Mapping Impervious Surface Changes in Watersheds in Part of South Eastern Region of Nigeria Using Landsat Data

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Key words: Impervious surface, Watershed delineation, Landsat images, Water quality.

SUMMARY

In Nigeria as a whole and South eastern region of Nigeria in particular, there are many natural water bodies ranging from small natural pools of less than 0.01 ha, rivers, streams, to lakes of over 1000 ha in size. This region has experienced some sort of rapid development – urbanization and industrialization since the 1980,s, and this gave rise to increase in impervious surface (IS) cover within the region. Impervious surfaces are mainly constructed surfaces - rooftops, sidewalks, roads, and parking lots - covered by impenetrable materials such as asphalt, concrete, brick, and stone. These materials seal surfaces, repel water and prevent precipitation from infiltrating soils. Increased impervious cover generally results in more storm water runoff and less ground water recharge. Less recharge means less ground water discharges to streams during dry periods. Also, impervious surfaces allow many types of pollutants, derived from a variety of sources, to accumulate upon them, and subsequently washed into water bodies by storm water runoff, severely degrading water quality (non-point source water pollution).

Impervious surfaces can therefore be considered a direct indicator as to the quality of surrounding surface water including streams, rivers, and lakes. In order to curb the possible effects of continued environmental damage the need to locate and quantify impervious surfaces has been suggested as a means to manage watersheds. Remote sensing imagery provides an ideal medium from which to directly estimate impervious surface. Satellite imagery (i.e. Landsat images) provides synoptic view of the Earth's surface capable of producing regular, repeatable land cover maps. With satellite images there is significant reductions in the amount of labor, time, and cost necessary for impervious surface delineation and monitoring.

In this paper, the quantification of the amount of impervious cover change in watersheds in part of southeastern region of Nigeria using Landsat data is presented. Procedure employed include: watershed delineation in the area of interest using the Automated Geospatial Watershed Assessment (AGWA); land cover and land use classification; percentage impervious surface cover computation for the delineated watershed based on the Impervious Surface Analysis Tool (ISAT); Impervious surface change computation between the year 1986 and year 2000; and prediction of change in percentage impervious surface cover within the area of interest.

Results are presented in maps, which depict land cover classes, watersheds, and the percent of impervious cover changes in the area.

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1. INTODUCTION

According to the most recent United Nations projections (Civco et al., 2005), the urban population of the developing countries is now growing at the annual rate of 2.3%, and at this rate it will double in 30 years, from 1.94 billion in 2000 to 3.88 billion in 2030. The average annual urban growth for a sample of 31 metropolitan areas in developing countries was 5.1 percent (Civco et al., 2005). Based on current settlement practices, this implies that, on average, cities in the developing countries will most likely double their built–up areas to accommodate the doubling of their present populations. As with many developing countries Nigeria has experienced some sort of rapid development – urbanization and industrialization. These resulted in the considerable growth in urban and suburban areas. All these will gave rise to increase in impervious surface cover within urban and suburban areas in Nigeria.

Impervious surfaces are defined as surfaces that prohibit the movement of water from the land surface into the underlying soil (Civco and Hurd, 1997; Hurd and Civco, 2004). They are mainly constructed surfaces - rooftops, sidewalks, roads, and parking lots - covered by impenetrable materials such as asphalt, concrete, brick, and stone. Impervious cover has been implicated in a number of significant watershed impacts (Jennings and Jarnagin 2000; Klein, 1979). Most of these impacts are related to hydrologic changes –the flow of water into and within the stream system. Increased impervious cover generally results in more storm water runoff and less ground water recharge. More runoff, in turn, increases stream flows during storm periods. Stream banks erode, more sediment is carried into the streams from surrounding lands, and aquatic habitats are disrupted and degraded. Less recharge means less ground water discharges to streams during dry periods. The reduced stream flow and more extreme stream temperatures will stress aquatic ecosystems. In addition, pollutants tend to be more concentrated because dilution is reduced. When storm water moves more quickly into streams, it also has a greater capacity to carry non-point source (NPS) pollutants into the water bodies (Prisloe et al., 2001). NPS includes nutrients, pathogens, metals, sand, and other materials that are picked up by water as it runs across the landscape. The hydrological impacts of urbanization, particularly impervious surfaces are depicted in figure 1. This implies that impervious surfaces can serve as an important indicator of water quality, since imperviousness has been consistently shown to affect stream hydrology and water quality, and it can be readily measured at a variety of scales *(i.e.,* from the parcel level to the watershed and regional levels) (Dougherty et al., 2004; Schueler, 1994).

Information of the types of surfaces that comprise total impervious cover can be extremely beneficial. Land use planners can use impervious surface measurements as a means of estimating the environmental status of a particular watershed. Planners can use this information to assist in the creation of future development plans and water resource protection programs (Arnold and Gibbons, 1996; Schueler, 1994). Understanding the degree and location of impervious surfaces and limiting the amount of impervious surface in a watershed is an important component of overall watershed management (Hurd and Civco, 2004). Coastal resource, land use managers, and water resources managers need to be able to determine the existing percent imperviousness for an area in order to develop appropriate watershed management and/or NPS mitigation plans. Resource managers and other professionals may effectively utilize the resulting data as they develop watershed management plans and tools. Surely mapping and geoinformation of impervious surface cover will promote better land administration and therefore good governance.

