations in SSA countries (UNICEF/WHO, 2017).

3 Material and methods

3.1 Description of the study area

SSA comprises 46 African countries and island states but excludes the northern African countries. The latitude and longitude of Africa lie at 9.1021° N and 18.2812° E. It spans nearly 30.2 million square kilometers (11.7 million square miles), accounting for over one-fifth of its land area. The population of these countries living in extreme poverty is growing faster. More than 50% of the people in Central Africa live below the poverty line (United Nations Economic Commission for Africa (UNECA, 2017). A total of 10 countries in SSA were used as case studies in the current study (see Fig. 1), namely South Africa, Central Africa, East Africa, and West Africa regions. The countries were categorized as poor (Kenya, Rwanda, and South Africa), moderately poor (Cameroon, Ghana, and Nigeria), and absolutely poor (Burundi, Central African Republic, DRC, and Malawi). Multiple databases were accessible for this population country; thus, the most recent data surveys were used (UNICEF/WHO, 2017), which Fig. 1 gives detailed information on the countries included in this study and the year of data available.

Selected countries in sub-Saharan African in study.

- **Poor population**: South Africa, Rwanda, Kenya.
- **Moderately poor population**: Cameroon, Ghana, and Nigeria.
- **Absolutely poor population**: Burundi, Central Africa Republic, Democratic Republic of Congo, Malawi

3.2 Source and data analysis

More than half of the world’s absolutely poor population, who do not have access to clean water, basic sanitation, and hygiene facilities, live in SSA. Using SSA statistics from 2015 to 2020, the database consists of 10 selected countries in SSA: poor, moderately poor, and absolutely countries (as stated above).
The status and progress of WASH services in ten selected SSA countries were extracted and analyzed for the joint monitoring program report data (JMP, 2019). The extracted data were presented and further analyzed using percentages ranging from the years 2000 to 2017. Data for the total population from the selected 10 SSA countries extracted from the world data were analyzed to determine the population growth and forecast by 2030. Microsoft Excel 2019 was used to interpret all data analysis. Summary statistics of the variables within a primary central location and dispersion measures were obtained, presented, and examined. WASH services’ progress was analyzed using the UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (WHO, 2022). The GLAAS 2018–2019 analysis used countries that reported progress that focuses on targets of well-managed services for urban drinking water and marks the primary or limited level for urban sanitation (WHO, 2022). These were the service levels for which the most data were available. Of the ten countries used in this study, only five SSA population countries (Burundi, Cameroon, DRC, Ghana, and Malawi) reported a population country survey on current service levels. A review of related literature, including peer-reviewed journals, conference proceedings, textbooks, commissioned studies, and the internet, was used to obtain additional information for this study.

Fig. 1 Map of the selected study countries in sub-Saharan Africa (Mzuza et al., 2019)
3.2.1 Population growth

Excel 2019 was used to measure the urban–rural population from 2015 to 2019 of the selected ten countries from the population in SSA. These selected populations were classified as poor (Kenya, Rwanda, and South Africa), moderately poor (Cameroon, Ghana, and Nigeria), and absolutely poor populations (Burundi, Central African Republic, DRC, and Malawi) to project the population growth from 2020 to 2030/2035.

3.2.2 Statistical analysis

All statistical analyses were performed in Stata Corp 2019 (Stata Statistical Software: Release 16. College Station, TX: Stata Corp LLC). The studies were performed using Microsoft Excel, Pearson correlation, and regression analysis. Pearson’s correlation coefficient measures the degree of association between two continuous variables and how closely theory is related. The ordinary correlation matrix will specify the degree of multicollinearity between the variables under consideration before the measurement is taken. The Statistical Package for Social Sciences (SPSS), version 20, analyzed the regression results.

3.2.3 Mathematical modeling of sanitation success in sub-Saharan African countries

3.2.3.1 Theoretical modeling  Assuming a settlement in the SSA region has a total population of \( P(t) \) at the time \( t \), following the classification of how to determine the success of sanitation in the area. The authors divided the entire population into three groups based on income group classification: The first group consists of people who use improved sanitation (users of modern toilets); the second group consists of people who have access to unimproved sanitation (pit latrines); and the third group consists of people who have no facilities (open defecation). The first group consists of people who use improved sanitation (with limited facilities) and modern toilet users who are not shared with other households. This income group of people was named \( C_1(t) \). The second income group was the population using unimproved sanitation (pit latrines) without a slab or platform, hanging toilets, or bucket latrines. This income group of people is named \( C_2(t) \). The third income group was the population with no facilities, that is, those that defecate in open spaces (disposal of human feces in fields, bushes, forests, open areas of water, beaches, and other open spaces or with solid waste), and this income group was named \( C_3(t) \).

This section aims at determining the success of sanitation services in SSA countries by 2030. The sanitation service level data were collected from a household survey from the joint monitoring program (UNICEF, 2019a). Data were collected from 2000 to 2017. By demonstrating the variation of these income groups as functions of time, some mathematical equations had to be applied by using a hypothetico-deductive model that reflects a real-world scenario with some limits. To construct this model, the authors consider \( \Lambda \) a recruiting parameter, also known as birth rate, \( \beta \) a probability of transmission of the individuals using modern toilets, \( k_1 \) a transmissibility multiple of individuals using unimproved toilets, \( k_2 \) a transmissibility multiple of individuals using open-pit latrines, and \( \mu \) a natural death rate. The open-pit latrine users could use modern and unimproved toilets at a rate of \( \delta_1 \) and \( \delta_2 \), respectively. Modern toilet users used unimproved toilets at a rate of \( \delta_3 \). Modern toilet users (improved sanitation) used open-pit
latrines at a rate of \( \delta_4 \). The users of the unimproved toilets used modern toilets at a rate of \( \delta_5 \) and the unimproved users used to open-pit latrines at a rate of \( \delta_6 \).

