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Research Article

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Spatial Distribution Pattern of Electrical Conductivity, Total Dissolved Solids and Potential of Hydrogen Using GIS Techniques

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Abstract: The present paper describes the application of remote sensing and Geographic Information System (GIS) techniques to study the spatial distribution patterns of selected water quality parameters within Gurara Reservoir, located in Northwest Nigeria. The water quality parameters were depicted by various colour combinations maps for different ranges of concentrations. Samples collected were analyzed for potential of hydrogen (ph), Electrical Conductivity (EC) and Total Dissolved Solid (TDS) to give better visual image and understanding of the spatial distribution pattern. The results of the study showed increasing trend of the pollution load towards the downstream part of the reservoir with the exception of potential of hydrogen in the upstrream part. The use of GIS techniques in the assessment of water quality is essential for regular monitoring of water bodies in the context of reservoir systems to effectively understand and manage water resources which further indicate the need for a strategic plan to protect the surface water resources of the Gurara reservoir in Nigeria.

Keywords: Remote Sening, GIS, Water Quality, Spatial Distribution and Gurara Reservoir

1. Introduction

The quality of water is a crucial and serious concern for humanity because of its connection to human health and well-being. Water is one of the most essential and valuable resources. While it is abundant on the Earth's surface, the issues of quality and quantity to meet its intended uses are where the challenges arise. The demand for water has increased over the years due to human activities, leading to water scarcity in many regions of the world, which has intensified the issues of water pollution and contamination due to rising population levels (Awodumi and Akeasa, 2017). The growth in population has become a significant global challenge as it raises concerns regarding water quality, alongside agricultural development and the impacts of climate change, which further influence fluctuations in precipitation patterns that correlate with water quality (Awodumi and Akeasa, 2017). This is due to various human-induced and natural factors such as irrigation techniques, geological conditions, and local climate, which are all contributing to the decline in water quality (Francis et al., 2021).

According to Balakrishnan (2012), the quality of water is a significant issue for humans since it is closely linked to their well-being. The rapid pace of industrialization and urban growth leads to a decline in the quality of surface water (Vasanthavigar et al., 2000). The condition of surface water held in reservoirs depends on the geochemical processes of the surrounding catchment area, activities carried out upstream by humans, local precipitation pattern and intensity, the quality of recharge water, and various hydrologic factors (Vasanthavigar et al., 2000).

The types and concentrations of minerals present in surrounding catchment region affect the water's usefulness for municipal, industrial, and irrigation uses, among other uses. Standards for water quality are usually established for various water uses. These criteria, which were created by several organizations, serve as a guide for determining whether water is suitable for a given use. A computer program called a GIS makes it easier to map large amounts of geo-referenced data. The analysis of spatial data makes considerable use of GIS. It improves spatial data management's accuracy and effectiveness. The use of GIS to analyze the geographical distribution of water quality metrics has become more popular recently. Because of its intuitive interface, GIS has become a powerful tool for data analysis, storage, and visualization.

In managing water resources, GIS are often employed for analyzing site suitability, evaluating the vulnerability of surface and groundwater to pollution, simulating surface and groundwater flow, and studying patterns of contamination transport. Furthermore, GIS can be combined with remote sensing data to create spatial decision support systems for investigations related to hydrology and hydrogeology.

in this regard, effective management of the Gurara reservoir is essential for both present and future national growth, as it serves as the source reservoir in the water transfer scheme to the Usman Dam, which supplies the Abuja water treatment plant managed by the Federal Capital Territory Water Board in Nigeria. This connection highlights the necessity of assessing the quality of Gurara's water to guarantee its safety and sustainability for use. Therefore, the aim of this study is to describe the distribution patterns of water quality by utilizing remote sensing and GIS techniques for the Gurara reservoir. Consequently, spatial distribution maps were created for specific water quality indicators such as EC, pH, and TDS to evaluate the distribution trends of water quality. Monitoring changes in water quality, especially in the reservoirs, which is crucial for assessing current water quality conditions and recognizing potential future contamination threats.

