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Assessment of Physicochemical Parameters of Groundwater in Federal Government College, Odi, Bayelsa State, Nigeria: A Comprehensive Study on Water Quality, Associated Risks, and Sustainable Management Strategies

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***Abstract:** Ground water is a very important source of water in the world and this fact is more pronounced in the Niger Delta region in Nigeria. In this case, the keys to this situation have been a wide-scale contamination of surface water due to widespread oil exploration drilling, point source of industrial effluents and poor disposable waste management procedures which have largely made most of the surface water sources unreliable and unsafe to consume. This is, in turn, causing some rural and semi-urban centers and even giant institutional settlements to rely more and more on groundwater as a source of daily water supply. To maintain the health of the people and avoid water-borne diseases, good quality of this indispensable resource is of paramount importance. The current paper carefully details physicochemical profiles of groundwater under the premises of Federal Government College, Odi, which is in Bayelsa State, Nigeria. Seven water samples were collected in systematic manner using different boreholes that are in use in the institution. Using these samples a full set of important parameters were determined: pH, turbidity, elections conductivity, salinity, total dissolved solids (TDS), biochemical oxygen demand (BOD), dissolved oxygen (DO) and concentration of major ions such as sodium (Na +), calcium (Ca 2+), chloride (Cl -) and iron (Fe). The results of the analytical procedures were further critically compared to the suggested advisory on drinking-water quality by the World Health Organization (2019). The result showed that although the majority of the evaluated parameters were within the WHO acceptable levels, some severe deviations were determined. The groundwater samples had pH values between 6.65 and 6.79 and this is slightly acidic. The levels of turbidity were always higher than the WHO guideline of 5 NTU with an 8.46-18.2 NTU range. It was found that sodium levels were slightly higher in certain samples to as high as 29.34 mg/L, an exceedance of the WHO defined limit of 20 mg/L. Additionally, there was an elevated degree of organic pollution indicated by samples with BOD levels of 9.5 mg/L, surpassing the World Health Organization's standard of 4 mg/L. Plumbing systems are rusting, which increases the likelihood of microbes in the water and poses the risk of saltwater seeping into the aquifer, among other hazards. These variations highlight the potential risks associated with plumbing systems. Adjusting the pH level, establishing effective filtration systems, beginning monitoring programs, and tightening control over sources of organic contaminants are some of the ways that the study recommends to prevent this*

from happening, based on these results. This study is significant because it provides a foundational point for Odi and helpful data for managing groundwater in the Niger Delta, another region that is presently facing comparable challenges.

Keywords: Groundwater, Physicochemical Parameters, Niger Delta, Water Quality, WHO Standards, Water Quality Index, Odi, Bayelsa State.

Introduction

There is a strong link between access to potable water, environmental health, socioeconomic development, and the health of the community. It has become very important to have groundwater in the Niger Delta region of Nigeria. It is the main or only source of water for domestic, agricultural, and industrial uses, all of which have been hurt by surface water sources. The Niger Delta is a place with a lot of hydrocarbon reserves. Luckily, the environment hasn't been badly damaged by decades of oil exploration, production, and other activities related to these. Surface water bodies have become very polluted because of these activities, frequent oil spills, and inadequate waste disposal systems. This makes the water toxic to aquatic life and bad for human health. Because the quality of surface water is getting worse faster, groundwater has been labeled as a critical resource. So, figuring out how to manage groundwater in the long term and evaluating its quality have become very important tasks. It is especially hard to find groundwater in rural and semi-urban areas, as well as in places that aren't always connected to a centrally treated water supply system. Because of this, these companies have to rely a lot on wells and boreholes that have to be dug by hand. Nevertheless, even groundwater is not Holy Graal. Many natural geochemical and human activities, such as agricultural runoff, saturation of polluted water population, septic tank effluents, and industrial effluents may have impacts on it. Thus, to assess the relevance of groundwater to its intended purposes, to determine possible risks to human health, and to develop appropriate protection and remedial measures, it is necessary to have a comprehensive knowledge of what groundwater can and will do according to its physicochemical characteristics.

Due to the increased awareness of groundwater in Nigeria, the groundwater quality has been a topic of several studies over the years. Indicatively, Amajor (1986) presented some of the initial geochemical examination of the groundwater in Port Harcourt, along with the affect of local geology and the potential the anthropogenic effects. Later, Udom, Esu, and Etu-Efeotor (1998) performed a hydrochemical assessment of the groundwater in sections of Port Harcourt and Tai-Eleme Local Government Areas, which further informed the knowledge on the differences in the water quality in the Niger Delta. In their examination of groundwater status in Nigeria, Edet, Nganje, Ukpong, and Ekwere (2011) were interested in a comprehensive review of status and the total chemistry and quality of groundwater in Nigeria synthesized existing data to draw conclusions about the identification of regional trends and common groundwater contamination problems, which include salinity intrusion, trace metal contamination, and organic pollution. Even more recent research has remained based on the same. The authors Nwankwoala, Amadi, Oborie, and Ushie (2014) did their work in Bayelsa State, the capital of which is Yenagoa, carrying out hydrochemical factor and correlation studies to know the controlling mechanisms of the chemistry of groundwater in this city. Oki and Akana (2016) have also examined the quality of ground water in Yenogoa, which provides further data on the physicochemical properties of ground water and drinking capacity. In a study by Oyinkuro and Rowland (2018) in ground water in the Ogbia Local Government Area, Bayelsa State, the both-in-one tool like Water Quality Index (WQI) and Geographic Information Systems (GIS) was used in evaluating the spatial quality of ground water that further supported the application of the same tool in the management of water resources. The quality of groundwater measured by the GIS-based WQI has also been researched beyond the Nigerian region, such as Aragaw and Gnanachandrasamy (2021) in urban Ethiopia, presenting the universality and applicability of such avenues of evaluation. In addition, Ovuru, Ayibawari, and EGA (2021) examined contamination of heavy metals in the Niger Delta, and in some areas of the groundwater, which highlighted the individual dangers that such pollutants have. These joint studies have continued to mention factors like high turbidity, acidity, ion concentration variability, salinity encroachment, and organic as well as inorganic pollution in the groundwater systems of the Niger Delta.

