Assessing Water Quality in Malawi: Contamination Sources, Public Health Impacts, and Sustainable Management Strategies

Abstract

This review investigates water quality issues in Malawi, revealing critical contamination sources such as industrial discharges, agricultural runoff, household waste, mining operations, and inadequate wastewater management. A systematic search was conducted across several databases, focusing on literature published from 2018 to 2024, encompassing peer-reviewed articles, reports, and government publications. Findings underscore significant public health risks associated with poor water quality, including waterborne diseases and long-term health effects. The study advocates for the implementation of a continuous water quality-monitoring framework, enhanced regulatory measures for wastewater discharge, and effective community education initiatives on sustainable water practices. The recommendations presented herein aim to inform policymakers, researchers, and local communities, guiding future research directions and practical solutions to mitigate water contamination and improve public health outcomes in Malawi.

Key Words: Water quality, Contamination, Public health, Sustainability, Malawi,

1. Introduction

Access to adequate, high-quality water is fundamental to sustainable development, supporting human health, food security, economic prosperity, and ecological balance. While freshwater sources are abundant globally, only a small fraction is accessible for human use-1% of surface water and 30% of groundwater (Brika, 2018; Ravindiran et al., 2023; Shehu et al., 2022). Surface water, though readily available, is increasingly unreliable due to seasonal variations, climate change, and pollution from untreated wastewater. As a result, groundwater has become an important resource for water supply system (Omran et al., 2019). However, groundwater quality has also deteriorated, raising concerns about global water sustainability(Lapworth et al., 2022).

Both natural and anthropogenic factors contribute to water quality degradation worldwide (Banda et al., 2024; Nowicki et al., 2023; Psyrillos and Tziritis, 2024; Zeb et al., 2024). Common contaminants include hazardous chemicals such as nitrates, fluoride, and arsenic, along with heavy metals and microbial pathogens (Addison et al., 2020a; Chakraborty et al., 2022; Dzinjalamala et al., 2024; Hasan and Muhammad, 2020; Majawa et al., 2024). Emerging pollutants, including pesticides, pharmaceuticals, microplastics, and endocrine-disrupting chemicals, further threaten water quality and public health (Liu et al., 2024; Ravindiran et al., 2023; Shehu et al., 2022; Shi et al., 2023). These pollutants disrupt aquatic ecosystems and contribute to waterborne diseases such as cholera, typhoid, and schistosomiasis, which remain major public health concerns, particularly in developing countries. Globally, 2.1 billion people lack access to safe drinking water, leading to approximately 2.2 million deaths annually, with 90% of diarrhea-related fatalities occurring in children under five (Shayo et al., 2023; Uhlenbrook, 2019; WHO, 2022).

Malawi, like many Sub-Saharan African nations, has made progress in improving drinking water access, with 80% of the population using improved sources (USAID, 2020). However, approximately 4 million people, predominantly in peri-urban and rural areas, still lack access to safe drinking water. This is due to limitations in the capacity of government utility providers (Water Boards) (Mkwate et al., 2017). Numerous studies have assessed water quality across Malawi, revealing regional contamination variations in both groundwater and surface water. For instance, excessive salinity has been reported in the Lower Shire (Missi and Atekwana, 2020) Elevated levels of nitrate and trace metals, including cadmium, have been documented in Chileka, Blantyre (Dzinjalamala et al., 2024). Microbial contamination has also been reported in areas such as Mpherembe in rural Mzimba, (Dzimbiri et al., 2021), Balaka (Mkwate et al., 2017), Blantyre (Dzinjalamala et al., 2024) and Lilongwe urban (Mussa and Kamoto, 2023). These studies, conducted at different times and locations, employed various water quality monitoring techniques, including chemical analysis and microbiological methods. They provide critical insights into regional contamination sources and the extent of pollution in Malawi. This review provides a comprehensive analysis of water quality, contamination pathways, and emerging pollutants in Malawi's groundwater and surface water. By identifying key sources of contamination and their public health implications, the study aims to inform evidence-based policy decisions and propose sustainable water management strategies. More broadly, it contributes to the understanding of global water sustainability challenges by examining the complex interactions among environmental factors, public health concerns, and the urgent need for effective regulatory frameworks and continuous water quality monitoring. Furthermore, the findings underscore the importance of integrated water management approaches and collaborative efforts to mitigate the impacts of climate change and ensure long-term water security in Malawi and other regions facing similar challenges.

2. Methodology

2.1 Study area and Water Resources in Malawi

Malawi is a landlocked country in southern Africa, located between latitudes 9°22´S and 17°03´S, and longitudes 32° and 35°55´E. It covers a total area of 118,480 km2 with a total length of about 900km and a maximum width of about 250 km. The country is considered rich in freshwater resources, with Lake Malawi, wetlands, and rivers covering 21% of the geographical area. Despite Malawi's large freshwater resources (Figure 1), the country faces water scarcity in some areas due to differences in distribution, management and quality (Chiluwe and Nkhata, 2014).