2. Materials and Methods

Study Area

The research on the spatial distribution of water quality was carried out using remote sensing and GIS methods in the Gurara Reservoir (See Figure. 1), situated in North Central Nigeria. Completed in 2007 and filled to capacity in 2010, the reservoir serves multiple purposes. With a total capacity of 800 × 10^6 m³, it is engineered to release water at a rate of 10 m³/s for downstream irrigation; additionally, a 75 km tunnel channels water supply system from the Gurara Reservoir to the Lower Usuma Reservoir at a flow rate of 8 m³/s, along with a hydropower system capable of generating 30 MW of electricity. The climate in this region is subtropical, with maximum temperatures ranging from 30°C to 38°C. The typical annual rainfall in the study area is 1,325 mm. The reservoir is located with a rural region comprising small villages. The primary occupation of the riparian population area is agriculture. The operations of the Gurara Reservoir are currently overseen by the Federal Ministry of Water Resources.

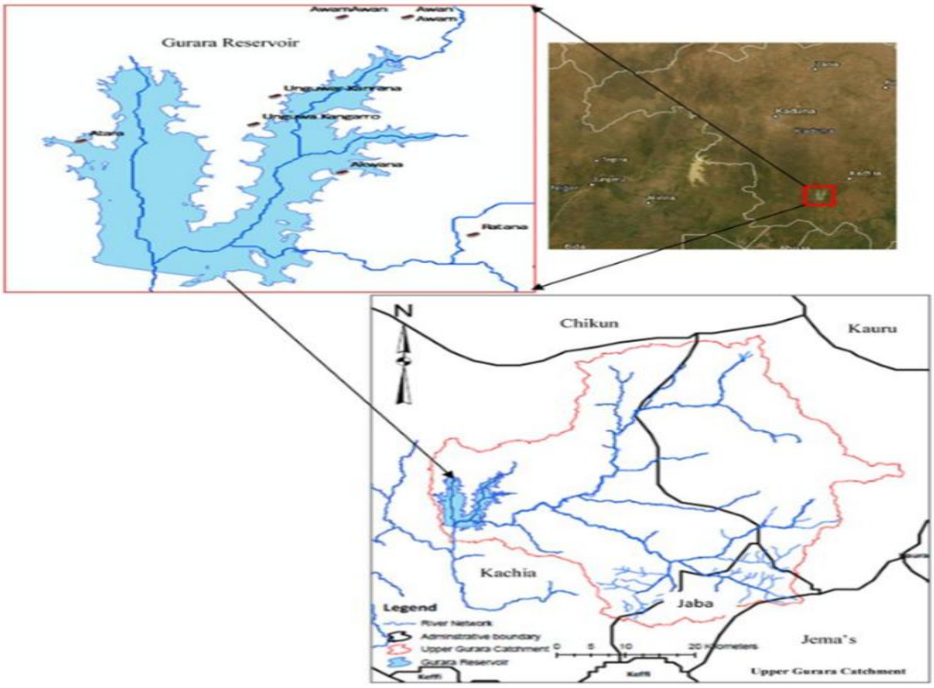

Figure 1: Gurara reservoir boundaries and country location (Source: Francis et al., 2021)

Methods

Sampling, Sample Collection and Analysis

The assessment of the surface water quality in the Gurara reservoir took place over two seasons (dry and wet). A total of twenty-four (24) surface water samples were collected using clean one-liter plastic bottles. Prior to sample collection, the bottles were thoroughly rinsed following sampling protocols that involved using acid-washed and pre-rinsed polyethylene containers. The collected samples were subjected to reliability analysis for physiochemical parameters, taking into account geographical variations with distances between sampling sites, at depths ranging from 5 m to 10 m, specifically for Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Potential of Hydrogen (pH) levels. The latitude and longitude of each sampling location were recorded using a global positioning system (GPS). The conventional measurement techniques and protocols were followed, in accordance with the recommendations from the American Public Health Association (APHA, 2012). All geographic coordinates of the sampling sites, along with sampling details, were imported into ArcGIS software to perform spatial analysis containing the background map of the research area was obtained from https://earthexplorer.usgs.-gov/

