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Integrated Analysis of Water Quality in Artificial Fishponds Using WQI and GIS in South-East Sierra Leone

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Abstract

Artificial fishponds play a pivotal role in global aquaculture, serving as a source of livelihood and nourishment for many communities. Ensuring the sustained health and productivity of Fishes in these environments relies heavily on water quality management. This assessment was done to determine the water quality of ten artificial fishponds in the south-eastern part of Sierra Leone using twelve physicochemical factors (pH, BOD, EC, TDS, turbidity, COD, Fe^{2+}, Mg^{2+}, Ca^{2+}, NH_3, NO_3^-, and alkalinity) to find out the Water Quality Index (WQI) and spatial distribution of respective parameters. The assessment of artificial fishponds using WQI and Inverse Distant Weighting (IDW) integration represents a relatively underexplored area within the domain of environmental water resources. The WQI was determined using the "Weighted Arithmetic Water Quality Index" method. The results of WQI in the study area range from 65.05 to 147.26. Several locations have water quality deemed unsuitable for consumption, while others range from good to very poor. It is essential to address and improve water quality in locations categorized as unsuitable for consumption and very poor to ensure safe and healthy water sources. It was also clear from the calculation that the smaller the mean concentration value of the pH as compared to the ideal value (7), the smaller the WQI value and the better the water quality. To keep the artificial fishpond water in good condition, mass domestic use should be controlled, and draining of surrounding organic matter should be stopped in ponds Bo_001, Kenema_001, and Kenema_002.

Keywords

Physicochemical Parameters, Water Quality Index, WQI-"Weighted

Arithmetic Index Method”

1. Introduction

The groundwater quality also varies with the depth of water, periodic changes, leached dissolved salts, and subsurface environment (Gebrehiwot et al., 2011). According to the World Health Organization (Cotruvo, 2017), about 80% of all diseases in human beings are water-borne. Once the groundwater is contaminated, it is difficult to ensure its restoration and proper quality by preventing the pollutants from entering the source (Yang et al., 2023). Groundwater is an indispensable renewable resource found on earth, significant for supporting habitat, maintaining hydrological balance as well as sustaining human needs (Asadi et al., 2007; Subbarao et al., 1997). Fishponds made artificially are essential to the world’s food production and economic growth. They are vital aquaculture hubs that provide communities all over the world with income and protein. However, controlling the water quality in these ponds is crucial to keeping the aquatic life healthy and productive. For fish farmers, poor water quality can result in illnesses, stunted growth, and financial losses. Thus, maintaining fishponds at their ideal water quality is crucial for long-term productivity and financial stability (Smith & Johnson, 2020). Fish is an affordable source of protein and has significant economic value in many parts of the world. For fish, water is a necessary medium for all of their life processes, including eating, swimming, reproducing, digesting food, and eliminating waste (Boyacioglu, 2010; Kramer, 1987).

This research aims to demonstrate the applicability of the water quality index (WQI) method for quality assessment and geographic information systems (GIS) for the spatial distribution of the parameters in the study area, thus enhancing water quality management practices within artificial fishponds and ultimately contributing to more sustainable and efficient aquaculture. The WQI abstracts huge amounts of data related to water quality into elementary terms (excellent, good, poor, very poor, and unsuitable) for reporting administrator and the communal on a regular basis (Boyacioglu, 2010). The WQI could be an effective machinery or tool for the comparison of different sources of aquatic water quality bodies and provides a general concept of possible water-related hazards in a specific area. The index is very effective and important in relating the propensity of water quality data with the management of water quality (Jagadeeswari & Ramesh, 2012). The assessment of the artificial fishponds using WQI and GIS integration represents a relatively underexplored research area within the domain of environmental water resources studies. By doing so, the research will contribute valuable insights into knowledge and methodologies that can enhance water quality management practices in artificial fishponds.

The WQI uses weighted arithmetic water quality index methods to simulate water quality changes, while the GIS analyzes spatial data for hotspot identification. The synergy between WQI and GIS provides comprehensive insights, aiding fishpond managers in effective water quality management for sustainable aquaculture (Ibrahim et al., 2023; Pádua et al., 2019; Panigrahi et al., 2020; Waite et al., 2014). The WQI and GIS techniques present an innovative and comprehensive method for monitoring and enhancing the water quality index in artificial fishponds (Brown et al., 1972). These approaches allow us to evaluate the spatial distribution of key parameters, predict water quality changes over time, and optimize management strategies for sustainable aquaculture practices (Ali & Ahmad, 2020; Singh et al., 2022).

Geographic Information Systems have developed into an efficient means of combining, evaluating, and presenting spatial data for a variety of planning, resource management, and monitoring applications (Khan et al., 2023). This is accomplished with the flexibility to use spatial data in a variety of fields within an integrated environment and in accordance with needs. It has become an important platform for resource management studies. It has been able to address multidimensional resource management challenges, such as water management, thanks to its accuracy in exploratory data analysis, its visualization capabilities, and its capacity to build models (Zeilhofer et al., 2007). It can be used to ease targeted interventions for resource management as well as analyze the spatial distribution of groundwater, and problems related to its quality, evaluate its vulnerability to pollution, and determine the distribution of related diseases and at-risk populations. It additionally offers an ideal platform for congregating information in relation to the environment and population aspects and manipulating spatial data into diverse forms as per the geo-social requirements. Therefore, GIS can be seen as the most appropriate multispectral spatial analysis tool, which can be applied in nearly all areas (even real-time data analysis) where spatial information has to be retrieved and analyzed (Longley, 2005). The study therefore also attempts to highlight the potential of geographical information system-based geostatistical techniques in assessing the groundwater quality of the region and investigating the water-borne disease susceptibility based on water quality indexing (Ali & Ahmad, 2020). While WQI and GIS are entrenched tools in environmental sciences, their application in the context of artificial fishponds is relatively limited (Gutierres et al., 2016). Existing studies primarily focus on natural water bodies like lakes and rivers. This research gap hinders our understanding of how these techniques can be effectively applied to manage water quality in artificial fishponds.

South-eastern Sierra Leone is known for their freshwater fish cultivation, contributing to food security and local livelihoods. Water quality management is critical in safeguarding the successful growth of fish species (Boyd, 2017); considering the unique characteristics and challenges of fishpond management in that area. Maintaining and improving water quality in these ponds is vital for the growth and health of aquatic organisms. Aquaculture, the controlled cultivation of aquatic organisms, has become a critical component of global food production, contributing substantially to food security and economic development

(FAO, 2020). Artificial fishponds have a storied past originating from ancient civilizations like the Chinese, Egyptians, and Romans, significantly contributing to sustainable farming and food stability. Today, they play a crucial role in global food security, offering employment, nutrition, and rural development opportunities. Yet, these fishponds face water quality challenges impacting aquatic life, demanding vigilant management of temperature, pH, dissolved oxygen, and nutrients. Traditional manual monitoring methods have limitations, prompting a shift towards advanced techniques like WQI and geospatial assessments. These limitations in terms of spatial and temporal coverage, labor intensiveness, and limited parameters measured; advanced techniques like WQI and geospatial assessments offer comprehensive, real-time, and cost-effective solutions, aiding in better water quality assessment and management.

