

Existing Published Evidence on Microbial Water Quality Monitoring under the umbrella of Water Safety Planning in Ethiopia and East Africa: A Systematic Review

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Systematic Review

Keywords: Water Quality, WSP, WQM, Indicators, Pathogens, Ethiopia, East Africa

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16
17 **Abstract**

18 **Background:** *Water Safety Planning (WSP) and Water Quality Monitoring (WQM)*
19 *implementation at the national level are two crucial steps to enhance the quality of drinking water.*

20 **Methodology:** *The objectives of this study were to contrast Ethiopia's WQM practices and methods*
21 *with those of other East African countries and the WHO's recommendations. Thus, the*
22 *microbiological data were generated by referring to relevant databases, including Scopus, Google*
23 *Scholar, and PubMed. Two independent reviewers examined the manuscripts. The analysis*
24 *included English-language publications on WQM subjects from 1990 to 2021. For the comparison,*
25 *eight representative Eastern African countries were chosen. These were Djibouti, Eritrea, Kenya,*
26 *Somalia, Sudan, Uganda, Rwanda, and Tanzania.*

Results: Under WQM topics, 3797 research papers were identified, and 3754 were selected after removing the duplicates (33) as relevant for the study. A total of 228 published articles were finally recruited for downstream analysis. Among these, 54 (24%) were from Ethiopia, whereas the remaining were from the indicated East African countries. Kenya had published the highest number, 74 (32.4%), whereas Uganda had 47 (21%), Tanzania 31 (14%), Sudan 13 (6%), Rwanda 5 (3%), Eritrea 1 (0.004%), Somalia 1 (0.004%), and Djibouti had none, respectively.

Discussion and Conclusion: Although various drawbacks were observed, there were some improvements or benefits as a result of applying WSP and WQM approaches at the city/town/regional level, but they were not sufficient.

Key Words; Water Quality, WSP, WQM, Indicators, Pathogens, Ethiopia, East Africa

Highlights

- East African regional research coverage had shown tremendous improvement on WQM topics, from none to 77%.
- Most research studies covered indicator testing rather than pathogens.
- In Ethiopia, the conventional culture technique was more extensively applied than the molecular technique.

Practitioner points

- Majority of the research activities conducted under the Water Quality Monitoring topic rather than Water Safety Planning, needs comprehensive approaches

- Environmental-based studies were dominated by clinical research articles, but balancing is mandatory to address the One Health issue.
- The detection of viral pathogens from water sources seen under detected in Ethiopia relatively compared to Kenya, Uganda and Tanzania, which needs attention

Graphical Abstract



Fig 1. Relationship between WQM and WSP

1. Introduction

Every individual on the globe must have access to safe water (WHO, 2017). Water is essential to life. It is one of nature's many gifts to all creatures. Regarding its consumption patterns by both people and animals, its quality and availability are also important. Numerous epidemics, illnesses,

and deaths have been reported as a result of drinking contaminated water. According to Agard et al. (2002), Osei et al. (2019), and Nguyen et al. (2017), all human, animal, microbiological, and chemical aspects of contamination contribute to the transformation of clean water into the most hazardous, unsafe water. By avoiding direct waste disposal into water bodies, open defecation, and animal infiltration, humans should ideally safeguard and maintain clean water supplies (Onda et al., 2012; Munene et al., 2019; Butterworth et al., 2013). But there are obstacles to these tendencies. In order to protect the community from serious illnesses, frequent implementation of water safety planning and water quality monitoring is becoming essential (WHO 2015; Hellar Kihmpa et al., 2017; Horman 2005; Lapworth et al., 2017).

There are already 9 billion people on the planet, and that number is rising. According to the 2017 study, 1250 million people from 56 countries make up 16% of these. Additionally, it is anticipated that Africa will grow its population by more than any other region of the world between now and 2050 (1.3 billion). Nearly all of this growth will take place in Sub-Saharan Africa's regions. As a result, it is difficult to supply clean water in proportion to such a large population. The ongoing catastrophic changes in climate conditions have made it more difficult to provide safe and sufficient water (Ahmeda et al., 2018; Akter et al., 2009; Anthonj et al., 2018; Simane, 2016). According to a study done in Ethiopia on the Upper Blue Nile Basin, the Nile River may encounter difficult circumstances in the future, such as decreased streamflow due to precipitation, rising evaporation, and decreased rainfall due to regional climate change (Roth et al., 2018).

There are physical, chemical, radiological, and microbiological risks to the quality of drinking water. Typhoid, typhus fever, diarrhea (including acute watery diarrhea), malaria, and viral-source illnesses, such as respiratory-related complications like tuberculosis, are among the common microbiologically infectious diseases in Ethiopia and the East African region that are either directly

or indirectly connected to water quality (WHO 2007). Additionally, there is no indication that the global level of Antimicrobial resistance (AMR) is decreasing (Kairigo et al., 2020; Adegoke et al., 2016; Kimosp et al., 2016).

1.1. Water Safety Planning and Water Quality Monitoring

Applying Water Safety Planning (WSP) and Water Quality Monitoring (WQM) activities at the national level is one way to enhance the quality of drinking water (Troyer et al., 2016; Wambu et al., 2016; Yergean et al., 2010). The foundation for supplying safe drinking water includes a water safety plan (WSP). By using a thorough risk assessment and risk management strategy that covers every stage of the water supply from catchment to user, this guarantees the safety of drinking water (Howard et al., 2006; Fuhrmann et al., 2014). It consists of three main parts and is an ongoing process. Determining whether the entire drinking water supply chain (up to the point of consumption) can provide water of a quality that satisfies health-based targets is known as system assessment (Omar et al., 2016; Rondi et al., 2015; Kanyesigy et al., 2019). The design evaluation standards for new systems are among them. Conversely, operational monitoring facilitates the identification of control methods in a drinking-water system that together identify risks and guarantee the achievement of health-based targets. An adequate method of operational monitoring should be established for every control measure to ensure that any variation from the desired performance is quickly identified. Actions to be conducted during the operation or incident conditions are outlined in the management plan (monitoring) section. Upgrades, enhancements, a monitoring and communication strategy, and future support initiatives are all included in the system assessment section (WHO 2012; Abu et al., 2020; Winkler et al., 2017).

Eleven steps or modules for implementing WSP procedures have been detailed in the WHO guideline. The first phase is to establish the WSP team, which is followed by an evaluation of the

system description. This module includes a description of the water safety system, identification of hazards and risks, validation of control mechanisms with risk prioritization, creation, implementation, and maintenance of improvement plans with an ongoing reassessment process. The third category is the monitoring step, which is carried out by establishing the control methods and confirming the WSP plans' efficacy. There are two modules in the management and communications process. These include creating supporting programs and formulating management procedures. The plans for improvement and feedback are covered in the final two modules. According to Okowa and Strover et al. (2018), these include creating and carrying out regular WSP review plans and making adjustments in response to accidents or emergencies.

Conversely, programs that are used to assess the quality of water under any conditions are the focus of water quality monitoring (WQM). Additionally, it includes many types of monitoring, such as source water monitoring, operational monitoring, verification monitoring, and so forth. It consists of an implementation strategy protocol (SOP) that covers method selection, sample collection and testing, surface and groundwater monitoring on a regular basis, and information on sampling, analytical techniques, data analysis, and reporting (WHO, 2012). It is one of the components and sub-components of WSP, and the monitoring component may also involve measuring or visually inspecting various chemical and microbiological elements, such as turbidity or pH (Alemayehu et al., 2019; Fuhrmann et al., 2016). There are currently few risk assessment and risk management programs in Ethiopia that support to improve the quality of drinking water. One such approach was RADWQ (Rapid Drinking Water Quality Risk Assessment Strategy) (Tadesse et al., 2010). In this trial, 1815 sites were chosen for cluster sampling between December 2004 and April 2005. Addis Ababa, Amhara, Dire Dawa, Oromia, Somalia, Tigray, and the Southern Nations, Nationalities, and Peoples' Region (SNNPR) were among the regions where the study was

undertaken. Using portable field kits for the physicochemical parameters and culture tests for microbial agents based on the WHO and the Ethiopian standard criteria, 1602 and 110 water samples were examined for thermotolerant coliforms and Fecal *Streptococci* enumeration. The findings disclosed 66.4% Fecal *Streptococci species* and 72% thermotolerant coliforms.

Such frameworks can be informed by water quality monitoring. Thus, the purpose of this review paper was to collect data on microbial water quality monitoring research outputs in Ethiopia and selected East African countries for a systematic evidence mapping and assessment of its relevance to water safety planning. Then, it focused on publication frequency as an indicator of the visibility and research activity of water-quality monitoring approaches and evaluated the microbiological findings, whether they were reports or articles. Research results covering various water sources, such as protected/unprotected wells, protected/unprotected springs, tap water, lakes, surface/river water, and household level, have received more attention. The dangers associated with microbiological drinking water quality that have been thoroughly investigated thus far and comparable reports were included for the regions in Eastern Africa.

2. Materials and Methods

The primary objective of this study was comparison of the published Ethiopian data with selected reputable Eastern African findings and the WHO guideline. Therefore, the PECO Cochrane standard format and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were used for formulating the research methodology.

Table 1 Research questions formulated for systematic review based on PECO.