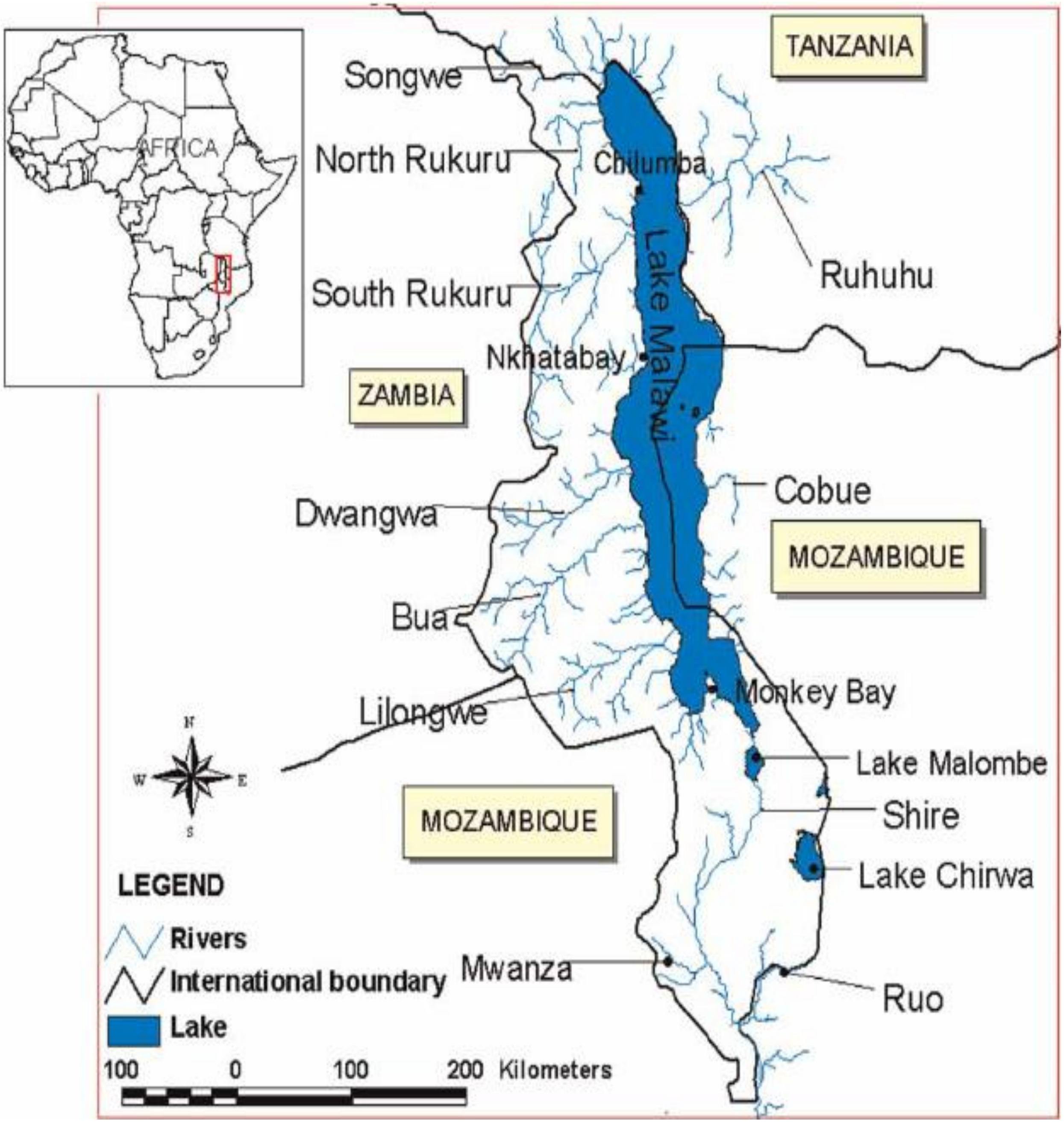

Figure 1: Map of Malawi showing distribution of water resources (Chiluwe and Nkhata, 2014).

2.2 Overview of Surface and Groundwater Resources

Malawi is endowed with significant water resources, encompassing both surface water and groundwater systems that serve as critical lifelines for domestic, agricultural, industrial, and ecological needs. Surface water resources include Lake Malawi, which accounts for approximately

20% of the country's total land area and is one of Africa's largest freshwater lakes. Other major surface water bodies include the Shire River, which flows out of Lake Malawi, as well as rivers such as the Ruo, Songwe, and Bua. These surface water bodies are vital for agriculture being the major use, domestic, municipal water supply, industry, hydropower generation, and fisheries, contributing significantly to the livelihoods of millions (Banda et al., 2024; Kumambala, 2010). However, their availability is increasingly affected by seasonal variability, sedimentation, and pollution from urban and agricultural activities, resulting to water shortages (Upton, 2018). Nevertheless, surface water remains the primary source for Government of Malawi water utilities, supplying cities such as Lilongwe, Blantyre, Zomba and Mzuzu, despite these challenges.

Groundwater resources, on the other hand, are equally, if not more, significant in Malawi due to their widespread availability and reliability, particularly in rural and peri-urban areas (Mkwate et al., 2017). Groundwater is primarily stored in weathered and fractured basement aquifers, alluvial aquifers, and Karoo sedimentary formations(Upton, 2018). The country's geology is largely underlain by Precambrian to Lower Palaeozoic crystalline basement rocks, which overlain in certain regions—notably in the north and south—by more recent sedimentary or volcanic formations. Extensive Quaternary alluvium is also found in valley bottoms and rift floor plains.

Two primary aquifer systems dominate Malawi's hydrogeology. The first comprises unconsolidated alluvium in major valleys and lakeshore plains, forming high-yielding aquifers that are vital for water supply in these areas. The second consists of crystalline basement rocks from the Precambrian basement gneiss complex, which constitutes approximately 85% of Malawi's geology. These basement aquifers are widely distributed but are typically low-yielding due to their limited permeability (Upton, 2018). These aquifers are primarily recharged through rainfall, making groundwater an essential resource during prolonged dry spells. Secondary recharge sources include infiltrations from the perennial rivers and streams.

2.3 Search criteria

A systematic literature search was conducted to identify relevant scientific publications and reports pertaining to water contamination in Malawi. The search focused on chemical parameters, heavy metals, faecal pollution, and emerging contaminants in freshwater environments, as well as the associated human health impacts. The search was performed using the following electronic databases: Web of Science, Google Scholar, and Google Search. Search terms included variations and combinations of keywords including “water contamination," "water quality," "heavy metals," "faecal coliform," "emerging contaminants in water," and "Malawi." The search was limited to documents published between 2018 and 2024, except two articles, which were published in 2010 and 2014. Government reports were also included.

