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Original article

Assessment of water quality variables of River Kaduna using remote sensing and geographic information system

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ABSTRACT

The study utilizes remote sensing and a geographic information system (GIS) for mapping water quality conditions of the River Kaduna, as a proxy to fish production. Spatial distribution of Nitrate, Phosphate, Dissolved oxygen, Water Temperature, Depth, Chloride, Alkalinity, Hardness, pH and Conductivity has been applied. The co-ordinate points of each identified sampling stations were taken using Global Positioning System (GPS). A Google Earth image from the Internet acquired in April 2012 was processed by digitizing. Overall map of the water bodies identified was produced by carving out the shape of the water body. Ten maps were. produced to geographically demonstrate the water quality parameters sampled using range values obtained. The results showed that stations III, IV and V of the river favour fish production than stations I and II. The study confirms that remote sensing coupled with GIS would be a very useful tool for mapping water quality.

Keywords: GIS, Remote Sensing, QGIS Google earth image, Mapping, fish production

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INTRODUCTION

In today's advanced era, billions of data are obtained daily and much of the information includes a component that tells the geographic location of the data. River Kaduna is not an exception to this, because any ecosystem depends on the essential life given properties that a body of water provides. As such, this study linked Remote Sensing and GIS concept to water quality in order to develop a data base that will emerge as spatial decision process on the quality of River Kaduna for fish productivity. The use of the physico-chemical properties to assess water quality gives a good impression of the status, productivity and sustainability of such water body. The water quality parameters were selected because of their significant impact on aquatic life and human consumption (Pehlivan and Yilmaz, 2005).

MATERIALS AND METHODS

Description of the Study Area

River Kaduna is the main tributary of Niger River, in central Nigeria. It rises from the Jos Plateau 18 miles (29 km) southwest of Jos town near Vom and flows in a north-westerly direction to bend 22 miles (35 km) northeast of Kaduna town (Iloeje, 1982). It then adopts a south-westerly and southerly course before completing its 340-mile (550-kilometre) flow to the Niger River in Nupeko village own by kuta Mureji (opposite Pategi) in Niger state.

The River Kaduna is located in the southern part of Kaduna Metropolis (Latitude 0327264 – 0327510N and Longitude 1160688 – 1161048E) about 645 meters above sea level. The stream takes its source within the Kalapanzy (Artillery) barracks in Kaduna south and joins other river-lets, which empty into River Kaduna (Mallo, 2001). It is a shallow, fast flowing stream. The area is characterized by flat land surface and easily worked sandy loam soil.

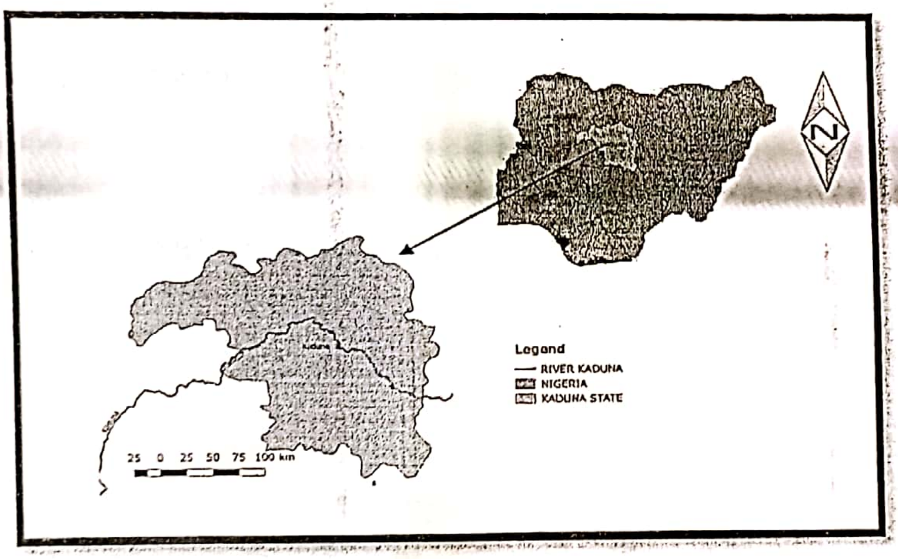

Figure 1: Nigeria indicating the study area of River Kaduna.