WQM	
Population P=Types of participants	Water sources/ Drinking water systems, Laboratories (National, Regional, water utilities, Research centers, Universities)

E= Types of Interventions Microbial contamination, monitoring methods, WSP Implementation,

C=Comparisons(Comparison group/ Controls) Alternative methods, Regions and countries

O= Types of Outcomes Microbial indicators, pathogens, monitoring coverages, Risk Management outcomes,

All published studies and Review reports were retrieved, using, Scopus, Google Scholar and PubMed Database, searching Engines. The sub-specific goals of the research question was also to gather information about any changes from the baseline study. Thus, the emphasis was, whether the implemented WSP and WQM initiatives prevailed any quantifiable improvements in laboratories and water utilities at the national and regional levels. Had it also brought adoption of professional training or new technologies? and such approaches were investigated. The following phrases were employed as keywords:

WQM: [*E. coli*, Total Coliforms, Thermotolerant Coliforms, *Enterococcus*, *S. aureus*, *C. perfringens*, *Bacteriophage*, *Salmonella*, *Shigella*, *Vibrio*, Acute Watery Diarrhea, *Campylobacter*, *Diarrheagenic E. coli*, *Cryptosporidium*, *Giardia*, *Enterovirus*, *Norovirus*, *Rotavirus*, *Adenovirus*, *Hepatitis B*, *C*, *E*] AND Water Quality [Drinking Water, Tap Water/Piped Water, Well, River/Surface Water, Borehole, Spring, Lake, Household, Reservoir] AND [Ethiopia, Kenya, Uganda, Tanzania, Eritrea, Djibouti, Somalia, Sudan, Rwanda].

Within various water type categories, the screened publications were sub-grouped based on the nine countries, the indicators, and pathogen test findings. WQM is regarded as the primary focus of the study. The study sites, the country, the sample size tested, the methodology applied, the primary findings, the year of publication, the authors names, and the journal name were all recorded in the Excel sheet for each selected paper.

For computing data in the region, Djibouti, Eritrea, Kenya, Somalia, Sudan, Uganda, Rwanda, and Tanzania were included. Being part of a region (around the Horn of Africa) was one of the requirements for participation. Additionally, the research outputs; the reported organisms were grouped by species. In order to create summarized data, the microbiological category reported within the specified period and the testing method applied were also recorded. The analysis included articles on WQM concerns that were written in English between 1990 and 2021. The sampling strategy, sampling frequency, representativeness, laboratory methodology, analytical validity and their objectives were also taken into consideration as part of quality/ bias assessment. Studies with sample sizes of at least five or more were included, aiming to maximize the number of articles. Test findings that were only relevant to the topic were retrieved if the papers contained additional findings that differed from the target organisms. The two reviewers first independently review manuscripts and then made a dialogue whether they agreed or disagreed on some of the ambiguous papers since both satisfied with the majority. Then after series discussions, mutual decisions were taken for inclusion or exclusion of the papers as a resolution or bias minimizing strategies.

2.1. Quality of study, Design, Execution and statistical tools computation

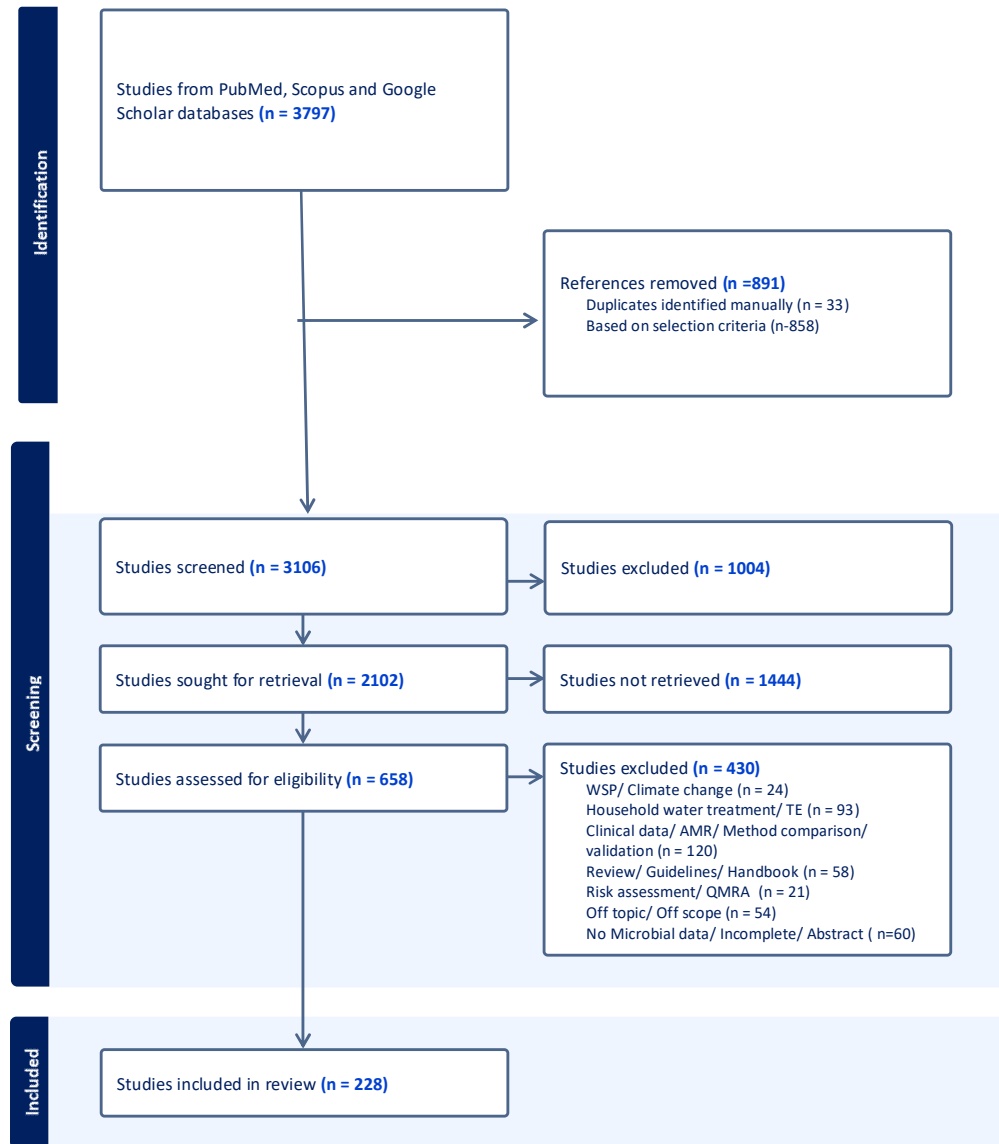
Reading the summaries of the gathered literature (EndNote or Mendeley) was the first step in the screening and selection process. After that, the complete articles were downloaded and evaluated. The duplicates were eliminated by sorting each reference alphabetically. Conversely, the collected literary works were removed if they addressed subjects unrelated to the current research area and their quality did not meet expectations. Too small a sample size and ambiguity were also considered as exclusion factors. In the end, an Excel database sheet was deployed to populate all the required data. The results of the recruited manuscripts' data were then pooled to evaluate the

189 overall quality. Using SPSS version 20, statistical values like proportions, mean, and standard
190 deviation with 95% confidence intervals were calculated. For the risk of bias assessment,
191 heterogenicity/variations among key domains were calculated and expressed in proportion.

192 Using both culture (presence/absence method, multiple tube fermentation methods, and membrane
193 filtration techniques) and molecular detection methods (PCR, real-time PCR, and sequencing), all
194 common indicators and pathogenic organisms reported from various water sources were also
195 maintained without any limitations.

196 **3. Results**

197 **Water Quality Monitoring (WQM)**



198

199 Figure 2: Flow diagram used for filtering the relevant papers

3797 research articles related to the WQM topic were retrieved by applying the specified databases: PubMed (1207), Scopus (796), and Google Scholar (735). Furthermore, two random keyword searches were conducted on Google Scholar to get additional information, such as grey or short report-published papers (604+455=1059). Then, 33 duplicates and 858 based on the screening criteria were removed in the first step. Then, 3106 were checked further, and 2102 were refined for inclusion; PubMed (677), Scopus (638), and Google Scholar (787) were used because they seemed pertinent to the study. Consequently, based on the criteria of abstract alignment with this project theme, 1444 were eliminated, and 658 manuscripts were chosen for the full-paper evaluation. Ultimately, 228 articles were deemed appropriate for the final evaluation, with the remaining 430 being excluded.

