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Assessment of Groundwater Quality and Domestic Water Demand in Yenagoa Metropolis, Bayelsa State

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ABSTRACT

Yenagoa, the study area, is naturally endowed with abundant surface freshwater resources; however, residents show a marked preference for groundwater as their primary source of domestic water. This study therefore assesses groundwater quality and domestic water demand in Yenagoa Metropolis, with particular emphasis on quality, accessibility, and sustainability. A quasi-experimental research design was adopted for the investigation. The descriptive results reveal significant challenges posed by iron and manganese in the groundwater supply. These contaminants necessitate aeration and filtration processes to mitigate problems such as water discoloration, unpleasant odour, staining of utensils, and the blockage of pipes and filtration media. Findings from the quasi-experimental analysis, using the Kruskal–Wallis H-Test, indicate high spatial concentrations of iron (27.18 mg/L) and manganese (0.07 mg/L) across the study area. Although field observations clearly show a shortfall in reliable groundwater supply due to the adverse effects of iron and manganese, the hypothesis testing produced results that contrast with these field-based realities. This discrepancy highlights the complex interaction between groundwater quality parameters and the statistical outcomes of non-parametric testing. Based on the findings, it is recommended that the current groundwater treatment system where aeration, sedimentation/deposition, and filtration occur in a single clustered chamber should be redesigned. These processes should be separated into distinct treatment chambers to enhance efficiency, improve water quality, and ensure sustainable groundwater supply in Yenagoa Metropolis.

Keywords: Groundwater Quality, Iron and Manganese Contamination, Domestic Water Supply, Quasi-Experimental Design, Yenagoa Metropolis

INTRODUCTION

Water is a fundamental component of human existence and is essential for the survival of all living organisms. It contains vital minerals such as calcium, magnesium, sodium, and potassium in varying but necessary proportions (World Health Organization, 2005). Groundwater—water stored beneath the earth's surface within the fissures, pores, and crevices of rocks and soil—is an important part of the hydrological cycle. It moves gradually through aquifers, which are geological formations composed of sand, soil, and rock capable of storing and transmitting water. Groundwater formation occurs through infiltration and percolation of surface water and precipitation, which drain into interconnected rock pores until saturation is reached.

Groundwater exists in three zones: the zone of non-saturation, found immediately below the surface; the zone of intermittent saturation, where moisture levels fluctuate in response to rainfall intensity; and the zone of permanent saturation, where all pores and rock fractures are filled with water. The upper boundary of this last zone is known as the water table (Alley, Baugh & Reilly, 2006).`

Globally, groundwater represents a critical freshwater resource for agricultural and domestic uses, accounting for approximately 97% of the Earth's accessible freshwater (Delleur, 1999). Currently, about 40% of irrigation water and 60% of domestic water supplies are sourced from groundwater. These figures may increase as surface water resources continue to decline due to pollution, climate change, industrial growth, and urban expansion (Qiu, 2010). Groundwater exploitation refers to the abstraction of water from aquifers—typically through boreholes fitted with mechanical pumps—to make it available for domestic, industrial, agricultural, and environmental uses (Ali, 2012). As noted by Gorelick (2015), no society can develop without dependable groundwater resources. However, increased abstraction has raised concerns regarding over-exploitation, declining hydraulic heads, deeper wells, and rising production costs.

Iron and manganese occur naturally in the earth's crust and often pose aesthetic and quality challenges in groundwater used for drinking (Kamble, Thakare & Ingle, 2013). Their occurrence in groundwater is a global phenomenon. For example, a study in Kalamia, Greece, revealed ferrous iron concentrations ranging from 0 to 361 mg/L, with spatial variations linked to borehole locations (Thalbonithy, Charlesworth, Keith, Bemmelem & 2021). In Nigeria, Ocheri (2010) reported varying iron concenrations in boreholes across rural communities in Benue State, with some levels high enough to make the water unsuitable for drinking].

Similarly, in Obubra, Cross River State, Odong, Chukwu, and Boniface (2018) attributed the failure of about 60% of boreholes to the widespread presence of iron and manganese. In Rivers State, Ngah and Nwankwoala (2013) observed significant iron and manganese contamination within Ahoada's coastal plains and freshwater swamp environments.

