MANAGEMENT OF WATERSHEDS WITH REMOTE SENSING AND GIS: A CASE STUDY OF RIVER NIGER DELTA REGION IN NIGERIA

Yaw A. Twumasi, Ph.D. Research Assistant Professor
Edmund C. Merem, Ph.D. Assistant Professor
Center for Hydrology, Soil Climatology, and Remote Sensing.
Department of Plant and Soil Science. P.O. Box 1208.
Alabama A&M University, Normal, AL 35762
Department of Urban and Regional Planning, Jackson State University.
Jackson, MS 39211 USA
yaw.twumasi@email.aamu.edu
edmund.c.merem@jsums.edu

ABSTRACT

The growing incidence of global environmental decline, especially the depletion of ozone layer, loss of biodiversity and degradation of large watersheds caused by deforestation, have attracted the attention of decision makers worldwide for quite sometime. After a series of global environmental conferences between 1987 through 1992, policy debates within the field of environmental protection identified the conditions of watersheds as a vital component of ecosystem health. While human impact on the environment has intensified, considerable attention has been directed towards the search for a means to preserve existing biodiversity and management of large watersheds. In the process the question of the watershed management in a tropical ecosystem continues to draw substantial interests from researchers. Increasingly, in the past decade, Nigeria's River Niger Delta has been under intense pressure because of the threat posed by multiple factors. Human activities inland have exerted a lot of pressure through intense use of land surrounding the watershed for oil and gas drilling, agriculture, logging, and fuelwood extraction and increasing reliance on the river for electricity consumption to satisfy both domestic and foreign exchange needs. Compounding the problems are the lack of efficient, inventorying and precise data to sustainably manage the watershed. Notwithstanding the gravity of these trends there has not been any major effort by resource managers aimed at examining these issues in watershed management within the Niger Delta Region of Southern Nigeria. This calls for the need to find appropriate tools to aid the management of the river. Perhaps the most important element in the efforts to manage the Niger Delta is the need to provide a baseline data about the ecology and forest cover to form the basis of future management. This study therefore adopts a remote sensing technique to provide baseline information about the surrounding ecology of River Niger Delta to facilitate future monitoring.

INTRODUCTION: BACKGROUND INFORMATION AND THE ISSUES

In the literature watersheds are described as an important source of water, energy and biological diversity. Furthermore, they are a source of such key resources as forests, agricultural products and of recreation. As a key ecosystem representing the complex and interrelated ecology of our planet, watershed environments are essential to the survival of global ecosystem (Heal 2000). From a planning standpoint, watershed is considered the most ideal unit for analysis and management of natural resources. For optimal use of environmental resources in a region, integrated watershed development approach is still viewed by many to be the most ideal as it helps in maintaining the ecological basis of resources utilization (Sahai 1988). Accordingly, watershed management deals with optimizing the use of land, water, vegetation, animal, and environment to prevent soil erosion, improve water availability, increase, food, fuel and timber production on a sustainable basis (Bhardwaj and Dogra 1997).

To further put the role of watersheds in a context as noted by (Heal 2000) requires a further digression towards the attributes and the importance of watersheds from a global perspective. In line with the goal of protecting the Earth's basic riparian resources and environmental systems, the conservation of watersheds is of great importance, in part because they are significant in their own right, but also because they cover many regions of the world in the form of as forests, which contribute genetic diversity. Additionally, conservation of watersheds enhances the protection of many habitats that are essential to other life support systems of the planet. To demonstrate this point, the world's 106 biggest watersheds cover 53 percent of the Earth's surface. Close to 3 billion people representing 50

percent of the world's population reside in them, and probably depend on these watersheds for water. Among them they offer the only breeding places for over 3000 species of fish and over 200 species of birds (Revenga and Murray; 1998). Notwithstanding these essential attributes, most watersheds as shown in the literature are, however rapidly experiencing some significant changes. They are vulnerable to accelerated erosion, water scarcity, landslides and rapid loss of habitat for genetic diversity as well as environmental degradation. On the human side, there is widespread poverty among watershed inhabitants as (Okoko 1998) showed in a field study that highlighted the touchy experiences of the Ibeno community fueled partly by environmental stress along Niger Delta watershed.

