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A Review on Pollutants Found in Drinking Water in Sub-Sahara African Rural Communities: Detection and Potential Low-cost Remediation Methods

Bienvenu Gael Fouda-Mbanga[1]*, Thulethu Seyisi[1], Yvonne Boitumelo Nthwane[2], Bothwell Nyoni[1,3]; Zikhona Tywabi-Ngeva[1]

[1]Department of Chemistry, Nelson Mandela University, Gqeberha, South Africa
[2]University of Johannesburg, Chemical Sciences, Doorfontein, Johannesburg, South Africa
[3]Department of Applied Chemistry, National University of Science and Technology, Bulawayo, Zimbabwe

*Correspondence: patsonp46@gmail.com

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ABSTRACT: Water is the most essential substance that supports various life mechanisms. It is a fundamental and necessary requirement for mankind and all other living creatures on the planet. Therefore, daily drinking water should be clean, readily available, sufficient, and free from harmful substances. However, in many rural areas, most sources of drinking water are assumed to be safe for human consumption, but this is not always the case. This work aims to provide a review of pollutants found in the drinking water of Sub-Saharan rural communities and explore potential low-cost remediation methods. The assessment of water pollutants and their remediation methods has been the primary focus of research for several years. Additionally, the World Health Organisation has established various minimum standards regarding the concentration of common pollutants in water. This review presents the major sources of water, the origin of contaminants, the different types of pollutants, and remediation methods to enhance the current knowledge in the field of rural drinking water contaminants.

KEYWORDS: Contaminants; drinking water; inorganic; organic; Sub-Sahara Africa

1. Introduction

People have migrated from villages to cities in search of better lifestyles associated with urbanization. As a result, the number of city residents is predicted to grow, leading to various environmental challenges, including difficulties in obtaining adequate water quality and quantity, as well as issues related to wastewater generation, treatment, and discharge. Common water sources include dams, rivers, lakes, and wells. After use, 60 to 80 percent of the total water supplied is typically discharged as wastewater. In underdeveloped nations, inadequate systems often result in partial or untreated discharge of wastewater, leading to percolation into the ground, contaminating potable water, or release into spontaneous waste systems, polluting downstream lakes, rivers, and bays. Groundwater is critical for sustainability as it is necessary for domestic use, manufacturing, and agriculture. Water used for individual consumption should be clean, odorless, transparent, and free of hazardous pollutants and pathogens [1]. The quality of water utilized is crucial, as a decline in water quality diminishes its effectiveness for humans and other species.

In urban areas, besides various industrial uses that necessitate high-quality water, the demand for potable water is likely to be the highest. Agriculture, being the biggest user of water, suffers when water supplies turn saline due to groundwater contamination. In most developing countries, water contamination is caused by sources such as domestic wastewater, commercial wastewater, leachate, and runoff from landfills and agricultural land. Domestic wastewater, in particular, is the primary contributor to water contamination in developing countries, especially in metropolitan cities [2]. Hence, it is critical to identify various types of contaminants that are emitted into different water bodies. Technologies for water treatment have been designed with a focus on urban areas, often neglecting the rights of rural communities to access safe water supplies to improve their livelihoods. The problem of freshwater availability, particularly in the Sub-Saharan African countries (SSA) region, has grown substantially with rapid economic development. Addressing the challenge of access to water resources is now becoming a global concern, given the importance of an adequate supply of drinking water for boosting the economy [3]. There is a need to develop detection methods for contaminants commonly found in drinking water, specifically for developing communities like the SSA region, to devise suitable remediation methods. This will help reduce the current shortage of drinking water and improve the livelihoods of people in rural areas. However, many contaminants detection methods are complex and require skilled personnel and analytical instruments. Moreover, with the emergence of new types of contaminants, traditional drinking water treatment technologies used in rural and some developing urban areas are found to be inadequate [4].

Currently, the most common water treatment technology in rural areas of the SSA region is slow sand filtration followed by boiling or sometimes chlorination [5, 6]. More effective water treatment methods, such as ion exchange resins, membrane technologies, and physicochemical treatments, are not easily accessible to rural and developing urban communities. However, with proper rural organizational structures, these methods can be applied to storage tanks of water from sources such as community boreholes. The purpose of this research was to present a review of pollutants found in drinking water in Sub-Saharan rural communities, their detection methods, and potential low-cost remediation methods. The review is divided into five sections with the introduction in section 1. Section 2 is a discussion focusing on the major sources of water in the Sub-Saharan region. Section 3 discusses the major sources of drinking water contaminants. Section 4 discusses the types of pollutants with a special focus on their detection methods and potential low-cost remediation practices. Lastly, Section 5 provides a conclusion and recommendations for the detection and remediation of contaminated drinking water for SSA communities.

2. Major Sources of Water

There is a consensus that main sources of drinking water for rural areas are divided into three, i.e., surface water, groundwater, and precipitation as illustrated in Figure 1 [7–10].

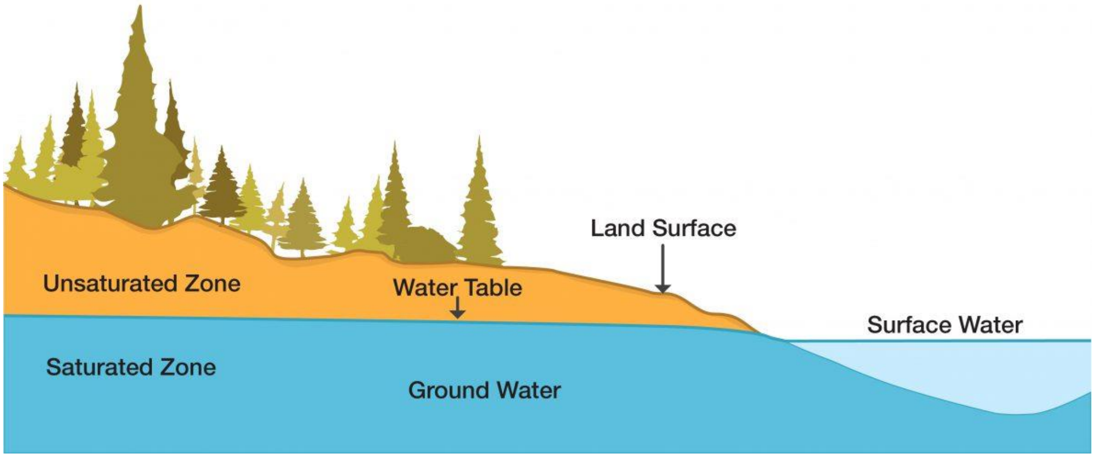

Figure 1: Sources of drinking water for rural areas [11].