2. Materials and Methods

2.1. Study Area

Sierra Leone, officially the Republic of Sierra Leone, is a country on the southwest coast of West Africa. It shares its southeastern border with Liberia, and the northern half of the nation is surrounded by Guinea. Covering a total area of 71,740 km^2 (27,699 sq. mi) (Figure 1). The southern and Eastern Provinces are two of the

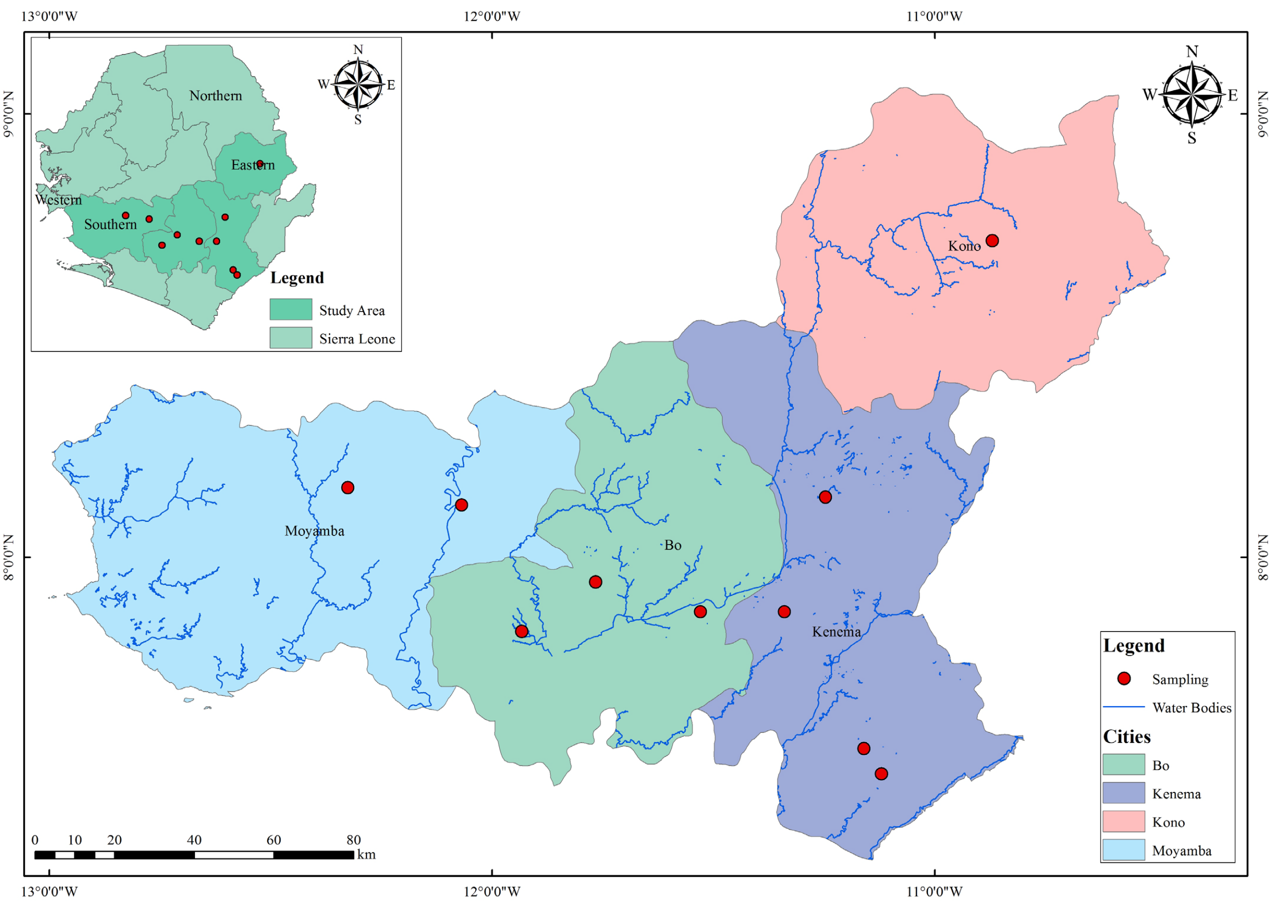

Figure 1. Study area map showing the sampling locations, city boundaries, and water bodies.

four provinces of Sierra Leone. It covers an area of 19,694 km^2 and 15,553 km^2 and a population of 1,441,308 and 1,642,370 (Statistics, 2021) respectively.

It has a tropical climate, with diverse environments ranging from savannas to rainforests. The research area for this particular study covers part of the southeastern province of Sierra Leone with geographical coordinates located between Latitudes 07˚53'06" to 08˚59'36"N and Longitude 010˚27'52" to 012˚32'07"W in the Republic of Sierra Leone. Temperatures are relatively uniform throughout the year, ranging from 24˚C to 28˚C. The lowest temperatures are from July to September, in the middle of the rainy season, and the highest temperatures are in February and March, near the end of the dry season (Lapworth et al., 2015). A major belt of late Precambrian (Upper Proterozoic) to Lower Palaeozoic age meta-sedimentary rocks, with some (Meta) volcanic rocks, occurs in this part of the country (Lapworth et al., 2015; Camus & Cukor, 2012). Rainfall is highest in the coastal areas with annual downpours above 3500 mm and can be torrential during July, August, and September.

Geological and Hydrogeological Setup

The South-east receives a significant amount of rain, with about 4200 - 3200 mm/yr. along the coast, rainfall varies from 3000 - 4000 mm/yr. The northern region receives the least amount of rainfall, less than 2400 mm/yr (Fileccia, 2018). Five main rivers flow from northeast to southwest across Sierra Leone that is the Little Scarcies, Rokel, Jong, Sewa, and Moa rivers. Between them, they drain most of the land surface of the country. In addition, six smaller drainage basins include; the Great Scarcies, Lokko, Rokel Estuary, Western, Robbi/Thauka, and Sherbro Water Resources Areas. River runoff is highly seasonal, reflecting the seasonal distribution of rainfall (Lapworth et al., 2015).

2.2. Sampling and Analytical Methods

Samples were collected in June 2023 (mid of the dry and rainy seasons), to presume a kind of balanced water table in the different fishponds. In the southeast, ten notable artificial fishponds were sampled due to their access, size, and productivity in fish production in the study area, and water samples were collected from the respective ponds. A total of twelve water quality parameters namely pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity (Alk), turbidity (NTU), magnesium (Mg^{2+}), calcium (Ca^{2+}), nitrate (NO_3^-), ammonium (NH_3), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and iron (Fe^{2+}) were taken for generating the water quality index (WQI). The Different physicochemical water quality parameters of the samples were examined by the standard protocol (Bhatnagar & Devi, 2013).