Determination of Potential of Hydrogen

The Potential of Hydrogen level of the water sample was assessed by using a pH/conductivity meter, which was placed directly into the sample after calibrating the Potential of Hydrogen meter with distilled water to ensure precise measurements. The results were documented.

Determination of Conductivity

Deionized water served as the control for calibrating the conductivity meter. Following this, the meter was placed into the water sample, and the reading was documented.

Determination of Total Dissolved Solids

TDS expresses the degree of salinization of water body. Although in-situ measurement of TDS is complex, sensitive index which is the total amount of dissolved solids, is used as an additional criteria (Singh and Kalra, 1975). Recall that electrical conductivity is directly related to the concentration of salts dissolved in water (Singh and Kalra, 1975), as such the TDS values for this study were estimated using electrical conductivity by converting the electrical conductivity using a factor that varies with the type of water (Singh and Kalra, 1975). As postulated by Hiscock (2005), it is possible to relate the TDS value to electrical conductivity (EC) as expressed by equation 1.

$$\text{TDS (mg l}^{-1}\text{)} = \text{ke EC } (\mu\text{S cm}^{-1}) \qquad (1)$$

Where the correlation factor, ke, is typically between 0.5 and 0.8 and can be determined for each field investigation. It should be noted that this relationship only provides an estimate. In this present study, TDS values were estimated using the following formula as shown in equation 2.

$$\text{TDS} = \text{EC} \times 0.64 \qquad (2)$$

However, when the salt concentration reaches a certain level, electrical conductivity is no longer directly related to salts concentration

GIS-based Technique

Spatial Distribution through Inverse Distance Weighted (IDW)

According to Singh et al. (2015), the IDW is a versatile tool that is easy to use and exhibits respectable accuracy under a range of circumstances. It well illustrates the extent of spatial distribution pattern. The pollution distribution maps were made using the Inverse Distance Weighting (IDW) interpolation method, which creates a surface by finding points in a neighborhood and giving them weights based on a power function. A lower power permits a more even distribution of weights among adjacent locations, whereas a higher power lessens the impact of points that are farther away (Chatterji and Raziuddin, 2002). IDW's efficiency and ease of use are two of its main advantages; it works best with equally spaced points but is also susceptible to outliers. Clusters of data that are not evenly dispersed, however, may introduce degree of errors.

Steps Followed Were;

In arcMAP → Arc Tool box →Spatial Analysis Tools → Interpolation→ IDW → Input point feature value field → Output raster → OK

Inverse Distance Weighted Interpolation

The IDW algorithm operates as a spatial interpolator that functions like a moving average, calculating cell values through a linear weighted blend of collected sample points (Balakrishnan et al., 2011). This interpolation method is categorized as deterministic and is considered an exact interpolator (Nasir et al., 2016). The values assigned to unknown locations are based on a weighted average of the known values. Therefore, a higher weight is given to the nearest point, with the weight decreasing as the distance increases. As noted by Nasir et al. (2016), the IDW technique computes a value for each grid node by examining the nearby data points within a specified search radius. The estimated value at the node is derived from the weighted average of all relevant points, using some or all of the data points considered during the interpolation.

