FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 8 No. 6, December, (Special Issue) 2024, pp 62 - 71
DOI: https://doi.org/10.33003/fjs-2024-0806-2853

EVALUATION OF THE GROUNDWATER QUALITY IN GISHIRI VILLAGE – KATAMPE, ABUJA USING WATER QUALITY INDEX

***Emmanuel Ubong Jones, Aliyu Adamu Dandajeh, Egbenya Musa Shaibu-Imodagbe and Samson Igbebe**

Department of Water Resources and Environmental Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria

*Corresponding authors’ email: ubyjones@live.com

ABSTRACT

Water quality is inherently linked with human health, poverty reduction, food security, livelihoods, preservation of ecosystems, economic growth, and social development of societies. This study evaluated the groundwater quality of Gishiri-Katampe, Abuja-Nigeria using statistical and geospatial techniques for water quality indexing. The study also used hydro-chemical parameters, geographical information, and statistical analysis to assess groundwater pollution potential; identify the most vulnerable areas, and generate a groundwater quality map. The Canadian Water Quality Index, the GIS mapping of the water quality of Gishiri indicates that the Water Quality Index is within the range of 76.87 to 92.53. Similarly, the WQI is predominantly good (62%), indicating a minor degree of threat. However, 38% of the area is occasionally threatened (fair) on the Canadian scale. However, some areas are occasionally threatened (fair) with the corresponding WQI of 28% within the study area. Moreover, out of the 11 water quality parameters analyzed, 6 parameters (dissolved oxygen DO, turbidity, chemical oxygen demand COD, NO_3, Na, and biological oxygen demand BOD) were identified as significant parameters as indicated by the correlation and regression analysis. This suggested that they strongly influenced the variability of the water quality.

Keywords: Groundwater, Geospatial, Hydro-chemical parameters, Pollution, Water quality index

INTRODUCTION

Groundwater is vital for the development of Abuja's Federal Capital Territory (FCT), with numerous establishments relying on wells for water supply (Agori, 2021). However, its exploitation is sensitive due to contamination and remediation challenges. Groundwater quality is crucial for human health, poverty alleviation, gender equality, food security, livelihoods, ecosystem preservation, economic growth, and social development (UNESCO, 2015). To be fit for human consumption, water must satisfy all three aspects. Efficient management strategies for sustainable groundwater resource utilization and protection are urgently needed. (Richard et al., 2019). Modern approaches, such as water quality indices (WQI), are suggested to convert large data into a single number and categorize water quality levels (Abbasi & Abbasi, 2012). These maps help raise public awareness, enforce waste management regulations, and impose restrictions on groundwater extraction, ultimately formulating effective management strategies for aquifer protection (Saeedi et al., 2010; Vadiati et al., 2016). Poor water quality evaluation can lead to disease transmission and poor taste, reducing water's beneficial uses. Industrial and human activities can negatively affect boreholes, especially in the Gishiri village, Katampe, Nigeria (Mohammed et al., 2022). Groundwater quality is a concern due to increasing anthropogenic activities and waste production. This study aims to assess groundwater quality in the Katampe District of Abuja using WQI, statistical, and geospatial techniques.

MATERIALS AND METHODS

Study Area

The research site is located on a low-lying plain below six meters above sea level, mainly composed of unconsolidated sediments. It is situated within the Greenwich Meridian latitudes and longitudes. The area experiences a high temperature of 36˚C during the dry season and a maximum of 24˚C during the rainy season. Annual rainfall ranges from 1100 mm to 1600 mm . (Mc-Curry 1985;Ajibade,1988).

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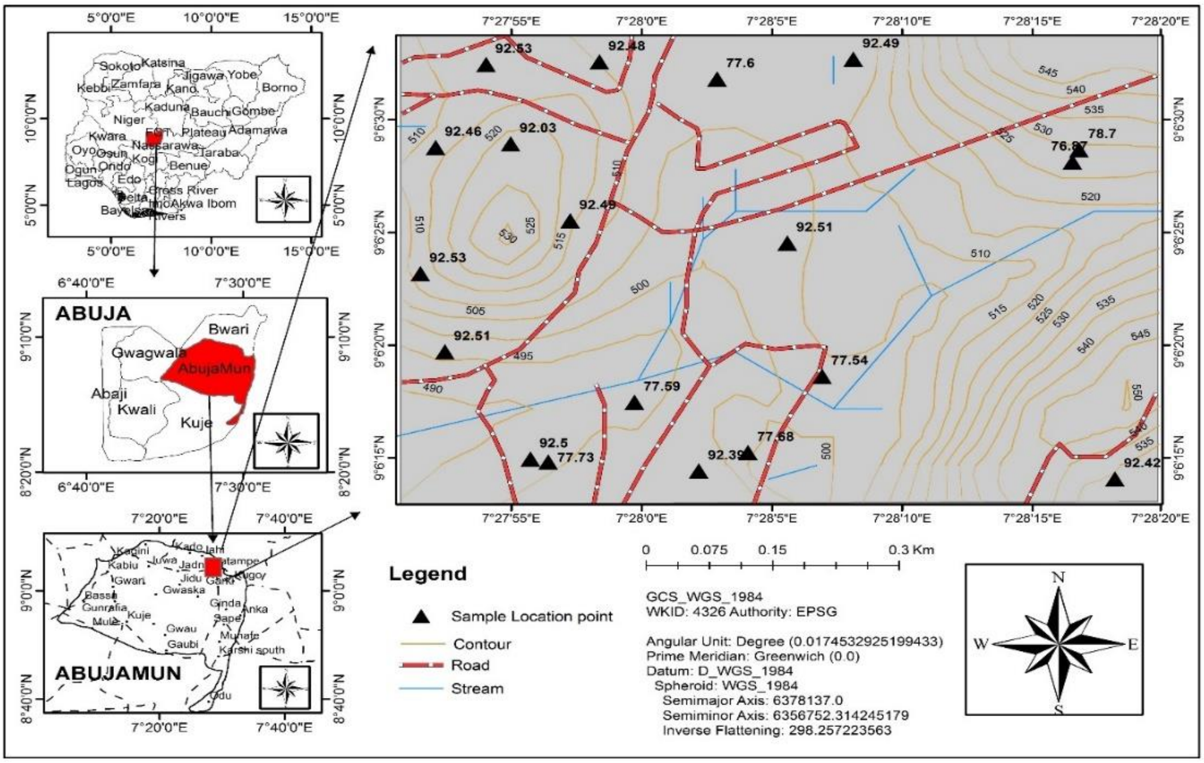