To access the water quality variables and primary productivity of River Kaduna using GIS methods, different materials were used ranging from digital camera, topographic maps, GPSMAP 76, Garmin Product; 4000C fish finder, Lovibond raw water test kits and research data from various reports and a number of GIS techniques to acquire the data. Data sources were based on primary and secondary sources

Primary data: This was generated through field surveys, water samples were collected in plastic jar. Depth and Temperature were measured *in-situ* at the study area. At each sampling site, field measurement was carried out; including: (i) - the geographic location, using a GPSMAP 76, Garmin Product; (ii) - water depth and temperature using a fish finder (4000c).

Table 1: Location of sampling points as Sources of Primary Data collected

Sampling Points	Location	Description
I	200m east of the River away from the road-bridge junction.	The stream is wider.
II	80m away from station I.	There are aquatic plants growing along the bank e.g. Water Hyacinth (Plate 3.1).
III	80m from station II.	Human activities here include farming. The vegetation is mainly grasses, creeping plants, and sugarcane and maize plants.
IV	80m away from station III	Irrigation is taking place on the catchment area. Human activity here is dumping of agricultural and industrial waste.
V	80m away from station IV	It is almost directly under the train bridge.

Secondary data

Organized primary data in different format such as e.g. Topography maps, Administrative map and the Google Earth Image covering the study area. The administrative map of Nigeria showing Kaduna (Figure 1) with scale of 1:750000 was acquired from OSM online and the study area was extracted from the map which was digitized and geo-referenced using QGIS software.

Spatial data

Spatial data gives information about the location of an object related to earth, usually in the form of X, Y, Z (3 dimensional coordinates, GPSMAP 76. Garmin product was used to acquire this data (figure 2).

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Limnological Sampling

Data on physico-chemical parameters of the water body were sampled monthly for four months, from (April-July 2012) using five sampling stations. Water samples were collected in 1 litre plastic container and transported to wet and dry laboratory of WAFT department, FUT Minna for analysis for pH, Alkalinity, Hardness, Chloride and conductivity using Lovibond Water Quality Test Kits, while dissolved oxygen (DO) bottle was used to collect water sample for Dissolved Oxygen analyses. Nutrient concentrations (phosphate-phosphorus, PO4-P; and nitrate-nitrogen, NO_3-N) were determined spectrophotometrically using a HACH DR/2000 direct reading spectrophotometer. Specific nutrient concentrations were read from calibration curves (APHA 1998

