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A Review On The Geographical Information System (Gis) In Aquatic Monitoring And Management In Nigeria

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ABSTRACT: *Geographic Information System (GIS) is a tool for making and using spatial information, and it is mainly concerned with the location of the features as well as properties/attributes of those features. It helps us gather, analyse, and visualize spatial data for different purposes. GIS has also opened up the underwater world of aquatic ecosystems allowing us to track and monitor the environments and species in an entirely new way. GIS, combined with other analytical tools and models, it allows for improved spatial monitoring and studies and, eventually, better and more effective management practices. Equipment such as radio telemetry, hydro acoustic telemetry, and side-scan sonar can now be incorporated into a GIS program to create a geographical representation for tracking renewable natural resources. Geographical information system (GIS) is been employed in several state's land forms, water bodies and forest or vegetation studies in Nigeria. For instance, GIS was used to map and monitor the Niger Delta Wetlands, GIS helped to assess the impact of climate change on the Lake Chad basin, also it was used to monitor water quality and identify sources of pollution in Ogun river basin and many more studies with the use of GIS in Nigeria. This review paper focuses on tracking renewable natural resources, management with special reference to importance of fish and fisheries in Nigeria using GIS, the scientific and technical issues encountered when applying GIS to Nigerian lakes, rivers, oceans and associated wetlands, and a survey of current literature emphasizing the various capabilities of GIS, The various applications of GIS and remote sensing to fisheries and aquatic ecosystem in Nigeria.*

Keywords: Geographical, Information, System, Hydrosphere, Surveillance, Management.

INTRODUCTION

Geographic Information System (GIS) is a tool for making and using spatial information, and it is mainly concerned with the location of the features as well as properties/attributes of those features. It helps us gather, analyse, and visualize spatial data for different purposes. By recording their coordinates, a GIS quantifies the locations of features, which are the numbers that explain the position of these features on Earth (**1**).

GIS has also opened up the underwater world of aquatic ecosystems allowing us to track and monitor the environments and species in an entirely new way according to (**2**). In the past, due to the difficulty in attaining spatial data on organisms/habitats in underwater environments, GIS was not a practical source for analysis. But when GIS, combined with other analytical tools and models, it allows for improved spatial monitoring and studies and, eventually, better and more effective management practices (**3**). Biologists have been able to track fish species and create databases with the advancement of radio telemetry, hydro acoustic telemetry, and side-scan sonar, and it incorporated into a GIS program to create a geographical representation.

Geographic information systems (GIS) emerged as a pivotal technology in the scientific study and management of renewable natural resources. Early evolution and applications of the technology centred on terrestrial resources (forestry, land-use planning, and wild- life). The next phase added rivers and streams, largely in the context of watershed analysis, modelling, and planning (**4)**

In Nigeria, geographical information system (GIS) is been employed in several state's land forms, water bodies and forest or vegetation studies. For instance, GIS was used to map and monitor the Niger Delta Wetlands, GIS helped to assess the impact climate change on the Lake Chad basin, also it was used to monitor water quality and identify sources of pollution in Ogun river basin and many more studies with the use of GIS in Nigeria(**5**).

Lake Chad, located in the central part of the Sahel region of Africa, is an economically significant lake. It serves as a major source of water for more than 30 million people living in the four countries (Chad, Cameroon, Niger, and Nigeria) surrounding it (**6**). The lake has been a trading hub offering economic opportunities and resources on which people living around it depend. Lamentably due to a number of anthropogenic and natural factors, the lake is currently exposed to potential modifications of its hydrological conditions especially its shorelines and spatial extents (**7**). Sediment supply, climate variability, and geomorphological attributes together with man-made changes are known to be playing significant roles in the lake's shoreline dynamics. (**8**) reveal that the lake had shrunk vividly from 24,596.66 km2 in the 1960s to 2,264.30 km2 in 2017. The shrinkage was attributed principally to low inflows, the increased water supply demands due to increased population, agricultural activities, climate change phenomena, and persistent drought among other factors. (**9**) has called the situation an "ecological

catastrophe" and predicted that the lake could disappear this century. Monitoring Shoreline is fundamental to the understanding of the dynamics of the land and water interface for informed decision-making (**10**). Understanding the shoreline changes is therefore essential to provide optimal shoreline management and protection solutions. It helps to identify the nature and processes that triggered these changes. It is also to help assess the human impact and to plan desired management strategies in any specific area. Much of the regulatory framework initiated by successive governments of the countries surrounding Lake Chad has failed to address the causal factors and mitigate the effects of the spatial changes of the lake. There is an absence of clear identification and recognition of areas of greatest change for prioritizing resource allocation to provide optimal management and protection solutions, especially as affects the changes in the lake's shoreline areas (**7**).