Though a lot of research has already been conducted regarding the quality of groundwater in the Niger Delta and Bayelsa State to be precise, there is a critical knowledge gap in regards to the particular site of Federal government College, Odi. It is a large, dense settlement with a high student and staff population relying upon groundwater, which is the primary source of water. No comprehensive physicochemical characterisation of groundwater quality of this institution has then far been done. This oversight of lack of site-specific data is critical; as it is the quality of the water that such large an entity consumes and thus, directly, its subsequent impact over the lives and well-being of the populace and the integrity with which the water distribution system of the institution in question operates. Hence, the current research will fill this void by conducting a highly detailed evaluation of the physicochemical characteristics of ground water supply at Federal Government College, Odi. The objectives of this study are as follows: (1) To assess the essential physicochemical characteristics of groundwater in the study area, such as pH, turbidity, conductivity, salinity, TDS, BOD, DO, and major ions (Na +, Ca2+, Fe, and Cl.). (2) To tie the analytical findings with the recommendations of the World Health Organization (2019) on drinking-water quality to notice whether it complies and to define the cases of deviation. (3) To determine possible infrastructural and health risks posed by the use and consumption of the ground water regarding the physicochemical properties. (4) To offer management recommendations that are science based to assist in realizing safe and sustainable usage of water in the institution and possibly to similar communities in the area. Through these purposes, the research is set to offer credible ground information and findings, which it suffices towards informed decisions, on the management of water resources in the Federal Government College, Odi, and contribute to a comparative framework of information on other settlements in the Niger Delta.

Study Area

The focus of this investigation is Federal Government College, situated in the town of Odi, within the Kolokuma/Opokuma Local Government Area of Bayelsa State, Nigeria. Geographically, Odi lies between latitudes 4°20′ N and 5°00′ N, and longitudes 5°40′ E and 6°00′ E, positioning it within the central Niger Delta Basin. The Niger Delta is a vast sedimentary basin formed by the accumulation of tertiary and quaternary deposits from the Niger River and its tributaries, characterized by a intricate network of rivers, creeks, and distributaries that empty into the Atlantic Ocean. The topography of Odi, typical of much of the central Niger Delta, is predominantly flat and low-lying, with elevations generally ranging from sea level to just a few meters above. This low relief coupled with high annual rainfall leads to poor natural drainage, and swampy conditions more so in the wet season. In contrast to the freshwater swamp forests found in the country's interior, mangroves thrive in coastal regions with high salt content. In nature, swamp forests play a significant role. Because of their sensitivity, these ecosystems are particularly vulnerable to changes in their surrounding environment. For the region's economy and ecology, they are also crucial.

Odi experiences heavy precipitation and consistently warm weather due to its humid tropical climate. The rainy season begins in April and continues through October, while the dry season begins in November and continues through March. The annual rainfall in this region of the Niger Delta is over 2500 millimeters, which is exceptionally high. Because it replenishes underground water sources, heavy precipitation plays a significant role in the hydrological cycle. But it complicates waste management and raises the prospect that pollutants may enter the water supply. The temperature ranges from 25 to 32 degrees Celsius, and the humidity remains consistently high throughout the year. This weather pattern, along with other geochemical and biological processes, can alter the amount of water required, which in turn can affect the water's potability.

The quantity and quality of groundwater in an area are greatly affected by its underlying geology. The subsurface of the Niger Delta Basin is composed of three main tertiary lithostratigraphic units, which from deepest to shallowest are the Akata Formation, the Agbada Formation, and the Benin Formation, overlain by varying thicknesses of quaternary deposits. The Benin Formation, also known as the Coastal Plain Sands, is the uppermost and most extensive of these units and constitutes the principal aquifer system in the region, including around Odi. This formation consists predominantly of coarse-grained sands and gravels, with intermittent intercalations of clay and shale. These sandy layers provide high permeability and porosity, making them excellent water-bearing units. The clayey intercalations, however, can create semi-confining layers, leading to a multi-aquifer system. In the Odi area, the Benin Formation sustains shallow unconfined aquifers that are extensively tapped for domestic water supply through boreholes, often at depths ranging from 20 to 40 meters below the ground surface. The unconfined nature of these shallow aquifers makes them particularly vulnerable to contamination from surface-derived pollutants, as there is no continuous impermeable layer to protect them. The specific sampling locations for this study within the Federal Government College, Odi, are illustrated in Figure 1.

