SPATIO-TEMPORAL ANALYSIS OF WETLAND CHANGE IN PORT HARCOURT METROPOLIS

Olatunde Sunday Eludoyin* and Olalekan Akinola

Department of geography and environmental management,
University of Port Harcourt,
Port Harcourt, Nigeria

**Corresponding Email Address: olatunde.eludoyin@uniport.edu.ng*

ABSTRACT

The study assessed changes of wetland in Port Harcourt Metropolis using geo-information techniques between 1984 and 2015. Landsat images of 1984, 2000 and 2015 of 30m x 30m resolution were used. Supervised classification was used for image classification using Maximum Likelihood Algorithm in Erdas Imagine 9.1 whereby five major landuse classes were identified namely thick vegetation, built up area, farmland/sparse vegetation, wetlands and waterbodies. Areas in squared kilometers of each landuse were calculated in ArcGIS 9.3 and simple arithmetic was used to compute the percentage change. Probability of landuse change in the next 10, 20 and 30 years was determined in Idrisi Selva 17.0 using Markovian Transition Estimator. Descriptive statistics were employed for data analysis. Finding shows that wetlands decreased from 150.17km^2 to 42.70km^2 (-87.5%) between 1984 and 2015. Thick vegetation and waterbodies decreased by 35.6% and 41.48% respectively while built up area increased from 81.63km^2 to 205.89km^2 between 1984 and 2015. Wetland had 13.51%, 23.75% and 32.88% chance of changing to built up area in the next 10, 20 and 30 years respectively. The study recommended that farming and construction activities diminishing the wetland should be carefully done.

Keywords: *Geo-information, Landsat Imagery, Landuse, Farming, Construction*

INTRODUCTION

Wetland management in the recent years is necessary because of its roles in the ecological balance and biodiversity management. The functions of wetland include flood storage and distribution, retention of sediments and nutrients, aquifer recharge, water quality improvement, aesthetic and educational benefits (Kindscher 1998, USEPA 2009, Obiefuna *et al*. 2013). USEPA (2011) also highlighted that wetland biodiversity has value to humans, supporting people's livelihoods in numerous ways, by creating highly productive ecosystem services such as food resources for a wide range of species.

Wetlands which are land areas covered with water or where water is present at or near the soil surface all year or varying periods of the year (Obiefuna *et al*. 2013) could undergo changes in terms of spatial extent and the species diversity of the fauna and flora deriving their livelihood from the wetland ecosystem. Davidson (2014) alerted that global extent of wetland has declined between 64-71% in the 20th century and this constitutes threat to wetland biodiversity.

Aggravating the problem of water management in Nigeria is the fact that wetlands which naturally recharge and protect both the surface and groundwater resources are being unscrupulously degraded at a rather alarming rate (Uluocha and Okeke 2004). Odine *et al.* (2011) opined that poor understanding of economic values of wetlands is one of the contributory factors that make people to see wetland as wastelands, culminating in massive destruction of this highly productive resource. Most importantly, poor control of development in urban areas has created major problems for existing tropical wetlands. Obiefuna *et al*. (2013) reported that more than 50% of the world's population currently resides in cities and urban settlements. UN Habitat (2010) noted that urbanization rates were expected in developing and least developed countries while Zhang et al (2008) also reported that 95% of the net increase in global population would be in cities of the developing world. Activities leading to industrialization and urban development are land clearing and land reclamation which often result to loss of wetlands.

However, wetland change is embedded in landuse change overtime and requires in-depth analysis in terms of the spatial coverage at a given time with the use of geo-information technologies. The use of geo-spatial information establishes a dialogue linking local knowledge and science; and national development strategies because of the provision of automate image-processing tasks (O'Hara 2001) with the use of high spectral resolution data that can provide an increased ability to differentiate land cover classes. Dahl (2006) viewed that remotely sensed imagery provides the primary data source for wetland change detection and the imagery is used in conjunction with reliable collateral data such as topographic maps, coastal navigation charts, soils information, and historic imagery or studies. Thus, the identification and delineation of wetland habitat through image analysis forms the foundation for deriving all subsequent wetland status and trend of change.