Shorelines move with time, their boundaries position are only the boundaries position on the date of the survey. Hence over time shoreline positions could become outdated due to their natural movement, rendering the recorded positions obsolete for useful decision-making purposes. Therefore it is important to monitor and analyze the shoreline "state" which is its trend at a location regularly (**11**).

Digital Shoreline Analysis System (DSAS) which is an extension tool for Esri ArcGIS desktop software, developed by USGS was used for examining past or present shoreline positions because of its simplicity and user-friendly interface with GIS software. The use of the DSAS tool in Shoreline change analysis enables the computation of the rate- of-change statistics for a time series of shoreline position and the shoreline retreat changes in the area of study. The time intervals between the images studied play an important role in detecting and quantifying the nature and timing of changes associated with anthropogenic impacts by better identifying the timing of major changes and by reconstituting baselines (**12**).

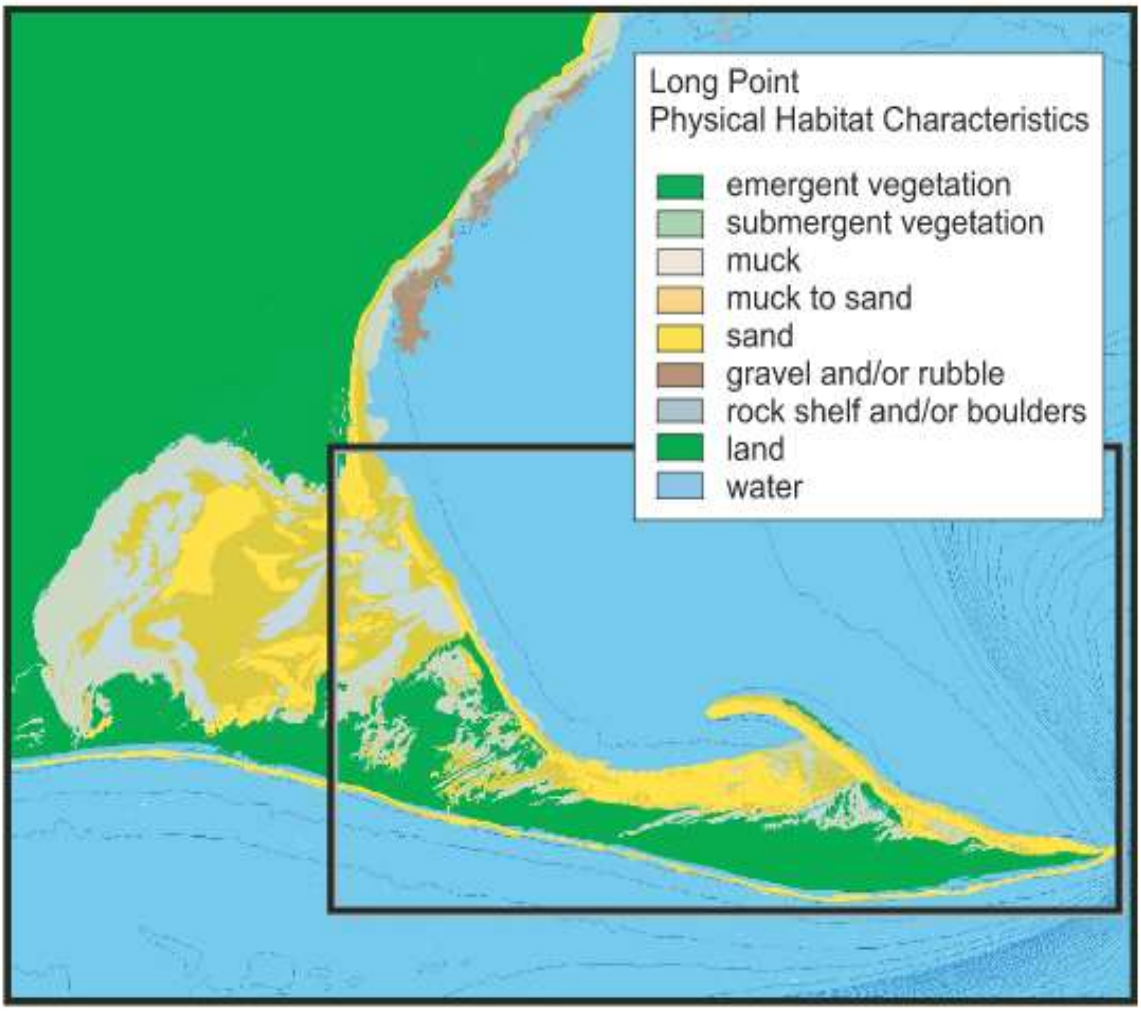

Plate 1: Nearshore physical habitat and the coast.