2.4 Water Availability and Demand

Malawi's water availability is influenced by its geographical and climatic conditions. The country receives an average annual rainfall ranging from 600 mm in the Lower Shire Valley to over 1,500 mm in highland areas. However, this rainfall is highly seasonal, with the majority occurring between November and April. Surface water flows are thus heavily dependent on rainfall, leading to significant fluctuations in water levels during dry and wet seasons.

The demand for water in Malawi has been steadily increasing due to population growth, urbanization, and agricultural expansion. As of 2023, Malawi's population surpassed 20 million, with an annual growth rate of approximately 2.5%(World Bank, 2024) . This has intensified pressure on existing water resources, particularly in urban centers like Lilongwe and Blantyre, where piped water supply systems are often inadequate to meet demand. Agriculture, which accounts for nearly 80% of Malawi's workforce and 30% of its GDP (WHO, 2022), is the largest consumer of water, primarily for irrigation. Industrial and domestic water demands are also rising, further straining the country’s limited resources.

Access to improved water sources in rural Malawi however, demonstrations significant disparities compared to urban areas. While the World Bank (2015) indicated that 95% of urban residents and 89% of rural residents had access to improved water sources, this metric masks a critical discrepancy. The World Health Organization's findings reveal that 42% of the rural population relies on hand-dug wells or surface water, often contaminated with bacteria, parasites, or chemicals, for essential daily activities such as washing, bathing, cooking, and drinking. This suggests that only 58% of rural Malawians use improved water sources, highlighting a substantial gap between reported access and actual safe usage (Marissa Getts, 2018).

3. Water Quality

Assessing water quality from both protected and unprotected sources is crucial for safeguarding public health, preventing waterborne diseases, and promoting economic growth. In Malawi, water quality remains poorly studied and documented, with significant knowledge gaps (Chidya et al., 2016a). Nevertheless, several studies have evaluated various physical and chemical parameters in both groundwater and surface water, revealing substantial spatial and temporal variations across the country

Total Dissolved Solids (TDS) is one of the most frequently studied parameters, showing considerable regional variation. For instance, Chidya et al. (2016b) reported total dissolved solids (TDS) instances exceeding the Malawi Standard (MS 733:2005) in Mzimba district while Kambuku et al. (2018) reported TDS levels within standards in the Rivirivi catchment . Banda et al. (2024a) documented TDS concentrations ranging from 23 to 2662 mg/L in the aquifer basins of Lake Malawi. Lapworth et al. (2020) highlighted significant spatial variability, with 8.1% ± 2.6% of samples in Malawi exceeding 1000 mg/L, a concentration notably higher than those observed in Ethiopia and Uganda. Elevated TDS levels indicate the presence of dissolved ions and organic matter, influenced by various hydrogeochemical processes.

pH levels, reflecting the chemical conditions of water, have also been studied. Elevated pH values, ranging from acidic to alkaline, have been reported in several regions. Some studies have reported lower pH values (acidic) in areas such as Likangala, (Kuntumanji et al., 2024), Domasi, (Kuntumanji et al., 2024b) and Karonga (Mapoma et al., 2017) in Karonga. Meanwhile, others have found values within the World Health Organization (WHO) and Malawi Bureau of Standards (MBS) guidelines(Missi and Atekwana, 2020). Seasonal variations also influence water quality, as shown by studies in the Bua River, Kasungu (Balaka and Chagoma, 2022) and the Nankhaka River, Lilongwe(Chirwa, 2024). During the dry season, higher temperatures, pH, Electrical Conductivity (EC), TDS, and salinity were recorded, indicating increased concentrations of dissolved ions. Nitrate concentrations have been observed to exceed WHO guidelines in some areas. For example,Ward et al. (2020) observed elevated nitrate concentrations, in rural Lilongwe with maximum values; 65.4 mg/L in dry season and 114.1 mg/L wet season, exceeding WHO (2017) guidelines. Similarly, Nkwanda et al. (2021) documented a gradual increase in nitrite levels in Upper Lilongwe River basin. However, other studies including those by Banda C et al. (2020), Mapoma et al. (2016) and Hinton et al. (2024) have generally reported low levels of nitrate in Malawi's basement and alluvial aquifers. This is so because nitrate minerals are typically negligible in the rocks (Banda et al., 2024).

Fluoride levels frequently exceed the drinking water threshold (1.6mg/L)(World Health Organization, 2024) in many regions of Malawi posing significant health risks (Addison et al., 2020a; Addison et al., 2020b; Wesley et al., 2023) . Elevated chloride and sodium concentrations have predominantly been observed in Lake Chilwa, Lake Malawi, and the lower Shire Valley, contributing to saline groundwater conditions (Forsberg, 2014; Missi and Atekwana, 2020). While calcium and magnesium levels show spatial variations, they generally remain within drinking water standards, with a few exceptions in certain areas.(Amalorepavanaden and Mony, 2017; Chidya et al., 2016c; Wanda et al., 2021).

Heavy metal contamination, including cadmium, lead, and chromium, is particularly alarming. Elevated cadmium levels have been reported in water sources in Chileka and urban rivers in Blantyre (Dzinjalamala et al., 2024) as well as in the Mudi, Naperi, Limbe, and Chirimba rivers (Chidulo, 2019). Similarly, chromium and lead concentrations have violated regulatory standards in these rivers. These elevated levels were attributed to the improper disposal of oils and paints without pretreatment. (Chidulo, 2019). Mapoma et al. (2016) identified high levels of cobalt, zinc, and aluminum in 50%-60% of water samples. While mercury and beryllium were undetected, manganese, arsenic, and iron occasionally exceeded regulatory threshold values of 400 µg/L, 10 µg/L, and 1,500 µg/L, respectively. Raymond et al. (2022) also assessed heavy metal contamination in Blantyre City wastewater treatment plants (WWTPs), revealing elevated Cd and Cr levels due to effluents predominantly sourced from industries. Manse WWTP, which receives 70% of its wastewater from industrial sources, exhibited significant heavy metal contamination, further confirmed by water samples from the plant. These findings highlight the urgent need for industrial wastewater monitoring and treatment improvements to mitigate heavy metal pollution in Malawi's water systems