Remote sensing techniques have been used successfully in the United States and Canada to detect and monitor wetlands by some studies which include Aldrich (1979), Lillesand and Kieffer (1987), Patience and Klemas (1993), National Research Council (1995), Tiner (1996), Dechka *et al*. (2002), Watmough *et al*. (2002) and Li and Chen (2005). The capability of geo-information has also been demonstrated in some wetland studies in Nigeria. Tijani *et al.* (2011) examined the impacts of urbanization on wetlands degradation in Eleyele Lake, South Western Nigeria; Obiefuna *et al*. (2013) determined the spatial changes in the wetlands of Lagos/Lekki Lagoons of Lagos, Nigeria; Mmom and Fred-Wagwu (2013) examined the landuse and land cover change around Port Harcourt City using a GIS; Taiwo and Areola (2009) investigated the spatio-temporal analysis of wetland losses in the Lagos Coastal region, southwestern Nigeria; Odunuga and Oyebande (2007) examined the change detection and hydrological implications in the lower Ogun flood plain, Ajibola *et al*. (2012) compared the wetland valuation purposes in Lagos metropolis and Niger Delta, Nigeria while Orimoogunje *et al*. (2009) examined the geospatial mapping of wetlands potential in Ilesa, Southwestern Nigeria. Although, most of these studies made use of geo-information technologies but none investigated wetland status in Port Harcourt metropolis. Against this background, the present study focuses at analyzing the spatio-temporal changes of wetland in Port Harcourt Metropolis between 1984 and 2015.

MATERIALS AND METHODS

Study Area

The study area was Port Harcourt Metropolis, Rivers State, Nigeria. It lies between latitudes 4^o 42' and 4^o 55'N and between longitudes 6^{o}53' and 7^o 08'E (Appendix 1). Port Harcourt features a tropical monsoon climate with lengthy and heavy rainy seasons and very short dry seasons. Only the months of December and January truly qualifies as dry season months in the city. Port Harcourt's heaviest precipitation occurs during September with an average of 3670 mm. Temperatures throughout the year in the city is relatively constant. Average temperatures are typically between 25 °C-28 °C in the city (The Weather Network, 2014). Port Harcourt lies on the low lying coastal plain with mean elevation of about 20 m. The vegetation are trees in the rainforest such as *Khaya grandifoliola*, *Triplochiton scleroxylon*, *Diospyros celebica*, *Elaeis guineensis* and economically valuable trees such as *Raphia hookeri* and mangrove forest such as *Rhizophora sp*. (Eludoyin et al. 2011). The study area is well drained with both fresh and salt water.

Image Geoprocessing and Wetland Mapping

This study made use of landsat satellite imageries of 1984, 2000 and 2015 of Port Harcourt Metropolis acquired from the United States Geological Survey 2015 (Table 1). Landsat has the ability to measure and monitor tropical forests and other landuse at a high spatial and spectral resolution. It contains six spectral bands of spatial resolution of 30 m x 30 m, one panchromatic band of 15m x 15m and one thermal band of resolution of 60m x 60 m (Feeley *et al*. 2005). The images were imported to Erdas Imagine 9.1 whereby the bands of the images were combined using COMPOSITE module and false colour composite images of bands 7, 4 and 2 were selected for further analysis. The shape file of Port Harcourt Metropolis boundary was generated in ArcGIS 9.3 and was used to clip the composite image of each year. Maximum likelihood supervised classifications were performed in Erdas Imagine 9.1 on the landsat imageries. The per-pixel supervised classifications groups satellite image pixels with the same or similar spectral reflectance features into the same information categories (Campbell, 2002). Five classes were identified namely built up area, wetland, waterbodies, farmland/sparse vegetation and thick vegetation; and the description of each of the classes according to Anderson *et al*. (2001) is shown in Table 2. The classified landuse images were thereafter converted to vector format to compute the area of landuse which in each year in squared kilometers using spatial query module in ArcGIS 9.3. The wetlands were separated from other landuse to generate a spatial distribution map of wetlands and simple arithmetic was used to determine the area, trend, direction and percentage of change of wetlands in Port Harcourt Metropolis. The percentage of wetland lost to other land use was also computed in ArcGIS 9.3. The probability of wetlands changing to another land use was predicted to 2025 (10 years), 2035 (20 years) and 2045 (30 years) using Markovian's Transition Estimator in Idrisi Selva. Descriptive statistics were used to explain the values of wetland change and the

Table 1: Characteristics of Landsat Satellite Images (Source: US Geological Survey, 2015)

Year	Date Acquired	Sensor	Cloud Cover (%)	Path	Row	Resolution
1984	13/12/1984	Landsat 5 MSS	0	188	57	30m x 30m
2000	17/12/2000	Landsat 7 ETM	0	188	57	30m x 30m
2015	09/01/2015	Landsat 7 ETM	0	188	57	30m x 30m

percentage change in the wetland per year under consideration.