Figure 1: Map of Abuja showing Gishiri Village – Katampe and Sampling Points

The Katampe district, situated near Jiruvillage and Mabushi District, is covered by Precambrian basement rocks, including porphyroblastic gneisses, granitic-gneisses, magmatic gneisses, amphibolites, Pan-African granites, and undifferentiated schists, covering 85% of the land surface and 15% by cretaceous sedimentary rocks from the Bida Basin as in Figure 2.

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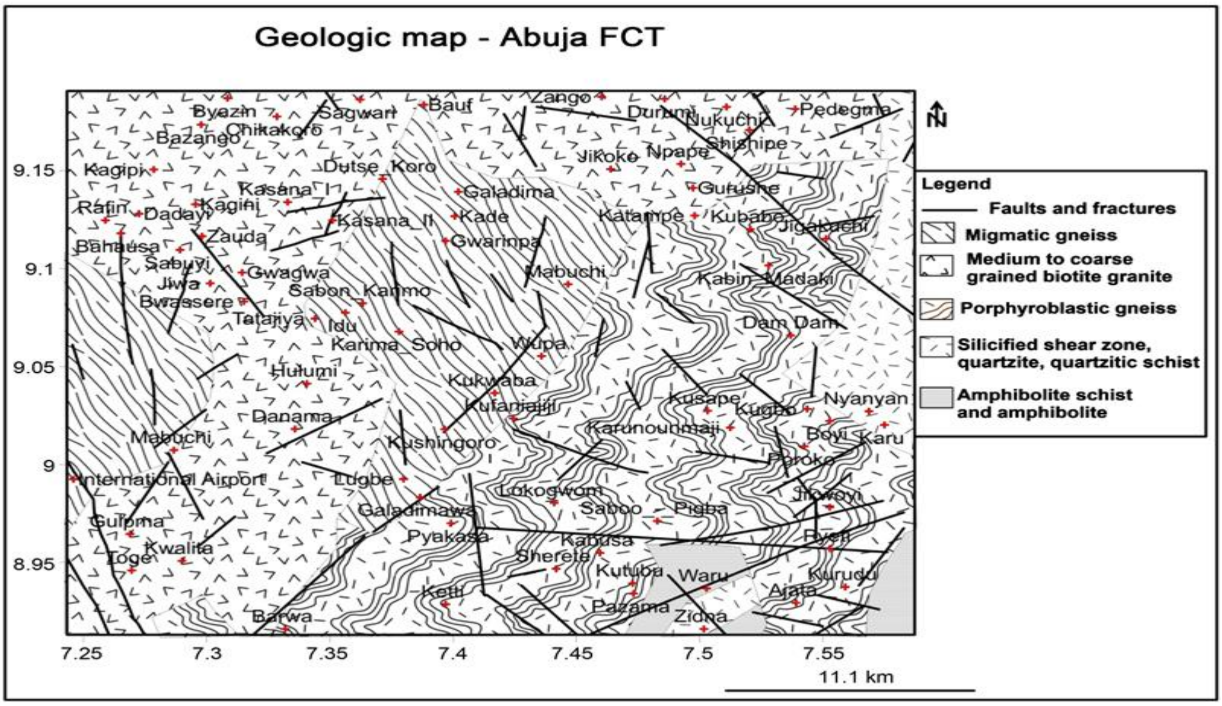

Figure 2: Geology of the Federal Capital Territory, Abuja

Mapping and Sampling

A field survey was conducted to collect 248 water samples from the study area, collected during both rainy and dry seasons. The sampling points were based on borehole water for domestic use. GPS coordinates were used to determine the sampling locations. Samples were kept in plastic bottles that had been meticulously cleaned with distilled water and then rinsed three times using the sample water itself. Each bottle was clearly labeled with the corresponding sampling point information and subsequently transported to a laboratory for thorough analysis. Following the procedure, the samples were preserved. (APHA, 2005).

Physicochemical Analysis of the Samples

The samples were analyzed following . (APHA, 2005). Eleven (11) parameters were analyzed in the samples collected. At the sampling stations, a series of measurements were performed for various parameters, including pH, temperature, electrical conductivity (EC), and dissolved oxygen (DO).

