GIS/Spatial Analyses in Fishery and Aquatic Sciences (Vol.5)
Ibrahim and Sadiku - Assessment of fish-cage culture and fish-production potentials of Shiroro Lake in Niger State, Nigeria, using a geographic information system and remote sensing (181-198)
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Assessment of fish-cage culture and fish-production potentials of Shiroro Lake in Niger State, Nigeria, using a geographic information system and remote sensing

S.U. IBRAHIM
Department of Water Resources, Aquaculture and Fisheries Technology,
School Of Agriculture and Agricultural Technology,
Federal University of Technology, Minna, Niger State, Nigeria
Phone: +234 (Nigeria) 70 3902 5846; +234 (Nigeria) 80 5595 7138
E-mail: isaratu@ymail.com

S.O.E. SADIKU
Department of Water Resources, Aquaculture and Fisheries Technology,
School Of Agriculture and Agricultural Technology,
Federal University of Technology, Minna, Niger State, Nigeria.

Abstract

This study examines the application of a geographic information system (GIS) and remote sensing to assess aquaculture and fish-production potentials of Shiroro Lake, by integrating physico-chemical parameters into the GIS. This also involved identifying and estimating potential areas for aquaculture development. To provide focus for the study, five sampling sites (stations) were selected within the lake basin. Multispectral-band satellite imaging was used to detect suitable areas of the lake for aquaculture and fish production. The suitability ratings, based on the ideal ranges of all the physico-chemical data obtained from the survey, identified station IV (River Dinya junction) as the most suitable site for aquaculture, station I (Dam Crest) as suitable, station V (River Munya junction) as moderately suitable, but stations II (River Kaduna junction) and III (River Sarkin Pawa junction) as unsuitable.

Keywords

aquaculture, fish, GIS, satellite image, physico-chemical, remote sensing, suitability criteria.

1. Introduction

Attempts to extrapolate spatial structure from the aquatic environment relied on very limited data, based primarily on catch information or fishermen's "word of mouth". Its dynamic nature posed many challenges to officials in charge of managing fisheries sustainably. The advent of advanced technologies such as geographic information systems (GIS) and remote sensing (RS) has given fisheries managers and commercial operators alike access to information that will help them to achieve their respective goals because data about inaccessible areas can now be obtained from both low- and high-resolution satellite images. We present a case study on the application of GIS for evaluating aquaculture and fisheries potentials of Shiroro Lake, Nigeria.

Several surveys have been conducted on Shiroro Lake, such as those in December 1984 and April 1985 by Narescon (1993) to evaluate the biological, physical, social and economic conditions for aquaculture development. Kolo (1996) undertook a study on the limnology of the lake and its major tributaries. Shekari (2001) carried out a study on the biodiversity of fishes in the lake. However, most of these surveys did not include systematic spatial data and planning activities that would cover the lake's aquaculture and fish-production potentials. Their combination in a GIS seemed promising for exploring the potentials of the lake. Our investigation is a pioneer effort in the use of this technology in the department of Water Resources, Aquaculture and Fisheries Technology, Federal University of Technology, Minna, Nigeria.

The objectives of the study are to identify the ecological potentials of the Shiroro Lake area and to develop a GIS database as a tool for the management of fisheries in the lake by integrating physico-chemical data with GIS and RS to identify and estimate potential areas of the lake for aquaculture development.

2. Materials and methods

Shiroro Lake, with a surface area of 31.2Ha and mean depth of 22.4m (Ita et al., 1985), is the second-largest man-made lake in Nigeria. It is situated at Shiroro Gorge (9°36'22"N; 6°33'15"E) on the Kaduna River approximately 55km downstream of its confluence with Dinya River, 90 km southwest of the city of Kaduna and about 66 km away from Minna (capital of Niger State, Nigeria). The lake is expected to provide favourable conditions for large scale fish-production and aquaculture development.