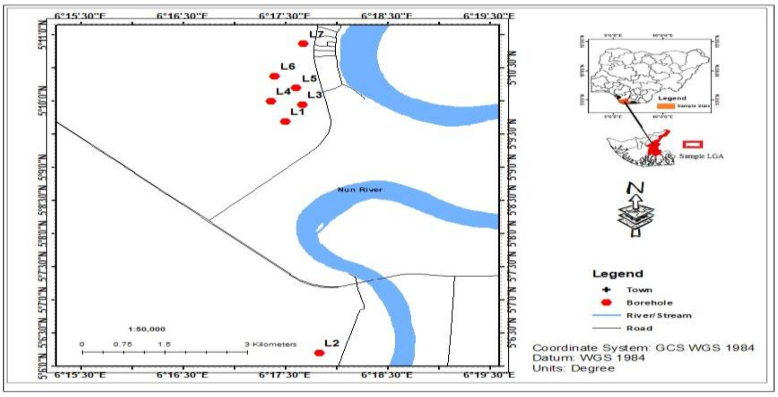

Figure 1: Sample Location Map in Federal Government College, Odi, Bayelsa State, Nigeria

Materials and Methods

The integrity and reliability of any water quality assessment hinge critically upon the meticulousness of the sampling procedures, the accuracy of analytical methodologies, and the rigor of data analysis. Some of the protocols that will be used in the current study to collect representative ground water samples, accurately analyze these samples to acquire a set of representative physicochemical parameters and subsequently analyze and interpret the derived data according to recognized standards are described in this section.

Sampling and Sample Preservation

Seven ground water samples were taken at well stated boreholes (BH1- BH7) spread within the Federation Government College covering odi. These boreholes form the major points of water supply to the different parts of the institution such as the student hostels, staff quarters and administrative blocks. The sampling established would take a representative sample of the ground water quality of the institution premises. All the sampling equipment and tools such as 0.5 L high-density polyethylene (HDPE) bottles were washed in advance to avoid cross-contamination. The sampled water was the ground water and the bottling procedures were performed through triple rinsing. To determine cation (Na +, Ca2 +, Fe) values in the water, a pocket of water was acidified in situ with a concentrated solution of nitric acid (HNO3) to a pH of less than 2. This acidification prevents the adsorption of metal ions onto the container walls and minimizes precipitation, ensuring the stability of the metals during transport and storage. Samples intended for Biochemical Oxygen Demand (BOD) analysis were collected in sterile, dark glass bottles to minimize photosynthetic activity and were kept at a temperature of approximately 4°C in ice-packed coolers during transportation to the laboratory. This preservation inhibits microbial action that could alter the BOD values before analysis. For other physicochemical parameters such as anions and general physico-chemical properties, samples were collected in clean HDPE bottles without acidification but were also transported to the laboratory in coolers and stored at 4°C until analysis. All samples were delivered to the laboratory within 12 hours of collection. The precise location of each sampling point was recorded using a handheld Global Positioning System (GPS) device.

Field Measurements

Several key physicochemical parameters were measured directly in the field at the time of sampling to obtain immediate, on-site readings that reflect the ambient conditions of the groundwater. These in-situ measurements are crucial as some parameters, notably pH, temperature, and dissolved oxygen, can change rapidly once a sample is removed from its source due to changes in temperature, pressure, and atmospheric exposure.

- **pH:** The pH of each water sample was measured using a calibrated, portable pH meter. pH is a critical parameter as it influences the solubility and speciation of various chemical constituents, the corrosiveness of water, and the efficacy of disinfection processes.
- **Temperature:** Water temperature was recorded using a calibrated digital thermometer. Temperature affects the rate of chemical reactions, dissolved oxygen content, biological activity, and the taste of water.
- **Turbidity:** Turbidity, a measure of water's cloudiness caused by suspended particles, was determined in the field using a portable turbidimeter. Turbidity is unsightly, makes disinfection more difficult, and may indicate the presence of pathogens.
- **Salinity:** Using a conventional salinity meter, the field salinity was found to be proportional to the conductivity. There is a pressing need for macuna farming in coastal areas where residents, like those in the Niger Delta, face the prospect of saltwater eventually inundating their land.

Laboratory Analysis

Several tests were conducted on lab-made samples of clean water during that time. The operational themes utilized to design water quality tests were derived from the regulations outlined in the 23rd edition of the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WEF, 2017). To guarantee that exams are administered consistently, accurately, and in a comparable manner, internationally acknowledged protocols will be utilized.