RESULTS

Wetland and other land use change analysis

The land use/land cover change in Port Harcourt Metropolis is presented in Table 3, Appendix 2-4 while Appendix 5-7 show the spatial extent of wetland only in Port Harcourt Metropolis between 1984 and 2015. The analysis shows that in 1984, thick vegetation had a spatial extent of 121.58 km^2 (26.53%), built up area covered 81.63 km^2 (17.81%), wetland covered 150.17 km^2 (32.77%), waterbodies covered 26.25 km^2 (5.73%) and farmland/sparse vegetation covered 78.59 km^2 (17.15%). In 2000, thick vegetation covered 106.81 km^2 (23.31%) of the total landuse while built up area, wetland, waterbodies and farmland/sparse vegetation covered 176.62 km^2 (38.54%), 57.51 km^2 (12.55%), 18.69 km^2 (4.08%) and 98.59 km^2 (21.52%) respectively. In 2015, thick vegetation covered 81.76 km^2 (17.84%), built up area covered 205.89 km^2 (44.93%), wetland covered 42.70 km^2 (9.32%), waterbodies covered 16.32 km^2 (3.56%) while farmland/ sparse vegetation covered 111.55 km^2 (24.34%). The analysis thus shows that wetland decreased between 1984 and 2015. In the same vein, thick vegetation, and water bodies reduced in terms of spatial extent while built up area and farmland/sparse vegetation increased over time.

Table 2: Landuse/Landcover Classification Scheme. Adapted from Anderson *et al*. (2001).

S/N	**Landuse Types**	**Description**
1	Thick vegetation	Thick forest, derived forest, mixed forest lands, palms, shrubs, herbs and others
2	Built Up Area	Residential, commercial and services, industrial, transportation, roads
3	Wetlands	Permanent and seasonal wetlands, low-lying areas, marshy land, swamps
4	Water bodies	Rivers, permanent open water, lakes, ponds, reservoirs, etc
5	Farmland/Sparse vegetation	Agricultural area, crop fields, fallow lands and vegetable lands

Table 3: Land use spatial pattern in 1984, 2000 and 2015

Land use	1984 (km^2)	%	2000 (km^2)	%	2015 (km^2)	%
Thick vegetation	121.58	26.53	106.81	23.31	81.76	17.84
Built Up Area	81.63	17.81	176.62	38.54	205.89	44.93
Wetland	**150.17**	**32.77**	**57.51**	**12.55**	**42.70**	**9.32**
Water bodies	26.25	5.73	18.69	4.08	16.32	3.56
Farmland/Sparse vegetation	78.59	17.15	98.59	21.52	111.55	24.34
Total	458.22	100.00	458.22	100.00	458.22	100.00

Magnitude, Trend and Percentage of Change of Wetland

Table 4: Magnitude, Trend and Percentage of Change of Land use between 1984 and 2015

Land use	1984 (km^2)	2000 (km^2)	Change (km^2)	% Change	2000 (km^2)	2015 (km^2)	Change (km^2)	% Change	Total Change (km^2)	Total % Change (1984-2015)
Thick vegetation	121.58	106.81	14.77	-12.15	106.81	81.76	25.05	-23.45	-39.82	-35.6
Built Up Area	81.63	176.62	-94.99	116.37	176.62	205.89	-29.27	16.57	+124.26	+132.94
Wetland	**150.17**	**57.51**	**92.66**	**-61.70**	**57.51**	**42.70**	**14.81**	**-25.75**	**-107.47**	**-87.45**
Water bodies	26.25	18.69	7.56	-28.8	18.69	16.32	2.37	-12.68	-9.93	-41.48
Farmland/Sparse vegetation	78.59	98.59	-20.00	25.43	98.59	111.55	-12.96	13.15	+32.96	+38.58

