**Challenges and Solutions for Drinking Water Quality Management in Rwanda: A Comprehensive Review**

# ****ABSTRACT****

Water quality management is a critical aspect of sustainable development in Rwanda, where rapid population growth, urbanization, and climate change are putting significant pressure on water resources. This review highlights the current water quality issues in Rwanda, focusing on water pollution challenges and emphasizing the need for a more integrated approach to addressing these problems. In Rwanda, the high population density, expanding industrialization and urbanization, inappropriate solid waste and wastewater management, and high rainfall intensity, are among the key sources of water pollution of drinking water. Eroded sediments entering rivers and lakes increase the cost of water treatment and reduce the quantity of clean water, particularly during the rainy season. Implementing soil erosion control measures, such as terraces, Conservation practices (conservation tillage, planting cover crops on drainage channels), forest preservation, slope stabilization with crops, bamboo revetments for riverbanks, and buffer zone regulations, offers significant benefits, enhancing both population health and climate resilience and also have been used to reduce nonpoint source pollution. It also supports the country's economy by reducing waterborne diseases, contributing to better living conditions, poverty reduction, and overall socio-economic development.

***Keywords****: Water quality, soil erosion, turbidity, WASAC, integrated watershed management*

# 1.Introduction

“Water degradation has worsened across the globe since the 1990s and is expected to escalate even further, leading to increased threats and negative impacts to human health and the environment. Global water quality challenges need urgent attention and cohesive informed actions to avoid a global water predicament in the near future” [1, 2]. “The water quality is compromised by agriculture activities and, industrial and the climate change creates heavy storms and alters rainfall patterns, which affect the elements found in runoff” [3-5]. “Soil erosion, nutrient cycling, tillage for seedbed preparation, land application of inorganic fertilizers or animal waste (manure/slurry), and pest and residue management all affect runoff, which in turn adversely impacts water quality” [6]. “Climate variability, involving changes in temperature, rainfall patterns, and precipitation, is increasing and heavily impacting water resources, water-related diseases, and, subsequently, human health, which relies on clean water” [7]. “Degradation of water poses a risk to human health, impairs ecological function, and impedes socioeconomic development” [1]. “Water quality is one of the major challenges facing society worldwide during the 21st century, and failure to address this challenge is likely to have serious implications for several sustainable development goals (SDGs). The most prevalent water quality problem on a global scale is nutrient loading, which, depending on the region, and mostly associated with pathogen loading through the deposition of untreated wastewater” [8]. “The management of natural resources in a sustainable way is one of the serious problems that each country must effectively address. Observing past events and having clear data on changes in land use are crucial for managing land and water resources in each country” [9].

“In Rwanda, the high population density, expanding industrialization and urbanization, inappropriate solid waste and wastewater management, and high rainfall intensity, are among the key sources of water pollution” [10, 11]. “Water pollution is directly related to population growth and has a significant impact on human health. As the population increases, the water demand also rises, ultimately affecting the quality of water resources” [7]. “Heavy rainfall increases surface runoff, ultimately leading to soil erosion. On the other hand, frequent and prolonged heavy rain can saturate soil profiles, leading to poor water infiltration” [12]. “The frequency and intensity of rainfall, land use and land cover, soil type (hydraulic conductivity and erodibility), slope length and angle, and processes like leaching, adsorption, and denitrification are some of the factors that affect the movement of Nitrogen (N), and phosphorus (P) and sediments” [13]. “Previous studies have highlighted some of these efforts, such as increased fertilizer application and the expansion of cropland on unprotected land, as key drivers of soil and water quality pollution. These efforts accelerate soil erosion and the release of phosphorus, nitrates, and ammonia from applied agrochemicals, which, in turn, cause water pollution and eutrophication” [11]**. “**In agricultural catchments, both N, and P can be washed into surface waters by overland runoff shortly after the application of fertilizers and manures, or during livestock grazing. N transport through groundwater, often in the form of nitrate, is slower” [14]. “Erosion and nutrient loss also lead to water quality problems and are the main source of nutrient and sediment pollution in surface water, groundwater and wetlands” [13].