2.1. Surface water.

The word "surface water" refers to any body of water on Earth, including rivers, lakes, wetlands, oceans, and estuaries [12–14]. Ice and snow are special types of surface water because they are in solid forms. However, snow can also be classified as precipitation (Fig. 1). The sources of surface water are exposed to the atmosphere. Surface water is seasonal, and it is very likely to contain microorganisms or contaminants that may lead to illness; hence, it will always require treatment. Furthermore, water from oceans is salty and must undergo desalination processes before being considered safe for use. Surface water has an advantage over other sources of water in that it is simple to extract through direct pumping [12].

2.2. Ground water.

Groundwater refers to the water below the earth's surface, e.g., natural springs, boreholes, and wells [13]. Groundwater fills the pores and fissures in underground materials like sand, gravel, and other rock, making it more protected and resilient than surface water. Drilling and pumping equipment are needed to access water from boreholes, wells, or natural springs, but this equipment is sometimes not accessible or maintainable, particularly in emerging nations. The advantage of groundwater sources is that the top layer of the soil functions as a filter against physical, chemical, and biological impairments, enhancing the quality and affordability of groundwater. Consequently, groundwater is considered the major or primary source of drinking water throughout the world [12].

2.3. Precipitation.

Precipitation is normally identified as the source for all fresh water in the hydrologic cycle; it falls nearly everywhere in the form of rain, snow, and hail [15]. Moreover, precipitation varies from year to year and over decades, and variations in amount, intensity, frequency, and type have an impact on the environment and society. It has been reported that the nature of precipitation has been changing over time and will continue to do so because of climate change [15]. Rainwater/snowfall harvesting approaches can be utilized to obtain a safe water supply in rural communities [16].

3. Sources of contaminants

The most prevalent provenances of water contamination range from entirely natural to manufactured, including the discharge of home chemicals into drinking water sources.

3.1. Agricultural wastes.

Agricultural waste (AW) is generated as a result of run-off from plowed areas and livestock farming (animal husbandry). Most commercial farms in developing countries are situated near rural areas. Furthermore, rural communities practice subsistence farming, which has a lesser environmental pollution impact. Farmers use a variety of agro-chemicals as fertilizers to enhance the development of fruits and vegetables, which has always resulted in a variety of soil contamination issues and could be harmful to aquatic life in the event of run-off. Due to the type of chemicals used, agricultural activities are responsible for diffuse nitrogen and phytosanitary pollution. Studies on the effect of farming waste on drinking water have been done. For example, Tăbăraşu et al. conducted a study that listed the main agricultural practices that have a negative influence on the surroundings. Furthermore, strategies of mitigating the effects of agricultural pollution were listed, amongst them was reducing the use of chemicals for crop protection, replacing the use of pesticides with ecologically clean biological means and methods, and using air treatments for agricultural lands next to water bodies [17]. Mateo-Sagasta et al. argued that farming for livestock is expanding and growing faster than crop production, and its associated waste poses a serious threat to the integrity of drinking water sources [18]. Rad et al. studied water pollution associated with pesticide use in agriculture, with a special focus on mathematical models used to reproduce and predict the ultimate fate of insecticides in water resources [19].

3.2. Domestic sewage.

n urban areas, domestic waste (DS) is utilized water from homes and apartments, primarily from the kitchen, bathroom, and laundry. The lack of adequate sewage treatment facilities in urban areas of under-developed countries is the major reason why drinking water sources are polluted by domestic waste. In rural communities, DS is directly disposed into water sources via human activity. For example, it is common practice in rural areas to do laundry in rivers and dams, which can result in significant health hazards for humans and animals due to the ingestion of detergent chemicals. However, organic matter and micro-organisms are the primary components of domestic waste [20].

3.3. Natural sources.

Contaminants may enter drinking water naturally via a variety of processes, namely, rainfall; the aerosphere (dust, storms); sub-surface rocks and volcanoes; natural runoff; and the surrounding flora. Rainwater is a major natural source of water contamination since it absorbs contaminants from the air and transports entrained particulate matter with it. For example, acid rain occurs as a result of the solubility of acid gases in precipitation, including sulfur and nitrogen oxides. Another source of contamination is the immediate deposit of particulate matter by gravity, known as dry deposition. The existence of subterranean rocks and volcanoes beneath the water bodies could also be a source of some salts [21]. However, the prevalence of volcanic eruptions in the SSA region is low [22].

4. Types of water pollutants

In this review, pollutants were classified into organic, inorganic (non-metal), heavy metals, microplastics, dangling solid sediments and microbials.

4.1. Organic Pollutants (OPs).

OPs are made up of the elements C, H, N, S and O. Organic substance emitted by sewage, urban wastewater, industrial wastewater, and AW. Examples include oleic acid ($C_{18}H_{34}O_2$), hexadecanoic acid ($C_{16}H_{32}O_2$), Lauroyl chloride ($C_{12}H_{23}ClO$), and docosanoic anhydride ($C_{44}H_{86}O_3$) [23]. OPs can be grouped into two types: biodegradable and synthetic waste. Biodegradable waste can be destroyed by bacterial activity with the consumption of oxygen. These contaminants deplete all of the oxygen in the water system, causing an anoxic situation in the environment. Food manufacturing units, slaughterhouses, pulp & paper businesses, leather tanning, breweries, distilleries, and other sectors produce a substantial biodegradable organic molecule in their effluents and wastewater. Synthetic organic pollutants, on the other hand, are not environment-friendly and can persist in water bodies for longer periods of time. Examples that are frequently cited include pesticides, medications, textiles, plastics, solvents, and volatile organic compounds (VOCs).

