AQUA
Water Infrastructure, Ecosystems and Society

© 2024 The Authors

AQUA — Water Infrastructure, Ecosystems and Society Vol 73 No 4, 737 doi: 10.2166/aqua.2024.240

Seasonal subsurface water quality variation of physiochemical and bacteriological characteristics in Kamutwa-Kigali, Rwanda

Alexis Bazambanza[a,*], Jean Pierre Bavumiragira[b], Theoneste Kananira[c] and Jean de Dieu Ndayisenga[a]
[a] University of Rwanda, College of Science and Technology, Kigali, Rwanda
[b] Tongji University Department of Environmental Engineering, Shanghai 200092, China
[c] Eduardo Mondlane University, Maputo, Mozambique
*Corresponding author. E-mail: bazalexis40@gmail.com

ABSTRACT

The study was conducted to assess subsurface water quality on a seasonal basis in dry (January–February and June–August) and rainy (March and October–December) seasons. Samples were collected in the rainy and dry seasons of the year 2022. The results of this study were compared with global drinking water guidelines of the World Health Organization (WHO) to understand its status in terms of threshold levels of pollution and protect public health. Total hardness (TH), pH, alkalinity, electrical conductivity (EC), total dissolved solids (TDS), nitrate, sulfate, heavy metals (Zn, Mn, and Fe), fecal, and total coliforms were examined, and the water quality index (WQI) was calculated to assess the level of water contamination. The results indicated that during the rainy season, all physiochemical parameters gradually increased and the values were well within the permissible limit as prescribed by the WHO. The bacteriological test showed that there were no fecal coliform (FC) and total coliform (TC) in all trials performed, and the calculated WQI showed excellent water quality characteristics, thus proving fit for human consumption.

Key words: bacteriological analysis, physicochemical, subsurface water, water quality

HIGHLIGHTS

- Treated water is scarce in Rwanda.
- This is a wake-up call for Rwanda to step up its investments in efficient, productive, equitable, and sustainable management of water resources.
- The majority of people of KAMUTWA still depend on this subsurface water.
- This study will help the people to know the risks associated with unusual subsurface water quality and how they can handle it before consumption.

1. INTRODUCTION

The quality of subsurface water determines whether it is suitable for drinking, irrigation, or industrial uses. Subsurface water is the largest supply of drinking water due to its extended retention time and the natural filtering effect of earth material (Zhu *et al.* 2020). In different countries, subsurface water serves as the primary source of water supply for the majority of their sectors. Due to the discharge of contaminants from various sources such as natural and anthropogenic activities, the subsurface water will be susceptible to contamination (Li *et al.* 2021).

The changes in climatic conditions, water residence time, aquifer materials, and soil inputs during water percolation or infiltration will also be the main causes of changes in subsurface water quality (Kumar *et al.* 2009). Poor water quality affects the well-being of humans and plant growth (Lin *et al.* 2022). One of the main causes of groundwater pollution, particularly in developing countries like Rwanda, is the use of uncontrolled fertilizers, manure in agriculture, and domestic pit latrines, where domestic sewage contributes to groundwater pollution (Kassegne & Leta 2020; Akhtar *et al.* 2021).

The water quality data of some existing usable groundwater resources are not available and there is no permanent or temporary monitoring of their quality changes due to the climate factors or other factors (Ntajal *et al.* 2022). Understanding the quality of subsurface water is essential for establishing its suitability for household, agricultural, and industrial use. Many aspects must be considered before discussing subsurface quality (El-Mostafa *et al.* 2014). Using the physicochemical and

---

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (http://creativecommons.org/licenses/by/4.0/).

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

bacteriological metrics for assessing water quality gives an accurate impression of the contamination condition of the groundwater body (Traoré *et al.* 2023), which helps to assess the chemical status and pollution levels of the aquifer (Subba Rao *et al.* 2022).

Groundwater from boreholes, shallow wells, and springs is the most frequent source of drinking water in Rwanda's small towns and rural areas. In many sections of the country, rural populations use groundwater for residential and drinking purposes without strict water quality monitoring and treatment (Nayar & Patel 2021).