“In most watersheds of Rwanda, sediment transported in rivers varies proportionally to the rate of erosion, due to river runoff and the land slope” [5] while soil nutrients (organic materials, nitrogen, phosphorus and potash) were lost due to soil erosion at rates of 945,200; 41,210; 200 and 3055 tons/year respectively [4]. “The quality of surface water, especially rivers may be deteriorated because of the variations in the land cover shapes or land utilization practices around the catchment as human activities rise” [15, 16]. “This also impacts surface water treatment costs because water treatment plants face the challenge of treating highly contaminated raw water (colloids, dissolved and suspended solids from eroded material) using various chemicals to meet acceptable drinking water quality standards” [16]. “Simultaneously, water pollution and ecological degradation have become predominant issues requiring urgent attention. In Rwanda, a country with a dense network of rivers and lakes” [17], water quality is increasingly due to different factors. The primary factors that contribute to poor water quality include (i) agricultural runoffs containing fertilizers and pesticides [11, 18]; (ii) discharge of untreated wastewater [19]; (iii) erosion-driven sediment transport leading to high water turbidity [20].

To address these issues, Rwanda has adopted measures to promote organic farming practices and the use of organic fertilizers to reduce the runoff of harmful chemicals into water bodies. Additionally, “the country aims to improve solid waste and wastewater management by increasing investment in wastewater treatment infrastructure to ensure the safe discharge of treated wastewater. Erosion control and sediment management will also be implemented through the construction of terraces and reforestation to reduce soil erosion and sedimentation in water bodies” [21]. “Rwanda should increase the construction of wetlands, which are efficient and effective in improving the quality of water from various sources, such as runoff from agriculture and urban areas, as well as domestic and industrial wastewater” [22].

This review paper presents a comprehensive analysis of how water quality responds to the implementation of conservation measures across watersheds, including erosion control and land use management. The knowledge gained will serve as a theoretical basis for reducing the risk of water quality problems in Rwanda.

# 2. Literature review

## 2.1 Water Source in Rwanda

Rwanda has a relatively high average annual rainfall of 1,200 mm, making rainwater harvesting (storage) an attractive alternative source of water to meet the increasing demands for human needs, socio-economic development, and environmental protection[23]. Rwanda has plentiful water resources: The western part receives most of the rainfall, while the eastern part is relatively dry. Thirty-three percent of the land is supplied with water by the Congo River basin, while the remaining 67% is supplied by the Nile River basin. There are 149,487 hectares of lakes, 278,536 hectares of wetlands, and 861 rivers (with a total length of 6,462 km) in Rwanda [23].

The quality of water in Rwanda is crucial for achieving universal access to safe drinking water [24]. Water Supply and Sanitation Corporation (WASAC) in 2018, observed the main problems related to water quality for major water sources. For example, the Nyabarongo River at Nzove exhibits issues with turbidity, color, organic matter, ammonia, iron, chromium, and cyanide. However, for groundwater at Nzove, the issues are turbidity, iron, and manganese. When comparing the water quality of the Nyabarongo River with that of the Yanze river, there are no major problems identified in the Yanze river. The annual average turbidity in Mugesera Lake is at a low level (21 NTU (Nephelometric turbidity units)). Additionally, the average concentrations of chromium (2.7 mg/L) and cyanide (1.93 mg/L) in the waters of the Nyabarongo River exceed Rwanda’s standards and World Health Organization (WHO) guidelines (0.05 mg/L and 0.01 mg/L) for drinking water quality by 54 and 193 times, respectively [25]. These values are considered abnormal for general surface water. The possible reason to consider is insufficient quality control (QC): during daily analysis, QC activities (such as duplicate tests, standard solution methods, standard addition methods, etc.) are not conducted at the laboratory of each water treatment plant (WTP).

“The surface water bodies in Rwanda are facing problems such as pollution from agricultural runoff, untreated wastewater discharge, severe flooding, and erosion and sedimentation” [26]. “Surface water sources like rivers, lakes and reservoirs may contain varying amounts of dissolved and suspended materials. These water quality parameters include turbidity, color, odor, taste, microorganisms, plants, fish, trees, trash, etc” [26].

“Groundwater is the often-used source of drinking water throughout the rural, as well as urban worlds, also including Rwanda. Heavy industrialization, as well as mismanaged agricultural activities, have added toxic pollutants (e.g., inorganic contaminants, and heavy metals) to the groundwater” [27].