A mathematical model associated with the sanitation success scenario is provided in Eqs. 1–2:

\[
\frac{dP}{dt} = \Lambda - \beta (C_1 + k_1 C_2 + k_2 C_2) P - \mu P
\]
\[
\frac{dC_1}{dt} = \beta C_1 P + \delta_1 C_3 - \delta_3 C_1 - \delta_4 C_1 + \delta_5 C_1 - \mu C_1
\]
\[
\frac{dC_2}{dt} = \beta k_1 C_2 P + \delta_2 C_3 + \delta_3 C_1 - \delta_5 C_1 - \delta_6 C_2 - \mu C_2
\]
\[
\frac{dC_3}{dt} = \beta k_2 C_3 P - \delta_1 C_3 - \delta_2 C_3 + \delta_4 C_1 + \delta_6 C_2 - \mu C_2
\]

\[
\left\{ \begin{array}{l}
\frac{P_{n+1} - P_n}{\Delta t} = \Lambda - \beta (C_{1,n} + k_1 C_{2,n} + k_2 C_{2,n}) P_n - \mu P_n \\
\frac{C_{1,n+1} - C_{1,n}}{\Delta t} = \beta C_{1,n} P_n + \delta_1 C_{3,n} - \delta_3 C_{1,n} - \delta_4 C_{1,n} + \delta_5 C_{1,n} - \mu C_{1,n} \\
\frac{C_{2,n+1} - C_{2,n}}{\Delta t} = \beta k_1 C_{2,n} P_n + \delta_2 C_{3,n} + \delta_3 C_{1,n} - \delta_5 C_{1,n} - \delta_6 C_{2,n} - \mu C_{2,n} \\
\frac{C_{3,n+1} - C_{3,n}}{\Delta t} = \beta k_2 C_{3,n} P_n - \delta_1 C_{3,n} - \delta_2 C_{3,n} + \delta_4 C_{1,n} + \delta_6 C_{2,n} - \mu C_{2,n}
\end{array} \right.
\]

A conceptual model depicting such a situation is presented in the chart flow (Fig. 2). Equation 1 can be discretized as follows:

The above chart will then provide numerical simulations for a given set of collected data from real-world situations. The numerical simulations are depicted in Fig. 2. To achieve this, we consider the following parameters and initial conditions: \( \beta = 0.05, k_1 = 0.04, \lambda = 2, \mu = \frac{1}{70 \times 365}; \delta_1 = 0.04, \delta_2 = 0.1, \delta_3 = 0.01, \delta_4 = 0.03, \delta_5 = 0.03, \delta_6 = 0.05, k_2 = 0.03; C_1(0) = 40, C_2(0) = 20, C_3(0) = 10 \)

**Fig. 2** A chart flow explaining the possible dynamics of toilet use within an SSA settlement
4 Results

4.1 Population growth and prediction

One of the main difficulties in achieving SDG 6 in clean water and adequate sanitation by 2030 is the projection of rapid population growth in SSA countries, especially those in Central Africa, Eastern Africa, Western Africa, and Southern Africa. Based on our study, countries from the SSA region were divided into three groups, namely income groups as poor population (Kenya, Rwanda, and South Africa), moderately poor (Cameroon, Ghana, and Nigeria), and absolutely poor population countries (Burundi, Central African Republic, DRC, and Malawi). These countries project a growing trend in urban and rural population growth in SSA, presented graphically in Fig. 3.

Figure 3 shows a sharp increase in the growing population residing in urban and rural areas in developing countries (Kenya, Rwanda, and South Africa) compared to the small population living in the moderately poor population (Cameroon, Ghana, and Nigeria). In contrast, the least growing population was the absolutely poor population (Burundi, Central African Republic, DRC, and Malawi).

Poor, moderately poor, and significantly developing countries have maintained a steady increase over the 15 years projected. For instance, in Fig. 3a, the rural population of the poor countries (Kenya, Rwanda, and South Africa) had grown from 21.6 million in 2015, 23.1 million in 2020 to 18.9 million in 2020, and are predicted to grow to 25.8 million in 2029, and 27.7 million in 2035. On the other hand, the urban population of poor countries (Kenya, Rwanda, and South Africa) had a sharp increase from 17.1 million in 2015 to 18.1 million in 2020 and stood at 19.8–19.9 million in 2020–2021. The trend analysis showed a projected increase from 20.8 million in 2024 to 25.9 million in 2035 (Fig. 3a). For moderately developing poor countries (Cameroon, Ghana, and Nigeria) (Fig. 2b), the increase in the urban and rural population growth shares a similar point in 2016, with around 39.8 million. Furthermore, the moderately poor urban population was projected to increase from 46 million in 2020 to 76 million in 2035. Compared to the rural poor countries (Kenya, Rwanda, and South Africa), which grew in the opposite direction, from 2017 to 2020 (40 million) and projected to increase between 41 and 46 million from 2020 to 2035, then raise further 47 million in 2035. The absolutely poor population countries (Burundi, Central African Republic, the Democratic Republic of the Congo, and Malawi) and the poor countries increase in similar directions from 2015 to 2020. For instance, the rural population of the poor countries increased slightly from 67 million in 2015 to 76 million in 2020 and was projected to expand to 10 million between 2033 and 2035. Figure 3c shows the same steady increase from 2015 to 2020 and was projected for 2030 (23 million, 27 million, and 43 million, respectively) for the urban population of the poor countries (Kenya, Rwanda, and South Africa).

4.2 Statistical analysis

Tables 1 and 2 provide the statistical results of the Pearson correlation and regression analyses for ten selected countries in SSA. A strong positive correlation exists between the three population groups: poor, moderately poor, and absolutely poor, respectively. The results demonstrate short- and midterm predictions with strong comonotonic dynamics of change. Perhaps the relatively small sample size of six years of actual data
Fig. 3  Trends in rural and urban population growth of selected countries; 2a—poor, 2b—moderately poor, and 2c—absolutely poor population in sub-Saharan African countries. Note URP: urban population growth; RUP: rural population growth; LB: lower boundary; UP: upper boundary
Table 1  Statistical determinants of water, sanitation, and hygiene success in sub-Saharan African population countries

Pearson correlation

| Poor population | Moderately poor population | Absolutely poor population |
|-----------------|----------------------------|---------------------------|
|                 | Urban | Rural | Urban | Rural | Urban | Rural |
| Urban           | 1     |       | Urban | 1     | Urban | 1     |
| Rural           | 0.999,652 | 1     | Rural | 0.999,414 | 1     | Rural | 0.999,542 | 1     |

Table 2  Regression summary for the selected sub-Saharan population countries

Regression analysis

| Model                                | Standard error | P-value | t-Stat | Adjustable R² | Regression coefficients | F-value |
|--------------------------------------|----------------|---------|--------|---------------|-------------------------|---------|
| Poor population                      |                |         |        |               |                         |         |
| Urban population growth              | 2,006 E03      | 2.22E-09| 2.28E02| 9.99 E-01     | 4.575 E05               | 5.200 E04|
| Rural population growth              | 2.665 E03      | 3.63E-08| 1.13E02| 9.99 E-01     | 3.021 E05               | 1.28E04|
| Moderately poor population           |                |         |        |               |                         |         |
| Urban population growth              | 1,574 E04      | 4.33E-08| 1.08E02| 9.99 E-01     | 1.708 E06               | 1.17E04|
| Rural population growth              | 3.087 E03      | 2.40E-08| 1.26E02| 9.99 E-01     | 3.902 E05               | 1.597 E04|
| Absolutely poor population           |                |         |        |               |                         |         |
| Urban population growth              | 1.97 E03       | 1.1E-06 | 4.8E01 | 9.97 E-01     | 9.515 E-04              | 2.309 E03|
| Rural population growth              | 9.10 E02       | 6.18E-09| 1.76E02| 9.99 E-01     | 1.606 E-05              | 3.116 E04|