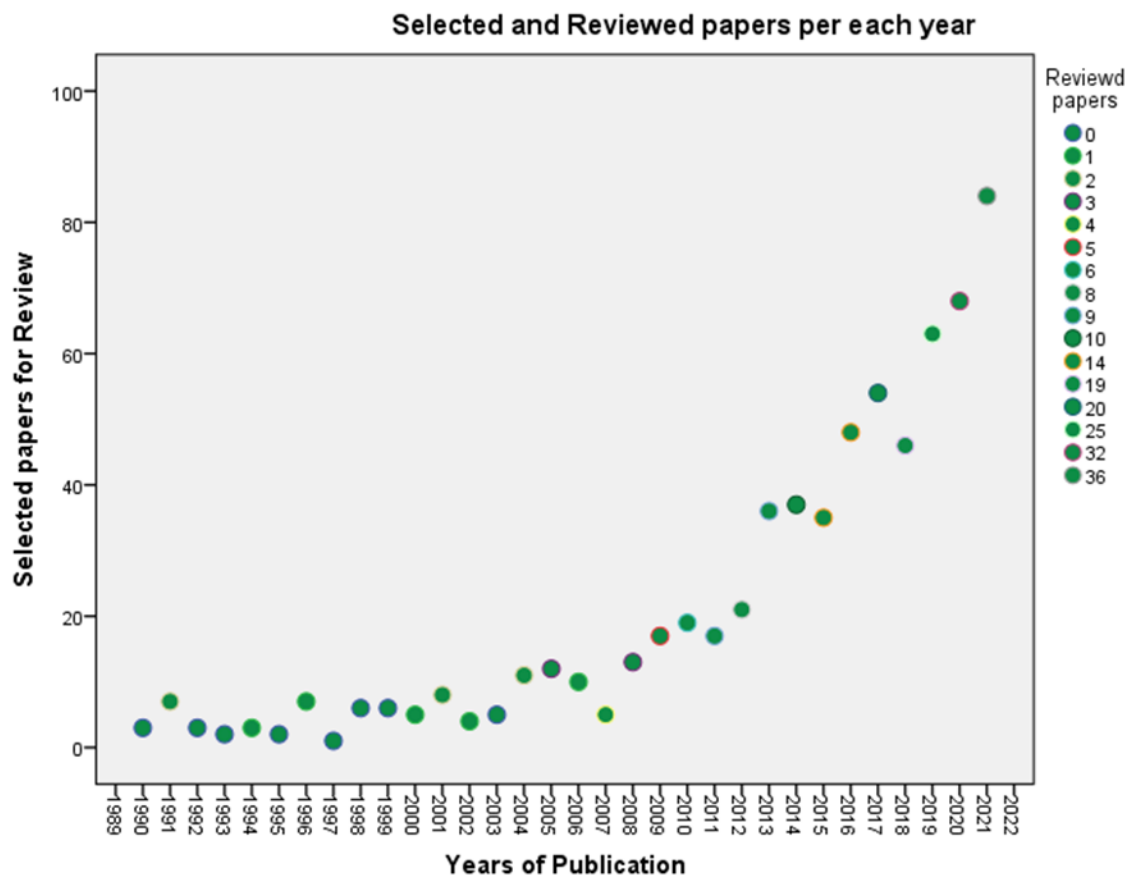


Figure 3. Numbers of published and selected articles under WQM topic per year.

The number of articles published increased from 1 to 84 between 1990 and 2021. Additionally, the number of final selected papers rose from 0 to 36 annually. The reviewed publications pertaining to Ethiopia are contrasted with the overall distribution of articles in the chosen Eastern African regions in the following two figures. Additionally, the first figure revealed the contribution of the countries in Eastern Africa.

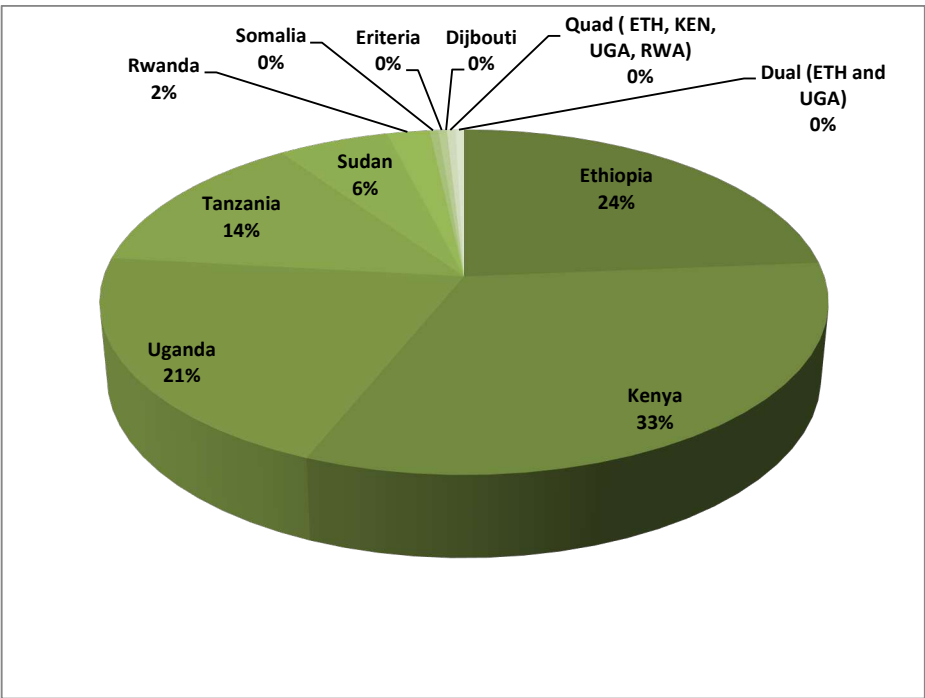
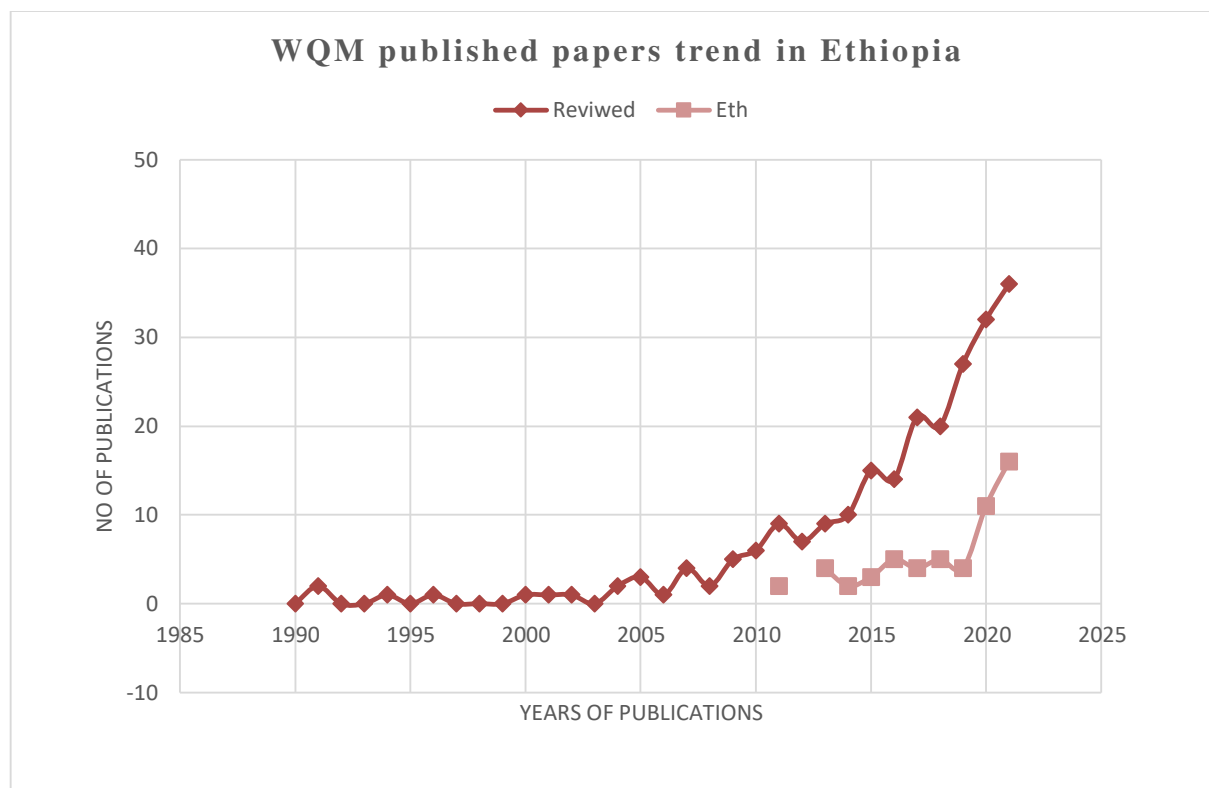


Figure 4. Papers examined for the East African study under WQM topics (Notes; Quad: Quadra national study, which encompassed four countries, Dual: When two nations are present, such as Ethiopia (ETH), Uganda (UGA), Kenya (KEN), and Rwanda (RWA))



222

223 Figure 5. Ethiopian papers published under the WQM topic in comparison to those from other

224 Eastern African nations.

225 Each region's contribution to the nation is computed. The largest number was found in the Amhara

226 region. The general distribution is shown in the following figure.