- **Total Dissolved Solids (TDS):** In order to get TDS, we evaporate the substance. As part of the measurement procedure, a portion of the filtered sample was selected. We next measured the sample's dry weight after allowing it to dry at a constant room temperature until it was completely weightless. It is the sum total of inorganic and organic material that is dissolved in the water.
- **Major Cations (Na^+, Ca^{2+}, Fe):** Atomic Absorption Spectrophotometry (AAS) was used to measure the concentrations of sodium (Na+), calcium (Ca2 +), and Iron (Fe). The method is very sensitive and specific to analyzing metals and can be readily performed to determine low concentration. Proper quality control such as the preparation of calibration standards using certified stock solution as well as analysis of method blanks was adopted so as to verify the reliability of the AAS results.
- **Chloride (Cl^-):** The concentration of the chloride was established through the Argentometric titration procedure (Mohr procedure) through titration of the specimen with a standard solution of Silver nitrate in the presence of potassium chromate as an indicator.
- **Biochemical Oxygen Demand (BOD):** Dilution method was used to determine BOD5 (the number of grams of oxygen that the microorganisms need in order to decompose organic matter in a period of 5 days) at 20degC. Winkler titration method or a calibrated DO meter was used as the means of measuring dissolved oxygen (DO) levels at the beginning and after incubating the system 5 days in the dark at the temperature of 20degC. BOD is calculated by the difference in DO levels between the 5 days period.
- **Dissolved Oxygen (DO):** As mentioned, DO was measured using the Winkler titration method, a highly accurate and reliable wet chemical technique, or a calibrated portable DO meter. DO is a vital parameter for assessing water quality, as it is essential for aquatic life and indicates the oxidative state of the water.

Quality Control/Quality Assurance (QA/QC)

Stringent QA/QC measures were integrated into all stages of the sampling and analytical process to guarantee the validity and reliability of the data. These measures included:

- **Calibration of Instruments:** All field meters (pH, conductivity, turbidity, salinity) and laboratory instruments (AAS, balances) were calibrated according to manufacturer's specifications before each use and at regular intervals during analytical batches using certified standard solutions.
- **Analytical Blanks:** Method blanks were analyzed regularly to check for any contamination from reagents or laboratory ware. A blank consists of deionized water taken through the entire analytical procedure.
- **Duplicate Analyses:** A percentage of samples (typically 10%) were analyzed in duplicate to assess the precision of the analytical methods. The relative percent difference (RPD) between duplicate results was calculated and was required to be within acceptable limits (generally <10%).
- **Certified Reference Materials (CRMs):** CRMs were compared where they exist to check the correctness of the process of the analytics. The resulting values were also compared to the certified values to check whether their values fell within the indicated uncertainties.
- **Standard Addition Method:** In complex matrix or in case of suspected matrix interferences, AAS was used to analyse differently because the measurement can be done accurately.

Data Analysis

The laboratory generated analytical data were statistically processed and analyzed. To summarize the data, descriptive statistics, such as standard deviation, mathematical range, and mean of each physicochemical parameter were calculated. The parameters obtained were compared with the drinking-water quality guideline values that were provided by the World Health Organization (WHO, 2019). Using this analogy, it became possible to see what parameters were going over the acceptable limit and even to tell the overall suitability of the whole ground water, as concerns consumption. Also, calculating a Water Quality Index (WQI), providing one, general, indication of the overall water quality scenario was done. It is a powerful effective tool of presenting vastly complicated water quality information in a recognizable form that an easy decision can be made by water resource managers and the population. The description of the specific calculational procedure (weighted arithmetic index) of WQI and the variables on which it is based when calculating it will be stipulated in the Results and Discussion section. The Pearson correlation analysis was also used to establish the level of significance of intersecting parameters of water quality that will provide indications on possible common sources or the commonly used geochemical processes that affect the chemistry of ground water.

Results and Discussion

The general analysis of the samples of the available Federal Government College groundwater located on the location of seven boreholes in a city of Odi, Bayelsa State presented a somewhat polyplankic perspective of water quality both at the same time in a combination of several parameters within reasonable ranges and in a multitude of serious disagreements with World Health Organization (WHO, 2019) requirements. Reduced in this part are the exact results and findings, how they interpreted the results presented, culminating on a summary of their implications to water use and water management in the institution. These results are properly tabulated to give the general physicochemical profile then the discussion on the Water Quality Index, the relations between the parameters and then the conclusion with comparison of those studies in the region.

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Physicochemical Parameters

In Table 1, range, mean values and WHO permitted limits in the physicochemical parameters of the samples of the Federal Government College, Odi groundwater are shown. The comparison perspective shown in this table is quite clear and by a mere look at it one is able to talk about the parameters that do or do not fall within the recommended range of potable water.

Table 1: Physicochemical Parameters of Groundwater in Federal Government College, Odi, Compared with WHO (2019) Standards