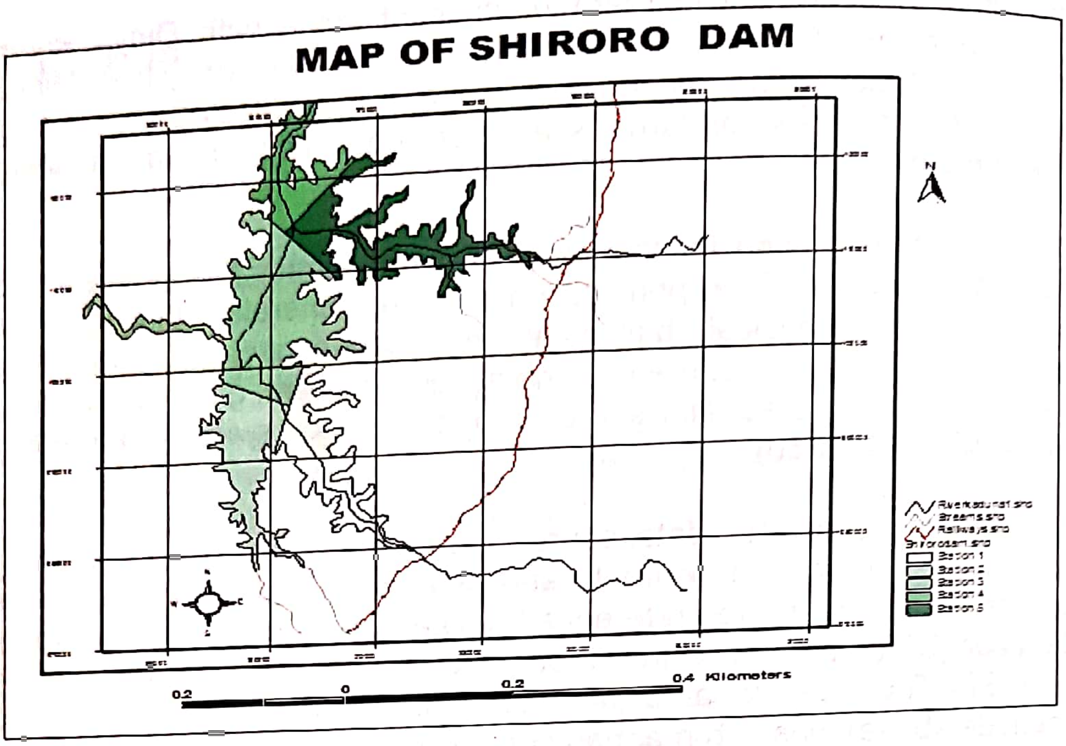
The data used for this study were obtained from primary and secondary sources. The primary data were generated through field surveys on the physical, biological and socio-economic factors that control the aquatic environment, using a digital camera, global positioning system, water samples, fish samples, vessels and Lovibond raw water test kit AF355(413550).

The secondary data source, consisting of organised primary data, was sourced from journals and seminars. The colour-composite satellite image was geo-referenced using the Universal Transverse Mercator (UTM) system. Under that system the study area is located in zone 31. The specific area of interest (the Lake; see latitude and longitude above) was sub-mapped out of the colour composite in order to reduce the ambiguity caused by the wide spatial extent covered by the satellite image.

The GIS used Arcview GIS for Windows (version 3.2a) software and Idrisi was used to extract, process and integrate other geo-spatial data. Topographic sheet 164 of 1967 at a scale 1:50 000 and 1:250 000, acquired from Niger State Ministry of Lands and Survey, Minna, was used as baseline information for the GIS. GPS coordinates were used to identify areas on the Nigeria Sat 1 image of 2003 (satellite imagery obtained from National Space Research Development Agency, Abuja). Geo-referencing used Idrisi software to indicate the location on the earth surface and to mask and export data to Arcview for digitization (Map 1). This was then built into geo-spatial data to enable queries and outputs.

3. Results

Criteria for suitability of Shiroro Lake for aquaculture and fisheries were based on twelve physico-chemical parameters (water temperature, pH, dissolved oxygen, turbidity, hardness, conductivity, CO_2, total dissolved solids, PO_4–P, NO_3–N, alkalinity and transparency). Suitable ranges and rating for fish production were identified for these parameters using ideal standards reported by various authors (Table 1). The interpretations of suitability classes for each parameter were classified against the scale of the ideal range.



Map.1 Digitized map of Shiroro Lake

3.1 Water temperature

A logic query was carried out based on range values for water temperature to ascertain the station suitability for fish yields. Based on the ideal range of 20–25°C (Table 1), values greater than 35°C or less than 20°C were classified unsuitable for fish production. The result of the query shows that water temperature at stations I and IV, with ranges of 15.0°C–33.2°C and 16.3°C–32.8°C respectively, are most suitable.

Station II had the widest range and highest mean value (Table 2), then station III; whereas station V had the narrowest range. The lowest temperature was recorded at station I and the highest at stations III and IV.