Source: Canadian Hydrographic Services

In the Niger Delta Region of Nigeria, oil production activity in the Delta has carved a remarkable economic landscape for the country with an enormous contribution to foreign exchange earnings, however, there is a negative side. Petroleum exploration has triggered adverse environmental impacts in the Delta through incessant environmental, socio- economic and physical disasters that accumulated over the years due to limited scrutiny and lack of assessment. Such institutionalized negligence has turned the area into an ecosystem under severe stress. For example, oil industries carried out oil exploration for over four decades with improper environmental impact assessment procedures. Under these circumstances, the benefits of oil and gas exploration in the region did not generate a positive multiplier effect for the inhabitants of the area (**13**). The United States Department of Energy (USDOE) shows that since the inception of oil and gas activities, severe environmental pollution in the Niger Delta involving uninterrupted gas flaring and oil and spillage remains rampant in the region. The area has experienced 4,000 oil spills since 1960 (**14**). One of the most noticeable impacts of the various oil spills and production activities has been the loss of mangrove trees. The mangrove was once a source of both fuel-wood for the local people and habitat for the area's biodiversity, but now it is unable to withstand the high toxicity levels of petrochemicals ravaging its habitat. The spills have had adverse effects on marine life that have become contaminated, and that in turn poses enormous risks to human health from consuming contaminated seafood. Oil and gas operations have not only caused degradation to the environment within an extremely sensitive ecosystem and destroyed the traditional livelihood of the Niger Delta; but at the same time, environmental pollution has affected weather conditions, soil fertility, waterways and habitats for wildlife and plant life, and has caused acid rain and decreased agricultural yield (**13**).

The state of the Niger Delta's environment has attracted national and international attention due to the enormous deposits of oil and gas, and the resultant impacts coupled with a controversial revenue sharing formula that has impoverished the communities. This continued growth which in the past has resulted in environmental problems such as coastal wetland loss, habitat degradation, and water pollution, gas flaring, destruction of forest vegetation and a host of other issues requires urgent environmental assessment anchored in the use of the latest advances in geospatial information systems such as remote sensing and geographic information systems (GIS) The problem facing the area have been compounded by gaps in previous research and limited emphasis on the assessment of change through spatial information technologies such as remote sensing and (GIS). For example, numerous studies in the literature examining environmental risk assessment, rightly point to the need for improved understanding, of monitoring on environmental issues faced by oil and gas producing communities but without geospatial technologies (**15**).

Notwithstanding previous initiatives, there has not been any major effort in the literature to undertake a remote sensing and GIS based assessment of the growing incidence of environmental change within coastal zone environments of the study area. Accordingly, the current problems in the Delta underscores the urgent need to design new approaches for managing remote costal resources in sensitive tropical environments effectively in order to maintain a balance between coastal resource conservation and rapid economic development in developing countries for sustainability. GIS technology as a tool used by geographers, archaeologists, geologists and other scientists in the social and natural sciences provide opportunities for storage, manipulation and mapping of data with a spatial reference. Using remotely sensed satellite imagery and GIS modeling, an analysis of the spatial distribution of land use, soil erodibility, and surface slope information in the Delta area can be obtained. This project will fill that void in the literature by exploring the applications of GIS and remote sensing in a tropical coastal zone environment with emphasis on the environmental impacts of development in the Niger Delta region of Southern Nigeria (**16**).

This review paper focuses on:

• Tracking renewable natural resources management with special reference to importance of fisheries management in Nigeria using GIS;

• The scientific and technical issues encountered when applying GIS to Nigerian lakes, rivers, oceans and associated wetlands;

• a survey of current literature emphasizing the various capabilities of GIS and the variety of applications of GIS and remote sensing to fisheries and aquatic ecosystem in Nigeria;

• Role of GIS in wetland ecosystem;

Importance of GIS in Fisheries Management

GIS is useful for a huge range of reasons. It allows practitioners the ability to 'see' data that they wouldn't otherwise be able to access, thanks to the use of satellite imagery. For example, activities such as mapping the seafloor were once near impossible until the developments in GIS technology occurred. It also allows for the combination of a range of different data types and sets so that changes or trends can be observed in any given topic. For aquatic environments, GIS gives us an insight into an otherwise largely

unknown world. Without GIS understanding the dynamics of marine areas and the creatures and resources we utilise from our oceans and waterways in Nigeria would be largely impossible (**16**).