Parameter	Range (Mean)	WHO (2019) Standard	Remarks
pH	6.65 – 6.79 (6.72)	6.8 – 8.5	All samples exhibited a pH slightly below the WHO lower limit, indicating mild acidity. This can lead to a metallic taste and increase the corrosive potential of the water, potentially damaging plumbing and leaching metals.
Temperature (°C)	28.0 – 33.0 (30.5)	No guideline*	Temperatures are typical for tropical groundwater and are within a range that does not pose direct health concerns, though higher temperatures can affect taste and promote microbial growth.
Turbidity (NTU)	8.46 – 18.2 (13.33)	≤ 5	Turbidity levels in all samples significantly exceeded the WHO guideline. High turbidity indicates the presence of suspended particles, which can harbor pathogens, interfere with disinfection, and affect aesthetics.
Salinity (ppm)	38 – 625 (331.5)	No guideline*	Salinity showed considerable variation. While no direct WHO guideline exists for salinity in drinking water, high levels can affect taste and indicate saltwater intrusion, a concern in coastal aquifers.
Total Dissolved Solids (TDS) (mg/L)	38 – 102 (70)	≤ 1000	TDS levels were well below the WHO guideline, indicating generally low mineralization of the groundwater, which is often desirable for taste and palatability.
Biochemical Oxygen Demand (BOD) (mg/L)	3.0 – 9.5 (6.25)	≤ 4**	BOD values exceeded the WHO guideline in several samples, indicating the presence of biodegradable organic matter. This suggests potential contamination from sources like sewage or septic systems, and can lead to oxygen depletion.
Dissolved Oxygen (DO) (mg/L)	7.5 – 11.0 (9.25)	No guideline*	DO levels were generally good, indicating well-aerated water, which is positive for aerobic aquatic life and can help oxidize certain contaminants.
Sodium (Na^+) (mg/L)	19.32 – 29.34 (24.33)	≤ 20	Sodium levels were slightly above the WHO guideline in some samples. While not typically a health concern for the general population at these levels, it can be an issue for individuals on sodium-restricted diets and affects taste.
Calcium (Ca^{2+}) (mg/L)	20 – 45.2 (32.6)	No guideline*	Calcium concentrations were within expected ranges for groundwater and contribute to water hardness. No health-based guideline exists, though very high levels can cause scaling.
Iron (Fe) (mg/L)	0.065 – 0.23 (0.1475)	≤ 0.3	Iron levels were well below the WHO guideline in all samples, which is positive as high iron can cause staining of laundry and plumbing, and impart a metallic taste.
Copper (Cu) (mg/L)	0.00 (0.00)	≤ 2.0	Copper was not detected in any of the samples, indicating no contamination from copper pipes or fittings at the time of sampling.

*While WHO does not establish specific health-based guideline values for temperature, conductivity, salinity, TDS (though a palatability guideline of <1000 mg/L exists), DO, and calcium, their measurement is important for overall water quality assessment, aesthetic considerations, and understanding geochemical processes. **The WHO guideline for BOD is not explicitly stated as a single value for drinking water in the same way as, for example, nitrate. However, a BOD below 4-5 mg/L is often considered an indicator of acceptable organic load for source water, and higher values suggest pollution. The comparison here uses 4 mg/L as a conservative threshold indicative of potential organic pollution issues.

The key findings from the physicochemical analysis warrant detailed discussion: The **pH** values, consistently slightly acidic (ranging from 6.65 to 6.79), fall marginally below the WHO recommended range of 6.8 to 8.5. While this degree of acidity is mild, it is not without consequence. Acidic water can have a corrosive effect on metal pipes and plumbing fixtures, potentially leading to the leaching of metals such as lead, copper, and iron into the water supply, which can pose health risks and cause staining or taste issues. Furthermore, low pH can affect the efficiency of chlorination, a common disinfection method, requiring higher chlorine doses to achieve effective pathogen control. The slightly acidic nature of the groundwater in Odi could be attributed to the dissolution of carbon dioxide from the atmosphere or soil zone, forming carbonic acid, or the oxidation of sulfide minerals if present in the aquifer matrix. Similar findings of near-acidic pH have been reported in other parts of the Niger Delta, such as in Yenagoa and Port Harcourt, where shallow aquifers are susceptible to such geochemical influences.

Turbidity levels were a significant concern, with all seven samples exhibiting values (8.46 to 18.2 NTU) well above the WHO guideline of 5 NTU. High turbidity is primarily caused by the presence of suspended particulate matter such as clay, silt, organic matter, algae, and microorganisms. This not only makes the water aesthetically unappealing but, more importantly, can interfere with disinfection processes by shielding pathogens from chemical disinfectants like chlorine. Suspended particles can also provide attachment sites for bacteria, potentially leading to microbial regrowth in distribution systems. The elevated turbidity in Odi's groundwater could be attributed to the nature of the shallow Benin Formation aquifer, which can yield water with fine particulates, especially if boreholes are not properly constructed or maintained, or if there is ingress of surface water during heavy rainfall events due to poor wellhead protection. The findings align with studies in Yenagoa and Port Harcourt, where shallow aquifers were also reported to have high turbidity due to particulate contamination.

Total Dissolved Solids (TDS) values, ranging from 38 to 102 mg/L, were considerably lower than the WHO guideline of 1000 mg/L. TDS represents the total concentration of inorganic salts and small amounts of organic matter dissolved in water. Low TDS water is generally considered to have good palatability. However, very low TDS water might also be considered "flat" tasting by some and may be more corrosive if it lacks sufficient mineral content to form a protective scale inside pipes. The observed TDS values suggest a relatively low degree of mineralization in the aquifer at Odi, which is consistent with the sandy nature of the Benin Formation aquifer, which typically yields fresh water in its inland parts.

