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Assessment of Groundwater Quality using the National Sanitation Foundation Water Quality Index within Benin City, Nigeria

Michael Ovbare Akharame[1*] and Macduff Asemota Ajayi[1]

[1]Department of Environmental Management and Toxicology,
University of Benin,
Benin City, Nigeria
Email: michael.akharame@uniben.edu

Abstract
This study assessed groundwater quality by utilising the National Sanitation Foundation Water Quality Index (NSFWQI) protocol to ascertain the suitability of the water for drinking. Ten (10) groundwater samples were collected within the Benin municipality area located in the South-South region of Nigeria. The analysed physicochemical and biological parameters were pH, temperature, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), phosphates, nitrates, turbidity, and total coliforms. All parameters were analysed using standard methods. The overall WQI values obtained for the samples were in the range of 55.3 – 68.44, indicating that all of the samples had a moderate or medium water quality and could be suitable for drinking only after proper treatment. The non-conforming physicochemical parameters as compared to the World Health Organisation (WHO) and Standard Organisation of Nigeria (SON) set guidelines were pH (4.51 - 6.65), PO_4^{3-} (0.29 - 0.82 mg/L), BOD (1.52 - 7.2 mg/L) coupled with the presence of total coliform (20 -160 MPN/100 mL). Hence, water from these locations requires minimal treatment before consumption and domestic use.

Keywords: Groundwater, Potable water, Water quality, NSFWQI, Benin City

INTRODUCTION
Water utilisation is a basic requirement for all living organisms on earth. It is needed for their growth, development, and survival. The available water quantity and quality is a major factor that determines how well humans and other organisms thrive in a particular area. Groundwater is often adjudged a purer form of water compared to surface water, due to its purification in the soil column by anaerobic decomposition, filtration, and ion exchange processes (Keesstra *et al.*, 2012). Consequently, there is a huge surge in the consumption and use of groundwater in rural and semi-urban areas globally (Kannan and Joseph, 2010), and it seldom gets further treatment before usage. Also, there is an increasing abstraction of groundwater to meet the water supply-demand of many growing urban populations (Tam and Nga, 2018). Groundwater plays a vital role in the development of urban and rural areas, supporting the human population, industrial enterprises, and vast agricultural ventures. However, groundwater sources can also be contaminated in various ways by factors such as urbanisation, industrialisation, the expansion of agricultural activities, as well as population growth (Harun *et al.*, 2021; Asadi *et al.*, 2019).

**Author for Correspondence*

The quality status of water is determined by its physical, chemical, and biological parameters (Ketata *et al.*, 2012). The assessment of water quality is vital before its usage for various purposes such as drinking and domestic use, agricultural, recreational, and industrial activities (Asadi *et al.*, 2019). A standard tool that can be used for the assessment of water quality is the Water Quality Index (WQI). According to de Oliveira *et al.* (2019), a Scientist known as Horton first introduced the concept of WQI in 1965 in the United States of America. The WQI is a concept that uses a single numerical value to represent water quality by pooling the measurements of the selected water quality parameters (Tyagi et al., 2013). Significant parameters are measured and rated by the weight of importance, and after that their analytical values are integrated into a defined mathematical equation to calculate the index. The index value is evaluated by comparison with a set rating scale, which classifies the overall quality of water from bad to excellent. The WQI has the unique advantage of assessing water quality status without interpreting the parameters individually (Kadam *et al.*, 2019).

In the metropolitan city of Benin, the government infrastructure for the provision of potable water is almost absent due to years of neglect, mismanagement, and obsolete treatment and distribution equipment. The situation has been further aggravated with the population growth and rapid development of the city, especially in the area of residential build-up. The challenge has led individuals to provide potable water for themselves within Benin City by sinking boreholes. More so, the city's significant surge in population, urbanisation, and industrial activities in recent times, might impair the groundwater quality. Consequently, there might be deterioration of the water quality, especially in areas contaminated with nitrates, phosphate, microorganisms such as *Escherichia coli,* and others. Hence, the need for continuous groundwater quality monitoring and assessment, especially in a fast-developing area like Benin City. This study sought to provide this much-needed groundwater quality data and contribute to the efforts in the monitoring of groundwater resources for sustainable management. The specific objective of the research was to use the WQI protocol to assess the suitability for human consumption of groundwater around Benin City.

