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Estimating fish stocking densities using Landsat imagery and geographic information systems

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Abstract

Fisheries and aquaculture in artificial or natural impoundments (small water bodies) in the Minna region of Niger State, Nigeria, appear to have excellent development potential if suitably identified and analyzed. Using 2005 LANDSAT imagery, ten water bodies were identified in the region and the surface area of each was calculated. Their total surface area was 4,767,622 square meters (m^2). Using an assumed upper rate of 5 fish m^{-2} and a lower rate of 3 fish m^{-2}, an estimate of catfish-stocking potential was calculated for each of the water bodies. A total potential carrying capacity of 24 million catfish for high-density stocking and 14 million catfish for low-density stocking was predicted. An overall map of the identified water bodies was produced showing their shapes and the co-ordinates of each were identified by global positioning system. The total-stocking-density estimates revealed that tonnes of fish could potentially be produced in the Minna region. The result also served as a database on water bodies in the region.

Key words

Artificial impoundment, LANDSAT imagery, surface area, stocking rate, stocking density, maps, global positioning system, database.

1. Introduction

Successful planning requires both reliable data and a way of processing them. Acquisition has been and remains a problem. The advent of geographical information systems (GIS) and remote sensing as tools for planning is now recognized and some of their applications have already been made. In this study, they have been applied to identify and analyze some small water bodies in the Minna region, to estimate potential stocking densities. Fish stocking, as a technical intervention in aquatic resource systems is quite complex. The growth of fish depends on the number of fish stocked and the number of other fishes present in the pond. The more fish that are stocked, the higher the yield, provided there is no competition for food. Stocking density refers to the number of fish that a pond can hold without exceeding its carrying capacity (Wokoma, 1986). It can be estimated from a calculation of surface area, in this case the surface area of each small water body. This could make an important contribution to the supply of fish in Minna region if properly managed.

The aim of the study, therefore, proposes to develop and use a GIS database to identify and analyze small water bodies in Minna region and to use their surface area to determine stocking density. With predictions of the fisheries potential and management of small water bodies, fisheries managers and commercial operators in Minna region will have access to information that will help them to achieve goals such as predicting fish health, welfare and productivity. Experienced farmers will know how much their system can hold because problems will occur if they exceed appropriate stocking densities. Many thousands of stocking events, involving millions of individual fish, take place annually in managed fisheries (Hickley, 1993). There should be considerable knowledge on stocking ratios and the associated management consequences for fish-stock enhancement. GIS is concerned with analysis and display of geographic/spatial data and allows us to view, understand, question, interpret and visualize the data in many ways. This reveals relationship patterns and trends in the form of maps, reports and charts. It can be used to calculate the surface area of each of the Minna region water bodies to estimate their fish-carrying capacity.

As mentioned above, the growth of fish in a water body depends on the number of fish stocked and the number of other fish already present. This is due to several factors that include density and competition (Rosario, 1984). The enhancement of small water bodies' fishery management through the use of new technologies and electronic instruments such as global positioning system (GPS) units and remote sensing will bring exploitation closer to the resources' potential, benefitting local fisherman in the communities. The technology also clarifies what methods are feasible methods in these small water bodies and provides a guideline for enhancement and management of fish production.

