SYSTEMATIC REVIEW

The nexus between improved water supply and water-borne diseases in urban areas in Africa: a scoping review [version 1; peer review: 2 approved]

Nyamai Mutono, Jim A Wright, Henry Mutembei, Josphat Muema, Mair L.H Thomas, Mumbua Mutunga, Samuel Mwangi Thumbi

1Wangari Maathai Institute for Peace and Environmental Studies, University of Nairobi, Nairobi, Kenya
2Washington State University Global Health Program - Kenya, Nairobi, Kenya
3Centre for Epidemiological Modelling and Analysis, University of Nairobi, Nairobi, Kenya
4Geography and Environmental Science, University of Southampton, Southampton, UK
5Department of Clinical Studies, Faculty of Veterinary Medicine, University of Nairobi, Nairobi, Kenya
6Institute of Tropical and Infectious Diseases, University of Nairobi, Nairobi, Kenya
7Paul G Allen School for Global Animal Health, Washington State University, Pullman, USA
8Institute of Immunology and Infection Research, University of Edinburgh, Edinburgh, UK

First published: 28 May 2021, 4:27
Latest published: 28 May 2021, 4:27
https://doi.org/10.12688/aasopenres.13225.1

Abstract

Background: The sub-Saharan Africa has the fastest rate of urbanisation in the world. However, infrastructure growth in the region is slower than urbanisation rates, leading to inadequate provision and access to basic services such as piped safe drinking water. Lack of sufficient access to safe water has the potential to increase the burden of waterborne diseases among these urbanising populations. This scoping review assesses how the relationship between waterborne diseases and water sufficiency in Africa has been studied.

Methods: In April 2020, we searched the Web of Science, PubMed, Embase and Google Scholar databases for studies of African cities that examined the effect of insufficient piped water supply on selected waterborne disease and syndromes (cholera, typhoid, diarrhea, amoebiasis, dysentery, gastroneteritis, cryptosporidium, cyclosporiasis, giardiasis, rotavirus). Only studies conducted in cities that had more than half a million residents in 2014 were included.

Results: A total of 32 studies in 24 cities from 17 countries were included in the study. Most studies used case-control, cross-sectional individual or ecological level study designs. Proportion of the study population with access to piped water was the common water availability metrics measured while amounts consumed per capita or water interruptions were seldom used in assessing sufficient water supply. Diarrhea, cholera and typhoid were the major diseases or syndromes used to understand the association between health and...
water sufficiency in urban areas. There was weak correlation between the study designs used and the association with health outcomes and water sufficiency metrics. Very few studies looked at change in health outcomes and water sufficiency over time.

**Conclusion:** Surveillance of health outcomes and the trends in piped water quantity and mode of access should be prioritised in urban areas in Africa in order to implement interventions towards reducing the burden associated with waterborne diseases and syndromes.

**Keywords**
water sufficiency, waterborne diseases, urban Africa, review

---

**Corresponding author:** Nyamai Mutono (mutono.nyamai@wsu.edu)

**Author roles:**
- **Mutono N:** Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing
- **Wright JA:** Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – Review & Editing
- **Mutembei H:** Methodology, Supervision, Writing – Review & Editing
- **Muema J:** Data Curation, Methodology, Validation, Writing – Original Draft Preparation, Writing – Review & Editing
- **Thomas MLH:** Investigation, Methodology, Validation, Writing – Review & Editing
- **Mutunga M:** Data Curation, Investigation, Validation, Visualization, Writing – Review & Editing
- **Thumbi SM:** Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing

**Competing interests:** No competing interests were disclosed.

**Grant information:** The author(s) declared that no grants were involved in supporting this work.

**Copyright:** © 2021 Mutono N et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

**How to cite this article:** Mutono N, Wright JA, Mutembei H et al. The nexus between improved water supply and water-borne diseases in urban areas in Africa: a scoping review [version 1; peer review: 2 approved] AAS Open Research 2021, 4:27 https://doi.org/10.12688/aasopenres.13225.1

**First published:** 28 May 2021, 4:27 https://doi.org/10.12688/aasopenres.13225.1
Introduction

The sub-Saharan Africa (SSA) has experienced the highest annual urban population growth rate (more than 3.5%) in the world\(^1\). However, the growth of urban infrastructure has been slower, leading to populations without access to adequate resources including water services, health facilities, and housing\(^2,3\).

Globally, it is estimated that one in every two people will be living in water stressed areas by 2025 increasing the challenge of water supply\(^4\). As of 2017, only half of the population residing in urban areas in SSA had access to improved water sources which included piped, boreholes, protected wells or springs, rainwater or packaged water\(^5\). However, going by The World Bank categorisation of piped water as the only major source of improved water in urban areas in SSA\(^6\), only 56% (230 million people) residing in urban areas in this region have access to clean water\(^7\).

More than half a million deaths in SSA have been attributed to diarrheal diseases, with water contamination being one of the key risk factors\(^8\). The global enteric multicenter study identified *Escherichia coli*, *Cryptosporidium*, *Aeromonas* spp, *Shigella* spp and *Entamoeba histolytica* to be associated with increased risk of death among children younger than 24 months with moderate-to-severe diarrhea\(^9\). Due to their high burden, several waterborne diseases including cholera, bloody diarrhea and typhoid are included in the Integrated Disease Surveillance Strategy used in most African countries to improve countries speed of detection and response to public health threats\(^10\).

The United Nations Sustainable Development Goals (SDGs) 3, 6 and 11 that focus on good health and wellbeing of populations; clean water and sanitation; and sustainable cities and communities directly or indirectly address this problem associated with rapid urbanisation in SSA\(^11\). The African Union Agenda 2063 aspires to have an African continent that is based on inclusive growth and sustainable development\(^12\). To reduce the burden of waterborne diseases in the context of an urbanising population, a good understanding of the relationship between water and these health outcomes is required.

Previous reviews have focused on water quality\(^13,14\), water availability\(^15,16\) and the reallocation of water from rural to urban regions in Africa\(^17\). Other reviews have also focused on the environmental determinants of waterborne disease outbreaks in Africa\(^18\), the link between waterborne diseases and water resource development in Africa\(^19\) and climate change globally\(^20\). To ensure a medium level of health concern, an access of at least 50 litres per person per day is required\(^21\). However, there is a gap on insufficient access to piped water (less than 50 litres per person per day) in urban areas in Africa and the association with waterborne diseases and syndromes in the African continent.

Here, we conduct a scoping review to assess the link between sufficient access to piped water supply and waterborne diseases and syndromes in African cities. Specifically, we answer the following questions: i) How has the relationship between waterborne diseases and piped water sufficiency been studied in Africa? ii) Are there under-utilised study designs, under-studied metrics of water sufficiency or under-studied syndromes or waterborne diseases?

Methods

Literature search methods

This scoping review was conducted following the Joanna Briggs Institute methodology guidance for scoping reviews\(^22\) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) extension guidelines for conducting scoping reviews\(^23,24\). Briefly, this approach involves: i) conducting a systematic literature search to identify articles that meet the inclusion criteria, ii) assessing the relevance of the articles to the study question(s), iii) assessment of the full text articles iv) data extraction and synthesis. The scoping review protocol for this study is published and available\(^25\).

Information sources and search strategy

In April 2020, literature searches were undertaken in the following four electronic databases: Embase, MEDLINE, Web of Science and Google Scholar (first 500 papers). These have been identified as the optimal combination of databases that would guarantee adequate and efficient coverage of studies for literature searches\(^26\). The exact dates when searches were conducted can be found in Table A1.

The search strategy consisted of a two-step process. The first step involved carrying out a limited search in MEDLINE, Embase and Web of Science databases to analyse the text words and index terms that are used to describe the articles. The second step included a keyword search in all four databases; index terms were also used. The search terms that were used in the study can be seen in Table 1. The search terms include a combination of names of all African cities that have a population of at least half a million residents as of 2014, as outlined in the protocol\(^24\), and terms representing the exposure (insufficient piped water supply) and outcome (waterborne diseases and syndromes). The study focused on publications that were written in the English or French language.

Data screening

Once searches were complete, the title and abstracts were extracted from the articles. Duplicates were removed and three

### Table A1. Exact dates when the searches were run in the databases.

| Database          | Date              |
|-------------------|-------------------|
| Embase            | 13th April, 2020  |
| MEDLINE           | 9th April, 2020   |
| Web of Science    | 9th April, 2020   |
| Google Scholar    | 10th April, 2020  |
reviewers (NM, JM, MM) independently screened the study titles and abstracts using the following criteria:

1) Studies that described the water sufficiency or water situation in cities with populations more than 500,000 in 2014

2) Studies that focused on cholera, typhoid, amoebiasis, cyclosporiasis or giardiasis as diseases, dysentery, diarrhea or gastroenteritis as symptoms or cryptosporidium or rotavirus as etiological agents for diarrheal diseases

3) Studies published in international scientific indexing (ISI) listed journals

Any inconsistencies between the three reviewers were discussed and a consensus was reached on whether to include or remove articles from the study.