Yenagoa, located on the alluvial sedimentary formations of the Niger Delta floodplain, lies roughly five meters above sea level and experiences annual flooding during the rainy season (Koinyan, Nwankwoala & Eludoyin, 2013). Despite its abundant groundwater potential, water supply remains a major challenge. Due to limited access to potable water and the contamination of existing sources, residents increasingly depend on private groundwater abstraction for daily needs.

The rapid growth of commercial groundwater businesses in Yenagoa reflects rising domestic water demand; however, it also raises critical questions regarding the quality and safety of groundwater consumed by households. Consequently, this study assesses groundwater and domestic water demand in Yenagoa metropolis, with particular attention to quality, accessibility, and sustainability.

Groundwater accounts for one-third of global freshwater consumption (Jie, Hao & Xinyan, 2016). Yet, potable water scarcity remains a persistent challenge across Sub-Saharan Africa. Despite initiatives such as the Millennium Development Goals (MDGs), millions still rely on shallow, unprotected wells, ponds, and rivers for water (Ali, 2012; Bonsor, MacDonald, & Calow, 2010; Obeta, 2019). This situation persists even though multiple institutions and policies have been established to enhance water availability (Baguma, Hashim, Aljunid & Loiskandl 2013).

The availability of groundwater for domestic use is constrained by several factors, including over-abstraction, climatic variability, contamination, inadequate treatment facilities, poor transportation systems, infrastructural decay, insufficient funding, and weak institutional frameworks. Excessive abstraction lowers the water table and increases pumping costs. Moreover, these challenges often vary spatially, influenced by geographical factors, industrial activities, urbanization patterns, and governance structures.

The Water Budget Theory

The Water Budget Theory is a valuable analytical tool for estimating water utilization, transport, storage, depletion, and replenishment on the Earth's surface. This approach helps authorities evaluate the sustainability of water resources and regulate their exploitation (Trenberth, 2007). Although water is renewable, geographic variations and human over-exploitation can render groundwater non-renewable, as observed in many arid regions where strict water taxes help control depletion.

In contrast, Yenagoa has abundant surface and groundwater resources but with uneven distribution of iron- and manganese-free zones. Over-exploitation by individuals and commercial water producers has led to the intrusion of undesirable heavy metals into previously clean aquifers (Wali, Umar & Abubakar, 2019). Globally, groundwater withdrawal estimated at about 1500 km³ annually exceeds natural recharge rates in many regions (Wali, Umar, Abubakar, Musa, Alhassan, & Sidi, 2019). Effective application of the Water Budget Theory, supported by political will, could mitigate such trends. Based on these concerns, this study hypothesizes that: Groundwater supply does not meet domestic households' water demand in Yenagoa metropolis in terms of quantity and quality.

MATERIALS AND METHODS

Study Area

Yenagoa, the capital of Bayelsa State in the Niger Delta Basin of Nigeria, is situated between latitudes 4°49'N and 5°23'N and longitudes 6°10'E and 6°33'E (Koinyan, Nwankwoala & Eludoyin, 2013)(Figure1). The metropolis is bordered to the north by Mbiama, to the south by Anyama, to the east by Elebele, and to the west by Tombia.

Geologically, Yenagoa forms part of the Niger Delta sedimentary basin and is underlain by continental, lacustrine, marine, and alluvial deposits dating from the Cretaceous period (approximately 120 million years ago) to the present. These formations comprise sandstone, sand, shale, clay, and limestone, which host significant deposits of crude oil, natural gas, and salt springs (Adegoke et al., 2017).

Research Design

A quasi-experimental research design was adopted for this study. This design was suitable for assessing the spatial variations of iron and manganese concentrations in groundwater across selected communities.

Sampling Procedure

A stratified sampling technique was employed through three major stages: Stage 1: Yenagoa metropolis was purposively selected due to the well-established challenges of domestic water supply in the area. Stage 2: Out of the 21 existing communities, ten (10) were purposively selected based on the severity of groundwater supply challenges. Stage 3: Each of the ten selected communities contributed two sampling locations, giving a total of twenty (20) groundwater sampling sites.