3.2 Negative log of Hydrogen ions (pH)

The result of the logic query performed on pH adopted numeric values less than 6 as unsuitable for fish production (Table 1). This shows that stations 1, II, III and V were unsuitable whereas station IV was found to be highly suitable. All the mean pH values obtained from the lake data (Table 2) fall within the ideal range of 6.5–9.0 Station I had the widest range, closely followed by station III, while stations IV and V had the narrowest range.

Table 1. Classification-criteria ranges for suitability scoring.

Parameter	Range	Suitability scoring
Water temperature	20–24.9	Moderately suitable
	25–29.9	Most suitable
	30–34.9	Suitable
	<20; ≥35	Unsuitable
Dissolved oxygen	2–4.9	Moderately suitable
	5–9.9	Most suitable
	10–14.9	Suitable
	<2; ≥15	Unsuitable
Alkalinity	20–99.9	Moderately suitable
	100–149.9	Most suitable
	150–199.9	Suitable
	≤200	Unsuitable
Carbon dioxide (CO_2)	6–20	Moderately suitable
	21–35	Most suitable
	36–50	Suitable
	>50	Unsuitable
PO_4–P	3.2–4.2	Moderately suitable
	4.3–5.2	Most suitable
	5.3–6.3	Suitable
	>6.3	Unsuitable
Transparency	11–43	Moderately suitable
	44–76	Most suitable
	77–109	Suitable
	>109	Unsuitable
pH	6–6.9	Moderately suitable
	7–7.9	Most suitable
	8–8.9	Suitable
	<6; >9	Unsuitable
Hardness	20-99.9	Moderately suitable
	100–199.9	Most suitable
	200–300	Suitable
	>300	Unsuitable
NO_3–N	10–19.9	Moderately suitable
	20–39.9	Most suitable
	40–50	Suitable
	>50	Unsuitable
Total dissolved solids	5–16	Moderately suitable
	17–28	Most suitable
	29–40	Suitable
	>40	Unsuitable
Turbidity	8–160	Moderately suitable
	161–240	Most suitable
	241–320	Suitable
	>320	Unsuitable
Conductivity	42–560	Moderately suitable
	561–1081	Most suitable
	1082–1600	Suitable
	<42; >1600	Unsuitable

Source: Researcher's compilation, 2004

Table 2. **The range and mean values for the physico-chemical parameters measured at different stations of Shiroro lake.**

PARAMETERS	STATIONS				
	I	II	III	IV	V
TEMPT (°C)	15.6-33	16.1-34	16.5-34	16.0-33	16.3-32
Mean	24.6	27	26.6	26	25.7
AIR TEMP (°C)	20.4-30.7	20.8-32.8	20.3-31.9	18.0-32.7	18.0-32.0
Mean	26.5	27.6	27.8	27.7	26.5
PH	5.6-8.2	5.6-7.5	5.7-7.7	6.0-7.5	5.9-9.4
Mean	6.8	6.8	6.8	6.7	6.7
DO (mg/l)	1.7-18.3	2.6-20.5	1.7-19.1	2.6-18.3	2.6-20.1
Mean	7.9	9.1	8.2	9.1	9.3
BOD (mg/l)	13-8.7	0-21.8	0.8-8.7	0.9-7.0	0.00-10
Mean	3.0-4.0	4.0-8.0	3.3	3.7	3.8
COND (umohs/cm)	46.0-98.0	45.0-235.0	38.0-114.0	42.0-92.0	48.0-88.0
Mean	69.6	76.7	71.1	66.7	68.9
HARD (mg/l)	12.0-80.0	8.0-70.0	13.0-96.0	14.0-75.0	13.0-72.0
Mean	28.6	30.7	31	28.8	30.6
ALK (mg/l)	4.0-90.0	4.0-60.0	4.0-50.0	4.0-50.0	6.0-50.0
Mean	23	23.3	21.1	21.5	20.7
TURB (jtu)	8.0-14.0	8.0-320	8.0-258	8.0-184	8.0-212
Mean	46	89.8	78.1	64.9	62.9
CO_2 (mg/l)	1.6-66.0	0.8-48.0	1.2-44.0	0.8-32.0	0.8-32.0
Mean	19.2	13.1	12.1	12	11.4
TRANS (m)	0.10-0.98	0.10-0.85	0.10-0.80	0.10-86.0	0.10-98.0
Mean	0.41	0.35	0.37	0.42	0.43
TDS (mg/l)	7.1-140	6.9-363	5.8-17.5	6.5-14.2	7.4-13.5
Mean	10.7	11.8	10.9	10.3	10.6
PHOS (mg/l)	0.10-2.00	0.18-2.40	0.12-1.88	0.151-88	0.15-1.88
Mean	0.63	0.77	0.69	0.68	1
NITR (mg/l)	0.09-1.92	0.12-1.82	0.09-1.28	0.07-1.48	0.06-1.92
Mean	0.5	0.52	0.49	0.47	0.49

