*__Review Article__*

# A Review of Water Resources Quality and Contamination Sources in Malawi: Implications for Sustainable Water Management and Public Health

## Abstract

This review examines the quality of water resources in Malawi, highlighting the critical challenges posed by contamination and the implications for public health and sustainable development. Despite the country's rich freshwater resources, access to safe drinking water remains a significant issue due to pollution from agricultural runoff, industrial discharges, and inadequate wastewater management. The review underscores the necessity of establishing a continuous water quality-monitoring framework aligned with World Health Organization guidelines and Malawi Standards to track contamination trends effectively. Furthermore, it advocates for public education on water treatment methods and stricter regulations on wastewater discharge. By promoting Integrated Water Resource Management (IWRM) and fostering collaborations among government agencies, research institutions, and communities, this study aims to enhance water sustainability and public health outcomes in Malawi, ultimately contributing to the broader goals of resilience and sustainable development in the face of climate change.

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

## 1. Introduction

Access to adequate and good-quality water is a fundamental pillar of sustainable development, as it underpins human health, food security, and economic growth while maintaining ecological balance through the sustenance of rivers, lakes, and wetlands. Despite the abundance of freshwater sources 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, has become increasingly unreliable due to seasonal fluctuations exacerbated by global warming, climate change, and pollution from untreated wastewater. Consequently, groundwater has become a critical resource for water supply systems (Omran et al., 2019). However groundwater quality has also deteriorated significantly, creating growing concerns for global water sustainability (Lapworth et al., 2022).

Both natural and anthropogenic factors contribute to the deterioration of water resources globally, as highlighted by various studies (Banda et al., 2024; Nowicki et al., 2023; Psyrillos and Tziritis, 2024; Zeb et al., 2024). Hazardous chemicals (e.g., nitrate, fluoride, and arsenic), heavy metals, and microbial pathogens being among the most common contaminants(Addison et al., 2020a; Chakraborty et al., 2022; Dzinjalamala et al., 2024; Hasan and Muhammad, 2020; Majawa et al., 2024a). Of recent, there has been also detection of emerging pollutants, such as pesticides, pharmaceuticals, micro plastics, and endocrine-disrupting chemicals, pose additional threats to water quality and public health(Liu et al., 2024; Ravindiran et al., 2023; Shehu et al., 2022; Shi et al., 2023).  These pollutants not only disrupt aquatic ecosystems but also contribute to waterborne diseases, such as cholera, typhoid, and schistosomiasis, which remain major public health concerns, particularly in developing countries. Globally, approximately 2.1 billion people lack access to safe drinking water, resulting in 2.2 million deaths annually, with 90% of diarrhea-related fatalities occurring in children under five (Shayo et al., 2023; Uhlenbrook, 2019; WHO, 2022).

Despite the fact that Malawi in the Sub-Saharan region has made progress in provision of improved drinking water sources by about 80% (USAID, 2020), the country still faces significant challenges. Approximately, 4 million people still lack access to safe drinking water and rely on untreated, potentially contaminated. The majority of these people are  in peri-urban and rural areas, constituting to 82% of 17.5 million (Government of Malawi, 2017a) not connected to piped water supplied by government utility providers (Water Boards) due to limitations in capacity (Mkwate et al., 2017). Groundwater, extracted via boreholes and wells, is widely used in these areas due to its consistent availability and natural filtration through geological formations. Yet, its quality is often compromised by geogenic contaminants such as fluoride and arsenic, as well as influences from agricultural runoff, waste disposal, and poor sanitation. Various studies have assessed water quality in selected districts of Malawi, highlighting the presence of geogenic contaminants such as fluoride in both groundwater and surface water (Addison et al., 2020a; Addison et al., 2020b; Vunain et al., 2019; Wesley et al., 2023). Excessive salinity has been reported in the Lower Shire (Missi and Atekwana, 2020; Monjerezi et al., 2011), while high concentrations of iron and manganese have been observed in Karonga (Mapoma et al., 2017). Elevated levels of nitrate and trace metals, including cadmium, have been documented in Chileka, Blantyre (Dzinjalamala et al., 2024). Microbial contamination has also been identified 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).

Surface water, including resources like Lake Malawi and the Shire River, faces contamination from sedimentation, urban wastewater, and agricultural pollutants, especially during floods. Climate change, population growth, and rapid urbanization exacerbate pressure on Malawi's water resources, affecting both quality and quantity. Erratic rainfall patterns, prolonged droughts, and flooding events disrupt water systems, introducing pollutants and concentrating harmful substances. The interconnected nature of surface water and groundwater underscores the need for integrated management approaches to ensure sustainable water use.