The major cation and trace metal amounts were determined by inductively coupled plasma mass spectrometry (ICPMS) within group 2C-MS at the Njala University Quality Control laboratory in Sierra Leone. Additionally, in-situ instruments were used i.e., pH meter, TDS Meter, Multiple test meter, and Delagua kit to determine the pH and TDS. The Spectrophotometer reagents and a

WTW photo Lab Spectral-12 Spectrophotometer were used for the determination of COD, phosphate, total phosphorous, NO_2^-, NO_3^-, and NH_3. The WTW Oxitop IS 6 Inductive Stirring System was used for the BOD. The data were analyzed with the help of MS Excel 2021, Origin 2023b and ArcGIS 10.7.1 (GIS tool). The water quality of the samples was assessed by calculating WQI values by using these guidelines ((Cotruvo, 2017; Khadse et al., 2011) as shown in **Tables 1-3**).

Table 1. Water quality levels for the culture of tropical fish species.

S/N	Parameter	Recommended values for aquatic life
01	Temperature	24˚C - 31˚C
02	Dissolved oxygen (mg/L)	Not below 4 ppm/mg/L
03	Turbidity (cm)	Clear water (30 cm depth)
04	TDS (mg/L)	Less than 1000 mg/L
05	TSS	>100 - <220 mg/L
06	pH	6.5 - 8.5
07	Total hardness	50 - 300 ppm/mgL
08	Alkalinity	50 - 200 ppm
10	Nitrate concentration (mg/L)	Less than 250 ppm/mg/L
12	Ammonia	Less than 0.05 ppm/mg/L
13	Iron	Less than 0 - 1 ppm
14	Lead	Less than 0.02 ppm
15	Hydrogen sulphide	Less than 0.003 ppm
16	Copper	Less than 0.0 ppm
17	Zinc	Less than 0.1 ppm

Source: Alabaster & Llyod (2013).

Table 2. pH range for fish culture and implication.

pH Range	Interpretation	Remarks
1.0 - 4.9	Extremely acidic	Toxic to fish
2.0 - 6.6	Moderately acidic	Low productivity
6.7 - 9.9	Suitable H^+ ion	Desirable for fish (High productivity)
9.1 - 11.0	Moderately Alkaline	Low productivity
11.1 - 14.0	Extremely Alkaline	Toxic to fish

Source: Olapade & Senesie (2015).

Table 3. Tolerance of fish to dissolved oxygen.

Dissolved Oxygen (mg/L)	Effect on fish
Less than 1	Death of Fish when exposed longer than a few hours.
2 to 4	Fish survive, but poor reproduction and a slow growth rate.
Greater than 5	Normal growth and reproduction

Source: Arch (1989).

Throughout the study, the data quality assurance and control (QA/QC) process has been considered. To verify QA/QC procedures, about half of the volume (500 ml) of samples were carefully separated and examined in the lab. Charge balance errors were used to validate the chemical analysis's accuracy, and samples with errors less than 5% were taken into consideration. To create spatial distribution maps, surface and groundwater quality parameters can now be spatially interpolated using the IDW interpolation technique, which was employed in this study (Balamurugan et al., 2020; Kawo & Karuppannan, 2018; Magesh et al., 2013; Sarfo & Karuppannan, 2020). The elucidated research framework, illustrated in **Figure 2**, provides a detailed depiction of the study's structured approach towards integrated analysis of water quality in artificial fishponds.

2.3. Water Quality Index Method

The Water Quality Index has been calculated using the weighted arithmetic method, which was originally proposed by (Horton, 1965) and developed by (Brown et al., 1972). According to (Brown et al., 1972), the value of quality rating or sub-index (Q_n) is calculated using the equation as given in Equation (3) below. The WQI has been determined using the Water quality levels for the culture of tropic fish species standard recommended by (Bhatnagar & Devi, 2013) as shown in **Tables 1-3**. **Table 4** presents a statistical analysis of groundwater quality parameters, juxtaposed with standards set by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS).

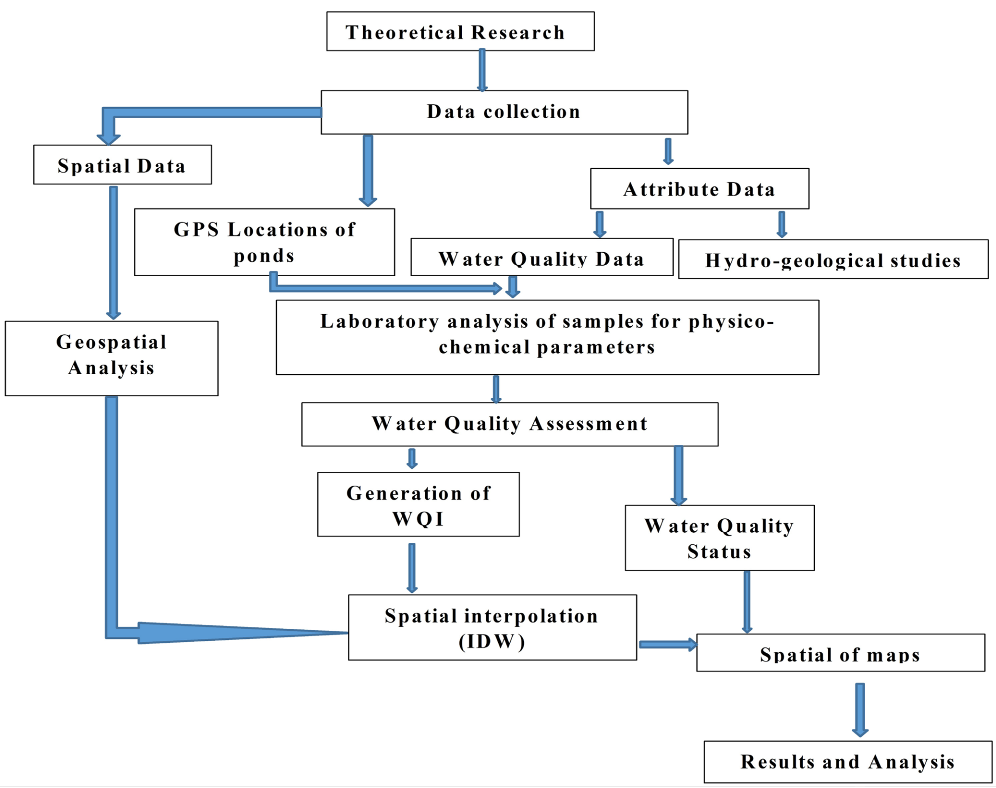

Figure 2. Detailed research framework chart utilized in this study.