SOURCE: KOLO (1996)

3.3 Dissolved oxygen

For dissolved oxygen, areas with concentration greater than 15mgl^{-1} were defined as poor for fish to thrive. The query showed that stations I and III with range values of 1.7–8.3 and 2.6–18.3 respectively were ideally suitable, while station II, IV and V were unsuitable; even so, all ranges more or less encompassed the recommended range of 2–15mg/l reported by Beadle (1981) and Ovie and Adeniji (1993). Station II had the broadest range, followed by station III, whereas station IV had the narrowest.

3.4 Turbidity

A logic query based on turbidity-range values of less than 8.0 and greater than 320 depict station II as unsuitable for fish production, whereas others are suitable. All mean values fall within the ideal range of 8–320 (Table 3). Station II had the widest range and highest mean followed by station III, whereas station 1 had the narrowest range and the lowest mean value.

Table 3. Ideal parameter ranges and standards reported by various authors.

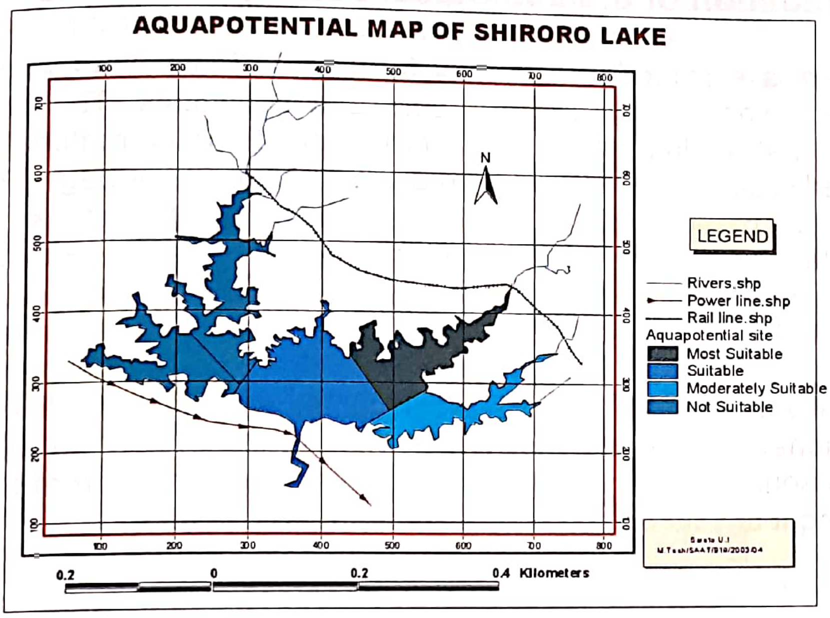
Parameter	Ideal range	Source
Water temperature	20–25°C	Dupree and Hunner, 1984
Hydrogen ion concentration (pH)	6.5–9.0	Ellis, 1939
Dissolved oxygen	2–15 mg l^{-1}	Beadle, 1981
Turbidity	8.0–320	Hem, 1970
Hardness	20–300 mg l^{-1}	Chakroff, 1978
Conductivity	20–1600uhos cm^{-3}	Boyd and Frobish, 1990
Total dissolve solids (TDS)	5–40 mg l^{-1}	APHA, 1992
Phosphate–phosphorous (PO_4–P)	3.2–630 mg l^{-1}	Beadle, 1981
Nitrate–nitrogen (NO_3–N)	9.6–49 mg l^{-1}	Beadle, 1981
Transparency	11.0–108.5 cm^3	APHA, 1992
Biochemical oxygen demand (BOD)	60–120 mg l^{-1}	APHA, 1992
Alkalinity	20–200 mg l^{-1}	Baird, et al. 1995

3.5 Hardness

Analysis shows that values equal to or greater than 75 mg l^{-1} represent areas of moderately hard water. Based on this, stations I, III, IV and V are classified as softer water, while station II is classified as moderately hard water. In respect of the suitability of the water for fish growth, values less than 20 mg l^{-1} or greater than 300 mg l^{-1} are considered unsuitable for fish (Table 3); on this basis station II is suitable while others are unsuitable. Hardness values (Table 4) showed that station III had the highest value, then station II, while station I had the lowest followed by station V.