4.1.1. Detection methods of OPs.

Chromatographic and spectroscopic approaches can be used to accomplish emerging organic pollutants detection. Chromatographic techniques are the most popular analytical techniques for identifying and detecting different compounds in any type of sample [24]. Gas chromatographic is the most frequently used technique for OPs detection. Instant analysis, high resolution, improved sample efficiency, reduced costs, and increased laboratory efficiency are the many advantages of GC [24]. Most OPs are semi-volatile, with polarities ranging from mild to non-polar. Because of these physicochemical features, most OPs are well suited to GC-MS. MS has recently become the most widely utilized detector for OPs analysis.

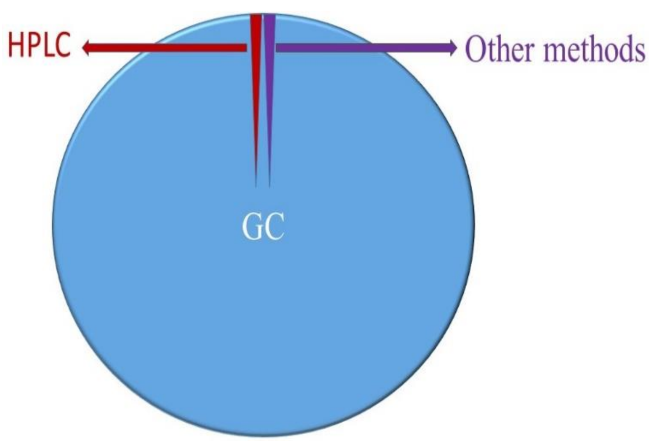

Figure 2: Detection methods of OPs in water resources [24].

To produce ions, several approaches are employed in MS. GC combined with MS in the selected ion mode is a frequently used technology for detecting OPs in food. The chosen ion mode can enhance selectivity by concentrating on a subset of relevant masses that correspond with analytes [25]. Other techniques applied for the detection of OPs include electron capture detection, high resolution mass spectrometry (HRMS), mass spectrometry coupled with mass spectrometry (ms/ms), and time of flight mass spectrometry (TOF-MS). Figure 2 shows Gas chromatography applied as the most commonly used detection technique and Table 1 presents the frequently used analytical method for the detection of OPs

Table 1: Commonly analytical used techniques for OPs detection [26].

Type	Method	Description
Separation	Gas chromatography (GC)	Excellent separation potential, but only for more volatile chemicals examples include high resolution gas chromatography
	Liquid chromatography (LC)	Excellent for the polar water-soluble class of chemicals, poor uncoupling potential example includes HPLC
	GCxGC	Excellent isolation potential, but limited to more volatile chemicals.
	ECD	The most widely used detecting approach, with restricted detection capabilities
Detection	Mass spectrometry in the negative chemical ionization mode	Excellent sensitivity, but limited to non-polar OPs
	Mass spectrometry in the selected ion monitoring mode	Good sensitivity, but the ion window set may need to be maintained.
	(HRMS)	Excellent sensitivity, but high-cost
	MS/MS	Enhances sensitivity and selectivity in comparison to single quadrupole
	TOF-MS	The mass analysis range is broad, however the detection limits of the instrument are inadequate.

4.1.2. Potential remediation technologies for OPs.

In recent years, various studies have considered new processes to eliminate OPs. These potential remediation technologies for OPs include carbon nanotubes, magnetic and metal nanoparticles, silica nanoparticles, graphene oxide nanoparticles, covalent framework and metallic organic frame-work [27]. Among these methods metal-organic frameworks (MOFs) have been recently researched for the removal of pollutants in water. Furthermore, these MOFs are promising materials for contaminant removal because they have many properties that benefit water treatment, such as large surface area, active sites, and so on.

4.1.2.1. Carbon nanotubes (CNTs).

CNTs have been used for the removal of POPs due to their attractive adsorptive characteristics. Studies have shown that total petroleum hydrocarbons have an 82% removal efficacy can be achieved using microwave-assisted CNTs, and that removal of Cr (VI) contaminated soil can be accomplished with carboxylated multi walled CNT-OH, multi walled CNT-COOH. or hydroxylated. Magnetic carbon black nanoparticles (MCBN) can also be used to biodegrade petroleum and immobilize heavy metals in polluted soil [25]. Gong et al. outlined the use of single and multi-walled CNTs for the elimination in hexachlorocyclohexane and dichlorobiphenyls-chloroethane (DDT) [28]. CNTs have ideal circumstances for 4 months, whereas SWCs have optimal conditions for 0.29 wt%. The effectiveness of CNTs in the removal procedure is determined by the time needed for sediment-sorbent and the dose. Abbasian et al. found that MWCNTS is utilized to promote bioremediation process of soil polluted by crude oil, boosting the population of microorganisms and lowering DDTs by 59%

and 93%, respectively [29]. Activated carbon (AC) at a concentration of 2 wt% can be used to treat soils, but is much more useful than MWCNT.

4.1.2.2. Magnetic and metal nanoparticles.

Metallic oxide and metal nanoparticles have been used to immobilize and remediate pollution in soil and groundwater. Cadmium and nickel remediation from calcareous and non-calcareous SiO_2 nanoparticles has been reported. Baragaño et al. detailed the application of nanospheres goethite (nGoethite) and nZVI for polluted terrain reconditioning. A reduction of 89.5% was seen when 2% nZVI was introduced. Magnetic nanoparticles (MNPs) are as well broadly applied in soil treatment due to their fast magnetic separation ability and special metal-ion adsorption [30].