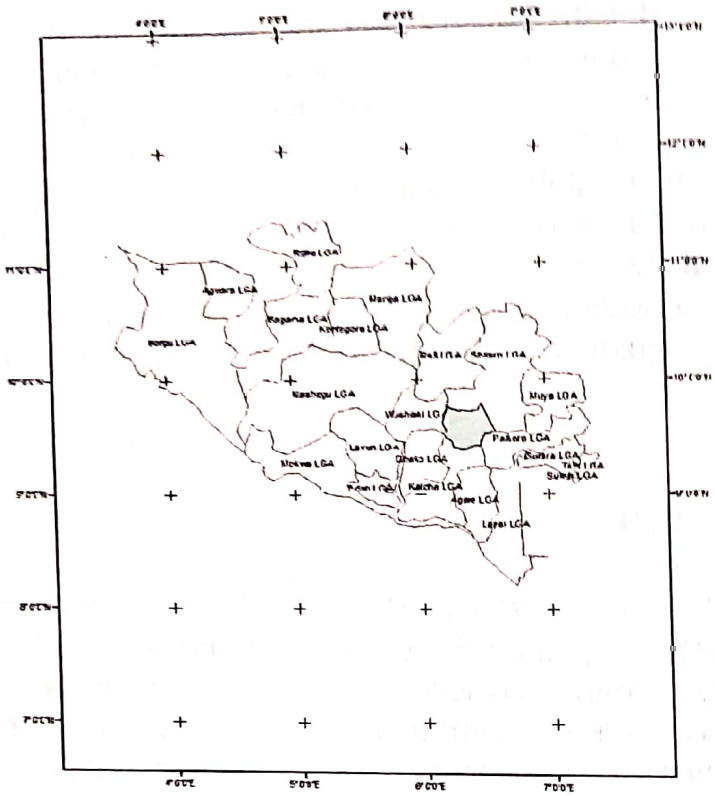
2. Study area

Minna, in which this was study was carried out, is the capital of Niger State, Nigeria (Map 1), since the creation of states in 1976. It is a small town comprising many villages and wards—such as Chanchaga, Tundunfulani, Maikunkele, Tunga, Kpakungu, Sango, Minna Township and Bosso, among others. Because Minna is the capital of Niger State it is an important political, administrative, commercial and industrial center (NSEEDS, 2004). It has a land area of about 885 hectares (ha), located approximately between latitudes 9°35' north (N) and 9°39'40" N and longitudes 6°25'26" east (E) and 6°25'26" E. It is situated on a geological base of undifferentiated basement complex of mainly gneiss and magnetite. Minna town is widely dispersed along the main spine spreading from Chanchaga in the south to Bosso in the north, a distance of about 16 kilometers (km). Rivers, lakes, streams and reservoirs in the area were the small water bodies examined to estimate the fish-stocking potential of the Minna region.

A 'small water body' is any significant accumulation of water that is either man-made (such as reservoirs) or a naturally occurring geographic feature. The smallest size range is a 10–100 km^2 catchment area for a river and a 0.5–1 km^2 area for lakes. No sizes are given for small transitional and coastal waters (REFCOND, 2000).

2.1 Bosso dam

Bosso dam is a man-made dam created in 1914 for the purpose of providing a reservoir of water for the Bosso Water Board town supply. The environment consists of green vegetation and the observed fishes are Cichlidae and Claridae, which are able to exploit most of the niches available in running water. The phytoplankton presence is an index of its biological productivity.



Map 1. Map of Nigeria Showing Minna, Niger State.

2.2 Tagwai dam

Tagwai dam is a large reservoir that retains water for the Chanchanga Water Board. The dam's environment is an ideal ecosystem, wherein fish find optimal conditions—temperature, dissolved oxygen, nutrients and food concentration—for feeding and reproduction. The dominant species present are Cichlidae, Claridae and other species that are able to exploit the niche (Plate 1).

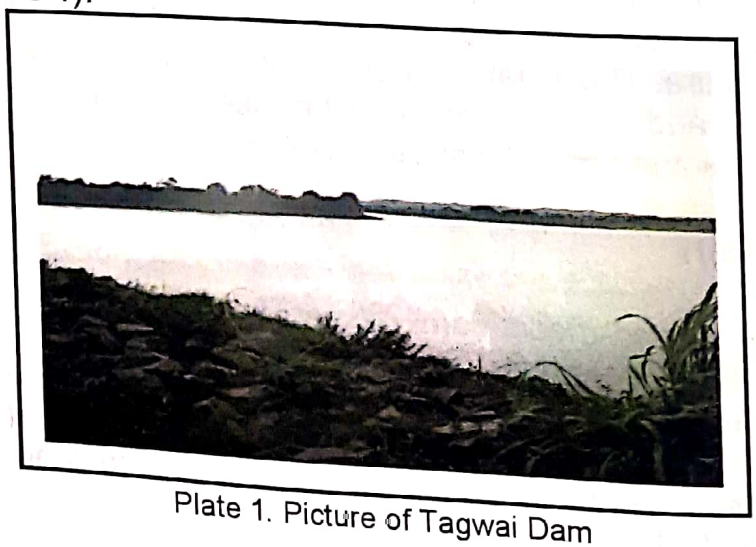


Plate 1. Picture of Tagwai Dam

2.3 Danzaria dam

Danzaria dam is a man-made dam created for the purpose of collecting runoff water from various sources. It contains various species of fish able to exploit the niches offered. No fishing activities were found there because is a known experimental/research site for the department of fisheries of the, Federal University of Technology (Plate 2).