GIS output helps to breakdown communication barriers and can bring people together to make better and more informed decisions. Fisheries planning and management have many spatial components and severe issues. Spatial components are movements and migrations of resources; the definition of fishing grounds, transportation networks, markets, and habitat loss, and environmental degradation can be grouped into spatial issues (**17**). Therefore, Fisheries biologists, Aquatic resource managers, and decision-makers have to address the problems of serious difficulty, especially in developing countries. But GIS is a technology that can aid in clarifying the problems and lead to solutions with the help of many spatial components. However, many people are still unaware or afraid of the technology and its potential for fisheries management (**17)**. Aquaculture management issues such as the multiple uses of estuarine waters, the impact of water quality on shellfish leases, aquaculture, and habitat availability, and conflict issues between aquaculture operations and marine waterfowl habitats have been addressed using GIS (Simms, 2002). By using GIS, intertidal areas (mudflats) were evaluated for the development of brackish water aquaculture (shrimp farming). The data were used for the analysis of site selection in India with the basis of some crucial parameters under six significant categories, i.e., engineering, water quality, soil quality, infrastructure facility, social restriction, and meteorological parameters (**18**). GIS as a management tool: Monitoring and analysing spatially-distributed factors such as resources abundance and composition, feeding and reproduction, nurseries, fishing efforts, harvest, tagging and recaptures, recruitment, regulatory zoning, control and surveillance, conflicts between gear and fleets, ecosystem conditions, etc. pose significant operational and management challenges to fisheries. The essential usefulness of GIS lies in its ability to manipulate and overlay data in several ways and to perform many analytical functions so that it can contribute to a faster and more efficient decision-making process in fisheries. (**19**). FAO has recently released a web-based portal, GIS Fish, which can obtain the global experience on Geographic Information Systems (GIS), Remote Sensing and Mapping as applied to Aquaculture and Inland fisheries.