Table 4. Statistical analysis of groundwater quality parameters and its coherence with BIS and WHO standards.

Parameters	Statistical analysis of observed value				BIS/WHO standards
	Min	Max	SD (σ)	Mean	
pH	3.99	8.3	1.2790952	5.112	8.5
EC (us/cm)	30.6	508	134.0772	190.92	3000
TDS (ppm)	10	115	32.466906	26.9	1000
BOD (mg O_2/L)	0.952	3.344	0.8241286	1.6938	300
Turbidity (NTU)	1.93	15.67	5.5084369	7.079	5
COD (mgO_2/L)	7.4	19.4	4.7548338	12.58	10
Fe^{2+} (mg/L)	0.08	2.18	0.7858534	0.609	1
Mg^{2+} (mg/L)	5.4	18.7	3.9784978	9.52	100
Ca^{2+} (ppm)	7.24656	12.97452	1.821102	8.360622	300
NH_3 (mg/L)	0.8	2.5	0.5015531	1.26	1
NO_3^- (mg/L)	11.4	17.5	2.4778127	13.98	50
Alkalinity (mg/L)	3.4	20.1	5.6938661	7.73	600

*The lower value denotes the acceptable/desirable limit and the higher value denotes the permissible limit in the absence of an alternate source (BIS).

2.3.1. Data Processing

Calculation Weighted arithmetic index method (Brown et al., 1972), the relative weight (W_n) or the unit weight of the n^{th} water quality parameter is computed from the following equations:

$$W_n = \frac{k}{s_n} \quad (1)$$

where,

$$k = \frac{1}{\frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} \ldots + \frac{1}{s_n}} = \frac{1}{\sum_{n=1}^{n} \frac{1}{s_n}} \quad (2)$$

S_n = Standard desirable value of the nth parameters.

On summation of all selected parameters unit weight factors, $W_n = 1$.

Calculate the sub-index (Q_n) value by using the formula.

$$Q_n = \left\{ \frac{V_n - V_o}{S_n - V_o} \right\} \times 100 \quad (3)$$

Q_n = the quality rating of the nth parameter;

V_n = mean concentration of the n^{th} parameter observed;

S_n = standard desirable or desirable value of the n^{th} parameters;

V_o = actual values of the parameters (generally $V_o = 0$ for most parameters except for pH);

n = number of water quality parameters.

All the ideal values (V_o) are taken as zero for drinking water except pH and dissolved oxygen (Tripathy & Sahu, 2005). In the case of pH, the ideal value is 7.0 (for natural/pure water) while the permissible value is 8.5 (for polluted water). Therefore, the quality rating for pH was calculated from the equations respectively as shown below:

$$Q_{\mathrm{pH}} = 100\left[\left(\frac{V_{\mathrm{pH}} - 7.0}{8.5 - 7.0}\right)\right] \tag{4}$$

where, V_{pH} = observed value of pH. If, $Q_n = 0$ implies a complete absence of contaminants, while $0 < Q_n < 100$ implies that, the contaminants are within the recommended standard. When $Q_n > 100$ implies that, the contaminants are above the standards. Water Quality Index (WQI) levels and the corresponding water quality status determined through the Weighted Arithmetic Index WQI method are presented in **Table 5**.

Combining steps 1 and 3, WQI is calculated as follows:

$$\mathrm{WQI} = \frac{\sum_{n=1}^{n} W_n Q_n}{\sum_{n=1}^{n} W_n} \tag{5}$$

2.3.2. Correlation Analysis

The physicochemical indices of the water were correlated by calculating the Pearson correlation coefficient (r). The formula is expressed as:

$$r = \frac{\sum_{i}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum_{i}^{n}\left(x_i - \bar{x}\right)^2}\sqrt{\sum_{i}^{n}\left(y_i - \bar{y}\right)^2}} \tag{6}$$

3. Results and Discussion

Several factors leading to the very poor or unsuitable consumption quality status of the artificial fishponds as mentioned, were linked to maintenance lapses, climate change, and irregular monitoring of the ponds. Two were good with respect to status at the time of research as shown (**Figure 3**). The **Table 6** below shows the apparent results for the different pond locations. It was also evident that the water quality of the fishponds is being negatively impacted by uneaten food, excrement, and metabolic wastes. The most significant factor influencing fish health and performance in aquaculture is water quality (Boyd, 2017; Tripathy & Sahu, 2005). In aquaculture, maintaining ideal water quality is essential to lowering disease incidence and stunted fish growth (Boyd, 2017). However, due to a lack of funding, limited resources, and expertise, maintaining water quality in small-scale aquaculture is difficult (Ssekyanzi et al., 2022; Tumwesigye et al., 2022).

3.1. Water Quality Indices of the Selected Monitoring Sites

The water quality index gives a brief indication of a large number of water quality

Table 5. Water quality index level and water quality status based on the weighted arithmetic index WQI method (Brown et al., 1972).

WQI	Water quality status
0 - 25	Excellent
26 - 50	Good
76 - 100	Very poor
Above 100	Unsuitable for consumption

Table 6. Water quality parameters and the specific sampling locations.

Parameters	Bo_001	Bo_002	Bo_003	Kenema_001	Kenema_002	Kenema_003	Kenema_004	Moyamba_001	Moyamba_002	Kono_001	Standard value (Sn)
pH	5.6	4.5	5.56	8.3	5.58	4.5	3.99	4.6	4.5	3.99	8.5
EC (us/cm)	185	167	252	508	149	167	30.6	175	245	30.6	3000
TDS (ppm)	16	10	14	115	10	10	21	10	42	21	1000
BOD (mg O_2/L)	1.78	0.952	1.68	3.344	2.964	0.952	1.44	1.056	1.33	1.44	300
Turbidity (NTU)	14.2	2.6	13.79	8.66	15.67	2.6	4.32	1.93	2.7	4.32	5
COD (mgO_2/L)	13.6	10.3	7.8	8.1	7.4	10.3	19.4	17.9	11.6	19.4	10
Fe^{2+} (mg/L)	1.87	0.19	0.37	2.18	0.18	0.19	0.08	0.08	0.87	0.08	1
Mg^{2+} (mg/L)	8.8	5.4	8.1	18.7	8.3	5.4	8.4	10	13.7	8.4	100
Ca^{2+} (ppm)	7.76538	7.24656	7.85892	12.97452	10.08912	7.24656	7.64976	7.87908	7.24656	7.64976	300
NH_3 (mg/L)	0.8	1	1.2	0.9	2.5	1	1.5	1.3	0.9	1.5	1
NO_3^- (mg/L)	11.5	13.5	16.6	17.1	17.5	13.5	11.4	15.4	11.9	11.4	50
Alkalinity (mg/L)	6.7	4.9	16.3	20.1	5.1	4.9	4.4	3.4	7.1	4.4	600