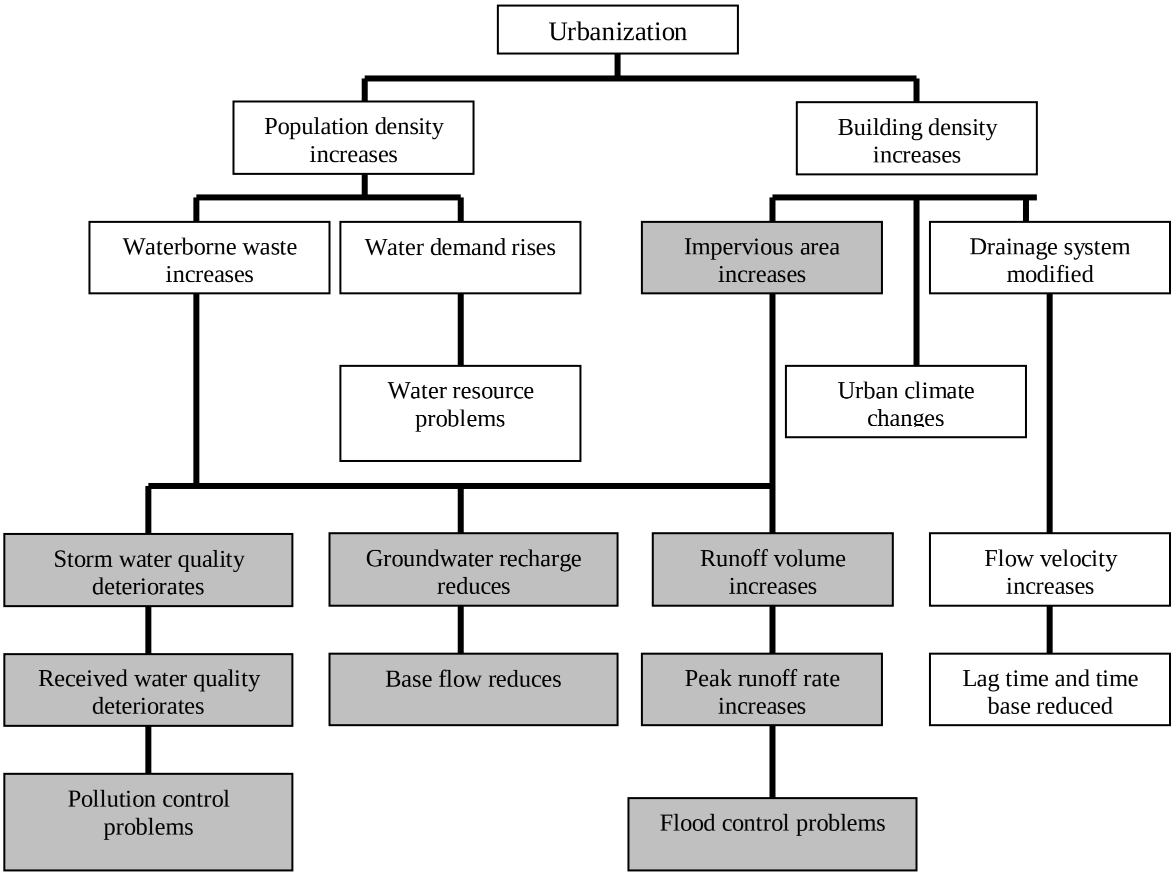

Figure 1: Hydrologic impact of urbanization. Gray boxes identify impacts directly related to impervious surfaces (adapted from (Hurd and Civco, 2004).

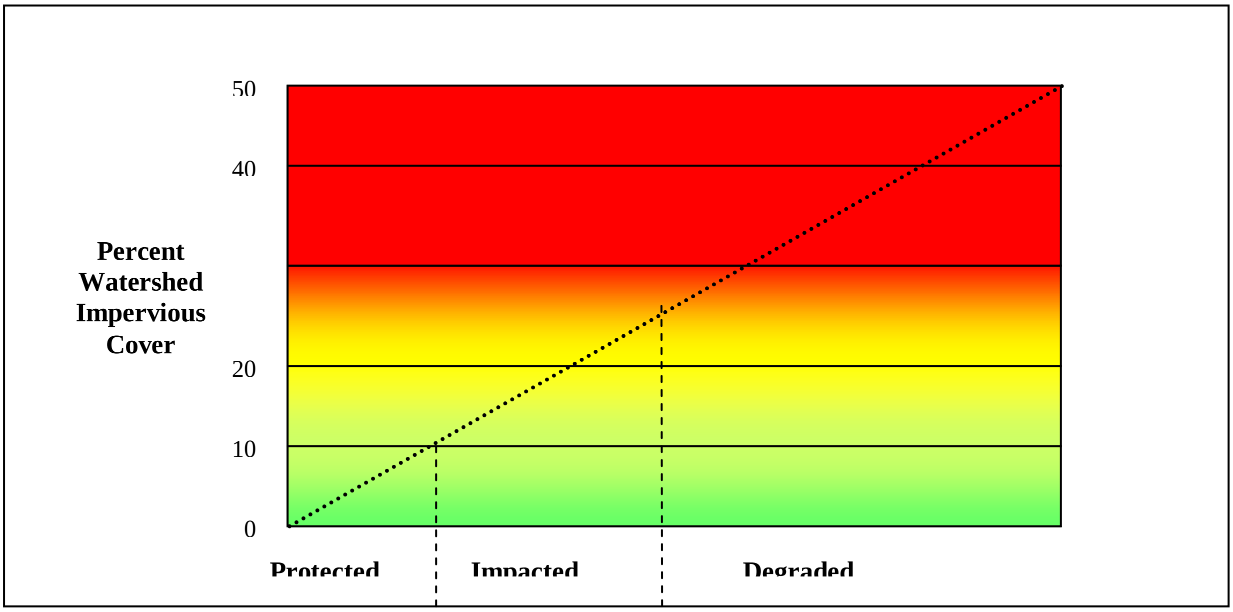

Figure 2: Percent watershed impervious cover versus water conditions (adapted from (Prisloe et al., 2001). The background colors correspond to stream quality conditions, from unpolluted and natural (green) to polluted and degraded (red).

Geospatial technologies provide effective tools to map and quantify impervious surfaces, and to monitor changes over time. Remote sensing imagery provides an ideal medium from which to directly estimate impervious surfaces at relatively modest cost, thereby providing a mechanism for measuring "imperviousness" at frequent, repeated intervals. Various researchers have developed methods of mapping impervious surfaces at different scales using remote sensing data. These include the works of Ji and Jensen (1999), Bird et al (2000), Flanagen and Civco (2001), Justice and Rubin (2002), Yang, et al. (2003), Dougherty et al (2004), and Hurd and Civco (2004).