MATERIALS AND METHODS

Study area

The study area encompasses Benin City, Edo state, located in southern Nigeria. Benin City lies between latitudes 6^0 20′ and 6^0 58′ N and longitudes 5^0 35 and 5^0 41′ E of the Greenwich Meridian situated in the sub-humid tropical region (Omon and Ojeifo, 2012), with an average elevation of 77.8 m above sea level and a total area of 1,204 square kilometers. Benin is a pre-colonial and the biggest city in Edo state with an estimated population of 1,719,258 as of 2015 (Dimuna and Olotuah, 2019). Benin City has two major seasons namely the rainy season (March/April – October/November) and the dry season (November/December – February/March). The city has an average annual rainfall and temperature of 2000 mm and 27 °C, respectively (Atedhor *et al.*, 2019).

Sample collection and preparation

The groundwater samples were collected from ten (10) different locations chosen at random within Benin City from the 17th to the 21st of April 2021. The sampling locations included Oluku (6^0 27′ 22′′ N and 5^0 35′ 38′′ E), Maingate (6^0 24′ 22′′ N and 5^0 36′ 29′′ E), Ikpoba Hill (6^0 20′ 46′′ N and 5^0 36′ 29′′ E), Ring Road (6^0 20′ 7′′ N and 5^0 37′ 19′′ E), Adolor (6^0 23′ 27′′ N and 5^0 35′ 51′′ E), Uselu (6^0 22′ 28′′ N and 5^0 36′ 34′′ E), Uwelu (6^0 22′ 59′′ N and 5^0 34′ 59′′ E), Mid-West (6^0 21′ 22′′ N and 5^0 37′ 15′′ E), Sapele Road (6^0 17′ 42′′ N and 5^0 37′ 45′′ E), and New Benin (6^0 21′ 2′′ N and 5^0 37′ 51′′ E). The sampling locations are shown on the map of the study area (Figure1). Each water sample was collected and stored in well-labelled one-litre plastic cans which were rinsed with the water sample thrice before collection. Water samples collected for dissolved oxygen (DO) and biological oxygen demand (BOD) were collected in a 100 mL dissolved oxygen bottle. For dissolved oxygen (DO), the samples were fixed immediately with Winkler A and then Winkler B reagent, while BOD samples were fixed after five days. The pH and temperature of the water samples were taken *in situ* and recorded. After collection, the samples were kept in an ice chest en route to the laboratory and stored at 4 ℃ until processing as recommended by APHA (1998).