This review aims to provide a comprehensive analysis of water quality in Malawi, focusing on spatial and temporal variations in groundwater and surface water. By identifying key contamination sources and their implications for public health, the study seeks to inform evidence-based policy decisions and propose sustainable water management strategies. Additionally, it highlights critical knowledge gaps to guide future research and interventions.

## 2. 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).

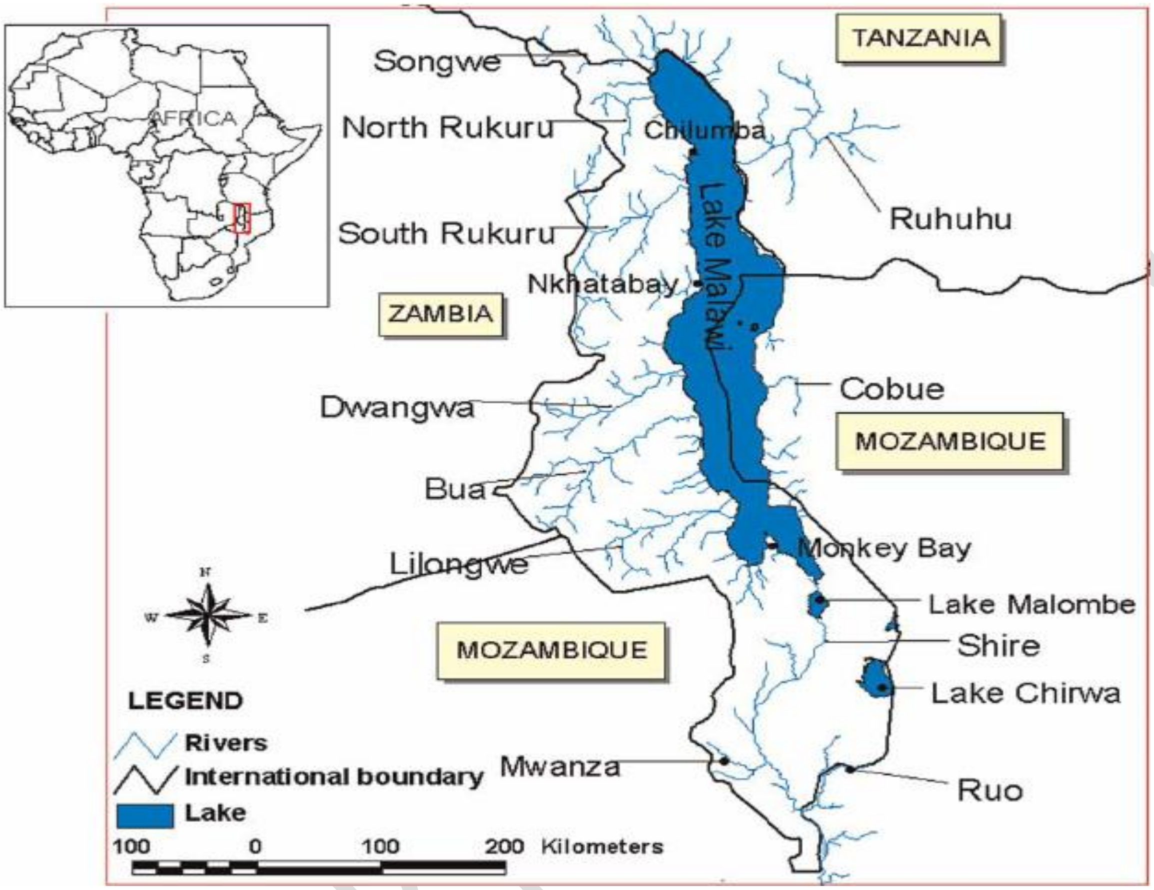


Figure 1: Map of Malawi showing distribution of water resources (Chiluwe and Nkhata, 2014).

## 2.1 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 (Pavelic et al., 2012; 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.



## 2.2 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 is 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.

## 3. Water Quality

The determination of water quality from both protected and unprotected water sources is essential for safeguarding public health, preventing waterborne diseases, and promoting economic growth. Unfortunately, water quality in Malawi remains poorly studied and documented, with significant gaps in knowledge (Chidya et al., 2016a). Nevertheless, several studies have assessed various physical and chemical parameters in both groundwater and surface water, highlighting substantial spatial and temporal variations in water quality across the country. One of the most frequently studied parameters is the Total Dissolved Solids (TDS), which has shown considerable variation across regions. 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 are another key indicator of water quality, reflecting the chemical conditions of water. Elevated pH values, ranging from acidic to alkaline, have been reported in several regions (Chirwa, 2024; Mapoma et al., 2016b; Mussa and Kamoto, 2023). Some lower pH values reported by Kuntumanji et al. (2024) in Likangala ; Kuntumanji et al. (2024b) in Domasi; Mapoma et al. (2017) in Karonga, with some studies reporting values within the World Health Organization (WHO) and Malawi Bureau of Standards (MBS) guidelines (Missi and Atekwana, 2020). 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). 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.