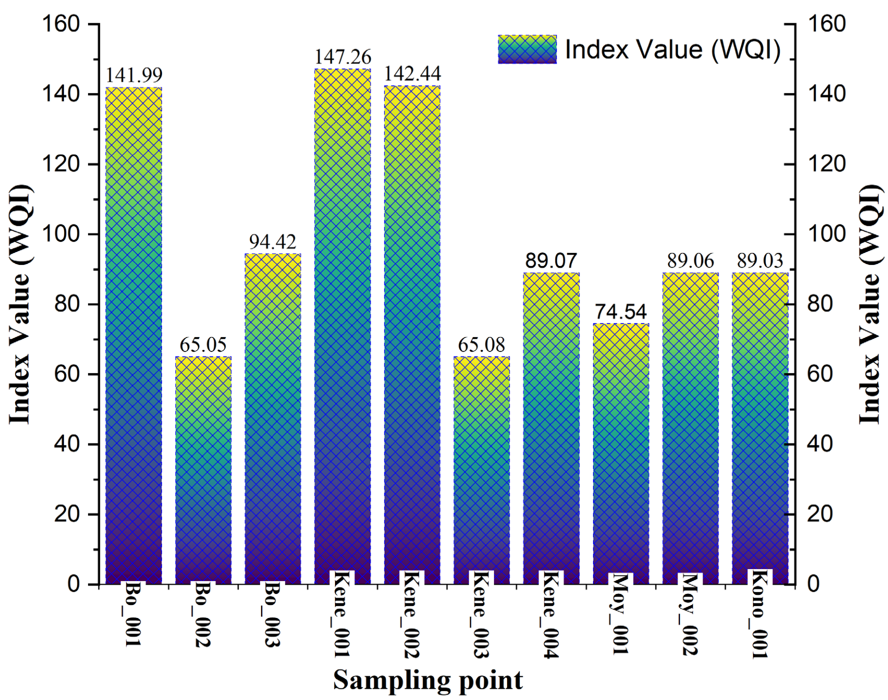

Figure 3. Shows the peak values of the different sites.

parameters into a single term (for example; excellent, good, poor, bad, unsuitable for drinking, etc.) based on WQI range level value for easy reporting to the concerned users (Boyacioglu, 2010). This will help in taking safety measures. The WQI was used to compare the quality of water for different water bodies in a particular region, and it gives an idea regarding the quality of water to the people (Jagadeeswari & Ramesh, 2012).

In this study based on the selected parameters as discussed above, the groundwater quality maps have been prepared with the help of ArcGIS software 10.7.1 (**Figures 4-7**). In the following line, the various parameters considered in the study area are discussed. Since the WQI is a summative compilation of several biophysical and chemical characteristics of water, it is indicative of its holistic quality. The computed WQI values for the whole study province range between 65.05 to 142.44 with overall higher WQI values and high spatial variability, giving rise to 50% of the samples from the region showing very poor, 30% unsuitable for drinking and 20% good category as per WQI.

3.1.1. Levels of Primary Physicochemical Parameters Determining the Total Quality of Water in the Study Area

1) pH: pH, which is defined as the negative logarithm of the hydrogen or hydroxonium ion concentration, is an important characteristic of water generally

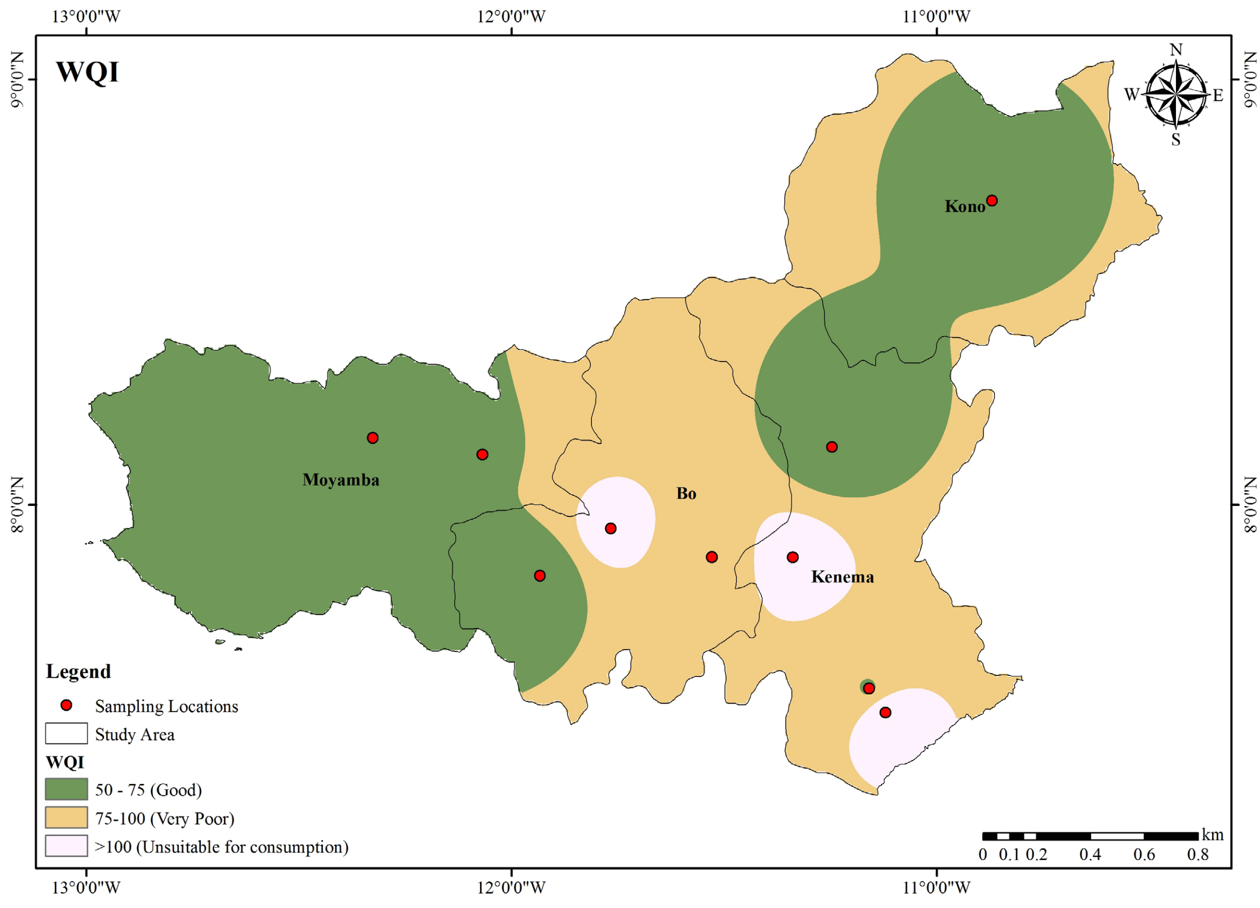

Figure 4. The WQI map of the study area.