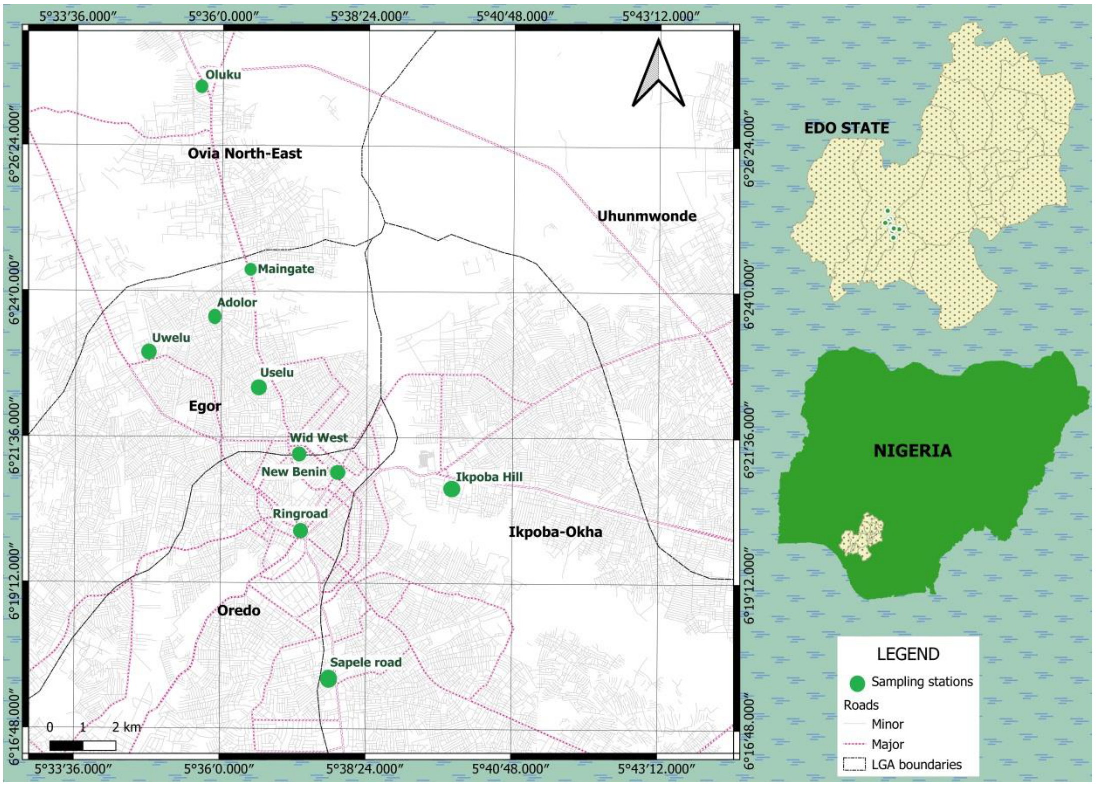

Figure 1: Map of the study area (insert: map of Edo State and Nigeria)

Analytical procedures for physicochemical parameters

The groundwater samples were analysed for the following physicochemical parameters; pH, temperature (℃), TDS (mg/L), turbidity (NTU), phosphate (mg/L), nitrate (mg/L), DO (mg/L), and BOD (mg/L). The analyses were done in triplicate using standard methods (APHA, 1998). The pH and temperature values were obtained *in situ* using a handheld HANNA pH/Temperature Tester (HANNA Instruments, USA). The nitrate, phosphate, and turbidity levels were determined using a HACH DR 2000 spectrophotometer (HACH, USA). Also, the TDS values were taken with a portable HACH CO 150 TDS/conductivity/salinity meter. Azide modification of the Winkler method was used to determine the DO content of the water sample. Subsequent incubation of the water samples for five days at 20 ℃, and analysis using the same azide modification of Winkler's method gave the final concentration of the DO in the samples. The BOD was thus calculated as follows:

BOD_5 = initial DO – DO at day five (DO_5)

Microbial analysis (*Total coliform*)

The total coliform count of the water samples was evaluated following the technique described by Cheesbrough (2005). The procedure was done in three stages including the presumptive stage, confirmatory stage, and completed stage respectively. To further identify the various sub-cultured colonies, biochemical characterisation tests such as methyl red, indole production, citrate utilisation, and Voges Proskauer were carried out.

Calculation of National Sanitation Foundation Water Quality Index (NSFWQI)
In this present study, NSFWQI was used to compute the water quality status. This index has been designed by the National Sanitation Foundation (NSF) with the Delphi technique. Nine water quality parameters were used to compute the WQI as prescribed by the NSFWQI (de Oliveira *et al*., 2019). These parameters and their specific weights are presented in Table 1. For each parameter, NSF has prepared a specific functional curve of which the parameter's concentration is converted to a standardised sub-index value (Q_i) ranging from zero to 100.

Table 1: Water quality parameters and their weights

Parameters	Weight
Dissolved Oxygen	0.17
Fecal Coliform	0.15
pH	0.12
BOD_5	0.10
NO^-_3	0.10
PO_4	0.10
Temperature Deviation	0.10
Turbidity	0.08
Total Dissolved Solids	0.08

Source: Brown *et al*. (1970)

The arithmetic sum was used to calculate WQI using sub-indices and exerting the parameters' weights, as shown below:

$$NSFWQI = \sum_{i=1}^{n} WiQi$$

Where $\mathbf{W_i}$ is the weight of the ith parameter and $\mathbf{Q_i}$ is the sub-index value of the ith parameter. After the calculation, the WQI values were then compared with the NSFWQI classification to ascertain the current water quality status of the groundwater samples. The various classification ranges are indicated as 0 – 25, 26 – 50, 51 – 70, 71 – 90, and 91 – 100 designated as very bad, bad, medium, good, and excellent, respectively.