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. (2016a) 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 in many regions of Malawi (Addison et al., 2020a; Addison et al., 2020b; Wesley et al., 2023; World Health Organization, 2024) posing significant health risk. 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 mental contamination including cadmium, lead, and chromium, is particular alarming. Elevated cadmium levels been reported in in Chileka and urban rivers in Blantyre water sources (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 (Chidulo, 2019). These elevated levels were attributed to the improper disposal of oils and paints without pretreatment. Mapoma et al. (2016a) identified high level of cobalt, zinc, and aluminum in 50%-60% of water samples. While mercury and beryllium were undetected, manganese, arsenic, and iron occasionally exceeded regulatory thresholds value of 400 µg/L, 10 µg/L, and 1500 µg/L, respectively.

Microbiological contamination remains a major concern, with pathogens such as E.coli and fecal coliforms detected in various water resources across Malawi. Urban areas such as Lilongwe (Mussa and Kamoto, 2023) and rural areas, such as Mpherembe (Dzimbiri et al., 2021) exhibit high level of microbial pollution in accordance to the WHO guidelines for total and fecal coliform concentrations. Dzinjalamala et al. (2024) found feacal 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 upto 5600cfu/100mL in open shallow wells in Balaka as compared to 1200 in hand-pumped boreholes in Lilongwe during the dry season. Hinton et al. (2024) documented 52.7% of their water sources samples to E.coli contamination. These high levels are primarily attributed to inadequate sanitation and wastewater management, especially in areas with poor infrastructure such as septic tanks. and use of pit latrines in Asia and Africa including Malawi (Kayembe et al., 2018). Inefficient wastewater treatment are also a potential source (Kayira and Wanda, 2021).

While organic contaminants such as Biochemical Oxygen Demand (BOD), 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 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.

Emerging contaminants, including pesticides, pharmaceuticals, and radioactive materials present significant long-term risks due to their persistence and bio-accumulate potential. Recent studies highlighted the presence of these pollutants in environment, underscoring their potential impacts on human health and ecosystems (Kosamu et al., 2020; Ngosi et al., 2024; Ripanda et al., 2022). Literature indicates only one recent study on water pollution by radioactive metals in Malawi. This study by Majawa et al. (2024b) 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.

### 4. 1 Major Contaminants of groundwater and surface water in Malawi

The quality of water resources in Malawi is compromised by a combination of natural and anthropogenic factors, with varying impacts across different regions. Globally, natural factors affecting water quality include the geological framework, mineral composition of the underlying geology, ion exchange, weathering and dissolution of minerals, evaporation, microbial activities, soil processes, and groundwater residence time (Alqaragholi et al., 2023; Islam, 2023a; Li et al., 2020; Manu et al., 2023). These factors are particularly significant in groundwater systems, where geological conditions largely dictate water composition.

In contrast, anthropogenic factors—such as the indiscriminate use of chemical fertilizers, animal manure, pesticides, groundwater abstraction, and sewage discharge—primarily affect surface water (Onyeanuna et al., 2019; Rai et al., 2023; Zhang et al., 2022). While natural factors are more commonly associated with groundwater contamination, and human activities are more linked to surface water, the interaction between the two systems is complex and dynamic. Both systems are interdependent, with surface water and groundwater relying on shared precipitation and subsurface flow processes. Groundwater sustains surface water flows during the dry season, particularly in rivers like the Shire, while surface water recharge supports shallow aquifers in floodplains and along riverbanks. This interconnectedness underscores the need for integrated water management, as contamination in one system can directly influence the other. For example, polluted surface water can infiltrate through soil layers and degrade groundwater quality, while saline intrusion into coastal aquifers may affect nearby surface water ecosystems.

These interactions contribute to the presence of four major contaminants in both groundwater and surface water systems (Figure 2). The sources of some key contaminants found in drinking water are summarized in Table 1.