Study selection
Where available, the full text articles were obtained for all studies that met the inclusion criteria. Two reviewers (NM and MM) assessed and characterised the studies by analysing if they primarily targeted urban residents and had evaluated the relationship between a health outcome and a water sufficiency metric. The data extracted from this screening process were stored in an Excel spreadsheet.

Data extraction, synthesis and presentation
Variables on author(s), study period, source of funding, geographical scope, study design, population inclusion criteria, sample size and statistical methodology used, and whether or not the study investigated a disease outbreak were extracted from the studies.

To understand piped water access and quality reported by the studies, we extracted information on the nature of the piped water supply, mode of accessing this piped water, measurement of the unit cost of water, the per capita daily water consumption, proportion of the population without access to piped water and water quality indicators from water samples collected for testing. The reported coping mechanisms employed to supplement water needs were also extracted. Information on the health outcomes studied and how diagnoses was made (self-reported, clinically diagnosed or culture confirmed) was also extracted from the articles. Table 2 provides a list of the variables extracted from the articles during the screening process.

Assessment of the study quality
We used the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist to analyse the quality of the studies included in the scoping review. We assessed the studies based on whether the study objective was comprehensively stated, the study design, description of study location and dates of data collection were provided, provision of participant eligibility criteria and rationale given for sample size, explanation of how missing data was handled and how they controlled for confounders. No study was excluded based on it being poor quality.

### Table 1. Search terms that were used to select studies from the different electronic databases.

| Parameter | Search terms |
|-----------|--------------|
| Population | Huambo OR Luanda OR Cotonou OR “Abomey-Calavi” OR “Abomey Calavi” OR Ouagadougou OR Bobo-Dioulasso OR “Bobo Dioulasso” OR Bunjumbura OR Younoude OR Yaounde OR Douala OR Bangui OR Niamea OR Brazaville OR Pointe-Noire OR “PointeNoire” OR Abidjan OR Bouake OR Kinshasa OR Cairo OR “Ale Gharirah” OR Al-Qahirah OR Alexandria OR “Al-Iskandariyah” OR “Al Iskandariyah” OR “Port Said” OR “Bur Said” OR “Addis Ababa” OR Libreville OR Banjul OR Accra OR Kumasi OR Conakry OR Nairobi OR Mombasa OR Monrovia OR Antananarivo OR Lilongwe OR “Blantyre-Limbe” OR “Blantyre Limbe” OR Bamako OR Nouakchott OR Casablanca OR “Dar-el-Beida” OR “Dar el Beida” OR Rabat OR Nampula OR Tetouan OR Fez OR Marrakech OR Tangier OR Tanger OR Meknes OR Agadir OR Maputo OR Matola OR Niamey OR Lagos OR Kaduna OR Akure OR Kano OR Abuja OR Aba OR Kigali OR Dakar OR Freetown OR “Cape Town” OR Durban OR Port Elizabeth OR Bloemfontein OR “Dar es Salaam” OR Arusha OR Mbeya OR Lome OR Kampala OR Kigali OR Lagos OR Harare OR Bulawayo OR “Benin City” OR Enugu OR Ibadan OR Ikorodu OR Ilorin OR Jos OR Maiduguri OR Nnewi OR Onitsha OR Oshogbo OR Owerri OR “Port Harcourt” OR Sokoto OR Umuhia OR Oyo OR Warri OR Zaria OR Hargeysa OR Merca OR Mogadishu OR Mogadisho OR Johannesburg OR Soshanguve OR Vereeniging OR Khartoum OR “Al-Khartum” OR “Al Khartum” OR Nyala OR Safaqis OR Tunis OR Mwanza OR Zanzibar OR Ndola OR Algiers OR “El Djazair” OR Wahran OR Oran OR Bukavu OR Kananga OR Kisangani OR Lubumbashi OR “Mbujju-Mayi” OR “Mbujj Mayi” OR Tshikapa OR Djibouti OR “Al Mansurah” OR “Al Mansurah” OR “As-Suways” OR “As Suways” OR Asmara OR “Sekondi Takoradi” OR Banghazi OR Misratah OR Tarabulus OR Tripoli |
| Exposure | water AND (scar* OR intermittent OR break* OR ratio* OR deficit OR deficien* OR unavailab* OR availab* OR continu* OR interrupt* OR stress OR supply OR sufficien* OR insufficien*) |
| Outcome | “water borne” OR “water-borne” OR cholera OR typhoid OR diarrhea* OR diarrhoea OR amoebiasis OR dysentery OR gastroenteritis OR cryptosporidii OR cyclosporiasis OR giardiasis OR rotavirus AND |
Table 2. Description of variables that were extracted from the articles during full-text screening.

| Variable                              | Description/ Example |
|---------------------------------------|----------------------|
| **Study design**                      |                      |
| Study period                          | Year(s)              |
| Geographical scope of the study       | City/ cities where the study was conducted |
| Source of funding                     | Government sponsored/ philanthropic foundation/ research institute/ not sponsored |
| Study design                          | Cross-sectional individual/ cross-sectional ecological/ case control/ case series/ cohort |
| Population inclusion criteria         | Households/ women/children/confirmed cases etc. |
| Sample size (people)                  | Number of respondents / households |
| Sample size                           | Number of water/ stool/ soil samples for testing |
| Outbreak investigation                | Yes/No               |
| **Statistical methodology used**      |                      |
| Bivariate methods                     | Chi-square tests, Fischer tests etc. |
| Multivariate methods and              | Linear models, logistic models etc. and confounders/ alternative transmission pathways / effect modifiers assessed |
| **Indicators of piped water sufficiency** |                      |
| Nature of piped water supply          | Continuous/ scheduled interruptions/unpredictable interruptions |
| Mode of water access                  | Inhouse piped connection, shared tap at yard, public tap/water kiosk |
| Unit cost of water reported           | Yes/No               |
| Measurement of per capita daily water consumption | Yes/No |
| Proportion of population without access to piped water | Metric |
| Water quality indicators from water samples collected for testing |                      |
| - Faecal indicator organism test      | e.g., total coliforms, Escherichia coli |
| - Dosage test for chlorine            | e.g., Free chlorine residual test |
| - Pathogen tested for                 | e.g., *Klebsiella pneumoniae, Salmonella spp., Shigella spp., Pseudomonas aeruginosa* |
| - Consumer reported organoleptic water characteristics | e.g., smell, taste, visual appearance |
| - Laboratory or organoleptic field tests | e.g., electroconductivity, pH and turbidity |
| **Coping mechanism employed to supplement water needs** |                      |
| - Use of storage tanks                | Yes/No               |
| - Storage of water in households in containers, bottles etc. | Yes/No |
| - Installation of pumps for piped water where water pressure is low | Yes/No |
| - Collecting water from rivers/streams, shallow wells, rainwater | Yes/No |
| - Drilling of wells/boreholes         | Yes/No               |
| - Installation of hand pumps/electric pumps for groundwater | Yes/No |
Connectedness of the study designs of the associations between water sufficiency and health outcomes

To understand the connectedness of the different study designs with the health outcomes and water sufficiency metrics and water quality, we used the principal component techniques. The main categories of the study designs employed in the selected publications were evaluated together with the health outcomes (self reported, clinically or culture confirmed) and a binary coding of assessment of water quality. The water sufficiency metrics were coded into either water access (mode of access, proportion with access, time/distance to water points) or water quantity (scheduled/ unscheduled interruptions, litres per person per day) categories. We carried out multiple factor analysis by grouping the study designs, health outcomes, water sufficiency metrics and whether water quality was assessed. We looked at the contributions of the first two axes and assessed the combinations of the variables that were connected, understudied and the outliers. The analysis was carried out using the FactomineR package in the statistical software R.

Results

Study selection

The initial database search revealed 3,099 articles. After removing duplicates, and assessing the abstracts for eligibility, 93 articles remained for full text review, with 32 of those studies meeting the inclusion criteria (Figure 1).

Quality of the studies

From our checklist, there were some strengths and weaknesses of the studies. All the studies had a clearly stated objective, study design and study location with date of data collection. The eligibility criteria of the study participants were also clearly stated by majority of the studies (n=31, 97%).