Plate 2. Picture of Danzaria Dam

2.4 Tungan–Goro stream

This small water body is located at Tunga–Goro bridge and at the time of identification consisted of a lotic environment. Various species of fishes and aquatic flora and fauna were observed, with high biological productivity that can be related to potential fish production (Plate 3).

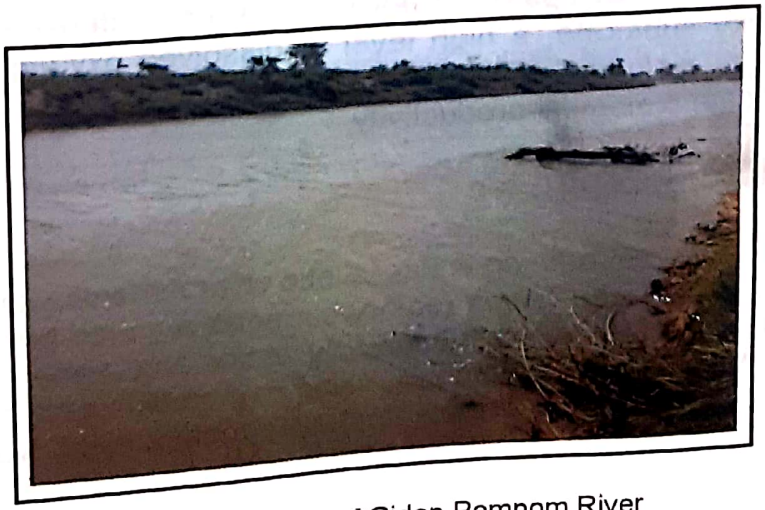


Plate 3. Picture of Gidan Pompom River

2.5 Gidan–Mangoro stream

This small water body was characterized by a swift current, a rocky substrate and a high level of dissolved oxygen. It would be a potential site for fishing activities and stocking. Various species like Cichlidae where found at the time of the visit.

2.6 Barikin Sale stream

This is known to be a natural stream but it receives its water source from other linking streams. It is characterized by a rocky substrate and a swift current. The environment displays a greenish pigment indicating the presence of phytoplankton. Fish species found were mostly Cichlidae and Claridae.

2.7 Chanchaga River

This small water body is a natural environment connected to Tagwai Lake, the source of its water. Numerous species of fish were found and fishing activities were apparent.

2.8 Bobby Lake

It was initially proposed to construct a dam on this Lake in the Maitumbi area but the plan was abandoned. It supports diverse species of fishes, but fishing activities was not observed at the time of visit.

2.9 Kpakungu stream

Kpakungu stream is an upstream environment characterized by a swift current, a rocky substrate, a high level of dissolved oxygen and warm temperature. Its biological environment and features like phytoplankton presence indicate biological productivity.

2.10 Gidan Pompom River

This river, consisting of running water (a lotic environment) with linkage to other water bodies in the Minna region, supports a varied biodiversity of fishes. Its environment was influenced by major and primary biological activity—the resultant photosynthesis, using carbon dioxide and releasing oxygen, being of use to aquatic life—and also good nutrient availability.

3. Materials and methods

Different methods and sources were used to acquire the data used, ranging from digital camera, satellite imagery, GPS research data from various reports and a number of GIS techniques.

3.1 Experimental design

Ten small water bodies were identified via the LANDSAT imagery of 2005 (Table 1). Subsequently the researchers visited each identified water body to:

- *take GPS coordinates (Table 2);*
- *take a digital photograph of the water body (e.g. Plate 1); and*
- *Observe water color, fishing activities and land-use, for ground-truth of the field work.*

Table 1. Ten small water bodies identified in the Minna region from a 2005 LANDSAT image.

Small water body	Location	Classification
1. Bosso dam	Tundun-Fulani	Man-made
2. Tagwai dam	Chanchaga	Man-made
3. Danzaria dam	Gidan-Kwanu	Man-made
4. Tunga–Goro stream	Tunga-Goro	Natural
5. Gidan–Mangoro stream	Gidan-Mangoro	Natural
6. Barikin Sale Stream	Barikin Sale	Natural
7. Chanchaga River	Chanchaga	Natural
8. Bobby Lake	Maitumbi	Natural
9. Kpakungu Stream	Kpakungu	Natural
10. Gidan Pompom River	Gidan-Pompom	Natural

Table 2. Northing and Easting co-ordinate points of ten small water bodies identified in the Minna region from a 2005 LANDSAT image.