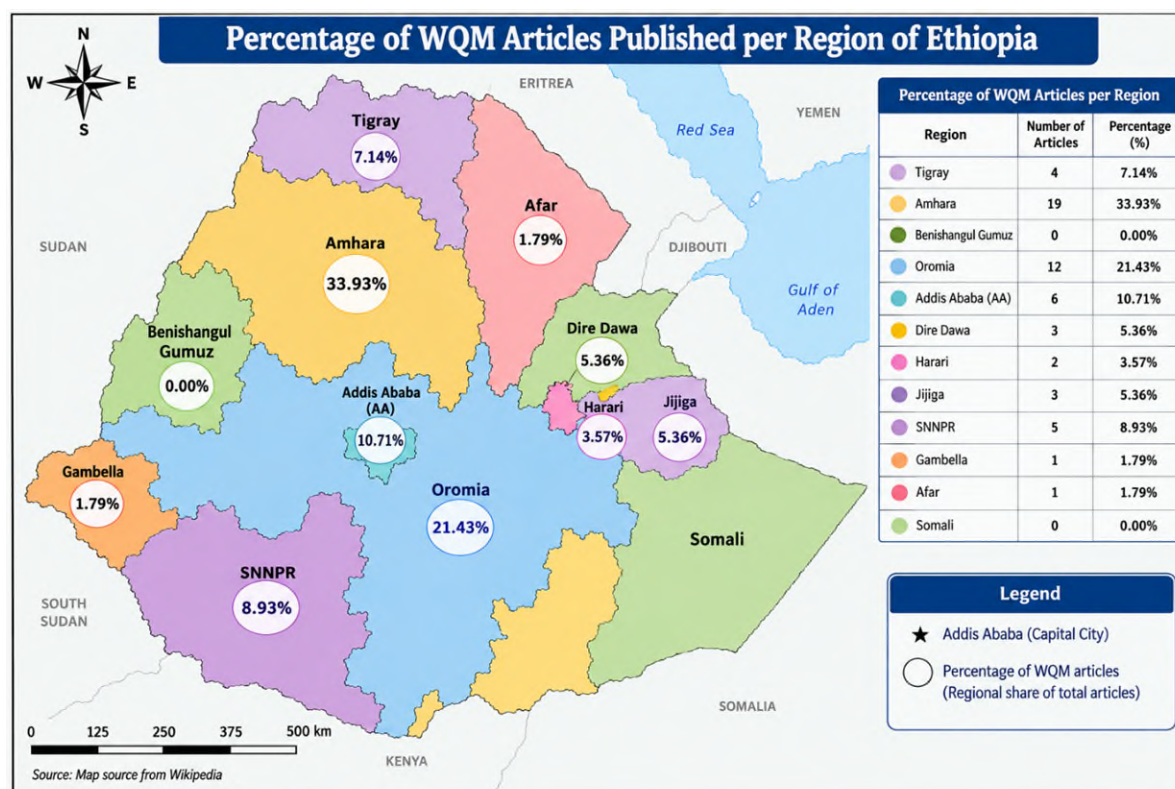


Figure 6; Frequency of WQM published papers per regions of Ethiopia (Notes; WQM- water Quality monitoring, SNNPR- South Nation and Nationalities and people Republic of Ethiopia)

There was no such publication in the Benishangul region

Table 2: Number of papers considered on indicators isolated from the water samples in comparison to the selected East African countries

Indicators	East African Countries									
	Djibouti	Eritrea	Ethiopia	Kenya	Rwanda	Somalia	Sudan	Tanzania	Uganda	Total
<i>E. coli</i>	—	1	30	43	1	1	5	18	19	118
T Coliform	—	1	33	26	3	1	2	11	15	92
F coliform/ - TTC	—	1	33	20	4	-	3	10	20	91
<i>F. streptococci</i>	-	-	2	4	1	-	1	4	3	15
Coliphage	-	-	1	-	-	-	-	-	-	1
<i>Enterococci</i>	-	-	2	6	-	-	1	4	1	14
<i>Bacteriodes</i>	-	-	-	1	-	-	-	2	-	3

<i>Clostridium perfringens</i>	-	1	1	5	-	-	-	2	-	9	2.6
Sorbitol Fermenting Bifido-bacteria	-	-	-	-	-	-	-	1	-	1	0.2
Total	0	4	102	105	9	2	12	52	58	344	

Besides, the distribution of indicator pathogens among the Eastern African countries was categorized. The following graphics display the pathogen distributions.

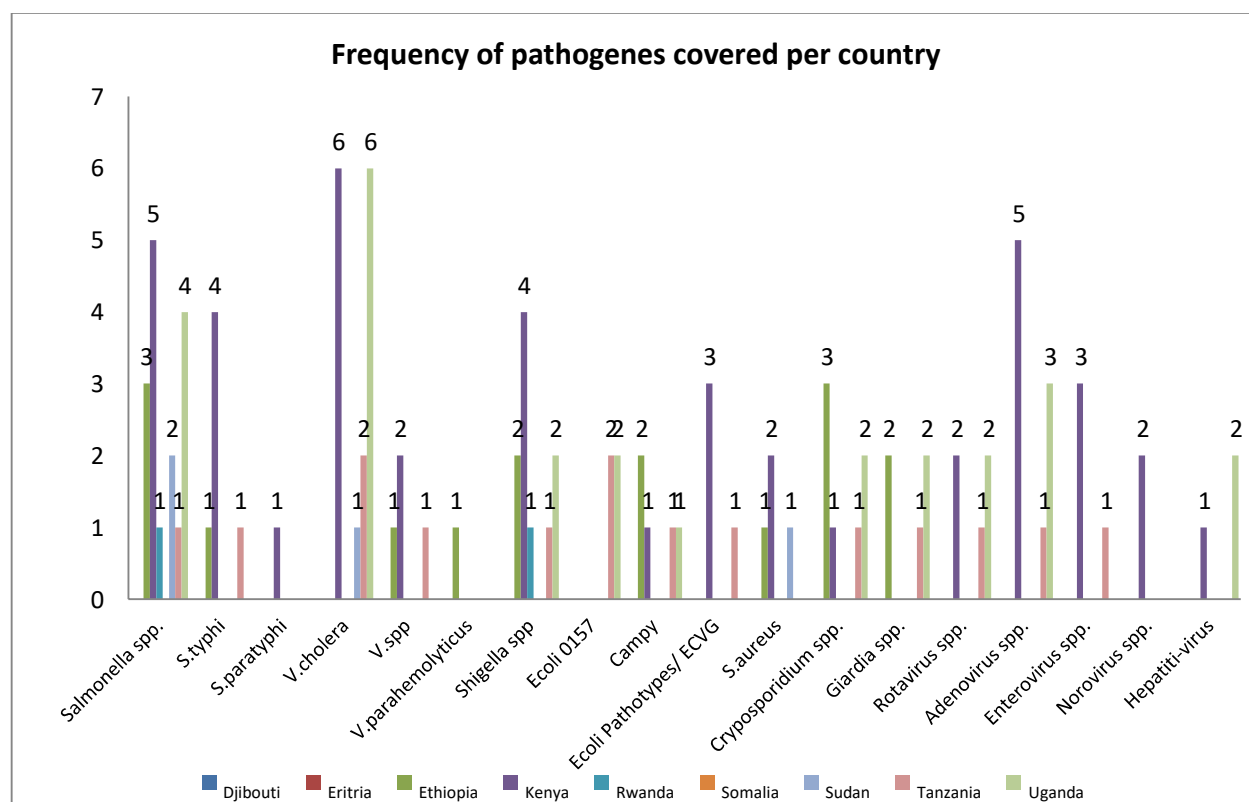


Figure 7; Frequency and types of pathogens isolated per country

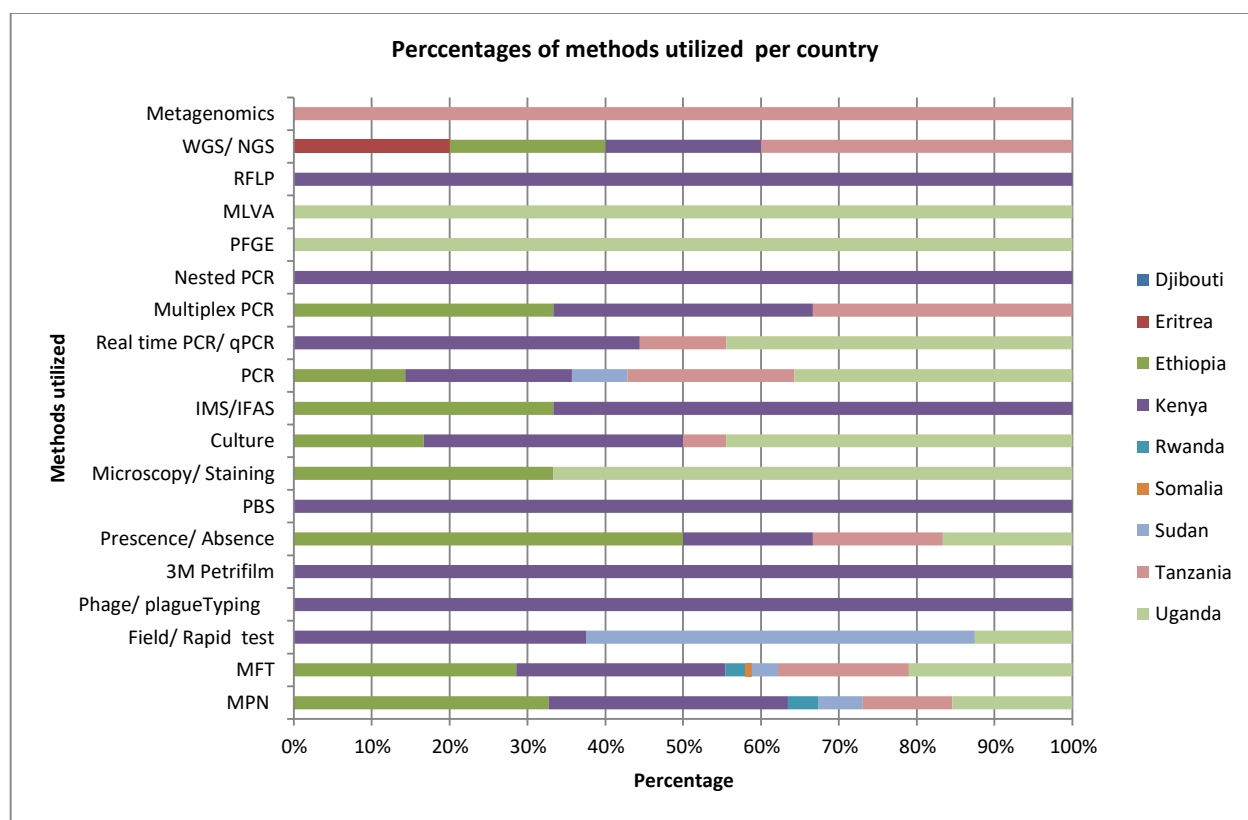


Figure 8: Types of methods utilized for testing per country (Notes; WGS/ NGS= Whole-genome sequencing/ Next generation sequencing, RFLP= Restriction Fragment Length Polymorphism, MLVA= Multiple-Locus Variable-number Tandem Repeat Analysis, PFGE= Pulse-Field Gel Electrophoresis, PCR= Polymerase Chain Reaction, qPCR =Quantitative Polymerase Chain Reaction, IMS/ IFAS=Immuno-magnetic Separation Assay/ Immuno-Fluorescence Antibody Staining Assay, PBS= Phosphate Buffered Saline, MFT=Membrane Filtration Test, MPN= Most probable Number)

In relation to the water sources, the number of indicator organisms reported was displayed in the following table.

