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Effect of Fuel Station Distances on Groundwater Pollution and its Quality for Domestic Uses in Makurdi Metropolis, Benue State, Nigeria

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ABSTRACT

The research assessed groundwater quality around fuel stations in Makurdi metropolis, Benue State Nigeria. The study ascertained the possibility of fuel station polluting groundwater sources as tanks are buried underground. Water samples were collected from twelve hand dug wells for analysis of physico-chemical parameters of Colour, Temperature, TDS, Iron, Zinc, Copper, Lead, Cadmium, Chromium, and Electrical Conductivity. Both field and laboratory analyses were done using standard methods. Result of the analyses showed that the colour averaged 4.7HU, mean temperature was 23.5°C, Total Dissolved Solids (TDS) 0.65 mg/l, turbidity was 9.8NTU. The result of chemical analyses had pH concentration of 6.58, Iron 3.0 mg/l while Zinc had a negative mean of -0.23 mg/l, Lead 0.56 mg/l, Copper 0.30 mg/l, Cadmium and Chromium had a mean of -0.1 and 0.5mg/l respectively, and electrical conductivity 713.6 µms/cm,. The total bacteria count was 290MPN/100ml. Distances of wells from the fuel stations averaged 364.9m while the mean depth of wells was 6.2m. The multiple correlation analysis showed that there is a significant relationship between depth of wells around the fuel station and the concentration of pollution level of all Wells. All the waters are slightly acidic, because all pH concentrations were high, Iron and Lead concentrations were high in some newer wells, hence they constitute health risks. The study concluded that with time groundwater may be highly polluted. It is recommended that, regulations and public awareness on operations, and health implications of siting distances of fuel stations to the groundwater sources must be given a priority.

Keywords: *Groundwater, Wells, Fuel station, Petroleum, Pollution, Water quality.*

1.0 INTRODUCTION

Water is one of the most essential natural resource that sustains the earth as the planet of life. It makes up about 71% of the earth's surface (American Geosciences Institute, 2023; Iwena, 2018), it makes 50- 97% of the weight of all plants and animals and about 70-75% of human body (U.S. Department of Energy, 2022; Phiri *et al*, 2005). Water is found everywhere in the earth's ecosystem and taken for granted in many parts of the world. Its distribution on the earth surface is uneven. About 97% occurs as saline water in seas and oceans. Of the remaining fresh water considerably more than one-half is locked up in the ice sheets and glaciers and another substantial volume occurs as groundwater (SpringerLink, 2022; Ward and Robinson, 1990).

Groundwater is defined as water found in cracks and spaces within soil, sand, and rocks. It serves two main functions: it is a significant source of water supply for both urban and rural populations and sustains many wetland ecosystems. Groundwater sources primarily depend on rainfall and the subsequent percolation of water into the earth, with soil type and quality also playing a crucial role (U.S. Geological Survey, 2024; The Groundwater Foundation, 2023; Altaff and Ameetha 2002). The sources of groundwater supply mostly depend upon the rainfall and the resulting percolation of the water in the earth, another important factor is the type and quality of soil (Handa, 1994). A typical human requires daily drinking water amounting to about 7% of their body weight, essential for healthy growth. However, this same water can become hazardous if contaminated with toxic substances, posing a threat to life (U.S. Geological Survey, 2023; Environmental Protection Agency, 2023). The quality of any body of surface or ground water is a function of either or both natural influence and anthropogenic activities.

Sources of groundwater contamination are widespread and include numerous factors such as accidental spills, landfills, surface waste ponds, underground storage tanks, pipelines, injection wells, saltwater intrusion, and acid mine drainage. Major contaminants of concern include petroleum hydrocarbons (like benzene, toluene, and xylene), chlorinated organics (such as perchloroethylene (PCE) and trichloroethylene (TCE)), and heavy metals (like lead, zinc, and chromium). These contaminants primarily result from human activities (Safe Drinking Water Foundation, 2023; U.S. Environmental Protection Agency, 2023; The Groundwater Foundation, 2023).

Groundwater is considered less polluted compared to surface water due to its reduced exposure to the external environment. However, lack of sanitation and improper waste management can significantly increase groundwater pollution levels, with about 40% or more disease outbreaks attributed to waterborne sources (IAEA, 2023; Babuji *et al.*, 2023). As urbanization continues, water pollution problems have intensified, causing serious ecological and environmental issues. Industrial activities without proper environmental considerations have exacerbated water and air pollution (IAEA, 2023; Shah and Patel, 2011).

In developing countries, around 80% of all diseases are linked to poor drinking water and unsanitary conditions (WHO, 2023). Many health issues in these regions are traced back to the lack of safe drinking water, with water-related diseases remaining a significant public health concern in parts of Africa, Latin America, and Asia (USGS, 2018). Globally, an estimated 1.8 million people die annually from waterborne diseases, while over 10 million suffer from preventable water-related ailments such as cholera, typhoid fever, and dysentery (WHO, 2023). The World Health Organization recommends that drinking water be free from pathogenic organisms to ensure the safety of humans and aquatic life (WHO, 2023).

The exponential growth of petrochemical and pharmaceutical industries has introduced a variety of complex organic wastes into the environment, posing significant risks to groundwater quality through accidental spills or leaks from tanks and pipelines of petroleum products, phenols, and chlorinated hydrocarbons (UK Groundwater Forum, 2012).

The most dominant contaminants of groundwater are inorganic contaminants such as salts and metals. The presence of metals in groundwater and soils can pose a significant threat to human health and ecological systems. Heavy metals are elements with atomic weights between 63.54 and 200.59 and specific gravities greater than 4, at least 5 times that of water (Tchounwou *et al.,* 2012). They exist in water in colloidal, particulate, and dissolved phases, occurring naturally (e.g., eroded minerals, leaching from ore deposits, volcanic emissions) or due to human activities (solid waste disposal, industrial or domestic effluents, harbor dredging) (Ali *et al.,* 2019).

While trace amounts of certain heavy metals are essential for life—such as calcium, magnesium, potassium, and sodium required for normal bodily functions, and cobalt, copper, iron, manganese, molybdenum, and zinc as enzyme catalysts—excessive exposure to heavy metals can lead to toxicity and harm (Jaishankar *et al.,* 2014; Mahurpawar, 2015). Metals also bind strongly to organic matter like humic acids, organic clays, and oxide coatings (Khan *et al.,* 2017).

The solubility of metals in soils and groundwater is primarily controlled by factors such as pH (Gadd, 2010), metal concentrations, cation exchange capacity (Alloway, 2013), organic carbon content (Wang *et al.,* 2019), and the oxidation state and redox potential of mineral components (Xiao *et al.,* 2017). Major anthropogenic sources of heavy metals include industrial waste from mining sites, manufacturing plants, metal finishing operations, domestic wastewater, and road runoff. Many of these trace metals, such as mercury (Hg), lead (Pb), cadmium (Cd), nickel (Ni), arsenic (As), and tin (Sn), are highly toxic to humans and undesirable in surface and underground water above specific concentrations (Zhang *et al.,* 2020).

Fuel stations, also known as gas stations or petrol stations, are facilities for storing and selling petroleum products derived from crude oil, including petrol, diesel fuel, engine oil, kerosene, and cooking gas. Crude oil itself is classified into light, heavy, sweet, and sour types based on its sulfur content (Speight, 2020).

Exposure to crude oil through air or water can be toxic and hazardous to human health, causing symptoms such as breathing problems, headaches, nausea, dizziness, and confusion. Long-term effects may include respiratory, liver, blood, and kidney damage, along with immune and nervous system disorders. Children and pregnant women are particularly vulnerable to these effects (Balali-Mood *et al.,* 2021).

Access to safe drinking water remains a challenge for many people in developing nations (WHO/UNICEF, 2021). Despite significant governmental investment in water supply programs in Nigeria, over 52% of the population lacks access to potable water (Adelodun *et al.*, 2020). In Makurdi, despite efforts by public water agencies to provide safe water through projects like the Greater Makurdi Water Works, acute water shortages persist, leading residents to rely heavily on hand-dug wells as alternative water sources. However, the proliferation of fuel stations across the town, often sited without consideration for long-term groundwater impacts or proximity to residential areas and water sources, threatens these water supplies.

Underground Storage Tanks (USTs) are commonly used at fuel stations, where gasoline, fuel oil, and other chemicals are stored at an average depth of approximately 4.27 meters (14 feet). If these tanks develop leaks, groundwater supplies can be seriously contaminated. Contamination, which may pose health risks to humans, is likely to occur if precautions or checks are not made on the siting and operations of the fuel stations. Thus, it becomes imperative to assess the groundwater quality around fuel stations in Makurdi town, Nigeria.