Three quarters of the studies reported on the statistical methods employed (n=24, 75%). Less than a third of the studies explained how the study size was calculated (n=8, 25%), the criteria used in choosing the quantitative variables (n=2, 6%) and how the studies controlled for confounders (n=9, 28%). None of the studies explained how they addressed missing data (Table 3).

Characteristics of the publications

A total of 32 articles that assessed the association of water sufficiency in urban areas and waterborne diseases and syndromes in SSA were published between 1998 and 2019. These studies focused on 24 cities in 17 countries across Western, Eastern and Southern Africa, with 22% (n=7) of the studies based in urban Nigeria (Figure 2). Seven of the articles (22%) were conducted in informal settlements. Nearly half the studies did not report the source of funding, with government and philanthropies supporting most of the studies that provided that information (Table 4).

Half of the studies (n=16, 50%) employed cross-sectional individual level study design, and only six percent (n=2) used cohort study designs, with the rest utilising case-control or cross-sectional ecological designs (Table 4). All these publications employed quantitative methods of data collection whereas only two publications (n=2, 6%) collected qualitative data to

| Variable                      | Description/ Example                                      |
|-------------------------------|-----------------------------------------------------------|
| Water treatment               | Yes/No                                                    |
| Purchasing water from vendors | Yes/No                                                    |
| Purchasing water from neighbors | Yes/No                                              |
| Water recycling               | Yes/No                                                    |
| Illegal water connections     | Yes/No                                                    |

| Indicators of health          | Description/ Example                                      |
|-------------------------------|-----------------------------------------------------------|
| Cholera                       | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Typhoid                       | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Amoebiasis                    | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Cyclosporiasis                | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Giardiasis                    | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Dysentery                     | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Diarrhea                      | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Gastroenteritis               | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Cryptosporidium               | Self-reported/Clinically diagnosed/ laboratory confirmed  |
| Rotavirus                     | Self-reported/Clinically diagnosed/ laboratory confirmed  |
complement the quantitative data. The studies’ target population included general households or respondents (n=17, 53%), confirmed cases or patients in hospitals being treated for waterborne diseases/syndromes (n=6, 19%), children below 10 years (n=6, 19%), women or mothers of infants (n=3, 9%) and HIV infected persons (n=3, 9%). The study subjects ranged from less than 100 (n=2, 6%) to more than 500 (n=11, 34%) and nearly a third of the articles (32%) were targeting outbreaks from cholera (n=9) or typhoid (n=1), which are epidemic-prone waterborne diseases (Table 4).

To understand the association between water and waterborne diseases and syndromes, the studies mainly used bivariate and multivariate methods of analysis. The common bivariate

Figure 1. Flow diagram summarising the number of articles included at each review stage.
analysis methods used included the chi-square tests, Fisher tests, Wald tests and the correlation coefficient methods while the multivariate analysis methods included regression models (linear, logistic, random effects) and ANOVA models. The multivariate analysis models controlled for confounders/ effect modifiers in the analysis using independent variables which included source of water, type of water storage container, presence of water treatment, household hygiene and sanitation conditions, household characteristics which included size, income, employment, and presence of children (Table 4). A study done by Machdar et al employed cost-effective analysis methods to assess the cost-effectiveness of interventions for reducing the disease burden from consumption of poor drinking water.  

Figure 2. Geographical distribution of the studies and cities included in the scoping review Basemap source (shapefile): Database of Global Administrative Areas.
Table 4. Characteristics of the 32 studies included in the scoping review.

| Characteristic | No. of studies (% of included studies) | References |
|----------------|----------------------------------------|------------|
| **Study period** |                                        |            |
| ≤2005          | 12 (38%)                               | 37,40,42–49 |
| 2006 – 2012    | 14 (43%)                               | 34,35,38,39,42,44,50–59 |
| ≥2013          | 8 (25%)                                | 33,36,41,60–64 |
| **Source of funding** |                                   |            |
| Not reported   | 15 (47%)                               | 34,39,40,44–48,53,55,56,61,63–65 |
| Government departments/ agencies | 6 (19%) | 35,36,38,43,58,59 |
| Philanthropic foundations | 5 (16%) | 50,52,56,57,62 |
| Research Institutes | 4 (13%) | 33,42,49,51 |
| Not sponsored  | 2 (6%)                                 | 41,54      |
| **Study design** |                                        |            |
| Cross-sectional individual-level | 16 (50%) | 34–36,38,40–42,49–51,53,57,60,62 |
| Case-control   | 9 (28%)                                | 33,39,46,55,56,58,59,64 |
| Cross-sectional ecological | 7 (22%) | 37,44,47,48,52,54 |
| Cohort         | 2 (6%)                                 | 43,61      |
| Cross-sectional ecological and individual level | 1 (3%) | 45 |
| Cross-sectional individual-level and case control | 1 (3%) | 63 |
| **Population inclusion criteria** |                                   |            |
| Households/ respondents | 17 (53%) | 34,38–41,43–45,49,52,53,55,57,59,62–64 |
| Confirmed cases/ people visiting health facilities for treatment of waterborne diseases | 6 (19%) | 37,45,47,48,54,61 |
| Children/ infants | 6 (19%) | 33,35,42,49,51,56 |
| Women or mothers of infants | 3 (9%) | 35,36,60 |
| HIV positive persons | 3 (9%) | 43,46,58 |
| **Study population sample size** |                                  |            |
| 100            | 2 (6%)                                 | 34,41      |
| 101–200        | 7 (22%)                                | 37,38,40,46,54,59,62 |
| 201–300        | 7 (22%)                                | 39,43,44,53,55,60,64 |
| 301–400        | 4 (13%)                                | 45,49,57,61 |
| 400–500        | 1 (3%)                                 | 58         |
| >500           | 11 (34%)                               | 33,35,36,42,47,48,50–52,56,63 |
| Study investigating an outbreak | 10 (31%) | 34,37,39,47,55,57,59,61,63,64 |
| **Statistical methodologies used (n=25)** |                               |            |
| Bivariate methods (chi-square tests, Fischer tests etc.) | 17 (68%) | 34–36,42,43,45,50,52–54,56–59,60–62,64 |
| Multivariate methods (Linear models, logistic models etc.) | 12 (48%) | 33,35,36,39,40,45,51,55,56,59,62,63 |
| **Nature of piped water supply** |                                    |            |
| Proportion with access to piped water | 23 (72%) | 34–40,42–46,48,50–53,56,58–62 |
| Characteristic                                      | No. of studies (% of included studies) | References |
|----------------------------------------------------|----------------------------------------|------------|
| Water interruptions (scheduled/unpredictable)      | 8 (25%)                                | 33–35,38,39,46,53,59 |
| Per capita daily water availability                | 5 (16%)                                | 33,49,51–53 |
| Cost / affordability of water metric               | 4 (13%)                                | 35,41,52,53 |
| Time used/distance to water point                  | 3 (9%)                                 | 51,53,56 |
| Samples collected†                                  |                                        |            |
| Water                                              | 19 (59%)                               | 33,34,38,41–49,54–56 |
| Stool                                              | 5 (16%)                                | 55,58,59,63,64 |
| Soil                                               | 1 (3%)                                 | 62         |
| Hand rinse                                         | 1 (3%)                                 | 62         |
| Water quality indicators (n=19)†                   |                                        |            |
| Faecal indicator organism test                     | 17 (89%)                               | 33,34,38,41–49,52,54–56,62,63 |
| Free chlorine residual test                        | 7 (37%)                                | 34,44,46,48,55,56,63 |
| Laboratory/field tests organoleptic water characteristics | 5 (26%)                           | 41,43,44,48,59 |
| Pathogen tests                                     | 5 (26%)                                | 38,42,45,49,54 |
| Coping mechanisms employed†                        |                                        |            |
| Collecting rainwater/ from rivers, streams, shallow wells etc. | 22 (69%)                           | 36–42,44,45,47–49,50–56,58,60,61,64 |
| Purchasing water from vendors                      | 16 (50%)                               | 34–38,43,45,46,50–53,56,59,60,64 |
| Storing water in the households                    | 11 (34%)                               | 33–35,38,43,46,51,55,56,59,62 |
| Water treatment                                    | 8 (25%)                                | 34,40,43,45,46,50,53,55 |
| Drilling wells/boreholes                           | 3 (9%)                                 | 41,48,54 |
| Purchasing water from neighbors                    | 1 (3%)                                 | 41         |
| Installing storage tanks in households              | 1 (3%)                                 | 41         |
| Purchasing pumps for ground water                  | 1 (3%)                                 | 41         |
| Illegal water connections                          | 1 (3%)                                 | 59         |
| Health outcomes- Self reported†                    |                                        |            |
| Diarrhea                                           | 15 (47%)                               | 33,35,36,39–43,46,50,51,55,58,60,62 |
| Cholera                                            | 4 (13%)                                | 34,53,57,63 |
| Dysentery                                          | 3 (9%)                                 | 41,50,53 |
| Typhoid                                            | 3 (9%)                                 | 41,50,53 |
| Clinically diagnosed†                              |                                        |            |
| Cholera                                            | 8 (25%)                                | 37,39,45,47,48,54,59,61 |
| Typhoid                                            | 4 (13%)                                | 44,45,54,61 |
| Cryptosporidium                                    | 1 (3%)                                 | 38         |
| Amoebiasis                                         | 1 (4%)                                 | 54         |
| Diarrhea (uncategorised)                           | 3 (9%)                                 | 44,52,54 |
| Moderate to severe diarrhea                        | 1 (3%)                                 | 56         |
| Gastroenteritis                                    | 3 (9%)                                 | 44,45,54 |
Piped water was mainly supplied by the utility companies to residents through inhouse connections, shared taps at compound or public taps/ water kiosks. However, the publications reported piped water insufficiency through proportion of the study population that had access to piped water (n=23, 72%), scheduled/ unpredictable water interruptions (n=8, 25%), per capita daily water availability (n=5, 16%) and time used/ distance to the water point (n=3, 9%). Four articles reported piped water inequality through the mode of access (n=3, 9%) and quantity (n=2, 6%)