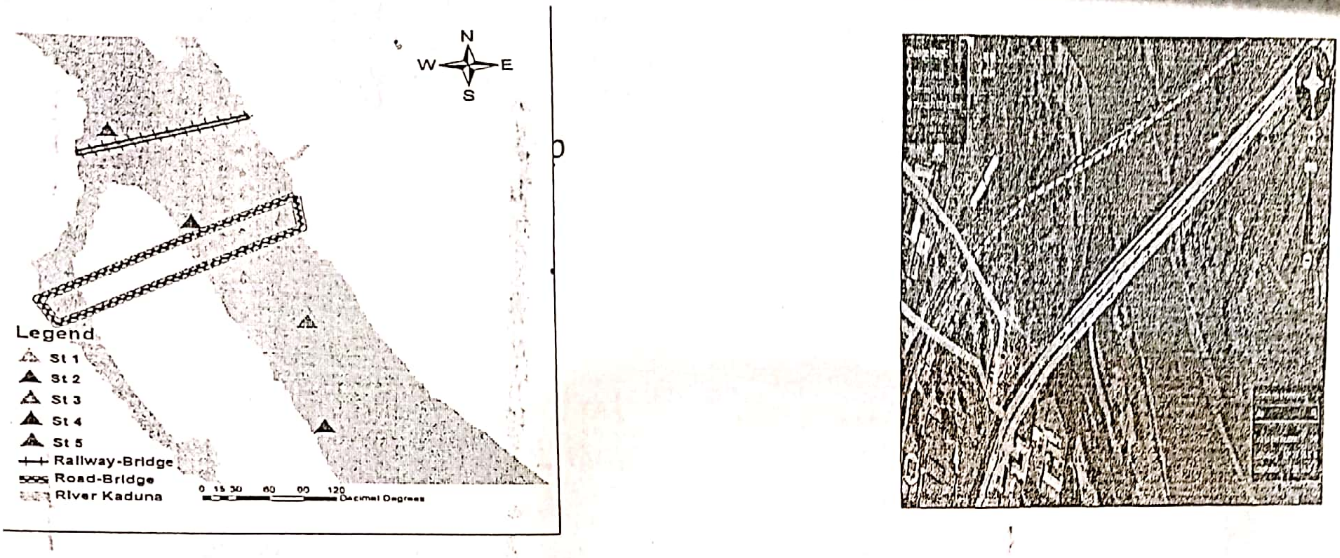


Figure 2 Sampling station and Google Earth Image of River Kaduna at stadium road in Kaduna

Data Analysis

Data collected was analyzed using the one-way analysis of variance (ANOVA) to determine the variations due to stations and months using a Statistical Package for Social Sciences (SPSS 19.0) (SAS Institute, 2003). Means were compared using the Duncan Multiple Range Test (DMRT) at $P<0.05$.

GIS Analysis:

The GIS analysis was carried out using QGIS software in order to make spatial distribution maps of the parameters. The boundary of the lake was digitized using the polygon shape file. The geographic locations (Longitudes and Latitudes) of the sampled sites were inserted as a basic separate layer and a database table containing the results of the different water quality parameters was created. For each parameter, the spatial analysis was applied based on the interpolation and surface analysis methods yielding a contour map. Then a clip image made up of the classified spatial distribution map for the measured water and plankton parameter was extracted.

RESULTS AND DISCUSSION

Physico-Chemical Parameters

Criteria for assessing the productivity of the river were based on eight parameters of Physico-chemical with ranges and rating based on the level of importance of the parameters that influenced the fish yield. Each parameter was classified on a scale of their ideal ranges (Table 1).

Table 1: The ideal Ranges by Various Authors

PARAMETERS	IDEAL RANGES	AUTHORS
Temperature	22-32°C	Dupree and Hunner (1984)
Hydrogen ions concentration (pH)	6.7-8.6	Boyd and Lichktoppler (1985)
Dissolved oxygen (D.O)	2-15mg/l	Beadle (1981)
Alkalinity	20-300mg/l	Boyd (1985)
Hardness	40-300mg/l	Boyd and Tucker (1992)
Conductivity	120 - 340μs/cm	WHO (1996)
Chloride	20-250mg/l	Hale and Groffman (2006)
Phosphate	0.1-0.2mg/l	Freeman (2002)
Nitrate	<10mg/l	USGS (1996 – 1998)

Source: Adapted from Ibrahim and Sadiku (2013).

Depth
There was no significant difference in the water depth recorded across the stations ($p<0.05$), from the lowest 3.11±1.49 (station I) to the highest 5.66±3.87 m (station V) (Table 3). Therefore, primary productivity is not greatly affected. This is in line with APHA (1980) that depth not greater than 10 meters does not affect primary productivity. There is a positive correlation between depth and dissolved oxygen throughout the stations. Depth was highest during the month of July (6.51±1.37) and lowest in the month of April (2.7±1.83). The highest depth recorded in station V (figure 3a) may be the reason why the dissolved oxygen recorded at the station was the lowest.