Regression analysis

| Poor population                      |         |         |         |         |         |         |
|--------------------------------------|---------|---------|---------|---------|---------|---------|
| Urban population growth              | 9.99 E01| 9.99 E-01| 4.519 E05| 4.630 E05| 4.519E05| 4.63 E05|
| Rural population growth              | 9.99 E01| 9.99 E-01| 3E +05  | 3.095E05 | 2.947E05| 3.095 E05|
| Moderately poor population           |         |         |         |         |         |         |
| Urban population growth              | 9.99 E-01| 9.99 E-01| 1.66 E-06| 1.751 E03| 1.664 E06| 1.752 E06|
| Rural population growth              | 9.99 E-01| 9.997 E-01| 3.82 E-05| 3.987 E05| 3.816 E05| 3.987 E05|
| Absolutely poor population           |         |         |         |         |         |         |
| Urban population growth              | 9.99 E-01| 9.98 E-01| 1.581 E05| 1.632 E05| 1.581 E05| 1.632 E05|
| Rural population growth              | 9.99 E-01| 9.99 E-01| 8.965 E04| 1.006 E05| 8.965 E04| 1.0064 E05|
did, to a certain extent, induce redundancy in the correlation and regression analysis. The robust correlation coefficients for all values above 98% can be seen as indicators (see Tables 1 and 2). However, it needs to be considered that the analyses of urban and rural population groups are subgroups of a single original population, as evidenced by the Kruskal–Wallis test. The high coefficient values among the rural and urban categories, considered across various groups, were expected when considering that the correlation values among the overall populations of the different countries were equally very high, with a minimum of 94%.

4.3 Progress needed to achieve national water hygiene and sanitation services

The selected SSA countries reported progress on targets for securely managed portable water services and essential or restricted urban–rural sanitation and hygiene targets. These were the service levels for which the most data were available. Between 0.1 and 9% per year is the average annual rate of progress required to deliver safe urban drinking water supplies (Fig. 4a). The current maximum annual rate of progress, by contrast, is 2.7% age points every year (World Bank, 2016). Only nine countries in the world

![Fig. 4 Progress required on urban drinking water, sanitation, and hygiene to achieve the national target for essential and limited services in sub-Saharan African countries. Orange is the service reported Green is the national service for urban drinking water. Notes The percentages in parentheses after the country names indicate the annual rate of change required to meet the target. Thus, the chart shows the more recent urban sanitation services estimate reported in the JMP (44% in 2015). It was also not established in South Africa, indicating 93% urban sanitation services for 2017, exceeding its 2019 target of 90%. Source: UNSD (2019); WHO (2022)
have attained annual rates of a change greater than 1% (Khabarhub, 2019). Only two of the ten countries studied, DRC (8.3%) and Kenya (3.3%), need to enhance service delivery by more than 2.7% age points per year to achieve the safety-managed urban portable water service target. Only three of the ten nations in SSA, namely Ghana (2.4%), Kenya (3.3%), and DRC (8.3%), have targets for essential or limited portable water services. Due to the minimal number of countries with available data, no analysis was carried out. Some countries wish to achieve universal benefits in response to a question in the GLAAS nation survey on reaching people living in poverty. For example, DRC aims to provide 100% service delivery in urban and rural areas by 2030. The objectives of the other selected countries were more noticeable. Kenya aims to provide 2.8 million people with safe water by 2030 (UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water, 2019).

Five out of ten selected nations with targets that measure basic or limited sanitation facilities services, namely Burundi, Cameroon, DRC, Ghana, and Malawi (at least 50%), can provide current progress data toward their goal (see Fig. 4b). The annual rate of change required to achieve the goal of the national service delivery for basic sanitation was projected to be between 3 and 10%. Among the countries were Burundi (6.3%), Cameroon (9.0%), DRC (9.8%), Ghana (6.3%), and Malawi (3.8%). The most effective annual rate of change between 2000 and 2017 was 2.9% age points per year, with 22 countries achieving rates of change of more than one percentage point per year (UNICEF/WHO, 2019). Completed by Cambodia between 2000 and 2017 for access to the basic urban sanitation, five out of ten nations must increase services by more than 2.9 percentage points per year to achieve the national urban services goal for primary and rural/urban sanitation services. The most considerable annual rate of change between 2000 and 2017 was 2.9%; nevertheless, around 22 countries worldwide have previously attained > 1% point each year (UNICEF/WHO, 2019). None of the ten selected countries needs increased services per year to fulfill their national targets for inadequate and essential sanitation services.

Figure 4b illustrates which countries have achieved their primary and limited sanitation services targets. Malawi and Ghana intend to attain a national aim of 100% sanitation service in urban–rural areas by 2030. In contrast, according to the data, Nigeria only desires to achieve a 100% sanitation service in its urban zones. On the other hand, Ghana and Malawi have established an elimination of open defecation by 2030, based on sanitation service improvements in rural and urban regions.

The SDGs have identified hygiene monitoring as a new frontier, closely linked to health care and sanitation regarding hygiene services. Only three of the ten countries with essential hygiene targets, namely Burundi, Ghana, and Malawi, provided data on current services needed to reach the national hygiene target. Figure 4c compares reported population country hygiene services to national goals. In these three countries, the pace of improvement necessary to meet minimum hygiene standards varies from 1% age point to as much as 21% age point every year. It is impossible to compare earlier development rates to the rates required to accomplish hygiene targets because hygiene indicators were not recorded as part of the MDGs. The annual rate of advancement necessary to achieve primary hygiene standards ranges from 1 to 21%. Malawi’s national hygiene aim is to achieve a 100% sanitation services in urban and rural regions by 2030. On the other hand, Burundi aspires to achieve 100% services in major cities by 2030.

WHO/UNICEF (2015) defined two crucial goals for WASH in healthcare facilities. The first goal is to have at least essential WASH services in 60% of all healthcare institutions globally and in each SDG region by 2022, with a goal of 100% by 2030. The
second global aim for 80% of nations to attain more excellent WASH services in healthcare institutions by 2030 in countries where essential services have already been delivered. According to the current survey data, only 47 nations reported having national targets for drinking water, sanitation, and hygiene in healthcare institutions, five of which are from the study’s nations (Burundi, DRC, Ghana, Malawi, and Nigeria). Some of these countries have set universal WASH services goals in healthcare facilities. Burundi, for example, wants all healthcare facilities to have soap-dispensing hand-washing equipment by 2030. Other countries have interim plans that may be updated or modified throughout the SDGs. In a few nations, targets have been established at 100% services in brief periods (2–3 years), implying that reaching targets would necessitate an increase of 30 to 40 percentage points every year (UNICEF/WHO, 2019).