Determination of Water Quality Index (WQI)

The Water Quality Index (WQI) was calculated according to the standards set by the Canadian Council of Ministers of Environment (CCME), a method that has been adopted by the Global Environmental Monitoring Systems. The method requires at least four variables (parameters), sampled at least four times. It is a suitable tool for water quality evaluation for a specific location relatively easy to calculate and is tolerant to missing values . (Shweta et al., 2013).

$$CCMEWQI = 100 - \frac{\sqrt{(F_1{}^2 + F_2{}^2 + F_3{}^2)}}{1.732} \qquad (1)$$

Where: F_1 (Scope) = Number of variables whose objectives are not met

$$F_1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100 \qquad (2)$$

F_2 (Frequency) = Number of times by which the objectives are not met

$$F_2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \times 100 \qquad (3)$$

F_3 (Amplitude) = Amount by which objectives are not met. It is calculated as shown below,

When the test value must not exceed the objective:

$$F_3 = \frac{nse}{0.01(nse) - 0.01} \qquad (4)$$

The normalized sum of excursions (nse), is calculated as shown below:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} \qquad (5)$$

Excursion refers to the frequency with which an individual concentration exceeds (or falls short of, if the objective is a minimum) the target objective.

$$excursion_i = \frac{Failed\ test\ value_i}{Objective_j} - 1 \qquad (6)$$

In instances where the test value is required to meet or exceed the specified objective:

$$excursion_i = \frac{Objective_i}{Failed\ test\ value_j} - 1 \qquad (7)$$

The F3 value is determined using an asymptotic function that adjusts the normalized sum of excursions from the objectives (nse), resulting in a value that ranges from 0 to 100.

$$F_3 = \frac{nse}{0.01(nse) - 0.01} \qquad (8)$$

RESULTS AND DISCUSSION

Groundwater Geochemistry

pH

pH is a vital water quality parameter that indicates the water's acidity or alkalinity. Acidic water is below 7, while alkaline water is above 7. The acceptable pH range for drinking water is between 6.5 and 8.5. Throughout the sampling period, pH levels showed minor variations, ranging from slightly acidic to alkaline. The mean values, spanning from 6.4 to 7.3 during both the dry and rainy seasons, adhered to the drinking water standards established by WHO/UNICEF (2015) and NSDWQ (2015) . This range indicates consistent pH concentration among samples. The increase in pH is attributed to reduced photosynthetic activity, carbon dioxide and bicarbonates assimilation, low oxygen levels, and high temperatures (Abugu et al., 2021). In the wet season, pH levels rise due to higher water levels, diluting alkaline substances (Sisodia and Moundiotiya, 2006). Factors contributing to groundwater acidity include chemical fertilizers, agricultural runoff, industrial and domestic waste leaching, sewage inflow, and human activities.

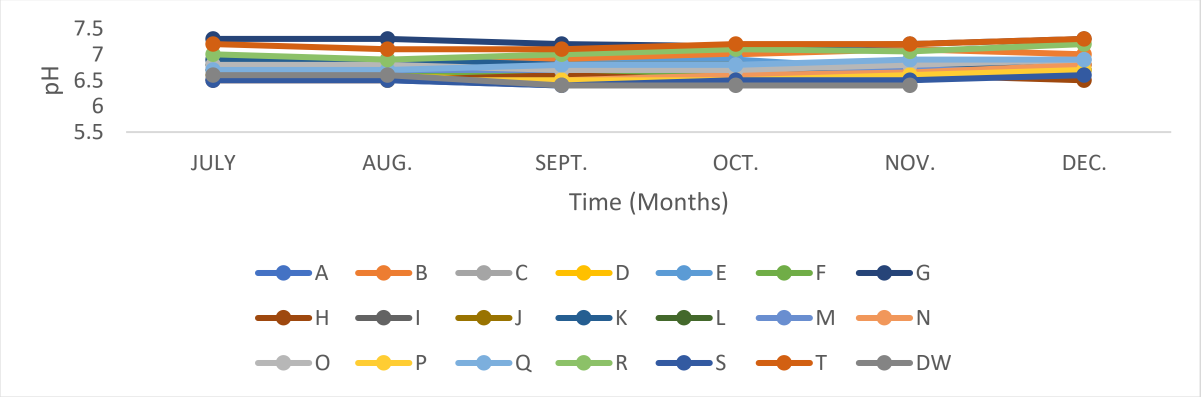

Figure 3: pH Concentration as a function of the season

Turbidity

The study found that turbidity concentration in the groundwater obtained from boreholes within the study area varies widely, with the highest concentration recorded at point O in September and the lowest at point I in August. Total Hardness (TH) was higher during the wet season due to high evaporation rates, percolation of industrial and domestic waste, and the presence of calcium and magnesium ions (Namdeo & Shrivastava, 2013). High turbidity affects water clarity and safety, making it crucial to reduce turbidity for effective disinfection and making water safe for drinking (WHO/UNICEF, 2015).