Rwanda possesses a relatively large quantity of surface water and underground water: rivers, lakes, and marshlands occupy a surface area of 211,000 ha, which is about 8% of the national territory (lakes: 128,000 ha, rivers: 7260 ha and marshlands: 77,000 ha). The outflow of the renewable underground resource is estimated at 66 m3/s, out of which 9 m3/s is produced by 22,000 known sources. In general, too little information is available especially on underground water aquifers[28]. Protection of water quality and sustainable management in Rwanda is in balance with the country’s socio-economic development needs” [29].

## 2.2 Contaminants of water sources in Rwanda

“Cosmopolitan economic growth is also water-dependent because of its properties as a universal solvent, coolant for factories, etc. In the last few decades, awareness and treatment for providing safe drinking water to the global community have improved significantly. According to statistics from World Water Research Agencies, around 1 billion people still lack access to clean drinking water, and research indicates that this situation will worsen by the year 2025” [27]. “In Rwanda, four out of five private households (82%) drink water from improved sources (drinking water includes water from: piped water, public taps, tube wells/boreholes, protected springs/wells, rainwater, and mineral water). There are variations between urban (96%) and rural areas (77%), as well as across provinces and districts. Unsafe drinking water used by private households in Rwanda mainly comes from unprotected springs/wells (11%) or from rivers/surface water (6%)” [28].

Water sources in Rwanda face several contaminants, which can vary depending on the location, land use, and human activities around the water bodies. Some of the common contaminants are detailed below:

### 2.2.1 Soil erosion

“The degradation of soil through erosion carries away not only the earth’s precious topsoil but also pollutants into our water bodies, compromising the health of aquatic ecosystems and the purity of our water resources [30]. Soil erosion does not only touch on agriculture productivity, but also off-site consequences are highly significant and well addressed; these consequences are related to the materials that arrive in the watercourses from the land surface” [31]. Rwandan soils are naturally fragile, a physico-chemical alteration of basic schistose, quartzite, gneissic, granite, and volcanic rocks [32]. Majoro et al. [33] reported “the degradation of soil quality (soil and nutrient losses, and lower infiltration rates), and the downstream river and lake sedimentation, are the main on-site and off-site damages of water erosion. Therefore, soil erosion control is the best option for enhancing raw water productivity while preventing river and lake sedimentation”.

## 2.2.2 Sediment and turbidity

“Sedimentation refers to the erosion; wash-off and silt load carried by streams and rivers and typically reflects the natural geophysical and hydrological characteristics of the upstream catchment” [34]. “The effects of sediment load on the performance of a water treatment plant are: high cost of coagulants in water treatment due to high level of turbidity, low quantity of water to be supplied due to increase of retention time, damage of valves and taps, filters blockages, and fills of tanks and pipes with mud” [35].

“Turbidity is a reduction in water clarity because of the presence of suspended matter absorbing or scattering downwelling light, and water is considered turbid when the presence of suspended particles becomes conspicuous. Soil erosion has a negative impact on water production. comprises summary of average seasonal monthly water production (in cubic meter), raw water turbidity (NTU), average total suspended solids, chemical cost per 1000 cubic meter, and chemical cost per 1000 cubic meter per unit of turbidity” [36].

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| --- | --- | --- | --- |
| **Point** | **Impact of high turbidity** | **Effect/Solutions** | **Reference** |
| Cost of treatment | Increase the cost of water treatment for various uses | Treated using a combination of physical and chemical processes.  After turbidity reduction, disinfect the water using **chlorination, ozone, or UV treatment** to kill pathogens. | [37] |
| Harmful microorganisms | Can provide hiding places for harmful microorganisms | High turbidity can shield bacteria, so disinfection is more effective after turbidity removal. | [38] |
| Water life | Provided suspended materials which can clog or damage fish gills, decreasing its resistance to diseases.  Reducing its growth rates, affecting egg and larval maturing, and  affecting the efficiency of fish catching method | Construction of artificial wetlands or detention basins to capture sediments before they enter natural water bodies.  Prevent industrial and domestic waste discharge | [39, 40] |
| Heavy metals | Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants (polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs)) | **Watershed protection (reduce soil erosion and runoff).** | **[41]** |
| Available food reduced | Higher turbidity raises water temperatures in light of the fact that suspended particles absorb more sun heat. The concentration of the dissolved oxygen (DO) can be decreased since warm water carries less dissolved oxygen than cold water, therefore the amount of available food reduced. | Allow the flocculated particles to settle in a **sedimentation basin or clarifier** | [41] |