Concern over the problem of water demand, consumption, and quality in Makurdi has been investigated by researchers. Studies on water demand and consumption patterns (Nwankwoala and Nwagbogwu, 2012; Duru *et al.,* 2019) and water quality from hand-dug wells (Adelana *et al.,* 2008; Ukah *et al.,* 2020) have been conducted. The aim of this study was to assess the groundwater quality around fuel stations in Makurdi metropolis, Benue State, to ascertain their suitability for human consumption in line with WHO standard guidelines for drinking water.

2. MATERIALS AND METHOD

2.1 Study Area

2.1.1 Location of the Study Sites

Makurdi is the capital city of Benue state traversed by the Benue River which divides the town into North and South banks respectively (Figure.1.1) (Figure 1). Makurdi town is situated between the coordinates of latitude 07^{0}43^{l}N, 07^{0}45^{l}N and longitude 08^{0}32^{l}E, 08^{0}38^{l}E. One fuel station (TONIMAS) was chosen from north bank area of Makurdi metropolis, three other fuel stations from the south bank area which are TOTAL fuel station in Wadata area; CONOIL fuel station opposite Benue State University main campus; and MOBIL fuel station in Kanshio area (Figure 1.1)(Figure 1).

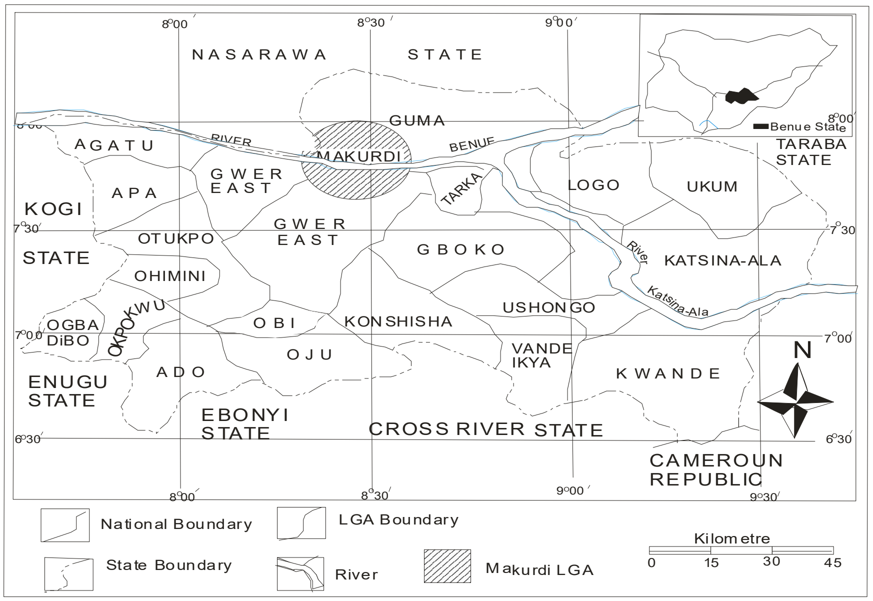

Figure 1.1: Map of Benue State Showing Makurdi Local Government Area .
Source: Ministry of Lands and Survey Makurdi

Geology and Soils: The geology of Makurdi town consists mainly of sedimentary formation of sandstones. The soils of the area are the tropical ferruginous soils that comprise of hydromorphics along flood plains and wetlands and lithosols off flood plains. The red ferrasols developed on sedimentary rocks are also found in the southern parts. The soils are a reflection of its parent materials developed by slope and climate.

The sandy nature of the topsoil makes infiltration easy which explains the usage of shallow wells in the area. The first aquifer is unconfined with precipitation infiltration through porous sandy environment as water source. The second aquifer also referred to as the semi-confined has the formation of highly consolidated and geologically made up of shales intercalated with sandstones of coarse grains exhibiting larger pores (BSU -GD, 2006).

Relief and Drainage: Makurdi town is generally located in a plain that slopes up gently on either side of the river. Thus, the elevation rises to the north about 154m at Daudu, and to the south about 216m at Ikpayongo (BSU- GD, 2006).

The Benue River forms the major drainage channel in Makurdi. It flows east to west dividing the region into the north and south banks. Other drainage channels mostly first order streams and the tributaries of River Benue also drains the region.

Climate: The climate of Makurdi town is the tropical Aw type with alternating wet and dry seasons which are also hot and cool. The climate is characterised by SW and NE monsoons. The north south annual movement of intertropical discontinuity (ITD), the convergence zone SW and NE monsoons, synoptic weather systems (such as thunder storms and squall line) and topography influenced rainfall distribution in the region.

The rainfall periods are from April to October, with amount ranging from 900 to 1200mm with the heaviest rain in June and September, declining with increasing latitude. The mean dates of onset and cessation of the rainy season are 15th April and 14th October respectively (BSU-GD, 2006). Tyubee (2005) identifies three temperature periods in the study area to includes: cool dry season, November – January (during the time of low sun), hot dry season, February – April (just preceding the rain), and hot wet season, May – October (during the rains).

Temperatures are generally high, with mean annual temperatures of 32.5^{0}C. The atmospheric humidity varies with seasons from 80% during the wet season to 30% during the dry season. Wind speed is generally light to moderate except the squall lines that often gust at66km/h (BSU-GD, 2006).

Vegetation: Vegetation of Makurdi is characterised by a mixture of trees and grasses of the guinea savanna specie. Human activities have depleted the natural vegetation due to increase in urbanization; the vegetation today is that of derived vegetation with patches of natural tree species along river courses and reserves. The trees include fruit trees such as cashew, citrus and mango alongside other economic trees like Mahogany, Obeche, Gmalina, and Iroko. The grasses are a mixture of shrubs useful for animal grazing and medication respectively.

Population: Makurdi town has a population of over 300,377 males and 146,239 females, giving a total of 446,616 people (2006 census). The population of the town makes up 7.01% of the state's population, with a density of 380 persons /km^2.

2.2 Site Locations and Water Sampling Technique

Four Fuel stations were purposively selected as; Tonimas,North bank; Total, Wadata; Con oil, Gboko road and Mobil, Otukpo road. Well Sample Points are designated as SB; (SBI, SBII, SBIII, SBIV), for the four sites (Figure1.3) (Figure 2). The choice of fuel stations was based on its age and the number of wells surrounding it within five hundred (500) meter radius. Two (2) old fuel stations (thirty years and above) and two (2) new stations (fifteen to twenty-nine years). The reason is that it takes years for leakages to sip down to groundwater to contaminate it.

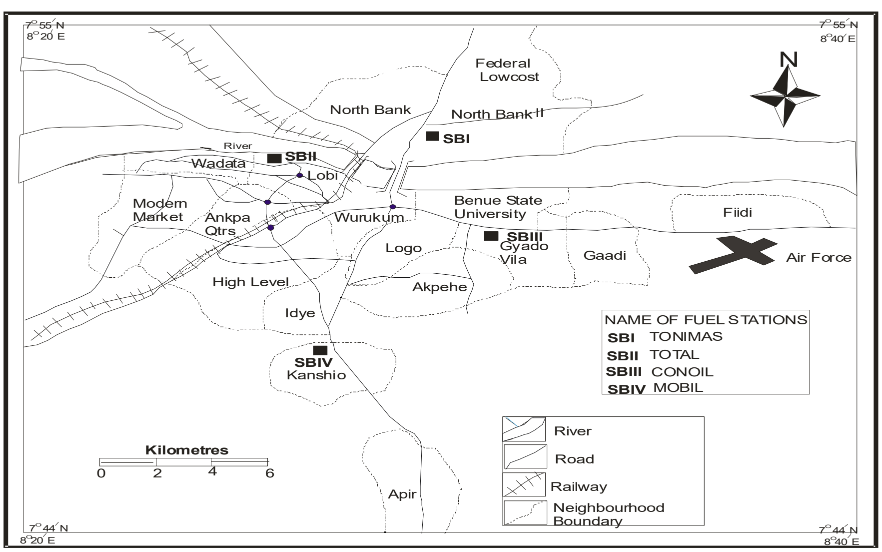

Figure 1.3: Map of Makurdi Town Showing Selected Fuel Stations
Source: Ministry of Lands and Survey Makurdi

2.2.1 Sample Collection and Data Analysis

Water samples at different locations were collected for laboratory analysis following laboratory standard procedures and methods, according to APHA/AWWA/WEF (2017). A total of twelve (12) hand-dug wells were selected. Three (3) wells were purposively sampled around each chosen fuel station, all within five-hundred-meter radius of the chosen fuel stations.