Numerous forms of water bodies ranging from small natural pools of less than 0.01 ha, rivers, streams, to lakes of over 1000 ha in size are to be found in various parts of Nigeria. The qualities of these water bodies are certainly affected directly or indirectly by the increase in impervious surfaces. For most developing countries including Nigeria, research activities in impervious surface mapping are rare, and that is basically the motivation for this paper. In this paper, the quantification of the amount of impervious surface cover and change in impervious surface cover in watersheds in Enugu area, South-eastern region of Nigeria, using Landsat data is presented. Procedure employed include: watershed delineation in the area of interest using the Automated Geospatial Watershed Assessment (AGWA); land cover and land use classification; percentage impervious surface cover computation for the delineated watershed based on the Impervious Surface Analysis Tool (ISAT); Impervious surface change computation between the year 1986 and year 2000; and prediction of change in percentage impervious surface cover within the area of interest.

2. METHODOLOGY

2.1 Study Area

The study area is Enugu city and its environs, made up of the urban areas and suburbs, with total area of about 333 square kilometers. The area extends from 6^{o} 21' to 6^{o} 31' North in latitude and 7^{o} 27' to 7^{o} 37' East in longitude. The town represents a typical city in South Eastern Nigeria and is in different developmental stages, which varies from heavily urbanized areas to a rural community, and suburban areas.

2.2 Data Set Used

Two sets of ortho-rectified Landsat images were the principal source of data for impervious surface mapping in this work. These are the Landsat TM (Path 188, Row 56) images from December 19, 1986 bands 3, 4, 5, and the Landsat ETM+ (Path 188, Row 56) images from December 17, 2000 bands 2, 4, 7. These data were obtained courtesy of the Tropical Rain Forest Information Center (TRFIC), who disseminate the Landsat 2000 ETM+, 1990 TM, and 1970 MSS ortho-rectified datasets to African researchers and research programs at the global community (TRFIC, 2005). These images have been geometrically corrected and resampled to a UTM/WGS84 projection using nearest neighbour (i.e. no interpolation). The Bands 2, 4, 7 have spatial resolution of 28.5 metres. To aid image interpretation bands 2, 4, 7 of landsat images of the year 2000 were used to produce image composite of the area of interest. Also for the 1986 data set, an RGB image composite of bands 3, 4, 5 was generated. These image composites of the project site for the years 1986, and 2000 are shown in figures 3 and 4 respectively.

For the delineation of watershed boundaries within the area of interest, the enhanced NASA Shuttle Radar Topographic Mission (SRTM) DEM covering south-eastern Nigeria was downloaded from their website (CIAT, 2005) and a subset DEM of the area of interest was obtained and shown in figure 5.

2.3 Land Cover Classification

Training data sets for use in supervised image classification were collected based on image interpretation of old aerial photographs of Enugu city and its environs. Nine land cover classes were identified and shown in table 1. Two sets of 30 samples of training data sets for each land cover class, for the years 1986 and 2000 were obtained. Using one set of the training data, a maximum likelihood supervised classification procedure was performed on the area of interest in ILWIS software environment. The other training data set was used for classification accuracy assessment.

2.4 Watershed Delineation

The delineation of the sub watersheds units within the area of interest was carried out using the Automated Geospatial Watershed Assessment (AGWA) tool, which divided the area into 10 sub watersheds. AGWA is a GIS- based multipurpose hydrologic analysis system for use by watershed, water resource, land use, and biological resource managers and scientists in performing watershed and basin scale studies (Semmens et al., 2004). AGWA was developed by the United States Department of Agriculture (USDA-ARS) Southwest Watershed Research Center and the United States Environmental Protection Agency (U.S.EPA) Office of Research and Development. It is an extension for ArcView GIS software and uses as input the Digital Elevation Model of an area to compute watershed boundaries. AGWA is designed to support landscape assessment at multiple spatial and temporal scales. AGWA creates a watershed outline, which is a grid based on the accumulated flow to the designated outlet (pour point) of the study area. A polygon shape file is built from the watershed outline grid. Based on the specified threshold of contributing area for the establishment of stream channels, the watershed is further divided into model elements required by the model of choice.

2.5 Impervious Surface Computation

Computation of the percentage impervious surface of the project site was implemented by the use of the Impervious Surface Analysis Tool (ISAT), which is designed to calculate the percentage of impervious surface area of user-selected geographic areas (e.g., watersheds, municipalities, and subdivisions). The tool was developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center and the University of Connecticut Nonpoint Education for Municipal Officials (NEMO) Program. ISAT is useful for coastal and natural resource managers and is available as an ArcView 3.x extension or an ArcView 8.x extension (NOAA, 2005). ISAT uses several assumptions that result in a simplification of real world processes. Assumptions include the following:

- Stream quality is a function of the percentage of impervious surface area
- Each watershed operates independently of upstream watersheds
- Watershed characteristics such as soils, topography, stream density, etc. are not considered
- No distinction is made between total and effective impervious area
- The spatial distribution of impervious surface and its proximity to drainage systems is ignored