4.1.2.3. Silica (SiO_2) nanoparticles.

Chen et al. developed mesoporous SiO_2 nanoparticles (MSNs) using an enhanced sol-gel process [31]. Their form was altered by varying the amount of ammonia transferred from flower-like nanospheres to nano-disks. Different samples' luminescence properties revealed that the shape of nanovesicles exhibited strong intensity and adsorption capacity. Mesoporous silica nanoparticles with a diameter of 165 nm and a surface area of 950 m^2/g are used to create non-harvested polyphenolic flavonoids. Nano-harvesting is the process of joining and transporting biomolecules outside of a living thing's cell. Peres et al. reported using a microwave to remove silica nanoparticles from the husk of rice. Both $nSiO_2$ and microwave-$nSiO_2$ are employed as adsorbents in the process of removing MB dye from aqueous solution [32]. According to studies, it is feasible to create an adsorbent with the highest adsorption capacity by using waste elements to create extremely tiny amounts of pure silica.

4.1.2.4. Graphene oxide (GO) nanoparticles.

Due to its large pore space, good conductivity, diverse surface chemistry, and extremely large surface area, GO is ideal for adsorption of organic pollutants from wastewater. The resonant, sheet-like, polyaromatic structures of the graphene branches have a significant effect on hydrogen bonding and interactions in organic pollutants. Owing to the photoelectric structural and physicochemical properties of 2D graphene, environmental photocatalytic activity has seen a significant increase. Researchers have sought to develop species in photo-catalytic innovation using hybrids based on graphene as catalyst platforms. Their potential applications to eliminate of antibiotics, phenols, medications, dyes have received significant attention [33–34]. Wang and Chen demonstrated graphene-nanosheet adsorption capabilities, with better absorption to 1-naphthol than naphthalene [35]. According to Huang et al., GO can be isolated from aqueous medium and is a potent adsorbent for the elimination of contaminants. To facilitate recycling, MnFe2O4 was added to Cu-zeolite/graphene oxide composites, which can be easily removed using an external magnet. $MnFe_2O_4$ has a high crystallinity, a short synthesis time, and a low cost. Magnetic extraction methods have been used to separate solids and liquids [36].

4.1.2.5. Covalent frame work (COFs).

COFs are a new type of crystalline porous polymers known for their structural symmetry, inherent absorbability, strong frameworks, and chemical stability. They are considered powerful adsorbents that effectively remove organic pollutants [37]. COFs are useful for sample preparation and coatings of solid-phase microextraction (SPME). A number of techniques may be used for the production of COFs and are adapted or functionalized in order to maintain their characteristics. For organic contaminants, the COF substances were able to achieve good extraction results through diverse testing methods [38]. COFs play a critical role in environmental applications namely separation, adsorption, and sensing [39].

4.1.2.6. Metal organic framework (MOFs).

MOFs are polymers with porous interaction generated by inorganic groups bound by organic ligands. They offer great adsorption, high modularity, and a wide range of efficiency and may be tailored by carefully selecting inorganic and organic components. [40]; According to Li et al., several contaminants found in the environment are predominantly in anionic forms and are abundant in water bodies. [41]. The thorium-based porous suspension cationic MOF (SCU-8) exhibits anion-exchange properties that have been observed by various anions. The underlying absorption mechanism was explored using quantum mechanical and molecular dynamics simulations. Gao et al. reported that photocatalysis on the basis of MOFs is a useful technology in the presence of visible light [42]. They found that the MOF material MIL-53(Fe) contained Fe and exhibited photocatalytic activity to decompose Orange Acid 7 from aqueous solution under visible LED light irradiation. This is controlled by adding an additional electron pair (e.g. persulfate). The MOF of various metals also acts as an adsorbent for organic pollutant cations and oxyanions. MOF nodes capture inorganic anionic contaminants through pseudo-ion exchange, where weak participating ligands are substituted by the coming pollutant [43]. MOFs' physicochemical assemblies can be made to exploit numerous non-covalent linking sites [44]. The zirconium-based MOF (Zr-MOF) exhibits significant thermal and chemical stability due to strong Zr(IV)–O bonding in Zr-based nodes and between the carboxylate groups and the binding node. These MOFs are remarkably stable in aqueous media with pH between 5 and 9. Wagner et al. observed that human evolution led to pollution of terrestrial and aquatic environments by toxic organic complexes, mainly POPs [45]. Chemical adsorbents and sensors designed for specific pest control work based on host-guest relationships to provide sensitivity and selectivity and, therefore, useful in detecting pathogens. target molecule.

4.2. Inorganic (non-metal) pollutants.

Significant amounts of inorganic compounds (IP) mainly halides, nitrate, nitrite, and ammonium in river water caused by draining farmlands, municipal/industrial sewage, and other factors cause a variety of health issues. Most inorganic compounds are associated with the risk of health issues such as stomach, liver and esophageal cancer [46].

4.2.1. Nutrients.

4.2.1.1. NO_3^-.

NO_3^- is an essential nutrient for plant growth. Nitrate in drinking water may lead to birth defects and gastrointestinal problems. In the human body, NO_3^- reacts with amines and amides to generate cancer-causing nitroso compounds. NO_3^- levels in water that are too high have been linked to health concerns in infants and adults. Organic nitrogen in ammonia is degraded by microbial enzymes [47].

4.2.1.2. PO_4^{3-}.

PO_4^{3-} is an important nutrient to plants, animals and human. In a few water systems, phosphorus (P) content is low enough to inhibit the expansion of algae and/or aquatic plants. P coupled with organic molecules comes in three forms: organic phosphorous, orthophosphate, and polyphosphates. PO_4^{3-} in water can cause algal blooms to form in waterbodies. A low quantity of PO_4^{3-} may promote the growth of algae and aquatic plants, resulting in eutrophication of the aqueous habitat. According to scientists, P is the limiting nutrient. The non-point source is the natural degradation of rocks, farm runoff, sedimentation, and animal input [48].