Dissolved Oxygen (D.O)
The dissolved oxygen concentration ranged between 13.0±5.29mg/l (station V) and 18.5±8.69mg/l (station I). Stations II and IV were within the recommended range of 2-15mg/l by Beadle, 1981 (Table 1) while I and III were a little above the recommended range for fish and primary production to thrive well. The least value was recorded in the month of April which is considered suitable for fish productivity. The highest dissolved oxygen recorded in July in stations III, IV and V was due to lower water temperature compared to station I and II, and it shows a negative correlation with Depth (Table 4). The dissolved oxygen values were higher at the faster flowing sampling stations than the gentle-flowing stations with the highest of 18.75mg/l observed in station III and the lowest 13.0mg/l in station V.

Temperature
The result (Figure 3c) showed that water temperatures at all stations were ideal for fish production. The mean temperatures were similar along the stations; no significant difference was observed ($P<0.05$) (Table 3). Maximum temperature of 27 °C was recorded in June, while the lowest temperature of 25 °C was recorded in April (Table 2). Highest surface water temperature recorded in station I, II and III throughout the sampling period may be due to surface heating and lesser mixing of the water unlike in station IV and V where water current is fast and turbulent, thus allowing an even distribution of heat throughout water column. Higher temperature values recorded in June were expected since heat from sunlight increases temperature of surface water. Similarly, the drop in water temperature in July is attributable to heavy rainfall experienced during the period. The water temperature correlated negatively ($- 0 \leq P \leq - 0.49$) with the Depth, DO, (Table 4) pH and Conductivity which means that an increase in the water

temperature brings about a reduction in the DO, pH and Conductivity but it has a positive correlation with Hardness, Alkalinity and Chloride. Also, increase in depth brings about reduction in the water temperature (Figure 1d). Alabaster and Lloyd, (1980) reported that temperature of natural inland waters in the tropics generally varies between 25°C and 35°C. This finding is similar with the results observed in the River Kaduna area.

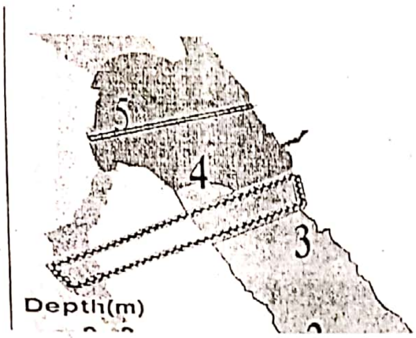
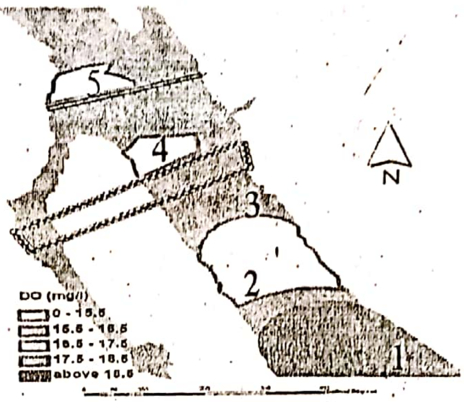
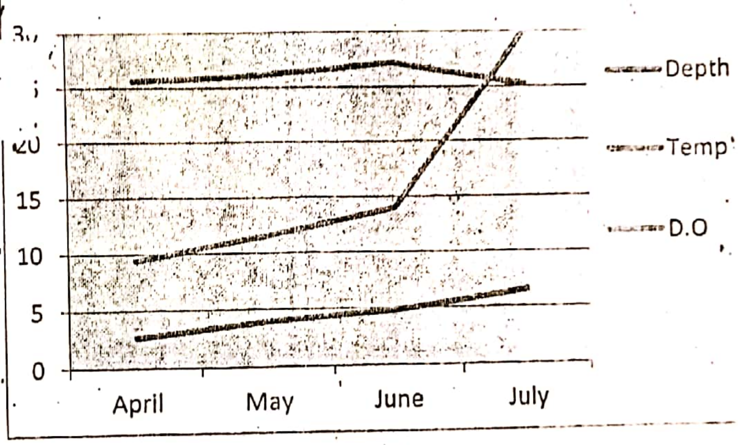