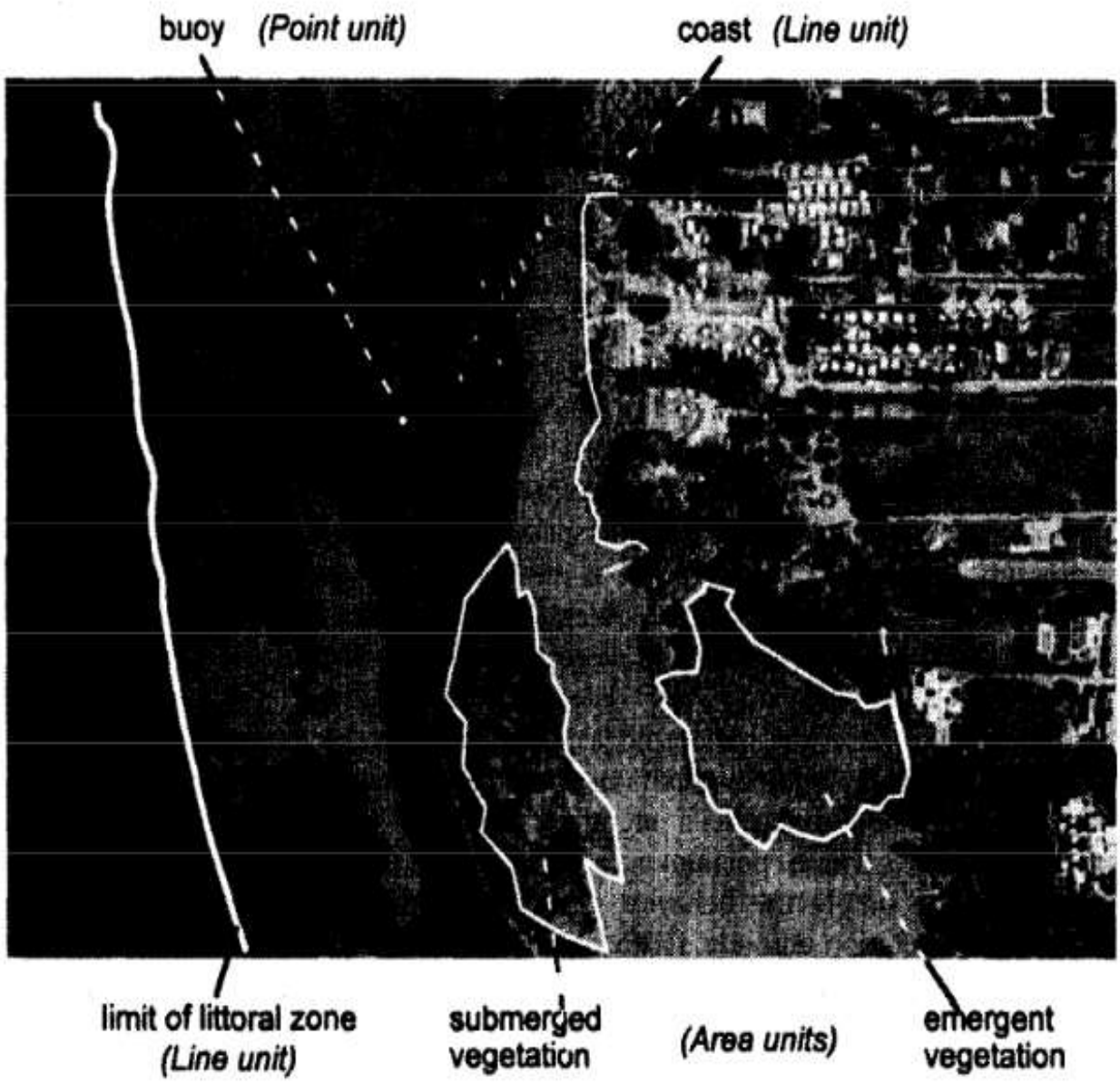

Plate 2: Habitate zonation and vegetation location
Source: Institute of geography, University of Fribourg, Switzerland.

Application of GIS and Remote Sensing in Fisheries and aquatic ecosystem

- Site selection for aquaculture or mariculture: This

The application of GIS and remote sensing is an original use of GIS in fisheries-related work. For any successful aquaculture activity, a suitable site is a pre-requisite. An optimal aquaculture site aids in better management of the aquaculture resources, and it ensures the sustainability of the farming activity. There are many criteria, guidelines, and essential factors for the selection of a site for aquaculture such as the topography of site, slope of land, water flow, volume availability, water quality, weather parameters, access and location of utilities, legislation concerning water rights, etc. helps in the decision making process. GIS gives the best platform to combine all this information and identify the areas that qualify the optimal set of parameters, which would be the best-suited areas for aquaculture (**20**).

- Modeling fish activity and movement: These

Applications area is just getting underway. Here the aim is to attach numerical models to a GIS to simulate, describe, or predict a range of processes. Examples include – movement models.

- Analysis of fisheries catches and effort: Fishery

Fisheries managers are interested in where fishing effort is concentrated; how much fish is caught where; what is the relationship between catch and effort, etc., and much exciting work is now being produced. Statistical output can be obtained from many GIS programs. Catches can be explained in terms of various environmental parameters or terms of fish life cycles (**21**).

- Matching fish distributions to environmental

Parameters: It will be of the utmost interest for those working in fisheries management or science to know the relationships between fish distributions and various environmental parameters. The types of parameters being commonly used include water temperatures (especially thermal fronts), upwelling indices, water depth, marine chlorophyll abundance, bottom sediment type, and salinity, electro-conductivity, pH levels, dissolved oxygen level, viscosity etc (**21**).

- Establishing regional and national fisheries

Databases: Although not directly a GIS application to fisheries management, it is clear that without substantial data inputs, then fisheries GISs could not function. So in some major fishery regions, a massive effort has gone into establishing databases, metadata sets, and in setting up regional data centres, e.g., in eastern Canada or at the various World Data Centres. Fisheries related data sets are slowly becoming accessible over the Internet (**21**).

- Identification of potential fishing zones by remote

Sensing: Remote sensing of ocean color is the only approach to provide a synoptic view of the abundance of the marine autotrophic community, which is at the basis of the marine food web. Areas with high phytoplankton biomass, as well as temperature fronts, have been related to increased abundance in fish. An Indian program, forecasting Potential Fishing Zones (PFZ), provides this useful information, free of charge, three times a week to artisanal fishers to increase their fishing efficiency and reduce their use of fuel. The locations of the PFZs are distributed to the fishing community through different media, in many cases, in the local language to facilitate the use of the information. Results strikingly show the benefits of using PFZ information, with a significant increase in fish catch and a reduction in search time. When the dissemination of the PFZ information is interrupted in areas (known as nurseries) and at time spawning peaks are identified; therefore, there is a need for the generation of a responsible fisheries forecasting program (**22**).