Microbiological contamination remains a major concern, with pathogens such as E. coli and fecal coliforms detected in various water resources across Malawi. Urban areas like Lilongwe and rural areas such as Mpherembe exhibit high levels of microbial pollution, exceeding WHO guidelines for total and fecal coliform concentrations.(Dzimbiri et al., 2021; Mussa and Kamoto, 2023). Dzinjalamala et al. (2024) found fecal contamination levels as high as 34,000 cfu/100 mL in surface water and 1,300 cfu/100 mL in groundwater in Blantyre. Ward et al. (2020) found up to 5,600 cfu/100 mL in open shallow wells in Balaka, compared to 1,200 cfu/100 mL in hand-pumped boreholes in Lilongwe during the dry season.. Hinton et al. (2024) documented that 52.7% of their water source samples were contaminated with E. coli. These high levels are primarily attributed to inadequate sanitation and wastewater management, especially in areas with poor infrastructure, such as septic tanks and the use of pit latrines(Kayembe et al., 2018). Inefficient wastewater treatment are also a potential source (Kayira and Wanda, 2021).

While organic contaminants such as Biochemical Oxygen Demand (Dzimbiri et al.), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) are indicative of wastewater contamination, they are not prioritized in water quality studies. One study conducted in the Mudi, Naperi, Limbe, and Chirimba Rivers found that BOD5, COD, and TSS levels exceeded WHO and Malawi standards, both upstream and downstream of wastewater treatment plants.(Chidulo, 2019). The study noted that domestic and industrial wastewater contributed to this pollution, with 92,382 m^3 of domestic wastewater generated daily in Blantyre, including high-density, medium-density, and low-density areas. Literature indicates only one recent study on water pollution by radioactive metals in Malawi. This study by found elevated concentrations of uranium (^{238}U) in the lower Sere River, which exceeded the WHO guideline for radioactivity, though other radioactive metals such as thorium and potassium were within safe levels(Majawa et al., 2022).

4. Emerging contaminants of groundwater and surface water in Malawi

Emerging contaminants refer to a broad category of chemicals introduced into the environment through routine human activities, including domestic, agricultural, and industrial processes, which are detected in environment but are not fully regulated or routinely monitored. Such contaminants are characterize as been persistent, bioaccumulation, they originate from agriculture, pharmaceuticals, industrial activities and household products, but yet lack national regulation to control them or lack established safety standards (Puri et al., 2023). Several emerging contaminants have been reported occurred in water resources.

In sub-Saharan Africa (Figure 2), emerging contaminants identified in recent reports include antibiotics, organochlorine pesticides, polychlorinated biphenyls (PCBs), tranquilizers, psychiatric drugs, pharmaceuticals and personal care products (PPCPs), per- and polyfluoroalkyl substances (PFAS), microplastics, pesticides, and endocrine-disrupting chemicals (EDCs) ((Ngosi et al., 2024; Puri et al., 2023; Ripanda et al., 2021; Shehu et al., 2022). Antibiotics and organochlorine pesticides are widely prevalent, with the latter found in higher concentrations in agricultural regions, raising concerns about food and water safety. Additionally, PCBs, a byproduct of industrial activities, contribute to pollution, while the presence of tranquilizers and psychiatric drugs in various environmental compartments suggests contamination from pharmaceutical waste. The use of wastewater for irrigation in countries like Zimbabwe further exacerbates the issue, leading to the accumulation of multiple active chemicals in water sources, underscoring the urgent need for improved wastewater management practices