Table 4. Showing stations scores

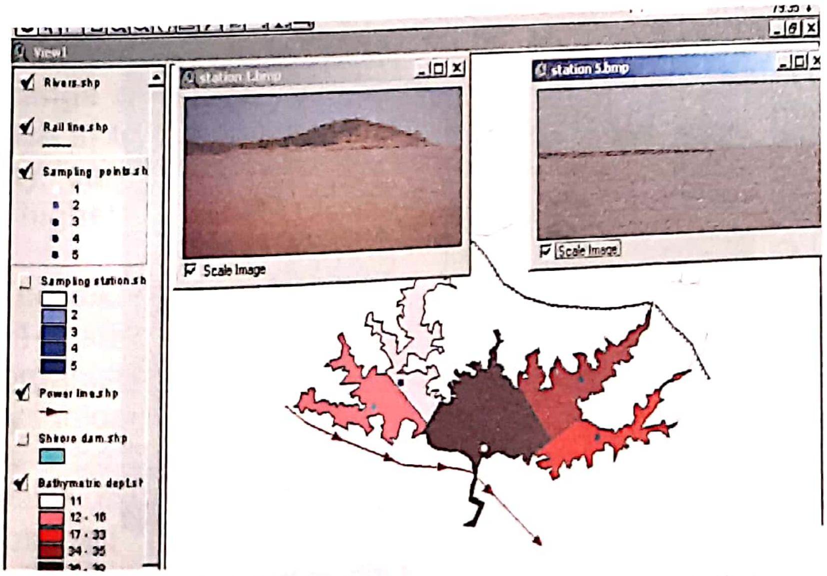
Parameter	Stations scores				
	I	II	III	IV	V
Temperature	5	0	0	5	0
Hydrogen ion concentration (pH)	0	0	0	5	0
Dissolved oxygen	5	0	5	0	0
Turbidity	5	0	5	5	5
Hardness	0	5	0	0	0
Conductivity	5	5	0	5	5
Carbon iv oxide	0	0	0	5	5
TDS, PO4-P, NO3-N, BOD and transparency	0	0	0	0	0
Total	15	10	10	20	15



Map 2. *Aquaculture potential map of Lake Shiroro showing the range of station suitability*

3.9 Bathymetry of the lake

The bathymetry of the reservoir varies with the station. These depth differences were used as a basis for the reviewing the suitability and potential for cage culture. Based on the bathymetry (Map 3), stations III, II and IV were classified most suitable (11m, 16m and 33m respectively), whereas stations V and I (35m and 39m) were classified unsuitable for cage culture.



Map 3. *The GIS bathymetry map for all the stations*

3.10 Degradation of the ecological setting of the lake

Shiroro Lake is surrounded by many farmlands (Plate 1) belonging to local farmers who mostly use fertilisers and chemicals. The principal concern is that pollutants arising from allochthonous material, from decomposed organic wastes and from discarded polythene bags (Plate 2) associated with market activities, will take their toll around the lake shore. The marketers move along the bank as the lake recedes. Phosphates and nitrates from fertilisers, together with an array of chemicals from pesticides, herbicides and insecticides, generate inputs from farmland. All the pollutants eventually find their way into the lake, perhaps creating excess fertility that could lead to eutrophication and ruin the value of the lake. Additionally, even the noise from market activities (buying and selling) is a source of pollution that may scare fishes away from the lake bank, making it unsuitable for fishing in the middle of the day.

Plate1. Farmlands at station IV

Plate 2. Allochthonous material at low water level

Wood abstraction for fuel wood (Plate 3), construction of fishing vessels and transportation, are other human activities that would have a marked effect on primary productivity (i.e. phytoplankton and zooplankton) of the lake.

Plate 3. Wood abstraction.

4. Discussion

The logic query result for water temperature indicates that station I and IV are most suitable for fish to thrive, could result from dynamic changes at station I because of constant power generation, less weathering and decay process, less water movement and hence lower temperature. The greater depth at stations I and IV could also account for the lower temperature.