Accordingly, the degradation of environmental systems such as watersheds and natural resources is now occurring at an alarming rate in both developed and developing countries (WCED 1987; Heal 2000; Sealman 2000; Myers and Kent 2001; UNEP 1999; UNEP 2003). While the existing literature posits that the demand for wood in major watersheds of the world already exceeds the regenerative capacity of forest woodland areas. The misuse of forest resources and wetlands, within major watersheds has led to a drastic reduction of forest cover with adverse impacts on natural habitats. It has been shown that economic growth and the effect of a growing population weaken the natural resources base of most watersheds in several countries. This continues to undermine sustainable development (WCED 1987; Sealman 2000). All of these anthropocentric intrusions have created the loss of bio-diversity, in conjunction with water scarcity. In the process, the growing incidence of global environmental decline, especially the depletion of ozone layer, loss of biodiversity and degradation of large watersheds caused by deforestation, have attracted the attention of decision makers worldwide for quite sometime (UNEP 2003; Myers and Kent 2001).

After a series of global environmental conferences between 1987 through 1992, policy debates within the field of environmental protection identified the effective management and monitoring of watersheds as a vital component of ecosystem health (Revenga and Murray; 1998). Convinced about the need to safeguard vulnerable watersheds from anthropocentric activities, The United Nations Environment Program (UNEP) in its document *Agenda 21* not only outlined the basis for integrated watershed management, coupled with research about the ecology and sustainable development of watersheds, but it also called for action plans from all nations by the year 2000.

While human impact on the environment has intensified, considerable attention has been directed towards the search for a means to preserve existing biodiversity and management of large watersheds (UNEP 1999;Revenga and Murray 1998). In the process, the question of watershed management in a tropical ecosystem continues to draw substantial interests from researchers. Increasingly, in the past decades, Nigeria's River Niger Delta has been under intense pressure because of the threat posed by multiple factors. The Niger Delta region has suffered all forms of pollution and degradation originating from oil and gas exploitation. This includes a decrease in agricultural productivity and loss of vegetation. Other prevailing problems in the region consist of rising concentrations of airborne pollutants, acidification of soil and rainwater, loss of marine organisms and fish population (Ologunorisa 2001).

The growing incidence of environmental degradation in the area as Okoko (1999) points out, can be buttressed with the frequency of oil spills between 1979 and 1980 which devastated communities along the Niger Delta watershed. In 1979, a storage tank owned by the Shell Petroleum Development Corporation ripped open and split 570,000 barrels of oil into the adjoining waters. In 1980, a blow out at Funiwa oil well 5 miles offshore led to the discharge of 400,000 barrels of crude oil that decimated marine ecosystem within close proximity to a coast line (Nwankwo and Ifedi 1986). Under this setting, human activities inland have exerted a lot of pressure through intense use of land surrounding the watershed for oil and gas drilling, agriculture, logging, and fuelwood extraction and increasing reliance on the river for electricity consumption to satisfy both domestic and foreign exchange needs.

Compounding the problems are the lack of efficient, inventorying and mapping of precise data to sustainably manage the watershed. Notwithstanding the gravity of these trends, there has not been any major effort by resource managers aimed at examining these issues in watershed management within the Niger Delta Region of Southern Nigeria. This calls for the need to find appropriate tools to aid the management of the river. Perhaps the most important element in the efforts to manage the Niger Delta is the need to provide a baseline data based on integrated GIS and remote sensing approach about the ecology and forest cover to form the basis of future management (Merem and Twumasi 2005). This approach is quite effective in monitoring the impacts of human activities on watershed environments in international development (Shultz and Saena 1998). In light of this, many authors view the widespread applications of GIS and remote sensing techniques in watershed management as a major step towards sustainability and resource conservation (Malczewski 2003; Tyson 2004),

In the literature, GIS and remote sensing techniques are widely used for studying Earth's resources at various levels (Deekshatulu 1991). In one study, Shaban et al (2005) notes how the use of integrated watershed assessment, especially relying on remote sensing and GIS has become a newly established procedure in river basin environmental management in developing countries. Using the Akar watershed in the Eastern Mediterranean, they

analyze watershed characteristics, land use and fabric. The study reveals that significant changes caused in part by anthropocentric factors. Elsewhere Biswas et al (2002), describe remote sensing and GIS based approach as handy and effective tools for the treatment and the conservation of watersheds in West Bengal Eastern India. In another study, (Saxena et al 2000) examine spatial data application in watershed characterization and management. While the core elements of the work cover a precise inventory of the watershed, components like drainage density and pattern, slope percentage and direction, physiography, soils, land use and land cover, were visually interpreted using the geocoded false color composites. In southwest China, (Jianchu 2005) explores the spatial and temporal dynamics of land use in Xizhuang watershed by analyzing aerial photographs and ASTER satellite imagery from 1987 to 2002. The study found that the forest cover significantly grew at the expense of decreasing farmland. From these reviews, it is evident that GIS are essential for georeferencing and manipulating spatial raster and vector data, while the processing of remotely sensed data relies on image analysis software (Paniconi et al 1999). Considering the numerous applications as shown in the literature, there is an urgent need for an integrated GIS and remote sensing applications to provide baseline information about changes in the surrounding ecology of River Niger Delta watershed in order to facilitate future and continuous monitoring of the delta ecosystem. This paper will fill that void in the literature.