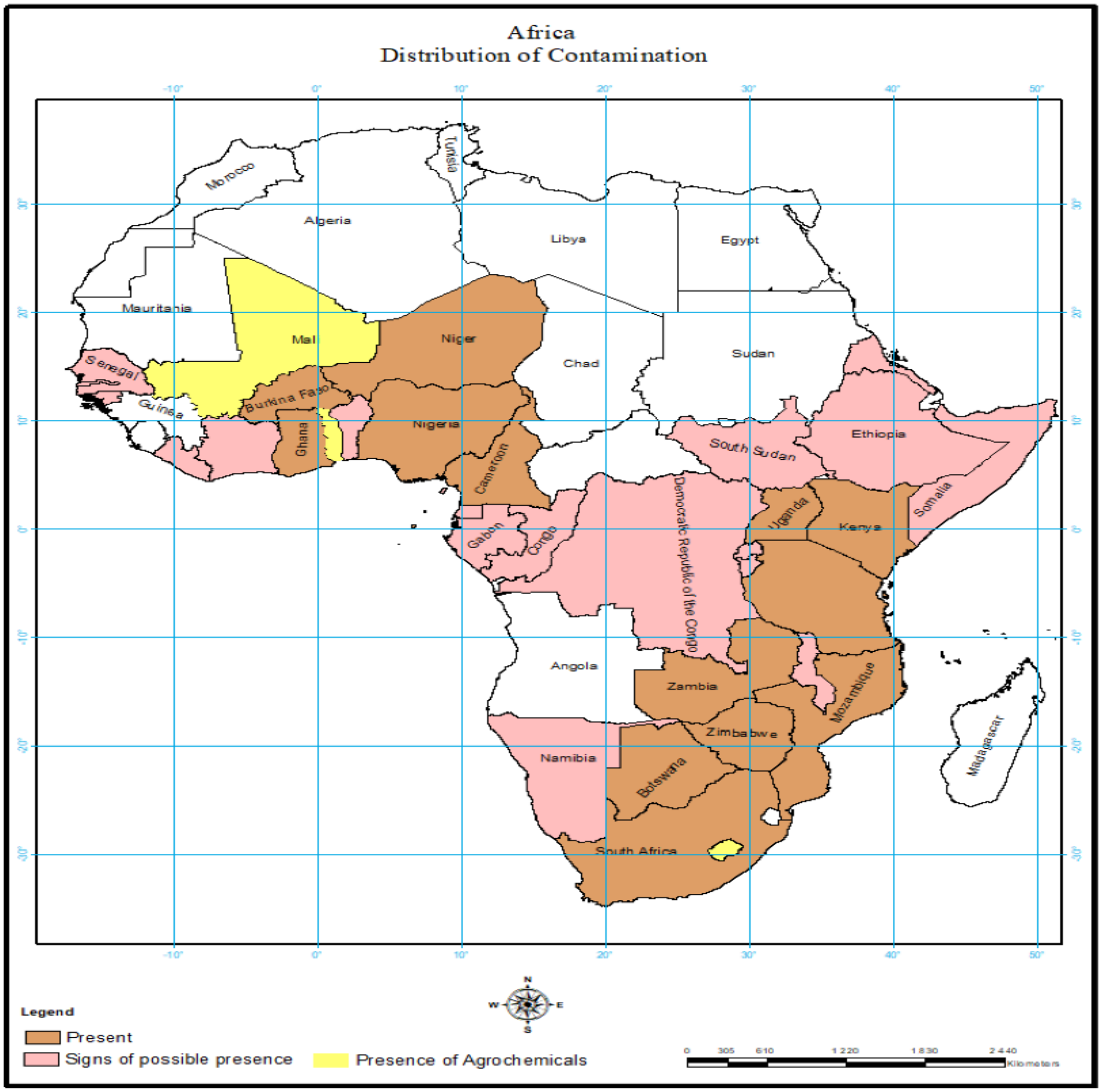

Figure 2. Map of sub-Saharan Africa indicating countries and active chemicals (emerging contaminants) reported Adopted (Ripanda et al., 2021)

However, there is limited research and lack of specific data on that show different classes of emerging contaminants in Malawi. At the same time, it was noted from regional data that these toxic chemicals possibly present in Malawi from agricultural activities, industrial discharges, mining, domestic waste, plastic pollution, and wastewater contamination are major potential sources of pollution in Malawi, contributing to the presence of emerging contaminants in water resources. These contaminants include Pharmaceuticals, personal care products, pesticide, industrial chemicals, radioactive, and microplastic, which are being increasingly detected in environment including water bodies, biodiversity, and public health.

Pharmaceuticals and Personal care products (PPCPs)

Like many developing countries, Malawi faces significant challenges in providing adequate sanitation facilities to its growing population. A large proportion of households and healthcare facilities are not connected to a conventional sewerage system, relying instead on poorly designed septic tanks or latrines, which often leak into groundwater. This contamination pathway poses a serious environmental and public health risk, as it allows the infiltration of toxic substances, including pharmaceuticals and personal care products (PPCPs), into water resources.

Despite the limited availability of data on the impact of PPCPs on Malawi's water resources, studies conducted across Africa, including Malawi, have documented the occurrence of antibiotics in aquatic environments (Middelkoop et al., 2014; Faleye et al., 2018; Ngqwala et al., 2020). The high prevalence of infectious diseases in the country has led to widespread antibiotic use, increasing the risk of antibiotic residues entering water bodies through untreated wastewater. This is particularly concerning given that Malawi lacks wastewater treatment infrastructure, meaning that most sewage and effluents are discharged directly into receiving water bodies, including lakes and rivers, without prior treatment (Ripanda et al., 2021; Shehu et al., 2022).

This situation underscores the urgent need for comprehensive monitoring programs to assess the extent of pharmaceutical contamination, as well as the implementation of effective wastewater treatment strategies to mitigate environmental and health risks.

Pesticides and fertilizer

In Malawi, small-scale farming plays a vital role in rural communities and is a significant contributor to the economy, accounting for 31% of GDP. The majority of the population is engaged in agricultural activities, making the use of fertilizers and pesticides widespread. Various pesticide were use in certain districts in Malawi such as in Nkhata Bay, Nkhotakota, and Chikwawa. The study found 16 vairous herbicides and insecticides, which more than half of them reported were toxic to aquatic system even in small amount. Some of them include ametryn, acetochlor, monosodium methylarsonate, and profenofos. The study does not report on the extend of water pollution from such toxic chemicals. Given the fact there is no restriction on the use of such pesticides is of great concern in the future. This is great concern since most of rivers in the North and south of the country drain into Lake Malawi (GoM, 2010).

The report also highlighted concerns about the mishandling of these toxic chemicals, which poses significant risks to local farmers and the environment. It recommended the establishment of a residue-monitoring program to assess the extent of pollution and emphasized the need for educational initiatives to raise awareness about safe pesticide use. There is a concern with improper handling of pesticide which pose environmental (surface and ground water) and health risk (Donga and Eklo, 2018; Kosamu et al., 2020). Carbaryl and cypermethrin, widely used insecticides in Malawian agriculture, were detected in soil and water samples from Lisungwi, Neno District, at concentrations exceeding recommended safety limits, particularly during the rainy season. These findings suggest a critical risk to aquatic ecosystems and human health, emphasizing the need for stringent pesticide regulation and improved water quality monitoring in agricultural regions (Kanyika-Mbewe et al., 2020).