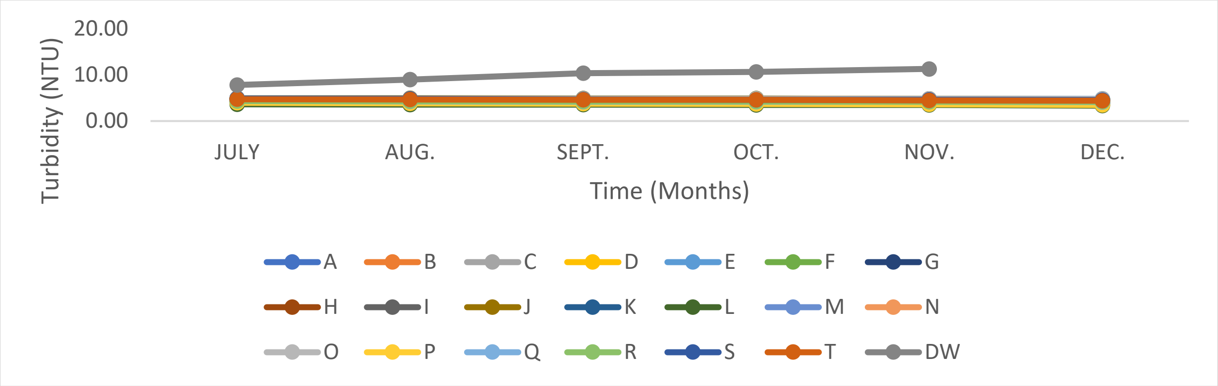

Figure 4: Turbidity Concentration as a function of the season

Electrical Conductivity (EC)

During the rainy season, the electrical conductivity (EC) values in various water sources were observed to be high. This suggests a significant influence of human activities or natural geochemical and biological processes in the area (Adekunle et al., 2007). According to the NSDWQ guidelines (2015), the recommended conductivity value for drinking water is 1000µS/cm. However, the observed mean conductivity values remained within this limit. The plot of EC and sampling points was mapped using Excel software, showing high EC values at points E and F, indicating the impact of human activities on groundwater salinity. During the dry season, the electrical conductivity (EC) of water samples exhibited significant variation. However, the narrower range of 28.9 - 98.97µs/cm³ is considered relatively low, given that good quality domestic water is recommended to have an EC value within 1000µS/cm³ as per NSDWQ guidelines (2015). The elevated electrical conductivity (EC) values can be attributed to the high concentration of ionic constituents present in the water bodies (Lenntech, 2016). EC is directly proportional to the total dissolved solids (Nair, 2006). Additionally, factors such as the percolation of industrial wastes, agricultural activities, land use practices, and sewage intrusion may further contribute to the increased EC values. These factors collectively influence the mineral content and electrical conductivity of the water.

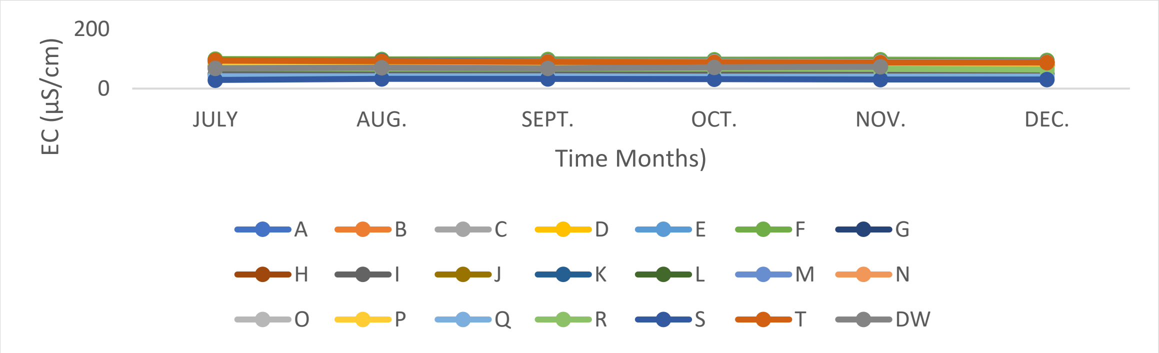

Figure 5: Electrical Conductivity Concentration as a function of the season

Dissolved Oxygen (DO)

Dissolved oxygen concentrations vary significantly at different sampling points, with the lowest value recorded at point D in November and the highest at point F in December. These fluctuations are attributed to temperature's impact on oxygen solubility in water. High temperatures decrease oxygen solubility, while lower temperatures increase it (Smith, 2019). During dry and rainy seasons, water temperatures remain within the (WHO/UNICEF, 2015) and (NSDWQ, 2015). permissible limits, except for areas with bacteriological contamination at points D, K, O, and S.