Materials for Experimental Data Collection

Experimental data were obtained using the following materials:

1. GPS instrument – for geo-referencing all sample locations.
2. Field notebook – for recording location coordinates, time, and sample numbers.
3. Electric generator – for powering submersible pumps during power outages.
4. Calibrated sampling bottles – for collecting groundwater samples.
5. Nitric acid (HNO_3) – for preserving samples against oxidation.
6. Nylon rope and measuring tape – for determining borehole depth.
7. Cooler with ice cubes – for preserving samples during transport to the laboratory.

Sample Collection Procedure

Only boreholes with properly fitted well covers and a minimum depth of 100 ft were selected to minimize surface contamination from human or animal activities. The borehole depth was measured by lowering a weighted nylon rope until it reached the bottom, after which the marked point was measured.

The installed submersible pump was allowed to run for five minutes to purge stagnant water and ensure a fresh sample from the aquifer. At each site, 500 ml of groundwater was collected using calibrated bottles. Immediately after collection, 1 ml of nitric acid was added to each sample to prevent oxidation. All samples were collected between 8:00 am and 9:00 am to reduce the impact of temperature-induced temporal variations.

Laboratory Analysis

Laboratory analysis was conducted to determine the concentrations of iron (Fe) and manganese (Mn) in the groundwater samples: Iron concentration was measured using an Atomic Absorption Spectrophotometer (AAS). The digested samples were aspirated into the photometric flame, and readings were taken based on light absorption. Manganese concentration was determined using Ultraviolet–Visible (UV–Vis) Spectrophotometry. Quantification resulted from interpreting colour intensity produced by reagent interactions with the digested water samples. Descriptive and inferential statistical techniques

were applied for data interpretation. The study hypothesis was tested using the Kruskal–Wallis H-Test, a non-parametric statistical test suitable for comparing three or more independent groups.
The formula is:

$$H = \frac{12}{N(N-I)} \left[\frac{R_1^2}{n_1} + \frac{R_2^2}{n_2} \quad \frac{R_k^2}{n_k} \right] - 3\,(N+1) \qquad \text{----------} \; (1)$$

Where:

H = Kruskal–Wallis statistic

N = total number of observations

k = number of groups

R_i = sum of ranks for group i

n_i = sample size in group i

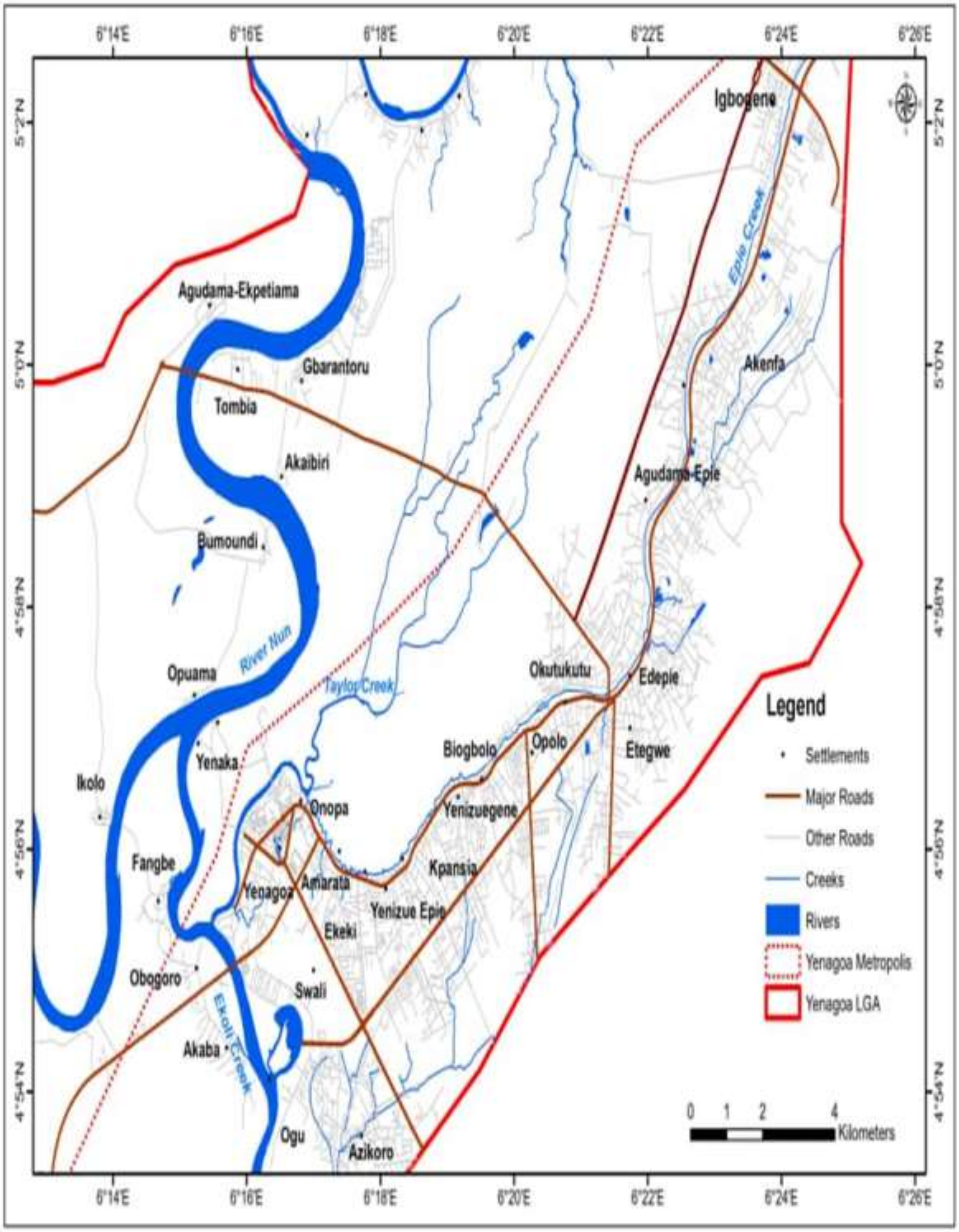

Figure 1: Yenagoa Metropolis
Source: Office of the Surveyor-General of Bayelsa State, 2020

RESULTS AND DISCUSSION

Figure 2 and 3 are derived result of groundwater samples that are tested for iron and manganese concentration respectively in Yenagoa metropolis, it indicates the spatial variation and concentration of the metals as they occur. Naz and Javed (2013), has earlier stated that groundwater exploitation in Yenagoa metropolis is impaired by heavy metals of which iron and manganese rank the highest. This is evident from the samples analyzed in the selected locations as shown in Figure 4.1 and 4.4. Akenfa Bore hole (BH) 1 showing a higher iron (Fe) concentration of 27.18 and Ekeki BH 2 with manganese concentration of 1.724. All sites recorded iron concentrations well above the recommended value of 0.05mg/L but with Igbogene 2,Akenfa 2,Etegwe 2, Onopa 1 and Yenagoa 2 that recorded manganese values less than the WHO threshold value of 0.3mg/L. This causes a major obstacle in making water available to the residents of Yenagoa metropolis.