THE PURPOSE AND ORGANIZATION OF THE RESEARCH

This study adopts a remote sensing and GIS based approach to provide baseline information about changes in the surrounding ecology and the watersheds of the River Niger Delta. Emphasis is on monitoring the extent and nature of environmental change occurring in the Niger Delta watersheds. The prime objective of the paper is to provide a viable system for monitoring the state of coastal watersheds in a developing nation. The second objective is to make a contribution to the literature. The third objective is to provide a decision support tool for watershed managers in evaluating the impacts of human activities in fragile ecosystems. The fourth objective is to assess the nature of change in a watershed ecosystem with latest innovations in geo-spatial information technologies and methods. The paper has five sections. Section one provides a description of the methods and the study area. Section two presents the results and data analysis, while section three discusses the findings and their significance to GIS and remote sensing applications in a watershed environment. The fourth section offers recommendations for change in policy. The final section summarizes the importance of the study to the future of watershed management along the Niger Delta.

BACKGROUND AND METHODS

The Study area: The Niger Delta Region

Nigeria is a former British colony and is bounded on the north by Niger, on the east by Cameroon, on the south by the Atlantic Ocean, and on the west by Republic of Benin. The study area lies along the east of the Niger Delta (Figure 1). It is located in latitude 04^0 40` 00``N and longitude $07^0$ 07` 00``E. The area is home to numerous creeks and rivers. The Niger Delta Region extends over an area of about 112,110 square kilometers representing about 12 per cent of Nigeria's total surface area. The region is situated along a coastline of 560 km, about two-thirds of the entire coastline of Nigeria. The region comprises nine of Nigeria's constituent states as shown in Table 1. At the time of the 1991 census, the total population of the region stood at about 20 million, (23% of the Nigerian population). Current estimates from the Government sources put the total population of the region at 27 million in 2005 (Niger Delta Development Commission; NNDC 2005).

Table 1. Population Projections High For The Niger Delta

State	2005	2010	2015	2020
Abia	3,230,000	3,763,000	4,383,000	5,106,000
Akwaibom	3,343,000	3,3895000	4,5537,000	5,285,000
Bayelsa	1,710,000	1,992,000	2,320,000	2,703,000
Cross River	2,736,000	3,187,000	3,712,000	4,325,000
Delta	3,594,000	4,186,000	4,877,000	5,681,000
Edo	3,018,000	3,516,000	4,096000	4,871,000
Imo	3,342,000	3,894,000	4,535,000	5,283,000
Ondo	3,025,000	3,524,000	4,105,000	4,782,000
Rivers	4,858,000	5,659,000	6,592,000	7,679,000
Total	**28,856,000**	**33,616,000**	**39,157,000**	**45,715,000**

The Niger delta represents a unique region that possesses the world's third largest wetlands with significant biological diversity. The region is endowed with rich and diverse mosaic of ecological types made up of five distinct ecological zones. The eco-zones range from barrier island forest and coastal vegetation areas to montane habitats. The first eco-zone has the features of a mangrove forest and coastal vegetation zone with chain of low sandy barrier islands that protects the coast of the Niger Delta, between the Benin and Imo estuaries, less than a meter above the high tides level, while the second type is characterized by the fresh water swamp forest zone covering approximately 17,000 square or about half of the region. Thirdly the lowland rain forest zone stretches over non-riverine or upland areas flanking the delta. Fourthly, the derived savannah zone is found in the northern parts of the region while the montane zone is fully concentrated in the northeastern part of Cross River state of the region (NNDC 2005.

Part of the major concerns facing the ecosystem of the delta as mentioned before emanates from the growing pressures mounted by development activities in the region (United States Department of Energy 2003). Because of improper management, various materials and effluents discharged into marine environment contain drill cuttings, drill muds and fluids used for stimulating production oil production. The construction of infrastructures for oil facilities in the region has occurred without environmental considerations. To facilitate road construction, wetlands and waterways are frequently dredged and diverted to other uses at the expense nature protection (Achi 2003; Worgu 2000). In light of these problems human activities in the study area, merits a rigorous environmental analysis and monitoring with the appropriate techniques.