Table 3: Types of indicator organisms identified per different water sample sources in selected East Africa regions.

Indicator organisms reported from source waters

Types of SW	Frequency	<i>E. coli</i>	TC	TTC	<i>F. strep.</i>	Enteroc.	Cl perf.	Colip.	Bacter.	X±SD
Ground water	120	70	57	50	9	6	6	-	1	28.4±26.2
Surface water	98	46	39	28	7	7	7	-	-	22.3±15.3
Drinking water	120	70	45	48	6	8	1	1	-	25.5±24.6
Rain water	18	12	6	6	2	3	1	-	-	5±3

Notes; SW= Source waters, **Ground water** (Well, Shallow, Deep well, Tube well, Pump well, Spring, Hot spring, Bore Hole, Hand Dug well, Dug outs, Hand pump, Scoop Holes, Beyiolle), **Surface water** (River, Surface, Lake, Lake shore, Swamps, Pond, Main source, Stream, Test Holes, Open water, Open drainage, Earth water pan, Sea, Dam, Wetland, Beaches/ channel, Bank), **Drinking water** (Tap, Piped, Household, Reservoir, Storage (tanker), Public water pots, Water points, Distribution networks, Treatment plant, Public storage, Tanker, HH water storage, Tanker, Public water, Coolers, HH untreated, Stored water, HH treated, Water vendor, Standpipe (Out of the house), In house water Storage) ; **Rain water** (Roof

water, Rain water, Rain water harvest); TC=Total Coliform; TTC=Thermotolerant Coliform, F strep = *Streptococcus fecalis*, Entero= *Enterococcus*, Colip= Coliphages, Cl perif=*Clostridium periferogens*; Bacter = Bacteroides; X=Mean, SD =Standard Deviation

4. Discussion

Access to clean drinking water is still the biggest challenge, despite the fact that many African countries have heavy rainfall each year (Yongsi et al., 2010). In most regions, research-based studies targeting clinical samples outnumbered those targeting environmental sources. Kenya, Uganda, and Tanzania were more likely to pursue health-related research, according to the Sub-Saharan review report (Wambu et al., 2016). Furthermore, water bodies such as wells were built downhill next to pit latrines or septic tanks in slum areas, where fecal contamination is more noticeable (Nigatu et al., 2015).

Instead of applying WSP regularly most of the selected papers focused on WQM concerns. Articles that evaluated at least one of the indicators, pathogen organisms, or both were seen. Our pooled findings revealed that investigations on pathogens were primarily conducted using clinical samples rather than environmental sources as explained above. This trend is similar in East Africa and in other underdeveloped nations. Although there were pertinent published articles from clinical samples in Somalia, Djibouti, and Eritrea, they were excluded because this was not the study's main emphasis.

4.1. WSP

In line with WQM, a random Google Scholar literature review was conducted, and data were retrieved under the WSP topic to show their connection. A total of 38 papers were collected, and 31 were selected as relevant based on off-topic and too-old criteria from the years 1990-2021. One paper appeared twice, and the duplicate was then removed. Finally, 25 papers were included for

WSP review. These were 16 from Ethiopia, 2 from Kenya, and 3 from Uganda. Two worldwide studies, which included one of the Eastern African countries. In a similar way to the other two studies, which encompass sub-Saharan African countries and focused on one of the Eastern African countries, these studies were incorporated.

The selected papers raised various topics, most of which were not directly covered all the WSP modules. If anybody needs such fully incorporated WSP reports, it is difficult to find. Therefore, the author urged to pick some related issues: WSP (5 papers), although not all the modules were included; risk assessment (3); climate resilience/change (12); monitoring and improvement (5); water supply management and sustainability (1); sanitation and hygiene (3); water safety planning and water quality monitoring (2). Some of the papers picked more than one of the above topics.

In Ethiopia, few published papers had elaborated that WSP measures that have been undertaken in the country are very few and confined only to some water utilities (Rickert et al., 2019; Van den Berg et al., 2019). The AAWSA (AA) and AWSEE (Adama) are the two major water treatment plants in the country and are authorized to regulate the Dire, Legedadi, Geferesa, and Adama treatment plants (KOKA dam), respectively. From a recent unpublished paper report, almost similar trends were observed in every town/city of the country in the implementation of WSP and WQM strategies. However, the deed had varied from place to place and was not as equivalent and firm as the above two.

In AAWSA and AWSEE, regular WSP and risk assessment activities to identify main threats in the water abstraction sites, in the pipeline system, and in the distribution area, including testing of water samples after passing the treatment phases for both microbial and physicochemical parameters, have been deployed. However, the improvement plan and control measures were taken mostly when the need arose and became very necessary, which hindered the implementation of

WSP as the standard criteria set by WHO. The main problem identified for the water utilities was quantity issues rather than quality, as reported. Although the government has devoted itself to digging of supplementary groundwater sources in every location, the population growth in the country has been alarmingly increasing from time to time. Furthermore, the life status of the community is continuously changing and relies on the consumption of huge volumes of water per day. Although such efforts have been made continuously, most of the communities get water intermittently.

A few projects supported these endeavors by WASH and other non-governmental stakeholders, like the S2TAB project, which have brought some improvements in the two indicated sites. Similarly, other East African countries also reported some progress regarding WSP, but not in regular, adequate, or complete terms. For instance, Parker and Summerill (Parker and Summerill, 2013) identified the main barriers and motivation factors. They reported that lack of cooperation, awareness, motivation, and involvement of key staffs were identified as main barriers since the procedure seeks multiple site visits and follow-ups. Additionally, the water utilities engaged in such activities were the only ones per city. Moreover, inadequate cooperation from the stakeholders was indicated as an additional barrier. Therefore, the key motivation factors reported were to motivate staffs and bring improvements in terms of upgrading standards, reducing Non-Revenue Water (NRW), and increasing savings by providing incentives. Support from other stakeholders and the utilities were also mentioned as crucial entities (Parker and Summerill, 2013).

4.2.WQM

The selected research activities linked to published data on WQM subjects were further refined. For the downstream analysis, 228 published papers in total were chosen (Fig. 2). Of these, 54/228 (24%) were from Ethiopia, and the rest came from the East African nations listed. Kenya published

more articles than Ethiopia, 74/228 (32.4%), followed by Uganda with 47/228 (21%), whereas Tanzania had 31/228 (14%), Sudan 13/228 (6%), Rwanda 6/228 (3%), Eritrea 1 (0.004%), Somalia 1 (0.004%), and Djibouti none (Fig. 4). From zero in 1990 to 36 papers in 2021, the overall publication trend (in keeping with this paper's goal) had shown a remarkable improvement (Fig. 3).

4.2.1. Ethiopia

Twelve river basins and about fourteen large lakes and reservoirs are among Ethiopia's diverse physical and climatic features (Merid et al., 2009). Compared to water safety planning, the majority of studies published in the nation focused on monitoring water quality (Fig. 5). Reports on the latter were few. Even the monitoring elements weren't as consistent as anticipated. Additionally, they were incorporated at a few water utilities, regional, and national laboratories. Regular microbiological and certain physicochemical parameters had been observed both before and after the water sources were treated, based on the site visit report in the two water utilities (Addis Ababa and Adama water and sewage laboratories). Nevertheless, because these findings were not formally published, they were not included. In terms of particular site distribution, the Amhara region published the most papers (19/54, or 35%), followed by Oromia (12/54, or 22.2%) (Fig. 6).

4.2.2. Indicators identified from water samples

Monitoring water quality activities requires the use of the culture technique to identify indicators and pathogens in the water sources. For example, the overall East African WQM published works showed a positive impression/increase. This facilitates the creation of evidence if the geographical mapping of the gathered data is illustrated. For example, fecal and total coliforms were utilized as

hygienic or sanitary markers for contaminated water. Their prevalence in the water samples was found to be 92/344 (26.7%) and 91/344 (26.4%), respectively, in the Eastern African regions, according to extensively studied literature. In terms of *E. coli*, which was thoroughly investigated in accordance with the WHO recommendation as a recent indicator of fecal contamination, it was covered in 118/344 (34.3%) cases (Table 2).

Many warm-blooded animals' guts are colonized with *E. coli*, which are further classified as intestinal and extraintestinal disease-causing species, and the majority harbor AMR genes. The pathogenic strains such as ETEC, EIEC, EPEC, EAEC, and STEC are also well known. Human intestinal and extraintestinal complications are also reported (Luther et al., 2017). Based on the Cambodian research findings, 437 (14.4%) of the 3,034 children who had medical examinations experienced diarrhea associated with *E. coli* (Yongsi, 2010). Likewise, another study from Cambodia found a strong correlation between diarrheal cases and *E. coli* concentration of more than 11 CFU per 100 mL (Vannavong et al., 2018).