- Applications in habitat mapping and change

Detection: The advantages of remote sensing, like synoptic view, multispectral data, multi-temporal coverage, and cost-effectiveness, plays a significant role in change detection and habitat mapping. It a practical approach to collect data from diverse, inaccessible ecosystems and to study complex geographic terrain types. The amalgamation of GIS and remote sensing is successfully applied in monitoring and mapping of the coastal and marine ecosystem. Since 1972, Satellite imagery is available for most of the world, with the launch of LANDSAT by the USA. This treasure trove of information helps us to map and monitor the changes that happened to our coastal areas. The changes include the destruction of mangroves, land reclamation, shrinkage of lakes, estuaries, and other water bodies that are directly linked to the fisheries sector. Satellite imagery permits monitoring different features of the landscape and helps to quantify the rates of change and eventually detect significant land cover changes. GIS and remote sensing are extensively used to map and monitor the habitats namely seagrass/seaweed/coral reef etc (**23)**.

Water Use by Industry in 2013

Nigeria	
Industry	Percentage
Agriculture	69
Industry	10
Domestic	21
USA	
Industry	Percentage
Agriculture	41
Industry	46
Domestic	13

Source: World Bank, CIA

Water Resources in Nigeria in Km^3/yr

Water resources	Year	Amount	Unit
Average precipitation	2005	1,150	mm/yr
Total precipitation	2005	1,062,336	Km^3/yr
Internal renewable water resources-total	2005	221,000	Km^3/yr
External renewable water resources-total	2005	65,200	Km^3/yr
Total water resources	2005	286,200	Km^3/yr
Irrigation water requirement	2000	1,650	Km^3/yr
Water withdrawal			
Agriculture	2000	5,507	Km^3/yr
Domestic	2000	1,687	Km^3/yr
Industrial	2000	810	Km^3/yr
Total	2000	8,000	Km^3/yr

Source: FAO 2005

Fresh Water Indicators for Nigeria 2011-2012

Internal renewable freshwater resources-	
Flows Billion Cu. M	221
Per capita cu. M 2011	1,346
Annual freshwater withdrawals	
Billion Cu. M	10.3
% of Internal resources	4.7
% for Agriculture	53
% for Industry	15
% of Domestic 2011	31
Access to an improved water source - 2012	
% of rural population- 2012	49
% of urban population	79

Source: World Bank

. Potential Surface Water Resources of Nigeria

River System	Catchment's Area (km^2)	Potential Surface Water (MCM)
River Niger	1,143,400	158,000
South West Region	100,500	35,400
South East Region	73,200	65,700
Lake Chad	188,000	8,200
Total	1,505,100	267,300

Source: Federal Ministry of Water Resources and Rural Development (FMWRRD) 1995

Fresh Water Indicators for Nigeria 2014

Internal Renewable Freshwater Resources-	
Flows Billion Cu.M	221.0
Per capita Cu. M	1,245
Annual Freshwater Withdrawals	
Billion Cu. M	13.1
% of Internal resources	5.9
% for Agriculture	54
% for Industry	15
% of Domestic	31
Access to an Improved Water Source - 2014-2015	
% of Rural population-	56-57
% of Urban population	81-81

Source: World Bank

. Summary of Percentage Change in Water Withdrawal for Nigeria, 2011-2014

Sectors	2011	2013	2014
Agriculture	53	69	54
Industry	15	10	15
Domestic	31	21	31

Source: World Bank

Examples of GIS applications in aquatic environment

GIS can play an important role in the monitoring and management of aquatic environment. GIS is ideally suited as a tool for the collection, collation, analysis and visualization of data derived from diverse sources including those from distributed measurement stations (e.g. field-based water quality sensors). The ability of GIS to aggregate data from various inputs and present them in map form is unique and helps in strengthening the awareness about the conditions of our environment. GIS is also a valuable tool in the decision-making process (**21**).

Monitoring of environmental parameters:

The environmental parameters like temperature, salinity, dissolved oxygen, nitrate etc. are very important and affect the species distribution and abundance of that aquatic system. GIS helps to analyse and make the depth and time profiles of different aquatic environmental variables which in turn aid us in better understanding the nature and properties of the system under study. For example, contour plots of temperature and salinity profiles of the coastal waters help us to understand the process of coastal upwelling in a better way (**21**).