Figure 3c: Water Temperature



3d: Relationship between Depth, Dissolved Oxygen
mperature



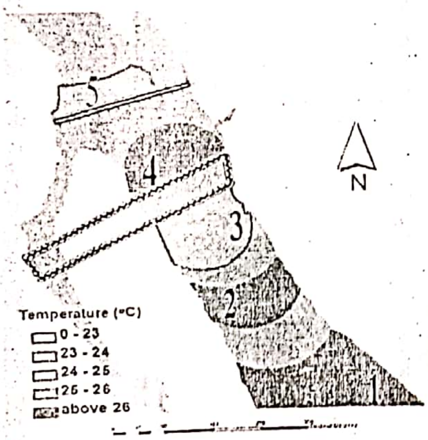


Table 3: Variation of the Parameters across the Stations.

Parameters	Station 1	Station 2	Station 3	Station 4	Station 5
Depth (m)	3.11±1.49^{a}	4.57±1.61^{a}	4.54±1.09^{a}	4.68±1.30^{a}	5.66±3.87^{a}
Temperature(°C)	26.75±2.22^{a}	26.63±0.95^{a}	25.25±0.96^{a}	26.18±0.24^{a}	25.50±1.08^{a}
D.O. mg/l	18.50±8.69^{a}	15.50±9.98^{a}	18.75±18.28^{a}	15.50±8.39^{a}	13.00±5.29^{a}
pH	6.69±0.09^{a}	7.13±0.33^{a}	7.11±0.34^{a}	7.16±0.42^{a}	7.06±0.34^{a}
Conductivity µs/cm	90.02±20.52^{a}	91.98±23.34^{a}	91.78±32.17^{a}	111.60±47.61^{a}	114.10±32.51^{a}
Hardness mg/l	53.00±4.76^{a}	56.00±10.71^{a}	51.50±10.63^{a}	52.00±18.76^{a}	44.50±13.30^{a}
Alkalinity mg/l	61.25±17.02^{a}	46.25±11.09^{a}	54.50±14.75^{a}	59.25±27.61^{a}	45.50±9.71^{a}
Chloride	36.72±17.67^{a}	37.97±18.51^{a}	39.05±14.33^{a}	65.73±46.27^{a}	53.15±24.55^{a}
Phosphate	0.26±0.19^{a}	0.15±0.22^{a}	0.14±0.12^{a}	0.22±0.19^{a}	0.35±0.53^{a}
Nitrate	1.97±0.57^{a}	2.05±0.74^{a}	1.93±0.40^{a}	1.87±0.58^{a}	1.89±1.21^{a}

Means in the same row having Different Superscripts are Statistically Different from each other ($P<0.05$)

Table 2: Monthly Variation of the Parameters.

Parameters	April	May	June	July
Depth (m)	2.7±1.83^{b}	3.99±1.63^{b}	4.83±1.68^{ab}	6.51±1.37^{a}
Temperature(°C)	25.6±0.65^{b}	26.2±0.27^{ab}	27.24±1.76^{a}	25.2±1.09^{b}
D.O. mg/l	9.4±1.95^{b}	11.6±1.67^{b}	14.00±7.07^{b}	30.00±9.69^{b}
Conductivity µs/cm	134.56±32.16^{a}	98.8±7.85^{b}	66.22±4.37^{c}	100.00±22.83^{b}
Hardness (mg/l)	60±9.69^{a}	42.00±0.49^{b}	51.60±7.54^{ab}	52.00±13.86^{ab}
Alkalinity (mg/l)	46.4±5.86^{a}	47.00±15.25^{a}	68.00±13.03^{a}	52.00±22.53^{a}
Chloride	35.00±4.95^{ab}	65.79±5.07^{a}	58.50±44.59^{a}	26.8±2.59^{b}
Phosphate	0.10±0.31^{b}	0.08±0.48^{a}	0.13±0.48^{a}	0.09±0.47^{a}
Nitrate	0.89±0.48^{b}	2.37±0.18^{a}	2.24±0.18^{a}	2.26±0.19^{a}