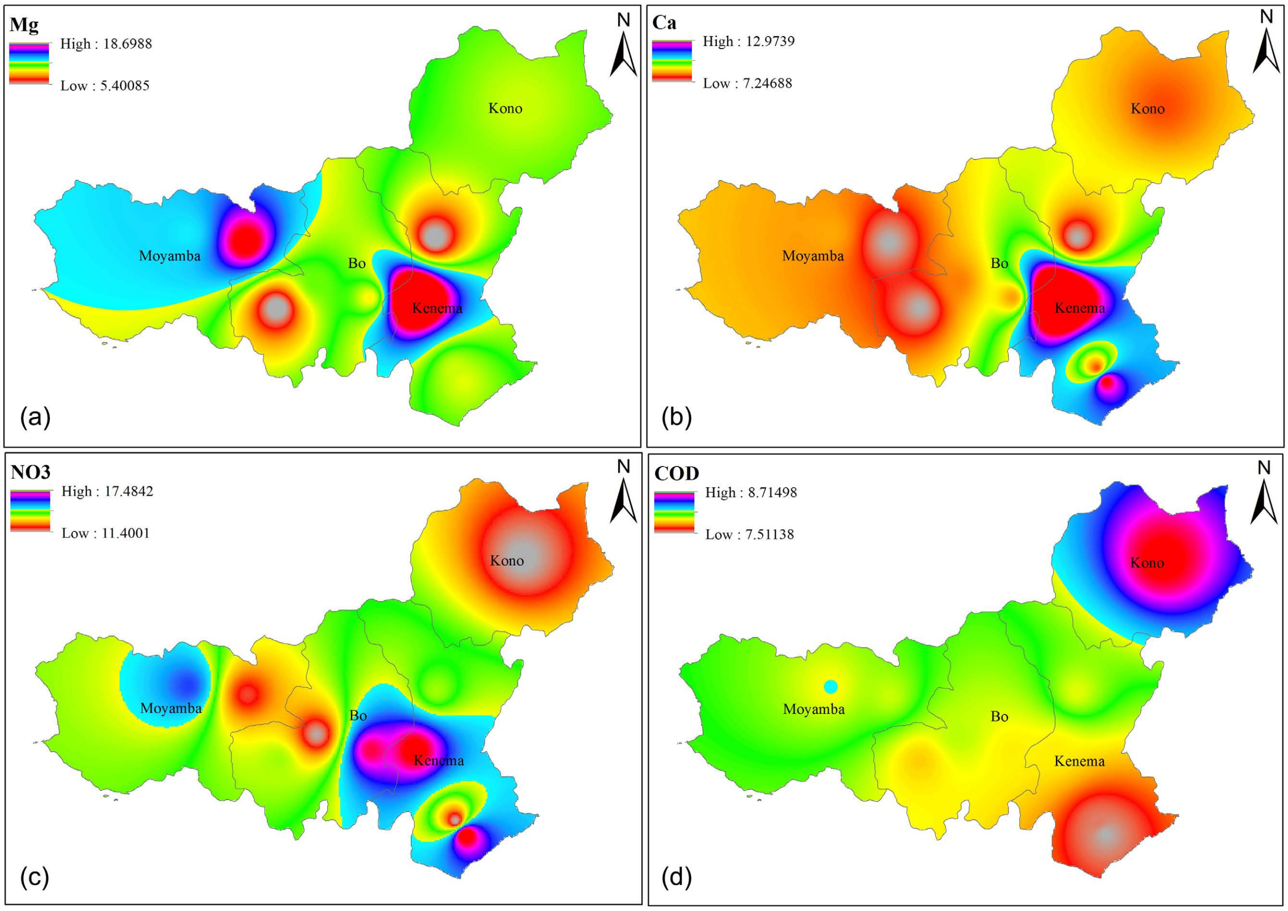

Figure 5. (a)-(d) Spatial distribution map of Mg^{2+}, Ca^{2+}, NO_3^- and COD.

and fishpond water in particular (Agbaire et al., 2015). The value of the pH of water samples is a pointer to the nature of the solution (acidity or alkalinity). It has been reported that fish have an average blood pH of 7.4; hence fishpond with a pH value close to the aforementioned pH value is considered favorable for fish cultivation (APHA et al., 2017). APHA et al. (2017), Beutler et al. (2014), Khan et al. (2023) opined that a pH between 6 and 9 was suitable for increased fish production. Extreme pH values (too acidic or too alkaline) can affect aquatic life. While a fluctuation outside the normal range might not directly affect the WQI, extreme values may indirectly contribute to poor water quality by impacting aquatic organisms' health. However, the pH values of the region are observed to be within permissible limits of the referenced standard (3.99 - 8.3).

2) Turbidity (NTU): High turbidity, caused by suspended particles, indicates poor water clarity. It can reduce sunlight penetration, affecting aquatic plant life, and can also impact fish by clogging their gills and reducing feeding efficiency, contributing to poor water quality. However, the turbidity values of the region are observed to be within (1.93 - 15.67), which shows four (4) sampling sites (Bo_001, Bo_003, Kene_001 and Kene_002) exceed permissible standard limit.

3) Chemical Oxygen Demand (COD): High COD values indicate the presence of organic pollutants. These can lead to oxygen depletion as microorganisms