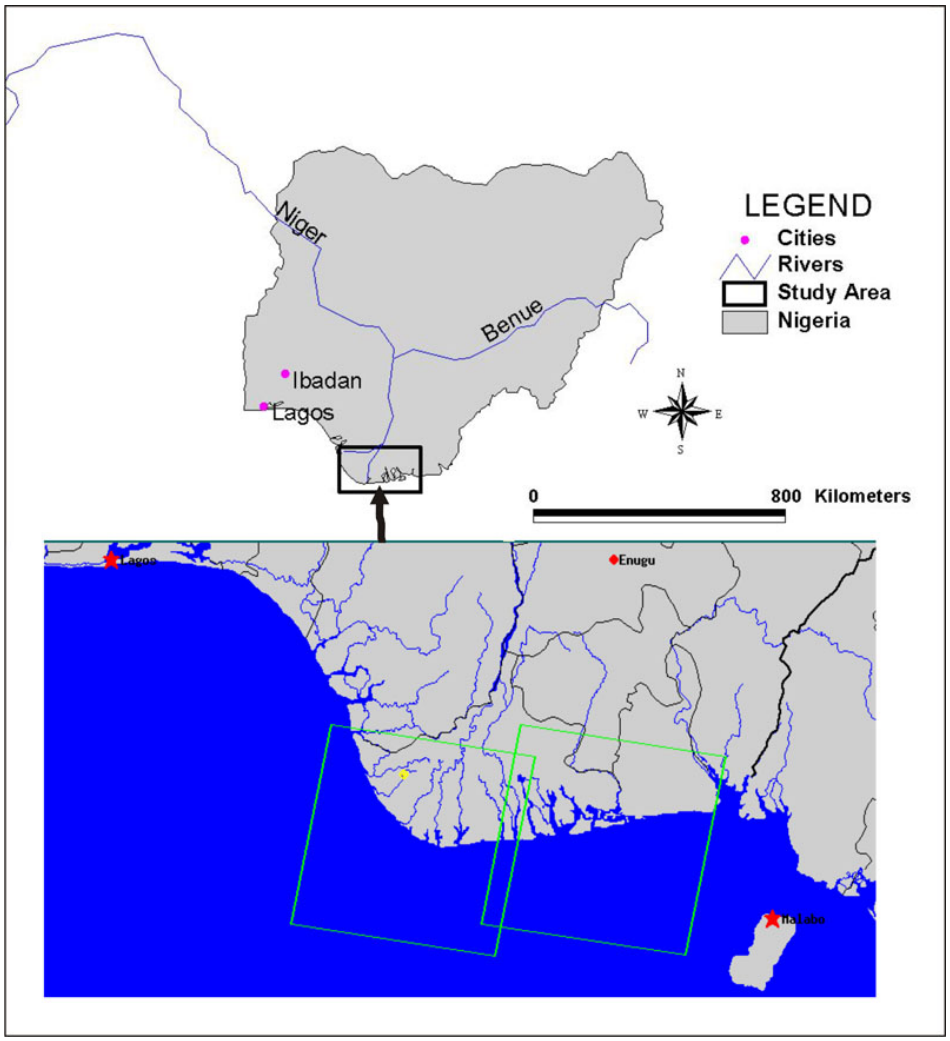

Figure 1. The Study Area.

Methods Used

This paper stresses a mix scale approach involving the integration of primary and secondary data provided through government sources and data bases from other organizations and a measure of descriptive statistics. The raw spatial data and satellite images used in the research were procured through The United States National Aeronautical and Space Administration NASA and the United States Geological Survey

Step 1: Data Acquisition

The first step involves the identification of the variables needed to assess environmental change at the regional level from 1986-2000. The variables consist of socioeconomic and environmental information, including amount of cropland, human settlement, water bodies, forest types, population, (See Tables 1 and 2). That process was followed by the design of data matrices for the variables covering the various periods from 1986 and 2000 and beyond. The process was facilitated by access to databases and abstracts that are presently available within the Federal archives in Nigeria, The United States Geological Survey Department (USGS) and host of other organizations. The spatial data acquired from the USGS consists of 2 Satellite images for the separate periods of 1986 and 2000. The path was 188 and 189; and 57 for the row.