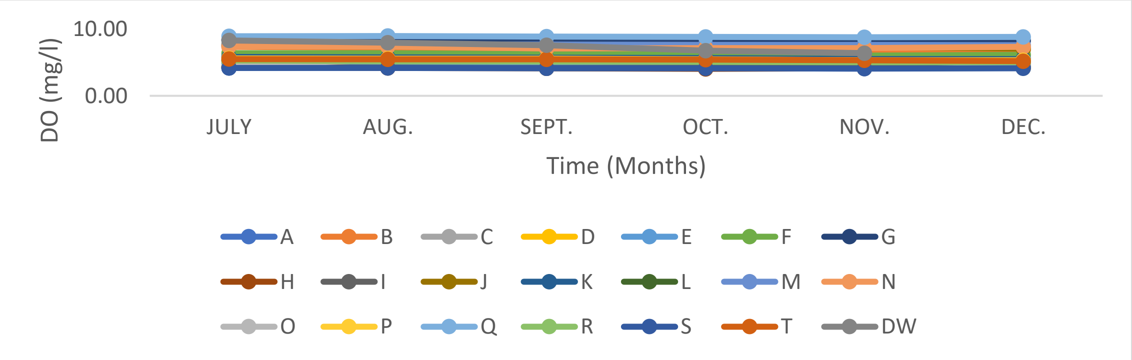

Figure 6: DO Concentration as a function of the season

Biological Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is a metric that quantifies the amount of organic matter in water that can be biologically oxidized. This parameter is a key indicator of the extent of organic contamination in the water. In July, August, and September, BOD concentrations were consistently higher at points A, B, F, G, K, L, O, and R, with the highest concentration of 0.8 mg/l recorded at points A and M. BOD values at all groundwater sampling stations are below the permissible limit of 1.0 mg/l during both dry and wet seasons. The increase in Biochemical Oxygen Demand (BOD) levels during the dry season can be linked to several factors. These include reduced groundwater recharge, the presence of decomposable organic matter, percolation of leachates, organic pollution, and chemical pollutants from industrial sources (Mishra, 2010). High BOD levels during the wet season may result from elevated concentrations of dissolved solids, increased input of organic pollutants, and heightened biological activity. Conversely, in the dry season, reduced flow rates and decreased biological activity due to higher temperatures lower the BOD (Palharya et al., 1993; Xue & Shukla ,1993).

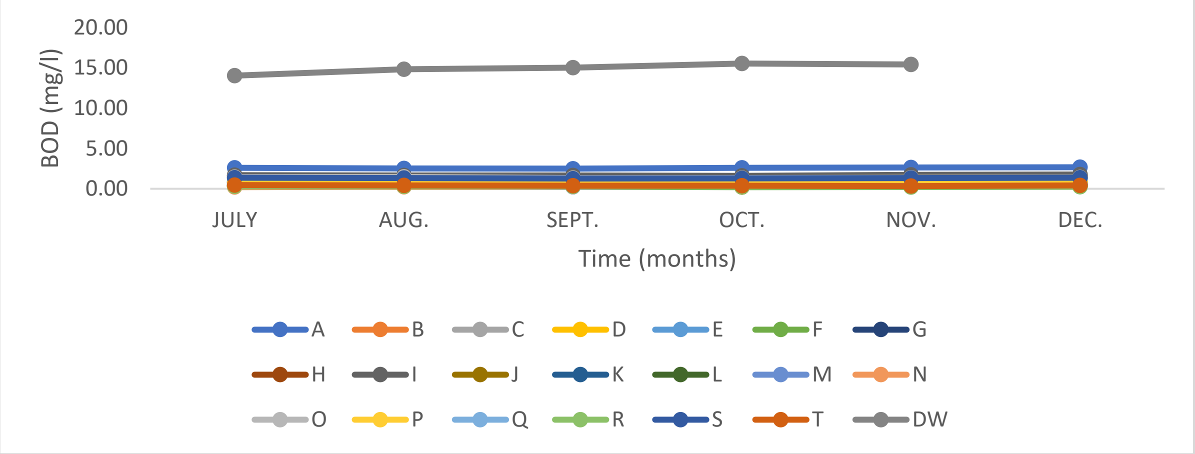

Figure 7: BOD Concentration as a function of the season

Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) values ranged between 10.00 and 89.83 mg/l during the dry season, and between 10.00 and 90.00 mg/l during the wet season. (Kumar & Puri, 2018; Singh & Singh, 2019, Sharma & Kansal, 2020) all reported similar findings. The COD values across all groundwater sampling locations during both the dry and wet seasons are significantly lower than the permissible limit of 10 - 20 mg/l, as specified by the NSDWQ (2015). COD is an indicator of pollution from biodegradable and chemically degradable organic matter (Elangovan & Dharmendirakumar, 2013). It also signifies the presence of organic matter that is susceptible to oxidation by chemical oxidants, which is characteristic of reduced organic and inorganic pollution in groundwater (Bhanja et al., 2000).