The main objective of this current study is to assess the quality of groundwater. For this purpose, physicochemical and bacteriological parameters have been assessed. Finally, the water quality index was calculated. Every year, more than 2 million people die worldwide from diarrheal infections, with poor sanitation and unsafe drinking water accounting for approximately 90% of deaths and disproportionately harming children (United Nations 2016). Poor drinking water quality causes over 50 different diseases, accounting for 80% of diseases and 50% of child mortality worldwide. However, water contamination causes diarrhea, skin ailments, malnutrition, and possibly cancer, among other problems that are associated with water pollution (Hardi *et al.* 2023).

Previously, no study has been done on the water quality status of the Kamutwa subsurface. Hence, it is paramount to evaluate the subsurface water quality based on climatic conditions by measuring the threshold levels to secure the Kamutwa people and the neighborhood by controlling the factors associated with pollution and taking sustainable measures to protect this water resource.

2. MATERIALS AND METHODS

2.1. Case study and description of the sampling site

The study area was located in Rwanda, Nyarugenge district, Kigali city with a latitude of 1° 56′ 35″ S and longitude of 30° 4′ 45″ E near the wetland, where the water catchment area was not protected; and thus subjected to activities that can contaminate the aquifer. The area is characterized by floods during rainy seasons. The water is discharged by gravity and it is thought to be from recharge infiltration from a habitat hill. People around this site depend on this subsurface water for their daily activities without being aware of the level of pollution.

2.2. Study area climatology

The study area experienced two rainy season regimes; March to May (MAM) locally known as the long rainy season, and September to November (SON) known as the short rainy season. 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. Such terminologies are based on the amount of rainfall during the rainy season (Ilunga *et al.* 2004). Both seasons were considered in this study.

2.3. Sample collection and equipment

Samples were collected during rainy and dry seasons to understand how variations in climate might affect water quality.

The sampling process is scheduled from January to December 2022 on a seasonal basis. The raw water samples were obtained from a tap of subsurface water immediately at the site after allowing the water to flow for 5 min and sterilizing the tip of the tap with a lighter. On the sampling site, three types of samples (physicochemical and bacteriological) were collected in plastic bottles of 0.5 L capacity for laboratory analysis for each month. Three samples from each site were collected in sterilized plastic bottles and preserved properly to keep the bacteria alive until the bacteriological analysis. Bacteriological tests were performed within 6 h of collection to avoid the death or growth of organisms in the sample (Gebrewahd *et al.* 2020). An isothermal cooling box, pH meter, and conductivity meter were used for site measurements. Samples were preserved in the refrigerator at 4 °C in the laboratory to avoid any contamination. Blank and reagent solutions were used under the specified analysis. To test for coliform bacteria, samples were gathered in specific bottles within the laboratory.

2.4. Sample analysis and procedures

2.4.1. Water hardness

The titration procedure relies on a calorimetric reaction. Initially, ammonium hydroxide–ammonium chloride buffer was used to raise the sample pH to above 10. Then, 0.1 g of the indicator dye was added as an indicator. When Ca^{2+} and

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

Mg^{2+} are present, the pH reaches 10, and the indicator dye will make the sample turn red wine-colored. The sample is titrated against ethylene diamine tetra acetic acid (EDTA) until the color changes.

Free Ca^{2+} and Mg^{2+} ions were successfully removed from the solution by EDTA. Red wine color changes to blue when all ions have been eliminated. The EDTA volume from the end-point is recorded and used to determine the hardness.

$$\text{Hardness(EDTA)as mg CaCO}_3) = \frac{1,000}{\text{mL of sample}} * (V * M * 100) \tag{1}$$

where V indicates EDTA titrant used in mL and M refers to molarity EDTA.

It is possible to quantify the separate ion concentrations (Ca^{2+} and Mg^{2+}) that contribute to hardness by titration or other methods. The quantitative method of individual ions is a technique preferred by WHO (2017).