Water samples collected were analysed in the laboratory for physicochemical characteristics and microbiological content. Physical characteristics determined were Colour, Odour, Temperature, Turbidity, TDS.The chemical parametres are: pH, Electrical Conductivity, Iron, Zinc, Lead, Copper, Cadmium and Chromium,and microbiological content is Total Bacteria Count. The laboratory result was further used to test the relationship between distance and pollution levels, depth of wells and pollution levels.

Distance of wells from the stations was measured manually using meter tape. The information on the year of design, construction and operation of the underground storage tanks (UST) system of the fuel stations in the study area; the remediation strategies put in place by the government and owners of the fuel stations was sourced through structured interview. Multiple Correlation Analysis was been used to determine the relationship between distance, depth and the quality of groundwater sources around fuel stations in the study area.

3. RESULTS AND DISCUSSIONS

3.1 Results

The result of analysis on the physico-chemical and microbiological characteristics of ground-water from the wells around fuel stations in Makurdi metropolis are presented in Table 1. The concentration levels of each of the parameters were analyzed based on the guidelines specified by the World Health Organization (WHO) (2017).

3.2 Discussion

3.2.1 Physical Parameters

Colour: Colour is one of the physical parameters examined in the groundwater sampled.According to WHO(2011), colour graded between 5-50 are acceptable, any grade above 50 is not acceptable for drinking. Sample SBI1 had the lowest value of 3 pt-to, while SBIV3 had the highest value of 7pt-to. Water colour some time occur as a result dissolved minerals or the growth of micro-organisms resulting from the influence of high temperature which may result to odour, and lead to water borne diseases (WHO, 2017). From the results, the colour found in all the water samples was within the permissible limit.

Temperature: The temperature values gotten from the water samples ranges between 17^{0}C and 32.4^{0}C (Figure 3). The WHO minimum standard temperature recommended for drinking water is 25^{0}C. The result therefore shows that all the water samples were within the WHO permissible standard for drinking water which is 25-40^{0}C.The low temperatures found in most of the samples might retard the biological activities in humans since low temperature affect the dissolution of oxygen.

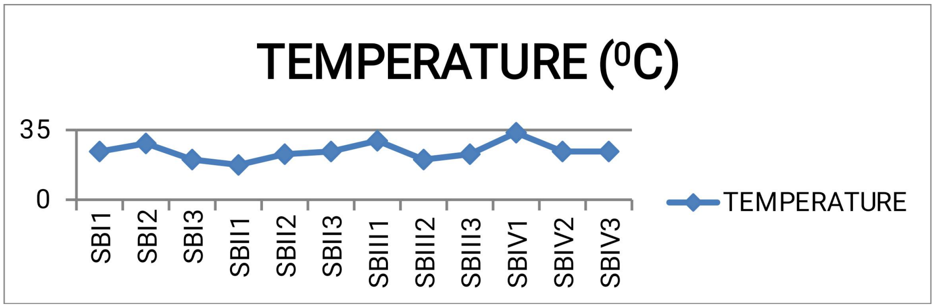

Figure 3: Temperature of Groundwater Samples

Turbidity: Water is said to be turbid when it lacks transparency as a result of dissolved elements, indicating pollution (Gao *et al.,* 2020). Turbidity is caused by suspended matter or impurities that interfere with the clarity of the water. These impurities may include clay, silt, finely divided inorganic and organic matter, soluble colored organic compounds, plankton, and other microscopic organisms (Sun *et al.,* 2019). Most turbidity of groundwater is based on the

Table 1: Result of Physicochemical and Microbiological Characteristics of Groundwater around Fuel Stations in Makurdi Metropolis

Parameters	**Unit**	**SBI1**	**SBI-2**	**SBI-3**	**SBII-1**	**SBII-2**	**SBII-3**	**SBIII-1**	**SBIII-2**	**SBIII-3**	**SBIV-1**	**SBIV-2**	**SBIV-3**	**WHO**
Distance	M	362	372	490	457	370	360	271	392	521	9.1	375	390	
Depth	M	7.93	8.32	7.25	7.84	3.41	4.21	7.82	7.50	1.72	6.22	5.37	6.72	
Temp	^{0}C	23	27	19	17	22	24	29	20	22	32.4	23	23.1	25-40
Colour	HU	Colorless 3	Colorless 4	Colorless 5	STRAW 5	Colorless 5	Colorless 4	Colorless 6	Colorless 5	Colorless 4	Colorless 4	Colorless 4	STRAW 7	5-50
Odour		Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Chlorious	Odorless	Musty	Odorless	Odorless	Earthy	
TDS	(mg/l)	0.40	0.80	0.60	1.20	0.80	0.40	0.40	0.40	0.40	0.80	0.40	1.20	500-1500
Turbidity	NTU	3.0	7.0	8.0	54.0	8.0	3.0	2.0	2.0	2.0	2.0	4.0	23.0	5-50
pH	@26^{0}C	5.70	6.35	6.55	6.25	6.20	6.25	6.95	7.00	6.75	7.15	6.95	6.90	65-85
Fe	(mg/l)	1.442	3.431	1.078	5.3549	2.627	1. 872	1.928	1.438	0.884	9.663	0.862	5.500	0.3-.0
Zn	(mg/l)	-0.101	-0.315	-0.510	-0.225	-0.031	0.537	-0.247	-0.392	-0.381	-0.421	-0.293	-0.359	0.01-0.1
Pb	mg/l	0.642	0.631	0.531	0.766	0.649	0.403	0.513	0.681	0.540	0.733	0.237	0.442	0.001-1.0
Cu	mg/l	0.265	0.228	0.306	0.334	0.351	0.284	0.463	0.296	0.227	0.324	0.243	0.314	1.0-2.00
Cd	mg/l	-0.027	-0.053	-0.181	-0.202	-0.259	-0.102	-0.038	-0.053	-0.098	-0.101	0.022	-0.004	0.003-3
Cr	mg/l	0.971	0.115	-0.486	0.099	-0.240	-1.352	0.037	-0.358	0.229	-2.391	-0.480	-2.392	0.05-0.50(p)
EC	µms/cm	766.0	1015.0	503.0	141.9	315.0	133.70	1968.00	1387.0	1260.0	247.0	231.0	596.0	400-2500
Total Bacteria count	MPN/100ml	Nil	180	>300	>480	>150	>150	>420	>300	>300	>400	>400	>400	10

dissolved minerals in the water. The sample site SBII1 had the highest turbidity of 54 NTU, while sample sites SBIII1, SBIII2, SBIII3, and SBIV1 had the lowest turbidity (Figure 4).The mean turbidity was 9.8 NTU. The high value obtained at sample site SBII1 could be due to poor well construction and improper coverage of the well. Apart from sample SBII1, the rest of the samples were within the permissible limit of 5-50 NTU. Umar *et al*. (2018) found turbidity ranging from 4.48-13.62 NTU in their study on the effect of refuse dumps on groundwater quality in Minna, Niger State, Nigeria, while Eze et al. (2019) reported a mean turbidity of 2.0 NTU in their study of wells around Federal Low-Cost Estate North-Bank, Makurdi.

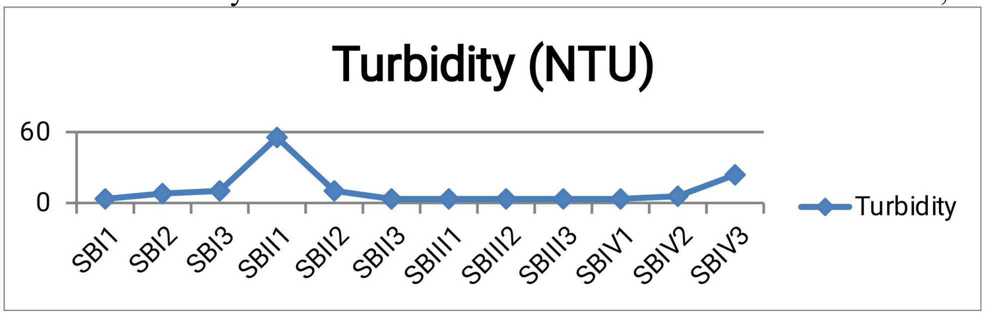

Figure 4: Turbidity of Groundwater Samples

The Total Dissolved Solids (TDS): refers to the total inorganic substances dissolved in water, indicating the general nature of water quality or salinity (EPA, 2021). An increase in TDS levels decreases the potability of water, potentially causing gastrointestinal irritation in humans and having a laxative effect (WHO, 2017). The amount of TDS affects the conductivity of water, as conductivity is a function of the number of dissolved solutes (Bhatnagar and Sillanpää, 2017).The TDS concentrations from the study area showed that sites SBI1, SBII3, SBIII1, SBIII2, SBIII3, and SBIV2 had the lowest TDS concentration of 0.4 mg/L, while sites SBII1 and SBIV3 had the highest concentration of 1.2 mg/L (Figure 5).The mean TDS was 0.65 mg/L. The degree of TDS is classified as fresh if it is less than 1000 mg/L; brackish if it is between 1000 and 10,000 mg/L; saline if it is between 10,000 to 100,000 mg/L; and brine if it is more than 100,000 mg/L (Freeze and Cherry, 1979). Using this classification system, all of the sampled wells were classified as fresh since all of them were below 1000 mg/L.