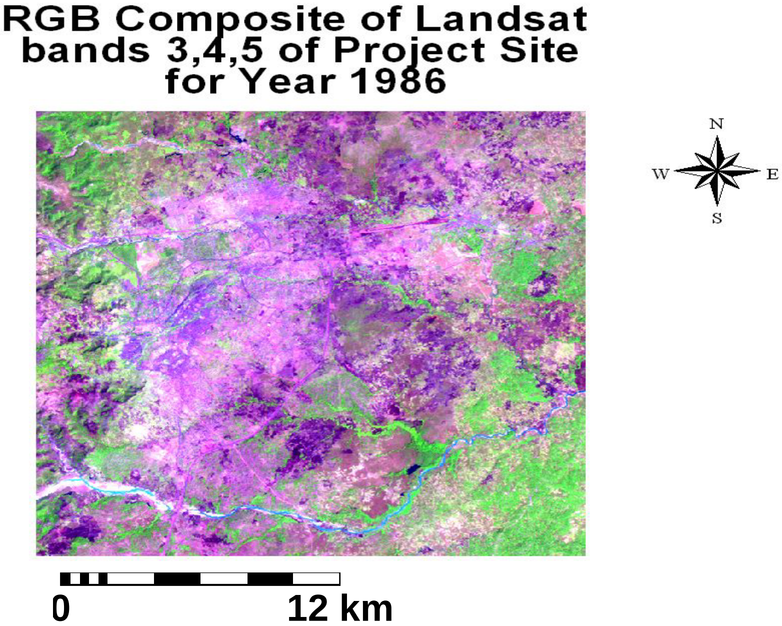

Figure 3: RGB composite of Landsat bands 3,4,5 of the project site for the year 1986

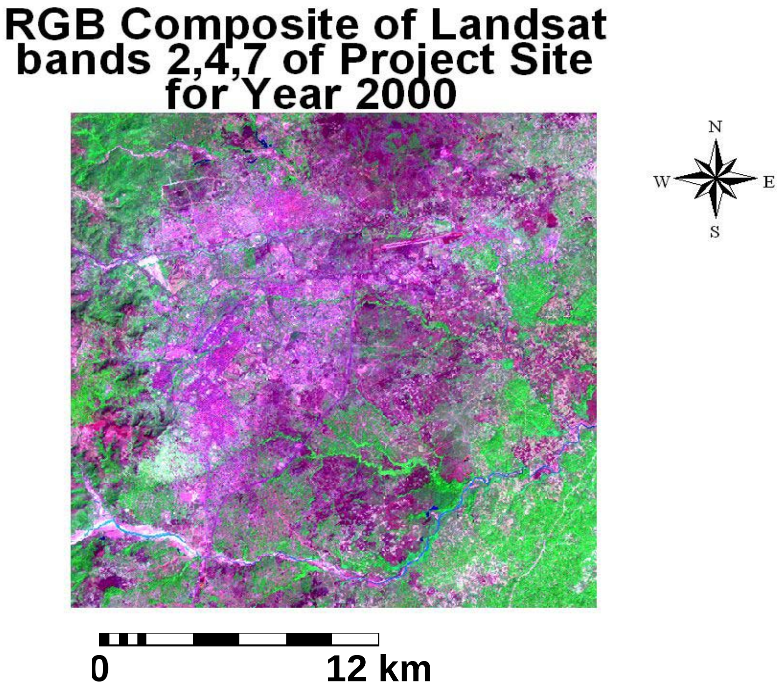

Figure 4: RGB composite of Landsat bands 2, 4, 7 of the project site for the year 2000

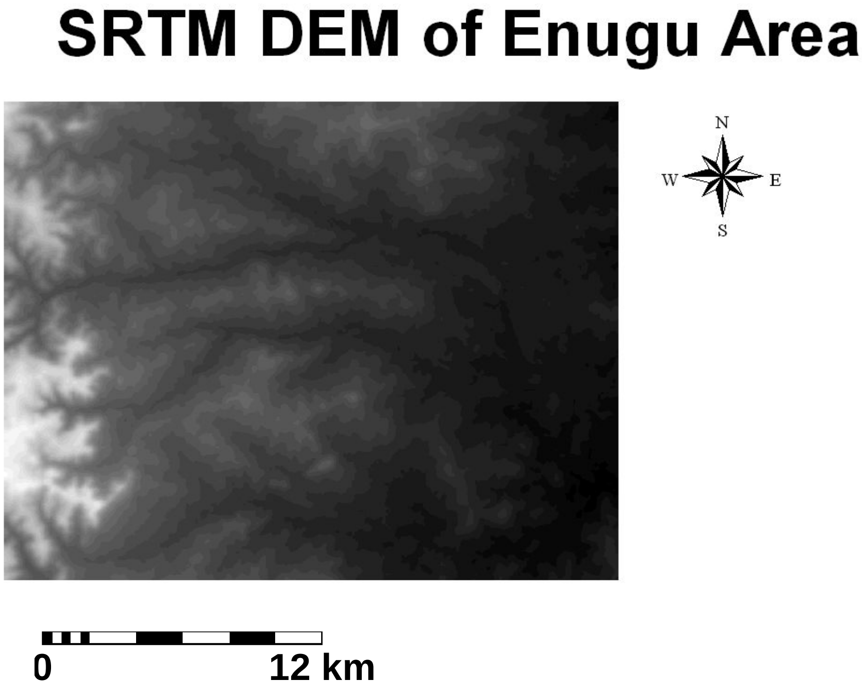

Figure 5: SRTM DEM of Enugu area

Value	Class Name	Description
0	Unclassified	Unclassified areas
1	High Intensity Developed	Highly developed zones in Enugu city
2	Low Intensity Developed	Scattered development in the urban and suburbs
3	Bare Land	Bare land, mostly sand and asphalt
4	Mixed Barren Land	Combinations of sands, gravels, grass mixed, etc
5	Tarred Road	Major tarred road
6	Lake	Lake
7	Stream	Stream
8	Red soil	Red soil, no vegetation
9	Mixed Forest	Vegetation, Trees, shrubs, herbaceous plants, etc,

Table 1: Land cover classes of area of interest

To compute the percentage impervious surface cover ISAT uses the following equation:

$$IS_w = \frac{\sum_{i=1}^{n} Area_i * IS_i}{Total\ Area}$$

Where IS_w is the impervious area percentage for each polygon, IS_i is the impervious surface coefficient for each land cover class, and $Area_i$ is area for each land cover class.The results of the calculations are used to assign temporarily percent impervious area value to each watershed. This value is used to select a display color of green, yellow or red that corresponds to stream quality. Green areas are labelled <10%, which corresponds to <10% impervious surface (Protected), yellow areas are labelled 10%-25%, which corresponds to 10% 25% impervious surface (Degraded), and red areas are >25%, which corresponds to >25% impervious surface (Impacted).