RESULTS AND DISCUSSION

Physicochemical assessment of water quality

Temperature assessment
The observed temperatures reflect a trend associated with the different sampling sites (Figure 2). The water temperature in this study ranged from 16.9 °C to 21.3 °C, with the minimum and maximum values occurring in New Benin and Uselu. The World Health Organisation (WHO) and Standard Organisation of Nigeria (SON) provided no allowable values for the temperature of potable water at the moment. However, high temperatures may result in lower dissolved oxygen in water, which affects the water quality (Bhateria and Jain, 2016). Generally, cool water tends to be more acceptable and palatable in comparison to warm water. High water temperature may affect the acceptability of other water constituents such as the chemical contaminants that may affect the overall characteristics; more so, elevated temperatures in water may encourage the proliferation of microorganisms and possibly aggravate problems associated with colour, odour, and taste (WHO, 2011).

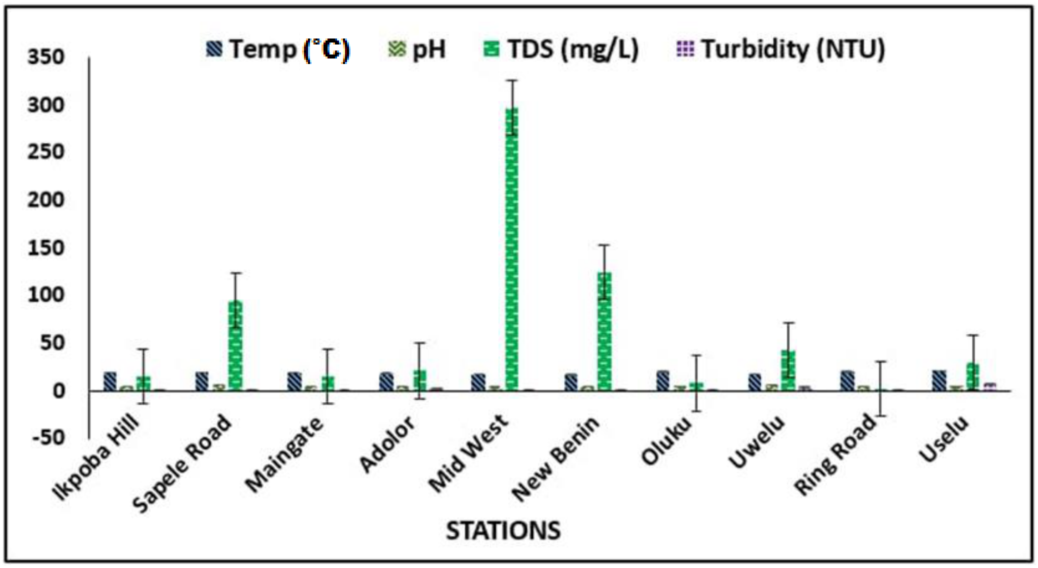

Figure 2: (a) Temperature, (b) pH, (c) TDS, and (d) turbidity of groundwater water at the different sites

pH assessment

The pH of water is a crucial operational water quality parameter. The pH of the water samples obtained for this investigation ranged from 4.51 to 6.65 as depicted in Figure 2. Maingate had the lowest pH value (4.51), while Uwelu had the highest value (6.65). Generally, water with a pH < 7.0 is considered acidic, whereas pH > 7.0 is considered basic. All the samples have pH values < 7.0 showing that they are acidic. The geology of the catchment area and its water buffering capacity are dominant contributors to the pH of groundwater (Muhamad et al., 2011). The low pH values in the aquifers of the study areas can be linked to the dominant acidic sandy-clayey soils and possible contributors like the ammonium sulphate and superphosphate fertilisers employed in agriculture (Appelo and Postma, 2005). Previous reports attribute the slightly acidic pH recorded in Benin City's underground aquifer to its geological formation and processes inherent therein (Akharame *et al.*, 2018; Iyasele and Idiata, 2012; Ezeigbo, 1989). The WHO has no set guideline value proposed for pH as it has no direct impact on consumers, however, the optimum pH required is often in the range of 6.5 – 9.5 (WHO, 2006). Similarly, the recorded pH values except the one recorded in Uwelu were lower than the range (6.5 to 8.5) stipulated by SON (SON, 2007).