The objective assessment of water safety was assessed by the studies via testing water samples (n=19, 59%). The water samples were collected from the dominant water points of the study population (n=9, 47%), water stored in the households (n=7, 37%), both dominant water points and stored water in the households (n=3, 16%) or hand rinse samples (n=1, 3%). Several studies assessed water contamination by testing for coliforms (n=17, 89%), effectiveness of measures of protecting water from contamination through testing for free residual chlorine (n=7, 37%), organoleptic characteristics of water by assessing turbidity and pH (32%, n=6) and presence of pathogens which included klebsiella pneumoniae, staphylococcus aureus, pseudomonas aeruginosa, among others (26%, n=5).

To complement their water needs, the study population employed coping mechanisms which included collecting rainwater/ water from rivers, streams or shallow wells (n=22, 69%), purchasing water either from vendors (n=16, 50%) or neighbors (n=1, 3%), storing water in the households (n=11, 34%), water treatment (n=8, 25%), drilling wells/ boreholes (n=3, 9%), installing storage tanks in households (n=1, 3%) and having illegal water connections (n=1, 3%) (Table 4). Four of the studies reported a relatively higher cost in the purchased water as compared to the cost of water supplied by the utility companies.

The publications focused on cholera (n=12, 38%), typhoid (n=8, 25%) and amoebiasis (n=2, 6%) as waterborne diseases, diarrhea (n=20, 32%), dysentery (n=7, 22%) and gastroenteritis (n=3, 9%) as symptoms and cryptosporidium (n=2, 6%) and rotavirus (n=1, 3%) as etiological agents of diarrheal diseases. The health outcomes were either self-reported, clinically confirmed or objectively assessed through collecting and culturing stool samples.

The most common self-reported waterborne diseases/ syndromes included diarrhea (n=15, 47%), cholera (n=4, 13%), dysentery (n=3, 9%) and typhoid (n=3, 9%). The clinically confirmed health outcomes were cholera (n=8,25%), typhoid (n=4, 13%), amoebiasis (n=1, 3%), dysentery (n=3, 9%), diarrhea (n=3,9%), moderate to severe diarrhea (n=1, 3%), gastroenteritis (n=3, 9%), dysentery (n=3, 9%) and rotavirus (n=1, 3%) while the culture confirmed health outcomes were typhoid (n=1, 3%), cholera (n=1, 3%) and cryptosporidium (n=1, 3%) (Table 4). One study reported mortality as well as morbidity of waterborne diseases and syndromes.

A comprehensive table containing the study characteristics can be found in Table B1.

### Connectedness of the study designs used

We assessed the connectedness in the study design methods used by the articles to understand the nexus between water sufficiency and health outcomes, as shown in Figure 3. The axes in the biplot represented the first two principal components of the input data which explained 27% of the total variability, showing weak correlation among the study designs.

The black triangle markers in Figure 3 represent the mean centres for the health outcomes and the characteristics of piped water supply that were studied by the articles. The correlation circle is portrayed by the uncolored hollow black circle. The colored confidence ellipses, which are plotted around the group mean points, represent the study design methods employed by the studies and the size of the ellipses are based on the variance of each group. The numbers represent each publication included in our study.

From this analysis, we observed that cross-sectional individual-level, cross-sectional ecological level and case control studies had a high variance and were the three commonly used study designs. Cross-sectional individual study designs were generally used in self-reported health outcomes while cross-sectional

### Table B1: Characteristics of Water Safety and Health Outcomes

| Characteristic | No. of studies (% of included studies) | References |
|---------------|--------------------------------------|------------|
| Dysentery     | 3 (9%)                               | 44,45,54   |
| Rotavirus     | 1 (3%)                               | 38         |
| **Culture confirmed** |                                      |           |
| Typhoid       | 1 (3%)                               | 55         |
| Cholera       | 1 (3%)                               | 64         |
| Cryptosporidium | 1 (3%)                              | 58         |