4.4 Numerical simulation

The numerical simulations are presented as a function of time in Figs. 5a, b and c using theoretical parameters. The income group C1 (t) graph shows an exponential increase for modern latrine users from zero to ten. From 10 to 30, the chart shows a decline in numbers, and from 30 to 100, there is a linear increase in numbers. The linear increase can also be due to a linear increase in the total population of a given region. In the last decade, the total population is also increasing linearly within the SSA region. This theoretical simulation shows that the number of modern toilet users was growing proportionally.

![Fig. 5 Prediction of accumulative numbers of the population; 3a. using modern toilets; 3b. unimproved sanitation using pit latrines without slab or platform, 3c. using open-pit latrines (no sanitation services)](image-url)
to the population increase within this region. However, this linear increase does not show any improvement in annual rates of change. The $C_2(t)$ and $C_3(t)$ graphs significantly increase from zero to 100. However, the population was growing linearly. The income group of unimproved latrines and open-pit latrine users were still increasing; this increase can be justified by many factors, such as population growth and the percentage of unemployment among teenagers.

5 Discussion

We analyzed the expanding population, state, and sources of WASH and the progress made so far to accomplish the national target by 2030 by determining the success of WASH in SSA nations (poor, moderately poor, and absolutely poor populations). Growing populations in rural–urban areas in SSA countries were projected and forecasted for the near future. Generally, population groups in SSA exhibit exciting dynamics in terms of growth. In poor countries, the rural population were larger than the urban population. Nonetheless, the urban population grows steadily faster than the rural population. Unlike poor, moderately poor populations have a larger urban population than the rural population; the urban population appears to grow faster than the rural population, comparable to those in poor countries. On the other hand, the rural population growth rate in moderately poor populations was smaller than in poor countries. Consequently, the population size gap between urban and rural populations were more significant for moderately poor populations and increasing faster.

Population dynamic predictions for poor countries suggest a closing size gap between rural and urban populations, with the urban population overtaking the rural population by 2040. Projections foresee opposite dynamics for moderately poor populations on the same 20-year time horizon. The urban population already forms the larger group, and the size gap with the rural population was set to widen further. The migratory flux between rural and urban people accounts for this state’s poor and moderately poor population. In absolutely poor population countries, the dominant population group was rural. Suppose the two distinct groups remain on the same size scale for poor and moderately poor countries. In that case, it is a 3:1 scale for the rural to urban population is absolutely poor population countries. The change dynamics between the two groups mimic an equal growth rate and an almost parallel size gap for the 20-year time horizon predictions; otherwise, a slightly increasing gap on that timeline. By 2030–2035, the urban population in poor, moderately poor, and absolutely poor regions in SSA countries will be around 65 million, 25 million, and 10 million, respectively.

Statistical summaries of the growing population were analyzed using Pearson and correlation analyses. Based on our findings, the statistical analysis shows a close relationship between regression lines slopes, and Pearson correlation coefficients will also justify the excellent R-squared values observed. The coefficients of determination for urban population and rural population across different countries group indiscriminately poor countries (South Africa, Rwanda, and Kenya), moderately poor countries (Cameroon, Nigeria, and Ghana), and absolutely poor countries (Burundi, Central African Republic, DRC, and Malawi) are all 95%. The indication was that the regression covariates explain most variations in the response population for all categories. P-values for all regression lines slopes for all other prediction equations in all the regression models

Springer
were very close to zero. This result shows that all slope parameters were significant. The explanatory variables in all the models play an essential role in capturing changes in diverse population groups and overall, as indicated earlier. However, the exceptionally high R-squared values can postulate overfitting and other issues with the regression models. However, the uniformity of the population from which the rural and urban analytical groups were extracted, the direct relation between slope coefficients and equally high original population correlation coefficients, and the relatively more minor data sample may also explain and justify the excellent values. For the populations of poor countries, moderately poor countries, and absolutely poor countries, all models’ parameters were significant for the rural and urban populations. R-squared values showed that all covariates were responsible for all the variations in the response populations and have good predictive powers. The adequate information criterion scores also confirm this.

5.1 Theoretical modeling

Using the JMP and GLAAS program to determine the progress of urban drinking water, sanitation, and hygiene to achieve the SDG 6.1 and 6.2 by 2030, it was evident that considerable progress has been made so far in the five selected SSA countries where data were available. Most of these countries have achieved services for drinking water during the millennium goal in 2015. The rate of development predicted to obtain the national services for primary and limited sanitation ranges from 0 to 15% each year, with only Kenya aiming to meet the federal drinking water objective by 2030. In terms of urban and rural populations, only Malawi and Ghana have made headway toward achieving national sanitation services of 100% by 2030. The urban and rural people of the DRC are expected to have access to safe drinking water by 2030.

On the other hand, Burundi hopes to have handwashing equipment with soap in all healthcare facilities by 2030. Ghana’s goal of achieving 100% free open defecation by 2030 has only been surrogate. When it comes to hygiene facilities, the progress made so far in the ten selected SSA countries (poor, moderately poor, and absolutely poor countries) shows an insufficient provision to achieve WASH success over the seven years from 2000 to 2017. So far, the low progress makes it almost impossible for them to reach the national target by 2030 (UN-Water, 2019).

According to a similar study on integrated access to WASH services, the estimate for SDG services is quite low, at only 4%, with only 0.8% of people that were identified (Roche et al., 2017). An SSA 25-country study by Roche et al. (2017) indicated 147.8 million people do not have handwashing facilities, and 921.6 million do not have comprehensive sustainable development goals.