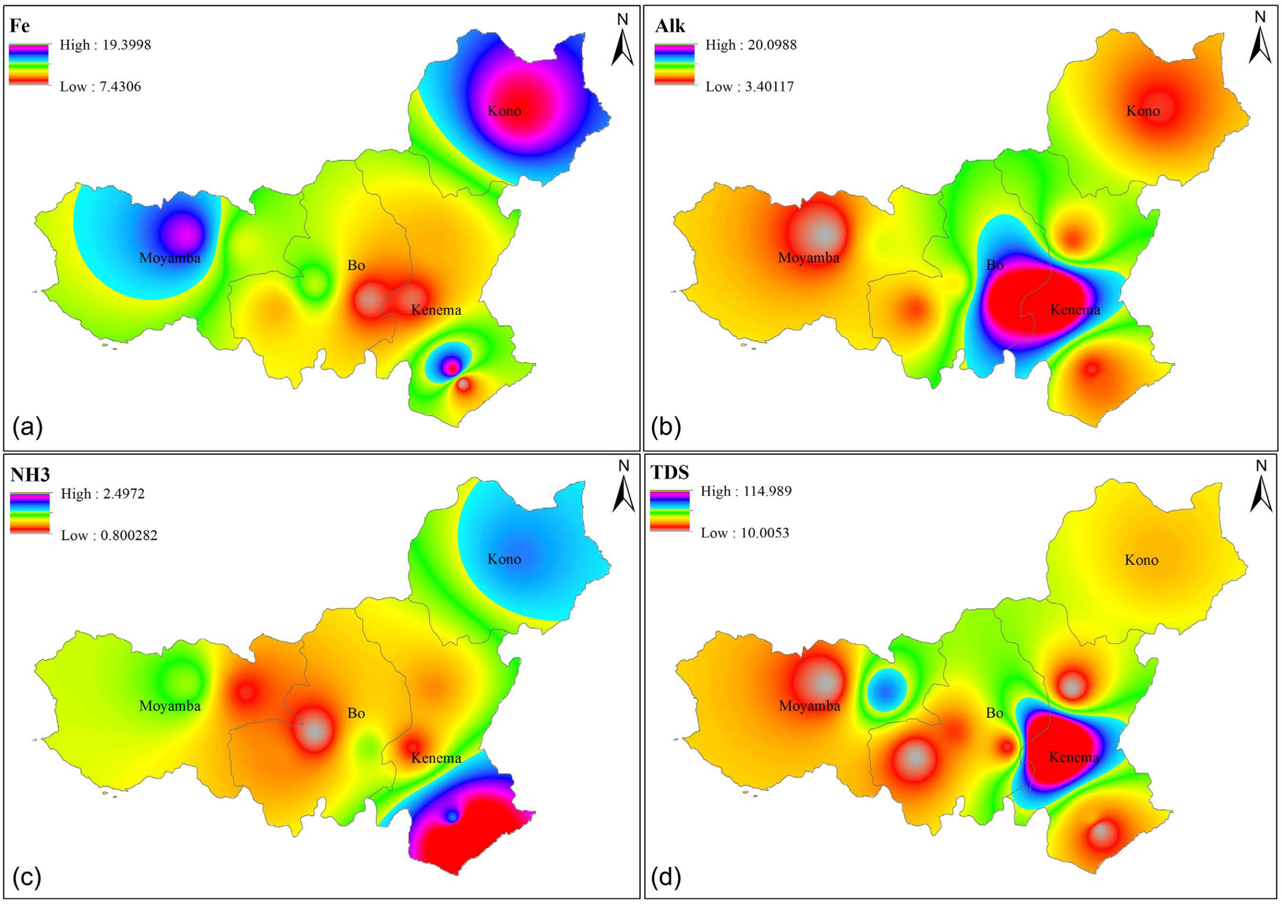

Figure 6. (a)-(d) Spatial distribution map of Fe^{2+}, Alk, NH_3, and TDS.

decompose the organic matter, causing harm to aquatic life and indicating poor water quality. Higher COD levels mean a greater amount of oxidizable organic material in the sample, which will reduce dissolved oxygen (DO) levels. A reduction in DO can lead to anaerobic conditions, which is deleterious to higher aquatic life forms (Ram et al., 2021). The COD values of the region are observed to be within (7.4 - 19.4), which shows seven sampling sites exceed the permissible standard limit with the exception of Bo_003, Kene_001, and Kene_002.

4) Iron (Fe^{2+}): Elevated Fe^{2+} levels can result from industrial discharges or natural sources. While not always directly harmful, high Fe^{2+} content can negatively impact water taste, stain plumbing fixtures, and in high concentrations, can affect aquatic life and contribute to poor water quality. The most common source of Fe^{2+} in groundwater is the weathering of iron-bearing minerals and rocks. Iron occurs naturally in the reduced Fe^{2+} state in the aquifer, but its dissolution increases its concentration in groundwater. Iron in this state is soluble and generally does not create any health hazard. If the Fe^{2+} state is oxidized to the Fe^{3+} state in contact with atmospheric oxygen or by the action of iron-related bacteria which forms insoluble hydroxides in groundwater, the concentration of Fe^{2+} in groundwater is often higher than that measured in surface water (Heiß et al., 2020). In the study area, the iron ranges between 0.08 to 2.18 mg/L. Only

Bo_001 and Kene_001 were found to be above the permissible limit of 1.0 mg/L.

5) Ammonia (NH_3): High concentrations of NH_3 can result from pollution (e.g., agricultural runoff, sewage). They can lead to eutrophication, excessive algae growth, oxygen depletion, and fish kills, contributing significantly to poor water quality. It was apparent from the results that the sampling points Bo_003, Kene_002, and 004, Moyamba_001 and Kono_001 are above the permissible limit of 1.0 mg/L.

Several locations have water quality deemed "unsuitable for consumption," while others range from "good" to "very poor." It is essential to address and improve water quality in locations categorized as "unsuitable for consumption" and "very poor" to ensure safe and healthy water sources (Figure 3). It was also clear from the calculation that the smaller the mean concentration value of the pH as compared to the ideal value (7.0) the smaller the WQI value and better the water quality.

3.1.2. Correlation Matrix Analysis

Correlation analysis is used to determine whether the ions in the hydrochemical components come from the same source (Hai et al., 2023). Table 7 shows Pearson's correlation matrix between the various 12 water quality parameters formed and analysed using MS Excel 2021. The correlation coefficient between the matching pairs of parameters is represented by each cell in the matrix. pH, EC, TDS, BOD, and Ca^{2+} have a strong positive correlation with all parameters reflecting more than 0.50 correlation value except for COD and NH_3, indicating a potential relationship between these parameters and also suggesting interdependence between these parameters.

COD has a strong negative correlation with almost all parameters, indicating potential relationships where increases in one parameter are associated with decreases in the other.

Table 7. Matrix of correlation coefficients for the 12 water quality variables from the study area.

	pH	EC	TDS	BOD	NTU	COD	Fe^{2+}	Mg^{2+}	Ca^{2+}	NH_3	NO_3^-	$CaCO_3^-$
pH	1.000											
EC	0.894	1.000										
TDS	0.790	0.809	1.000									
BOD	0.835	0.579	0.650	1.000								
NTU	0.513	0.219	0.022	0.660	1.000							
COD	−0.603	−0.648	−0.263	−0.480	−0.495	1.000						
Fe^{2+}	0.788	0.745	0.733	0.565	0.370	−0.320	1.000					
Mg^{2+}	0.709	0.761	0.914	0.624	0.059	−0.157	0.705	1.000				
Ca^{2+}	0.901	0.724	0.804	0.925	0.397	−0.435	0.584	0.725	1.000			
NH_3	−0.145	−0.416	−0.321	0.353	0.353	0.001	−0.511	−0.238	0.171	1.000		
NO_3^-	0.648	0.579	0.276	0.612	0.451	−0.667	0.084	0.272	0.665	0.361	1.000	
$CaCO_3^-$	0.840	0.844	0.741	0.610	0.411	−0.569	0.627	0.645	0.672	−0.305	0.547	1.000