2.4.2. Alkalinity

Alkalinity (carbonate (CO_3^{2-}) and hydrogen carbonate (HCO_3^{2-}) ions were determined using a volumetric method (Omer *et al.* 2020). The amount of acid (such as sulfuric acid) required for the water sample to reach a pH of 4.2 is measured and reported as mg/L $CaCO_3$. All water sample alkaline chemicals have been consumed at this pH. Sulfuric acid that has been diluted (0.1 N or 0.02 N of H_2SO_4) is used as a titrant and a pH meter is used to determine the pH. 5 mg of $CaCO_3$ is contained in 1 mL of H_2SO_4, while 1 mL of 0.02 N H_2SO_4 has 1 mg of $CaCO_3$.

2.4.3. Total dissolved solid and electrical conductivity

Measurement of electrical conductivity (EC) using a conductivity probe is a common method for the analysis of total dissolved solid (TDS) in water suppliers that detect the presence of ions in water samples (Xianhong *et al.* 2021). Depending on the type of water, conductivity measurements were multiplied by a factor to produce TDS values. High TDS concentration can also be measured gravimetrically, although this method excludes volatile organics.

2.4.4. Iron, zinc, nitrate, sulfate, and manganese

Iron, zinc, and manganese levels in the water were measured by atomic absorption spectrometer using respective hollow cathode lamps (Anwar *et al.* 2023). Analysis of nitrate and sulfate was carried out using the HACH DR 5000 instrument by the procedures of the HACH manual.

2.4.5. Bacteriological test

It is determined by the presence of an organism that serves as a pollutant indicator, in this case, total and fecal coliforms were considered. The total coliform (TC) and fecal coliform (FC) colonies were counted after 24 h of incubation at 37 and 44 °C, respectively, using membrane filtration and membrane lauryl sulfate broth techniques. Tests were carried out with 100 mL of water aseptically filtered via a nitrocellulose filter. The filters were then placed on membrane lauryl sulfate broth for TC and FC. Yellow colonies in both TC and FC were counted using the colony counter (Montiel *et al.* 2023).

2.5. Water Quality Index

In this study, water quality and pollution levels were evaluated with reference to the guidelines and requirements established (WHO 2017). Furthermore, the Water Quality Index (WQI), a useful technique for combining physicochemical water quality factors, was used to assess pollution. The WQI is a regularly used metric approach for determining the degree of water pollution. This is the total water quality as a result of the combined impact of many quality measurements. The determination of the WQI is based on the method described by Batabyal & Chakraborty (2015). Eleven important parameters (pH, EC, TDS, total hardness (TH), alkalinity, NO_3^-, $SO4^{2-}$, Mn^{2+}, Fe^{2+}, Zn^{2+}, and turbidity) were used. After calculation of the WQI index, using the following scale, the equivalent quality was determined: excellent (50), good (50–100), poor (100–200), very poor

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

(200–300), and unfit for drinking (>300) (Verma *et al.* 2019). The WQI was calculated using the following formula:

$$\mathrm{WQI} = \frac{\sum Q_n W_n}{\sum W_n} \tag{2}$$

$$Q_n = \frac{V_n - V_{\mathrm{id}}}{S_n - V_{\mathrm{id}}} \times 100 \tag{3}$$

$$W_n = \frac{K}{S_n} \tag{4}$$

$$K = \frac{1}{\sum \frac{1}{S_n = 1, 2, \ldots\ldots\ldots, n}} \tag{5}$$

Here, Q_n refers to the quality of nth water quality parameter; W_n refers to the unit weight of nth water quality parameter; S_n refers to the the permissible value of the nth water quality parameter; V_n refers to the estimated value of nth water quality parameter at a given sample location; V_{id} refers to the ideal value for the nth parameter in pure water (0 for all other parameters except the $\mathrm{pH} = 7$).

$$Q_{\mathrm{pH}} = \frac{V_{\mathrm{pH}} - 7}{8.5 - 7} * 100 \tag{6}$$

k is the proportionality constant.