Dupree and Hunner (1984) found that warm-water fish such as channel catfish grow best at temperatures between 25°C and 32°C and that this is the recommended range for fishery activities. This agrees with the ideal range obtained from Shiroro Lake. Madera et al. (1982) state that increase in temperature is associated with a consequent increase in conductivity, varying by 2% per 1°C. This implies that the warmer the water, the higher the conductivity and hence an increase in fish yield.

The alkalinity or acidity (pH) of substances, ranked on a scale from 1 to 14, affects many chemical and biological processes in water. Different organisms flourish within different pH ranges. The result of the logic query indicating only station IV to be suitable for fish survival based on pH could be because the site is characterized by flat terrain and shallow water that concentrates the effect of ions. The pH range of 5.6–8.2 obtained from the range values agreed in all stations with the range of 6.5–9.0 recommended as most suitable for fish production (Ellis, 1939).

The low alkalinity values in all stations except station I indicate that Shiroro Lake has low productivity potential. This is in line with Khan *et al* (1983) who associated low alkalinity with a consequent low productivity in an aquatic ecosystem. Baird et al. 1995 indicate that the ideal range for alkalinity is 20–200 mg l^{-1}. The range of 4.0–90.0 mg l^{-1} obtained from Shiroro Lake agrees with the range of 75–200 mg l^{-1} given by Hem (1970) for productive warm water. The total alkalinity for natural waters may range from 5 mg l^{-1} to more than 500 mg l^{-1}. Mairs (1966) reported that greater productivity does not result directly from higher alkalinity but rather from higher levels of phosphate and other essential elements that increase along with alkalinity. This could mean that an increase in alkalinity imply a corresponding or proportional increase in other essential nutrients.

Fish, invertebrates, plants and aerobic bacteria all require oxygen for respiration. Oxygen, measured as dissolved oxygen, comes largely from the atmosphere after dissolving at the lake surface.

The result of query indicates that stations I and II were ideally suitable based on dissolved oxygen. This could be due to the sites' locations and other factors. Station I is characterised by wood-free vegetation and greater depth, resulting in lower temperature. This is in line with Huet (1972) who indicates that depending on the specific nature of the lake/stream, temperature tends to determine the amount of dissolved gases such as oxygen. Thus the higher the temperature of water body, the lower the dissolved oxygen and vice versa.

Station III, while also classified suitable, might have been thought unsuitable due to its submerged woody vegetation, shallower depths and high water temperature. Its suitability could result from swifter water movement agitating the entire water column, thereby aerating the water and sending more oxygen into solution.

All observed ranges agreed with the recommended range of 2–15 mg l^{-1} (Beadle, 1981; and Ovie and Adeniji,1993), but were inconsistent with Brimley's (1944) finding that the minimum level of dissolved oxygen known to sustain a viable population in water is 4 mg l^{-1}—a lower level might result in mass deaths of organisms. Ellis (1937) indicated that an average stream condition of 3 mg l^{-1} or less of dissolved oxygen should be regarded as hazardous for fish and that for a good varied fish fauna the dissolved oxygen concentration should be 5 mg l^{-1} or more. In general, a minimum constant value of 5 mg l^{-1} of dissolved oxygen is satisfactory for most species and stages of aquatic life (EIFACT/T19, 1973).

Turbidity is a measure of muddiness or clarity in water. It was indicated that only Station II is unsuitable for fish production probably because run-off from catchment areas there brings in water overloaded with allochthonous materials. For fish culture, turbidity due to phytoplankton is more appropriate.

Hard water is said to be more productive biologically than soft water. Baird (1985) points out that total hardness concentration should be similar to the total alkalinity in most waters. Chakroff (1978) recommended a range of 50–300 mg l^{-1} for water for aquatic production in tropical climates. And the range value obtained is within the range. The logic query result based on hardness revealed that station II is suitable for fish, perhaps because of the closeness of the site to mountainous terrain that could enhance bedrock weathering and run-off, bringing in allochthonous material. This is in line with the observation of Rand and Petrocelli (1985) as cited by Abari (2004) that mineralisation of the parent rock of the lake basin and lower temperature are known to enhance water hardness. According to Thurston et al. (1979), water of 0–75 mg l^{-1} (CaCO3) are softer whereas those of 75–150 mg l^{-1} are moderately hard. The logic query revealed that except for Station II which is moderately hard, the water at stations I, III, IV and V were all soft; hence, the water of Shiroro Lake and its tributaries are generally soft and such waters have been designated less-productive and poor for fish production.