†A study appeared in more than one category
| No | author(s)                          | Study period | Study design                  | Target population | Study population sample size | Sample and size | Water insufficiency metric | Coping mechanisms employed | Disease/ Syndrome studied (method of measuring) | Type of water tested | Water quality tests | Outbreak investigation | Analysis methods | Confounders/ effect modifiers/ other transmission pathways included in analysis |
|----|-----------------------------------|--------------|-------------------------------|-------------------|------------------------------|----------------|-----------------------------|-----------------------------|-----------------------------------------------|---------------------|--------------------|------------------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------|
| 1  | Degbey et al (2011)               | 2008-2009    | Cross-sectional ecological    | Patients, health facilities | 110                          | No Water-110      | NR                          | Digging wells, collecting water from alternative sources | Cholera (C), typhoid (C), amebiasis (C), diarrhea (C), gastroenteritis (C) | Water points       | Faecal indicator organism test, pathogens test | No                     | Bivariate (Pearson chi-square tests, Fischer exact test) |                                                                                                                                 |
| 2  | Nana-Darkwahmond et al (2018)     | 2016         | Cross-sectional individual    | Households         | 142                          | Yes Soil from outdoor location closest to the house entrance- 142; Water- 244 Hand rinse samples- 142 | Proportion with running tap water | Water storage in household | Diarrhea (SR) | Stored water in household | Organoleptic water quality, Faecal indicator organism test | No                 | Multivariate (multiple regression models, bivariate (Pearson correlation coefficients)) | Facial indicator organism test result for soil, handwashing water, hands before eating, diarrhea incidence, number of assets owned, sanitation (presence of animals, toilet structure, toilet cleanliness, toilet location), household hygiene (presence of fresh, presence of flies), location of handwashing facility, presence of soap and water in handwashing facility, Organoleptic quality of stored water, type of opening of water storage container |
| 3  | Triane et al (2013)               | 2008-2009    | Cross-sectional ecological    | Municipalities      | 13,705                       | No Water-150      | Proportion with access to piped water, L/10 | Purchasing water, Collecting water from alternative sources | Diarrhea (C) | Water points | Facial indicator organism test | No                | Bivariate (Correlation coefficient) | Quality of water, incidence of waterborne disease/ syndrome |
| 4  | Sipano et al (2018)               | 2017-2018    | Cross-sectional individual - KAP Case control | Households         | 367,205                       | No Water-220, stool-4 | NR | NR | Cholera (SR) | Water points | Faecal indicator organism test, free chlorine residual | Yes | Multivariate (NR) | Contact with a person with cholera, consumption of untreated water, gender |
| 5  | Ak et al (2009)                   | 1995-2006    | Cross-sectional ecological    | Households         | 300                          | No Water-10       | Proportion with access to piped water | Collecting water from alternative sources | Typhoid (C), diarrhea (C), gastroenteritis (C), gastroenteritis (G) | Water points | Faecal indicator organism test, organoleptic water quality, free chlorine residual | No | NR |                                                                                                                                 |
| 6  | Winter et al (2019)               | 2016         | Cross-sectional individual    | Women              | 550                          | No N/A            | Proportion with access to piped water | Purchasing water, Collecting water from alternative sources | Diarrhea (SR) | N/A | N/A | No | Bivariate (Pearson chi-square tests), multivariate (logistic regression) | Age, level of education, employed, has children, level of household income, type of toilet used during the day and at night, source of water, toilet hygiene and accessibility, WASH knowledge and practices |
| 7  | Saliege (2019)                    | 2018         | Cross-sectional individual    | Households         | 32                           | No Water-3        | NR | Drilling boreholes, collecting water from alternative sources, purchasing water, storage tanks | Typhoid (SR), diarrhea (SR), dysentery (SR) | Water points | Organoleptic water quality, Faecal indicator organism test | No | NR |                                                                                                                                 |
| No. | Authors | Study period | Study design | Target population | Study population size | Sample type and size | Water insufficiency metric | Coping mechanism employed | Disease/ Syndrome studied (method of measuring) | Type of water tested | Water quality tests | Outbreak investigation | Analysis methods | Confounders/ effect modifiers/ other transmission pathways included in analysis |
|-----|---------|--------------|--------------|-------------------|----------------------|----------------------|---------------------------|--------------------------|-----------------------------------------------|-------------------|---------------------|----------------------|----------------|--------------------------------------------------|
| 8   | Mull et al. (2014) | 2011 | Case-control individual | respondents | 230 | No | Water-25 Stool-NR | NR | Typhoid (CC), diarrhoea (GI) | Water points | Free chlorine residual, faecal indicator organism test | Yes | Multivariate (RF) | Burst sewer pipe within 500 metres from home, typhoid contact at home, water from an alternative source, type of storage water container, boil drinking water |
| 9   | Oguntibe et al. (2009) | 1999-2004 | Cross-sectional ecological, cross-sectional individual | Patients visiting health facilities, households | 350 | No | Water-NR | Availability of piped water | Collecting water from alternative sources, purchasing water, water treatment, rainwater harvesting | Cholera (C), typhoid (C), dysentery (C), gastroenteritis (C) | Stored water in household | faecal indicator organism test, pathogen test | No | Bivariate (correlation coefficient) Multivariate (simple linear regression model) | Water treatment, level of income, household size |
| 10  | Dos Santos et al. (2015) | 2012 | Cross-sectional individual | children under 10 years | 702 | No | N/A | LAPD-Proportion with access to piped water, time spent to collect water | Purchasing water, water storage in household, rainwater harvesting | Diarrhoea (SR) | N/A | N/A | No | Multivariate (logistic regression model) | Main source of drinking water, time spent in water collection, per capita water available, type of water storage container, use of ananewater, handwashing before eating, sex of household head, level of education of household head, household head economic status of household head, number of children in the household, type of sanitation |
| 11  | Essayaghi et al. (2019) | 2013-2016 | Cohort | Typhoid confirmed cases | 322 | Yes | N/A | Proportion with access to piped water | Collecting water from alternative sources | Typhoid (C) | N/A | N/A | Yes | Bivariate (Wilcoxon Test) | |
| 12  | Barley et al. (2011) | 2005 | Cohort | HIV positive women | 243 | Yes | Water (baseline-242, followup visits-187) | Proportion with an improved water supply | water storage at households, water treatment purchasing water | Diarrhoea (SR) | Stored water in household | organoleptic water quality, No | Bivariate (Wilcoxon Signed Rank Test, Wilcoxon’s Rank Sums test) | |
| 13  | Baker et al. (2013) | 2007-2010 | Case-control | children<5 years | 4,066 | Yes | Water-63 | Time taken in fetching water, proportion with access to piped water | Purchasing water, Collecting water from alternative sources, water storage in households | Diarrhoea (C) | Water points and stored water in household | faecal indicator organism test, free residual chlorine | No | Bivariate (Pearson chi-square tests, Fisher exact test, T-tests), Multivariate (logistic regression models) | Collecting water, continuous access to water, time taken to collect water, breastfeeding, both parents living at home, wealth quintile index, caretaker’s level of education |
| 14  | Kone- Coulibaly et al. (2010) | 2008 | Case-control | households | 280 | Yes | N/A | Unpredictable interruptions, proportion with access to piped water | Collecting water from alternative sources | Cholera (C), diarrhoea (GI) | N/A | N/A | Yes | Multivariate (logistic regression models) | Contact with a diarrhoea patient, experiencing unpredictable water interruptions, level of education, source of drinking water, attending a gathering, consuming hot food, consuming cold food, having received health education on cholera |
| No | author(s) | Study period | Study design | Target population | Study population size | Rationale given for sample size | Sample type and size | Water insufficiency metric | Coping mechanism employed | Disease/Syndrome studied (method of measuring) | Type of water tested | Water quality tests | Outbreak investigation | Analysis methods | Confounders/other transmission pathways included in analysis |
|---|-----------|--------------|-------------|-------------------|----------------------|-----------------------------|---------------------|---------------------------|--------------------------|---------------------------------|-------------------|----------------|-------------------|----------------|----------------------------------------------------------|
| 15 | Yilgaw et al. (2013) | 2005 | Cross-sectional individual | Households | 200 | No | N/A | Proportion with access to piped water | Water treatment, collecting water from alternative sources | Diarrhea (SR) | N/A | N/A | No | Multivariate logistic regression model | Family size, Number of children in the household, educational status of household head, income level of household head, Domestic source of water, water treatment |
| 16 | Schaetti et al. (2013) | 2008 | Cross-sectional individual | Respondents | 356 | No | N/A | Proportion with access to piped water, unpredictable interruptions | Water storage in household, purchasing water, water treatment | Diarrhea (SR) | N/A | N/A | Yes | Bivariate (Wilcoxon test, Kruskal-Wallis test, Pearson chi-square test, Fischer exact test) | |
| 17 | Dunne et al. (2013) | 1999 | Case-control | Cases-households of women who attended HIV clinic | 120 | No | Water-120 | Proportion with access to piped water, unpredictable interruptions | Water storage in household, purchasing water, water treatment | Diarrhea (SR) | N/A | N/A | No | NR |
| 18 | Machdar et al. (2010) | 2010 | Cross-sectional individual | Households | 110 | No | Water-110 | Proportion with access to piped water, unpredictable interruptions | Water storage in household, purchasing water, collecting water from alternative sources | Rotavirus (SR), Cryptosporidium (SR), Diarrhea (SR) | Stored water in household | N/A | N/A | No | Cost effective analysis |
| 19 | Usman et al. (2009) | 1995-2001 | Cross-sectional ecological | Patients visiting health facilities | 6,165 | No | Water-6,165 | Proportion with access to piped water | Water treatment, collecting water from alternative sources | Cholera (C) | Water points | N/A | Yes | Bivariate (Pearson chi-square test) | Source of water consumed, water treatment, level of hygiene/sanitation, type of food consumed, attended a gathering |
| 20 | Endris et al. (2011) | 2016 | Case-control | Households | 300 | Yes | Stool-300 | Proportion with access to piped water | Collecting water from alternative sources, purchasing water | Cholera (CC) | N/A | N/A | Yes | Bivariate (Pearson correlation coefficients, Chi-square test) | |
| 21 | Uboi (2018) | 2018 | Cross-sectional individual | Mothers of infants 0-6 months | 202 | No | N/A | Proportion with access to piped water | Collecting water from alternative sources, purchasing water | Diarrhea (SR) | N/A | N/A | No | Bivariate (Pearson correlation coefficients, Chi-square test) | Exclusive breastfeeding, piped water supply |
| 22 | Blanton et al. (2015) | 2010 | Cross-sectional individual | Households | 39 | No | Water-39 | Proportion with access to piped water, scheduled water interruptions | Water storage in household, purchasing water, water treatment | Cholera (SR) | Water points and stored water in household | N/A | N/A | Yes | Bivariate (T-tests, Pearson chi-square test, Wilcoxon rank-sum test) | |
| 23 | Kuichare et al. (2008) | 2007 | Cross-sectional individual | Households | 1,397 | No | N/A | Proportion with access to piped water | Collecting water from alternative sources, water treatment, purchasing water | Dysentery (SR), Diarrhea (SR), Typhoid (SR) | N/A | N/A | No | Bivariate (Pearson correla Wallis H-test) | |
| No | Author(s) | Study period | Study design | Target population | Study population sample size | Rationale given sample size | Sample type and size | Water insufficiency metric | Coping mechanism employed | Disease/ Syndrome studied (method of measuring) | Type of water tested | Water quality tests | Outbreak investigation | Analysis methods | Confounders/ effect modifiers/ other transmission pathways included in analysis |
|----|-----------|--------------|--------------|-------------------|-----------------------------|-----------------------------|----------------------|---------------------------|--------------------------|----------------------------|------------------|----------------|------------------|----------------|------------------------------------------------------------------|
| 24 | Yongi (2010) | 2002; 2003 | Cross-sectional individual | Children between 6-59 months | 3,084 | No | Water-508 | Proportion with access to piped water | Collecting water from alternative sources | Diarrhea (SR) | Water points and Stored water in household | N/A | N/A | No | Bivariate (COH square test); spatial analysis |
| 25 | Abaje et al. (2009) | 2008 | Cross-sectional individual | Households | 220 | No | N/A | Proportion with access to piped water | Collecting water from alternative sources, purchasing water, water treatment | Cholera (SR), Typhoid (PR), Dysentery (SR) | N/A | N/A | N/A | Bivariate (COH square test) |
| 26 | Nkhuwa et al. (2011) | 2003 | Cross-sectional ecological | Patients visiting health facilities | 1,864 in 1999, 6219 in 1999 | No | Water-14 | Proportion with access to piped water | Collecting water from alternative sources, drilling boreholes | Cholera (C) | Water points | N/A | N/A | Yes | NR |
| 27 | Sow et al. (2012) | 1995-1996 | Cross-sectional ecological | Cholera cases in health facilities | 141 in 1995, 182 in 1996 | No | N/A | Proportion with access to piped water | Purchasing water, collecting water from alternative sources | Cholera (C) | Water points | N/A | N/A | Yes | NR |
| 28 | Julvez et al. (2018) | 1995, 1997; 1999, 2003 | Cross-sectional ecological | Households | 322 people, 161 children | No | Water-15 | L/P/D | Collecting water from alternative sources | Amebiasis (SR) | Water points | N/A | N/A | No | Multivariate (Multiple logistic regression models) |
| 29 | Adane et al. (2017) | 2014 | Case-control | Children <5 years | 760 | Yes | Water-192 | Proportion with access to piped water | Collecting water from alternative sources | Water storage in households; L/P/D, | Diarrhea (SR) | Stored water in household | N/A | N/A | No | Multivariate (Multiple logistic regression models) |
| 30 | Alembia et al. (2010) | 2008-2009 | Case-control | HIV-infected persons | 500 | No | Stool-500 | Proportion with access to piped water | Collecting water from alternative sources | Cryptosporidium (CC), diarrhea (SR) | N/A | N/A | No | Bivariate (Pearson ch-square test) |
| 31 | Nguyen et al. (2014) | 2012 | Case-control | Individuals >= 5 years | 147 | No | Water-80, Stool-90 | Proportion with access to an improved source of water, scheduled interruptions | Water storage in households, purchasing water, illegal connections | Cholera (C) | Stored water in household | organoleptic water quality | Yes | Multivariate (Multiple logistic regression models), Bivariate (Wald Test) | Vended water, unsafe water, education level of household head, consuming hot food, consuming crab, consuming okra, consuming meat, consuming a variety of foods, drinking water, bathroom expense, days of water rationing |
| 32 | Stoler et al. (2011) | 2009-2010 | Cross-sectional individual | Women, children | 2092 women, 810 children | Yes | N/A | Scheduled water interruptions, proportion with access to piped water | Purchasing water, water storage in households | Diarrhea (SR) | N/A | N/A | No | Multivariate (Multiple logistic regression models, random mixed effects models), Bivariate (ANOVA, chi-square test) | Mother’s self-reported overall health, purchased water as primary source of drinking water, daily bathroom expenses, days of water rationing |