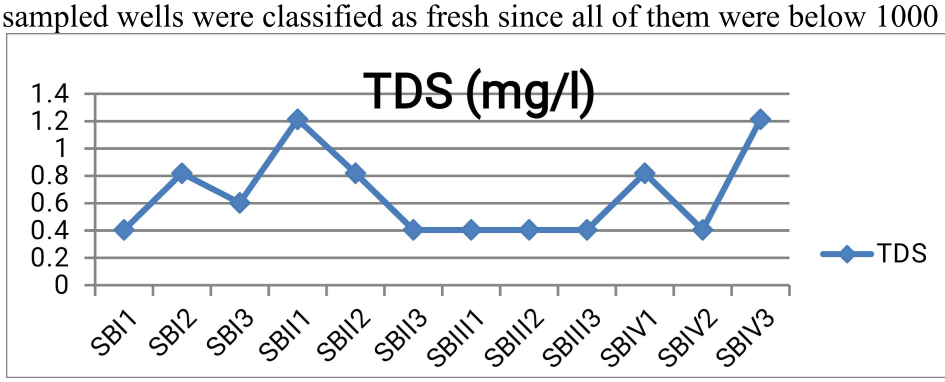

Figure 5: The Total Dissolved Solids of the Sampled Water

Total Bacteria Count: Microbiological analysis of the water samples showed the total bacteria count was found to have the minimum count of 0MPN/100ml at site SBI1, the maximum count of 480MPN/100ml at site SBII1, (Figure 6). Thus, apart from site SBI1 which was 0MPN, the rest of the samples were found to have exceeded the WHO (2018) standard (Figure 6). Biological degradation happens when microorganisms, such as bacteria and fungi, are present in the water. Coliform bacteria must not be detectable in any 100 ml sample of all water intended for drinking. By implication the wells around the selected fuel stations are not free for drinking in line with microbial standard.

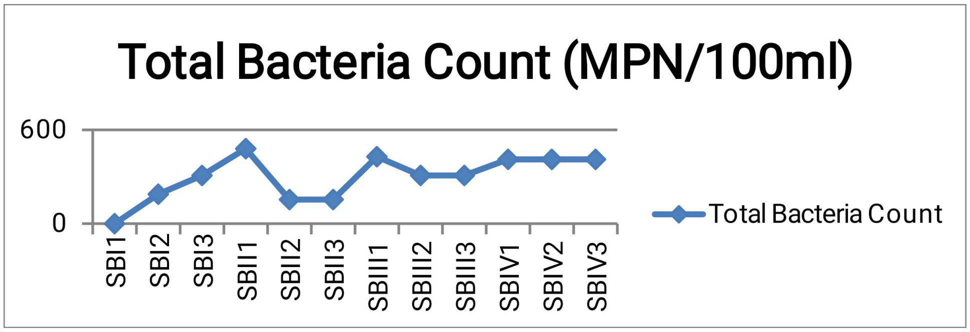

Figure 6: The Total Bacteria Count of the Sampled Water

3.2.2 Chemical Parameters

Hydrogen Potential (pH): The pH is a measure of the intensity of acidity or alkalinity and measures the concentration of hydrogen ions in water. Basically, the pH is determined by the amount if dissolved carbon dioxide (CO_2), which forms carbonic acid in water. According to Todd (1980), pH of ground water can also be lowered by organic acids from decaying vegetation, or by the dissolution of sulphide minerals. The pH values below 7.0 mg/l are considered acidic, while pH values above 7.0 mg/l are known to be alkaline.

The pH values of the sampled groundwater varied from 5.7 mg/l to 7.15mg/l. Sample point SBI1 had the lowest value, while sample point SBIV1had the highest values, (Figure7). The mean pH value of the sampled area is 6.58. This is within the WHO (2018) standard range for drinking water which is 6.50mg/l to 8.50mg/l. Almost all the water in the study area is acidic. WHO (2011) opined that pH is of no serious health concern. However, a low value, below 4.0 will produce sour taste and higher value above 8.5 shows alkaline taste (Obeta and Ocheje, 2013).

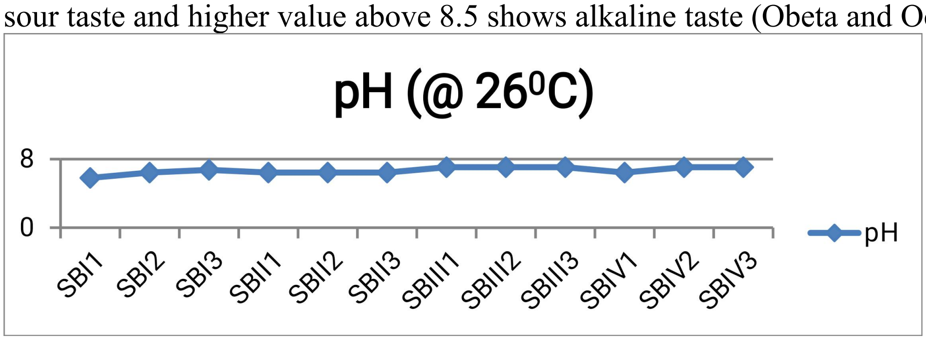

Figure 7: pH concentrations from Analyzed Water Samples

Electric Conductivity (EC) refers to the ability of water to conduct electrical current, which is an indicator of the concentration of dissolved ions, particularly from inorganic compounds (WHO, 2017). The WHO standard for drinking water sets EC between 400 and 2500 µS/cm. The results of the sampled water showed that EC ranged between 133.7 to 1968 µS/cm, with the lowest at site SBII3 and the highest at site SBIII1 (Figure 8). The mean EC was 713.63 µS/cm.

Samples from SBII1, SBII2, SBII3, SBIV1, and SBIV2 were below the WHO standard, while all other samples were within the accepted boundaries. This suggests that other ions not specifically measured contributed significantly to the EC of the water samples across different sites, as the total metal burdens did not correspond directly to the measured EC values (Nwankwoala and Nwagbogwu, 2012). High EC in drinking water is a concern due to its association with elevated concentrations of dissolved ions, which may originate from various inorganic sources (Iorwua, *et al.*, 2018).

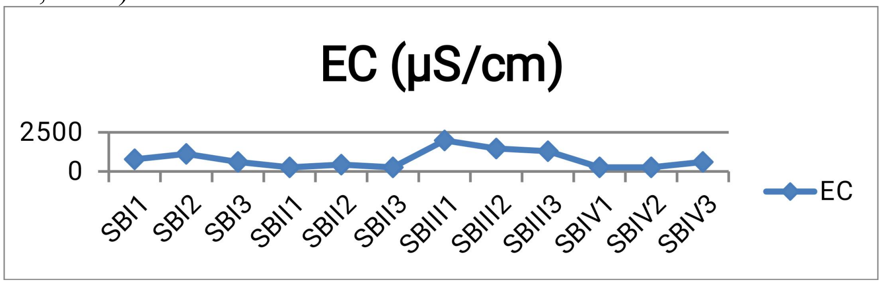

Figure 8: The Electrical Conductivity of the groundwater Samples

The Iron (Fe) concentration: WHO recommends that the iron content of drinking water should be between 0.3-1.00 mg/L. In the sampled water, the maximum Fe^{2+} concentration was found at site SBIV1 with 9.794 mg/L and the minimum at site SBIV2 with 0.831 mg/L, with a mean of approximately 3.02 mg/L. Apart from sites SBIII3 and SBIV3, the rest were found to have exceeded the WHO standard for drinking water (Figure 9). Constant consumption of such water can lead to the formation of blue baby syndrome in infants and goitre in adults (Gupta *et al.,* 2013; Mohammed and Akinbile, 2018).