Step 2: Geo Spatial Data Processing and Analysis

Two Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) multi-seasonal images of 20 May 1986 and 19 June 2000 were obtained for this study. The Landsat TM and ETM+ satellite data were processed using ERDAS IMAGINE 8.7 image processing software. The images were imported into ERDAS using ERDAS native file format GEOTIFF. Since the images were in single bands, they were stacked together using ERDAS layer stack module to form a floating scene. Path 188 and 189 were mosaicked to form seamless image. The 1986 image was co-registered with the 2000 image and later geo-linked to allow for the subset of the both images to the study area. Enhancement of all the images using histogram equalization techniques was later performed. The images were classified using an unsupervised classification technique to identify land cover features within the study area. The remaining procedure involves spatial analysis and output (maps-tables-text) covering the study period, using ARCVIEW GIS. The spatial units of analysis consisted of the states located in the delta region counties (Figure 1). Outputs for the region were mapped and compared across time. This process helped show the spatial evolution of costal environmental change in the delta as well as changes in other variables.

RESULTS

This section presents the results of the data analysis by first providing a brief synthesis of the descriptive statistics and geospatial analysis (GIS and Remote sensing analysis) of the changes along the watershed. Later, it discusses some of the findings along with brief highlights of the factors associated with change in environmental resources in the study area and the GIS and remote sensing frameworks in place to reverse the trends.

Assessment of Environmental Change 1985-2000

The results of 1985 and 2000 classified images are provided in Table 2 and Figures 2 and 3. The accuracy of the results was compared to government statistics and available information on the area. From Figures 2 and 3, and Table 2, water bodies experienced slight decline from 343,654 to 343,513 hectares. Mangrove and closed forest also posted a decline from an initial estimate of 55,410 hectares in 1985 to 37,117 hectares for mangrove; and from 250,161 hectares in 1985 to 175,609 hectares for closed forest representing an overall decrease of 33.01 and 29.80 percent respectively. While mangrove, water bodies and closed forest were decreasing, settlement; cropland and mixed forest were increasing as well. For instance, between 1985 and 2000, agricultural activities increased from 16,495 hectares to 23,974 hectares representing a change of 45.34 percent. Mixed forest also posted a slight change from 162,916 hectares in 1985 to 192,436 hectares in 2000, an increase of 29,520 hectares. Settlement had the highest increase in the area. For example, from the initial estimate of 52,738 hectares in 1985, it doubled to 108,725 hectares in 2000 representing an overall increase of 106.16 percent.