As stated by Watson and Philip (1985), data points that are positioned farther from the node exert a considerably reduced effect on the computed value in comparison to those that are closer. Generally, the influence of any given point is inversely proportional to its distance from the reference point. By applying the IDW method, the property at each unknown site where a solution is needed can be mathematically expressed through equations 1, 2, and 3.

$$\check{Z}(S_o) = \sum_{i=1}^{n} \lambda_1 (S_o)\, Z\, (S_i) \tag{1}$$

$$\check{Z}\, (S_o) = \lambda_o^T\, Z \tag{2}$$

$$\lambda_1\, (S_o) = \frac{\frac{1}{d^{\beta}(S_0, S_i)}}{\sum_{t=o}^{n} \frac{1}{(S_O, (S_i))}} \tag{3}$$

Where: λ_i – is the weight for neighbour 1 (the sum of weights must be unity to ensure an unbiased interpolator); $d(S_o, S_i)$ – is the distance from the new point to a known sampled point; β – is a coefficient that is used to adjust the weights and n – is the total number of points in the neighbourhood analysis.

3. Results and Discussion

Seasonal Physicochemical Variation

The time frame spanning July to October is known as the wet season, whereas the duration from November to June is called the dry season. The average values for physiochemical parameters obtained from the water quality assessment during the dry season are shown in Table 1, while those for the wet season are displayed in Table 2.

Table 1: Mean values for physiochemical parameters in dry season

S/N	Parameters/Units	Sample Location			
		GRU	STDEV	GRD	STDEV
1	pH	6.60	±0.079	6.220	± 0.128
2	EC (µS/cm)	33.0	±7.480	33.30	±10.71
3	TDS (mg/l)	21.12	±0.06	21.13	±0.13

Note: GRU Grurara reservoir upstream STDEV Standard Deviation and GRD Gurara Reseroir downstream

Table 2: Mean values of physiochemical parameters in wet season

S/N	Parameters/Units	Sample Location			
		GRU	STDEV	GRD	STDEV
1	pH	5.770	±1.059	6.700	± 0.075
2	EC (µS/cm)	100.00	±1.181	52.8	±2.720
3	TDS (mg/l)	64.00	± 2.12	33.79	± 0.56

Note: GRU Grurara reservoir upstream STDEV Standard Deviation and GRD Gurara Reseroir downstream

Electrical Conductivity Concentration

Electrical conductivity indicates the capacity for carrying electrical current (Aktar et al., 2010). Therefore, an increase in the concentration of dissolved salts leads to a corresponding rise in conductivity (Krishna et al., 2015). The measured electrical conductivity ranges from 25.05 to 33.3 $\mathbf{\mu Scm^{-1}}$ during the dry season and from

42.1 to 100 1000 $\boldsymbol{\mu}\mathbf{Scm}^{-1}$ in the wet season. The World Health Organization and Nigerian Standard for Drinking Water Quality stipulate that the acceptable limit for EC is 1000$\boldsymbol{\mu}\mathbf{Scm}^{-1}$.

Total Dissolved Solids Concentration

The TDS levels varied from 21.12 mg/l to 21.13 mg/l in the dry season, while during the wet season, they ranged from 16.03 mg/l to 24.95 mg/l. According to standards, the permissible limit for TDS is set at 600 mg/l by WHO (2012) and 500 mg/l by NSDWQ (2007). The TDS values from the water samples of the Gurara reservoir fall within 4% of the maximum allowable limit of 1000 mg/l.

Potential of Hydrogen Concentration

The Potential of Hydrogen in a water sample indicates the concentration of hydrogen ions in a solution. Solutions with a high hydrogen ion concentration exhibit a low pH, whereas solutions with a low concentration of H+ ions demonstrate a high Potential of Hydrogen. The values recorded fall within the acceptable range of 6.5 to 8.5 (WHO, 2012: NSDWQ, 2007). In the study area, the Potential of Hydrogen levels during the dry season range from 6.41 to 7.65, while in the wet season, they vary from 6.24 to 6.5.