Means in the same row having Different Superscripts are Statistically Different from each other ($P<0.05$)

Table 4: Correlation Matrix of the Parameters

		Po4	No3	Do	PH	EC	HARD	Alk	CL	Depth	Temp
Correlation	Po4	1.000	-.949	-.302	-.552	.555	.399	-.166	-.214	-.646	-.115
	No3	-.949	1.000	.308	.550	-.581	-.482	.156	.243	.608	.168
	Do	-.302	.308	1.000	.534	-.259	-.050	.062	-.419	.372	-.092
	PH	-.552	.550	.534	1.000	-.073	-.409	-.388	-.150	.471	-.205
	EC	.555	-.581	-.259	-.073	1.000	.341	-.314	-.183	-.114	-.373
	HARD	.399	-.482	-.050	-.409	.341	1.000	.126	-.200	-.219	.029
	Alk	-.166	.156	.062	-.388	-.314	.126	1.000	.327	-.040	.173
	CL	-.214	.243	-.419	-.150	-.183	-.200	.327	1.000	-.008	.054
	Depth	-.646	.608	.372	.471	-.114	-.219	-.040	-.008	1.000	-.216
	Temp	-.115	.168	-.092	-.205	-.373	.029	.173	.054	-.216	1.000

Conductivity

Generally, an increasing trend was observed from station I to V with mean values varying from 90.02µs/cm ± 20.52(Station I) to 114.10 ± 32.51 (Station V) which are within the ideal range suitable for fish production (120 - 340µs/cm) Egborge, 1994 (Table 1).This could be attributed to nutrient regeneration from bottom sediments, decomposition and mineralization of microbes downstream as noted by Dibia, (2006). It was observed that conductivity does not significantly correlate with temperature and pH, which does not agree with Boyd and Lichktoppler (1984).The conductivity results (90.02 ± 20.52 – 114.10±32.51µs/cm-1) of the River Kaduna showed that the water is fresh as noted by Egborge (1994) in his study of the Warri River, Niger Delta classified waters with conductivity value above 40,000mscm-1 as marine, below 1000mscm-1 as fresh and in between the two units as brackish.