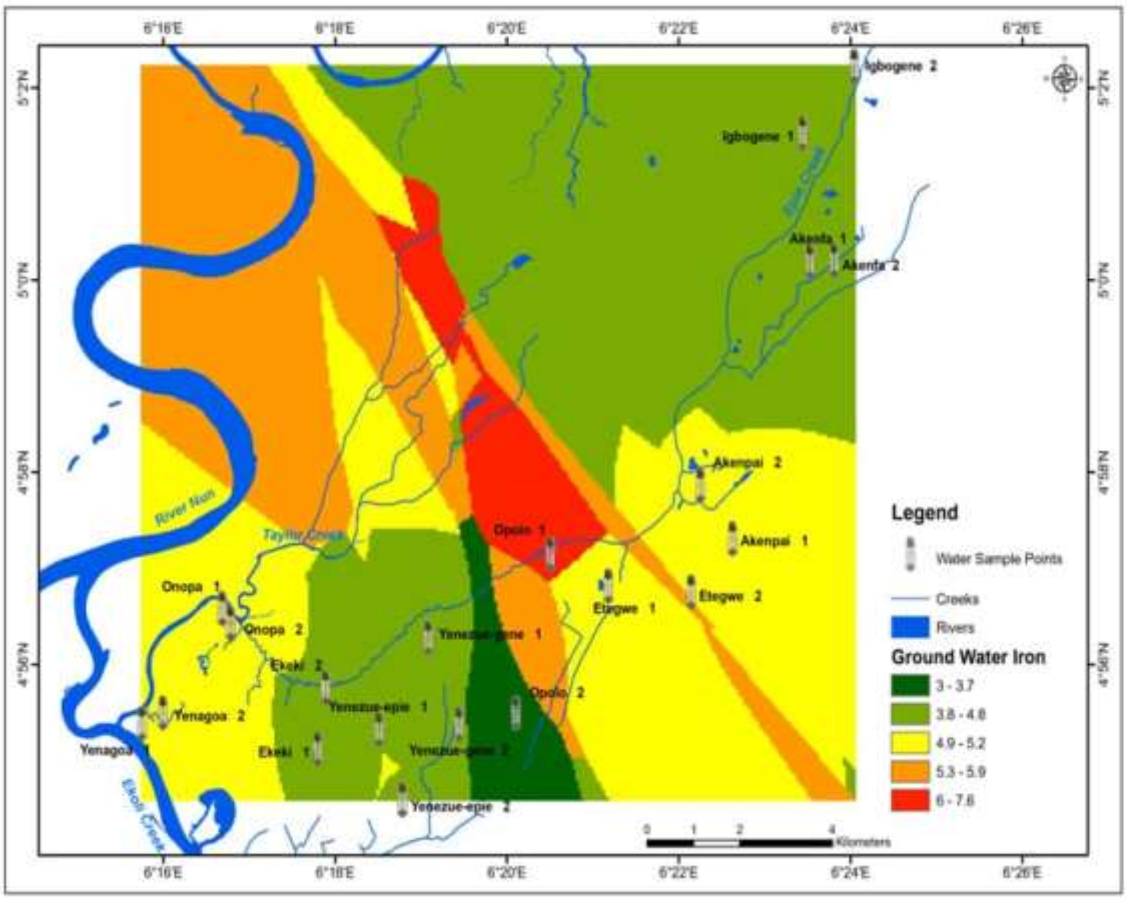

Figure 2: Iron Concentration in Yenagoa Metropolis
Source: Fieldwork, 2022

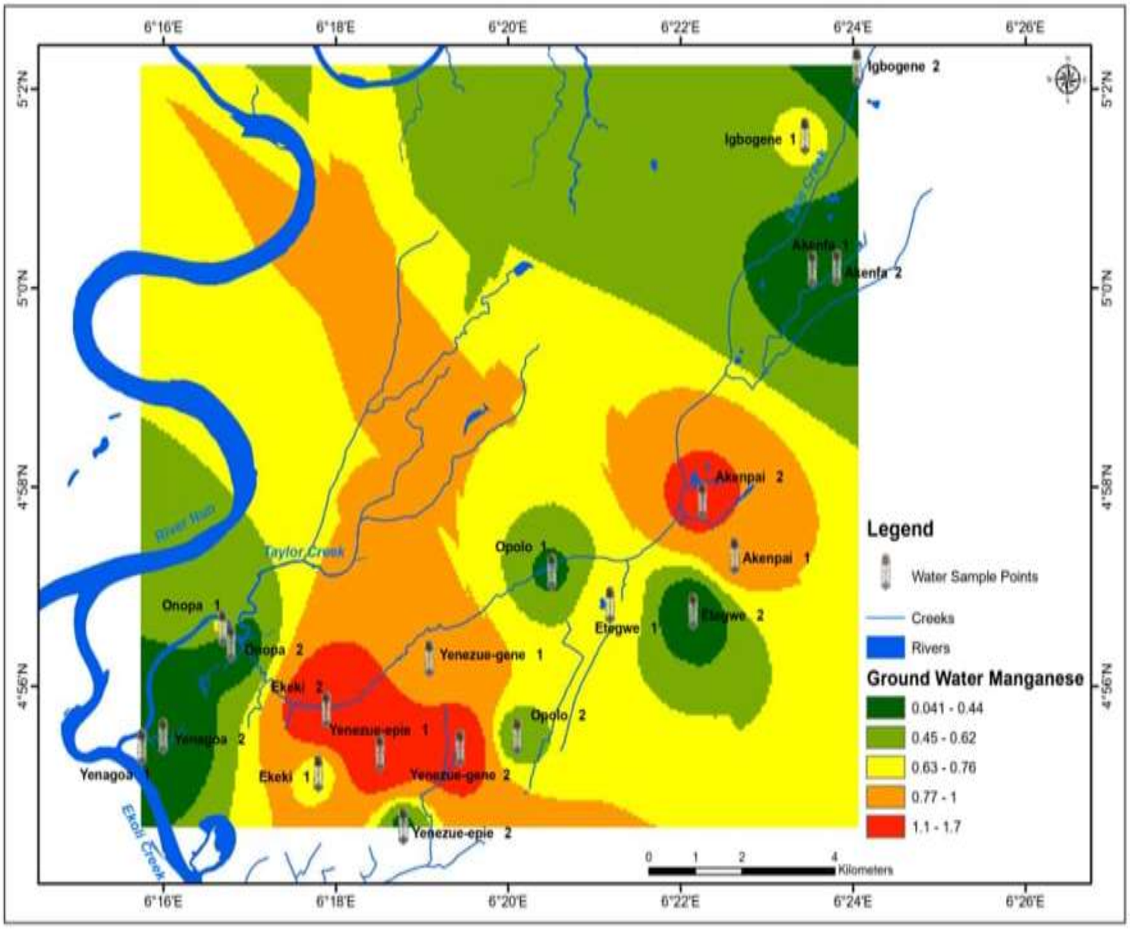

Figure 3: Manganese Concentration in Yenagoa Metropolis
Source: Fieldwork, 2022

In Yenagoa metropolis, iron and manganese occur in groundwater in concentrations greater than 0.3 mg/L for iron and 0.05 mg/L for manganese. These concentrations compromise the quality of water in plumbing fixtures and laundered cloths are often stained. Although discoloration from precipitates is the most visible and serious problem associated with water supplies with iron and manganese water contamination, foul odours and tastes often produced by the growth of iron bacteria in water abstracted from household wells and boreholes. The iron bacteria use reduced iron as an energy source to precipitates and cause pipe encrustations, furthermore, the decay of the accumulated bacterial slimes cause very serious odour and taste.

Iron and manganese are disposed throughout the metropolitan area to great depths in the alluvial deposits, impounded water surfaces, anaerobic hypolimnions (stagnant bottom water layers) and bottom muds. The concentration of iron and manganese also affect and influences the cost of water in Yenagoa metropolis. Residents of Yenagoa preferred groundwater to meet their domestic water needs. This however comes with its challenges of contaminations, with particular reference to iron and manganese, which according to Nav & Javed, (2013) ranks the highest and in turn has impaired groundwater exploitation in Yenagoa. Iron and manganese has been confirmed to occur in spatial variation in Yenagoa metropolis.

Akenfa bore hole (BH) 1 showing a higher iron (Fe) concentration of 27.18 and Ekeki BH 2 with manganese concentration of 1.724. All sites recorded iron concentration well above the recommended value of 0.05mg/L but with Igbogene 2, Akenfa 2, Etegwe 2, Onopa 1 and Yenagoa 2 that recorded manganese values less than the WHO threshold value of 0.3mg/L. This causes a major variation in treatment intensity and forms across Yenagoa metropolis. Yenagoa is peculiarly affected by both elements (Mn and Fe) with the latter making water exploitation and domestic supply difficult.

Groundwater exploitation for domestic use according to Nwankwoala and Ngala, (2015), has not attained a high level of development due to the difficult environmental conditions, low level of the general underdevelopment and lack of funds. This is further compounded by the presence of dissolved iron and manganese that occurs in the groundwater in Yenagoa metropolis as is observed in this research. The works of Kousa, Kumulaimen, Hatakka, Backman, & Hartikainen (2021) has it that iron and manganese in Yenagoa groundwater, occur in soluble state (Fe2 and Mn2) and is thus required to be converted to the insoluble state as part of the steps required to make the water usable which also comes with various aesthetic features such as odour, colour, stains, depositions and even taste.