Total dissolved solids assessment

Total dissolved solids measure the combined content of all inorganic and organic substances contained in liquids in molecular, ionized, or microgranular suspended form (WHO, 2006). These include calcium, magnesium, sodium, and potassium cation, as well as carbonate, chloride, bicarbonate, sulfate, and nitrate. The samples recorded a TDS concentration range of 8 mg/L to 298 mg/L (Figure 2), while the average TDS value obtained was 89 mg/L. All the samples recorded TDS levels below the permissible limit of 500 mg/L as stipulated by SON. High TDS levels may impact objectionable taste in water, whereas extremely low value produces a flat, insipid taste (WHO, 2006).

Turbidity assessment

Turbidity is an important parameter for characterising the quality of water as it is critical to consumers' acceptability of water (WHO, 2011). The turbidity values in the water samples varied between 0 NTU and 7 NTU (Figure 2). The highest value (7 NTU) was recorded at

Uselu which was above the maximum permissible limit (5 NTU) prescribed by WHO and the SON. Conversely, five points (Main gate, Mid-west, New Benin, Ring road, and Oluku) recorded 0 NTU, indicating a probable healthy and well-functioning ecosystem in the aquifers (Rajendran and Mansiya, 2015). Turbidity in drinking water is majorly associated with the presence of particulate matter (WHO, 2011). The particulates tend to protect microorganisms during water disinfection and can encourage the growth of bacteria (WHO, 2011); hence, low turbidity is essential for effective disinfection to be carried in water. Also, the colloidal materials may provide sorption sites for chemicals that can cause adverse health effects or add undesirable tastes or odours to water (Adekunle *et al.*, 2007).

Dissolved oxygen assessment

Dissolved oxygen is a measure of how much oxygen is dissolved in water, and its measurement is a primary parameter in all water quality studies (USEPA, 1976). The DO values for the water samples were between 5.84 and 13.60 mg/L. Mid-west had the lowest DO value (5.84 mg/L), while Uselu had the highest dissolved oxygen value (13.60 mg/L) as shown in Figure 3. Sapele road, Ring road, New Benin, Adolor road, Uwelu, Ikpoba hill, Maingate, and Oluku had DO values in the following order; 12.88 mg/L, 12.56 mg/L, 10.96 mg/L, 9.28 mg/L, 8.72 mg/L, 8.48 mg/L, 6.64 mg/L, and 6.56 mg/L, respectively. Although no health-based set value is stipulated for DO in drinking, depleted DO levels can cause discoloration in water when the water is aerated, due to the concentration of ferrous iron in the solution (WHO, 2011). Also, a low level of DO may encourage the microbial reduction of nitrate to nitrite which is more toxic to humans (Sato *et al.*, 2018).

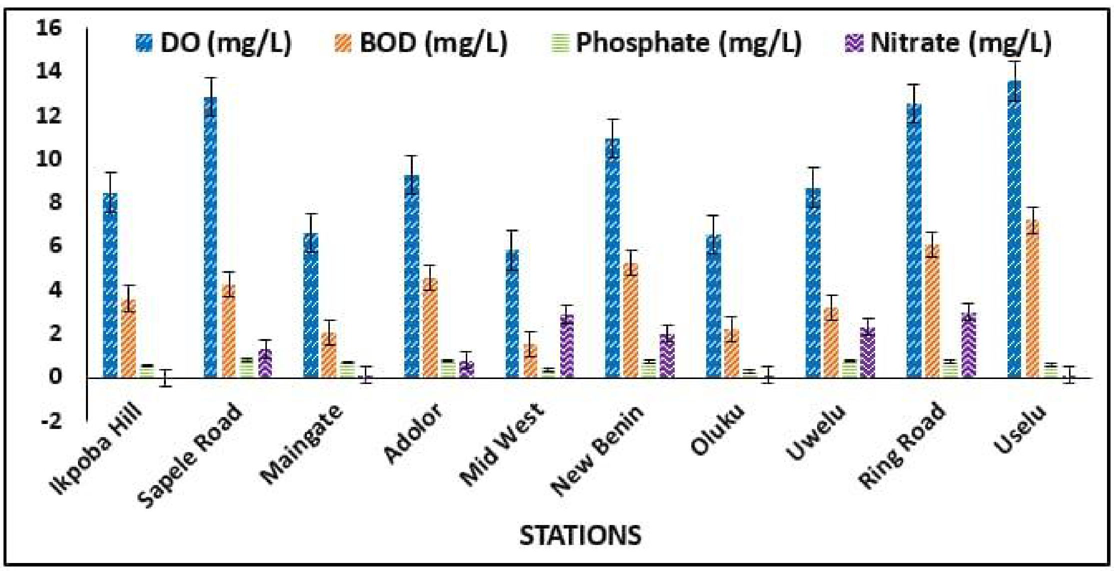

Figure 3: (a) DO, (b) BOD, (c) phosphate, and (d) nitrate levels of groundwater water at the different sites