The high ionic-conductivity values recorded for all stations are indicative of enhanced electric current generation. This confirms the logic query result that stations I, II, IV and V are highly suitable for fish production and is consistent with Abohweyere (1990) that the correlation between conductivity and estimated potential fish yield is positive and significant. Ryder (1965) also stated that conductivity and mean depth of reservoir could be used to calculate the potential fish yield of a lake:

(1) Ryder morpho edaphic index (MEI) =conductivity (uhos/cm^3)/mean depth (m)

Fresh waters normally have conductivities of 20–1500 uhos cm^{-3}, while for inland waters the proportions of different ions in water vary greatly with climatic and edaphic factors (Boyd and Frobish, 1990). Furthermore, fish species differ in their requirement for osmotic pressure and consequently optimum conductivity (Boyd and Lichtkoppler, 1979). This is in line with APHA (1992) studies of inland fresh waters, which indicate that stream/lake waters supporting good mixed fisheries have a range of 150–1500 uhos cm^{-3}conductivity; values outside this range could indicate that the water is not suitable for certain species of fish or micro-invertebrates.

Station III, which was classified unsuitable based on conductivity, might be due to its proximity to mountainous terrain, which could have enhanced more weathering process of bedrock and ionic dissolution process hence, accounting for higher conductivity.

Considering carbon dioxide (CO_2), the logic query result indicates stations IV and V as suitable for fish productivity. This could be because the sites are calm-water locations associated with their gentle terrain. Stations I, II and III were classified unsuitable. For station I this might be due to lower temperature, which is said to increase the solubility of carbon dioxide. Hadrian (1985) and Stirling and Philip (1990) indicate that depth reduces dissolves oxygen, which Rouse (1979) and Hadrian (1985) said increases carbon dioxide in water. Station III unsuitability could be due to the shallow and submerged woody vegetation of the site, with decaying organic matter using up dissolved oxygen and releasing carbon dioxide. Station II unsuitability could be due to waters overloaded with allochthonous material from the catchment area.

The index of the logic query result which indicates TDS, PO_4–P, NO_3–N, BOD and transparency as unsuitable. It is possibly attributable to their sources: from run off from road and farmland (stations IV and V); from submerged woody vegetation (Station III); from effluent discharge (Site II); and from soil erosion and animal manure (stations IV and V).

The range of 60–1920 mg l^{-1} of NO_3–N obtained from the data suggests that the lake has greater primary productivity potential in terms of NO_3 concentration when compared to ranges of other lakes: 0–200 mg l^{-1} for Kariba Lake, Uganda; 50–160 mg l^{-1} for Volta Lake, Ghana; and 40–200 mg l^{-1} for Asejire Lake, Nigeria [Talling and Talling (1965); Biswa (1978); and Egborge and Sagaye (1979) respectively; and cited by Kolo (1996)]. A range of 9.6–49 mg l^{-1} was recommended by Beadle (1981) for some African productive waters, which is consistent with the logic query classification as unsuitable for fish due to Shiroro Lake's high concentration of 60–1920 mg l^{-1}.

The range of PO_4–P obtained as 0.10–2.40 was low when compared with the standard of 3.2–630 mg l^{-1} recommended by Beadle (1981). This also explains why the reservoir was found not suitable by the logic query result.

The inverse relationship observed between NO_3–N and PO_4–P in this lake, as observed by Kolo (1996), attested to the differences in their mineralization process and the rate at which they are used up by organisms or lost to sediment-or reflected the 10:1 N:P ratio phenomenon observed by Beadle (1981) in his study of "Tropical African inland waters".

5. Conclusion

The study provides an index for establishing a fisheries database using a geographic information system and remote sensing. It demonstrated the capacity for GIS to analyze complex spatial data. The station-suitability map derived for Shiroro Lake's aquaculture and fishery potential was partly verified by field surveys, analysis of satellite images and published data.

6. Recommendation

Shiroro Lake has high potential for fishery production. However, proper planning and management should not be neglected if sustainable fish production is to be ensured. Secondary use of the lake should be initiated in conjunction with the primary use, promoting and improving utilization of the lake's capacity. Aquaculture practices such as cage culture could be introduced, as this would not have a negative impact on the power-generation activities of the lake as once practised in the Kainji.

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