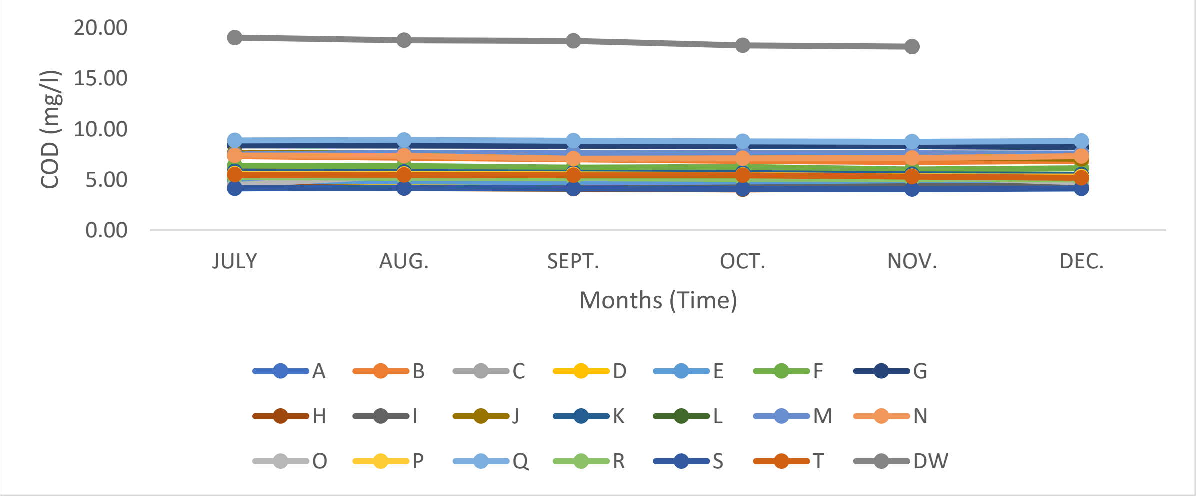

Figure 8: COD Concentration as a function of the season

Nitrate

Groundwater nitrate concentrations above 2 mg/l typically signal the influence of human activities. Such elevated levels are associated with various health issues, including methemoglobinemia, gastric cancer, goiter, birth defects, and hypertension (Mueller & Helsel, 1996; Majumdar & Gupta, 2000). Elevated nitrate levels are especially alarming for infants, as they can lead to symptoms such as paleness, bluish discoloration of the mucous membranes, and problems with digestion and respiration (McCasland et al., 2007). The high nitrate concentrations found in hand-dug wells and boreholes during the rainy season are linked to the dissolution of waste materials and sewage effluents. These concentrations fall within the (NSDWQ, 2015) recommended limit of 50 mg/l and also similar to that obtained by Mshelia et al, 2023. Nitrate contamination is closely linked to agricultural practices, seepage from septic tanks, sewage discharge, and the erosion of natural deposits. The infiltration of domestic sewage, industrial waste, garbage disposal, and leakage from septic tanks contribute to increased nitrate levels (Jameel & Hussain, 2011). The elevated nitrate concentration observed during the dry season can be linked to decreased groundwater recharge resulting from low precipitation, higher temperatures, and increased evaporation. Additional factors contributing to the high levels of nitrate and chloride include organic pollution from sewage mixing, an increase in animal waste, inadequate sewerage and solid waste disposal systems, high temperatures, evapotranspiration, leaky sewers, numerous septic tanks and soak pits, and the common practice of discharging sewage through open surface drains (Haran et al., 2002, Majagi et al., 2008, Shanthi et al., 2002, Sivakumar et al., 2002).

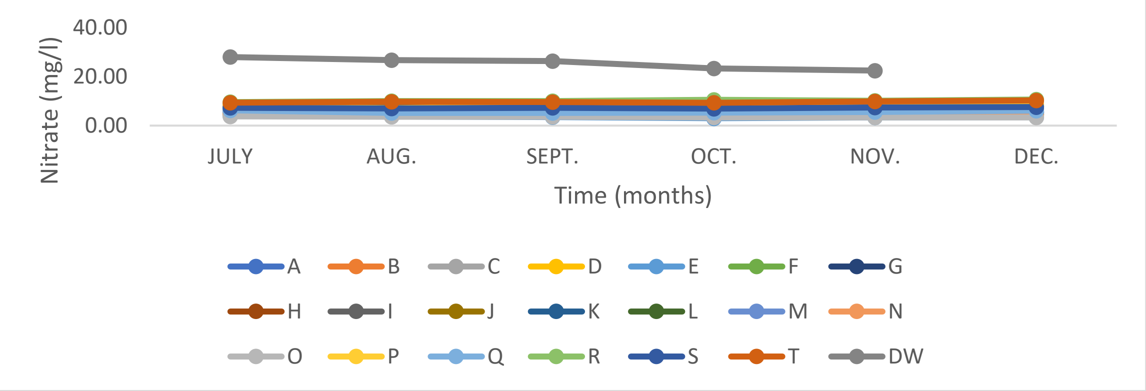

Figure 9: Nitrate Concentration as a function of the season

Sodium

Sodium concentrations in groundwater show a consistent trend, with the highest concentration in December at point P and the lowest in August at point L. Almost similar findings were found by (Liu et al., 2004) who conducted a study on Seasonal Variations in Sodium Concentrations in River Water and observed sodium concentrations in river water over different seasons. Seasonal variations in sodium concentrations in river water have been observed, with the highest recorded concentration in January and lowest in July.

Sodium in groundwater can come from various sources, including weathering soil minerals, salt-bearing geological formations, salt spray deposition, road de-icing, and salty ocean water intrusion. High sodium intake can affect conditions like hypertension, a common chronic health issue. The average sodium concentrations in different water sources remained below the recommended limit of 200 mg/l set by WHO/UNICEF (2015) and NSDWQ (2015) during both the rainy and dry seasons.