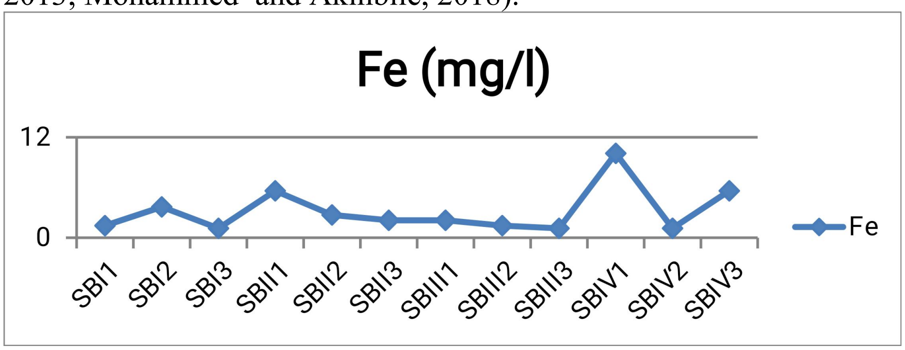

Figure 9: Iron (Fe) Concentration in Groundwater samples

Zinc (Zn) Concentration: WHO recommends that the chemical concentration of zinc in drinking should be within 0.01-1.0mg/l. Zinc concentration in the samples at site $SBII_3$ was the only sample with a positive as well as highest concentration and yet within the permissive value of 0.537 while the rest were not detected, (Figure 10).

Lead (Pb) Concentration: The permissible concentration of lead in drinking water by WHO ranged between 0.001-1.0mg/l (A_1T), for good health concern of children within the age of five and below (WHO, 2011). The lead levels in all the samples ranged from 0.237 to 0.766mg/l, with the lowest at site $SBIV_2$ while the highest at $SBII_1$, (Figure 11), with a mean of 0.564.

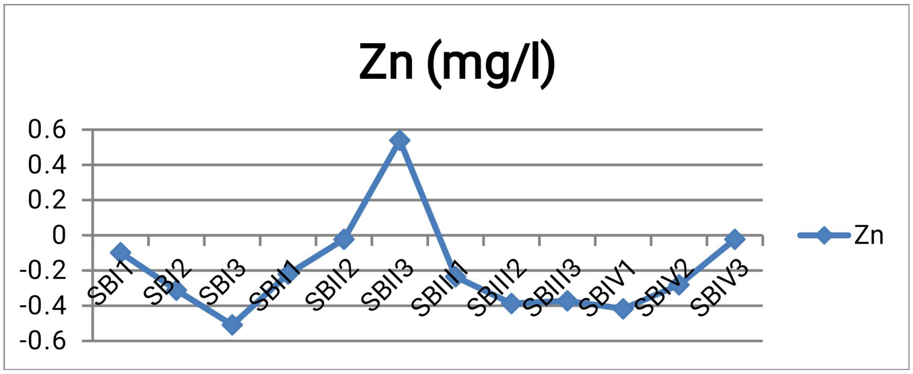

Figure 10: Zinc (Zn) Concentration in Groundwater samples

Deviation at 0.1512 and the coefficient of variation rating of 0. 268817.This might be probably influenced by geology, because the concentration was more in the newer fuel station.

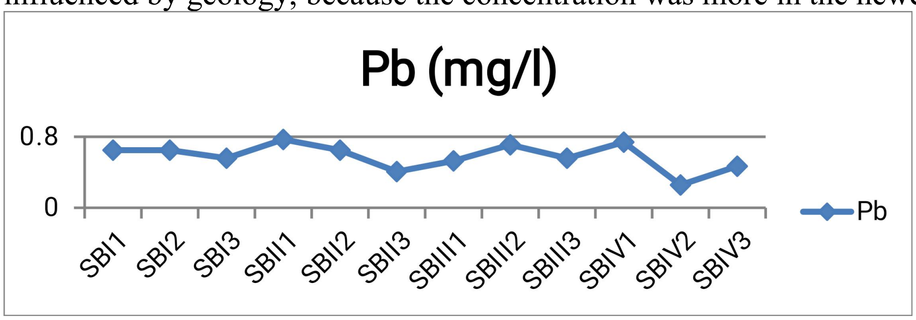

Figure 11: Lead (Pb) Concentration in Groundwater samples

Copper (Cu) Concentration: WHO standard for drinking water recommends that permissive concentration of copper in drinking water ranges between 1.0 to2.0mg/minimum concentration was found to be 0.227 at site$SBII_1$ and maximum was 0.463mg/l (Figure 12). All site concentrations were within the guide limits for drinking water.

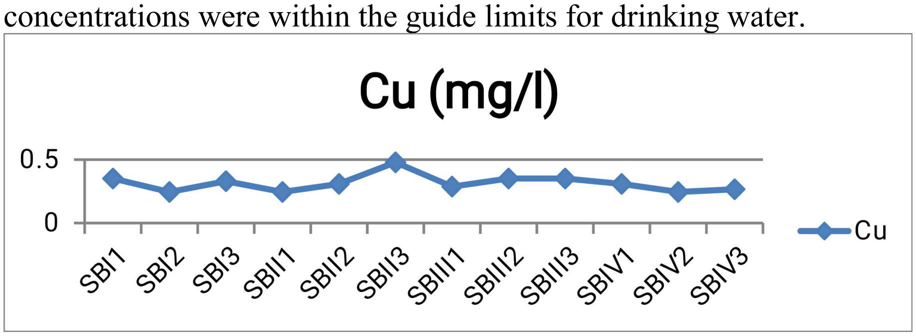

Figure12: Copper (Cu) Concentration in Groundwater samples

Cadmium (Cd) Concentration: The values of Cadmium investigated for all the samples ranged from -0.259 to 0.022mg/l. Site $SBII_2$ had the lowest concentration of -0.259mg/l while site $SBIV_2$ had the highest value of 0.022mg/l (Figure13). Thus, all the sites had cadmium concentrations within the guide limits for drinking water (0.003-3.0) mg/l as recommended by WHO (2011). The findings were at variance with the range of 0.016 to 0.045mg/l obtained by Adewuyi and Olowu (2012) in wells around NNPC Oil Depot Apata, Ibadan Metropolis.

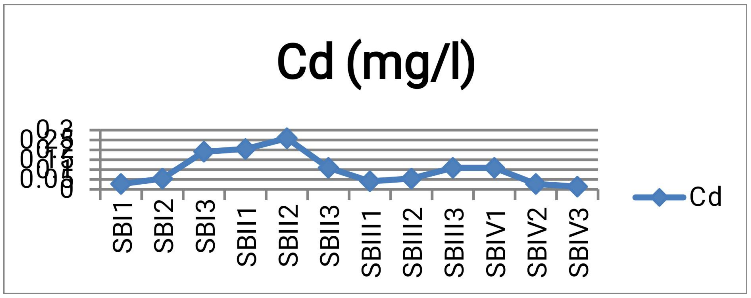

Figure 13: Cadmium (Cd) Concentration in Groundwater samples

Chromium (Cr) Concentration: The permissive range of Chromium concentration for drinking water is between 0.05 to 0.50mg/l The minimum concentration of Chromium from the study area was -2.392 at site SBIV-3 while maximum concentration was 0.971mg/l at site SBI-1(Figure 14). This implies that not every site was detected of having Chromium. Chromium concentration ranges from 0.01 mg/l to 0.18 mg/l as found by Nwankwoala, *et al*, (2011) in their investigation on some heavy metal in groundwater sources in Yenagoa, Bayelsa State, Nigeria. Chromium salt can be toxic to organisms at higher oxidation states (Eneji *et al,* 2012).

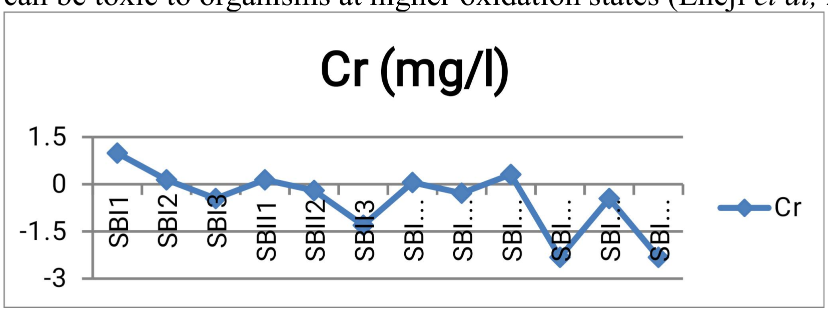

Figure 14: Chromium Concentration in Groundwater samples

3.2.3 Distance of Water Sample Points from Fuel Stations

All the wells sampled were collected within five hundred (500m) meter radius exception in site $SBIII_3$ where the required number of wells to be sampled was not found within the range, but the next well was 21 meters outside the range, hence, the maximum distance was 521m; while the minimum was 9.1m. The mean distance was 364.925m with the standard deviation of 129.960M and the coefficient of variation of .35613% (Table1) (Figure15).