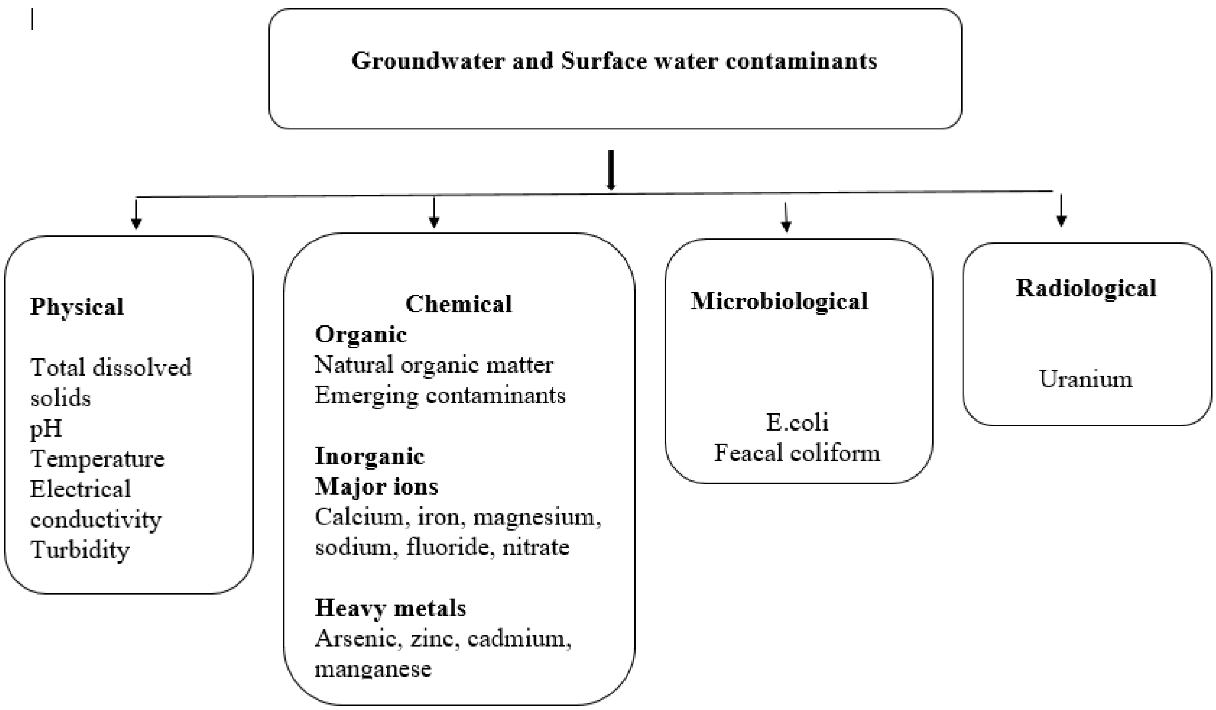


**Figure 2:** Major contaminants and some of their frequent monitored parameters

**Table 1: Some contaminants and their primary sources**

| **Contaminant** | **Definition** | **Primary Source** | **Sources** |
|---|---|---|---|
| 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) |
| Flouride | Major ion | Dissolution of fluoride-bearing minerals like fluorite | (Addison et al., 2020a) |
| Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) | Organic matter | Sewage discharges, industrial wastewater | (Chidulo, 2019) |
| Iron, manganese (Mn) and arsenic (As), lead, cadmium, chromium etc | Trace metals | Industrial wastewater such as oils, dye paints, coal, domestic wastewater<br>Natural processes especially for As and Mn | (Chidulo, 2019; Dzinjalamala et al., 2024; Mapoma et al., 2016a) |
| 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, which compromises disinfection processes and increases 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 fecal coliforms have been reported (Dzimbiri et al., 2021; Dzinjalamala et al., 2024; Kayira and Wanda, 2021; Mussa and Kamoto, 2023).

Chronic exposure to chemical contaminants in water presents long-term health risks. For instance, high fluoride concentrations with 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). Elevated nitrate levels including Chileka and Lilongwe, are linked to methemoglobinemia (blue baby syndrome) in infants and has 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 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 results into eutrophication causing depletion of dissolved oxygen in water bodies, hence disruption of aquatic ecosystem (Ullberg, 2015).

## 6. Water Quality Monitoring Standards and Governance and Policies

Malawi has established well-documented standards (MS 214:2013) (Malawi Bureau of Standards, 2013) for drinking water, complemented by the adoption of World Health Organization (WHO) guidelines for water quality monitoring. These standards form the backbone of national efforts to ensure safe drinking water. Recently, the adoption of the water quality index (WQI) has emerged as a critical tool for assessing the overall health and suitability of water sources, enabling a more holistic evaluation. 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. Additionally, the widespread faecal contamination highlighted in most microbiological studies reveals significant public health risks, emphasizing the urgent need for water treatment before consumption.