For the prediction of change in impervious surface cover with the study area, ISAT was used to predict the effect that land cover change (e.g., further development of a watershed) will have on water quality by actually changing the land cover classes within the themes to high intensity class.

The impervious surface coefficients have been fixed to the values listed in table 2. This is based on a modification of an example of impervious surface coefficient list provided in the manual of ISAT.

3. RESULTS

The maximum likelihood classification scheme performed fairly well in extracting land cover information. For the year 1986 data sets, the average classification accuracy achieved was 87.79 %, average reliability 93.33 %, and overall accuracy 94.20 %. Table 3 shows reliability and accuracy for the land cover classification of the year 1986 data sets. For the year 2000 data sets, the average classification accuracy achieved was 75.53 %, average reliability 83.69 %, and overall accuracy 79.29 %. Table 4 shows reliability and accuracy for the land cover classification of the year 2000 data sets. Figures 6 and 7 show the results of the maximum likelihood classifications of the year 1986 and 2000 data sets respectively. Figure 8 shows the boundaries of the 10 sub watersheds of the project site delineated by the software AGWA using SRTM DEM of the project site as input. The primary results of this project are 1986 and 2000 impervious surface computations for the 10 watersheds in Enugu area. Figure 9 and 10 show the percentage impervious cover of the project site for high population density for the years 1986 and 2000 respectively. Figure 9 shows that watersheds Enugu 5, Enugu 6, and Enugu 9 have over 25% impervious cover (red), Enugu 1 has less than 10% impervious cover, and the rest have between 10% to 25% impervious surface cover. On the other hand figure 10 shows that watersheds Enugu 2, Enugu 3, Enugu 5, Enugu 6, Enugu 7, and Enugu 9 have over 25% impervious cover (red), and the rest of the watersheds have between 10% and 25% impervious surface cover. There is no watershed with less than 10% impervious cover. This shows a marked increase in impervious surface cover between 1986 and 2000. Details of this increase are depicted in the plot of figure 11 for high density population. Figures 12 and 13 show similar changes in percentage impervious surface cover between 1986 and 2000 for medium and low population densities respectively. A prediction of the effect that land cover change will have on water quality in the 10 watersheds by a change of all land cover classes in the project site to high density developed is shown in figure 14. It is predicted that under this land cover change scenario, all watersheds within the project site will have over 25% impervious surface cover.

Value	Class Name	High	Medium	Low
0	Unclassified	0	0	0
1	Low Intensity Developed	41.3	30.2	22.9
2	High Intensity Developed	59.5	39.1	30.2
3	Bare Land	18.6	42.2	11.8
4	Mixed Barren Land	18.6	42.2	11.8
5	Tarred Road	30.5	20.1	12.5
6	Lake	0	0	0
7	Stream	0	0	0
8	Red soil	18.6	42.4	11.8
9	Mixed Forest	3.9	4.9	2.1

Table 2: Impervious Surface Coefficients

Land Cover Class	Reliability	Accuracy
Bare land	0.77	1.00
High density developed	0.97	0.94
Lake	0.91	0.89
Low density developed	1.00	0.99
Mixed barren land	0.99	0.76
Mixed forest	1.00	0.99
Red soil	1.00	0.71
Stream	1.00	0.75
Tarred road	0.77	0.86

Table 3: Accuracy and reliability of land cover classification of the year 1986 data sets

Land Cover Class	Reliability	Accuracy
Bare land	0.90	1.00
High density developed	0.99	0.56
Lake	1.00	0.54
Low density developed	0.57	0.99
Mixed barren land	1.00	0.39
Mixed forest	1.00	0.94
Red soil	0.31	0.99
Stream	0.77	0.96
Tarred road	1.00	0.42

Table 4: Accuracy and reliability of land cover classification of the year 2000 data sets.