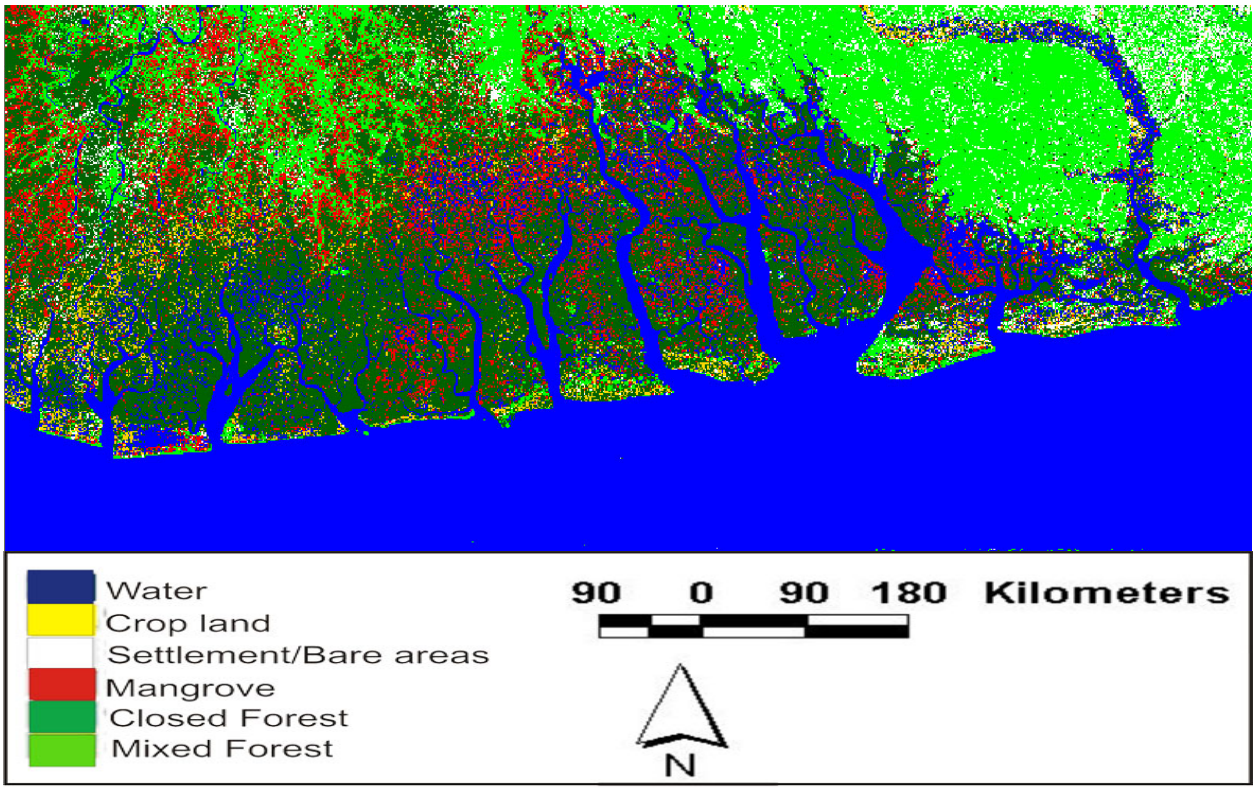

Figure 2. Classified image of Landsat TM, May 20, 1986.

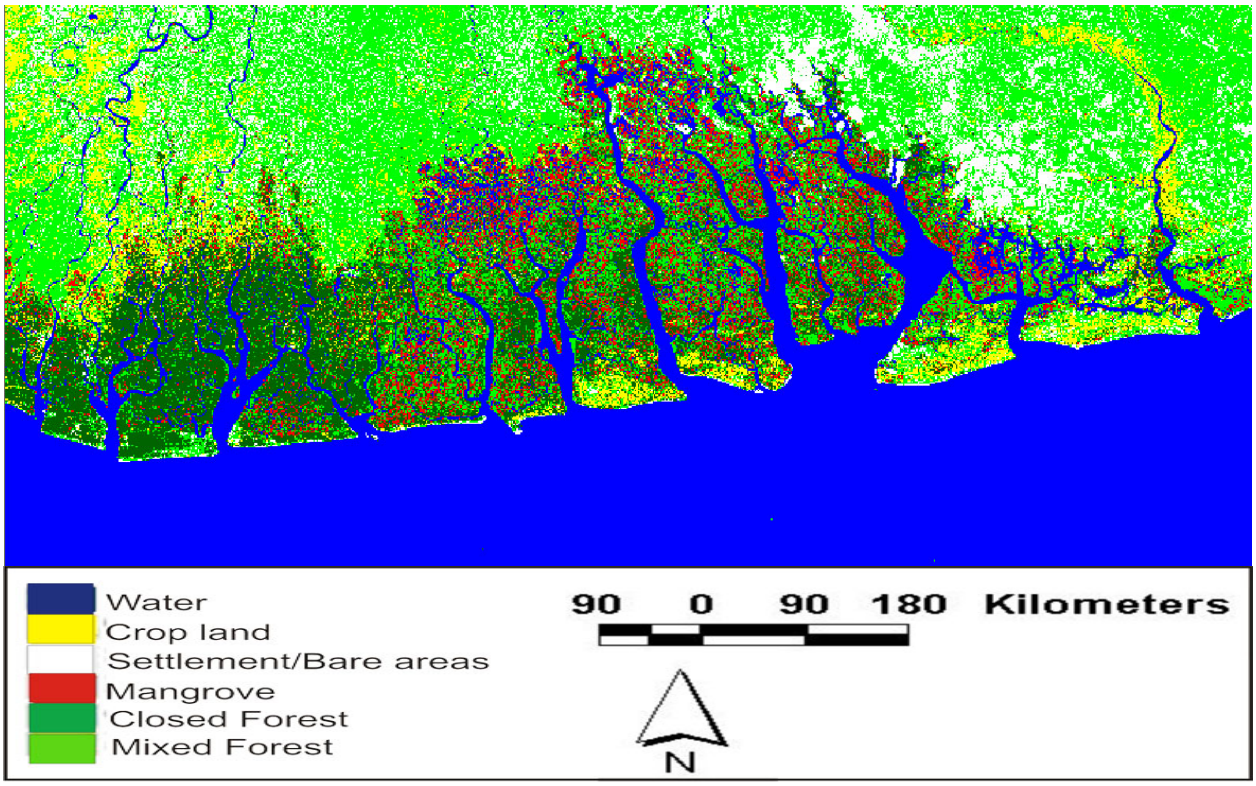

Figure 3. Classified image of Landsat TM, June 19, 2000.

Table 2. Results of the classified 1986 and 2000 images.