*CC: Culture confirmed, C: Clinically confirmed, SR: self-reported, NR: Not Reported, N/A: Not Available*
ecological and case control study designs were used in assessing clinically confirmed and culture confirmed health outcomes respectively. Water quantity and quality were mainly assessed using cross-sectional individual and ecological level study designs, whereas water access was mainly assessed using cross-sectional individual-level study designs. An unusual combination of self-reported typhoid and water quantity was observed as an outlier (Figure 3). Use of cohort study designs in assessing the association between waterborne diseases and syndromes and water sufficiency was under-utilised.

Discussion
Our study presents the results of a scoping review on associations between water supply and waterborne diseases and syndromes in large cities across Africa. We find that majority of the studies have been published since 2005. The relationship between piped water sufficiency and waterborne diseases/syndromes has mainly been studied using cross-sectional individual level study designs employing bivariate statistical methods. The main measures of water sufficiency used are access levels to piped water and water quality assessments while the health indicators mainly used are self-reported or clinically confirmed health outcomes. Cohort study design methods, measure of availability of piped water using quantifiable measures that include either per capita daily water consumption or water interruptions, cryptosporidium, cyclosporiasis, amoebiasis, rotavirus water borne diseases and culture confirmed assessment of health outcomes have been under-utilised. Similarly, multivariate methods which are important in assessing the confounders or alternative transmission pathways have been seldomly used.

Piped water has been listed as the primary source of improved water in this region, however results from this review contest to this with no evidence of sufficient piped water supply in the urban areas. Daily per capita water consumption and mode of

Figure 3. Included studies and study design types, plotted against the first two principal components derived from study design characteristics.
access have been reported to be inversely proportional to the level of health concern, in outbreak and non-outbreak conditions\textsuperscript{51}. However, these two variables were under-studied and only assessed by two studies, neither of which investigated an outbreak\textsuperscript{51,53}.

The use of alternative or secondary water sources, that are often unimproved (as classified by the Joint Monitoring Programme (JMP) of the World Health Organisation (WHO) and United Nation’s International Children’s Emergency Fund (UNICEF)), have been listed as one of the prevalent transmission pathways for water-related pathogens, due to high exposure to faecal contamination\textsuperscript{1,67}. Adequate water treatment has the potential to reduce contamination of these water supplies by half\textsuperscript{69}. The studies included in this review reported use of alternative water sources as a key coping mechanism for poor or intermittent water supply while only a small proportion reported use of water treatment. Water contamination tests were a common assessment of water quality, contributing to the increased evidence of contamination in the predominant coping mechanisms employed by residents in urban areas.

Water storage, which was the second major coping mechanisms employed by the residents in urban areas, was observed as having the potential to increase the burden associated with waterborne diseases and syndromes. Low income earners, who account for 61% of the population in Africa, regularly practice poor water storage\textsuperscript{68,69}. On the other hand, residents with a high income mainly invest in large storage tanks to ensure they enjoy safe storage and adequate water consumption even during periods of irregular water supply\textsuperscript{70}. The in-depth qualitative assessment of poor water storage practices and their association with waterborne diseases was under-studied. None of the studies focused on user reported organoleptic characteristics of stored water in their households.

Diarrhea and cholera were the majorly self-reported and clinically confirmed health outcomes respectively while cryptosporidium, cyclosporiasis, amoebiasis, rotavirus water borne diseases were under-studied. These four waterborne diseases are among the major etiological agents associated with moderate to severe diarrhea in children below five years\textsuperscript{51,61}. Additionally, clinically and culture confirmed health outcomes are the two main approaches used in case definition of diseases of public health concern, with cases confirmed through objective assessment of samples at the laboratory\textsuperscript{72}. However, culturally confirmed health outcomes were seldomly employed in these studies, making it difficult to assess the public health burden associated with waterborne diseases.

Cross-sectional ecological and individual-level studies and case control studies were the main study designs used to understand the association between water sufficiency and health. Cohort study designs and multivariate statistical methods were under-utilised, limiting the detection of hotspots.

One of the limitations of our study was a lack of studies in Luanda, Kinshasa, Cairo, Johannesburg, Khartoum cities that had a population of more than 5 million people as at 2014 and are expected to be mega-cities by 2030\textsuperscript{73}. Furthermore, there were no studies on cyclosporiasis which was one of the waterborne diseases under our study criteria. Another limitation of our study was potential bias introduced through the choice of databases to conduct the search. Furthermore, we did not omit any studies based on the quality appraisal conducted on the included publications. These limitations have also been reported in other scoping reviews\textsuperscript{74}. The use of a non-conventional analysis method in our review may have also been a limitation assessing the connectedness of the study designs, health outcomes, water sufficiency and assessment of water quality. Similarly, our analysis methods deviated from the published protocol found here\textsuperscript{25} where we had proposed to conduct cluster analysis to differentiate self-reported diarrheal diseases with etiological agents. This was not possible due to the diverging water sufficiency characteristics reported by the studies. We also did not present digital maps which overlayed the study locations and the water scarcity peer reviewed maps, as stated in the scoping review protocol. This is because the main outcome of our study was depicting under utilised study designs, health outcomes and water sufficiency metrics.

**Conclusion**

Monitoring of health outcomes and the trends in availability and mode of access of piped water should be prioritised in urban areas in Africa in order to implement interventions towards reducing the burden associated with waterborne diseases and syndromes. This will contribute towards understanding the exposure pathways. Similarly, this is an area that can be used to assess the strategies of Africa being closer to achieving the United Nations SDGs regarding sustainable cities, adequate water, good health and wellbeing of its citizens and the Africa Union aspiration of having an African continent that is based on growth and sustainable development while coping with water insufficiency.