4.2.2. Halides.

The most prevalent halides found in natural water are Cl^-, F^-, bromide Br^-, and I^-. These ions are highly soluble and can be found in all plain water sources, including lakes, streams, rivers, and groundwater. Hard rock weathering, herbicides and fertilizers, industrial discharge, and other sources of halides are also possible. Cl^- and Br^- are both conservative elements, and their ratio is employed to provide salinity in coastal aquifers. Because these components are conservative, they inhibit biological absorption as well as deposition [49].

4.2.2.1. Fluorides (F^-).

F^- has the greatest electronegative value of any chemical element. It possesses a strong propensity for forming fluoride ions in solution. The principal supply of F^- in groundwater is thought to be geological processes, primarily volcanic rocks. F^- bearing minerals include fluorspar, apatite, mica, amphiboles, and certain clay. Anthropogenic sources of F^- in water include chemicals applied in agriculture and the brick industry. pH, the solubility of fluoride-bearing minerals, and temperature, all have an effect on fluoride concentrations in water. The recommended intake of F^- as advised by the U.S. Department of Health and Human Services (HHS) is 0.7 mg/l [50]. Significant intake of F^- could lead to dental fluorosis and skeletal fluorosis [51].

4.2.2.2. Chlorides.

The most abundant component in water, chlorine, leads to the deterioration of several metals. Ion exchange mechanisms, farmland surplus, unprocessed effluents from industries and other sources of chloride in water resources are all sources of chloride in water resources [52].

4.2.2.3. Bromides.

As an inorganic salt, bromide naturally concentrates in water from natural water sources. Freshwater bromide concentrations can occur naturally from rainfall, but significant amounts can occur from the combustion of leaded gasoline. High levels of bromide produced by industrial waste and agricultural runoff. Bromide has been used as an indicator of saltwater intrusion, as a salt source, and as a pollutant in coastal aquifers. However, large amounts of bromine can be fatal to aquatic life. High levels of bromide in plants can cause stunting and poor germination [53]

4.2.3. Potential remediation technologies for inorganic compounds.

Techniques for removing inorganic compounds such as halides have been divided roughly into three groups: membrane, adsorptive and electrochemical. Figure 3, shows the various techniques for removal of inorganic compounds in water.

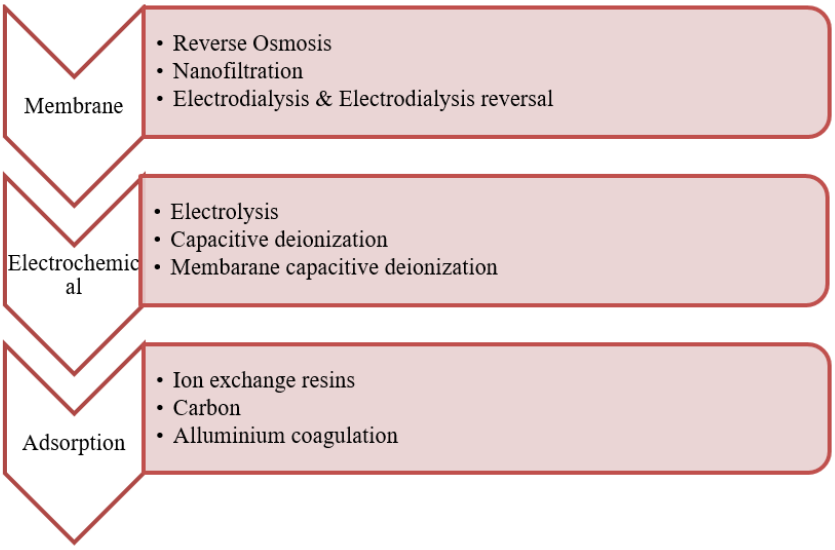

Figure 3: Techniques for removal of halides in water [54].

4.2.3.1. Membrane.

Membrane innovations have evolved into a differentiated extraction technique having major trade uses in the water sector during the last decades. With rising water needs and dwindling water resources owing to increasing numbers of people, deterioration of the environment, and climate change, membrane technologies are being used to create high-quality drinkable water from contaminated and alternative water sources. Membrane technologies such as reverse osmosis (RO), nanofiltration (NF), ion exchange membranes, electrodialysis (ED), and electrodialysis reversal (EDR) are covered in the sections that follow [55]. Reverse osmosis is a method of purifying water that involves forcing water through a semipermeable membrane under pressure to remove organic pollutants and minerals. The majority of commercially viable reverse osmosis membranes are thin-film composites with a top ultra-thin active filtration layer made of crosslinked polyamide, however alternative polymers such as piperazine and others are also used. To give the requisite mechanical stability, this thin layer is supported by an intermediate porous polysulfone support and a grid of polyester fibers. Reverse osmosis is a tried-and-true technology for removing a wide range of pollutants, and it was the most successful bromide and iodide removal technique of all those tested. Importantly, this technology can remove both organic and inorganic Dysinfectant by-product precursors at the same time, making it invaluable in the reduction of Dysinfectant by-products. Nevertheless, reverse osmosis is still highly expensive, necessitates significant pretreatment, consumes a lot of energy due to high operating pressures, and is prone to scale [55].

Nanofiltration is a pressure-driven membrane method that is a cross between reverse osmosis (non-porous diffusion) and ultrafiltration membrane processes. When contrasted to reverse osmosis, nanofiltration often operates at lower pressures, lowering energy expenditures. It also has fewer barriers to both solvent and solute flow. Though there are numerous membrane varieties, most nanofiltration applications employ polyamide thin-film composite membranes in a spiral wound arrangement. In comparison to reverse osmosis, nanofiltration has slightly lower capital costs, significantly lower operational costs due to lower operating pressures, and can be operated at a higher water recovery, resulting in a smaller waste concentrated stream while accomplishing similar bromide and iodide removals. Because of these benefits, the use of nanofiltration has grown, particularly in industrial applications and drinking water purification. This membrane technology suffers from the same restrictions as reverse osmosis, albeit to a lower extent. Nanofiltration necessitates substantial pre-treatment, consumes medium to high amounts of energy, and is prone to scaling [56].