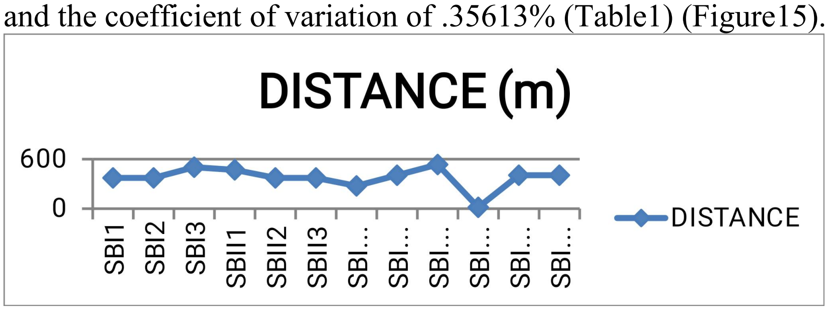

Figure 15: Distance of Water Sample Points from Fuel Stations

The Depth of Wells Sampled: The maximum depth of the sampled wells was found to be 8.32m at site SBI_2 while the minimum was 1.72m at site $SBIII_3$.The mean depth was 6.1925m with the standard deviation of 2.096912m and the coefficient of variation of 0.338621% (Figure 16).

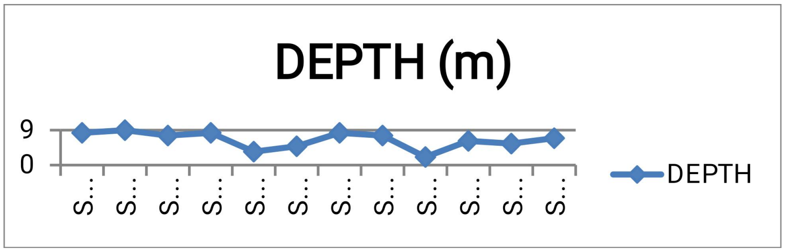

Figure 16: The Depth of Wells Sampled

3.3 Concentration of Physicochemical and Microbiological Characteristics around the Fuel Stations

The result of the analyzed statistics showed concentration of all the parameters investigated exhibited spatial variability as shown in Table 2. Temperatures showed a very clear disparity among the samples, influenced by seasonal variation in atmospheric temperature (Smith et al., 2021). The low temperatures found in most of the samples might retard biological activities in groundwater, as lower temperatures affect the dissolution of oxygen (Feng *et al.,* 2019).

The pH, a measure of acidity or alkalinity, varied among the samples, with one being neutral, one alkaline, and the rest acidic, likely due to dissolved toxic metals and minerals (Jones and Lee, 2020). Acidic water poses health risks and would require treatment to mitigate these risks.

Turbidity showed uniformity, except for two samples that exhibited higher variation but remained within recommended limits (EPA, 2022). Total Dissolved Solids (TDS) analysis indicated low variability across the samples. Total bacteria count showed minimal disparity among the samples, indicating stable biological degradation processes (Nwachukwu and Eze, 2018).

Table 2. Variability of Physicochemical and Microbiological Characteristics of Ground water around the Fuel Stations

Parameters	Minimum	Maximum	Mean	Std. Dev.	Coeff. of Var.	WHO
Temp	17	32.4	23.45833	4.283681	0.182608	25-40
Turbidity	2	54	9.8333	15.11070	0.182099	5-50
TDS	0.4	1.2	0.65	0.308957	0.475318	500-1500
pH	5.7	7.15	6.583333	0.436585	0.066317	6.5-8.5
EC	133.7	1968	713.6333	583.8691	0.818164	400-2500
Fe	0.831	9.794	3.022417	2.689777	0.889942	0.3-1.0
Zn	-0.51	0.537	-0.228167	0.275774	-1.20865	0.01-0.1
Pb	0.237	0.766	0.564	0.151613	0.268817	0.001-1.0(A₁T)
Cu	0.227	0.463	0.302917	0.064871	0.214154	1.0-2.00
Cd	-0.259	0.022	-0.091333	0.08477	-0.92814	0.003-3
Cr	-2.392	0.971	-0.520667	1.030682	-1.97954	0.05-0.50(p)
Bacteria Count.	0.00	480	290.00	143.019	0.604167	10
Distance	9.1	521	364.925	129.9607	0.35613	
Depth	1.72	8.32	6.1925	2.096912	0.338621	

In the process, contaminants break down, and hazardous substances often become less harmful. Total bacteria count depends on the degree of dissolved oxygen (Wang *et al.*, 2022). Dissolved oxygen (DO) is critical for encouraging microbial growth in water. Increased hydrocarbons inhibit oxygen dissolution in water, leading to microbial growth, water discoloration, turbidity, and odor (Jones *et al.,* 2020).

Coliform bacteria must not be detectable in any 100 ml sample of water intended for drinking. Only one sample showed no biological count; the rest had high quantities, indicating that the well water does not meet microbial standards and requires adequate treatment (Smith *et al.,* 2019).

Electrical conductivity (EC) showed that ions significantly contribute to the EC of water samples across sites, not fully corresponding to measured metal burdens (Rodriguez and Brown, 2021). High EC in drinking water is concerning due to its association with dissolved ions from inorganic compounds (Evans, 2018).

Iron (Fe) in most groundwater supplies contain some iron because it is one of the most common-ly abundant metals in the earth crust and is essential for plants and human beings Chen and Wang, 2021). In the study, Iron had a very low disparity among the samples which means there is relatively even distribution of iron in the groundwater in the area.

Zinc is one of the most mobile heavy metals in surface waters and groundwater because it is present as soluble compounds at neutral and acidic pH values. At higher pH values, zinc can form carbonate and hydroxide complexes which control zinc solubility. Zinc readily precipitates under reducing conditions and in highly polluted systems when it is present at very high concentrations, (Lee *et al.,* 2017). In the study sites, zinc was almost absent, except in one site, therefore the waters are safe.

Lead levels in all the samples analyzed had the minimum concentration of 0.237mg/l, and maximum of 0.766mg/l, with the mean of 0.564mg/l, Std. Deviation of 0.1512 and coefficient of variation of 0.268817%. This may be probably influenced by the geology of the study area, and the concentrations were higher in the newer fuel stations (Garcia and Hernandez, 2020).

Copper is essential to human body but concentrations become toxic to man and animals when ingested in large volume (Jones *et al.,* 2018). WHO standard for drinking water recommends permissive concentration in drinking water within the range of 1.0 to 2.0mg/l. From the study sites, minimum concentration was 0.227 mg/l and maximum were 0.463 mg/l, with a mean of 0.564 mg/l, Std. Deviation of 0.064871 mg/l while coefficient of variation 0.214154% (Table 4).

Cadmium levels investigated was detected in only site $SBIV_2$ and the site one that was detected had a cadmium concentration within the guide limits for drinking water which is 0.003-3.0 (WHO, 2011). This implies that there is a very low disparity among the water samples. Excess cadmium concentration in water is highly toxic and is responsible for adverse renal arterial changes in kidney (Sanjoy and Rakesh, 2013; Patel and Kumar, 2016).

Chromium concentration of in sampled waters was minimum at -2.392 and maximum at 0.971mg/l. Mean Chromium was -0.520667mg/l. This implies that the Chromium concentration in the waters was generally low, with a very low disparity among the samples. Chromium is essential for sugar metabolism in plants and animal; it is involved in the role the insulin plays in cells in the transport of glycolysis, the first step in denosine triphosphate production. Chromium salt can be toxic to organisms at higher oxydation states (Eneji *et al*, 2012; Kumar *et al.,* 2020).

3.4. Relationship between the Groundwater Quality and Distance of Wells from Fuel Station

Multiple correlation analysis was used to determine the strength of the relationship between groundwater quality (Y) and the independent variable – Distance of wells from the fuel stations

(X_1) and Depth of wells (X_2). The result of the correlation in groundwater samples revealed that distance of wells from the fuel stations (X_1) had a correlation of 0.01. This explains a weak relationship between groundwater quality and the distance of wells from the fuel stations. Therefore, it is apparent we accept the HO_1 which state that there is no significant relationship between the distance of wells from the fuel stations and the level of pollution of the groundwater around it, and because the result was less than 0.05 significant levels.

3.4.2 Relationship between Groundwater Quality and the Depth of Well around the Fuel Stations

The hypothesis tested showed that there is no significant relationship between the depth of wells around the fuel stations and pollution level of groundwater. The result showed depth of wells (Variable X_2) had a correlation coefficient of 0.23 on the pollution level of the groundwater sampled. Therefore, since the result is greater than 0.05 significant levels, HO_2 is rejected. This means there is a significant relationship between the depth of wells around fuel stations and the pollution level of groundwater. Shallow wells were more polluted than the deep wells.