Hypothesis testing

To test whether groundwater supply does not meet domestic households' water demand in Yenagoa metropolis in quantity and quality, water samples from three locations i.e. Igbogene, Akenfa and Etegwe were collected to examine the variations in supply and demand in terms of quantity (%) Iron (Fe) and Manganese (Mn) concentration level in Mg/L. In this analysis, the Kruskal-Wallis H Test statistical test was used. The formula is:

$$H = \frac{12}{N(N - I)} \left[\frac{R_1^2 + R_2^2 \quad R_k^2}{n_1 \quad n_2 \quad n_k} \right] - 3\,(N+1)$$

Where: R_1 =Sum of ranks of sample

n_1 = Size of sample

R_2 = Sum of ranks of sample 2

n_2 = Size of sample 1

R_k = Sum of ranks of sample K

n_k = Size of sample K

$N = n_1 + n^2$ ----- n_k

K = Number of groups (3 -1 =2)

df = K – 1 (chi-square tables)

The critical Table values @ 0.05 = 5.991

@ 0.01 = 9.210

Table 1: Water Quantity, Fe and Mn Concentration

Location	Water Quantity (%) A	Fe(Mg/L) B	Mn(Mg/L) C
Igbogene 1	8.6	2.06	0.70
Igbogene 2	20.7	1.90	0.14
Akenfa 1	31.7	2.12	0.40
Akenfa 2	9.0	1.04	0.18
Etegwe 1	16.0	1.63	0.74
Etegwe 2	14.0	1.32	0.12
Total	100.0	10.07	2.28

Arrange all the data from the lowest to highest and rank each value.

Table 2: Water Quantity, Fe and Mn Concentration

Amount	Category	Rank
0.12	C	1
0.14	C	2
0.18	C	3
0.40	C	4
0.70	C	5
0.74	C	6
1.04	B	7
1.34	B	8
1.63	B	9
Amount	Category	Rank
1.90	B	10
2.06	B	11
2.12	B	12
8.60	A	13
9.00	A	14
14.00	A	15
16.00	A	16
20.70	A	17
31.70	A	18

To find the sum of the ranks of each category,

C = 1 + 2 + 3 + 4 + 5 + 6 = 21

B = 7 + 8 + 9 + 10 + 11 + 12 = 27

C = 13 + 14 + 15 + 16 + 17 + 18 = 93

We now substitute in the formula

$$H = \frac{12}{N(N+I)} \left[\frac{R_1^2}{n_1} + \frac{R_2^2}{n_2} \frac{R_3^2}{n_3} \right] - 3(N+1)$$

Where N = 18; $R_1 = 21$; $R_2 = 57$; and $R_3 = 93$

$n_1 = n_2 = n_3 = 6$

$$H = \frac{}{18(18+1)} \left[\frac{12}{666} - 3(18+1) \frac{12^2}{} + \frac{57^2}{} + \frac{93^2}{} \right]$$

$$H = \frac{12}{342} \left[\frac{441}{6} + \frac{3249}{6} + \frac{8649}{6} \right] - 3(19)$$

$$H = 0.0351\ (73.5 + 541.5 + 1441.5) - 57$$

$$H = 0.0351\ (2056.5) – 57$$

$$H = 72.183 = 15.183$$

Since the test value H(15.18) is greater than the critical table value at 0.05 and 0.01, that is 5.991 and 9.210 respectively, we therefore reject the null hypothesis and accept the alternate hypothesis. It is therefore concluded that groundwater supplies meet the domestic households' demand despite the occurrence of iron and manganese contaminations in Yenagoa metropolis.

CONCLUSION AND RECOMMENDATIONS

This study has revealed that the residents of Yenagoa metropolis rely on groundwater exploitation to meet their daily water need which comes with iron and manganese contamination challenges. The cost of providing groundwater to meet the domestic needs in Yenagoa metropolis is enormous especially when the use goes beyond bathing, washing and cooking. However, these observed challenges can be ameliorated if residents can make sacrifices to improve on their conceived methods of water abstraction and treatment by first ensuring a minimum of 200ft borehole depth and by encouraging a minimum of 30 meters distance away from septic tanks to reduce the risk of bacteriological and anthropogenic contaminations. It is therefore recommended that the processes of aeration, sedimentation/deposition and filtration which are already found clustered in a chamber be separated into different chambers.

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