Poor sanitation and untreated sewage contribute to the presence of pharmaceuticals, endocrine-disrupting chemicals (EDCs), and microplastics in Malawi's water bodies, exacerbating environmental and public health risks. The rising levels of pharmaceutical and personal care products (PPCPs) and per- and polyfluoroalkyl substances (PFAS) in wastewater further highlight the need for improved waste management and regulatory measures to mitigate contamination

Plastic and Microplastic pollution

While research on plastic (microplastic) pollution in Malawi remains limited, emerging evidence suggests its potential threat to both surface and groundwater quality. Studies on plastic pollution have been largely confined to marine environment however anthropogenic plastic debris on freshwater shorelines has been increasingly recognized (Kalina et al., 2022; Mayoma et al., 2019). In Malawi, plastic waste from industrial, commercial, and domestic sources contributes to environmental degradation, particularly in rivers, streams, and Lake Malawi. Due to the lack of adequate solid waste management infrastructure and systems, plastic waste often enters water bodies through runoff, illegal dumping, and inefficient waste disposal. This pollution presents significant environmental and human health risks to water contamination and aquatic ecosystem and human health risks (Arias et al., 2023; Tumwesigye et al., 2023).

These interactions, driven by both anthropogenic activities and natural processes, contribute to the presence of four major contaminants in groundwater and surface water systems (Figure 3). The sources of key contaminants found in drinking water, arising from human-induced pollution and natural geochemical processes, are summarized in Table 1.

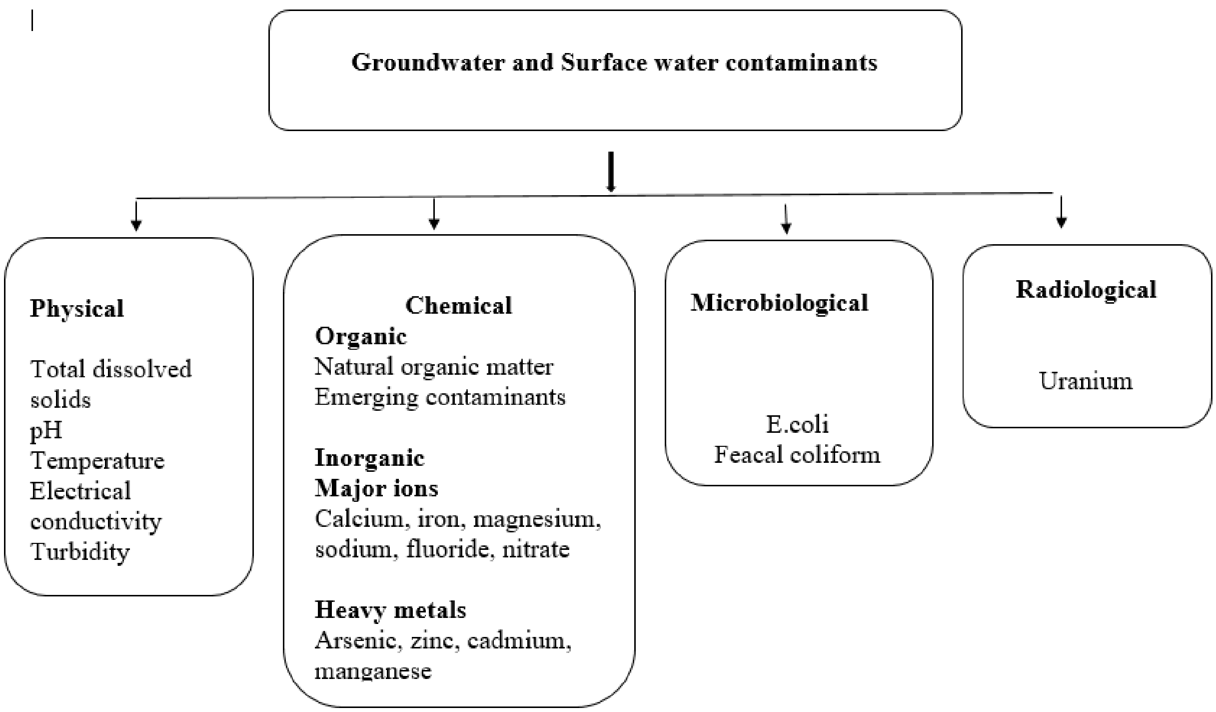

Figure 3: Major contaminants and some of their frequent monitored parameters

Table 1: Some contaminants and their primary sources

Contaminant	Definition	Primary Source	Sources
Geogenic Contaminations (Naturally Occuring)			
Flouride	Major ion	Dissolution of fluoride-bearing minerals like fluorite	(Addison et al., 2020a)
Calcium and Magnesium	Measures the hardness of water	Weathering and dissolution of dolomite, calcite	(Amalorepavanaden and Mony, 2017; Wanda et al., 2021)
Chloride and Sodium	These contributes to salinity of water	Evaporation and dissolution of evaporite minerals, dump sites, pit latrines	(Missi and Atekwana, 2020; Ward et al., 2020)
Nitrate	Primarily byproduct of nitrifying bacteria	Anthropogenic activities including agricultural runoff, animal manure and human feaces	(Hinton et al., 2024; Ullberg, 2015; Ward et al., 2020)
Iron, manganese arsenic (As), lead, cadmium, chromium etc	Trace metals	Industrial wastewater such as oils, dye paints, coal, domestic wastewater Common in groundwater, particularly in areas like Karonga Natural processes especially for As and Mn	(Chidulo, 2019; Dzinjalamala et al., 2024; Mapoma et al., 2016) Mapoma et al., 2017
Salinity (Total Dissolved		High salinity levels have been reported in	(Missi & Atekwana, 2020).