**Table1: The impact of turbidity on water quality**

### 2.2.3 Agrochemicals substances

Agrochemicals, also known as pesticides, are chemicals that kill living organisms and are used in the control of pests [42]. “This concern refers to the pesticide and herbicide residues in surface waters that are harmful to aquatic ecosystems and/or users of the water. Sources include spray drift of pesticides/herbicides into surface water courses, the wash off of pesticides into surface and groundwater during rainfall events or irrigation of crops, or accidental spillages at storage facilities or during loading operations. If the rainfall is characterized by higher intensity, there is a greater potential for by-pass surface runoff to occur, which flushes out pesticides and other contaminants horizontally towards neighboring surface water bodies, as well as vertically into deeper soil layers and groundwater aquifers” [12]. Overuse of pesticides in agriculture has also elevated the levels of inorganic contamination of soil, groundwater, and surface water, which is not good for human health [27]. Farmers should be educated about the impacts of pesticides and herbicides on aquatic ecosystems and human health and the responsible application of these agrochemicals on their crops to protect receiving waters.

### 2.2.4 Microbiological pollution

“Microbial pollution is the presence of microorganisms and parasites that cause diseases in humans, animals, and plants. Most waterborne pathogens occur in human or animal feces and enter waterways via various pathways[43]. Microorganisms include protozoa (e.g. Giardia & Cryptosporidium), bacteria (e.g. E. coli), bacterial infections (e.g. Shigella), viruses (e.g. hepatitis), and helminths. The microbial content of water represents one of the primary determinants of fitness for use. Human settlements, inadequate sanitation and waste removal practices, stormwater wash-offs, and sewage spills are the major sources of deteriorating microbiological water quality in Rwanda. REMA [29] counts the E-coli at all the Congo basin sampling sites were found to be far above the acceptable standard of 4 cfu / 100 ml. These concentrations varied from 21.3 cfu / 100 ml at to 1,166.6 cfu /100 ml. A very important biological indicator of water and pollution is the group of bacteria called coliforms. Consequently, water that has been recently contaminated with sewage will always contain coliforms. A particular species of coliforms found in domestic sewage is *Escherichia coli* (*E.coli*). Even if the water is only slightly polluted, they are very likely to be found [44]. “*E.coli* are considered an indicator of fecal matter. These bacteria are very useful in giving us the levels of contamination. The contamination of raw water was very high in rainy seasons compared to dry seasons due to soil erosion and rainwater runoff from the uphill areas. The pollution of water is enhanced by the rainfall, which naturally burdened sediments and other wastes into water courses, and this in turn, eased to increasing the water pollution probability” [45].

2.2.5 Salinization

Salinity refers to the total dissolved inorganic compounds in the water and is measured as total dissolved solids (TDS). Human activities that contribute to salinity include the discharge of municipal and industrial effluent; irrigation return water; urban storm-water runoff; surface mobilisation of pollutants from mining and industrial operations and seepage from waste disposal sites [46]. Ho et al [47] found a negative impact of salinity on carbon dioxide (CO2) and nitrous oxide (N2O) emissions, which may be due to the decrease in both salinity and water quality. Furthermore, when water was polluted, salinity had negative impacts on methane (CH4) gas emissions, while an increase in salinity had relatively no impact on CH4 gas emissions when the water quality of the area was acceptable or good.

In Rwanda, salinization appears in the areas of Rubavu, Karongi and Rusizi towns, due to an increase in water pollution activities induced by surface runoff or domestic and industrial wastewater dumping. REMA [29] found that TDS concentrations in the Congo basin sampling sites varied from 9.9 to 525.3 mg/L. Rwanda Water and Forestry Authority (RWFA) [48] indicated most of the rivers in Rwanda have low salinity and a guideline value of 1000 µS/cm. With the exception of a few hotspots where industrial effluent discharges may increase salinity, the salinization of rivers in Rwanda is not a major concern. However, the situation should be monitored in light of the industrial expansion that is envisaged for Rwanda.

### 2.2.6 Nutrient pollution

Pollution by nutrients is recognized as the most widespread cause of water quality degradation, with runoff from agriculture as a major source of nutrient and sediment pollution [49]. “Nutrient enrichment refers to the accumulation of plant nutrients in rivers and dams over natural requirements resulting in nutrient enrichment or eutrophication which may impact the composition and functioning of the natural aquatic biota” [50].