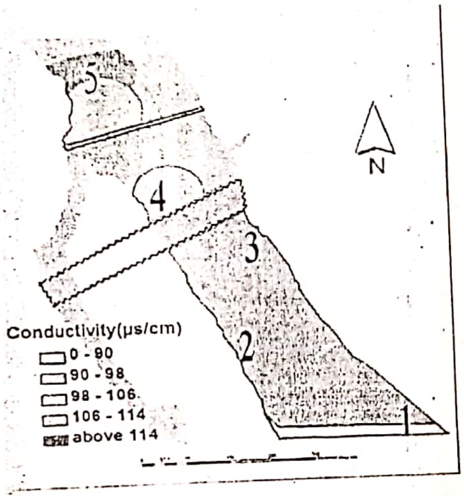


Figure 4: GIS Map of Conductivity

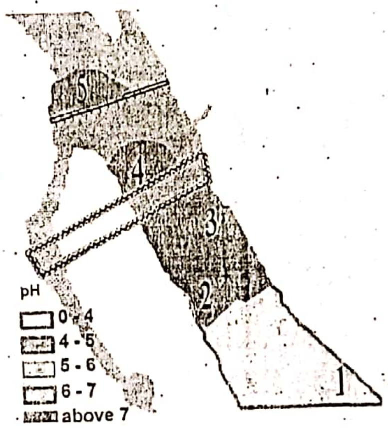


Figure 5: GIS Map of pH

pH

The higher pH recorded in the months of May and July throughout the sites and lower in other months may be attributed to increase and decrease in biogenic activities of the system. The pH of 6.71 to 7.59 (Figure 5) in River Kaduna area is within safe range for aquatic life which was only slightly acidic with low alkaline conditions. However, pH values recorded in this study were well within the preferred pH of 6.5 to 9.0 recommended for optimal fish production (Boyd and Lichktoppler 1985). The spatial distribution of pH ranging from 6.68±0.07 to 7.03±0.05 is characteristics of a tidal brackish water environment as noted by and Fagade, (2002). The pH of the water also depends on the relative quantities of calcium, carbonates and bicarbonates. High pH has been reported for most fluvial (Emere, 2000; Adakole and Annune, 2003) and lacustrine ecosystems (Kemdirim, 2005) in Northern Nigeria. This may be due to the granite, which forms the basement rock of these water bodies.

Hardness

The hardness of surface water varied from 44.5 to 56.0mg/ in the study area. Water was generally harder in July (mean 60 ± 9.69mg/l) compared to May (mean 42 ± 0.49mg/l) (Table 2). In respect to the ideal range of water hardness for fish growth, the sampled River Kaduna water is classified as ideal for fish growth. Using Thurston *et al*, 1979 classification of (0 – 75mg/l) of $CaCO_3$ hardness. GIS result (Figure 6) shows that the water can be referred to as soft water and soft water is designated to be less productive and poor for fish production. This may be due to the absence of mountainous terrain which could enhance the weathering process of the bedrock.

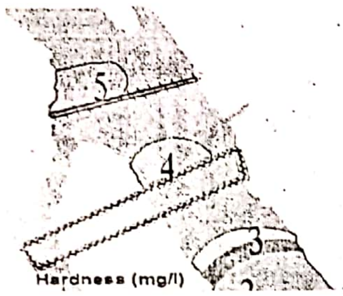


Figure 6: GIS Map of Hardness

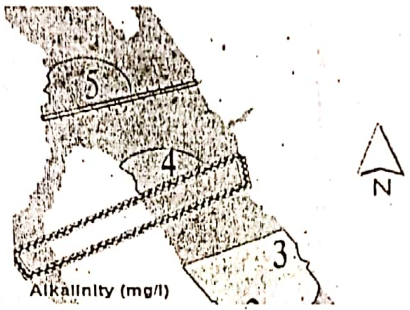


Figure 7: GIS Map of Alkalinity

Total Alkalinity

Total alkalinity recorded range from 45.5 to 61.25 mg/l during the study period. There was no significant difference ($p>0.05$) in the level of this parameter in all the stations (Table 3), however, least alkalinity was recorded in station V (45.5± 9.71mg/l) and the highest in station I (61.25±17.02). The total alkalinity recorded in July can be due to biological activity in water and lowest alkalinity in April may be due to the effect of rainfall as suggested by USGS, (1998). According to Stirling, (1985), water bodies having total alkalinity above 50 mg/l can be considered productive and this present finding showed stations I, III, and IV in River Kaduna as being productive during the study period (fig 4.8). Alkalinity was mainly due to bicarbonates. It showed an increasing tendency during second half of the year with values>50 (June and July).

Chloride

The chloride concentration varied from 36.72 mg/L to 65.73 mg/L. No water sample at any of the stations falls below or exceeds the maximum allowable limit of 250 mg/L (Table 1). Depth, DO, pH, EC and Hardness and were negatively correlated to Chloride. While total Alkalinity and Temperature correlated positively to Chloride (Table 4). The result showed that Chloride ions in stations I - IV falls within the suitable range of 25-250 mg/l considered as normal in freshwater. (Figure 8). Fish are less sensitive to chloride exposure than small, free-floating planktonic crustaceans (Evans and Frick, 2001).