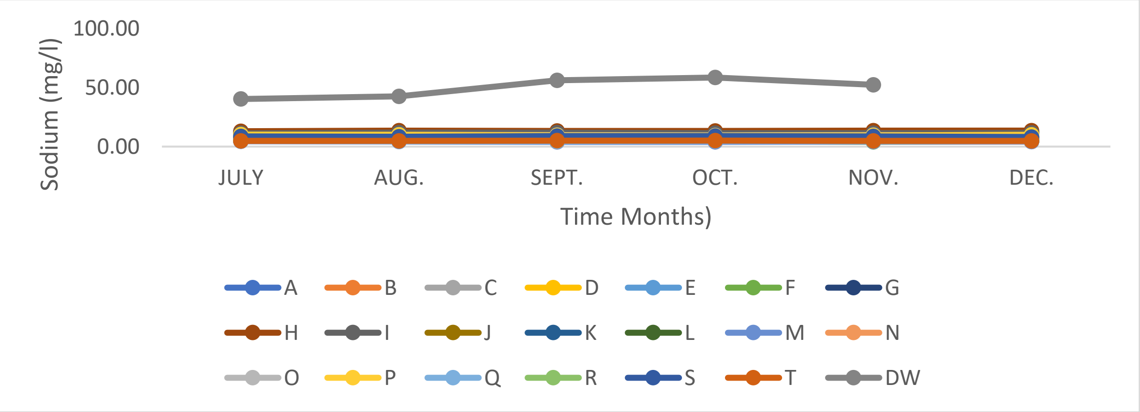

Figure 10: Sodium Concentration as a function of the season

Total Hardness

Water hardness is crucial for industrial applications, as it can cause scale formation in heat exchangers, boilers, and pipelines. However, some hardness is beneficial in plumbing systems to prevent pipe corrosion. Water hardness is mainly influenced by the geological characteristics of the area it comes from, and it is largely due to the presence of calcium and magnesium. A study revealed that the total hardness of borehole water varied between 31 and 70.3 mg/l, with an average value of 13.44 mg/l. Another study reported hardness levels between 30 mg/l and 75 mg/l, with an average value of 52.5 mg/l (Akinbile & Yusoff, 2011). Extremely hard water is not known to have any negative health effects and might be more appealing to drink compared to soft water. When hardness levels are below 80 mg/l, the water can become corrosive. Conversely, hardness levels above 100 mg/l can lead to the need for more soap, the formation of scum and curd, yellowing of fabrics, toughening of vegetables, and the development of scale deposits in pipes, heaters, and boilers.

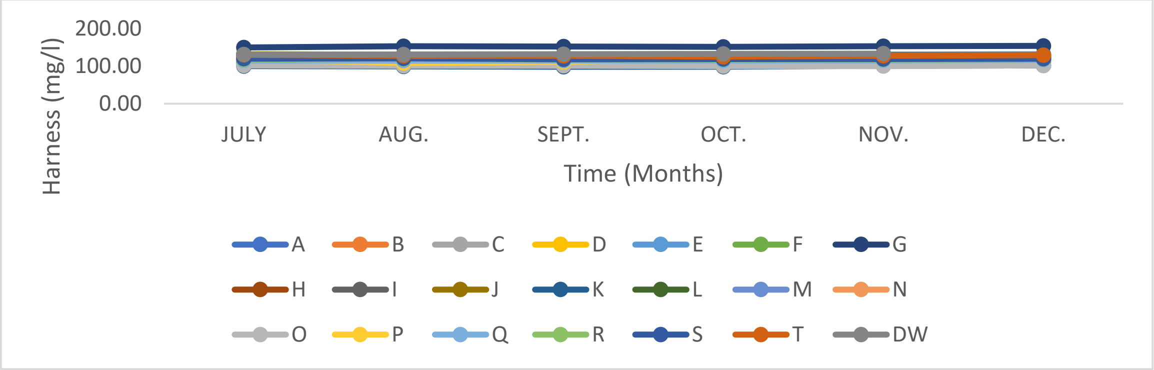

Figure 11: Hardness Concentration as a function of the season

E-Coli

A bacteriological study found that e-coli counts in borehole water were highest in Point A during July and August, with a value of 5.0 cfu/100ml. This contamination was similar to that in Alberta, Canada, where E. coli contamination peaked in July (Invik et al., 2017). The study highlighted the need for increased monitoring due to seasonal variations in contamination levels. The coliform counts in water samples at sampling points A, D, H I, K, O, and S were generally high, exceeding the standard requirement of zero coliform counts per 100ml . (WHO/UNICEF, 2015). and . (NSDWQ, 2015). . The high coliform counts suggest that the water from boreholes has been contaminated with faecal matter, possibly due to human waste from soak-away pits or animal waste disposal in hand-dug wells. The lowest coliform count was recorded at locations B, C, E, F, G, J, L, M, N, P, Q, and R, likely due to fewer human and animal activities and distance between soak-away pits and borehole wells. The E-coli counts from certain water sources indicate bacteriological contamination, rendering them unsafe for human consumption without proper treatment (Orebiyi et al., 2010). Consuming bacteriologically contaminated water can result in outbreaks of waterborne diseases, including cholera, dysentery, typhoid fever, diarrhea, hepatitis, and cryptosporidiosis (Okeke & Oyebande, 2009).

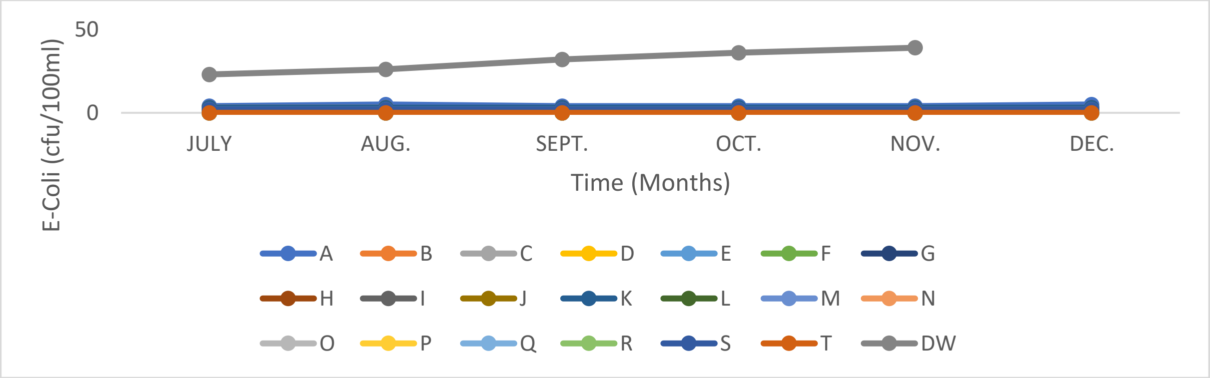

Figure 12: E-Coli Concentration as a function of the season

Water Quality Index (WQI)