Applications in habitat mapping and change detection:

Remote sensing, due to its advantages like synoptic view, multispectral data, multi-temporal coverage and cost effectiveness, plays a major role in habitat mapping and change detection. It has proved to be a practical approach to study complex geographic terrain types and to collect data from diverse, inaccessible ecosystems. Integrated GIS and remote sensing have already been successfully applied to map and monitor marine and coastal ecosystems. Satellite imagery is available for most of the world since 1972, with the launch of LANDSAT by USA. This treasure trove of information help us to map and monitor the changes that happened to our coastal areas like land reclamation, destruction of mangroves, shrinkage of estuaries, lakes and other water bodies that are directly linked to fisheries. The multi-date nature of satellite imagery permits monitoring dynamic features of landscape and thus provides a means to detect major land cover changes and quantify the rates of change. GIS and remote sensing are widely used to monitor and map the habitats namely seagrass/seaweed/coral reef (**23**).

Aquaculture site selection:

A suitable site is a pre-requisite for any successful aquaculture activity. Optimal aquaculture sites aids in better management of the resources and ensuring sustainability of the farming
activity. There are lot of reported works on the identification suitable sites for aquaculture using GIS. There are many criteria, guideline and essential factor for selection of site for aquaculture. The parameters such as reported water flow, volume availability, water quality, weather parameters, access and location of utilities, topography of site, slope of land, legislation concerning water rights etc. goes into the decision making process. GIS offers the best platform to combine all these information and identify the areas that qualify optimal set of parameters which would be the best suited areas for aquaculture. Weighted overlay is one of the most used operations in GIS in such analyses (**18**).

There are many more applications of GIS in the field of aquatic environment and readers are advised to go through the references sited below to get an idea about the use of GIS in general and in the study of aquatic environment.

Application of GIS in Marine fisheries management and conservation of marine resources:

The GIS-based studies will give a clear picture of the Spatio-temporal distribution of fishes in the selected study area and help in identification of critical fishing grounds in terms of fishery and marine biodiversity (**24**). The analysis of information collected in layers will help in identifying spawning period, spawning area, juvenile segregation, juvenile migration, in situ growth of different species, resident taxa of particular fishing ground, multi group assemblages, and the basis forthe multi-group gatherings and their dependencies. Application of GIS in marine fisheries is being implemented as a project for the first time in India along Karnataka coast, where this study based on the database created on the trawl fisheries of the Karnataka coast (**25**). The other uses of GIS are for defining fish habitat and organizing and executing living marine resources (i.e.,the dynamics of marine objects), tracking marine mammals and analyzing their hunting and migrant lines; which can assess the efficiency of marine protected areas, and answer to problems related to
environmental ruins (**26**).