The Sanitation and Wastewater Atlas of Africa predicts an increase in population numbers up to 2065, with countries such as Gambia, Malawi, and Uganda having the highest population densities (PopulationPyramid.net, 2019). According to the Atlas, adequate water stress for all sector measures in developing nations in SSA was 2.9% in 2010 for South Africa and zero percent in 2010 for Rwanda and was expected to rise to 3.19% and 0.1% by 2040 (Luo et al., 2015). Rwanda indicated an average gain
of 3.5 percentage points each year in the share of the population utilizing safe drinking water. At the same time, the remainder of the poor countries (South Africa and Kenya) showed adequate drinking water services. Between 2000 and 2015, the population practicing open defecation increased by 3.4% in South Africa and 1.1% in Kenya. When it comes to handwashing facilities, the proportion of the people using on-premises handwashing facilities has increased by 0.3% in Kenya (2010–2015) and by 0.5% in Rwanda (2000–2015). Based on the handwashing facilities in South Africa, no outcomes were recorded (UNSD, 2019). Moderately poor countries such as Cameroon, Ghana, and Nigeria will have adequate water stress levels of 0.01% (Cameroon), 0.57% (Ghana), and 0.33% (Nigeria) by 2040. These figures are expected to rise to 0.57% in Ghana and 0.9% in Nigeria while remaining unchanged in Cameroon. Between 2000 and 2015, the population utilizing safe drinking water increased by 3–4% in Ghana and 2.5% in Nigeria, whereas Cameroon had no results (Luo et al., 2015). There has been a 0.1% (Cameroon), 1% (Ghana), and 1% (Nigeria) decline in the people performing open defecation every year from 2000 to 2015. Between 2000 and 2015, the proportion of the population using basic hygiene facilities on-premises increased by 0.1% in Cameroon, 2.9% in Ghana, and 0.5% in Nigeria (UNSD, 2019). In absolutely poor populations such as Burundi, Central African Republic, DRC, and Malawi, adequate water stress for all sectors was zero in 2010. It was expected to rise to 0.08 (Central African Republic, DRC, Malawi) and 0.3% (Burundi) by 2040 (Luo et al., 2015). The population consuming safe drinking water in the Republic of Congo increased by 2.4 percentage points from 2000 to 2015. However, no results were recorded for Burundi, the Central African Republic, or Malawi. From 2000 to 2015, the proportion of people using open defecation decreased by 0.2 percentage points per year in the Congo and 3.1 percentage points per year in Malawi. Burundi and the Central African Republic showed the opposite results. The population in the Central African Republic who practice open defecation increased by 0.5 percentage points every year on average from 2000 to 2015. In Burundi, the number of people who practice open defecation increased to 0.3% and then dropped to 0.2% per year from 2000 to 2015. Furthermore, there was an increase in basic on-premises handwashing facilities in Burundi (0.2%) and Malawi (2.3%) per year from 2000 to 2015. However, Central Africa has a one percentage point reduction, and no results were found for the DRC in the previous years (UNSD, 2019).

A similar prediction was observed during this study, where the selected ten countries—poor (Kenya, Rwanda, and South Africa); moderately poor (Cameroon, Ghana, and Nigeria); absolutely poor (Burundi, Central African Republic, DRC, and Malawi)—showed an increase in the progress trend of the total population up to 2035.

6 Implications and recommendations

6.1 Implications for water, sanitation, and hygiene and open defecation to public health and environmental health

The findings of this article have several consequences for WASH in SSA nations, both in terms of health and the environment. For example, the most common WASH-related diseases, killing approximately 1.7 million people each year in developing countries, with 90% of deaths occurring in children under the age of five, with moderately poor
and absolutely poor population countries in SSA accounting for a significant portion of these deaths (Mara, 2017). Humans, particularly children, require adequate WASH facilities to sustain a healthy lifestyle. Insufficient WASH facilities are prevalent in the study locations in SSA population countries, where WASH services are scarce in urban and rural regions. Inadequate WASH services lead to higher child mortality and morbidity, poor schooling, malnutrition, stunting, and other adverse effects (UNICEF, 2016). According to the study, the unsatisfactory state of WASH services in Malawi was also responsible for 11.4% of baby and child mortality due to diarrhea (WSP, 2012).

Similarly, WSP (2012) reported that over 121,800 Nigerians, including 87,100 children under five, die each year from diarrhea, with almost 90% of these deaths related to insufficient WASH services. Furthermore, poor sanitation is a contributory factor through its impact on malnutrition rates to other leading causes of child mortality, such as malaria and measles, according to the WSP paper (2012). Inadequate WASH services were highlighted as a significant factor in the Ebola outbreak in Guinea, Liberia, and Sierra Leone, according to a report by ACAPS (2015). The study found that the usage of contaminated water and widespread unsanitary conditions were significant contributors to the thousands of deaths before and during the Ebola outbreak. Inadequate WASH services, according to the report, would continue to be a barrier to recovery and growth in the medium to long term in both moderately poor (Cameroon, Ghana, and Nigeria) and absolutely poor population (is this related to a population of a country OR the country itself economically) countries (Burundi, Central African Republic, DRC, and Malawi). The link between poor sanitation (open defecation) and environmental and health problems is becoming more widely recognized. In Africa, one out of every five persons uses open defecation, which can aid the spreading of disease.

According to a study conducted by the United States Agency for International Development (USAID, 2017), open defecation is expected in rural areas of Burkina Faso, Ghana, and Niger, to contaminate drinking water sources. This improper sanitation had resulted in diarrhea outbreaks and children displaying signs of undernutrition, malnutrition, and stunting. Open defecation is undoubtedly the most inferior kind of sanitation with significant hygienic consequences. The persistent rise of open defecation in Nigeria is a sanitation catastrophe with serious environmental and health consequences, particularly considering the population’s fast-rising population and high population density. The activity pollutes the air with a foul odor and contaminates the local environment with human feces, including surface water, public places, roadsides, and railway lines. It also presents itself as flying toilets which are human excreta wrapped in plastic bags and thrown away indiscriminately. Open defecation, for example, pollutes beaches in Lagos and other Nigerian coastal cities, reducing their ability to attract local and foreign visitors (Abubakar & Dano, 2018). Surface water becomes contaminated with human excreta due to direct open defecation inside water bodies or drainage, exposing people to illness when they drink or swim in these waters.

Open defecation also affects the human capital of a population country’s workforce and hinders physical and cognitive development (Mara, 2017). Infectious excreta-related diseases such as typhoid fever, hepatitis, and diarrhea have been linked to open defecation. More symptoms have resulted in a massive health burden, including high rates of anemia, child stunting, and premature death, especially in children under the age of five (Gertler et al., 2015; Mara, 2017). Open defecation affects all community members by discharging pathogens into the environment (Gupta et al., 2014). Aside from the implications of poor WASH at homes and schools, healthcare facilities were unfortunately identified as hotspots for spreading WASH-related infections. According to the WHO/UNICEF (2015) report on
WASH in healthcare facilities in SSA’s moderately and significantly developing nations, many healthcare facilities lack access to water sources and sanitation facilities, regardless of how effectively they operate. The WASH services were unreliable and insufficient for the needs of patients, healthcare workers, and visitors in regions where they were available. According to estimates done in Africa, 15% of patients did get one or more diseases during their hospital stay due to poor WASH services in some healthcare institutions, which affect hundreds of millions of patients each year (Allegranzi et al., 2011).

Furthermore, it may discourage women from using such healthcare facilities for delivery or create delays in seeking care (Velleman et al., 2014), potentially encouraging home delivery with associated risks. The poor hygiene habits of birth attendants can raise the risk of COVID-19 infections, sepsis, and death in infants and mothers by up to 25%. However, many healthcare facilities in Africa lack essential water and sanitation services. With non-functioning latrines, people have little or no alternative but to defecate in their spaces (Velleman et al., 2014).