Solids – TDS)		the Lower Shire region, affecting drinking water suitability	
Anthropogenic Pollutants (Human – Induced Contaminants)			
Nitrate		Linked to agricultural runoff, poor sanitation, and wastewater infiltration.	(Dzinjalamala et al., 2024)
Heavy Metals (Cadmium, Lead, Chromium, etc.)		Originating from industrial activities and improper waste disposal	(Dzinjalamala et al., 2024)
Microbial Pathogens (E. coli, Total Coliforms, etc.)		Caused by inadequate sanitation and contaminated water sources, leading to waterborne diseases	(Mkwate et al., 2017; Mussa & Kamoto, 2023).
Pharmaceutical Residues		Increasingly detected due to improper disposal and wastewater contamination	(Liu et al., 2024)
Microplastics		Emerging pollutants from urban and industrial waste entering water bodies	(Shi et al., 2023)
Biochemical Oxygen Demand (Dzimbiri et al.), Chemical Oxygen Demand (COD)	Organic matter	Sewage discharges, industrial wastewater	(Chidulo, 2019)
Contaminants of emerging concern (CEC)	Pollutants detected at very low quantity and	Pharmaceuticals such as antibiotics and personal care products (PPCPs), pesticides,	(Kosamu et al., 2020; Ngosi et al., 2024)

	previously not recognized for water quality monitoring		
Microbial contaminants	Organisms such as bacteria, viruses and protozoa	Human/animal faecal, sewage discharge from and natural occurring bacteria	(Dzimbiri et al., 2021; Dzinjalamala et al., 2024; Hinton et al., 2024)
Uranium	Metals known for difficulty to degrade.	Natural radioactive materials	(Majawa et al., 2022)

5. Implications of Contaminated Water in Malawi

Safe drinking water, as defined by the World Health Organization (WHO, 2022), , poses no significant risk to health over a lifetime of consumption, accounting for varying sensitivities across life stages. However, in Malawi, water quality remains a persistent challenge, with both surface and groundwater contamination posing significant risks to public health, agriculture, and socioeconomic development.

Health Implications

Turbidity is a critical parameter for assessing surface water quality, particularly during the rainy season when soil erosion and runoff lead to elevated levels. High turbidity is often associated with microbial contamination, compromising disinfection processes and increasing the prevalence of waterborne diseases, such as diarrhea and cholera. Microbiological contamination is particularly concerning in areas such as Mpherembe, Lilongwe, Blantyre, Mzuzu, Balaka, and Nkhatabay, where pathogens like feacal coliforms have been reported (Dzimbiri et al., 2021; Dzinjalamala et al., 2024; Kayira and Wanda, 2021; Mussa and Kamoto, 2023). Recently, a total of 36 943 cases, including 1210 deaths due to Cholera, have been reported from all 29 districts in Malawi (World Health Organization, 2023).

Although pH itself does not directly impact human health, acidic waters can accelerate the dissolution of heavy metals, potentially harming both human health and aquatic ecosystems (Iqbal et al., 2021). Chronic exposure to chemical contaminants in water presents long-term health risks. For instance, high fluoride concentrations frequently surpassing WHO guidelines in districts like Balaka, Chiradzulu, Chikwawa, and Phalombe are strongly associated with skeletal and dental fluorosis(Vunain et al., 2019; Wesley et al., 2023). Prolonged exposure can result in severe bone deformities and chronic pain, significantly reducing quality of life (Addison et al., 2020a). levated nitrate levels, including those in Chileka and Lilongwe, are linked to methemoglobinemia (blue baby syndrome) in infants and have also been associated with an increased risk of gastrointestinal cancers in adults (World Health Organization, 2024). Aside calcium and magnesium contributing to bitter taste in water, long-term exposure to high concentrations of these ions has been linked to cardiovascular diseases (Kozisek, 2020). Fortunately, most studies in Malawi report magnesium and sodium levels within permissible drinking water standards.

Heavy metals, including arsenic, lead, and cadmium, pose severe health risks, including organ damage (such as lungs, liver, kidneys, and brain), diabetes, and cancer (Chidulo, 2019; Dzinjalamala et al., 2024; World Health Organization, 2024). Emerging pollutants, including pharmaceuticals and personal care products, are linked to long-term risks such as cancer and neurological disorders (Ngosi et al., 2024).

Agricultural and Environmental Implications

Contaminated water also significantly affects agriculture, particularly through salinity and high concentrations of dissolved ions. Studies from Mzimba have reported undesirable salinity levels in water sources, rendering them unsuitable for irrigation (Wanda, 2014). Similarly, Reuben et al. (2022) found poor water quality for irrigation in the Katumba irrigation scheme. Saline water reduces soil infiltration capacity and alters soil structure, making water absorption by crops difficult. Consequently, crops become water-stressed, leading to reduced yields and productivity. It is also important to note that excess levels of nitrate result in eutrophication, causing depletion of dissolved oxygen in water bodies, hence disrupting aquatic ecosystems(Ullberg, 2015).

6. Water Quality Monitoring Standards

Malawi has established well-documented standards (MS 214:2013) (Malawi Bureau of Standards, 2013) which specifies the physical, biological, and chemical requirements for potable water. These national standards align with the World Health Organization (WHO) guidelines, forming the foundation of the country's efforts to ensure safe drinking water. The adoption of the Water Quality Index (WQI) has further enhanced the assessment of water sources, providing a holistic evaluation of their health and suitability.

Recent studies utilizing the WQI have revealed varying water quality across the country. For instance, Mapoma et al. (2017) reported that 36% of water samples in Karonga were of very poor quality, with 16% deemed unfit for drinking. In contrast, Mussa and Kamoto (2023) documented that 70% of samples in Lilongwe exhibited good water quality, with one sample classified as excellent. Meanwhile, Kuntumanji et al. (2024) found that 61.5% of groundwater samples were unsuitable for drinking. These findings underscore the critical need for proactive water management practices, such as identifying sources that should be abandoned, implementing targeted treatment interventions, and designing strategies to ensure sustainable access to safe water resources.