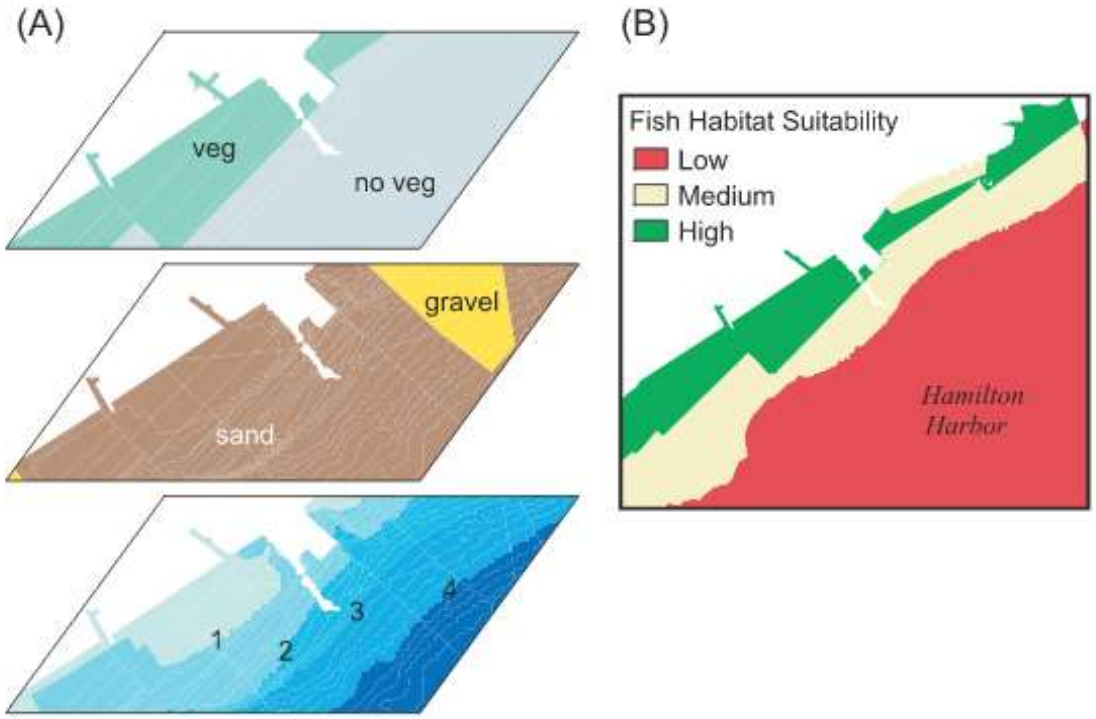

Plate 3: Fish Habitat Suitability
Source: Hamilton Harbor

Mapping and Geospatial Technique in Wetland:
It is important to have an inventory of wetlands and their catchments in terms of conservation and management of wetland resources. Digital maps are potent tools to achieve this. Therefore, Maps are essential for monitoring and quantifying the change over time scale, and it helps in decision making. The technique used in the preparation of the map started with the ground survey. The Survey of India (SOI) topographical maps are the earliest correct maps of India, which shows various land use/cover classes, including wetlands. Remote sensing is recognized as an essential tool for making decisions, viewing, analyzing, and characterizing land, water, and atmospheric components. Space Applications Centre (ISRO), Ahmedabad, which has carried out the first scientific mapping of wetlands of India by using remote sensing data from Indian Remote Sensing satellites (IRS-Series) during 1992-93 (**27**).

GIS for aquatic applications
As GIS can be used for many different purposes on land, it can also do the same when used in aquatic environments. In aquatic environments, GIS allows us to 'see-through' water and investigate things that are happening beneath the surface and on the seafloor. Example of how GIS can be used in the aquatic environment is the tracking of marine mammals. Many large sea creatures such as sharks and whales can be fitted with GPS tagging devices. As the GPS gives off signals, these locations can be mapped using a GIS and, in this way, the migratory, hunting or movement patterns of these species can be tracked (**28**). Knowing this information can then assist specialists in managing populations and environments for the benefit of these creatures. Interactive, real-time tracking of sea creatures can be accessed online at:
GIS can also be used to store and monitor data such as sea levels, and in conjunction with other data can provide an insight into the relationships which may occur between sea-level rise and global temperatures (**29**).

Role of GIS in the Wetland ecosystem:
The wetland boundary should ideally include all open water, aquatic vegetation (eg, aquatic vegetation like submerged, floating, and emergent weeds) and satellite images must give a clear sign of the wetland extent. The presence of vegetation in wetlands provides necessary information about its trophic condition. By using optical remote sensing data, there is a possibility to delineate floating and emergent types of vegetation (**30**).

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Uses of GIS and Environmental Management

GIS has a number of applications. At the most basic level, GIS can be used to determine the location of features and the relationships between features; however, it can be used for much more than that. GIS is an excellent tool for helping with problem-solving and decision making (**31).**

In the environmental sector, GIS can be used to assist with putting together practical plans for monitoring, managing and mitigating environmental impacts, or monitoring the ongoing health or size of a specific population (Padua n.d).Without GIS, methods of environmental management and monitoring would be much more laborious and time-intensive (**32**). GIS gives us the ability to investigate areas of the world that we may not otherwise be able to explore. As technology continues to develop the ways that we are able to use GIS will continue to increase further expanding the ways we can obtain data and the applications this can have. If enough data is available, it is also possible to use GIS to show how an area has changed over time, for example, the growth and spread of Perth City, or how an area is affected and regrows following a bush fire. Due to the ability to show spatial data visually, GIS is extremely useful when making maps and images of these changes and helping technical specialist and non-specialist communicate and develop better environmental outcomes. Also GIS can be used to predict sea-level rises especially in Nigeria (**32, 33, 34**)

Conclusion:

GIS has the capabilities to link theoretically oriented ecological studies with practical applica- tions in resource planning and management. Scientists in Nigeria need to assess the impact of management practices on the aquatic environment using GIS applications and general environmental practices in Nigeria. It is also essential to effectively utilize the application of GIS in renewable natural resources, management with special reference to importance of fish and fisheries in Nigeria, including GIS in the aquatic environment, remote sensing in fisheries, marine fisheries management and conservation of marine resources. and the variety of applications of GIS to the aquatic ecosystems in Nigeria.

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