**Data availability**

All data underlying the results are available as part of the article and no additional source data are required.

**Reporting guidelines**

Open Science Framework. PRISMA-ScR reporting checklist for “The nexus between improved water supply and waterborne diseases in urban areas in Africa: a scoping review” DOI: https://doi.org/10.17605/OSFJO/8TKSR\textsuperscript{75}

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).
References

1. World Bank: Population growth (% annual). 2019; (accessed Jul. 06, 2020). Reference Source
2. Zhang XQ: The trends, promises and challenges of urbanisation in the world. Habitat Int. 2016; 54(13): 241-252. Publisher Full Text
3. Dos Santos S, Adams AE, Neville G, et al.: Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. Sci Total Environ. 2017; 607-608: 497-508. Published Abstract | Publisher Full Text
4. WHO: Water. 2020; (accessed Jul. 07, 2020). Reference Source
5. UNICEF and WHO: JMP Ladder chart. 2017. (accessed Sep. 29, 2020). Reference Source
6. Vivien F, Briscoe-Garmendia C: Africa's Infrastructure: A Time for Transformation. World Bank, 2010. Reference Source
7. UNICEF and WHO: Progress on household drinking water, sanitation and hygiene 2000-2017. Special focus on inequalities. 2019. Reference Source
8. GBD 2016 Diarrhoeal Disease Collaborators: Estimates of the global, regional, and national burden of diarrhoea in 195 countries: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Infect Dis. 2018; 18(11): 1211-1228. Published Abstract | Publisher Full Text | Free Full Text
9. Levine MM, Narin D, Ackcio S, et al.: Diarrhoeal disease and subsequent risk of death in infants and children residing in low-income and middle-income countries: analysis of the GEMS case-control study and 12-month GEMS-1A follow-on study. Lancet Glob Health. 2020; 8(2): e204-e214. Published Abstract | Publisher Full Text | Free Full Text
10. Fall IS, Rajatannina S, Yahaya AA, et al.: Integrated Disease Surveillance and Response (IDSR) strategy: Current status, challenges and perspectives for the future in Africa. BMC Glob Health. 2015; 4(6): e001427. Published Abstract | Publisher Full Text | Free Full Text
11. United Nations: Sustainable Development Goals: 17 Goals to Transform our World. United Nations, 2015; (accessed Jan. 02, 2018). Reference Source
12. African Union: Agenda 2063: The Africa we want. 2015. Publisher Full Text
13. Bain R, Cronk R, Hossain R, et al.: Global assessment of exposure to faecal contamination through drinking water based on a systematic review. Trop Med Int Health. 2014; 19(8): 917-927. Published Abstract | Publisher Full Text | Free Full Text
14. Wright J, Gundry S, Conroy R: Household drinking water in developing countries: A systematic review of microbiological contamination between source and point-of-use. Trop Med Int Health. 2004; 9(1): 106-117. Published Abstract | Publisher Full Text
15. Rebaudet S, Sudre B, Faucher B, et al.: Environmental determinants of cholera outbreaks in inland africa: A systematic review of main transmission foci and propagation routes. J Infect Dis. 2013; 208 Suppl 1: S45-54. Published Abstract | Publisher Full Text
16. Thomas MLH, Channon AA, Bain RES, et al.: Household-reported availability of drinking water in Africa: A systematic review. Water (Switzerland). 2020; 12(9): 1-28. Publisher Full Text
17. Garrick D, De Stefano L, Yu W, et al.: Rural water for thirsty cities: A systematic review of water reallocation from rural to urban regions. Environ Res Lett. 2019; 14(4): 043003. Publisher Full Text
18. Rebaudet S, Sudre B, Faucher B, et al.: Cholera in Coastal Africa: A systematic review of its heterogeneous environmental determinants. J Infect Dis. 2013; 208 Suppl 1: 598-106. Published Abstract | Publisher Full Text
19. Steinman A, Kremer BM, Greenberg D: Hyposthenuria and water resources development: systematic review, meta-analysis, and estimates of people at risk. J Infect Dis. 2006; 6(7): 411-425. Published Abstract | Publisher Full Text
20. Levy K, Wolfe AP, Goldstein RS, et al.: Untangling the Impacts of Climate Change on Waterborne Diseases: A Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Droughts. Environ Sci Technol. 2016; 50(1): 4095-4022. Published Abstract | Publisher Full Text | Free Full Text
21. WHO: Domestic Water Quantity, Service Level and Health. second edition. 2020. Reference Source
22. Peters M, Godfrey C, Mcinerney P, et al.: Chapter 11:Scoping Reviews (2020 version), Joanna Briggs Institute Reviewer's Manual. Aromatasis E, Munz M (Editors). 2020. Reference Source
23. Tricco AC, Lillie E, Zarin W, et al.: A scoping review on the conduct and reporting of scoping reviews. BMC Med Res Methodol. 2016; 16(1): 15. Published Abstract | Publisher Full Text | Free Full Text
24. Khalil H, Peters M, Godfrey CM, et al.: An Evidence-Based Approach to Scoping Reviews. Worldviews Evid Based Nurs. 2016; 13(2): 118-123. Published Abstract | Publisher Full Text
25. Mutono N, Wright J, Mutembei H, et al.: The nexus between improved water supply and water-borne diseases in urban areas in Africa: a scoping review protocol [version 2; peer review: 2 approved]. AAS Open Res. 2020; 3: 8. Published Abstract | Publisher Full Text | Free Full Text
26. Kramer WM, Rethlefsen ML, Kleijnen J, et al.: Optimal database combinations for literature searches in systematic reviews: A prospective exploratory study. Syst Rev. 2017; 6(1): 245. Published Abstract | Publisher Full Text | Free Full Text
27. Ashbolt NJ: Microbial contamination of drinking water and disease outcomes in developing regions. Toxicology. 2004; 198(1-3): 229-238. Published Abstract | Publisher Full Text | Free Full Text
28. Sharmila S, Kumar N: Dynamics of a waterborne pathogen model under the influence of environmental pollution. Appl Math Comput. 2019; 346: 219–243. Publisher Full Text
29. von Elm E, Altman DG, Egger M, et al.: The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. PLoS Med. 2007; 4(10): e296. Published Abstract | Publisher Full Text | Free Full Text
30. Calliams RM, Spake R, Brown KA, et al.: A rapid assessment of drinking water quality in informal settlements after a cholera outbreak in Nairobi, Kenya. J Water Health. 2015; 13(3): 714–725. Published Abstract | Publisher Full Text
31. Blanton E, Wilhelm N, O’Reilly C, et al.: A rapid assessment of drinking water quality in informal settlements after a cholera outbreak in Nairobi, Kenya. J Water Health. 2015; 13(3): 714–725. Published Abstract | Publisher Full Text
32. Stalter J, Fink G, Weeks Jr, et al.: When urban taps run dry: Sachet water consumption and health effects in low income neighborhoods of Accra, Ghana. Heal Place. 2012; 18(2): 250-262. Published Abstract | Publisher Full Text | Free Full Text
33. Winter S, Drombo MN, Barchi F, Exploring the complex relationship between women’s sanitation practices and household diarrhea in the slums of Nairobi: A cross-sectional study. BMC Infect Dis. 2019; 19(1): 242. Published Abstract | Publisher Full Text | Free Full Text
34. S, P, et al.: The 1995-1996 cholera epidemics in Dakar (Senegal). Med Mal Infect. 1999. Published Abstract | Publisher Full Text
35. Machdar E, van der Steen NP, Raschd-Sally L, et al.: Application of Quantitative Microbial Risk Assessment to analyze the public health risk from poor drinking water quality in a low income area in Accra, Ghana. Sci Total Environ. 2013; 449: 134-142. Published Abstract | Publisher Full Text
36. Kone-Coulibaly A, Thiamanga M, Shambira G, et al.: Risk factors associated with cholera in Harare City, Zimbabwe, 2008. East Afr J Public Health. 2010; 7(4): 311-317. Published Abstract | Publisher Full Text
37. Yilgwan C, Yilgwan G, Ishaya AI: Access to drinking-water in rural Nigeria: A descriptive study. J Heal Popul Nutr. 2010; 28(3): 424-435. Published Abstract | Publisher Full Text | Free Full Text
38. Yongsi HBN: Suffering for water, suffering from water: Access to drinking-water and associated health risks in Cameroon. J Heal Popul Nutr. 2010; 28(3): 424-435. Published Abstract | Publisher Full Text | Free Full Text
39. Barzilay EJ, Aghoghovbia TS, Blanton EM, et al.: Diarrhea prevention in people living with HIV: An evaluation of a point-of-use water quality intervention in Lagos, Nigeria. AIDS Care. 2011; 23(3): 330-339. Published Abstract | Publisher Full Text | Free Full Text
40. Oguntoke O, Aboderin OJ, Bankole AM: Association of water-borne diseases
morbidty pattern and water quality in parts of Ibadan City, Nigeria. Tansan J Health Res. 2009; 11(4): 189-195.