3. RESULTS AND DISCUSSION

The mean values of all physiochemical and bacteriological parameters have been analyzed on a seasonal basis and compared with WHO standards as shown in Table 1.

The lower value represents the acceptable /desirable limit and the higher value represents the permissible limit (WHO 2017).

3.1. Physicochemical analysis

3.1.1. pH

From Table 1, the seasonal mean pH of Kamutwa subsurface water was generally found to be slightly acidic (below $\mathrm{pH} = 7.0$) with pH ranging from 6.53 to 6.77 depending on dry and wet season, respectively. This water presents no contaminants (organic or inorganic) that can change the pH extreme values and mean average. Thus, the water presents a normal range value for domestic use within acceptable and the permissible limit in both seasons (WHO 2017).

3.1.2. Turbidity

Turbidity is a measure of liquid relative clarity, and the intensity of dispersed light increases with increasing turbidity (Wilmoth & Sundaravadivel 2022). From Table 1, the seasonal mean turbidity of water samples varied from 0.515 and 0.945 NTU concerning dry and wet seasons, both below acceptable limits (WHO 2017). The mean increased as shown in Figure 1.

The presence of suspended matter in water, such as clay, silts, finely organic and inorganic matter, and other microscopic organisms during the wet season, caused the highest turbidity. Rainfall can mobilize and transport sediments and pollutants

Table 1 | Seasonal mean values of physicochemical and bacteriological parameters and WHO standards

Parameters/Seasons	pH	EC µS /cm	TDS (mg/L)	TH (mg/L)	Fe^{2+} (mg/L)	Alkalinity (mg/L)	NO_3^- (mg/L)	Mn^{2+} (mg/L)	SO_4^{2-} (mg/L)	Zn^{2+} (mg/L)	Turbidity NTU	TC (cfu/mL)	FC (cfu/mL)
Dry	6.53	750.41	377.58	78	0.05	53.16	4.44	0.14	9.94	0.127	0.515	0	0
Wet	6.77	605.66	304.16	54.08	0.03	56	9.85	0.19	24	0.125	0.915	0	0
WHO	6.5–8.5	NA	1,000	200	0.3	NA	50	0.4	250	0.3	5	0	0

NA, not applicable.

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

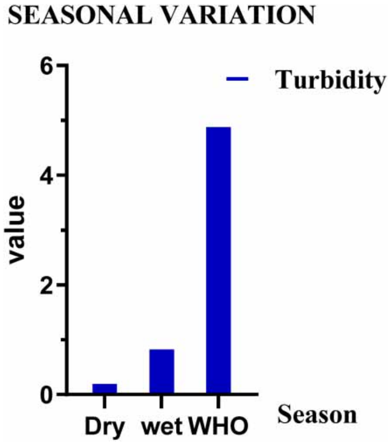

Figure 1 | Turbidity.

and dissolve them in the water along with small clay mineral particles. Seasonal rainfall, on the other hand, can have an impact on the complex relationship between discharge and turbidity in urban watersheds (Rafiee 2020).

3.1.3. TDS and EC

In this study, the mean conductivity and total dissolved values recorded in Table 1 for both seasons are 377.58, 304.16 mg/L and 750.41, 605.66 μS/cm for the dry and wet seasons. The results of the study indicated that the season average TDS ranged to an acceptable level (WHO 2017). Besides that, WHO does not have the guidelines standard of EC for drinking water.

The highest mean TDS and EC values were measured in the dry season (JF and JJA) over the duration of the study. This might be as a result of the higher temperatures experienced during the dry season, which promoted weathering, desorption, ion exchange capacity, and dissolution processes. Additionally, water evaporated and ion concentrations rose throughout the dry season. High conductivity values also indicate large concentrations of dissolved inorganic matter in ionized form (Pandey *et al.* 2020).