Biochemical oxygen demand assessment

The BOD is a measure of the level of organic pollution in aquatic systems, and it significantly impacts the water quality (Olaniran *et al.*, 2014). The SON and WHO guidelines have not indicated the permissible levels for BOD, thus indicating that it should not be present in potable water samples. Essentially, drinking water should be free from BOD. All the samples have shown a definite BOD value ranging from 1.52 mg/L to 7.2 mg/L. Mid-west had the lowest BOD value (1.52 mg/L), while Uselu had the highest value (7.2 mg/L). The result indicates that the groundwater in the study area is inhabited and moderately polluted by microbial populations. This result is almost synonymous with that of Yisa et al. (2012) with a range of 1.71 – 6.64 recorded in the groundwater in the Maikunkele area of Niger State, Nigeria.

Phosphates assessment

The phosphates values of all samples ranged from 0.29 to 0.82 mg/L and are above the limit (0.1 mg/L) set by WHO (1996). Essentially, phosphates levels above the set 0.1 mg/L limit may interfere with coagulation processes in water treatment plants (USEPA, 1976). Oluku had the lowest phosphate value (0.29 mg/L), while Sapele road had the highest phosphate value (0.82 mg/L). Low concentrations of phosphates are not harmful to human health (Fadiran *et al.*, 2008), as they are important components of all cells (Beardsley, 2011). The significance of phosphorus is principally in regard to the phenomenon of eutrophication (Akharame *et al.*, 2017), which promotes the growth of algae and other aquatic plants.

Nitrates assessment

Groundwater nitrate levels are usually low, but elevated levels may result from leaching or runoff from farmland or contamination from human or animal waste due to the oxidation of ammonia and similar sources (WHO, 2006). The concentration of nitrate in the study area varied between 0 mg/L and 3.0 mg/L (Figure 3), with an average value of 1.26 mg/L. Ikpoba hill had a nitrate value of 0 mg/L. Oluku, Uselu, and Maingate had the same nitrate value of 0.1 mg/L, while Ring road had the highest nitrate value of 3.0 mg/L. The nitrate values for all samples are within the set limit (maximum of 50 mg/L NO_3; i.e. 11.3 mg/L NO_3-N) recommended by the WHO (WHO, 2006). Nitrate contamination in groundwater is considered a major issue in the water quality assessment due to its possible human health issues, especially for infants (Ramalingam *et al.*, 2022). High levels of nitrate in water can lead to methemoglobinemia or blue baby syndrome in infants.

Bacteriological assessment of water quality

Total coliform bacteria (*E. coli* and thermotolerant coliforms) are the most commonly used indicators of fecal pollution in water (WHO, 2006). The total coliforms of the water samples varied between 20 and 160 MPN/100 mL (Figure 4). The highest value was observed in six locations (Uwelu, Sapele road, Mid-west, New Benin, Maingate, and Ikpoba hill), while the lowest count value (20 MPN/100 mL) was recorded at Ring road. A fecal coliform count of over 200 MPN/100 mL of water samples is indicative of a possible occurrence of pathogenic organisms (Rajendran and Mansiya, 2015). The presence of high levels of coliform counts in water may pose adverse health effects for human consumption (Adekunle *et al.*, 2007).