From the literature reviewed, rivers and other surface water sources are found to be significantly more polluted, particularly in terms of faecal coliforms, turbidity, nitrates, and heavy metals, often exceeding WHO and MS 214:2013 standards. This is attributed to direct discharge of untreated wastewater, agricultural runoff, and erosion during the rainy season. Groundwater, on the other hand, exhibits greater vulnerability to chemical parameters such as fluoride, iron, and manganese, primarily due to natural geological processes, although nitrates in most cases result from anthropogenic activities like poor sanitation practices and agricultural leaching.

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. Malawi's alignment with global objectives, including Sustainable Development Goal 6 (SDG 6), which focuses on clean water and sanitation for all, further strengthens its commitment to sustainable water management.

However, significant challenges impede the effective implementation of these policies. Overlapping responsibilities between urban water boards and district assemblies that are responsible for rural water supply create governance inefficiencies. Financial constraints in both district assemblies and water boards hinder the upgrading, maintenance, and operation of water supply infrastructure needed to meet the demands of a growing population. Additionally, many agencies lack adequate laboratory equipment, such as atomic absorption spectrometry (AAS) for heavy metals, spectrophotometry for nutrients, and high-performance liquid chromatography (HPLC) for pesticides. This limitation restricts advanced analyses, particularly for trace elements and emerging contaminants. With only two central laboratories nationwide, timely and adequate water sample analysis is challenging. Moreover, water boards lack the capacity to monitor complex substances such as pesticides, pharmaceuticals, and cosmetics, which are increasingly detected in water systems (Kosamu et al., 2020).

Kosamu et al. (2020) also identified the lack of a comprehensive system for sustainably managing used pesticide containers. Currently, the Pesticide Act does not mandate pesticide importers, formulators, or retailers to adopt life-cycle management for their products, including empty containers, from "cradle to grave." While the Malawi Standard on Pesticide Containers (MBS 89:

1991) stipulates that containers should be safely disposed of by removing caps or lids, flattening, and breaking, puncturing, and burying them in locations that prevent pollution of surface or groundwater, implementation remains weak. This regulatory gap poses significant risks to water quality, as the improper disposal of pesticide containers can lead to the leaching of hazardous chemicals into surface and groundwater systems, exacerbating contamination issues. Addressing this challenge through stronger enforcement of standards and policy reforms is essential for safeguarding public health and the environment.

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

Despite advancements in water quality research, several gaps persist in Malawi, limiting the effectiveness of sustainable water management and public health interventions. A key gap is the lack of research on emerging contaminants, including pesticides, pharmaceuticals, micro plastics, and endocrine-disrupting chemicals. These pollutants, often introduced through agricultural runoff, improper waste disposal, and untreated wastewater, have been documented globally for their long-term ecological and health impacts (Ngosi et al., 2024; Wanda et al., 2017). However, their presence, pathways, and effects in Malawi remain largely unexplored, leaving critical blind spots in understanding water pollution. Similarly, there is little information on trace elements in groundwater. The lack of data on potentially toxic elements such as antimony, cadmium, chromium, lead, nickel, and selenium does not necessarily imply their absence or low concentrations. These elements could pose significant health risks if unmonitored(Chidulo, 2019).

Another significant issue is the geographic disparity in research coverage. While water quality studies are concentrated in urban areas like Lilongwe, Blantyre, and Chikwawa, rural districts where reliance on untreated water sources is highest remain underrepresented. This uneven distribution of research limits comprehensive assessments and may underestimate contamination risks in less-studied regions. Temporal gaps further undermine water quality monitoring efforts. Most studies are project-based and short-term, lacking the continuity needed to identify trends and seasonal variability in contamination. For instance, fluctuations in microbial contamination during rainy and dry seasons are poorly documented, hindering the development of timely and adaptive management strategies.

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.

## Conclusion

This review emphasizes the critical need for enhanced water resource management in Malawi, particularly given the persistent challenges posed by pollution. Despite notable advancements in access to safe drinking water, significant gaps remain in our understanding of water quality, especially concerning emerging contaminants and heavy metals. Establishing a continuous water quality-monitoring framework that aligns with World Health Organization guidelines is essential for tracking contamination trends and informing adaptive management strategies. Furthermore, public education initiatives on the importance of water quality and effective treatment methods are vital for community empowerment. Stricter regulations on industrial wastewater discharge, coupled with the integration of advanced monitoring technologies such as Geographic Information Systems (GIS), can significantly improve the management of groundwater resources. Addressing these multifaceted challenges is crucial for enhancing public health outcomes and ensuring the sustainable use of water resources in Malawi, ultimately contributing to broader goals of sustainable development and resilience in the face of climate change.

## 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 (GIS) 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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