3.1.4. Alkalinity and TH

From Table 1, the alkalinity of the Kamutwa subsurface was found in the range of 53.16 and 56 mg/L. During the wet season, pH was higher than in the dry season indicating higher acidity. The seasonal average hardness of the Kamutwa subsurface water was varying between 78 and 54.08 mg/L for dry and rainy seasons. The values were acceptable and within the permitted range in both seasons (WHO 2017).

The highest TH value was observed in the dry season (JF and JJA) throughout the period of 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 (WHO 2017). The primary factors that contribute to water hardness are dissolved calcium and magnesium, which are predominantly the byproducts of dissolved dolomite and limestone from rock and soil components. Because of the high levels of TH in the groundwater, human beings may get kidney stones and heart diseases (Mohammad *et al.* 2015).

3.1.5. Heavy metals (zinc, manganese, and iron)

The level of heavy metals presented in a specific area varies according to the type of activities that are abundantly dominant in that region (Wang *et al.* 2021). Water frequently contains trace amounts of metals, which are typically safe for human health. Metals can dissolve in water naturally when it comes contact with rock or soil, but they can also dissolve in water as a result of contamination.

Heavy metals analyzed (Table 1) show that iron and zinc were increased during the dry season compared to the rainy season. This could occur as a result of evaporation during the dry season and dilution effects during the wet season (Edokpayi *et al.* 2017). The level of concentration was in the range of 0.05 and 0.03 mg/L for iron. Zinc was around 0.127 and 0.125 mg/L, respectively, in dry and wet seasons while manganese was in the range of 0.14 mg/L in the dry season and increased to 0.19 mg/L

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

in the wet season (Figure 3). The entire seasons were compiled with the permissible limit (WHO 2017) for drinking water as shown in Table 1.

3.1.6. Nitrate and sulfate

Nitrate and sulfate are two major ions found in natural water, because of their impacts on the quality and the taste of drinking water (Figure 2). The range of nitrate and sulfate levels found varied from 8.44 to 15.85 g/L and 11.94 to 24.00, respectively, for dry and wet seasons. The concentration of these nutrients increased but within the acceptable and the permissible limit during both the seasons (WHO 2017) (Figure 4). The high levels of these nutrients are due to water runoff and infiltration that are caused by different anthropogenic activities around water resources compared to the dry season. If the concentration is higher than the permissible limit, it poses a health risk (Kumar *et al.* 2012; Krishna Kumar *et al.* 2015).

3.2. Bacteriological analysis

Bacteria are one among the main issues causing water contamination (Singh *et al.* 2019). The experiments performed on bacteriological analysis during both seasons generally indicated that the samples analyzed were free from indicators of FC and TC and complied with standard levels (WHO 2017). Some researchers indicated that subsurface water could be polluted with fecal materials due to inadequate protection, position and distance relative to latrine houses, unhygienic practices at the source, and poor environmental sanitation (Takal & Quaye-Ballard 2018).

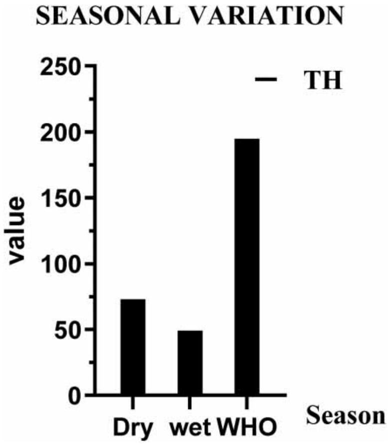

Figure 2 | Total hardness (TH).

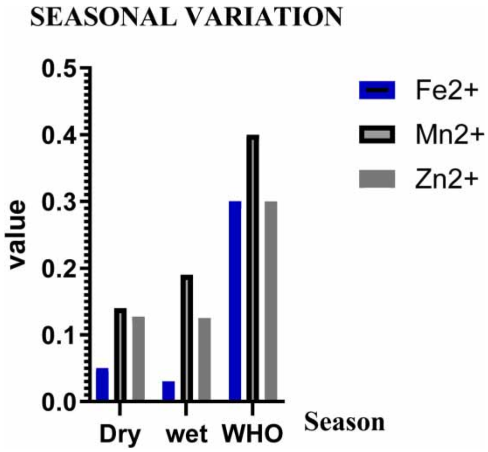

Figure 3 | Heavy metals.