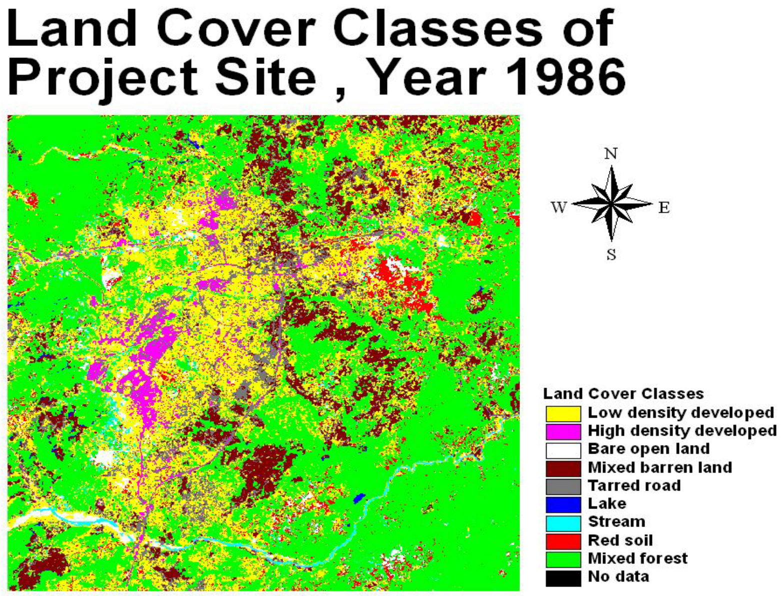

Figure 6: Result of maximum likelihood classification of 1986 landsat data set

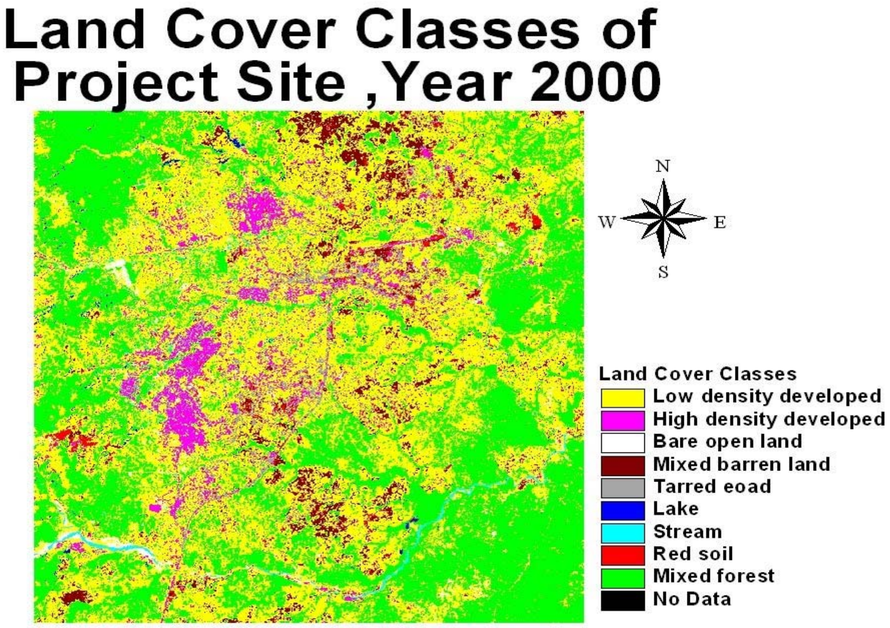

Figure 7: Result of maximum likelihood classification of 2000 landsat data set

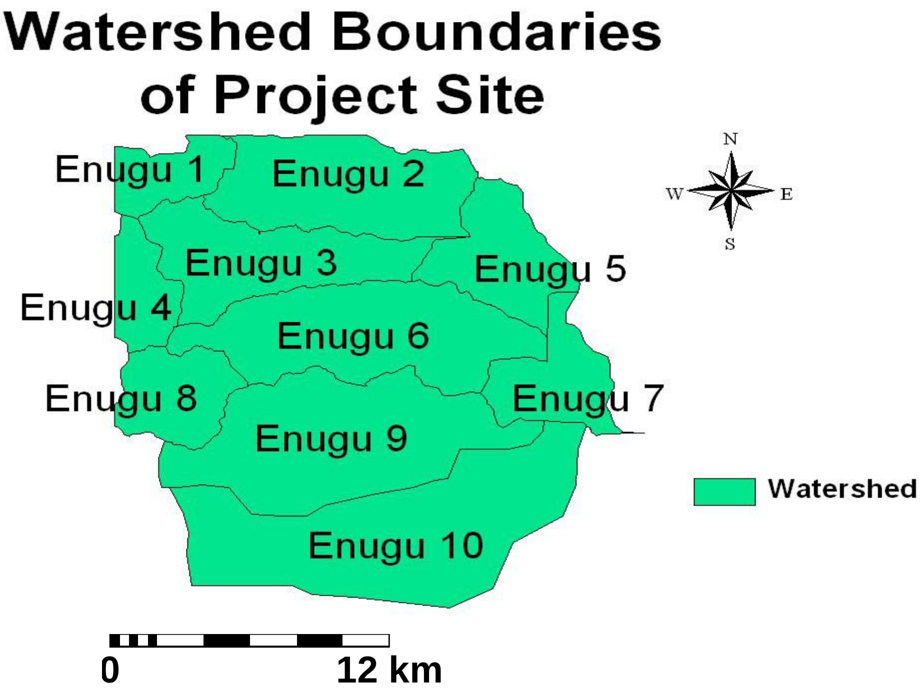

Figure 8: Watershed boundaries of project site produced with AGWA software

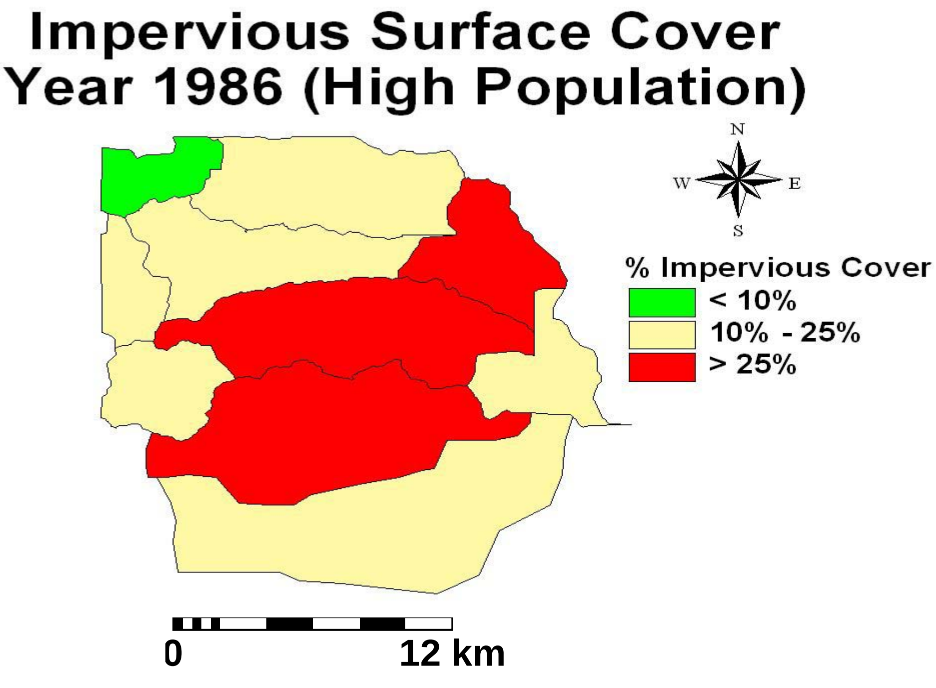