Table 1 presents the results of the calculated Water Quality Index (WQI) for both the dry and wet seasons. The spatial distribution of the WQI, as shown in Table 1, indicates that the highest water quality was observed, with 12.5% and 40% of groundwater samples categorized as excellent to good quality during the respective seasons. These two categories depict the southern and southeastern sections of the aquifer, which correspond to the recharge zone. During the wet season, water samples classified as poor quality, very poor quality, and unsuitable for drinking accounted for 35.5%, 5%, and 7.5% of the groundwater samples, respectively. This pattern showed no significant difference in the dry season, and these conditions were predominantly observed in the central and northern parts of the aquifer. Arroyo-Figueroa et al. (2024) reported comparable results, noting substantial differences in water quality between the dry and wet seasons. Over 50% of the samples failed to meet drinking water standards due to high concentrations of dissolved minerals. Similarly, Ganiyu et al. (2018) discovered that groundwater quality is impacted by mineral dissolution, interactions between groundwater and rocks, weathering processes, and human activities, as identified through principal component analysis (PCA).

Table 1: Water Quality Index (WQI) in the study area

points	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
WQI	77.72	92.53	92.49	77.70	92.39	92.48	92.03	77.68	77.73	92.49	78.70
points	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	
WQI	92.51	92.46	92.50	77.54	92.53	92.53	92.51	77.60	92.42	76.87	

Table 1 indicates that the water quality at sampling locations A, D, H, I, K, O, S, and U is classified as fair during both the dry and rainy seasons according to the Canadian Council of Ministers and Environment Water Quality Index. The other sampling points—**B, C, E, F, G, J, L, M, N, P, Q, R,** and **T**—are rated as good, indicating a minor degree of threat.

Spatial Variation of Water Quality Index

Figure 14, displayed below, provides a spatial representation of the variations in the Water Quality Index (WQI) across the study area. The figure indicates the distribution as well as the concentrations of WQI across the area under consideration. As captured in the figure, the WQI ranged from 76.87 to 92.53%. Sample point U recorded the lowest WQI, while sample points B, E, and F had the highest WQI.

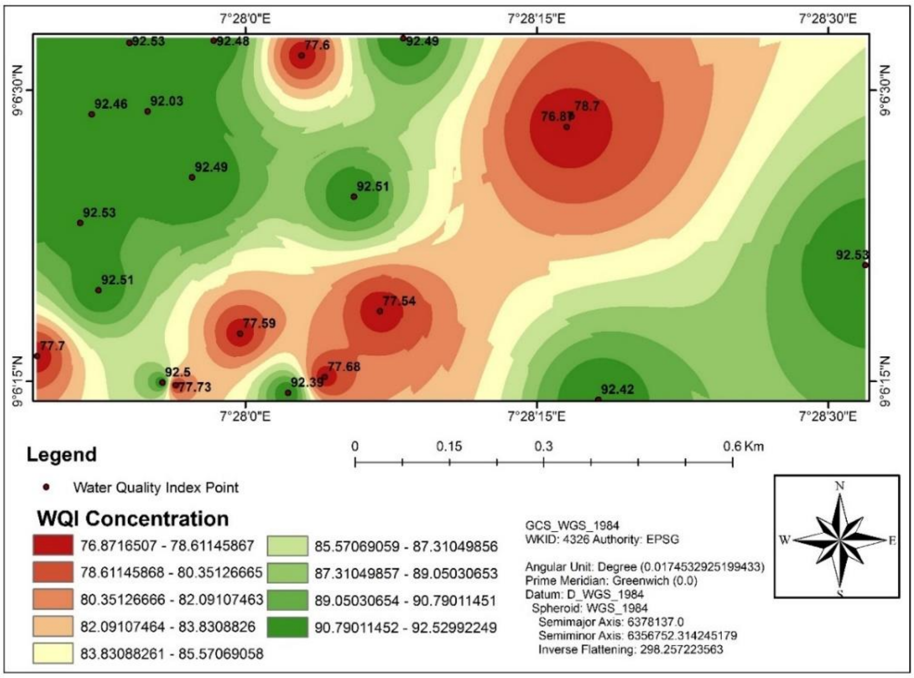

Figure 13: Spatial Variation of Water Quality Index

CONCLUSION

The spatial distribution of groundwater quality parameters exhibited variation throughout the study area. According to the Canadian Water Quality Index, GIS mapping of Gishiri's water quality reveals that the Water Quality Index ranges from 76.87 to 92.53. The elevated levels of certain parameters are attributed to both anthropogenic activities and natural sources, with primary influences from agricultural and domestic activities, as well as seawater intrusion. The pH levels in the study area range from 6.4 to 7.3, suggesting that the water samples are slightly acidic to slightly alkaline. Moreover, the mean values for Hardness (113.14 mg/l), BOD (15.53 mg/l), and E. coli (2.15 CFU/100 mL) exceeded the recommended drinking water quality standards in both the dry and wet seasons at sample locations A, D, H, I, K, O, S, and U. These samples were collected from both shallow and deep aquifers, including hand-dug wells and boreholes. The Water Quality Index (WQI) of Gishiri-Katampe is mostly good (72%), indicating a minor degree of threat according to the Canadian scale. However, some areas are occasionally at risk (fair), representing 28% of the study area.

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