Spatial Distribution Map and Pattern

Electrical Conductivity

The map illustrating the spatial distribution of electrical conductivity in Figure 2 indicates that locations downstream of the reservoir exhibit higher concentration values in μScm^{-1}, compared to those upstream. The downstream areas, which include the Gurara river and the spillway, show heightened concentration levels due to restricted water movement, leading to an increase in concentration (Udosen et al., 2006). While significant differences in electrical conductivity values within the system remain unidentified (Azrina et al., 2011), it has been noted that these differences arise from a variety of factors, such as agricultural and industrial activities and land use alterations, which impact the mineral content and consequently the electrical conductivity of the water body (Krishna et al., 2015). Although conductivity itself does not directly affect human health, it is measured for various reasons, including assessing the mineralization rate (the presence of minerals like potassium, calcium, and sodium) and estimating the quantity of chemical reagents required for water treatment (Krishna et al., 2015). In water bodies, elevated levels of electrical conductivity can diminish the visual appeal of the water by imparting a mineral flavor (Udosen et al., 2006). Water that exhibits high electrical conductivity may result in the corrosion of metal surfaces on equipment, including household appliances like water heaters and faucets, particularly when it is used for domestic water supply, such as in the Gurara reservoir

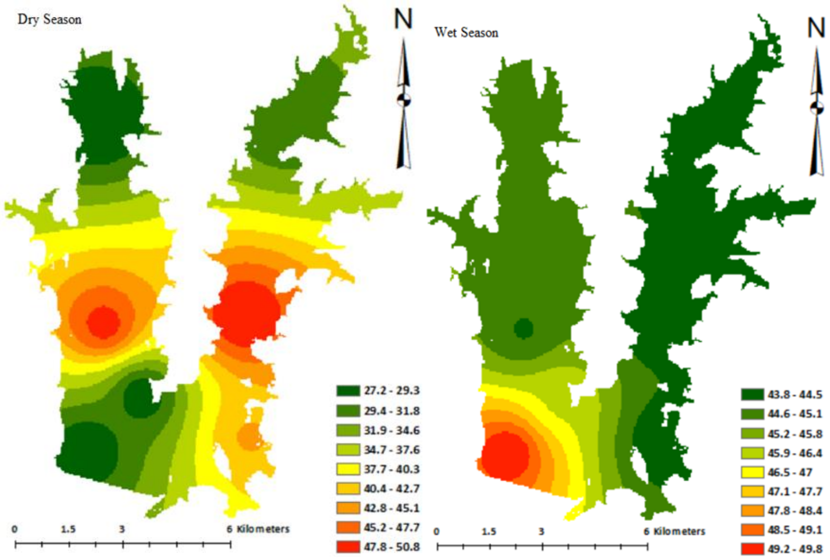

Figure 2: Spatial distribution map of EC concentration levels at Gurara reservoir

Total Dissolved Solids (TDS)

Figure 3 illustrates the geospatial distribution of TDS patterns during both the dry and wet seasons. The highest concentrations of TDS are found in the upstream section for both seasons, with a more pronounced concentration observed in the wet season. The slightly elevated levels during the wet season may be linked to pollution from organic matter, the presence of suspended particles, and surface runoff from the surrounding catchment area. While it is challenging to characterize the variation of TDS between upstream and downstream locations across seasons in reservoirs, the spatial distribution mapping using GIS has facilitated the quantification of these variations during the studied seasons and may enhance the understanding of the salinization processes related to TDS.

The lower TDS values observed in the downstream areas indicate that these locations experience reduced salinization. This suggests that the water is likely influenced by artificial and/or natural turbulence processes (Krishna et al., 2015).