46. Dunne EF, Angorgan-Bénédic H, Kamel-Tano A, et al. Is Drinking Water in Abidjan, Côte d'Ivoire, safe for Infant Formula? J Acquir Immune Defic Syndr. 2001; 28(4): 393-398.

47. Usman A, Sarkinfada F, Mufunja J, et al. Recurrent cholera epidemics in Kano—northern Nigeria. Cent Afr J Med. 2005; 51(3-4): 34-38.

48. Nikhuwa DCW. Human activities and threats of chronic diseases in a fragile geologic environment. Phys Chem Earth. 2003; 28(20-27): 1139-1145.

49. Julvez J, Badé MA, Mathieu L, et al. Les parasitoses intestinales dans l'environnement urbain au Sahel. Étude dans un quartier de Niamey, Niger. Bull Is Soc Pathol Exot. 1998; 91(5): 424-427.

50. Dorie K, Kabeye K, Véronique B, et al. Water supply, sanitation and health risks in Yaoundé, Cameroon. Sci Technol. 2008; 2(11): 379-386.

51. Dos Santos S, De Charles Ouédraogo F, Soura AB. Water-related factors and childhood diarrhoea in African informal settlements. A cross-sectional study in Ouagadougou (Burkina Faso). J Water Health. 2015; 13(2): 562-574.

52. Traoré D, Sy I, Utzinger J, et al. Water quality and health in a Sahelian semi-arid urban context: An integrated geographical approach in Nouakchott, Mauritania. Geospat Health. 2013; 8(1): 53-63.

53. Abaje IB, Ati OF, Ishaya S. Nature of Potable Water Supply and Demand in Jema’a Local Government Area of Kaduna State, Nigeria. Res J Environ Earth Sci. 2009; 1(1): 16-21.

54. Degheye C, Makoitude M, Aqueh V, et al. [Factors associated with the quality of well water and the prevalence of waterborne diseases in the municipality of Abomey-Calavi in Benin]. Sante. 2008; 21(1): 47-55.

55. Mutu M, Gombe N, Tshimanga M, et al. Typhoid outbreak investigation in Dizavesekewa, suburb of Harare City, Zimbabwe, 2011. Pan Afr Med J. 2014; 18: 309.

56. Baecker KK, Sow SO, Kotloff KL, et al. Quality of piped and stored water in households with children under five years of age enrolled in the Mali site of the Global Enteric Multi-Center Study (GEMS). Am J Trap Med Hyg. 2013; 89(2): 214-222.

57. Schaetti C, Sundaram N, Merten S, et al. Comparing sociocultural features of cholera in three endemic African settings. BMC Med. 2013; 11(1): 206.

58. Akinbo FO, Okoike CE, Omorogbe R, et al. Molecular Characterization of Cryptosporidium spp. in HIV-infected Persons in Benin City, Edo State, Nigeria. Foglin J Heal Sci. 2010; 2(3-4): 85-89.

59. Von Nguyen D, Sneivisvan N, Lam E, et al. Cholera epidemic associated with consumption of unsafe drinking water and street-vented water—Eastern Freetown, Sierra Leone, 2012. Am J Trop Med Hyg. 2014; 90(3): 518-523.

60. Ubosi NE. Prevalence of diarrhoea among infants of child welfare clinics at two teaching hospitals in Lagos, Nigeria. J Appl Sci Environ Manag. 2018; 22(10): 1707.

61. Essayagh M, El Rhaffouli A, Essayagh S, et al. Epidemiology profile of fever typhoid in Meknes (Morocco) 2013-2016. Rev Epidemiol Sante Publique. 2019; 68(1): 45-49.

62. Navab-Daneshmand T, Friedrich MND, Gächter M, et al. Escherichia coli contamination across multiple environmental compartments (soil, hands, drinking water, and handwashing water) in urban Harare: Correlations and risk factors. Am J Trap Med Hyg. 2018; 98(3): 803-813.

63. Sinyange N, Brunkard JM, Kapata N, et al. Cholera Epidemic — Lusaka, Zambia, October 2017 - May 2018. MMWR Mortal Mortal Wkly Rep. 2018; 67(19): 556-559.

64. Endris AA, Tadesse M, Alemu E, et al. A case-control study to assess risk factors related to cholera outbreak in addis ababa, ethiopia, july 2016. Pan Afr Med J. 2019; 34: 128.

65. Sow PS, Diop BM, Maynart-Badiane M, et al. L’épidémie de choléra de 1995-1996 à Dakar The 1995-1996 cholera epidemics in Dakar (Senegal). Med Mal Infect. 1999; 29(2): 105-109.

66. World Bank and Infrastructure Consortium for Africa: Africa's Infrastructure: A Time for Transformation. 2010; 1-28.

67. Amroze S, Burt Z, Ray I. Safe Drinking Water for Low-Income Regions. Annu Rev Environ Resour. 2015; 40: 283-281.

68. World Bank and Infrastructure Consortium for Africa: Africa's Infrastructure: A Time for Transformation. 2010; 1-28.

69. AAS Open Research 2021, 4:27 Last updated: 20 JUL 2021
Open Peer Review

Current Peer Review Status: ✓ ✓

Version 1

Reviewer Report 20 July 2021

https://doi.org/10.21956/aasopenres.14345.r28652

© 2021 Antwi-Agyei P. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Prince Antwi-Agyei
University of Energy and Natural Resources, Sunyani, Ghana

Introduction:
1. “The sub-Saharan Africa (SSA) has experienced the highest annual urban population growth rate (more than 3.5%) in the world”. Which year or period is the growth rate being referenced to?

Methodology:
1. Any justification why authors used 2014 as the baseline year for the literature search? Meanwhile, the results section presented studies which were conducted before 2014. Some clarity is needed on this.

2. Also, any reason why the authors selected cities with population more than 500,000 as of 2014 as part of the inclusion criteria? This has also been stated in the abstract.

3. Table 1: The study focuses on urban African cities and there are over 50 countries in Africa and so what informed the choice of the ‘search terms’ for the cities listed under population? More explanation is needed to clarify this.

Results and discussion:
1. “A total of 32 articles that assessed the association of water sufficiency in urban areas and waterborne diseases and syndromes in SSA were published between 1998 and 2019”. Probably, the authors should provide some clarity because my understanding was that only studies from 2014 were included as part of the inclusion criteria in the methods section.

2. Figure 1 shows that a total of 2619 articles were recorded from the search which is different from what was stated in the main text under study selection of the results section (3099). Try and reconcile the two.

3. It is unclear why authors did not consider the quality of the published studies as one of their inclusion criteria. This seems important and would have influenced the outcome of the
scoping review and it is unclear how many of the final 32 studies were of poor quality. It would have been good for the authors to discuss the quality of the paper and link it to the strength of evidence these studies provided in terms of any associations between improved drinking water and water-borne diseases.

**Are the rationale for, and objectives of, the Systematic Review clearly stated?**
Yes

**Are sufficient details of the methods and analysis provided to allow replication by others?**
Yes

**Is the statistical analysis and its interpretation appropriate?**
Yes

**Are the conclusions drawn adequately supported by the results presented in the review?**
Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental Engineering, WASH, Solid waste management, faecal sludge management, Water quality, health risk assessment

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

---

Dickson W. Lwetoijera D. 1 Environmental Health and Ecological Science Department, Ifakara Health Institute, Ifakara, Tanzania 2 School of Life Sciences, Nelson Mandela African Institute of Science and Technology, Arusha, Tanzania

The reported scoping review is very detailed, and the provided methodology description is very detailed to allow replication. I do applaud the authors for jotting down a number of limitations that are important to consider, and they contextualized these finding across different cities in Africa. In the review studies, the authors noted that only 8 out of 32 studies provided details on sample size calculation; owing to the importance of this variable, especially when studies focus on quantitative data collection; it is important for the authors to recognize this as one of the
limitations. This is because the recorded findings/conclusion from included studies without sample size calculation details might have been either overstated or understated.

Are the rationale for, and objectives of, the Systematic Review clearly stated?
Yes

Are sufficient details of the methods and analysis provided to allow replication by others?
Yes

Is the statistical analysis and its interpretation appropriate?
Yes

Are the conclusions drawn adequately supported by the results presented in the review?
Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental Health Scientists, Medical entomologists,

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.