The investigation of REMA [29] showed that values for the dissolved inorganic nitrogen (DIN) in the Congo basin sites were all below the maximum acceptable standard limit of 3 mg/l. Recorded concentrations were varying between 0.5 and 2.2 mg/l. The highest values were found at Lake Kivu, on the Nyamasheke side with 2.2 mg/l and at the outlet of Sebeya River with 2.1 mg/l respectively. Recorded values for the total dissolved phosphorous (DIP) in the Congo basin sites were all below the maximum acceptable standard of 5 mg/l. Concentrations varied between 0.1 and 1.4 mg/l. The highest concentration was found at the outlet of Koko River (1.4 mg/l).

### 2.2.7 Organic and inorganic contaminants

“Organic pollution refers to the discharge of organic or bio-degradable material to surface water that consumes oxygen when they decay, leading to low dissolved oxygen (DO) concentrations in the water. Low levels of dissolved oxygen in water are a sign of contamination and are an important factor in determining water quality, pollution control, and treatment process. Additionally, most aquatic plants and animals require oxygen to survive; fish, for example, cannot survive for long in water with DO levels below 5 mg/L” [51]. “Elevated concentrations of organic matter from decomposing plant matter can occur naturally in water but can be aggravated by poor waste disposal practices. The main sources of organic enrichment of rivers include domestic sewage, food-processing plants, breweries and vegetable canning, animal feedlots, abattoirs and cattle grazing” [52]. “Maintaining high DO concentrations in rivers and lakes is essential to protect aquatic ecosystems. Pollution controls should be implemented to protect receiving water bodies in Rwanda because many communities depend on the aquatic ecosystem services that these water bodies provide” [29]. “Wastewater industries may have huge concentrations of toxic heavy metals along with other pollutants as well, which may damage the environment and living entity of any ecosystem”[53].

“Inorganic pollution affecting water quality in Rwanda includes heavy metals like lead, cadmium, copper, zinc, chromium, and mercury, which can be present in significant concentrations due to industrial waste discharge, particularly around urban areas. Alongside elevated levels of nitrates, sulfates, chlorides, and other minerals like manganese and iron, often stemming from agricultural runoff and soil erosion” [54]. “Natural suspended sediments (SS) have a chemical and mineralogical composition that can be specific for a certain time and location, although they normally are enriched with inorganic particles (60−90%) such as clays, silt, and sand, in addition to a fraction of organic matter which consists of decomposed material and microorganisms” [55].

### 2.2.8 Solid waste

Up to 75% of the 1.5 million tonnes of solid waste produced annually in Rwanda is organic. The National Institute of Statistics Rwanda (NISR) projects that by 2035, there will be 17.6 million people living in Rwanda, up from the current population of about 13.6 million[28]. This will have an impact on the amount of waste produced. There are serious threats to the environment and general public health associated with inadequate development in the waste management (WM) sector. Illegal solid waste dumping and water contamination contribute to poor hygiene and serve as havens for vector-borne illnesses [56].

Urban stormwater runoff can be polluted by, inter alia, nutrients, low pH (acidity), microorganisms, toxic organics, heavy metals, litter/debris, oils, surfactants, and increased water temperature.

While litter may appear to have a mainly visual and aesthetic impact on the aquatic ecosystem of urban streams and rivers, it can have serious impacts on the aquatic ecosystem of urban streams and rivers.

The growing population needs more drinking water and changing consumption patterns will produce more solid and liquid waste. This requires improvement in transportation and treatment for solid waste and management.

3. Seasonal variability of water quality

“The quality of water changes with seasonal variations. These seasonal changes can have both positive and harmful impacts on water quality. Different seasons are associated with various temperature fluctuations. Along with temperature, all other physical and chemical parameters of water fluctuate with the changing seasons. Monitoring water quality is essential for environmental safety and human health” [57].

“In Rwanda, there are two rainy seasons: March to May (MAM) locally known as the long rainy season, and September to November (SON) known as the short rainy season. There is also two dry seasons, June–August (JJA) locally known as the long dry season, and December–February (DJF) locally known as the short dry season on its annual cycle [58].The highest total hardness (TH) value was observed in the dry season (JF and JJA) throughout the study. This could be caused by the higher EC and TDS that occurred during the dry season. TH was raised during the dry season because of the high number of dissolved inorganic compounds in an ionized state and the concentration of salts dissolved in water” [59].