Table 5: Markov's probability of landuse change in the next 10 years, 20 years and 30 years

Land use/Landcover	Thick vegetation	Built Up Area	Farmland/Sparse vegetation	Wetland	Water bodies
10 Years Prediction					
Thick vegetation	0.3344	0.2593	0.2806	0.1255	0.0001
Built Up Area	0.0501	0.9314	0.0000	0.0141	0.0045
Farmland/Sparse vegetation	0.1975	0.1915	0.6110	0.0000	0.0000
Wetland	0.2564	0.1351	0.3852	0.0271	0.0271
Water bodies	0.0000	0.0000	0.0000	0.6895	0.6895
20 Years Prediction					
Thick vegetation	0.2856	0.3447	0.2644	0.1031	0.0022
Built Up Area	0.0671	0.9001	0.0035	0.0220	0.0073
Farmland/Sparse vegetation	0.1925	0.2945	0.5130	0.0000	0.0000
Wetland	0.2321	0.2375	0.3499	0.1561	0.0244
Water bodies	0.0000	0.0036	0.0000	0.4251	0.5713
30 Years Prediction					
Thick vegetation	0.2432	0.4205	0.2482	0.0839	0.0041
Built Up Area	0.0749	0.8722	0.0167	0.0270	0.0092
Farmland/Sparse vegetation	0.1829	0.3838	0.4268	0.0065	0.0000
Wetland	0.2103	0.3288	0.3169	0.1220	0.0220
Water bodies	0.0164	0.0648	0.0000	0.4526	0.4662

The percentage changes of wetland and other landuse in Port Harcourt Metropolis between 1984 and 2015 are shown in Table 4. The total change and percentage change analysis therefore revealed that the thick vegetation lost 39.82 km^2 (35.6%), built up land area increased by 124.26km^2 (132.94%), while wetlands lost 107.47km^2 (87.45%), water bodies also reduced by 9.93km^2 (41.48%) while the farmland/sparse vegetation increased by 32.96 km^2 (38.58%).

Predicting probability of wetland changing to other land use

Probability of change of wetland changing to another land use within Port Harcourt Metropolis is presented in Table 5. In 2025, the analysis revealed that 25.64%, 13.51%, 38.52% and 2.71% of thick vegetation, built up area, farmland/sparse vegetation and water bodies, respectively had a chance of changing to wetland. In 2035, it is revealed that 23.21%, 23.75%, 34.99% and 2.44% of thick vegetation, built up area, farmland/sparse vegetation and water bodies, respectively had a chance of changing to wetland. In 2045, it is shown that 21.03% of thick vegetation, 32.88% of built up area, 31.69% of farmland/open space and 2.20% of water bodies had a chance of changing to wetland.

DISCUSSION

Wetland change pattern between 1984 and 2015

Findings showed that wetlands reduced from 150.17km^2 in 1984 to 57.51km^2 in 2000 and further reduced to 42.70km^2 in 2015 (Table 3). This shows that spatial extent of wetlands decreased over time. This may be due to the fact that wetland is being converted to other land use type, which may include farmland and built up areas. Mundia and Aniya (2006) and Jat *et al*. (2008) reported that the rapid changes of land use/land cover than ever before, particularly in developing nations, are often characterized by rampant urban sprawling, land degradation by agricultural development and tourism industry. Similarly, Johnson *et al*. (2002) reported that non-forested vegetation and wetland or marsh features have shown the greatest amount of decrease in Mississippi Gulf Coast, with forest vegetation decreasing by slightly more than 30% and coastal marshes decreasing by 35% and that overall changes in the landscape showed an increased trend for urban development (53%) with non-forested vegetation and coastal wetlands suffering the consequences. However, rapid urbanization is known to generate negative impacts on the environment as it leads to changes in landscape patterns, ecosystem functions and the capacity to perform functions in support of human populations (UN-Habitat 2010). Also, Savard *et al*. (2000) and Gupta (2002) reported that the biggest current source of loss for freshwater wetlands is from urban sprawl while USEPA (1994) observed that urbanization is a major cause of impairment of wetlands it has resulted in direct loss and degradation of wetland acreage. The continuous increase in built up areas is due to increase in the inflow of population that places heavy demand on the environment and thus leading to great increase in the size of the settlement in both the city center and the suburbs (Suleiman *et al*. 2014). However, depletion of wetlands in Port Harcourt Metropolis may result to the reduction of mangroves and swamps, loss of biodiversity, reduction in the ecological services, reduction in flood retention and reduced aquifer recharge, loss of breeding grounds for aquatic lives and livelihoods (Obiefuna *et al*. 2013).