Biochemical Oxygen Demand (BOD), an indicator of the amount of organic matter present that can be oxidized by microorganisms, ranged from 3.0 to 9.5 mg/L. Several samples exceeded the commonly referenced threshold of 4 mg/L for source water, indicating a significant presence of biodegradable organic pollutants. Elevated BOD is a serious concern as it signifies potential contamination from sewage, septic tank effluent, or other organic waste sources. The microbial decomposition of this organic matter consumes dissolved oxygen, potentially leading to anaerobic conditions that favor the growth of pathogenic bacteria and produce undesirable tastes and odors. The presence of elevated BOD in Odi's groundwater suggests possible leakage from septic systems or improper waste disposal practices within the college campus or its immediate vicinity, allowing organic pollutants to percolate into the shallow aquifer.

Sodium (Na^+) concentrations ranged from 19.32 to 29.34 mg/L, with some samples marginally exceeding the WHO guideline of 20 mg/L. While elevated sodium is not typically a direct health hazard for the general population at these levels, it can be of concern for individuals with hypertension, heart disease, or kidney problems who may require sodium-restricted diets. Furthermore, high sodium levels can impart a salty taste to water. The presence of slightly elevated sodium in some boreholes at Odi could be an early indicator of saline intrusion, especially given the coastal location of Bayelsa State and the flat topography, which makes inland aquifers vulnerable to encroachment by saline groundwater from the creeks and rivers. This trend of sodium enrichment due to salinity intrusion has been observed in other parts of the Niger Delta.

Iron (Fe) concentrations (0.065 to 0.23 mg/L) were well below the WHO guideline of 0.3 mg/L. This is a positive finding, as elevated iron can cause reddish-brown staining of laundry and plumbing fixtures, and impart a metallic taste to water. The low iron levels suggest that the aquifer matrix or the groundwater conditions are not conducive to high iron dissolution or mobilization. Copper (Cu) was not detected in any of the samples, which is also favorable, indicating no significant leaching from copper plumbing or contamination from other copper sources. Calcium (Ca^{2+}) levels were within expected ranges and contribute to the overall hardness of the water, which was not assessed in detail in this study but is generally not a health concern at typical concentrations found in natural waters. The groundwater contains an adequate amount of oxygen, as evidenced by the good levels of dissolved oxygen (DO), which range from 7.5 to 11.0 mg/L. This allows for the maintenance of aerobic conditions while reducing the solubility of certain undesirable elements, such as manganese and iron.

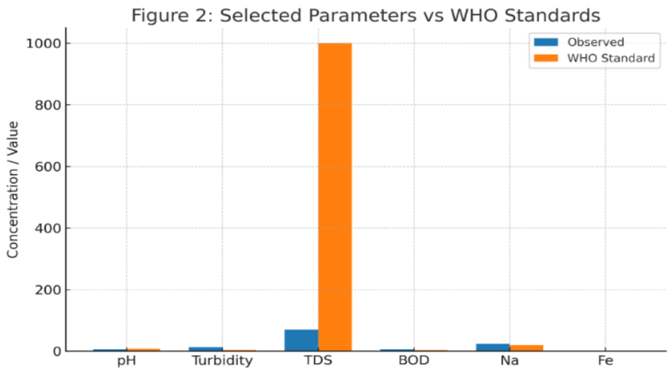

Figure 2: Bar Chart of Physicochemical Parameters and WHO Limits

Water Quality Index (WQI) Analysis

Water Quality Index (WQI) is a mathematical model that provides a more straightforward representation of water quality conditions. The calculation of groundwater quality on campus of the Federal Government College in Odi was reached by calculating the weighted arithmetic index. The method involves assigning the parameter a weight (Wi), with respect to the extent to which the parameter is part of the water quality, and as a proportion of concentration with respect to some well-defined benchmark. A quality rating (Qi) is then formed according to each of the parameters, and the summation of weighted quality ratings formed the overall WQI. The parameters chosen to calculate WQI in the analysis were based on their relevance to the quality of drinking water, as well as the availability of WHO guideline values (pH, Turbidity, TDS, BOD, DO, Na+, Ca2+, and Fe).

The calculated WQI for the groundwater samples from Federal Government College, Odi, was determined to be approximately 102. This WQI value falls within the "poor water quality" category, which typically corresponds to a WQI range of 100 to 200 (classification schemes can vary slightly, but a WQI above 100 generally indicates water that requires treatment before consumption). This overall classification underscores the concerns raised by the individual parameter analysis, particularly the elevated turbidity and BOD, and the slightly low pH and sodium levels. The WQI calculation revealed the major degrading factors contributing to this "poor" rating. Turbidity was the most significant contributor, accounting for approximately 49% of the WQI degradation. This is consistent with its consistent exceedance of WHO limits across all samples. Biochemical Oxygen Demand (BOD) was the second major contributor, at around 29%, reflecting the impact of organic pollution. Sodium levels contributed approximately 18% to the WQI degradation, due to their marginal exceedance of the WHO guideline in some samples. The combined effect of these parameters, despite others being within acceptable limits, results in an overall water quality that is not ideal for direct consumption without treatment. The WQI analysis thus corroborates the detailed physicochemical assessment and provides a powerful, single metric for communicating the water quality status to stakeholders at Federal Government College, emphasizing the need for intervention.