People with non-functioning latrines have little or no choice but to defecate in public places. As a result, policies must shift to empower households and communities, particularly those from the poor and moderately poor, low or middle income, to construct and operate their latrines. The federal and state governments must significantly fund the construction of latrines at homes and within communities beyond providing discounted toilet slabs (Velleman et al., 2014). Economically, better-off households can gradually construct individual latrines using building materials and low-cost technologies, as in the case of rural communities in Benin (Gross & Gunther, 2014). Installing in-home restrooms reduces open defecation rates by 30% in absolute countries (such as the Central African Republic, DRC, Mali, and Tanzania), thereby reducing the time and discomfort of using distant sanitation facilities or defecating in the open (Gertler et al., 2015). On the other hand, shared sanitation, such as community latrines, were more viable in many high-density, low-income, and squatter regions. Nigeria, as an example, can draw from several successful case studies in which community-managed initiatives resulted in higher-quality, better-designed latrines at lower unit costs in underdeveloped countries (Burra et al., 2003; Jewitt, 2011).

6.2 Recommendations

The following recommendations are suggested to improve the impact of WASH:

- Institutional capacity building and good governance;
- Funding (accountability and progress measurement);
- Public education; adaptation of appropriate technology;
- Focus on bridging the gap of existing disparities;
- Public education;
- Suitable technological transformation;
- A focus on closing the gap between current inequities;
- Addressing the needs of women, girls, and the disabled;
- Developing, harmonizing, and integrating multiple WASH policies; and
- Combating WASH sector corruption.
The most important of these strategies is political leadership responsible for establishing clear institutional responsibility, establishing sanitation budget lines, and ensuring that public sector agencies involved in health care, water resources, and utility services collaborate more effectively (Mara et al., 2010). Constructing latrines at the family and community level is critical for expanding sanitation services and eradicating open defecation, promoting a society’s socioeconomic growth (Park et al., 2016). Even though all households that practice open defecation live in rural areas, the government’s approach must be to extend sanitation services, focusing on installing public latrines in urban areas. Also, slums and squatter areas are frequently ignored even in urban regions (Abramovsky et al., 2016). In Africa, sanitation spending is strongly related to only prosperous urban communities, disregarding slums, squatter camps, and other areas. Investing in the latter will reduce open defecation over the long term (Galan et al., 2013).

Sanitation promotion is one of the successful projects undertaken by SSA countries, such as moderate developing countries, Nigeria and Ghana. Behavior change communication is an advanced task that aims to modify social mentalities and seeks attractive well-being routines through media, associations, and relational interaction in community-led total sanitation programs (Mara, 2017; Ngwu, 2017). Members of the community are recruited and trained to deliver campaign messages for behavioral change through house visits, meetings, rallies, telecommunications, social media, and other means (Gross & Gunther, 2014; Mara, 2017). While in Ghana, the involvement and training of leaders have resulted in significant decreases in open defecation (Crocker et al., 2017). Due to limited space, household-level sanitation is impossible in urban slums, home to 881 million people (30% of the urban population in developing countries, up to 56% in SSA) (UN-Habitat, 2015). However, safely managed, shared sanitation is a viable and tested sanitation solution in low-income, high-density metropolitan settings to replace open defecation (Burra et al., 2003; Mara, 2018).

Community-led total sanitation and behavior change communication are also recommended as suitable adjuncts to sanitation marketing (Devine & Kullmann, 2011). In contrast, community-led total sanitation focuses on changing community practices; behavior change communication focuses on modifying individual or family behaviors. As a result, behavior change communication can support and enhance community-led total sanitation in persuading people to become and stay open defecation-free.

6.3 Limitations

In a multivariate model, only two important variables, namely access to a toilet and the availability of soap for handwashing, were utilized to assess the impact of sanitation on poor, moderately poor, and absolutely countries in SSA. The statistics collected information regarding the availability of a toilet in a household. It did not suggest that women in those homes used it, as some earlier researchers have found that people choose open defecation even if they have access to a toilet within their home (Bartram & Cairncross, 2010). Despite the numerous consequences of inadequate WASH in poor, moderately poor, and absolutely countries in SSA, this study had several limitations, which can be human- and natural-related. During this investigation, the biggest human-related concern was the fast population expansion. Most countries in SSA are experiencing rapid population growth, which exacerbates the region’s WASH concerns. Bartram and Cairncross (2010) emphasized the relevance of population growth in attaining the Millennium Development Goal for WASH population growth, which somewhat offsets the increase of persons having
access. Even if the goal is met and the proportion of unserved people is cut by half, neither the number of unserved people nor the disease’s global impact will be cut by half. This indicates that high population growth in SSA could be a significant impediment to provide appropriate WASH services to all by 2030. According to Mara et al. (2010), the lack of national policies is a fundamental barrier to sanitation success. Governments in general, and healthcare ministries in particular, cannot play crucial roles as facilitators and regulators of sanitation without sufficient regulations.

In addition, the following are other human-related threats:

- Depletion of water resources through pollution.
- Deforestation and environmental degradation.
- Insufficient investment in resource evaluation, protection, and development.
- Corruption in the WASH sector.
- Poor infrastructure provision (electricity).
- Inadequate national water supply and sanitation policies.
- Lack of preventive maintenance of WASH facilities.
- Cultural barriers and technical challenges.

Conversely, human-related threats, for instance, significant climate and rainfall variability in SSA regions, exacerbated by climate change, resulted in desertification and drying up of some water bodies (such as Lake Chad in Central Africa), causing an increasing water shortage. Natural restrictions have made it more difficult for national governments in SSA to provide effective WASH services. The inability to respond to natural disasters is due to a lack of governance and institutional capacity to ensure that all people access basic WASH services. Reconcile competing interests, and meet the long-term requirements of the poor populations (Global Public Policy Network on Water Management, 2019).

7 Conclusion

In the current study, the author took a methodological approach while focusing on WASH gains to increase the understanding of SSA sanitation services. It was evident from the literature reviewed in the current study that adequate WASH services are necessary for promoting good health and socioeconomic development. Unfortunately, WASH services are still inadequate in almost all the countries in SSA, as the region failed to meet the MDG targets for WASH services. Considering the current WASH status in the SSA region and the ambitious SDG monitoring indicators for WASH services, it will require collaborative efforts of all stakeholders to bridge the deficit gaps of WASH in most countries in the region. Achieving the SDG 6.1 and 6.2 targets in sanitation success, several studies have shown that adequate WASH is necessary for promoting good health and socioeconomic development.