Probability of wetland changing to other landuse

Findings from the present study revealed that there is a probability of wetland changing to built up area by 0.135 (13.5%) in 2025, and 0.232 (23.2%) in 2035 and 0.3288 (32.88%) in 2045 (Table 5). This means that urban sprawl may continue to reduce the spatial extent of wetland and this could increase the unsustainable environmental ecosystem in the wetlands in Port Harcourt Metropolis. Moreover, areas covered with wetland are being sand-filled for building purposes. The influence of thick vegetation (25.64% to 21.03%) and farmland/sparse vegetation (38.52% to 31.69%) on wetlands reduced in terms of spatial extent between 2025 and 2045 (Table 5). However, thick vegetation decreased between 1984 and 2015 while farmland/sparse vegetation continued to increase with time. The decrease in thick vegetation may be due to the human activities, which are farming and constructions of buildings. The increase in the farmland/sparse vegetation is a revelation that majority are involved in the urban or peri urban farming which is an indication of food sustainability in the study area. Lambin *et al*. (2003) reported that humans have increased agricultural output mainly by bringing more land into cultivation.

CONCLUSION AND RECOMMENDATIONS

The present study has revealed the spatio-temporal analysis of wetland and its allied land use in Port Harcourt Metropolis. It can be concluded that the spatial extent of wetland reduced between 1984 and 2015. However, thick vegetation and water bodies also reduced over time while built up area and farmland/sparse vegetation increased. The wetlands in Port Harcourt Metropolis is gradually losing its spatial extent, in order to prevent further loss of wetlands size, is recommended that human activities diminishing wetlands size should be critically looked into by the government and increased efforts should be directed on those activities that encourage wetland conservation, focus should be shifted from the immediate benefits derived from conversion of wetlands areas to agriculture/construction to sustainable benefits from proper wetlands management in future, and well-coordinated and concise research should be conducted regularly on wetlands, in a bid to promoting adequate wetlands assessment and management.

REFERENCES

Ajibola, MO, Ogungbemi AO, and Adenipekun MT 2012 A Comparison of Wetland Valuation Purposes in Lagos Metropolis and the Niger Delta, Nigeria. *Ethiopian Journal of Environmental Studies and Management***5** (4) (Suppl.1):452-460.

Aldrich, RC 1979 *Remote sensing of wildland resources: A state-of-the-art-review*. USDA Forest Service, General Technical Report Rm-71, Rocky Mt, Forest and Range Experiment Station, Ft. Collins, Co. 56P.

Anderson JR, Hardy EE, Roach JT and Witmer RE 2001 *A Landuse and Land Cover Classification System for Use with Remote Sensor Data.* Geological Survey Professional Paper 964. A revision of the land use classification system as presented in U.S. Geological Survey Circular 671. 41P.

Campbell JB 2002 *Introduction to Remote Sensing*. 3rd ed. New York: Gulford. 622P.

Dahl TE 2006 Remote Sensing as a Tool for Monitoring Wetland Habitat change. U.S. fish and wildlife service, Branch of Habitat Assessment, Fish and Wildlife Resource Centre, 555 Lester Ave. Onalaska. 8P.

Davidson NC 2014 How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* **65**(10):934-941. http://dx.doi.org/10.1071/MF14173

Dectika JA, Franklin SE, Watmough MD, Bennett RP and Ingstrup DW 2002 Classification of wetland Habitat and vegetation communities using multi-temporal ikonos imagery in Southern Saskatchewan. *Can. J. Remote Sensing* **28**(5):679-685.

Eludoyin OS, Wokocha CC and Ayolagha G 2011 GIS Assessment of Land use and Land cover Changes in Obio/Akpor LGA., Rivers State, Nigeria. *Research Journal of Environmental and Earth Sciences* **3**(4): 307-313

Feeley KJ, Gillespie TW and Terborgh JW 2005 The utility of spectral indices from Landsat ETM+ for measuring the structure and composition of tropical dry forests. *Biotropica* **37**(4):508-519.