Comparing the month of April for rain seasons and July for dry seasons in year 2017, the data showed that the average turbidity decreased from 2253.46 NTU to 869.92NTU, while the average quantities of water treatment chemicals decreased from 163.44Kg to 114.21Kg and the cubic meters of treated water have increased from 8056.63 m3 to 9269.11 m3, equivalent to the increasing rate of 13.08% of produced water. The same situation was observed in years 2018 and 2019, where the increasing rates calculated were 21.50% and 16.98% respectively [60]. The rainfall acted effortlessly as a driver of water pollution, where a higher metal index (MI) was recorded during the rainy season than MI during the dry season. Mukanyandwi et al [61] reported rainfall undermines water quality as it facilitates easy pollutants runoff down water bodies. Majoro et al [35] assessed for example the effect of soil erosion on Gihira WTP while considering raw water quality in terms of turbidity and südfloc consumed seasonally. The turbidity due to high river sediment loads is higher in the rainy season than in the dry season. The removal efficiency of turbidity is very high (about 99%). All turbidity values of the treated water comply with World Health Organization (WHO) and Rwanda drinking water standards of ≤ 5 NTU [26, 44]. If the turbidity of raw water increases, the südfloc consumption will also increase for the same quantity of raw water to be treated. During the rainy season, both suspended sediments and turbidity increase due to soil erosion [25].

4. Water quality control through watershed management

Improving water quality, minimizing sediment transit and buildup, and reducing riverbank erosion and biodiversity preservation are critical goals for watershed management [62]. **Figure 1** shows the key elements to consider in water quality control through IWM. “Integrated watershed management (IWM) may greatly enhance water quality by addressing pollution sources and encouraging sustainable practices when it is properly implemented. A comprehensive strategy for managing water resources within a watershed through IWM should combine social, economic, and environmental aspects” [63].



**Fig 1: Key priority elements in water quality control through IWM [62]**

“Integrated watershed management helps minimize negative impacts, prevent environmental degradation, increase biomass production, and improve water output by using natural resources efficiently. It promotes sustainable land-use practices in forestry and agriculture, along with complementary soil and water conservation measures. These practices help maintain long-term health of the watershed's natural resources while ensuring adequate production levels” **[62]**.

## 5. Government regulations on water quality

“The regulation establishes the legal and technical principles necessary to prevent water pollution in line with sustainable development goals, in order to protect both underground and surface water resources and ensure their optimal use. It sets forth planning principles and prohibitions regarding water quality protection, principles for wastewater discharge and discharge permits, guidelines for wastewater infrastructure facilities, and monitoring and inspection procedures, all aimed at preventing water pollution” [64].

The water quality control, treatment, and supply of drinking water in Rwanda are managed by the WASAC, a state-owned public company, affiliated with the Rwandan Ministry of Infrastructure (Mininfra) [25, 61]. WASAC is headed by a government-nominated Chief Executive Officer (CEO) and Deputy CEO. They are supported by the corporate planning, legal advisory, internal audit, company secretary, and public relations units. On the technical side, WASAC operates in all provinces of Rwanda. WASAC’s commitment is to enhance its water treatment methods to ensure efficiency and effectiveness in providing safe and clean drinking water [65].

In Rwanda, the key institution responsible for the protection and management of water resources, including the protection of catchments for major streams and rivers, is the Rwanda Water Resources Board (RWB), while the protection of catchments for smaller streams falls under the responsibility of the district authorities. The Ministry of Environment is the coordinating institution for the environment and natural resources sector in Rwanda. It must also ensure the safeguarding of a green and climate-resilient economy and ensure the optimal and rational utilization of water resources, land, and forests for sustainable national development.

## 6. Challenges of water quality management in Rwanda

A comprehensive approach that includes **community engagement, improved monitoring systems**, and **regulatory enforcement** is essential to achieve long-term water quality improvements in Rwanda. Water quality monitoring allows the country to meet goals including attaining regulatory compliance, evaluating long-term environmental changes, or quantifying the impact of an emergency event [66]. An effective and useable water quality monitoring readily available for community use would be a positive step toward community engagement and effective water resource management [67]. **Table 2** shows the challenges facing the water quality in Rwanda and their solutions.