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

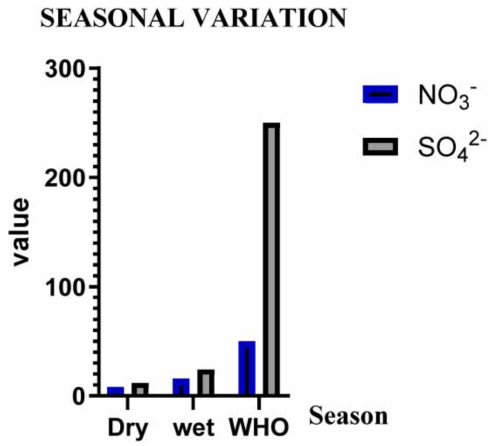

Figure 4 | Nitrate and sulfate.

Table 2 | Water quality and status classification using the weighted arithmetic WQI method.

Water quality index	**Water quality status**
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
>100	Unfit for consumption
Season	**Index value**
Dry	**11.31489**
Wet	**12.05076**

Source: The WQI developed by Brown *et al.* (WHO 2017).

3.3. Assessment of subsurface water pollution using the WQI

The WQI approach was used to assess water contamination. The WQI values were 11.31 and 12.050 with respect to dry and wet seasons. Both seasons have shown excellent water quality, and are well fit for human consumption (Table 2).

4. CONCLUSION

Seasonal variability of the water quality characteristics of the Kamutwa subsurface has shown that during the rainy season almost all parameters increased. The pH values reveal that the subsurface water was slightly acidic in nature. The number of heavy metals (iron, manganese, and zinc), TH, alkalinity, and nutrients (nitrate and sulfate) were increased during the wet season compared to the dry season and the analysis indicated that all parameters analyzed in both seasons are within the permissible limit. The WQI has been calculated, indicating that water quality in the study area was 'excellent'. No pollution has occurred even if the WQI is high during the wet season. The non-presence of high levels of contaminants may be due to the recharge area that is far from its discharge and other protective practices done around the source. Kamutwa subsurface water is good for domestic and drinking purposes but periodic monitoring and inspection of water quality should be conducted to look at different plausible pollution.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A. & Umar, K. 2021 Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water* **13** (19), 2660.

Anwar, S., Syed, Q. A., Ullah, A., Arshad, M., Khan, S. N. & Hussain, M. I. 2023 Detection of heavy metals using atomic absorption and emission spectroscopy in drinking water of Faisalabad, Pakistan: Microbial safety and quality status assessment. *Toxin Reviews* **43** (9), 1–17.

Batabyal, A. K. & Chakraborty, S. 2015 Hydrogeochemistry and water quality index in the assessment of groundwater quality for drinking uses. *Water Environment Research* **87** (7), 607–617. https://doi.org/10.2175/106143015x14212658613956.

Edokpayi, J., Odiyo, J., Popoola, O. & Msagati, T. A. M. 2017 Evaluation of temporary seasonal variation of heavy metals and their potential ecological risk in Nzhelele River, South Africa. *Open Chemistry* **15**. https://doi.org/10.1515/chem-2017-0033.

El-Mostafa, K., El Kharrassi, Y., Badreddine, A., Andreoletti, P., Vamecq, J., Kebbaj, M. H., Latruffe, N., Lizard, G., Nasser, B. & Cherkaoui-Malki, M. 2014 Nopal Cactus (Opuntia ficus-indica) as a source of bioactive compounds for nutrition, health and disease. *Molecules (Basel, Switzerland)* **19**, 14879–14901. https://doi.org/10.3390/molecules190914879.