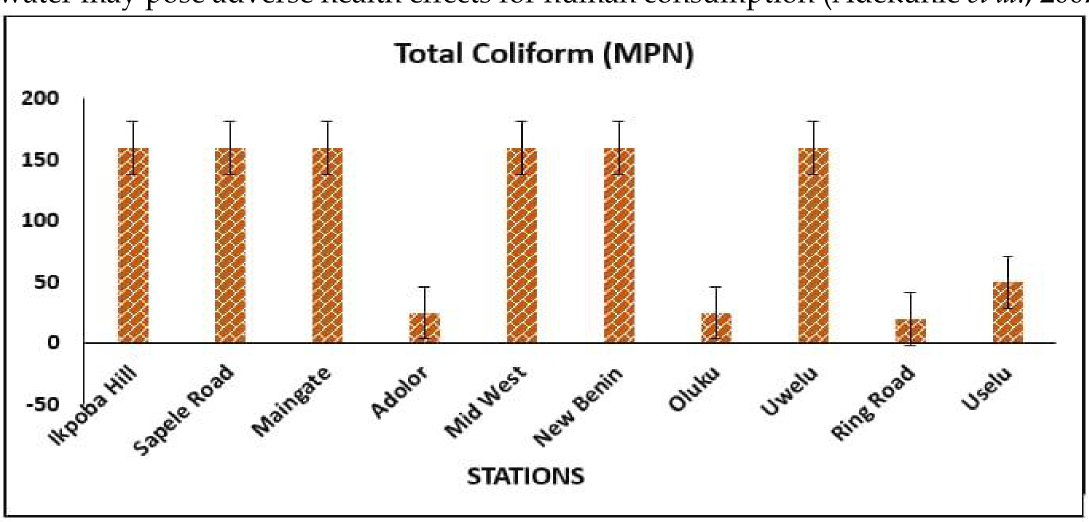

Figure 4: Spatial variation of the total coliform count of water samples

The cultural, physiological, and biochemical characterisation of the bacterial isolates found in the water samples are depicted in Table 2, while the distribution pattern of total coliform identified at various sample stations is presented in Table 3.

Table 2: Cultural, physiological, and biological characterization of the coliform

Parameter	I	II	III
Cultural			
Shape	Round	Round	Filamentous
Elevation	Flat	Flat	Flat
Colour on EMB	Metallic green	Pink	Pink
Morphological			
Gram stain	Negative	Negative	Negative
Cell type	Rod	Rod	Rod
Cell arrangement	Single	Single	Single
Biochemical			
Methyl red	-	-	-
Indole production	+	+	-
Citrate utilization	+	+	+
Voges Proskauer	+	+	+
Tentative identity	*Escherichia coli*	*Klebsiella pneumonia*	*Klebsiella mobilis*

Table 3: Distribution pattern of total coliform

Sample stations	*Escherichia coli*	*Klebsiella pneumoniae*	*Klebsiella mobilis*
Uselu			+
Adolor		+	
Oluku		+	
Uwelu	+		
New Benin		+	
Maingate	+		
Ring road	+		
Midwest		+	
Ikpoba hill			+
Sapele road	+		

National Sanitation Foundation Water Quality Index (NSFWQI)

The WQI values obtained in this study as per the National Sanitation Foundation method ranged from 55.30 to 68.44 (Figure 5). The WQI values depicting increasing water quality for the various locations were 55.30<58.09<59.40<59.60<61.20<62.97<63.21<66.08<67.31<68.44 for Uselu, Mid-west, Maingate, Ring road, New Benin, Sapele road, Ikpoba hill, Adolor, Oluku, and Uwelu, respectively. Using the NSFWQI water quality classification, 100% of the sampled stations were found to have moderate water quality as the WQI value of all the sampled stations fell within the 51 – 70 WQI range corresponding to moderate water quality. The implication is that the water samples assayed in these sampling points were not potable; hence, not suitable for drinking. The findings conform to the results of Yisa *et al.* (2012) who reported a 'bad' to 'moderate' water quality for groundwater sources in the Maikunkele region of Niger State in Nigeria which connote the unsuitability of the water for drinking. A similar study by Olasehinde *et al.* (2015) reported a "poor" WQI status for the groundwater in Ogbomosho, Southwest, Nigeria, whereas a WQI status of "good to very good" was observed by Ishaku *et al.* (2012) for the groundwater in Jada, Northeast, Nigeria. The "poor" groundwater status reported by Olasehinde *et al.* (2015) was posited to be due to the enrichment of the groundwater with fluoride, major ions, and heavy metals. Generally, anthropogenic contamination, natural mineralization, reverse cation exchange, and cation exchange are major contributors to groundwater chemistry (Ishaku *et al.*, 2012).