These diseases mostly affect rural dwellers who depend on alternative water sources, such as rivers and boreholes, for personal and household cleaning purposes. The risk is significantly larger because the standard treatment approach could not be extended to these areas, as in the case of urban piped water customers. The Ugandan study report examined the levels of anti-flagellin IgG and the Environmental Enteric Dysfunction (EED) marker for *E. coli* infection in toddlers who used rainwater against those who consumed other water sources. The latter patients had low IgGAB and EED indicators, even lower than individuals who used improved water sources (Lauer et al., 2019). These demonstrated that, when compared to even piped water, rainfall typically has lower *E. coli* counts in most cases; however, these circumstances may not always be true, as demonstrated in a study conducted in Laos and Thailand (Vannavong et al., 2018). Besides, such

water sources can acquire antibiotic-resistant genes from the contaminated environment, which is a recurring challenge that is detrimental to both human health and the country's economy. Additionally, it presents a number of risks to the environment and public health (Igwaran et al., 2018). A few articles from Eastern Africa also mentioned other indicators, such as *Clostridium perfringens*, *Bacteroides*, *Streptococcus fecalis*, and *Enterococcus species*, including the *Coliphages*, which Skraber et al. investigated as a viral source contamination indicator (Table 2) (Skraber et al., 2004).

Total dissolved substances (TDS), total suspended substances (TSS), biological oxygen demand (BOD), nitrate and phosphate concentrations, turbidity, and electrical conductivity are some of the examples of physicochemical analyses that are regarded as positive indicators for chemical risk quantification but were not included in this study because they were deemed off-topic (Yasin et al., 2015).

4.2.3. Types of indicators and pathogens isolated from the selected East African countries

A total of 102 literary works were gathered in Ethiopia. 33 of these were found to be indicator organisms. Total. Coliform, thermotolerant coliform, and *E. coli* were the most frequently examined indicator species, appearing in 33 (32.3%), 33 (32.3%), and 30 (29%) investigations, respectively. With an isolation range of 1 to 8, *Salmonella*, *Vibrio*, and *Shigella* were the most studied species from the perspective of pathogenic organisms in 4 out of 8 (50%) studies. From surface water and spring samples, Negera and Gebrewahd (Negera et al., 2017; Gebrewahd et al., 2020) isolated 8/93 (8.6%) *Salmonella* and 7/290 (2.4%) *Shigella species*, respectively. Additionally, 2/8 (25%) of the experiments reported *Giardia* and *Cryptosporidium species*. Kenya was the first East African nation to report a variety of pathogens, including up to eight genera of

viral origin (*Rotavirus*, *Norovirus*, *Enterovirus*, *Hepatitis virus*, *Astrovirus*, *Sapovirus*, *Adenovirus*, and *PMMOV virus*) (Kiulia et al., 2010 and Van Zyl et al., 2019).

4.2.4. Isolated pathogens from water samples

According to Okaali and Hofstru (2018), most of the pathogens identified from East African water samples are considered high-risk disease-causing organisms worldwide (Fig. 7). For example, diarrheagenic *E. coli* causes urinary hemolytic syndrome and generates toxins. The pathogen spreads through the fecal-oral route as a result of environmental pollution and interpersonal contact. For example, in 2006, Tanzania reported that patients with diarrhea had *E. coli* O157, which produced Shiga toxin. STEC O157:H7 was also found in goat and sheep feces (4.7%), skin swabs (8.7%), carcasses before and after washing (8.1%), water samples (4.2%), and beef, mutton, and chevon (8, 2.5, and 2%), according to reports from Kenya and Ethiopia (Lupindu et al., 2017). Mekonen et al. (2014) is the only author to publish in the water samples, from Ethiopia before the year 2022.

According to four investigations, the prevalence of *Salmonella* and *Shigella species* in Ethiopian reservoir samples was as high as 20% (Asfaw et al., 2016). It is generally known that *Salmonella* can induce typhoid fever and potentially fatal diarrhea in children and other age groups. It has been isolated from water sources in various studies, including those conducted in East Africa.

In addition to the above-mentioned pathogens, *Campylobacter* is a foodborne and waterborne organism that can cause a number of threats for both humans and animals. Few studies had examined water samples in the East African region. From South Africa, for instance, three types of *Campylobacter species* were reported from drinking water sources: *Campylobacter jejuni* was found to be 13.2% and 35.7% in stored tap water and well water, respectively, while

417 *Campylobacter coli* was 10% and 30%. *Campylobacter upsaliensis* was revealed to be 100%
418 susceptible to imipenem (Chukwu et al., 2019).

419 Concurrently, acute watery diarrhea caused by the other pathogen, *Vibrio cholerae*, can be lethal
420 if left untreated. From August 2006 to September 2008, O1 Inaba variant's resistance to
421 cotrimoxazole, chloramphenicol, ampicillin, erythromycin, tetracycline, and ciprofloxacin was
422 reported from Kenya. Similarly, from 1998 to 1999, O1 strain resistant to tetracycline,
423 spectinomycin, chloramphenicol, and cotrimoxazole was recorded in another Kenyan report.
424 Cotrimoxazole-resistant O1 EL Tor was also detected in Rwanda in 1994 (Osunla C.A. and Okoh
425 A.I. 2017). According to four publications, up to 20% of Ethiopian water samples (reservoirs) had
426 *Vibrio cholerae* (Asfaw et al., 2016).

427 Besides bacterial pathogens, the protozoan parasites *Giardia duodenalis* and *Cryptosporidium*
428 *species* are also known to be linked to waterborne epidemics. (Limehelluw et al., 2019). Their
429 survival mechanism in water sources is facilitated by their ability to resist chemical disinfectants
430 and their stability to remain viable for six to twelve months in the environment. To be acceptable
431 in treated drinking water, their oocyst (cyst) (size 1–17 µm) concentration should be as low as 1
432 per 10 liters. *Rotavirus* is the sole pathogen that outcompetes *Cryptosporidium* (Ahmeda et al.,
433 2018) by causing moderate to severe diarrhea in infants under two years of age. According to
434 Fikre's article, 22 water samples from Ethiopia contained *Cryptosporidium* oocysts, and 73%
435 *Giardia* cysts (Fikre et al., 2008).

436 The other viral index pathogen, *Enterovirus species*, was extensively recognized due to its high
437 proliferation in ambient and sewage samples (Muir et al., 1998). Their survival mechanisms
438 include proliferation and aggregating in sewage and water sources, facilitating the emergence of
439 resistance to common disinfectants. For example, out of 95 water samples, they were isolated from

48.4%. However, according to the Peshawar, KPK, Pakistan study report, ultrafiltration or the use of more potent agents like sodium deoxycholate or chloroform could prevent such viral action (Ahmed et al., 2016). Using the RT-PCR method, Miao et al. (2018) reported a 9.2% association between *Enterovirus* and the sanitation indicator, total coliform count in surface waters. Though it was not reported since 2021 from Ethiopia, it was recorded in children under five years of age. Seven *Enterovirus* A, twelve *Enterovirus* B, and twelve *Enterovirus* C related infections were uncovered in the Amhara region (Altan et al., 2018). Tiwari S. and Dhole T. N. and Rusinol M. and Girones, R. (Tiwari S. and Dhole T. N., 2018; Rusinol M. and Girones, R., 2017) reported similar findings from other water sources outside of Ethiopia.

Likewise, since *Rotavirus* was thought to be the most common cause of diarrhea in children under two, many researchers were drawn to it (Ahmad et al., 2016; Ochieng et al., 2019; Kiulia et al., 2010; Rusinol, M., and Girones, R., 2017). Each gram of feces from an infected person is indicated to contain 10^{10} – 10^{12} *Rotavirus*. 2% of children in Kenya were admitted to hospitals because of group A *Rotavirus* infection (Nokos et al., 2008). Additionally, it was detected in surface water at rates as high as 70.8% (Miao et al., 2018). *Rotavirus* infection, related to water treatment emission reduction (Okaali & Hofström, 2018), different *Rotavirus* genotypes (Michaile et al., 2017), and *Rotavirus* infection associated with vaccination (Malekalinga et al., 2019) had all been the subject of numerous studies or reviews. A prevalence rate of 6–56% in patients with diarrhea was observed in one of the Kenyan review reports. Up until 2002, G1 genotype cases were more common, however, G9 and G8 had lately been recorded in emergency situations (Kiulia et al., 2008). Similarly, out of 95 water samples examined in rural Peshawar, KPK, Pakistan, 9.47% proved positive for RV (Ahmad et al., 2016). In Ethiopia, no such studies had been communicated from water sources since 2022.

From surface waters, *Norovirus* strains (NoVs (GI and GII)) were reported from South Africa and Kenya. The most common genotype rooted in the majority of studies was strain NoVGII. 4. Similar studies witnessed G11 in 81.3% of surface waters (Miao et al., 2018) and GII.3 and GII.6 (Mans et al., 2016). While Kenya and Tanzania reported comparable results, Ethiopia did not. G1 21/73 (53.8%) contributed the most distribution among *Norovirus* strains per the Michale et al., 2017 study. Based on Tanzanian reports, the efficacy of the *Norovirus* vaccine ranged from 53% to 75% (Malakalinga et al., 2015). Similarly, Mattioli et al. (2015) reported 5% *Norovirus* GII strain from mothers' hand rinse samples. In contrast to *Enterovirus species*, *Norovirus* had been thoroughly covered in relation to water contamination (RT-PCR) (Fout et al., 2016; Altan et al., 2018; Rusinol, M., and Girones, R., 2017; Cheng et al., 2017).