Gupta A. 2002 Geo-indicators for Tropical Urbanization Environmental. *Geology* **42**:736- 742.

Jat MK, Garg PK and Khare D 2008 Monitoring and modeling of urban sprawl using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation*, **10**(1), pp 26-43.

Johnson AM, Truax DD, O'Hara CG and Cartwright J 2002 *Remote sensing, GIS, and land use and land cover mapping along the i-10 corridor*. Integrating Remote Sensing at the Global, Regional and Local Scale Pecora 15/Land Satellite Information IV Conference, Denver, CO between 10th - 15th November, 2002. 9P

Kindscher K, Fraser A, Jakubauskas ME, and Debinski DM 1998 Identifying Wetland Meadows in Grand Teton National Park Using Remote Sensing and Average Wetland Values. *Wetlands Ecology and Management* **5**:265-273.

Lambin EF, Geist HJ, and Lepers H 2003 Dynamics of land-use and land-cover Change in tropical regions. *Annu. Rev. Environ. Resources*. **28**:205–41.

Li J, and Chen W 2005 A Rule-based Method for Mapping Canada's Wetlands Using Optical, Radar and DEM Data. *International Journal of Remote Sensing*, **26**(22):5051-5069. http://dx.doi.org/10.1080/01431160500166516.

Lillesand TM and Kieffer RW 1987 *Remote sensing and image interpretation*. 2nd edition John Wiley and Sons, N.Y. 721P.

Mmom PC and Fred-Wagwu FW 2013 Analysis of Landuse and Landcover Change around the City of Port Harcourt, Nigeria. *Global Advanced Research Journal of Geography and Regional Planning* **2**(5):076 - 086.

Mundia CN and Aniya M 2006 Dynamics of land use/ cover changes and degradation of Nairobi City, Kenya. *Land Degradation and Development* **17**(1):97–108.

National Research Council (1995): *Wetlands*: characteristics and boundaries. Committee on Characterization of wetlands, Water Science and Technology Board. National Academy Press, Washington, D.C. 268p.

O'Hara CG 2001 *Remote Sensing and Geospatial Applications for Wetland Mapping and Assessment Technology Guide*: NCRSTE_TG003, http://www.ncrste.mssstate.edu/publications/ncrste_tg003.pdf, 13P.

Obiefuna JN, Nwilo PC, Atagbaza AO and Okolie CJ 2013 Spatial Changes in the Wetlands of Lagos/Lekki Lagoons of Lagos, Nigeria *Journal of Sustainable Development* **6**(7):123-133.

Odine AI, Shittu AM, Ayinde IA, and Olubanjo O.O. 2011 Assessment of the Economic Value of Selected Wetlands in Southwest Nigeria. *Africa Geoscience Review* **18**(4):91-101.

Odunuga S and Oyebande L 2007 Change Detection and Hydrological Implications in the Lower Ogun Flood Plain, SW Nigeria. In Owe, M., & Neale, C. (Eds). Proceedings of Symposium on Remote Sensing For Environmental Change Detection. *International Association of Hydrological Sciences (IAHS)* **316**:91-99.

Orimoogunje OO, Oyinloye RO and Soumah M 2009 Geospatial Mapping of wetlands potential in Ilesa, Southwestern Nigeria. *FIG Working Sheet 2009*. Surveyors key role in Accelerated Development, Eilat, Israel, 3-8 May, 2009.

Patience N and Klemas V 1993 *Wetland functional health assessment using remote sensing and other techniques: Literature search*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, SE Fisheries Science Center, Beaufort laboratory, Beaufort, NC. 60P.

Savard JL, Clergau P, and Mennechez G 2000 Biodiversity concepts and urban ecosystems. *Landscape and Urban Planning* **48**:131–142.

Suleiman YM, Saidu S, Abdulrazaq SA, Hassan AB and Abubakar AN 2014 The Dynamics of Land Use Land Cover Change: Using Geospatial Techniques to Promote Sustainable Urban Development in Ilorin Metropolis, Nigeria. *Asian Review of Environmental and Earth Sciences* **1**(1):8-15.