This result is quite significant as most residents in Benin City drink and utilise for domestic purposes the groundwater obtained from their boreholes without any form of treatment. The parameters of concern as compared to the SON and WHO set guidelines were pH (4.51 - 6.65), PO_4^{3-} (0.29 - 0.82 mg/L), and BOD (1.52 - 7.2 mg/L) coupled with the presence of total coliform (20 - 160 MPN/100 mL). The total coliforms are indicators of pathogenic organisms and should not be found in drinking water (Ekhosuehi *et al.*, 2018; WHO, 1996). In this regard, experts or qualified personnel who understand the importance of adequate spacing between the borehole and human waste holding systems (soakaway or septic tank) should be consulted for borehole sinking jobs. As stipulated by WHO guidelines of 2001, a borehole should be up-slope at a minimum distance of 30 metres away from any potential source of pollution (Suleiman *et al.*, 2021).

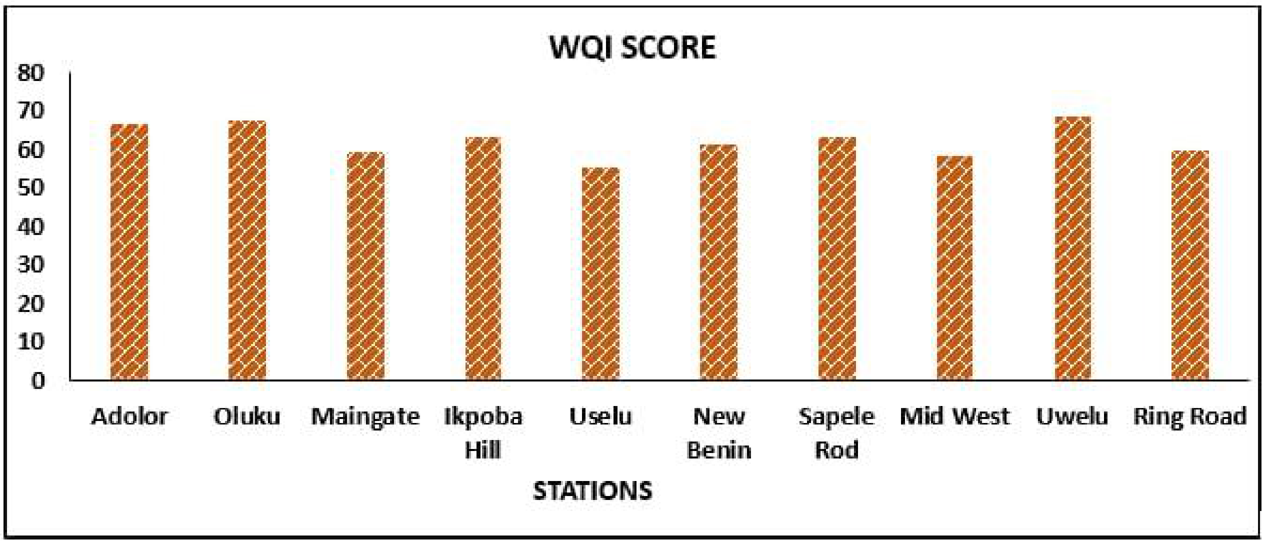

Figure 5: Water quality index for the different sampling points. Classification ranges; are very bad (0 – 25), bad (26 – 50), medium (51 – 70), good (71 – 90), and excellent (91 – 100)

CONCLUSION

In this study, an investigation of groundwater quality was conducted using the NSFWQI protocol. The WQI values obtained ranged from 55.30 to 68.44 corresponding to moderate water quality. The results revealed that the groundwater quality of the selected locations within Benin City was not fit for human consumption during this study. The parameters of concern ranged between pH (4.51 - 6.65), PO_4^{3-} (0.29 - 0.82 mg/L) and BOD (1.52 - 7.2 mg/L) coupled with total coliform (20 -160 MPN/100 mL). Consequently, it is recommended that water from these locations should be treated before consumption. This study further reinstates the significance of WQI in water quality assessment and monitoring. The WQI protocol can easily capture the composite impact of the different water quality parameters and communicates water quality information in a single unit for easy understanding to the public. Apart from health considerations, it is recommended that regular assessments should be made to monitor the area's groundwater status to ensure proper water quality management, protection, and sustainability.

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