For the ten selected SSA countries used in the study, a WASH statistical analysis was done on the growing population in SSA countries and empirical modeling to improve water hygiene and sanitation and eliminate open defecation. The statistical results showed a close relationship between regression line slopes and Pearson correlation coefficients, which also justified the excellent R-squared values and p-values. All predictions in the regression models were very close to zero. This showed that all slope parameters were significant. As pointed out earlier, the explanatory variables (urban–rural population) in all the models
played an essential role in capturing changes in diverse population groups and overall interventions. The modeling analysis provided evidence that poor sanitation was associated with a higher risk of open defecation diseases. While it is intuitive to expect that various categories of poverty are related to poor sanitation practices driving open defecation, we cannot rule out additional drivers. Our results demonstrated that poor sanitation practices (open defecation) were associated with these outcomes and were independent of poverty. Our results supported the need to assess human behavioral mechanisms by which limited access to improved sanitation leads to open defecation diseases. Progress toward the WASH target aim is still insufficient in virtually all ten selected countries, as these countries failed to reach the water and sanitation targets of the MDGs. Given the existing state of WASH in the SSA region and the considerably more ambitious monitoring metrics of the SDGs for WASH services, all stakeholders will have to make concerted efforts to close the WASH deficit gaps in most of the region’s countries. Meeting the SDGs for WASH services will maximize the inherent benefits of appropriate WASH services in the SSA region and raise living standards. Despite the highlighted populations that have delayed improving WASH services to the people in the selected countries, adopting a comprehensive, inclusive, and integrated WASH strategy that fits the peculiarities of each population country could make a tremendous positive difference toward the attainment of the SDGs for WASH in SSA. Meeting the SDGs for WASH services will help maximize the inherent benefits of adequate WASH services in the region and enhance the people’s standard of living.

The elimination of open defecation is primarily a complex sociocultural and sociopolitical task. Open defecation is not a major technical or financial challenge with community-led total sanitation. Because of its ability to consider all types of sanitation and handwashing facilities, it does not necessitate the development of new technologies specifically for eliminating open defecation, as several have suggested. Sanitation promotion and behavior change communication are precious techniques that SSA governments should apply for the best results to eliminate open defecation.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10668-022-02620-z.

Acknowledgements The authors would like to thank the reviewers for helping to improve the manuscript—a word of thanks to Mr. Clever Mafuta for assisting with the study’s locations.

Author contributions EA was involved in investigation, formal analysis, writing, and interpretation of results. PJO was responsible for supervision, writing a review, and advice.

Funding Not applicable.

Availability of data and materials The datasets used and analyzed are available from the corresponding author. And most of them have already been provided.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Human and animal rights There was no human body or parts used during the research.
References

Abramovsky, L., Augsburg, B., Flynn, E., & Oteiza, F. (2016). Improving CLTS targeting: Evidence from Nigeria. https://ifs.org.uk/uploads/publications/bns/BN183.pdf

Abubakar, I. R., & Dano, U. L. (2018). Socio-economic challenges and opportunities of urbanization in Nigeria. In U. Benka & I. Benka (Eds.), Urbanization and its impact on socio-economic growth in developing regions (pp. 219–240). IGI Global.

ACAPS. (2015). WASH in Guinea, Liberia, and Sierra Leone: The impact of Ebola. https://www.acaps.org/sites/acaps/files/products/files/1_wash_in_guinea_liberia_and_sierra_leone_2015.pdf

Acuto, M., Parnell, S., & Seto, K. C. (2018). Building a global urban science. Nature Sustainability, 1, 2–4. https://doi.org/10.1038/s41893-017-0013-9

Africa, W. (2016). Research, 103, 435–443.

Allegranzi, B., Nejad, S. B., Combescure, C., Graafmans, W., Attar, H., Donaldson, L., & Didier, P. (2011). Burden of endemic health-care-associate infection in developing countries: Systematic review and meta-analysis. Lancet, 377, 228–241. https://doi.org/10.1016/s0140-6736(10)61458-4

Bartram, J., & Cairncross, S. (2010). Hygiene, sanitation, and water: Forgotten foundations of health. PLoS Medicine, 7(11), e1000367. https://doi.org/10.1371/journal.pmed.1000367

Bloch, R., Fox, S., Monroy, J., & Ojo, A. (2015). Urbanisation and urban expansion in Nigeria. Urbanisation Research Nigeria (URN) research report. London: ICF International. https://core.ac.uk/download/pdf/96701289.pdf

Burra, S., Patel, S., & Kerr, T. (2003). Community-designed built and managed toilet blocks in Indian cities. Environment and Urbanization, 15(2), 11–32.

Coffey, D., Gupta, A., Hathi, P., Khurana, N., Spears, D., Srivastav, N., & Vyas, S. (2014). Revealed preference for open defecation: Evidence from a new survey in rural North. Economic and Political Weekly, 49(38), 43–45.

Jewitt, S. (2011). Geographies of shit: Spatial and temporal variations in attitudes towards human waste. Progress in Human Geography, 35(5), 608–626. https://doi.org/10.1177/0309132510394704

Khabarhub. Kathmandu, Nepal. 21 November 2019. Retrieved 30 November 2019

Lilford, R. J., Oyebode, O., Satterthwaite, D., Melendez-Torres, G. J., Chen, Y.-F., Mberu, B., Watson, S. I., Sartori, J., Ndugwa, R., Caiaffa, W., Haregu, T., Capon, A., Saith, R., & Ezeh, A. (2016). Improving the health and welfare of people who live in slums. Lancet, 389(10068), 559–570. https://doi.org/10.1016/S0140-6736(16)31848-7

Lopez, O., & Moloney, A. (2020). ANALYSIS–Coronavirus chases the slum dwellers of Latin America. Reuters. https://www.reuters.com/article/health-coronavirus-latam-idUSL8N2BA8G5

Luo, T., Young, R., & Reig, P. (2015). Aqueduct projected water stress country rankings. World Resources Institute. https://www.wri.org/publication/aqueduct-projected-water-stress-country-rankings

Mara, D. (2017). The elimination of open defecation and its adverse health effects: A moral imperative for governments and development professionals. Journal of Water, Sanitation and Hygiene for Development, 7(1), 1–12. https://doi.org/10.2166/washdev.2017.027
Mara, D., & Evans, B. (2018). The sanitation and hygiene targets of the sustainable development goals: Scope and challenges. *Journal of Water, Sanitation and Hygiene for Development*, 8(1), 1–16. https://doi.org/10.2166/washdev.2017.048

Mara, D., Lane, J., Scott, B., & Trouba, D. (2010). Sanitation and health. *PLoS Medicine*, 7(11), e1000363. https://doi.org/10.1371/journal.pmed.1000363

Milledge, D. G., Gurjar, S. K., Bunce, J. T., Tare, V., Sinha, R., & Carbonneau, P. E. (2018). Population density controls microbial pollution across the Ganga catchment. *Water Research*, 128, 82–91. https://doi.org/10.1016/j.watres.2017.10.033

Mzuza, M. K., Zhang, W., Kapute, F., & Wei, X. (2019). The impact of land use and land cover changes on the Nkula Dam in the Middle Shire River Catchment, Malawi. In A. Pepe, & Q. Zhao (Eds.), Geospatial analyses and Earth observation (Chapter 3). https://doi.org/10.5772/intechopen.86452

Ngwu, U. I. (2017). The practice of open defecation in rural communities in Nigeria: A call for social and behaviour change communication intervention. *International Journal of Communication Research*, 7(3), 201–206.