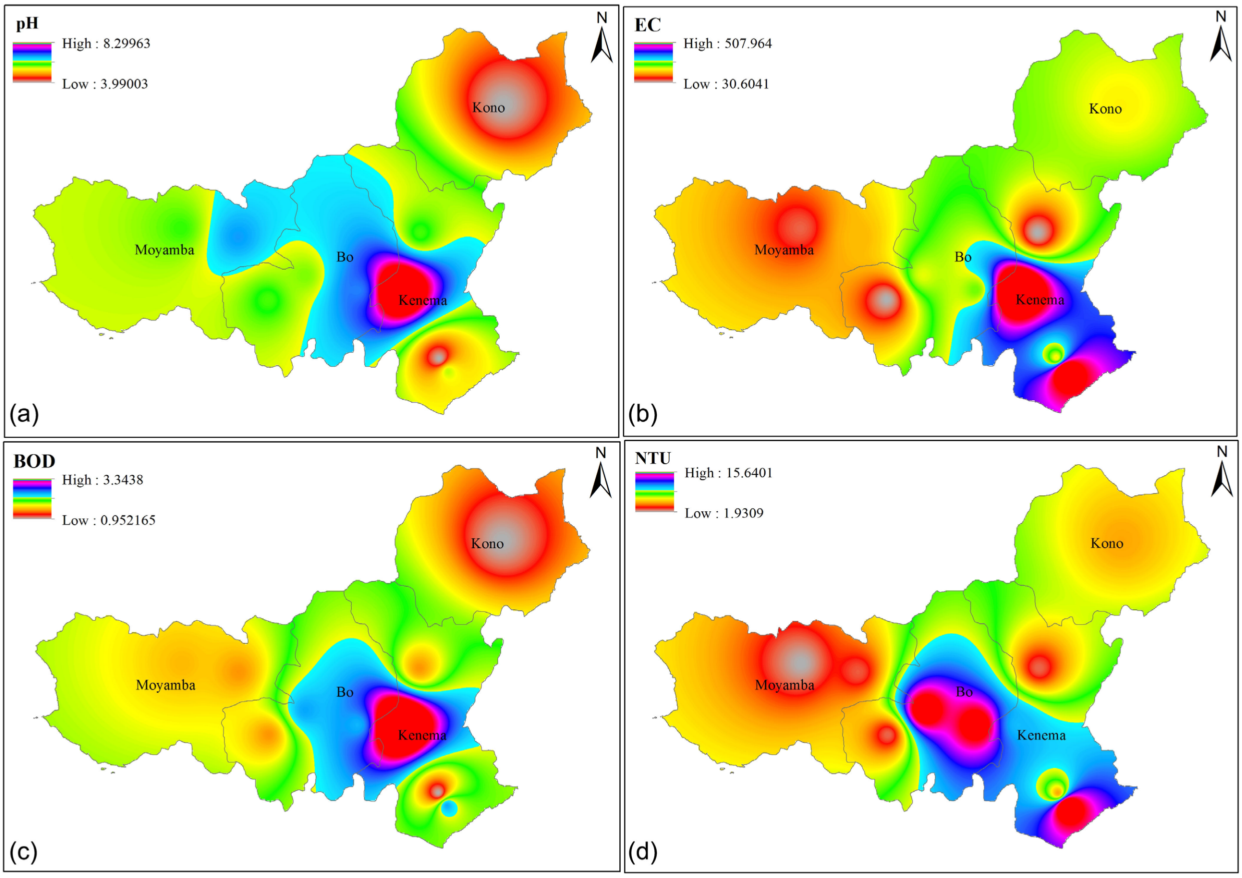

Figure 7. (a)-(d) Spatial distribution map of pH, EC, BOD, and NTU.

NTU, NH_3, and NO_3^- show weak correlations with several other parameters, suggesting a less pronounced relationship.

Further, BOD vs Ca^{2+}, TDS vs EC, pH vs EC, TDS as $CaCO_3^-$ vs Ca^{2+} and Mg^{2+}, $CaCO_3$ vs Fe^{2+}, Mg^{2+} and Ca^{2+}, BOD vs NTU, Mg^{2+} and Fe^{2+} reveals the most pertinent correlation, which has a greater influence on the overall evaluation of groundwater quality than any other major radicals and physical parameters (Ram et al., 2021). However, the majority of quality parameters are positively correlated with each other

3.2. Spatial Distribution Pattern

The spatial distribution pattern of the maps of the artificial fishpond water quality assessment parameters has been generated (Figures 5-7). The spatial distribution pattern of the pH indicates that the central part across the Kenema and Kono districts has a low pH, indicating an acidic status. Kono and Moyamba districts have high concentrations of Fe^{2+}. The eastern portion of the district in Kenema has high TDS (Figure 6(d)) due to poor fluxing and anthropogenic activities. Similarly, EC is mainly highest (508 mg/L) in the eastern district part of Kenema (Figure 7(b)). This aligns with the higher TDS (significant positive correlation with EC). The alkalinity map clearly and significantly indicates that it is highest in the central part bordering Bo and Kenema by gradually decreasing alkalinity outwards (**Figure 6(b)**).

The spatial distribution map of Ca^{2+} suggests varying concentrations within permissible limits throughout the study area (**Figure 5(b)**) due to the presence of alkali feldspar in granite. Similarly, Mg^{2+} is also distributed unevenly but falls within permissible limits with an exception in the Moyamba district (**Figure 5(a)**). Nitrate (NO_3^-) in groundwater is mainly anthropogenic which could be due to leaching from waste disposal, sanitary landfills, over-application of inorganic nitrate fertilizer or improper manure management practice (Beutler et al., 2014).

In this study, it was observed that NO_3^- is within permissible limits in all districts but high in Moyamba and Kenema districts respectively (**Figure 5(c)**). The high values of nitrate in groundwater samples in the area may be due to unlined septic tanks and unplanned sewerage system that contaminates to the phreatic aquifer (Beutler et al., 2014).

4. Conclusion

The assessment of water quality across various sites reveals a diverse range of conditions, with some locations experiencing water quality issues that pose significant risks to the fish species and by extension human health. A high value of WQI has been found, which is due to higher levels of turbidity, COD, NH_3, and Fe^{2+}. Specifically, Bo_002, Kene_003, and Moy_001 sites were good with the remaining sites being identified as either very poor or unsuitable for consumption, highlighting ongoing challenges in maintaining acceptable water quality standards. This study provides a valuable reference for the development, management, and utilization of artificial fishponds in the study area. A comprehensive and multifaceted approach is essential to address the diverse water quality challenges identified across the sites. Immediate actions, ongoing monitoring, community engagement, and collaboration with stakeholders are key components of a sustainable strategy to improve and maintain water quality in the region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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