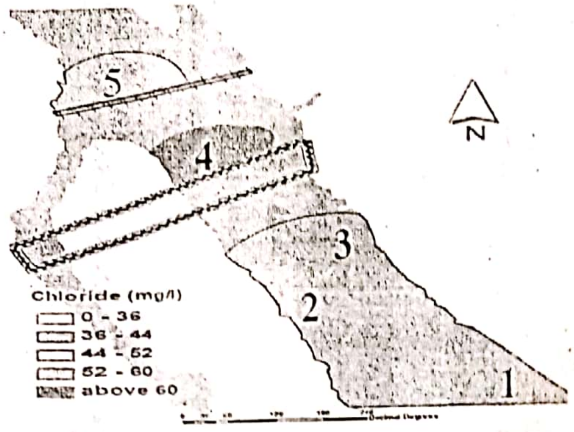


Figure 8: GIS Map of Chloride

Phosphate and Nitrate

Values of phosphates and nitrates in the stations and in various months are shown in (Table 4 and 5). Phosphate value was lowest 0.14±0.12 (station III) and highest 0.35±0.53 (station V). The concentration of Phosphate was considered suitable at stations II (0.15±0.22) and III (0.14±0.12) according to the ideal range classification (0.1 - 0.2mg/l) Freeman, (2002) (Table 1), while values at stations I, III and IV do not fall within the ideal range (Figure 9a and 9b). Nitrate values were ideal throughout the stations and it showed a strong positive correlation with depth, which means that as the water depth was increasing as a result of the rains, the nitrate values was increasing too. Also, Phosphate correlated with Conductivity positively (Table 4). The result of phosphate and nitrate depicts high values for nutrient concentrations which could be explained by increased rainfall and the entry of saltwater, especially during May to June. The reverse was the case in the Month of April, which recorded the lowest value of primary productivity

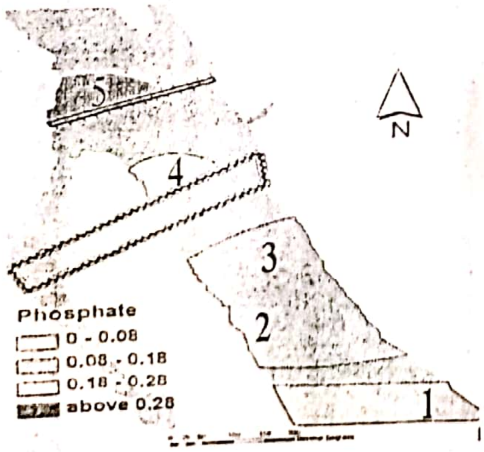


Fig 4.9a: Map of Phosphate

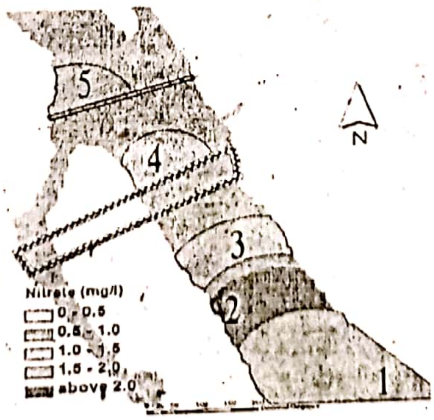


Fig 4.9b: Map of Nitrate

CONCLUSION

There is need for conservation of the aquatic resources of River Kaduna, in order to prevent overexploitation and total destruction of the habitat. With the knowledge of all the properties of physico-chemical parameters and spatial or location related data collected and all the vast amount of data source can be handled by branch of computer science known as Geographic Information System allowed a graphical representation of the regionalization results on the performance and fisheries productivity of River Kaduna

RECOMMENDATIONS

- There is need to constantly study the water quality of the river and to avoid eutrophication such as pollution from nearby farmland, through the use of herbicides, pesticides and insecticides.
- A digitized map of water bodies should be available to interested users e.g. Water Board and environmentalist that would like to make use of the information on the river.
- This research should be a guiding tool to other researchers in the department of fisheries who may want to carry out research in Geographic Information System as a tool for planning.

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