Taiwo OJ and Areola O 2009 *A Spatial Temporal Analysis of Wetland Losses in the Lagos Coastal Region, Southwestern Nigeria, using Multi-date satellite Imagery*. Paper presented at IGARSS Annual Conference, Cape Town, South Africa, Sept. 2009 **3**:111-928

The Weather Network 2014 *Statistics Port Harcourt*, Nigeria. www.twn.com, Retrieved online 24/10/2014.

Tijani MN, Olaleye AO and Olubanjo OO 2011 *Impact of Urbanization on Wetland Degradation: A Case Study of Eleyele Wetland, Ibadan, South West, Nigeria*. Proceedings of the Environmental Management Conference, Federal University of Agriculture, Abeokuta, Nigeria, 2011. 434-456.

Tiner RW 1996 Wetlands, In: Mannual of Photographic interpretation, second edition. *American Society for Photogrammetry and Remote Sensing*, Falls Church, VA. 2440P.

Uluocha NO and Okeke IC 2004 Implications of wetlands degradation for water resources management: Lessons from Nigeria. *Geojournal*, **16**:151-154.

UN-Habitat 2010 *Urban Development, Biodiversity and Wetland Management: Expert Workshop Report.* Expert Workshop in Kenya Wildlife Training Institute, Naivasha, Kenya, 16 - 17 November, 2009.

United Nations Environment Programme (UNEP) 2007 *The status of the Nigerian coastal zones*. Retrieved online, www.unep.org, on the 9th January, 2015.

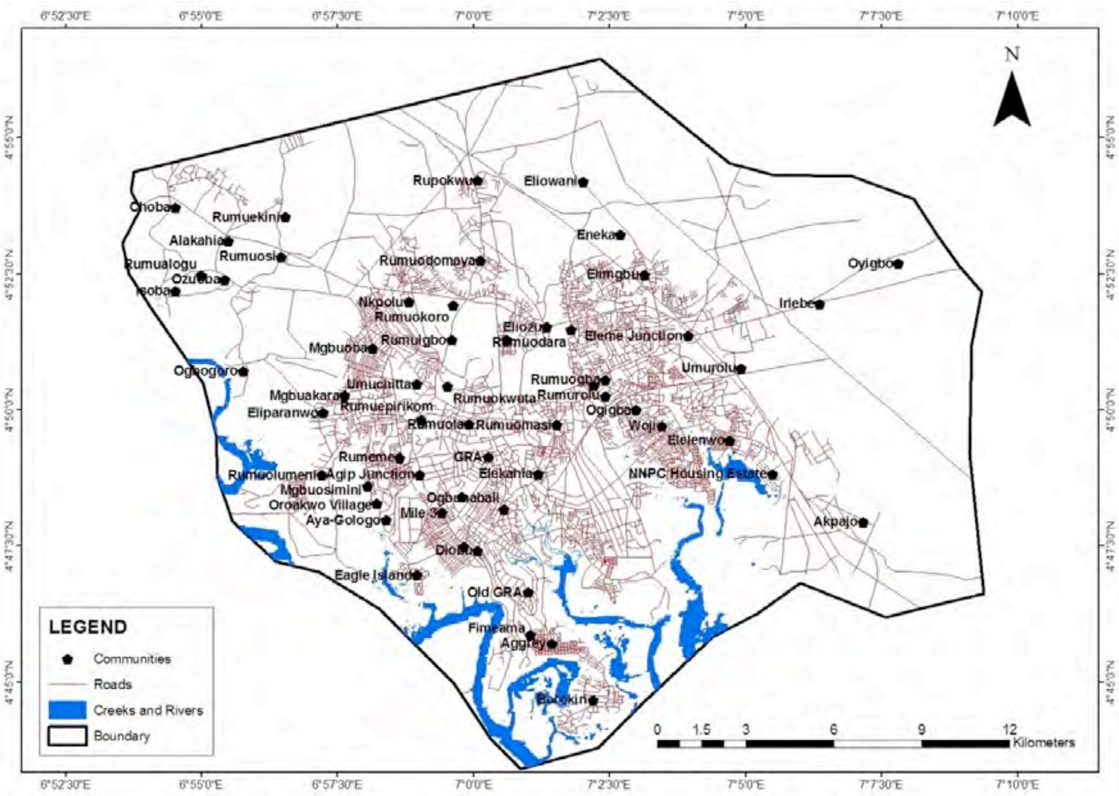
United States Environmental Protection Agency (USEPA) 2011 *Functions of wetlands*. www.epa.gov/wetland, Accessed on the 25th September, 2014.