The electrodialysis technique employs a direct current driving force to transport ionic species across cell pairs with oppositely charged membranes, permitting them separation from the source water. The key advantages of electrodialysis over other membrane techniques are mainly minimum pre-treatment of input water is necessary, better water recovery can be accomplished than with reverse osmosis, and despite the fact that electrodialysis reversal technique recoveries ought to be comparable to nanofiltration [56].

4.2.3.2. Electrochemical.

In recent years, electrochemical oxidation has attracted more attention for the treatment of PFASs due to its ability to break down a variety of persistent micro-pollutants. However, it is less effective for breaking down shorter chain PFASs and may cause electrode corrosion as well as the production of unwelcome toxic byproducts (such as hydrogen fluoride, chlorine gas, absorbable organic halides, etc.) when co-contaminants are present [54].

4.2.3.3 Adsorption.

It is a widely used method for removing pollutants from the water, that uses a variety of materials as adsorbents [57]. The adsorption technique is thought to be a superior method for treating water because it is more affordable, environmentally friendly, highly effective, simple to design, simple to use, and insensitive to toxic substances. On the other hand, the adsorption capacity and adsorption efficiency of the sorbent determine the choice of an appropriate adsorbent for a specific adsorbate. However, bulk solution chemistry, which includes temperature, dosage, rate of mixing, solution pH, initial level of pollutants, properties of the adsorbate, and the adsorbent, also affects adsorption behavior [54].

4.3. Heavy metals (HMs).

HMs are metals or metalloids with a high atomic mass and density, and they are frequently thought to be poisonous even at small amounts. HMs sources can be either from human activities or natural. Human activities sources of HMs contamination in water include mining, the release of industrial effluents, and fertilizers applied in agricultural activities [58]. Some selected HMs that are considered toxics and their impact on human health are discussed in supporting information.

4.3.1. Detection methods for HMs.

A metal ion detector is a tool or instrument that can identify and, in some cases, quantify the presence of metal ions in its environment. Before toxic metal ions are removed from the water, the detection method is necessary to identify the possible pollutants in the water. Additionally, there are various methods for the detection of heavy metal ions as discussed below:

4.3.1.1. Spectroscopic detection.

Atomic absorption spectroscopy, inductively coupled plasma mass spectrometry, X-ray fluorescence spectrometry, neutron activation analysis, and inductively coupled plasma-optical emission spectrometry are highly sensitive methods for detection of heavy metal ions. Figure 4 below consists of a primary light source, atomizer to produce gas-phase atoms or ions for analysis, a monochromator, a detector and an electronic readout system [59].

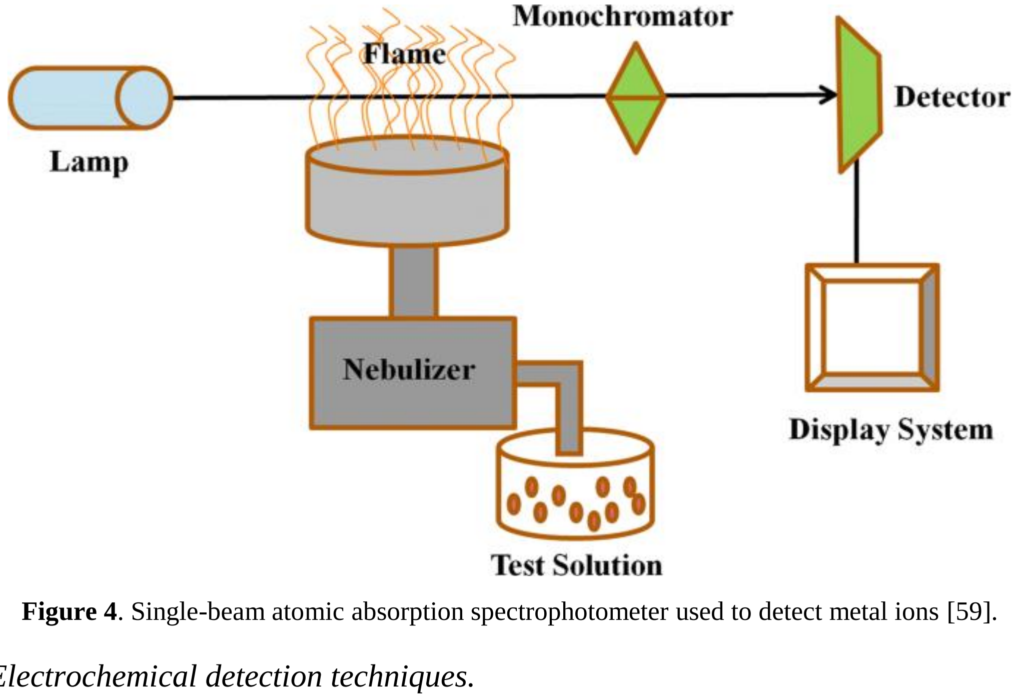

Figure 4. Single-beam atomic absorption spectrophotometer used to detect metal ions [59].

4.3.2. Electrochemical detection techniques.

These techniques are reliable, affordable, user-friendly where simple procedures are used to monitor contaminated samples. The reduced analytical time required by electrochemical methods when compared to other spectroscopic approaches is another benefit. Low sensitivity and higher detection limits are the disadvantages of electrochemical detection techniques, excluding the spectroscopic and optical methods. Figure 5 below consists of X-ray source, sample chamber, fluorescence detector, data processing and display system used to determine the elemental composition [59].