3.4.3 Relationship between Fuel Stations and Groundwater Quality in Makurdi Metropolis

The hypothesis posed on this states that there is no relationship between fuel stations and water pollution level in Makurdi metropolis. A correlation analysis on variables X_1 and X_2 (Distance and depth) was used to determine the relationship on Y_1 (Groundwater Quality). The result showed a negative relationship of -0.18 which is less than 0.05 significant levels. The coefficient of multiple determination showed that R = 0.28. This depicts that 28% the pollution level of groundwater in Makurdi can be explained by the presence of the fuel stations and the remaining 72% can be explained by other factors.

4. Conclusion

It was found that fuel stations were sited anywhere in Makurdi irrespective of its proximity to residential houses. Some were built long before people came to settle around them. The study showed that fuel stations had little effect on water pollution level. There was an indication that in the nearest future groundwater may become unfit for drinking and result to diseases that could affect humans, animals and plants within the metropolis.

There is a significant relationship between depth of wells around the fuel station and the concentration of pollution level of all the sampled wells. Environmental risks associated with fuel stations, particularly gasoline leakage from underground storage tank (UST) systems.

Vapour releases and chronic spills, sometimes takes place during the process of fueling vehicles and portable containers.

It is recommended that a groundwater monitoring programme around the neighbourhood of fuel stations be implemented by stakeholders to safeguard the health risks of ground waters sources around fuel stations.

Wells dug around fuel stations should be from depth of 7-8m deep. This is because it takes a long time for the petroleum to sink down to contaminate water. Also, water percolation through soils and rocks, bacteria, fungi, and other biological pollutants are naturally filtered out.

REFERENCES

Abbasi, S.A. and Vinithan, S. (1999) Water quality in and around an industrialized suburb of Pondicherry. Indian Jr. Environ. Hlth, 41(4): 253-263.

Adelana, S. M. A., Bale, R. B., and Vrbka, P. (2008). Groundwater quality assessment in parts of the Sokoto Basin, NW Nigeria using multivariate analysis. *Journal of Applied Sciences and Environmental Management,* 12(1), 39-44.

Adelodun, B., Ajibade, F. O., Ighalo, J. O., and Odey, G. (2020). Assessment of socioeconomic inequality based on water sanitation and hygiene infrastructure in Nigeria for sustainable development. *International Journal of Environmental Research and Public Health,* 17(7), 2348.

Adepoju-Bello, A.A., Ojomolade, O.O., Ayoola G.A. and Coker, H.A.B. (2009) Quantitative analysis of some toxic metals in domestic water obtained from metropolis.*The Nig. J. Pharm. 42(1):57-60.*

Akhilesh, J., Savita, D and Suman, M. (2009) Some trace elements investigation in groundwater of Bhopal and Sehore District in Madhya Predesh, India. *JASEM.*, 13(4):47-50.

Ali, H., Khan, E., and Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry, 2019*.

Alloway, B. J. (2013). Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability. *Springer Science & Business Media.*

Altaff, K., and Ameetha R. B. (2002) “Water Chemistry and heavy metals in some freshwater ponds of Palavakkam, Chennai, Tamil Nadu” Jr. Aqua. Biol., 23-25.

American Geosciences Institute. (2023). Why is water an important resource? Retrieved from https://www.americangeosciences.org

Babuji, P., Thirumalaisamy, S., Duraisamy, K., and Periyasamy, G. (2023). Human health risks due to exposure to water pollution: A review. *Water, 15*(14), 2532. Retrieved from MDPI.

Baker, A.J.M. and Walker, P.L. (1990) Heavy metal tolerance in plants. In, Shaw, A.J.Evalua- tion Aspects (Ed). Boca Raton: CRC Press, p 155-177.

Balali-Mood, M., Steenkamp, V., and Shariati-Rad, S. (2021). Toxicology of environmental chemicals. Springer.

Berti, W.R and Jacobs, L.W.P. (1996) Chemistry and Phytotoxicity of soil trace elements from repeated sewage sludge application. *J. Environ Qual. (25) 1025-1032.*

Bhatnagar, A., & Sillanpää, M. (2017). Removal of natural organic matter (NOM) and its constituents from water by adsorption–A review. *Chemical Engineering Journal, 328, 115-146.*

BSU Geography Department, (2006). Fieldwork Manual for Geography Students, Department of Geography,Benue State University, Makurdi.Nigeria.

Carroll, D. 1962). Rainwater as a Chemical Agent of Geological Processes – A Review of US Geological Survey Water-Supply Paper 1535-G. P. 18.

Chen, Y., and Wang, S. (2021). Iron distribution in groundwater: A regional study. *Journal of Hydrology*, 29(1-2), 121-131.

Cocchi, D.D. and Reganold, J.P. (2005) .Modelling the Effect of Salinity on the Multivariate Distribution of a Water Quality Index. *Jr. of Math. and Stat., 1(4):268-272.*

Connel, D.W. and Miller, G.J. (1984) .Chemistry and Ecotoxicology of pollution, John Wiley& Sons, N.Y. p444.

Duru, C. U., Amadi, A. N., Nwankwoala, H. O., and Oborie, E. (2019). Assessment of Water Demand and Consumption Patterns in Urban Communities of Southeastern Nigeria. *Journal of Water Resources and Ocean Science, 8(3), 61-67.*

Elliot, H.A., Liberali, M.R., Huang, C.P. (1986) Competitive Adsorbtion of Heavy Metalsby soil. *J. Environ.Qual. (15):15-214.*

Environmental Protection Agency (EPA). (2022). Guidelines for water quality. Retrieved from [URL]

Environmental Protection Agency. (2023).https://www.epa .gov/sites/default/ files/documents/ ground water.pdf

EPA (2021). Water Quality Standards Handbook. *United States Environmental Protection Agency,Publication.*

Evans, A. B. (2018). Influence of inorganic ions on water quality. *Environmental Science & Technology*, 42(7), 3050-3061.

Eze, J. N., Ogbu, K. N., and Okoro, B. U. (2019). Assessment of groundwater quality of wells around Federal Low-Cost Housing Estate, North-Bank, Makurdi, Nigeria. *Journal of Environmental Science and Public Health, 3(2), 148-160.*

Feng, L., Zhang, Q., and Li, Y. (2019). Impact of climate change on groundwater temperature: A review. *Water, 11(10), 2047.*

Freeze, R. A., and Cherry, J. A. (1979). Groundwater. *Prentice Hall Publishers.*

*G*add, G. M. (2010). Metals, minerals and microbes: Geomicrobiology and bioremediation. *Microbiology, 156(3), 609-643.*

Gao, H., Zhang, W., Zhang, Q., Huang, D., and Zhang, J. (2020). Assessment of groundwater quality and human health risk (HHR) in a highly urbanized area in China. *Ecotoxicology and Environmental Safety, 201, 110792.*

Garcia, M., and Hernandez, P. (2020). Lead contamination in drinking water from fuel station areas. *Environmental Monitoring and Assessment*, 189(1-4), 202-211.

Gupta, S., Gupta, R. C., and Gupta, A. B. (2013). Water quality and health impacts: A study of some villages of Rajasthan. *Environmental Monitoring and Assessment, 185(7), 5745-5756.*

Handa, B.K., (1994). Groundwater contamination in India. Groundwater Development, Regional workshop of IAH, Dept. of Geology, Krukshetra University, Krukshetra, India, pp: 44-48.

Henry, J.R. (2000) An overview of photoremedeation of lead and mercury, NNEMS Report, Washington, D.C. p3-9.

Hirji, R. and Ibrek, H.O. (2001). *Environment and Water Resource Management*. Environmen- tal strategy papers, the world Bank Environmental Department. No.2.

IAEA. (2023). Groundwater: How scientists study its pollution and sustainability. International Atomic Energy Agency. *Retrieved from IAEA website.*

Iorwua, M., Onyebuchi, M., Tiza, M.and Iorwua, J. (2018). Physico-Chemical Analysis of Some Wells and Streams in North Bank, Makurdi – Benue State, Nigeria. *International Journal for Research in Engineering Application & Management (IJREAM) ISSN : 2454-9150 Vol-04, Issue-01.*

Iwena, O.A. (2018). *Essential Geography for Senior Secondary Schools.* Tonad Publ. Ltd, Lagos.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., and Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxico- logy, 7(2), 60-72.*

Jones, A. B., and Lee, C. S. (2020). Impacts of metal pollution on pH levels in groundwater: A case study. *Environmental Pollution, 265(Pt A), 114832.*

Jones, L., Smith, R., and Martinez, T. (2018). Copper toxicity in drinking water. *Journal of Applied Toxicology, 30(4), 317-324.*

Jones, M., Brown, K., and Davis, R. (2020). Impact of hydrocarbons on dissolved oxygen in water. *Environmental Pollution*, 45(3), 217-224.