Lately, the most contagious viral pathogens, such as *Hepatitis A* and *Hepatitis E* viruses, are identified in association with the other viral pathogen, *Adenovirus species*, as an index pathogen. They are durable in difficult conditions because they are resistant to strong chemicals and disinfectants, including UV radiation (Guerrero-Latorre L. et al., 2011). In Peshawar, KPK, Pakistan, it was reported as high as 38.94% for HAdV (Ahmad et al., 2016). Miao et al. (2018) also reported 91.7% from surface water. Several studies approved that *Adenovirus* could act as a viral contamination indicator for HAV and HEV contamination of water sources.(Altan et al., 2018; Rusinol, M., and Girones, R., 2017). There were no similar reports from Ethiopia up to 2022.

Hepatitis viruses can also induce Liver inflammation and be spread by tainted water (Rusinol, M. and Girones, R., 2017; Grabow et al., 1996; Ochwoto et al., 2016). The known subtypes that can cause both acute and chronic liver disorders are HAV, HBV, HCV, HDV, and HEV. According to the WHO 2013 worldwide data, chronic liver disease caused by HBV and HCV afflicted around

240 million and 150 million individuals, respectively. Ethiopia is endemic for all forms of viral hepatitis. The nation is categorized by the WHO as one of the geographical areas where viral hepatitis infection is intermediate to hyperendemic. According to the Belyhun et al. (2016) review report, the anti-*Hepatitis C* virus antibody (anti-HCV) was disclosed as 3.1% (95% CI: 2.2–4.4), and the overall pooled prevalence of *Hepatitis B* virus (HBV) was 7.4% (95% CI: 6.5–8.4) from the years 1968–2015. The majority of the studies concurred that the results were underestimated due to testing gaps and lack of attention. For instance, HAV in surface water was found to be 12.63% in Pakistan (Ahmad et al., 2016). As with the viral-related communications mentioned above, there were no reports from Ethiopian from the water sources till the end of 2021.

4.3. Methodologies applied for testing

Nineteen different methods were utilized for the microbiological testing per this review paper theme (Fig. 8). The Membrane Filtration Technique (MFT) and Most Probable Number (MPN) accounted for 84% of the study reports, making them the most popular in Ethiopia. Bedada et al. (2018) and Fikre et al. (2008) applied phage typing and immunofluorescence assay, respectively. A single study applied microscopy to verify stained slides for the identification of *Giardia* and *Cryptosporidium species*, while four investigations deployed fast kit/strip testing. In Kenya (Kiulia et al., 2010; Van Zyl et al., 2019), Uganda (Katikiza et al., 2013), and Tanzania (Mattiolet et al., 2014), advanced methods like PCR/RT-PCR and molecular marker detection were used. These techniques detect microbial nucleic acid. However, these do not necessarily verify the presence of viable organisms in the samples, since the test parameters have the potential to screen and quantify dead organisms. It might also not tell the infectious dose or human disease risk. Man et al. (2014) from Kenya and G. Hilemichael et al. (2021) from Eritrea also used Illumina and Next-generation

techniques for nucleotide sequencing. Based on these data, it may be inferred that Ethiopia had very few advanced technology applications trend before 2021.

4.4. Types of water sources

Thirty-one water source types were categorized into four streams per the reports collected in the selected manuscripts (Table 3). Besides, two major classifications, improved water sources (pipes, wells, reservoirs, and springs) and unimproved water sources (rivers/surface water, lakes, ponds, boreholes, and hand pumps), were listed in the Excel worksheet. The majority of studies conducted in Ethiopia focused on drinking water and groundwater (N = 120 for each). Their computed mean and standard deviation were 28.4 ± 26.2 and 25.5 ± 24.6 , respectively. Regarding individual source coverage, piped/tap water was tested by 21/31 (68%), well water by 19/31 (61%), and spring water by 16/31 (52%) studies. In terms of different sampling categories, Guo D et al. (2021) covered seven water sources from Tanzania, followed by Ambel et al. (2020) and Negara et al. (2017), who investigated five water type groups.

There was no statistically significant overall association between countries and the type of water-quality indicators published in papers based on the Pearson chi-square tests. However, there was a linear positive relationship between the indicator species and the water sources with $r > 0.92$. The chi-square ($\chi^2(56)=14.83$, p -value of 0.83) and one-way ANOVA (F-statistic (1.46, $p=0.247$)) results revealed an insignificant distribution across the four water categories at a 95% confidence level.

The quality evaluation verified that the statistical programs utilized for sample collection and result analysis adhered to the specified guidelines in every study. Additionally, the majority of the results that were communicated were computed using percentages, which were then followed by mean,

530 median, odds ratio, correlations, *p-value*, and various graphical plots to further explain the
531 findings. In this review study, since there wasn't sufficient data on the pathogens, indicator values
532 were incorporated to compare the relationships between countries' findings.

533 Risk of Bias estimation was assessed to validate which domain might have more heterogeneity
534 among the sampling strategy, sample representativeness, Laboratory method utilized, the sample
535 size, Quality control and the statistical analysis. Based on the risk of bias estimation, sample sizes
536 revealed more heterogeneity than the remaining from 6-1030 range, estimated as moderate risk
537 scores of 50%. The majority of others (>90%) lie in the low-risk category.

538 In conclusion, in order to determine potential intervention strategies in each region, the nation
539 requires such evidence-based study results. Additionally, comparable projects, programs, and
540 activities have to be carried out continuously. The majority of Ethiopian publications pertaining to
541 water sources concentrated on indicator species. Pathogens such as *Salmonella*, *Shigella*, *Vibrio*,
542 *Cryptosporidium*, and *Giardia species* are mentioned in a few publications. In contrast to Kenya,
543 Uganda, and Tanzania, viral diseases are virtually untouched or studied from the perspective of
544 water supplies. These could be due to several factors, such as limited molecular capacity, cost, lack
545 of reagents, lack of surveillance programs, or research priorities.

546 Furthermore, the conventional culture approach with low-sensitivity biochemical assays and
547 minimal use of cutting-edge technology were noted. In some investigations, a small number of
548 molecular technologies were used, although their coverage was lower than that of the three nations.
549 Overall, the adoption of modern advanced methodology and technology transfer initiatives by
550 laboratories were found to be quite modest, or applied only from the perspective of clinical
551 laboratories.

However, this does not mean the molecular methods overruled culture, but instead both are complementary. This is because culture tests always remain important since it provides viable organism detection, phenotypic characterization, antimicrobial susceptibility testing, and lower-cost surveillance. On the contrary, molecular methods support greater sensitivity, faster detection, specific pathogen confirmation, strain characterization, and genomic epidemiology. Therefore, upgrading the integrated diagnostic capacity is crucial.

For many years, there has been minimal advancement in the discipline of Public Health Microbiology (MOH), which is involved in Food/ water testing and research. Examining the National Public Health Microbiology Laboratory makes it easy to see how serious the issue is. Due to prolonged supply constraints, its ability to use cutting-edge technology like RT-PCR and whole-genome sequencing is nearly nonexistent till 2021. The viewpoint of the water utility is similar to this one as well (MOWIE). The donor-oriented research initiatives encompassed some of the advanced methodologies that were employed by PhD or MSc students who interact with research organizations or foreign universities. These circumstances make it more difficult for researchers to plan novel, creative, or fascinating investigations. High-to medium-level adjustments regarding such required issues in Africa are lagging behind.

Therefore, based on the identified gaps in indicator, pathogen and molecular surveillance and to develop timely detection capabilities and intervention strategies, a four-tier national monitoring framework model was proposed;

Table 4; Projected practical national research/monitoring framework model

	Tier 1	Tier 2	Tier 3	Tier 4
	Routine surveillance	Targeted pathogen surveillance	Molecular surveillance	Outbreak Response

Settings	Every relevant drinking-water monitoring system/ regional laboratories	High risk pathogens detection centers	Selected Reference laboratories	Rapid diagnostic laboratories/ technologies
Sampling strategy for detecting or identification	<i>E.coli</i> ; turbidity; residual disinfectants; basic physicochemical parameters; sanitary inspection.	<i>Salmonella</i> ; <i>Shigella</i> ; <i>Vibrio</i> ; <i>Campylobacter</i> ; <i>Giardia</i> ; <i>Cryptosporidium</i>	Enteric viruses	Environmental sampling
Methodology	Culture and Rapid tests	Culture	Pathogen specific PCR/ RT-PCR	Molecular testing/ Metagenomics where applicable
Association	Contamination/ pollution level	AMR profiling	AMR genes	Epidemiological linkage
Investigation	Quality and quantity analysis	Phenotypic characterization	Genomic characterization	Genomic typing when appropriate

572

573 On the other hand, applying the WSP and WQM activities at the county level resulted in some
574 gains or benefits, despite a number of drawbacks. For example, AAWSA, AWSEE, and EPHI
575 benefited from the previously deployed S2TAB project in Ethiopia. A few details from the prior
576 trend are expanded upon in the following table:

577 Table 5. A few examples of WSP & WQM approaches related to a single project conducted at the
578 two water utilities in Ethiopia (AWSSA and AWSEE)

Overall improvements/ Benefits observed	WSP	WQM
Capacity building	More ground water providing wells were dug for the expansion process	Lab expansion (Manpower development trainings were provided, Materials & equipment were purchased)
Risk assessment	Risks assessed & prioritized in the two water utilities	Microbial Risks from source water samples were collected & tested