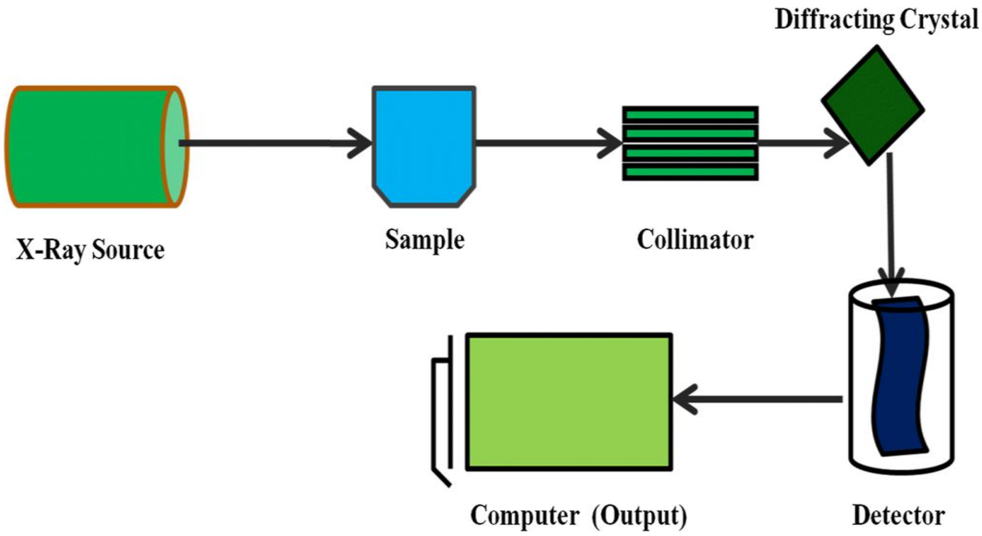

Figure 5. A block diagram of X-ray fluorescence spectrometer [59].

4.3.3. Optical methods of detection.

Typical techniques for absorption, reflection, or luminescence spectrometry can be used to identify the materials' optical effects. For the optical detection of heavy metal ions, optical fibers, integrated optics, capillary-type devices, particular indicator dyes, ionophores, etc. are more frequently used. Additionally, optical ion sensing has limitations despite being useful for the detection of some HMs [59].

4.4. Potential remediation methods for HMs.

Once the presence and quantity of a certain metal ion in water have been identified by one of the detection techniques, its removal is critical to ensure the water is safe for human consumption. Because a minor excess of metal ion above its permitted limit can be hazardous to human health, the removal process is just as critical as detection. HMs can be removed from water using a variety of processes, including chemical precipitation, adsorption, ion exchange, and so on;

4.4.1. Chemical precipitation method.

This is one of the most successful methods for removing HMs from wastewater. In this technique, chemical reagents are used to produce an insoluble precipitate by interacting with the heavy metal ions in the wastewater. To remove harmful metals from water, insoluble precipitates are removed by sedimentation or filtration. [59].

4.4.2. Adsorption method.

Adsorption is considered desirable because of its low cost, simple design, and reliable operation, especially in terms of removal efficiency. Many standard processes such as chemical precipitation, flocculation, membrane separation, ion exchange, etc., are unsuitable in many cases because they have low capacities and removal rates for metals other than Hg (II). Some of the most commonly used adsorbents for the removal of HM are activated carbon, biomaterials, layered double hydroxides and carbon nanotube-based materials. [59].

4.4.3. Ion exchange method.

Due to the high removal efficiency and fast kinetics of ion exchange materials, ion exchange is another interesting technology for the removal of harmful heavy metal ions from wastewater. Both synthetic and natural ion exchange resins are used for this purpose, with synthetic resins being preferred due to their better ability to extract heavy metals from solutions [59].

4.5. Microplastics.

Microplastics (µP) are small plastic chunks lesser than 5 mm long that can be harmful to our oceans and aquatic life. The provenance of µPs could be used to classify them. We have two main types: primary µPs that are solidly formed to be that size, whereas secondary µPs are tiny particles of plastic that break down from larger chunks [60–61]. The difficulty with µPs is that they are so small that they are typically not removed by water filtering and end up in rivers and oceans. µPs are harmful because they are consumed by fish and other aquatic species, causing them to die or suffer from health problems. µPs pose severe dangers to creatures if consumed. The repercussions include intestinal obstruction, reluctance to release stomach enzymes, a reduced eating stimulation, decreased steroid hormone levels, ovulation disruption and reproductive failure [62].

4.5.1. Detection methods for µPs.

The common techniques most applied for detection and characterize microplastics in water include microscopal techniques. However, these methods present some limitations related to partial outcomes in the analysis of tiny particles. Table 2 illustrates the advantages and limitation of the detection techniques for microplastics pollutants.

Table 2: Detection methods for microplastics pollutants [60, 63, 64].

Technique	Advantages	Limitations
Stereo/dissecting microscopy	-Allows three-dimension analysis -Easy to use to study objects that cannot be seen with visible eyes	-Particles smaller than 100 µm that are transparent or have specific structures are arduous to characterize. - Packed sediment samples can obstruct microscopic detection of microplastic contaminants on filter paper. -Detection is compromised when the sample has material which may not be eliminated by chemical digestion
Fluorescence microscopy	-Decrease the identification failure of microplastics -Lower the size of the detected microplastic pollutants	- The fluorescence characteristics can be influenced by chemical additions employed in the synthesis process. - The presence of nanoparticles can be wrongly attributed to the intensity of total fluorescence in cells following exposure.
Scan electron microscope	-Time effective and low costs -Versatile technique where small particles can be observed without high energy and voltage	-Samples usually are not reusable for other techniques.
Atomic force microscopy	-Production of images within high resolution of a few nanometers -Samples surface preservation -Use to investigate the surface of nonconducting micropollutants	-Cannot prevent outside factors like contaminations. -The contact could release fragments, in case of adhesive polymers, to the tip

Technique	Advantages	Limitations
	-Useful for the analysis of nanocomposite materials -Avoids radiation damage of the sample	and could produce an incorrect image of the sample.
Raman spectroscopy	-Allows non-destructive analysis of materials	-Fluorescence may be a concern.
Thermal analysis	-Use to identify of primary microplastics like microbeads	-Melting of plastics over a wide range of temperatures. - When describing a mixture of MPs with closely spaced melting temperatures, there is a lack of specificity. -Overlapping of melting points.
Nile red	-Allow rapid detection and quantification of microplastics -Higly selective	-Co-staining of natural organic material.
Sensors	-Unique for nonplanar sample detection. -Differentiation of the microplastic type and size by combining two optical detection methods.	Further development prototypes are needed for a better and more acceptable detection process.