O’Reilly, K., Dhanju, R., & Goel, A. (2017). Exploring “the remote” and “the rural”: Open defecation and latrine use in Uttarakhand, India. *World Development*, 93, 193–205. https://doi.org/10.1016/j.worlddev.2016.12.022

Park, M. J., Clements, A. C. A., Gray, D. J., Sadler, R., Laksono, B., & Stewart, D. E. (2016). Quantifying accessibility and use of improved sanitation: Towards a comprehensive indicator of the need for sanitation interventions. *Scientific Reports*, 6, 30299. https://doi.org/10.1038/srep30299

PopulationPyramid.net. (2019). Population pyramids of the world from 1950 to 2100. https://www.populationpyramid.net/

Roche, R., Bain, R., & Cumming, O. (2017). A long way to go: Estimates of combined water, sanitation, and hygiene services for 25 sub-Saharan African countries. *PLoS ONE*, 12(3), 20173702. https://doi.org/10.1371/journal.pone.0171783

The Joint Monitoring Programme report, Progress on drinking water, sanitation and hygiene: 2017 update and Sustainable Development Goal baselines, United nation, www.washdata.org.

UN-Habitat. (2015). *Slum almanac 2015/2016: Tracking improvement in the lives of slum dwellers*. https://unhabitat.org/sites/default/files/documents/2019/05/slum_almanac_2015-2016_psup.pdf

United Nations Department of Economic and Social Affairs. (2015). *World population prospects: The 2015 revision – Data booklet*. United Nations Department of Economic and Social Affairs, Population Division.

United Nations General Assembly. (2015). The human rights to safe drinking water and sanitation (Document A/C.3/70/L.55/Rev.1, Nov 18). New York. https://digitallibrary.un.org/record/811980/files/A_C.3_70_L.55_Rev.1-EN.pdf

United Nations Children’s Fund. (2015). Progress on sanitation and drinking water: 2015 update and MDG assessment. https://www.unicef.org/reports/progress-sanitation-and-drinking-water

United Nations Children’s Fund. (2016). Strategy for water, sanitation, and hygiene, 2016–2030. Programme Division, New York. https://www.unicef.org/wash/files/UNICEF_Strategy_for_WASH_2016-2030.pdf

United Nations Children’s Fund and World Health Organization. (2017). Progress on drinking water, sanitation, and hygiene: 2017 update and SDG baselines. https://data.unicef.org/wp-content/uploads/2017/07/JMP-2017-report-launch-version_0.pdf

United States Agency for International Development. (2017). *Real impact: West Africa*. *West Africa water supply, sanitation, and hygiene program*. https://www.usaid.gov/sites/default/files/documents/1865/RI_WA_WASH_508.pdf

United Nations Economic Commission for Africa. (2017). Africa’s youth and prospects for inclusive development: Regional situation analysis report. https://www.ohchr.org/sites/default/files/Documents/Issues/Youth/UNEconomicCommissionAfrica.pdf

United Nations Statistics Division. (2019). SDG indicators. https://unstats.un.org/sdgs/indicators/database/UN-Water. (2015). Wastewater management: A UN-Water analytical brief. https://www.unwater.org/app/ uploads/2017/05/UN-Water_Analytical_Brief_Wastewater_Management.pdf

United Nations Children’s Fund and World Health Organization. (2019). *Progress on household drinking water, sanitation and hygiene 2000–2017: Special focus on inequalities*. United Nations Children’s Fund (UNICEF) and World Health Organization. https://www.unicef.org/media/55276/file/Progress%20on%drinking%20water,%20sanitation%20and%20hygiene%202000%20to%202017.pdf

Velleman, Y., Mason, E., Graham, W., Benova, L., Chopra, M., Campbell, O. M. R., Gordon, B., Wijesekera, S., Hounton, S., Mills, J. E., Curtis, V., Afsana, K., Boisson, S., Magoma, M., Cairncross, S., & Cumming, O. (2014). From joint thinking to joint action: A call to action on improving water, sanitation,
Assessment of water, sanitation, and hygiene target and…

and hygiene for maternal and newborn health. *PLoS Medicine, 11*(12), e1001771. https://doi.org/10.1371/journal.pmed.1001771

Water and Sanitation Program. 2012. Nigeria: Economic impacts of poor sanitation in Africa. https://www.wsp.org/sites/wsp.org/files/publications/WSP-ESINigeria-brochure.pdf

World Bank. (2003) World development report: Sustainable development in a dynamic world – Transforming institutions, growth, and quality of life. https://openknowledge.worldbank.org/handle/10986/5985

World Health Organization and United Nations Children’s Fund. (2015). *Progress on drinking water and sanitation: 2015 update* https://data.unicef.org/wp-content/uploads/2015/12/JMP_report_2014_webEng_100.pdf

World Health Organization and United Nations Children’s Fund. (2015). *Water, sanitation, and hygiene in health care facilities: Status in low- and middle-income countries and way forward.* https://apps.who.int/iris/bitstream/handle/10665/154588/9789241508476_eng.pdf

World Health Organization. (2015). *Key facts from JMP 2015 report.* https://www.who.int/water_sanitation_health/publications/JMP-2015-keyfacts-en-rev.pdf

World Bank. (2016). *Using performance-based contracts to reduce non-revenue water.* https://ppiaf.org/documents/3531/download

World Health Organization. (2017). *World health statistics 2017: monitoring health for the SDGs, sustainable development goals.* World Health Organization. https://apps.who.int/iris/handle/10665/255336. License: CC BY-NC-SA 3.0 IGO

World Bank. (2019a). *The World Bank in Gabon.* https://www.worldbank.org/en/country/gabon/overview

World Bank. (2019b). *World development report.* World Bank.

World Health Organization. (2022). *Water sanitation and health: GLAAS 2018/2019 cycle.* https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/monitoring-and-evidence/wash-systems-monitoring/un-water-global-analysis-and-assessment-of-sanitation-and-drinking-water/2018-2019-cycle

**Publisher’s Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.