Gebrewahd, A., Adhanom, G., Gebremichail, G., Kahsay, T., Berhe, B., Asfaw, Z., Tadesse, S., Gebremedhin, H., Negash, H., Tesfanchal, B., Haileselasie, H. & Weldetinsaa, H. L. 2020 Bacteriological quality and associated risk factors of drinking water in eastern zone, Tigrai, Ethiopia, 2019. *Tropical Diseases, Travel Medicine and Vaccines* **6** (1), 15. https://doi.org/10.1186/s40794-020-00116-0.

Hardi, G. W., Putri, S. D. & Nurohmat, N. 2023 The influence of groundwater on skin disease rates in Tenajar village, Indramayu district. *Prepotif: Jurnal Kesehatan Masyarakat* **7** (3), 16563–16571.

Ilunga, L., Muhire, I. & Mbaragijimana, C. 2004 Saisons pluviométriques et origine des pluies au Rwanda Pluviometric seasons and rainfall origin in Rwanda. *Geo-eco-trop* **28**, 61–68.

Kassegne, A. B. & Leta, S. 2020 Assessment of physicochemical and bacteriological water quality of drinking water in Ankober district, Amhara region, Ethiopia. *Cogent Environmental Science* **6** (1), 1791461.

Krishna kumar, S., Logeshkumaran, A., Magesh, N. S., Godson, P. S. & Chandrasekar, N. 2015 Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Applied Water Science* **5** (4), 335–343. https://doi.org/10.1007/s13201-014-0196-4.

Kumar, S. K., Rammohan, V., Sahayam, J. D. & Jeevanandam, M. 2009 Assessment of groundwater quality and hydrogeochemistry of Manimuktha River basin, Tamil Nadu, India. *Environmental Monitoring and Assessment* **159**, 341–351.

Kumar, S. K., Chandrasekar, N., Seralathan, P., Godson, P. S. & Magesh, N. S. 2012 Hydrogeochemical study of shallow carbonate aquifers, Rameswaram Island, India. *Environmental Monitoring and Assessment* **184** (7), 4127–4138. https://doi.org/10.1007/s10661-011-2249-6.

Li, P., Karunanidhi, D., Subramani, T. & Srinivasamoorthy, K. 2021 Sources and consequences of groundwater contamination. *Archives of Environmental Contamination and Toxicology* **80** (1), 1–10. https://doi.org/10.1007/s00244-020-00805-z.

Lin, L., Yang, H. & Xu, X. 2022 Effects of water pollution on human health and disease heterogeneity: A review. *Frontiers in Environmental Science* **10**, 880246. https://doi.org/10.3389/fenvs.2022.880246.

Mohammad, A. H., Almomani, T. & Alhejoj, I. 2015 Groundwater vulnerability for the surface outcropping aquifers in Jordan. *Journal of Environmental Protection* **6** (3), 9, Article 54823. https://doi.org/10.4236/jep.2015.63025.

Montiel, M., Villalba-Briones, R., Berruz, J., Castillo, T., González-Narváez, M., Ruiz-Barzola, O., Tiscama-Checa, N., Paredes-Sánchez, A. & Morales, F. 2023 Assessment of spatio-temporal variation in microbial quality of groundwater for irrigation and drinking water: A case study in Santa Lucia canton, Ecuador. *Groundwater for Sustainable Development* **23**, 101033.

Nayar, R. & Patel, R. 2021 Rural water quality monitoring and exploring Low-Cost treatment technology with water Hyacinth. *Edelweiss Applied Science and Technology* **5** (1), 9–13. https://doi.org/10.33805/2576-8484.188.

Ntajal, J., Höllermann, B., Falkenberg, T., Kistemann, T. & Evers, M. 2022 Water and health nexus – –Land use dynamics, flooding, and water-Borne diseases in the Odaw River Basin, Ghana. *Water* **14**, 461. https://doi.org/10.3390/w14030461.

Omer, H. E., Hafez, B., Alshamsi, M. S. & Ghani, M. A. 2020 Online novel techniques for selective simultaneous determination of alkalinity/Bicarbonate and hardness in drinking water by skalar san ++ segmented flow analysis. *Moroccan Journal of Chemistry* **8** (1), 8–11, 2124–2146.