All of the microplastic detection technologies mentioned above have proven to be efficient and unique, and improved detection methods are desperately needed. To discover microplastics at the nanoscale, advanced microscopic techniques, such as atomic force microscopy, can be combined with spectroscopic techniques. Microplastic separation methods for water and other samples should be developed. Microplastic detection is another application for the sensors. The sensors are capable of detecting microplastic at a low level with high speed and specificity [64, 65].

4.5.2. Potential remediation methods of µPs.

Green technology development for the elimination of µPs is still a novel obstacle. A range of new methods has been developed recently for the effective removal of MPs, with promising outcomes. They include membrane filtration, adsorption, chemical-induced coagulation-flocculation-sedimentation, bioremediation, and improved oxidative processes [66]. It is generally known that ultrafiltration (UF) membranes have been widely used and will continue to be in the next decades due to the outstanding effluent quality they generate [67, 68]. Coagulation is now the primary method for pollutant removal in water plants [69]. The removal behavior of microplastics during the coagulation and membrane filtration processes, which is important for human health, has, however, received little study [70].

4.6. Dangling solids and sediments.

The proportion of inorganic and organic matter held in the water column of a watercourse by instability is referred to as dangling solids and sediments (DSS). Particle size with a diameter less than 62 mm is typically found in DSS. The effect of DSS on freshwater ecosystems is determined by four important factors: (1) the amount of DSS, (2) the timeframe of interaction with DSS, (3) the geo-chemistry of DSS, and (4) the particle-size distribution of DSS. The presence of dangled particulates in water could block natural light entry that is required for photosynthesis. Finer dangling particles can cause fish gill damage and oxygen deprivation [71].

4.6.1. Detection methods for DSS

The approach utilizing tandem mass spectrometry has been utilized to identify target chemicals with excellent selectivity and sensitivity, However, this approach was unable to offer comprehensive data on compounds found in the environment [72, 73]. The screening procedures utilizing high-resolution mass spectrometry technologies like quadrupole time-of-flight and orbit rap have lately elicited interest as a way to get around the limitations of conventional target analysis methods. The high-resolution mass spectrometry methods' potent features, including precise mass measurement and broad ranges, allow for the accurate identification of thousands of chemicals at once [74].

4.6.2. Potential remediation methods of DSS.

Aerobic biodegradation, filtration, flocculation, adsorption, froth flotation, and electrocoagulation are the principal treatments now available for removing dangling solids, sediments, and micropollutants [75]. Nevertheless, certain additional approaches, such as electro-Fenton, electro-oxidation, and photo-electro-Fenton, have been used in conjunction to address the drawbacks of individual processes. Electrocoagulation is preferred over a number of photo-assisted electrochemical and other electrochemical processes for the removal of DSS in water. Because the EC approach employs such a small amount of chemicals and leaves no room for secondary contamination, there is no need for a neutralization process [76].

4.7. Microbial contamination (MC).

Harmful bacteria enter the water from a variety of provenances, including wastewater discharges and industrial wastes. Waterborne infections may be caused by viruses and bacteria including Cryptosporidium, Campylobacter, Salmonella and Sheela. Cholera and hepatitis are some of the main illnesses induced by water pollution in humans. When tainted water makes contact with air, soil, or deposits it is quickly polluted by saprophytic microorganisms. The unregulated dumping of sewerage into bodies of water and human excreta has resulted in a high level of pathogen pollution [51] .

4.7.1. Detection methods for MCs.

A widely used molecular biology technique for detecting a wide range of microorganisms in diverse clinical samples is polymerase chain reaction (PCR) [77]. *Salmonella* spp., *V. cholera*, and *E. coli* may be found in a range of sample types, including water, using the PCR tests that have been designed for this purpose [78, 79]. indirect fluorescent antibody (IFA) staining has been seen as an alternative for the detection of microbes such as Cryptosporidium oocysts and Giardia cysts in wastewater [80].

4.7.2. Potential remediation methods of MC.

Membrane filtration has been seen as one of the interesting techniques for detecting microbial with larger volumes [81]. For analyzing water samples, techniques such as dead-end ultrafiltration (DEUF) are an option since they can handle vast quantities of water concurrently concentrating protozoa based on size exclusion, viruses and bacteria. Extensive research has already tested ultrafiltration as an alternative to reduce microbial pollutants in water. Biofilm

[82], Ultraviolet irradiation [83], Aerobic granulation [84], and Microbial fuel cell [85] technology has been utilized by researchers for the elimination of microbial pollutants in water.

5. Conclusion and perspectives

Water contamination is a key ecological issue causing global concern. Humans contribute significantly to water contamination by throwing, disposing rubbish, and washing clothes, among other activities. During the dry season and in the continent's major arid zones, groundwater for consumption is critical in both rural and semi-urban regions. Notwithstanding its significance, groundwater in Africa little has been known and continues to be a little-known. Teaching sustainability appears to be extremely important, especially in schools and must be included in the education curriculum. This study has provided some pollutants found in drinking water of Sub-Saharan rural communities, their detection methods and potential low-cost remediation methods. Further investigations should be conducted in developing more techniques for the detection of pollutants at very low levels in water as well as the provision of suitable inexpensive methods for the remediation of these pollutants.

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Declaration of Competing Interest

The authors declare that there is no conflict of interest that could have risen in the making of this work.

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