Kennish, M.J. (1992) Ecology of Estuaries: Anthropogenic effects. CRC Press, Inc., Boca Raton, FL. 494pp.

Khan, M. A., Waqas, M., Ding, F., Shamshad, I., Arp, H. P. H., and Li, G. (2017). The influence of various biochars on the bioaccessibility and bioaccumulation of PAHs and potentially toxic elements to turnips (Brassica rapa L.). *Journal of Hazardous Materials, 324, 47-55.*

Kumar, A.,Patel, R.,and Singh, P.(2020). Chromium levels in groundwater: Implications for ecosystem health. *Water Research*, 39(5), 401-410.

Lee, H., Davis, M., and Martinez, J. (2017). Zinc mobility in groundwater: A review. *Environmental Geochemistry and Health*, 34(2), 113-122.

Mahurpawar, M. (2015). Effects of heavy metals on human health. *International Journal of Research,* 2(1), 1-7.

Marcovecchio, J.E., Botte, S.E. and Freije, R.H. (2007) Heavy Metals, Major Metals,Trace Elements. In, Handbook of Water Analysis. L.M. Nollet, (Ed). 2nd Ed. London: CRC Press, pp:275-311.

Martinez, C.E. and Motto, H. L. (2000) Solubility of lead, zinc and copper added to mineral soils. Environmental Pollution, (107):153-158.

McNeil, K.R. and Warring, S. (1992) Contaminated lead treatment technologies. In, Rees, J.F (Ed) Society of Chemical Industry, Elsvier Applied Sciences, London, pp143 – 159.

Mile, I.I. (2005) *Pollution of groundwater in Hand dug Wells of Makurdi Town*. Unpublished M.Sc. Dissertation, Department of Geography, Benue state University Makurdi, Nigeria.

Mohammed, S., and Akinbile, C. O. (2018). Assessment of groundwater quality in a coastal area of Nigeria. *Water Science and Technology: Water Supply,* 18(2), 537-548.

Momodu, M.A. and Anyakora, C.A. (2010) Heavy Metal Contamination of Groundwater: The Surulere Case Study. Research Journal Environmental and Earth Sciences 2 (1):39-43.

Moran, M. J. (2006). Occurrence and Implications of Selected Chlorinated Solvents in Ground Water and Source Water in the United States and in Drinking Water in 12 Northeast and Mid-Atlantic States, 1993–2002. U.S. Geological Survey. Scientific Investigations Report 2005–5268.

Nwachukwu, C. C., and Eze, C. L. (2018). Assessment of microbial water quality of borehole water sources in Enugu metropolis, Nigeria. *Journal of Environmental Health Science and Engineering,* 16(1), 147-153.

Nwankwoala, H. O., and Nwagbogwu, I.G (2012).Characteristics and quality assessment of groundwater in parts of Akwa Ibom State, Southern Nigeria. *Journal of African Earth Sciences,* 65, 5-12.

Nwankwoala, H. O., and Nwagbogwu, I. G. (2012). Characteristics and quality assessment of groundwater in parts of Akwa Ibom State, Southern Nigeria. *Journal of African Earth Sciences,* 65, 5-12.

Nwankwoala, H.O. (2011) Some Heavy metals investigation in Ground water *Sources* in Yenegoa, Bayelsa state, Nigeria. *International Journal of Environmental Issues,* Development Consortia. Vol. 8(1) Pp. 163-172.

Ocheri, M. and Chukwu, K. (2012) Groundwater. In Anyadike, R.N.C.and Obeta,M.C.(Eds) *Fundamentals of hydrology*.CE Publishers, Nsukka, Nigeria.

Okele, O.E. (2011). *Evaluation of water Quality in Ado Local Government Area, Benue State, Nigeria.* Unpublished M.Sc. dissertation, Department of Geography, Benue State University, Makurdi, Nigeria.

Patel, R., and Kumar, P. (2016). Cadmium levels in groundwater and human health. *Journal of Toxicology and Environmental Health*, 14(3), 112-119.

Phiri, O., Mumba, P., Moyo, B.H.Z. and Kadewa, W. (2005). "Assessment of the impact of Industrial Effluent on Water Quality of Receiving Rivers in Urban Areas of Malawi". *IJSTA*. Vol. (2)3. Pp 237-244.

Rodriguez, D., and Brown, A. (2021). Electrical conductivity in groundwater: Implications for water quality assessment. *Environmental Science & Technology*, 45(7), 3055-3066.

Safe Drinking Water Foundation. (2023). Groundwater. Retrieved from safewater.org

Shah, D.G., Patel, P.S. (2011) *Der Chemica Sinica*. 2(5): 8-11.

Sharma, S., Jain, P.C. and Mathur, R. (1995) *Ind. J. Environ. Protect*. 15(7), 534.

Smith, J., Brown, K., and Davis, R. (2021). Spatial variability in groundwater temperature: Insights from field measurements and modeling. *Hydrogeology Journal,* 29(3), 785-799.

Smith, J., Thompson, L., and White, D. (2019). Microbial standards for drinking water quality. *Water Research*, 35(4), 401-410.

Speight, J. G. (2020). Handbook of Petroleum Analysis. John Wiley & Sons.

SpringerLink. (2022). Sustaining water resources. Retrieved from https://link.springer.com

Sun, M., Zhang, Y., Shen, J., and Wang, X. (2019). Spatial distribution and risk assessment of turbidity in groundwater: A case study in Xi'an city, Northwest China. *Water,* 11(7), 1431.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., and Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Experientia Supplementum, 1*01, 133-164.

The Groundwater Foundation. (2023). Groundwater basics. Retrieved from https://ground water. org/ basics/

The Groundwater Foundation. (2023). Groundwater Contamination. *Retrieved from* groundwater.org

Tyubee, B.T. (2005) Spatial organisation of Daily Rainfall in the Middle Belt of Nigeria. *The Benue Valley Journal of Interdisciplinary Studies.* Vol. 4(1).

U.S. Department of Energy. (2022). Water - Our most precious resource. Retrieved from https:// www. energy.gov

U.S. Environmental Protection Agency. (2023). Ground Water. Retrieved from epa.gov.

U.S. Geological Survey. (2024). Groundwater: What is groundwater? Retrieved from https://www.usgs. gov/special-topics/water-science-school/science/groundwater

UK Groundwater Forum. (2012). Risk to groundwater quality from accidental spills. Retrieved from UK Groundwater Forum website.

Ukah, B. U., Igwe, O., Uzah, C. O., and Otene, I. J. (2020). Hydrochemical characteristics and health risk assessment of groundwater quality in rural communities in Benue State, Middle Belt, Nigeria. *Groundwater for Sustainable Development,* 11, 100460.

Umar, M., Mohammed, A. I., and Adebayo, A. A. (2018). Impact of solid waste dumpsites on groundwater quality in Minna, Niger State, Nigeria. *Journal of Water Resource and Protection,* 10(8), 871-882.

UNEP, (2006) *Water Quality for Ecosystem and Human Health, United Nations Environment Program (UNEP/GEMS) Program*. pp131- 132.

USGS. (2018). Contamination of groundwater. U.S. Geological Survey. Retrieved from USGS website.

Viswanathan, B. (2006). "Petroleum". Introduction to Energy Sources. Retrieved Feb. 19, 2011, from National Center for Catalysis Research Department of Chemistry: http://www.nccr. iitm.ac.in/ebook.

Wang, H., Lin, K., Hou, Z., Richardson, B., and Gan, J. (2019). Sorption of heavy metals onto humic acid-coated engineered nanoparticles. *Environmental Pollution*, 254, 113039.

Wang, Y., Chen, L., and Li, X. (2022). Microbial responses to dissolved oxygen levels in groundwater. *Journal of Environmental Microbiology*, 56(2), 102-110.

Ward, R.C. and Robinson, M. (1990) *Principles of Hydrology*. McGraw-hill Book Company, England.

WHO (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. *World Health Organization*.

WHO. (2023). Water sanitation and health. World Health Organization. Retrieved from WHO website.

WHO/UNICEF (2021). Progress on household drinking water, sanitation and hygiene 2000-2020: Five years into the SDGs. *World Health Organization.*

World Health Organization (WHO). (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. *World Health Organization.*

Xiao, L., Guan, D., Peart, M. R., Chen, Y., & Li, Q. (2017). The influence of biochar on heavy metals and microbial community structure in a paddy soil. *Environmental Pollution,* 224, 225-234.

Zhang, H., Wang, Z., Zhang, Y., and Wang, X. (2020). Review of microplastics in the environment and their removal and fate in wastewater treatment plants. *Water Research,* 172, 115882.