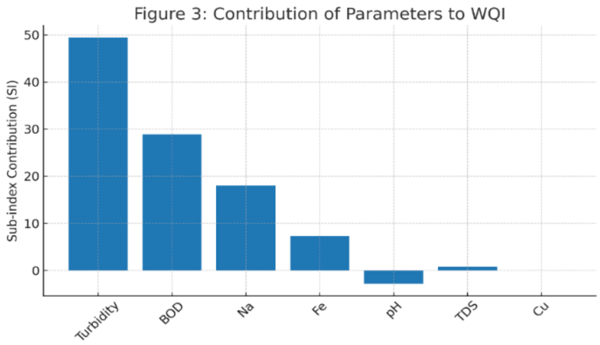

Figure 3: Contribution of Parameters to WQI

Pearson Correlation Analysis

A Pearson correlation analysis was conducted to explore the statistical relationships between the different physicochemical parameters. This analysis helps to identify potential common sources of contamination or underlying geochemical processes that may be influencing the water chemistry. A strong positive correlation (e.g., $r > 0.7$) between two parameters suggests they may originate from a similar source or be influenced by the same environmental factor, while a strong negative correlation indicates an inverse relationship.

The results of the Pearson correlation analysis revealed several significant relationships:

- A strong positive correlation was observed between **Salinity and Sodium (Na^+)**. This is an expected finding, as sodium is a major constituent of salts, and its concentration is a primary driver of salinity in water. This strong correlation further supports the possibility of saline intrusion influencing the sodium levels in some of the boreholes at Odi.
- A significant positive correlation was found between **Turbidity and BOD**. This relationship suggests that the sources contributing to suspended particles (high turbidity) may also be sources of biodegradable organic matter (high BOD). This could point towards common contamination pathways, such as surface runoff carrying organic debris and soil particles into poorly sealed boreholes, or leakage from waste systems that introduce both particulates and organic pollutants.
- A negative correlation was observed between **Dissolved Oxygen (DO) and BOD**. This inverse relationship is consistent with the biochemical processes occurring in water: as microorganisms consume organic matter (measured as BOD), they utilize dissolved oxygen, leading to lower DO levels. While DO levels in this study were generally adequate, the negative correlation with BOD confirms the expected oxygen demand exerted by the organic pollutants present.

TDS and major cations like Sodium (Na +) and Calcium (Ca2 +), were also positively correlated. It demonstrates that the amount of these dissolved ions is to a large extent predetermined by the general mineral content (TDS) of the ground water.

The implications on the correlation can be conducive to the consideration of all the water-quality parameters interaction, and it may be employed in an attempt to trace the contamination origin. Using the example, the relation between turbidity and BOD would elicit some evidence on how organizational practice in having the ingress of the particulate matter (e.g., improved head protection, encroaching filtration) may also address the problem of organic contamination.

Comparison with Past Research

These findings are also consistent with the direction of previous work of groundwater quality carried in other parts of the Niger delta like origins of somewhat acidic PH, high turbidity likely is indicative of the presence of organic pollution in the form of BOD. Indicatively, Nwankoi et al. (2014) discovered a high degree of turbidity and acidity in ground water samples in

Yenagoa, Bayelsa State because of the nature of shallow aquifers and the proximity of anthropogenic influence. In the same manner Udom et al. (1998) reported an indication of particulate and organic contamination interfering with the quality of groundwater in latter portions of Port Harcourt and Tai-Eleme Local Government Areas. The problem of sodium enrichment and the possibility of saline intrusion, indicated by mildly high sodium readings and a strong correlation between salinity and sodium as observed in the present study, is in line with the results provided by Edet et al. (2011) in a comprehensive review of the groundwater chemistry of Niger Delta which emphasized an intrusion of salinity being a major problem in the coastal ground water. The consistency of these findings across different locations within the Niger Delta underscores the pervasive nature of these water quality challenges in shallow, unconfined aquifers in the region, often linked to a combination of natural geochemical processes and anthropogenic pressures such as inadequate waste management and the inherent vulnerability of these aquifers to surface-derived contamination.

Implications of Water Use

The physicochemical characteristics of the groundwater at Federal Government College, Odi, have several important implications for its use, particularly for drinking purposes, and for the associated infrastructure. The consistently elevated turbidity and BOD levels are of primary concern from a public health perspective. High turbidity not only indicates poor aesthetic quality but, more critically, can shield microorganisms from disinfection processes and provide a medium for their growth. Elevated BOD signifies the presence of organic pollutants, which can serve as nutrients for harmful bacteria and lead to oxygen depletion in the water, creating conditions favorable for pathogens. These factors combined suggest a potential risk of waterborne diseases if the water is consumed without adequate treatment. The slightly acidic pH of the water poses a risk to the water distribution infrastructure. Acidic water is corrosive and can degrade metal pipes, fittings, and storage tanks over time. This corrosion can lead to leaks, reduced lifespan of plumbing systems, and, as mentioned earlier, the leaching of metals such as lead and copper into the water supply, which can have serious health implications. The marginally elevated sodium levels, while not an immediate health threat to the general population, warrant attention, especially for individuals with specific dietary restrictions. More importantly, the variability in salinity and the correlation with sodium suggest a potential vulnerability of the aquifer to saltwater intrusion. This is a significant sustainability risk for a coastal community like Odi, as progressive salinization can render freshwater resources unusable over time. Continuous monitoring of sodium and chloride levels is crucial to detect early signs of intrusion and implement protective measures. The overall "poor" WQI rating further reinforces these concerns, indicating that the groundwater, as it stands, is not optimal for direct consumption and requires management interventions to ensure its safety and sustainability for the Federal Government College community.