Methodology	WSP Modules were communicated and incorporated	Methods for water quality analysis upgraded up to molecular level, SOPS and protocols were developed
Training	Training delivered on WSP risk assessment and Management topics	Training delivered on WQM membrane filtration and RT-PCR techniques
Sample collection & analysis (Monitoring)	Risks re-assessed and measurements were taken for improvement	WQM were performed in eight rounds, including studies on the seasonal approach
Research	WSP related review papers; one is published and the second is ongoing.	WQM research papers were finalized b/c of this program
Expansion programs	Similar programs were planned to be delivered to other regions of Ethiopia	Similar programs and initiatives were planned to other regional levels
Collaboration	Around nine institutions were collaborated in & out of Ethiopia	Around nine institutions were collaborated in & out of Ethiopia
Reports for the policy developers	Few Published papers disseminated for all relevant organizations; WASH, Water utilities, NGOs like WHO, MOH & UNICEF	Baseline technical reports were submitted for EPHI for the Water utilities and other relevant organizations and also continues

Limitations and strength of the Systematic Review

The systematic review's shortcomings and strengths: Even though the reviewers gathered all the material from the chosen research submissions, it was challenging to get all the details for some of the studies. Because the articles offered pertinent summary reports, the writer was therefore required to use their abstracts rather than the specific findings in these situations. Incomplete publisher data, unclear (biased) information, and missing volume or issue statistics for some of the reports were also found. These, these papers were not included. If a few publications were not shown in the applied literature acquisition engines, they may be accidentally overlooked. Besides, environmental-health research outputs in low-and middle-income countries were also published outside major biomedical databases, in which such manuscripts were omitted targeting to cover only the familiar databases. English-only restriction and grey literature search exclusion also limited the inclusion criteria, though random scrolling on Google Scholar to get such reports were

covered. However, since the data were huge, the reviewers confined themselves only to the selected databases. The aforementioned circumstances may led to varying degrees of bias, which could be interpreted as this study's limitation. Furthermore, this systematic review wasn't registered in the formal protocol registration platform and also didn't utilize the PRISMA website, except for using the formula to generate and analyze data manually. The strength was that, no such thorough analysis has been conducted in the region to demonstrate the gaps under this topic so unique. At the very least, this evidence might support the formulation of pertinent measures to close the significant gaps.

5. Conclusions

This essential study's main goal was to compile data on Ethiopia's current water quality monitoring practices and initiatives. The goal was to raise awareness about water monitoring techniques associated with water-borne diarrhea and other related illnesses among consumers, policymakers, and researchers. For example, the assessment report of Djibouti explained that among French military personnel, the annual incidence rate of diarrhea ranged from 260 to 349 cases per 1000 persons per five years (data gathered during 2005-2009) (Olivier et al., 2010). In Tanzania, *Rotavirus* infection was also found in 26.4% (73/277) of children under the age of five who experienced diarrhea (Michaile et al., 2017). The current population of Rwanda was anticipated to be 12 million, and by 2050, that number is expected to rise to 25 million. Additionally, it was estimated that the temperature had grown by 1.4°C since 1970 and expected to increase by 2.5°C by 2050, which would affect the amount and quality of water resources (Mukanyandwira et al., 2018). In line with these, an evaluation of the microbiological water quality in Rwanda's capital, Kigali City, reported that river water and groundwater contained *Escherichia coli*, *Enterobacter*,

614 *Klebsiella, and Staphylococcus* (Nigatu et al., 2015; Uwimpuhwe et al., 2014; Rutanga et al.,
615 2014).

616 The percentage of Burundians who have access to an improved source of drinking water within
617 500 meters in urban areas and 1 kilometer in rural regions is another definition of "improved water
618 supply" in that country. This access should be reasonably priced, and provide a sufficient amount
619 (at least 25 liters per person per day, according to USAID 2014). The report claimed that sanitary
620 services were even more scarce and the basic expectations for targeted potable water delivery for
621 the general public were not fulfilled.

622 The circumstances in Ethiopia are nearly the same. More research is required to cover the entire
623 nation, particularly in areas like the Benishangul region that had not have a publication on the site
624 till the end of 2021. As a result, it should be a top priority to address potential intervention strategies
625 based on the data. This critical review's focused on providing a thorough report on WQM
626 approaches, including what had been done in the past, what we are doing now, and what needs to
627 be done going forward. The primary goal was to highlight our coverage, gaps, and advantages and
628 disadvantages for potential future interventions.

629 As an East African citizen, one couldn't say anything after observing the distribution of those
630 articles across the region. No such items were published in Djibouti during the specified time
631 frame. One paper was published in each of Somalia and Eritrea. There were just six papers shared
632 in Rwanda. The authors concluded that the aforementioned four nations undoubtedly engage in
633 WQM operations. However, like the internal reports found in the logbooks of Ethiopian water
634 utilities, they were not disseminated (published). It is strongly advised to refer to publication trends
635 to identify the main issues in each nation and then concentrate on improving the intervention
636 strategies.

637 Furthermore, only one to three East African nations used the most cutting-edge technologies, and
638 it was upsetting to see such disparities in East Africa when compared to Western nations. Why
639 does the WHO priorities distributing these technologies to every Ministry of Health and Water
640 organization worldwide? Was the loss of targets or budgetary problems the true cause? When will
641 the ideal catchphrase, "Health for all; equity in health-related good practices, technologies, and
642 capacities," be embraced and used worldwide? When will the Public Health Microbiology wings,
643 such as food and water laboratories throughout East African nations, participate in regular
644 activities like clinical ones? Thus, the following proposals for the future were disclosed in light of
645 the shortcomings that were observed.

646 1. In order to minimize water-related risks and produce safe water for all citizens/countries, WSP
647 and WQM approaches are essential. As a result, they ought to be exercised every day.

648 2. By implementing these strategies in every area of the country, together with a number of follow-
649 ups and recurring monitoring, water utilities should enhance their performance (WQM).

650 3. The current trend should be communicated to the organizations involved in the monitoring
651 efforts. In order for researchers to provide up-to-date information on indicator bacteria as well as
652 current viruses and parasites from water sources, they must embrace new technology in these
653 fields. This kind of thinking requires a paradigm change.

654 4. It was also recommended that future Ethiopian water surveillance or monitoring strategy should
655 consider covering ESBL-producing Enterobacteracea groups; carbapenem resistance;
656 *Salmonella/Shigella* resistance; antimicrobial-resistance genes; wastewater-associated AMR;
657 hospital effluent; livestock/agricultural interfaces. These are highly relevant to a One Health
658 approach.

5. Accommodation of seasonal-oriented research (Rainfall, flooding, cold/ dry seasons), also best fit to see the variations among extreme weather events.

6. The component of the budget flow is tedious. In the annual budget, millions of money have been set aside for research activities; however, the majority of these funds are either not fully utilized or are used for unplanned initiatives that are not targeted. However, the crucial component of Public Health Microbiology research outputs has consistently stayed unchanged, with few advancements. It is obvious that the budgetary outlay for specialized and conventional research exceeds the purchase of equipment. It is essential to implement a comparable paradigm shift in order to alter the system as a whole, adopting the One Health Approach, which includes: Human health (Clinical enteric pathogens/ outbreaks), Environmental Health (Food/ Water contamination/ waste water/ surface water), Animal health (livestock/ poultry/ dairy/ Zoonotic organisms) and Antimicrobial Resistance (resistant organisms/ resistance genes and antibiotic residues).

7. Another issue that needs to be brought up here is teamwork, intra- and inter-collaboration, and Public-private partnership. Improvements are always the result of collaboration. There may be new methods on the plate. But after the program is over, sustainability concerns remain. What would happen to the plate? Continuity? As the saying goes, initiatives for change must originate from within, from the current context. For the benefit of the community, we should first identify the primary issues. Furthermore, those who work in all sectors ought to make noticeable advancements in their fields; at the very least, they ought to make an effort.

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688 **Abbreviations**

689 AAWSA: Addis Ababa Water and Sewage Association

690 AWD: Acute Watery Diarrhea

691 AWSEE: Adama Water Sewage and Service Enterprise

692 EED: Environmental Enteric Dysfunction

693 EPHI: Ethiopian Public Health Institute

694 HAdV: Human Adenovirus

695 HAV: Hepatitis A Virus

696 HBV: Hepatitis B Virus

697 HCV: Hepatitis C Virus

698 HDV: Hepatitis D Virus

699 HEV: Hepatitis E Virus

700 HIV: Human Immunodeficiency virus

701 IgG: Immuno globulin Gamma

702 IgGAB: Immuno-globulin Gamma Antibody

703 IMS/ IFAS: Immuno-Magnetic Separation/ Immuno-Fluorescence assay

704 MFT: Membrane Filtration Technique

705 MLVA: Multiple Locus Variable-Number Tandem Repeat Analysis

706 MOH: Ministry Of Health

707 MOWIE: Ministry of Water, Irrigation and Energy

708 MPN: Most Probable Number

709 NGO: Non-Governmental Organization

710 NGS: Next Generation Sequencing

711 NRW: Non Revenue Water

712 PCR: Polymerase Chain Reaction

713 PFGE: Pulse Field Gel Electrophoresis
 714 PBS: Phosphate Buffered saline
 715 RADWQ: Rapid Assessment of Drinking Water Quality
 716 RFLP: Restriction Fragment Length Polymorphism
 717 RT-PCR: Reverse Transcriptase - Polymerase Chain Reaction
 718 S2TAB: Source To Tap and Back
 719 SNNPR: Southern National and Nationality of People Republic
 720 SOP: Standard Operating Procedures
 721 TB: Tuberculosis
 722 TDS: Total Dissolved Solids
 723 TSS: Total Suspended Solution
 724 UNICEF: United Nations International Children Economic Fund
 725 WASH: Water, Sanitation and Hygiene
 726 WGS: Whole Genomics Sequencing
 727 WHO: World Health Organization
 728 WHO: World Health Organization
 729 WQM: Water Quality Monitoring
 730 WSP: Water Safety Planning

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732 **References for Discussions**

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