**Table 2: Challenges and solutions for water quality management in Rwanda**

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| --- | --- |
| **Challenges** | **Solutions** |
| Lack of updated database for available water quality test recording | Rwanda to engage all partners working in water sector to contribute to the database with their independent research findings  Use geographical information system (**GIS) mapping and remote sensing technology** to visualize and analyze water quality trends. |
| The soil erosion affects the quality of raw water by increasing its turbidity and reduction capacity of treated water | To increase investment in the environmental protection measures  To control soil erosion such as digging channels, making radical terraces, progressive terraces and planting anti erosive crops, and make their regular maintenance.  To make rainwater harvesting and dig the retention holes for overflow for all communities, and reuse in irrigation.  Create buffer and protection of bank rivers, lakes. |
| Sedimentation affects the stability of dams, reduces the reservoirs storage and the carrying capacity of rivers. | To invest in sewerage treatment projects  Protection of riverbank with bamboo plant  To provide pre-sedimentation reservoir to reduce the quantity of sediments reaching the dam  To Construct wetlands countrywide for wastewater purification |
| Poor management of solid waste | To improve the solid waste collection, transport and treatment by adapting 3 Rs (Reduce, Reuse, and Recycle) |
| Lack of centralized wastewater treatment facilities | Construction and maintenance of centralized wastewater treatment facilities |

**Source:** **Authors**

# 7. Responses to water quality management in Rwanda

Surface waters are susceptible to pollution due to their utilization for wastewater disposal in many countries. The quality of surface water in a particular area is influenced by a combination of natural processes and human activities [68]. The catchment is representative of the environmental problems encountered in many similar headwater catchments in the region. Overexploitation of resources, drainage of wetlands for land reclamation, settlement, and urbanization, industrial development and road construction have caused water quality and wetland degradation [26]. Rwanda, which has the highest population density in Africa (440.8 inh./km2) [69], experiences rapid conversion of wetlands to agricultural land, with government policies to convert up to 80% of wetlands, expanding the farmed area four-fold between 2006 and 2020.Constructed wetlands (CWs) are human-made systems designed to utilize naturally occurring processes similar to those occurring in natural wetlands but in a controlled environment, for wastewater purification [44, 49].

Industries are a major contributor to water pollution in Rwanda, mainly through the release of untreated effluent in streams, rivers, and marshlands. Rwanda is addressing these issues through the regulatory role of the Rwanda Environment Management Authority (REMA), the continued development of industrial and wastewater standards by the Rwandan Bureau of Standards (RBS), and the recent establishment of land use and development laws and planning controls [70].

# 8. Conclusion

Poor water quality, which contains harmful bacteria, viruses, and chemicals, leads to diseases like cholera, diarrhea, and lead poisoning, and affecting human well-being. Water quality monitoring allows country to meet goals including attaining regulatory compliance, evaluating long-term environmental changes, and finding out the solutions if any issues are raised.

The eroded deposits and sediments carried into rivers and lakes negatively impact surface water treatment for domestic use by increasing the unit cost of water treatment, especially the cost of water treatment chemicals, and reducing the amount of clean water needed by the people during the rainy season. Increasing the implementation of soil erosion control measures, including terraces, forest preservation, slope stabilization techniques, cover crops, and plants, as well as stabilizing riverbanks with bamboo revetments and regulating buffer zones, can help in water quality management for sustainable development and o mitigate the water quality issues.

To improve wastewater and solid waste management by implementing appropriate wastewater facilities and improving solid waste collection, transport and treatment. To prevent industrial and domestic waste discharge that contributes to water turbidity and increase investment in wastewater treatment infrastructure to ensure the safe discharge of treated wastewater in the environment.

# 9. Recommendations

The government of Rwanda should develop the largest water supply projects over the next 3 to 5 years, focusing on enhancing both the quality and quantity of drinking water available to the Rwandan population.

Records of water quality analysis should be meticulously maintained for each water scheme for future reference, and with immediate action taken whenever negative changes are detected, ensuring prompt resolution of potential issues.

Strong management practices should be established and monitored, with a focus on compliance with relevant laws and regulations. Additionally, for water quality control, modern water technologies should be adopted in water supply management to efficiently address issues of leakage, repairs, and regular monitoring.

Rwanda should engage **universities, research institutions, and non-governmental organizations (NGOs)** to contribute to the database of water quality with their independent research findings.

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Option 1:

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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