Figure 9: Impervious surface cover of 1986 data set for high population density

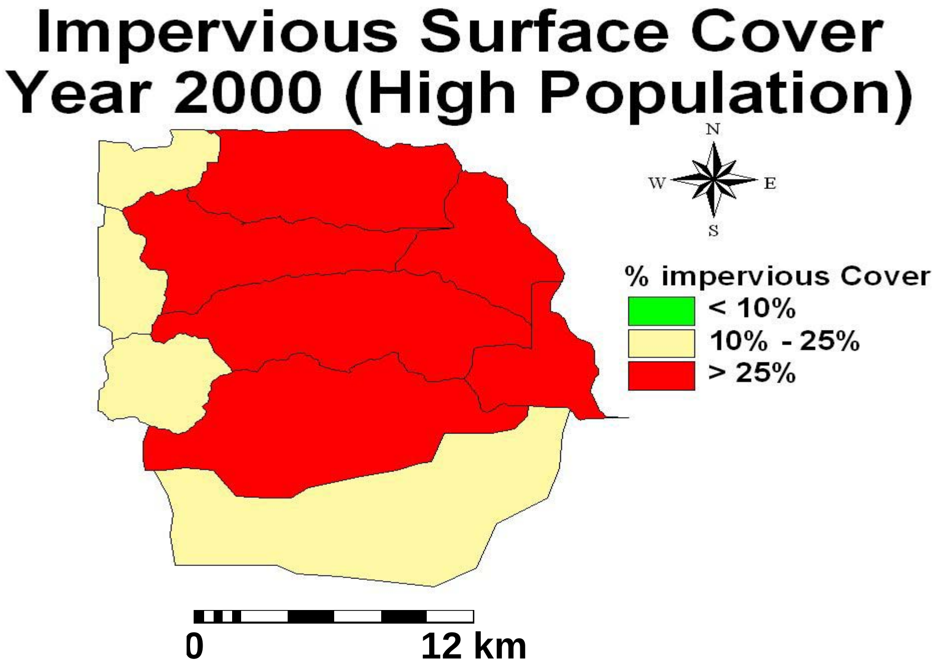

Figure 10: Impervious surface cover of 2000 data set for high population density

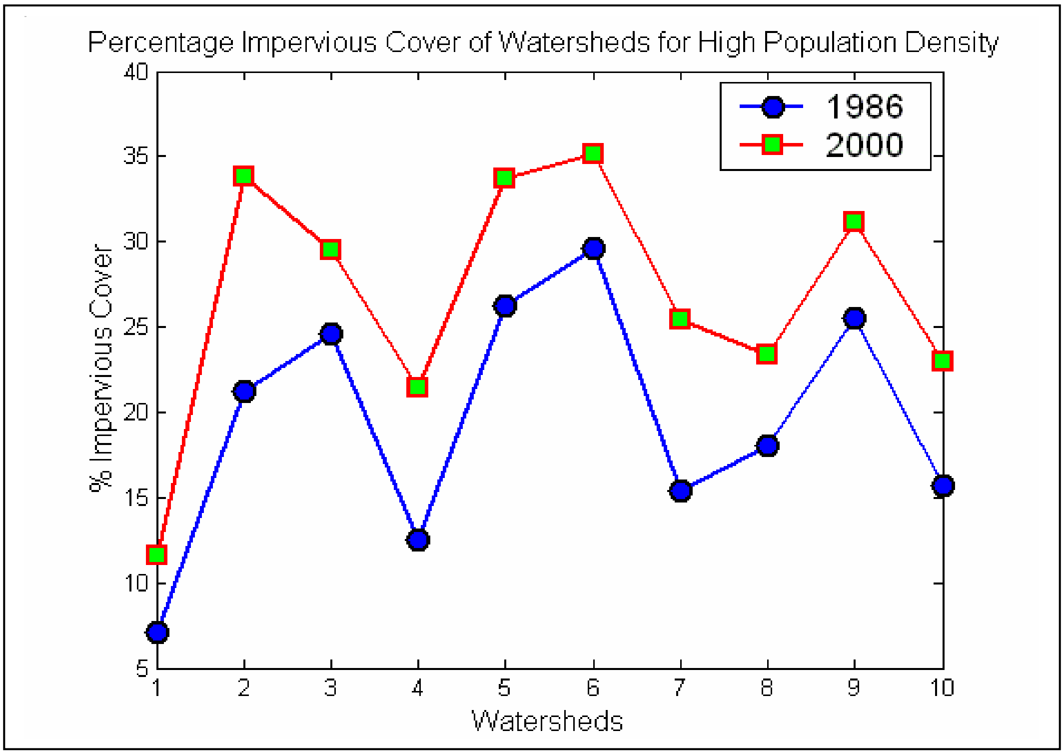

Figure 11: Impervious surface cover change from 1986 to 2000 for high population density

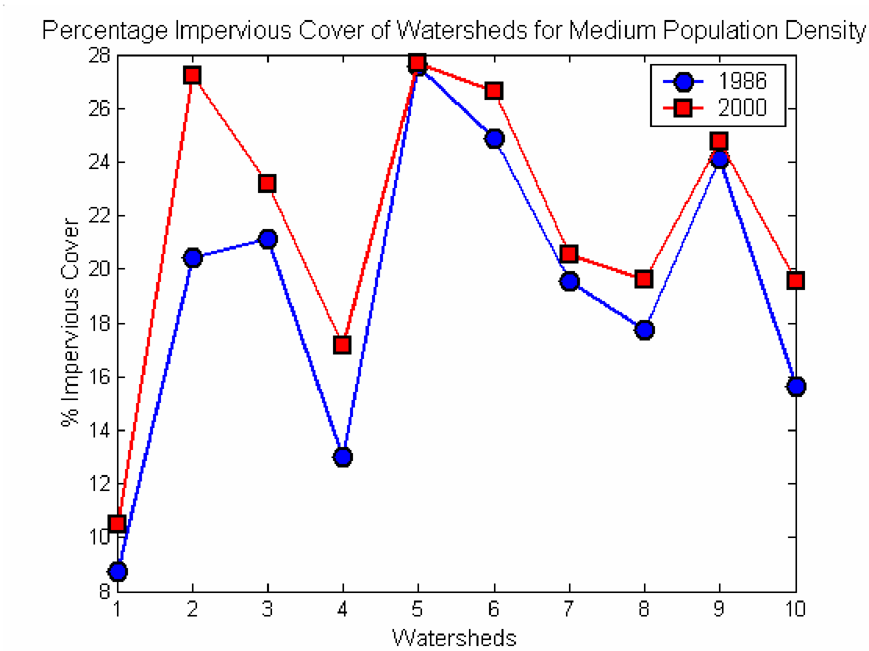

Figure 12: Impervious surface cover change from 1986 to 2000 for medium population