Classes	Area (ha) in 1986	Area (ha) in 2000	% change (1986-2000)
Water	642,469	501,760	-22
Crop land	90,619	357,450	294
Settlement / bare areas	72,068	245,384	240
Mangrove	135,668	98,669	-27
Closed forest	502,312	433,589	-14
Mixed forest	484,752	291,036	-40

DISCUSSION

The results not only revel that the study area experienced some significant changes in its watershed environments, but the region remains an ecosystem under stress. The nature and extent of this change showed some variations across time and space. These changes are attributed to socio-economic and environmental variables and host of other factors. Over all the results point to a decline in waterbodies, mangrove forests, and increase in human settlement, mixed forests, cropland and agricultural intensification which posed a major threat to the environmental and natural systems of the region. Other interesting findings touch on an impending population explosion in the coastal region of Niger Delta in Southern Nigeria. This will not only threaten the carrying capacity of an already fragile ecosystem, but it poses enormous challenges for both environmental and natural resource managers and policy makers in the region if not confronted with urgency it deserves.

In light of this finding, the practical use of a mix scale approach involving secondary data, GIS and remote sensing in tracking costal environment change stands an update to current literature on watershed management in the Niger delta region of Nigeria. Considering that minor efforts were made in the past to examine environmental issues confronting the Delta ecosystem, GIS technology as used in this paper has fulfilled a useful purpose by manipulating and mapping watershed data. It also stands as an effective tool for watershed resource management. Integrated data analysis using remotely sensed satellite imagery and GIS modeling, facilitated the analysis of the spatial diffusion of environmental change involving land use, land cover classification, forest cover and hydrology changes occurring in the Niger Delta environment.

RECOMMENDATION AND CONCLUSIONS

To address some of the concerns that were identified in the current research, four recommendations anchored in integrated watershed management are hereby made as part of the remedies.

1) ***Adopt Integrated Watershed Management.*** Considering the widespread growth and the pressure on the area's environmental indicators such as wetlands, rivers and forests cover. The states located along the Niger Delta watershed should adopt an ecosystem based integrated GIS and remote sensing watershed management approach in order to quicken the periodic monitoring of the Delta's ecosystem health and the interaction between human activities and the environment in the region.

2) ***Encourage Citizen Participation.*** One of the major policy defects in the Delta watershed hinges on the lack of consultation and citizen involvement in decisions fuelling the embers of resources exploitation most likely associated with the rapid ecological decline of watershed. Considering the effects of lack local input in development activities along the delta, government entities should encourage active community involvement in matters associated with economic development in the area and the way it impacts on the area's fragile ecosystem.

3) ***Promote Coastal Zone Management.*** An integrated costal resource management approach is needed to address the broad set of environmental problems confronting the Niger Delta watershed. Integrated Coastal zone management encompasses holistic planning and coordinating process capable of guaranteeing that large economic and social benefits from resources in the Niger Delta are not squandered through ecologically destructive programs.

4) ***Design a Regional Geo-spatial Data Infrastructure.*** During the time of the current research, the study area lacked accessible regional geo-spatial information system capable of computing the interactions between humans and the environment. Developing such an inventory will offer the decision makers access to the appropriate temporal-spatial data for monitoring the pressures mounted on the areas ecosystem by development activities. Such a tool could act as an effective decision support system in order to keep development in harmony with environmental sustainability.

CONCLUSION

This project has analyzed the applications of GIS and remote sensing tools in watershed management with emphasis on the need to provide a baseline data about change in the ecology and forest cover that forms the basis of future management of the Niger Delta watershed of Southern Nigeria. The paper presented a concise overview of the attributes and benefits of watershed approach in general, issues in the literature, review of the major environmental effects and factors associated with the problem, and a series of suggestions to mitigate the problems. Notwithstanding the gravity of these trends there has not been any major effort by resource managers aimed at examining these issues in watershed management within the Niger Delta Region of Southern. Considering the growing pressures mounted by human activities in the region, the results from the data analysis revel that the study area experienced some significant changes in its coastal environments especially on the surrounding ecology of River Niger made up of forest and land cover. These changes are attributed to socio-economic and environmental variables and host of other factors. The results also point to a decline in water bodies, mangrove forests, and increase in human settlement, mixed forests, cropland and agricultural intensification as well as several cases of oil spillages. Other interesting findings touched on the potentials for population growth. This will not only threaten the carrying capacity of an already fragile ecosystem, but it poses enormous challenges for environmental and watershed resource managers and policy makers in the region if not confronted with urgency. To deal wit these problems, the paper offers some recommendations as part of the watershed conservation strategies for the region. The recommendations consist of watershed management, citizens' participation, coastal zone management and the design of a regional data infrastructure.