Pandey, V., Ray, M. & Kumar, V. 2020 Assessment of water-quality parameters of groundwater contaminated by fly ash leachate near Koradi thermal power plant, Nagpur. *Environmental Science and Pollution Research International* **27** (22), 27422–27434. https://doi.org/10.1007/s11356-019-06167-x.

Rafiee, P. 2020 Comparison coagulant performance of chloroferric and polyelectrolyte (LT25) in removing organic materials turbidity in Raw water resources of ardabil treatment plant. *Journal of Research in Science, Engineering and Technology* **8**, 7–13. https://doi.org/10.24200/jrset.vol8iss1pp7-13.

Singh, A. K., Das, S., Singh, S., Pradhan, N., Gajamer, V. R., Kumar, S., Lepcha, Y. D. & Tiwari, H. K. 2019 Physicochemical parameters and alarming coliform count of the potable water of eastern Himalayan State Sikkim: An indication of severe fecal contamination and immediate health risk. *Front Public Health* **7**, 174. https://doi.org/10.3389/fpubh.2019.00174.

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest

Subba Rao, N., Dinakar, A. & & Sun, L. 2022 Estimation of groundwater pollution levels and specific ionic sources in the groundwater, using a comprehensive approach of geochemical ratios, pollution index of groundwater, unmix model and land use/land cover – A case study. *Journal of Contaminant Hydrology* **248**, 103990. https://doi.org/10.1016/j.jconhyd.2022.103990.

Takal, J. & Quaye-Ballard, J. 2018 Bacteriological contamination of groundwater in relation to septic tanks location in Ashanti Region, Ghana. *Cogent Environmental Science* **4**. https://doi.org/10.1080/23311843.2018.1556197.

Traoré, O., Kpoda, D. S., Dembélé, R., Saba, C. K., Cairns, J., Barro, N. & Haukka, K. 2023 Microbiological and physicochemical quality of groundwater and risk factors for Its pollution in Ouagadougou, Burkina Faso. *Water* **15**, 21.

United Nations 2016 *The sustainable development goals 2016*. United Nations, New York.

Verma, P., Singh, P. K., Sinha, R. R. & Tiwari, A. K. 2019 Assessment of groundwater quality status by using water quality index (WQI) and geographic information system (GIS) approaches: A case study of the Bokaro district, India. *Applied Water Science* **10** (1), 27. https://doi.org/10.1007/s13201-019-1088-4.

Wang, F., Dong, W., Zhao, Z., Wang, H., Li, W., Chen, G., Wang, F., Zhao, Y., Huang, J. & Zhou, T. 2021 Heavy metal pollution in urban river sediment of different urban functional areas and its influence on microbial community structure. *Science of the Total Environment* **778**, 146383.

WHO 2017 Guidelines for Drinking-Water Quality, 4th edn., incorporating the 1st addendum. World Health Organization, Geneva.

Wilmoth, P. & Sundaravadivel, P. 2022 Easy-Turb: Light-weight cost-effective turbidity sensors for distributed underwater sensing systems. https://doi.org/10.1109/OCEANS47191.2022.9977148.

Xianhong, Y., Shijun, L., Jian, H. & Jie, X. 2021 Application analysis of conductivity in drinking water quality analysis. *IOP Conference Series: Earth and Environmental Science* **784** (1), 012028. https://doi.org/10.1088/1755-1315/784/1/012028.

Zhu, Y., Zhai, Y., Teng, Y., Wang, G., Du, Q., Wang, J. & Yang, G. 2020 Water supply safety of riverbank filtration wells under the impact of surface water-groundwater interaction: Evidence from long-term field pumping tests. *Science of the Total Environment* **711**, 135141.

First received 22 September 2023; accepted in revised form 21 February 2024. Available online 5 March 2024

Downloaded from http://iwaponline.com/aqua/article-pdf/73/4/737/1409890/jws0730737.pdf
by guest