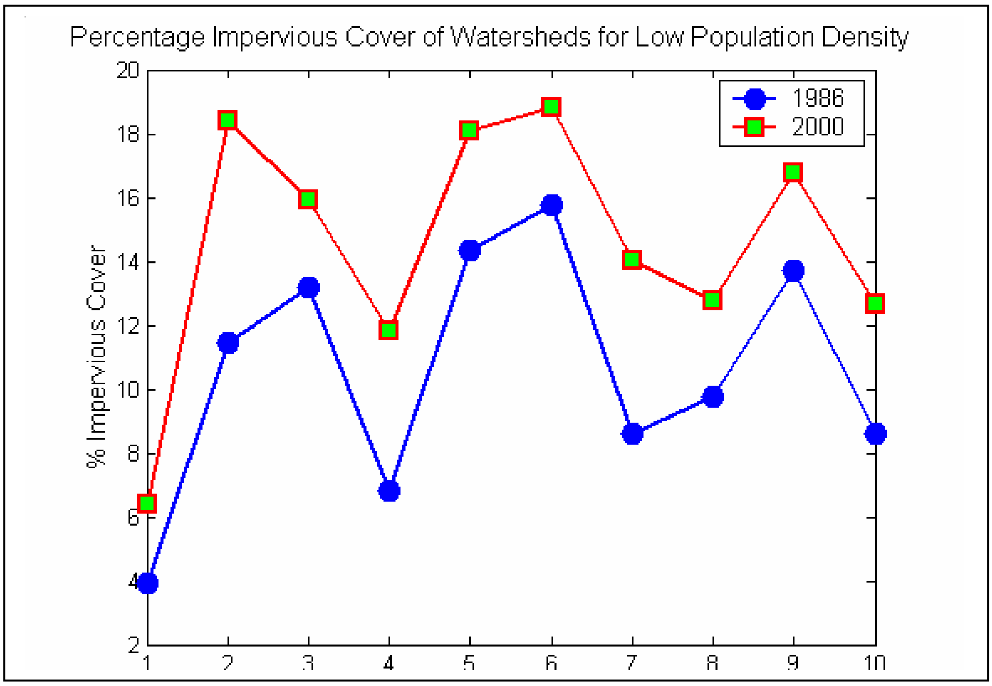

Figure 13: Impervious surface cover change from 1986 to 2000 for low population density

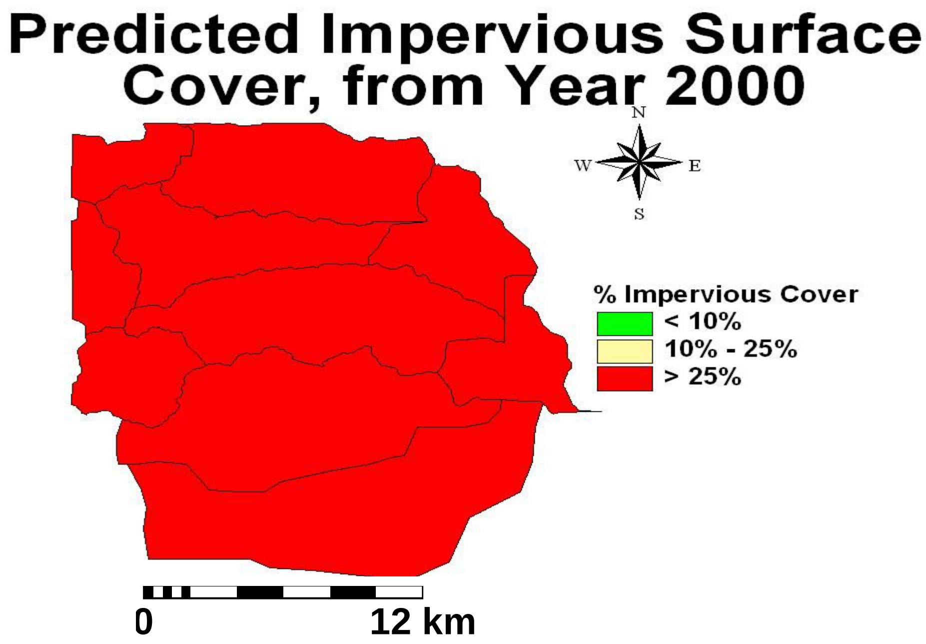

Figure 14: Predicted impervious surface cover for a land cover change scenario

4. CONCLUSION

This work represents a first attempt in producing impervious surface estimates and impervious surface changes of part of southeastern Nigeria over a 14-year period. The basic conclusion of this study is that percentage impervious surface cover within part of southeastern Nigeria increased over the period between 1986 and 2000. While these results are not surprising, this study provides the first quantitative estimate of the extent of the change. The same conclusion could be drawn for most cities and urban areas in Nigeria. Outside the problem of waste disposal, the result in this work will go a long way to hint on how natural water qualities have deteriorated in Nigeria.

This work also demonstrates how remote sensing data (Landsat, SRTM DEM) in combination with GIS software (ArcView) and it's extensions (AGWA, ISAT) are used for the computation of impervious surface cover and changes in impervious surface cover within a period of time.

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