The practical use of a mix scale approach involving GIS and remote sensing as analytical tools and use of secondary data for the analysis of ecological change due to human activities provides some interesting results towards watershed management in the delta of Nigeria. Moreso, it is evident that GIS technology as used by scientists for manipulation and mapping of data with a spatial reference stands as an effective tool for watershed management and the provision of baseline information about the surrounding ecology of River Niger Delta for future monitoring. Using remotely sensed satellite imagery and GIS modeling, quickened analysis of the geographic diffusion of ecological change involving land use, land cover classification, forest cover and hydrology and demographic issues facing the Niger Delta. In closing, it is our belief that successful implementation of some of the strategies could lead to effective watershed management in the Niger Delta region. Furthermore, the paper serves as a decision support tool for watershed managers.

BIBLIOGRAPHY

Achi, C. 2003. Hydrocarbon Exploitation, Environmental Degradation and Poverty: The Niger Delta Experience. *In Proceedings of The Diffuse Pollution Conference*, Dublin.

Biswas, S. 2002. Remote sensing and geographic information system bases approach for watershed conservation. *Journal of Surveying Engineering*, 128:3: 108.

Heal, G. (2000). *Nature and the marketplace.* Washington, DC: Island Press.

Jianchu, X. 2005. Exploring the spatial and temporal dynamics of land use in Xizhuang watershed of Yunna, southwest China. *International Journal of Applied Earth Observation and Geoinformation*, 7:4:299-309.

Malczewski, J. 2003. GIS –multicriteria evaluation with ordered weighted averaging (OWA): case study of developing watershed management strategies. *Environmental and Planning*, 35:10:1769-1784

Merem, E. C., and Y.A. Twumasi. 2005. GIS and remote sensing applications in the assessment of change within a coastal environment in the Niger Delta region of Nigeria in *the proceedings of the 2nd International conference on latest advances in environmental health*, Jackson, Mississippi.

Myers, N. and J. Kent. 2001. *Perverse Subsidies: How Tax Dollars Undercut the Environment and the Economy*. Washington, DC: Island Press.

Niger Delta Development Commission NNDC 2005b. *Niger Delta Regional Development Master Plan.* Port Harcourt Nigeria.

Okoko, E. W.1999. December men and Environmental Change In The Delta, Nigeria Evidence From Ibeno Gender Place, and Culture: *A Journal of Feminist Geography* 6:4: 1-5.

Ologunorisa, T (2001 September) A review of the effects of gas flaring on the Niger Delta environment *International Journal for Sustainable Development and World Ecology*, 8:1.

Oronto, D. 2000. *Nigeria: Using a Variety of Advocacy Tools In The Niger Delta Environmental Rights Action*. Friends of The Earth Nigeria Port Harcourt

Panicioni, C, S. Kleinfeldt, and J. Deckmyn. 1999. Integrating GIS and data visualization tools for distributed hydrologic modeling. *Transactions in GIS*, 3:2.

Research Consortium on Africa. 2002. *Nigeria's Environmental Challenges* Albany: NY.

Revenga. C., and S. Murray.1998. *Watersheds of the world.* Washington, DC: World Resources Institute and World Watch Institute.

Saxena, R. K., K.S.Verma, and G.R. Chary. 2000. IRS-ICdata application in watershed characterization and management. *International Journal of Remote Sensing.* 21:17:3197-3208.

Selman, P. 2000. *Environmental Planning*. London: UK Sage Publications.

Shaban, A. 2005. Watershed characteristics, land use and fabric: the application of remote sensing and geographicinformation systems. *Lakes and Reservoirs:Research and Management*, 10:2: 85-92.

Shultz, S., and F Saenz. 1998. Linking people to watershed protection planning with a GIS: a case study of central American watershed.

Tyson, B. 2004. Layering natural resource and human resource data for planning watershed conservation strategies, *Society and Natural Resources*, 17: 2:163-170.

United Nations Environment Program (UNEP).1999. *Unsafe Water: 3.3 Billion Illnesses and 5.3 Million Deaths*.New York: United Nations Environment Program.

United Nations Environment Program (UNEP).2003. *Agenda 21*. New York: United Nations Environment Program

United States Department of Energy. 2003. *Country Area Analysis Nigeria: Environmental Issues*, Washington D.C: US DOE.

WCED :World Commission On Environment and Development.1987. *Our Common Future*. Oxford, UK: Oxford University Press

Were, J. 2001. Niger *Delta Swamp Forests* Peer Review In Process World Wildlife Fund.

Worgu, S. 2000. *Hydrocarbon Exploitation Environmental Degradation and Poverty In The Niger Delta Region of Nigeria*. Lund: Lund University Sweden.