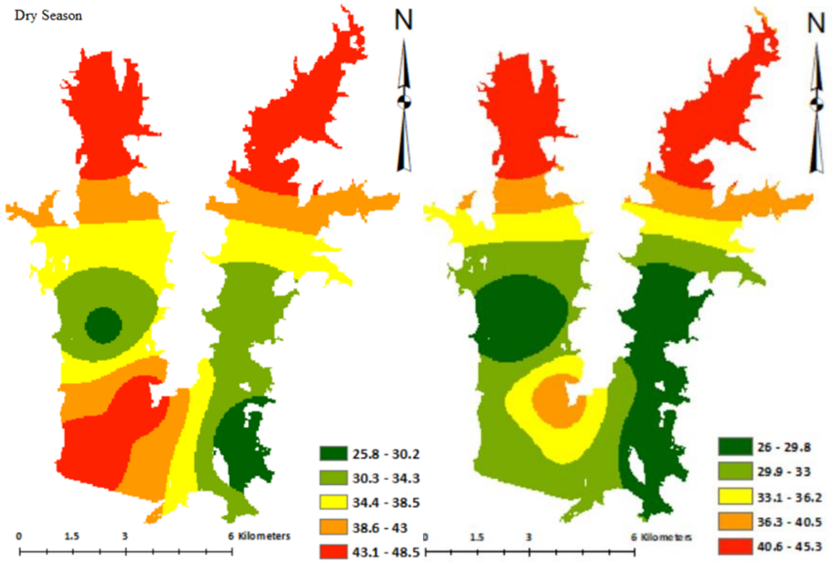

Figure 3: Spatial distribution map of TDS concentration levels at Gurara reservoir

Potential of Hydrogen

The pH map's spatial distribution is illustrated in Figure 4. The interpolated pH levels are generally higher in the upstream areas of the reservoir compared to the downstream sections. The elevated pH levels in the upstream locations can be linked to the weathering of rocks that contribute to the water body via surface runoff from the surrounding catchment area. The pH of water is typically influenced by the concentration of hydrogen ions present, with a scale that ranges from 0 to 14 (Krishna et al., 2015), where a value of seven (7) indicates neutrality, signifying a balance between acidity and alkalinity (Nagaraju et al., 2012).

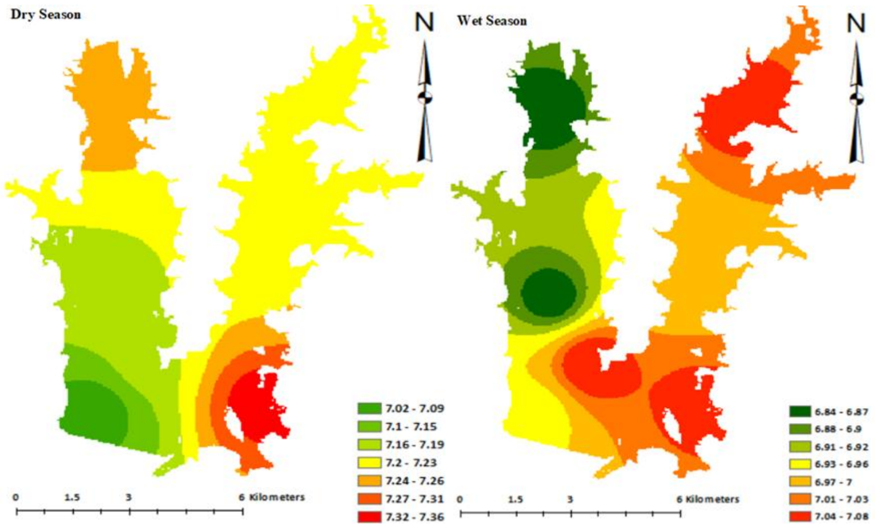

Figure 4: Spatial distribution map of Potential of Hydrogen concentration levels at Gurara reservoir

4. Conclusion

Utilizing GIS techniques to create the spatial variation map for parameters like pH, EC, and TDS shows that the concentrations are generally higher near the downstream areas of the sampled Gurrara reservoir, with the exception of pH, which exhibited higher average concentration levels upstream.

The maps additionally demonstrate that enhancing the Inverse Distance Weighted method with numerical interpolation techniques for water quality mapping can effectively depict the pollution distribution patterns in both upstream and downstream areas. This approach can serve as a foundation for creating a comprehensive strategy to ensure ongoing monitoring of reservoir water quality in the future while maintaining its current quality status.

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