Small water body	Northing	Easting
1. Bosso dam	229088.5	1070671.25
2. Tagwai dam	243699	1058248.6
3. Danzaria dam	220275.5	1052213.6
4. Tunga–Goro Stream	234401	1057149.5
5. Gidan–Mangoro Stream	226390.5	1059028.5
6. Barikin Sale Stream	228817.5	1061258.5
7. Chanchaga River	233982.3	1054632.5
8. Bobby Lake	234138	1061041
9. Kpakungu Stream	227944.5	1061818.3
10. Gidan–Pompom River	224951.5	1052629.5

3.2 Data used

The various data used were:

- *Ecological features map: Topographic sheet 164 of 1967, at a scale 1:50 000, covered the Minna study area. It is the first edition acquired from the Niger State Ministry of Lands and Surveying, Minna, Niger State, Nigeria.*
- *GPS data: A Garman Etrex 2008 simultaneously provided the horizontal and vertical geographic coordinates of a point.*
- *Digital camera images: A Nokia 3.2 mega pixel digital zoom camera was used to photograph the ten water bodies to facilitate direct comparison between the photos and the satellite imagery.*
- *Remote-sensing imagery: Nigeria Sat 1 Image of Niger State, acquired in 2005, covering the Minna region.*

3.3 Software used

- *Idrisi software was used for geo-referencing and registering of coordinate system of the map.*
- *Auto Cad software was used in tracing and carving out the image to display small water body characteristics on the map.*
- *Arc View 3.2a software was used in processing and integrating geo-spatial data.*

Field data collected with the aid of GPS were input into the Landsat image to locate the exact small water bodies before they were digitized to determine their surface area.

3.4 Estimating stocking densities for the ten water bodies

The stocking densities for catfish were estimated using 5 fish m^2 for high stocking and 3 fish m^2 for low stocking densities Yisa,A.T (2003), (Table 3). Using these rates the total stocking capacities were calculated after the surface areas were converted from hectares to square meters (using the conversion 1ha = 10 000m^2).

4. Results

The results obtained (Table 3) are interpreted on the basis of the quantity of fishes that can be supported in each of the small water bodies at high and low stocking densities. This has use for fish farmers and fisheries managers who need to determine the stocking densities for these various small water bodies of the Minna region and who may be encouraged to engage in cage culture in them.

Table 3 suggests good potential for fisheries production and management of these small water bodies. GIS are useful in supporting management creation of a system-oriented model for aquaculture and fisheries development.

Table 3. Surface area and the estimated fish-holding capacity of the ten small water bodies.

Small water body	Surface area (m^2)	Total number stocked at a rate of:	
		5 fish m^{-2}	3 fish m^{-2}
Bosso dam	83 450	417 250	250 350
Tagwai dam	4 497 930	22 489 650	13 493 790
Danzaria dam	8 898	44 495	26 697
Tunga–Goro stream	20 06 056	100 3028	60 18016
Gidan–Mangoro stream	9 455	47 276	28 365
Barikin Sale stream	6 435	32 177	19 306
Chanchaga River	6 983	34 916	20 949
Bobby Lake	11 538	57 692	34 615
Kpankungu stream	6 640	33 202	19 921
Gidan–Pompom River	116 230	581 150	348 690
Total	4 767 621	23 838 109	14 052 763

[Printer: Right-justify the columns of numbers]

Factors affecting fish production in water bodies include among other things the stocking density. Unsuitable stocking density affects the growth, survival and production of fish. Huet (1971) states that high stocking density with respect to the number of fish results in better use of natural food then reduced stocking. At low stocking density the amount of food in the water body is higher for each individual fish and the excess food is not utilized. In other words increased stocking density of a particular water impoundment would amount to higher production then low stocking densities.

The total potential fish production in these ten Minna small water bodies is estimated at 23 838 109 fish and 14 052 763 fish respectively (about 19 million fish on average), depending on stocking rate per square meter, which equates to about 19 million kilograms (19 thousand metric tonne) if each catfish averages 1 kg.

5. Recommendations

- A digitized map of small water bodies should be available to potential users (such as farm managers and extension workers) to encourage formal requests to the department.
- This research should be used as a guide to other researchers in the department of fisheries who want to carry out research on the use of GIS as a tool for planning.
- Development and management plans to sustain small water bodies should take stock enhancement into account, supported by using GIS as a planning tool.
- Research on fish-stocking enhancement should be conducted regularly in support of fish production in the Minna region.

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