Study Limitations

The study focused on a selected set of physicochemical parameters. While these parameters are key indicators of water quality and are aligned with WHO guidelines, a broader suite of analyses, including microbial testing for coliform bacteria and other pathogens, as well as screening for a wider range of trace metals and organic pollutants potentially associated with oil-related activities in the Niger Delta, would offer a more complete assessment of the water's safety for consumption. The absence of microbial analysis, in particular, is a limitation given the elevated BOD and turbidity, which can be indicators of microbial contamination. While the study identifies potential sources of contamination (e.g., saline intrusion, organic pollution from waste), detailed source apportionment studies, possibly using isotopic analysis or more advanced fingerprinting techniques, would be needed to definitively identify the origins and pathways of these contaminants. Despite these limitations, the findings of this study are significant and provide a crucial foundation for water management decisions at Federal Government College, Odi, and for future, more extensive research in the area.

Conclusion

A total evaluation of the physicochemical parameters in the groundwater at the Federal Government College, Odi, Bayelsa State, Nigeria, has revealed that most of the studied physicochemical parameters are within the recommended limit of the World Health Organization (2019) regarding the quality of drinking water, but some critical anomalies are likely to lead to health hazards and infrastructural damages. The groundwater consistently exhibits a slight acidity (pH 6.65–6.79), elevated turbidity (8.46–18.2 NTU), instances of high Biochemical Oxygen Demand (up to 9.5 mg/L), and marginally elevated sodium content (up to 29.34 mg/L). These deviations from standard guidelines highlight concerns regarding potential microbial contamination due to high turbidity and BOD, the corrosive nature of acidic water on plumbing systems, and the early signs of possible saline intrusion. The computed Water Quality Index (WQI) of the ground water of about 102 is such that it is described as poor and it can be affirmed that the groundwater needs to be treated prior to domestic use. These results highlight that the instability of shallow unconfined aquifers, including those found in the Niger Delta (e.g. the Benin Formation aquifer) against natural geochemical processes, as well as anthropogenic contamination. The research presents important baseline information on the Federal Government College, Odi, and it adds to the general knowledge base regarding the groundwater quality issues in the area. It highlights the importance of proactive water quality management, frequent observation and ensuring proper mitigation measures to maintain the safety and sustainability of this crucial water source to the institution and other related communities in the Niger Delta.

Recommendations

Based on the findings of this study, the following recommendations are proposed to address the identified water quality issues and ensure the provision of safe and sustainable water at Federal Government College, Odi:

1. **pH Adjustment:** To mitigate the corrosive potential of the slightly acidic groundwater and improve its aesthetic qualities, pH adjustment should be considered. This can be achieved through the addition of alkaline substances, such as food-grade lime (calcium hydroxide) or soda ash (sodium carbonate), in a controlled manner using a dosing system. The treatment should be designed to raise the pH to within the WHO recommended range of 6.8 to 8.5, ideally closer to neutral (pH 7).

2. **Filtration Systems:** Given the consistently high turbidity levels, the implementation of effective filtration systems is paramount. A multi-stage filtration approach is recommended:

    - **Pre-filtration/Sedimentation:** Initial removal of larger suspended particles through settling tanks or coarse filters.

    - **Sand Filtration:** Use of rapid sand filters or slow sand filters to effectively remove finer suspended solids and reduce turbidity to levels below the WHO guideline of 5 NTU. Slow sand filters also have the advantage of removing some microorganisms through biological activity in the schmutzdecke layer.

    - **Activated Carbon Filtration:** To address the elevated BOD and improve taste and odor, activated carbon filters can be employed. These filters are effective at adsorbing a wide range of organic compounds and some inorganic contaminants.

3. **Control of Organic Pollution:** The sources of organic pollution contributing to high BOD levels must be identified and remediated. This involves a thorough inspection of sewage and septic tank systems within the college campus to detect and repair any leaks or overflows. Proper waste management practices should be enforced to prevent indiscriminate disposal of organic wastes that could leach into the groundwater.

4. **Continuous Monitoring of Sodium/Salinity Levels:** To detect and manage the risk of saline intrusion, a regular monitoring program for sodium and chloride (or general salinity) should be established. Quarterly testing of these parameters in all boreholes is recommended. If increasing trends are observed, more detailed hydrogeological investigations may be necessary to understand the intrusion pathways and implement protective measures, such as optimizing pumping rates to minimize drawdown of saline water.

5. **Quarterly Water Quality Testing:** A comprehensive water quality testing program should be instituted, with samples from all boreholes analyzed at least quarterly for the full suite of physicochemical parameters assessed in this study, plus microbial parameters (total coliforms, E. coli). This regular monitoring will allow for the early detection of any deterioration in water quality and the evaluation of the effectiveness of implemented treatment measures.

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