7. Policy and Governance

The Ministry of Water and Sanitation oversees water, sanitation, and hygiene (WASH) matters, providing policy direction through its Water Resources Department. The National Water Resources Authority is tasked with managing, conserving, and regulating the use of water resources, including acquiring and granting rights for water usage. Additionally, the Water Supply Services Division mandates municipal water utilities—Blantyre, Southern, Northern, Lilongwe, and Central water boards—to supply potable water to urban areas. Key frameworks such as the National Water Policy (2021) and the Water Resources Act (2013) guide water governance in Malawi. These policies emphasize Integrated Water Resource Management (IWRM), equitable access to water, and the protection of water resources. Nations like India, Bangladesh, and China have effectively embraced IWRM, an approach aimed at coordinating the management of water resources across sectors. IWRM promotes the sustainable use of water by considering the interdependencies among various water uses, thereby facilitating cooperation between multiple stakeholders. In China, for instance, the government has implemented the Water Ten Plan, an extensive policy intended to reduce water pollution, enhance conservation, and promote the quality of water through improved regulations on wastewater discharge and water-saving technologies(www.weforum.org/stories/2024/06/, 2024). In Malawi, significant challenges impede the effective implementation of these policies. The state of water legislation shows a lack of enforcement, and the public is often unaware of its existence (Chunga, 2022).

7. Key Challenges in Water Quality Management: Gaps and Regional Disparities in Malawi

Despite advancements in water quality research, Malawi faces significant challenges that hinder sustainable water management and public health interventions. A primary issue is the lack of enforcement of existing water policies, coupled with limited public awareness of these regulations.

This deficiency has led to environmental degradation, exacerbating water quality problems across the country

Governance inefficiencies further complicate water management efforts. Overlapping responsibilities between urban water boards and district assemblies, which are tasked with rural water supply, create administrative challenges. For instance, while legislation assigns sewage treatment management to water boards, in practice, local councils handle this responsibility, leading to coordination difficulties and infrastructure management issues.

Financial constraints within both district assemblies and water boards impede the upgrading, maintenance, and operation of water supply infrastructure necessary to meet the demands of a growing population. These limitations are compounded by a lack of adequate laboratory equipment, such as atomic absorption spectrometry (AAS) for heavy metals and high-performance liquid chromatography (HPLC) for pesticides. This shortfall restricts advanced analyses, particularly for trace elements and emerging contaminants. Consequently, water boards are unable to monitor complex substances like pesticides, pharmaceuticals, and cosmetics, which are increasingly detected in water systems (Kosamu et al., 2020).

Furthermore, the absence of detailed hydrogeological studies on groundwater recharge and aquifer sustainability remains a pressing issue. As Malawi increasingly relies on groundwater for domestic and agricultural needs, understanding recharge rates, aquifer storage capacity, and the impact of over-extraction is critical for preventing resource depletion and contamination.

Finally, the impacts of climate change on water resources have not been adequately studied. Erratic rainfall, prolonged droughts, and rising temperatures are expected to exacerbate water quality and availability issues, yet research on these dynamics remains insufficient to guide long-term adaptive strategies. Climate change poses challenges to water resource management, particularly in Sub-Saharan Africa, where the majority of communities rely heavily on rain-fed agriculture. Rising temperatures, altered precipitation patterns, and an increase in the frequency and intensity of droughts are expected to exacerbate water scarcity, affecting food security and livelihood sustainability. For instance, studies indicate that water availability in certain regions like the Sahel is projected to decrease by up to 70% by 2100 due to climate shifts. (Anders Jagerskog & Al-Ju Huang, 2023).

Moreover, the interaction between climate change and water resource management is increasingly recognized as a priority for sustainable governance. A nexus approach that addresses the interconnectedness between water, land, and food is crucial for developing integrated strategies that can adapt to changing climatic conditions. For example, recognizing the intricate links (Samuel Appiah Ofori, 2021).

Conclusion

The findings of this review highlight the urgent need for enhanced oversight of pollution sources, including industrial discharges and agricultural runoff, while advocating for the establishment of a robust water quality-monitoring framework. By implementing the recommended policies and fostering collaborations among stakeholders, Malawi can safeguard public health and promote sustainable water management practices. Continued research and proactive interventions are essential to ensure that water resources are protected for current and future generations, ultimately contributing to the nation's environmental resilience and public well-being.

Recommendations

1. Although a high-level Climate Change Planning Cross-Sectoral Committee, coordinated by the National Planning Committee (NPC) through the Sector Working Groups (SWGs), exists, its responsibilities primarily focus on water resources and climate change. This committee does not specifically monitor water quality but instead oversees water resource management and service provision. Therefore, establishing a dedicated technical taskforce for National Water Quality Monitoring is essential, with representatives from key government bodies, researchers, NGOs, and the private sector to ensure effective oversight, develop relevant guidelines and policies, and secure necessary resources, including funding.
2. Establish an ongoing monitoring program in accordance with WHO guidelines and/or MS733:2005. This will require dedicated support from the government in terms of funding.
3. Implement educational initiatives to raise awareness about the importance of water quality and simple water treatment methods, including bacterial disinfection and the use of bicarbonate soda to increase low pH levels. Additionally, increase awareness regarding the

impact of agricultural practices, such as manure and fertilizer use, on groundwater contamination.

4. Enforce stricter regulations on industrial wastewater discharge to reduce contamination from anthropogenic sources.
5. Utilize groundwater monitoring and management tools, such as Geographic Information Systems and remote sensing, to map aquifers, monitor water extraction rates, and identify contamination hotspots. These tools are particularly useful for predicting areas of over-extraction and ensuring sustainable groundwater use.
6. Foster partnerships between government agencies, research institutions, and international organizations to improve understanding of water contamination trends and support the development of innovative solutions.
7. Promote Integrated Water Resource Management (IWRM) that considers the interconnectedness of surface and groundwater, as well as the social, economic, and environmental dimensions of water use. This approach should involve stakeholders at all levels, including local communities.

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Memory Mwale: Conceptualization, material preparation, writing-original draft, writing - review & editing, validation, submission.

Teema Biko: Validation, writing - review & editing

Fatmata Sesay: Review & editing

Omar Osman Omar: Review & editing

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT,COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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