USEPA 2009 *What are Wetlands? Wetlands.* Retrieved from www.epa.gov./owow/wetlands, Accessed on the 20th November, 2014.

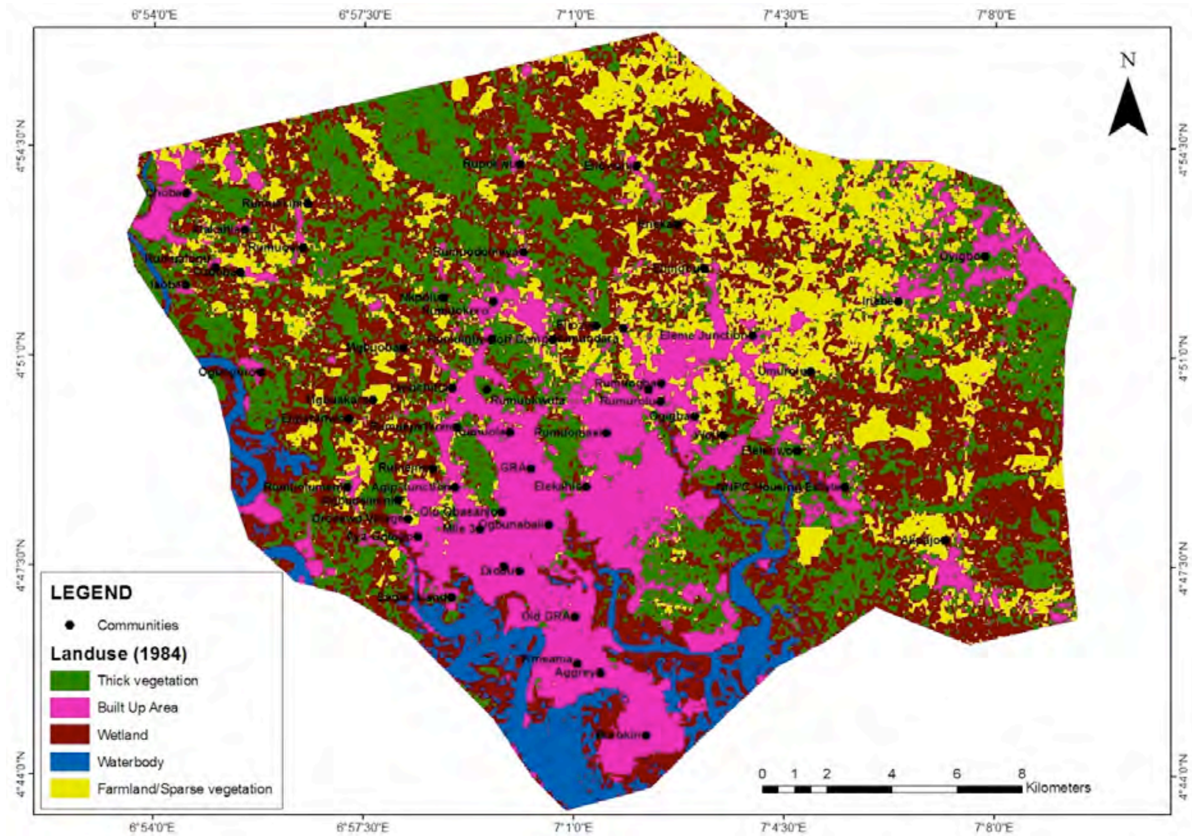
Watmough MD, Ingstrup DW, Duncan DC and Schinke HJ 2002 *Prairie Habitat Joint Venture Habitat Monitoring Program Phase 1: Recent Habitat trends in NAWMP targeted landscapes.* Technical report series No. 391, Canadian Wildlife Service, Edmonton, Alberta, Canada. 93P.

Zhang Q, Ban Y, Liu J, Shu Q and Hu Y 2008 *Analysis of Landscape Dynamics in Shanghai Using Landscape Metrics: Effects of Spatial Resolutions.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B 6b, Beijing.

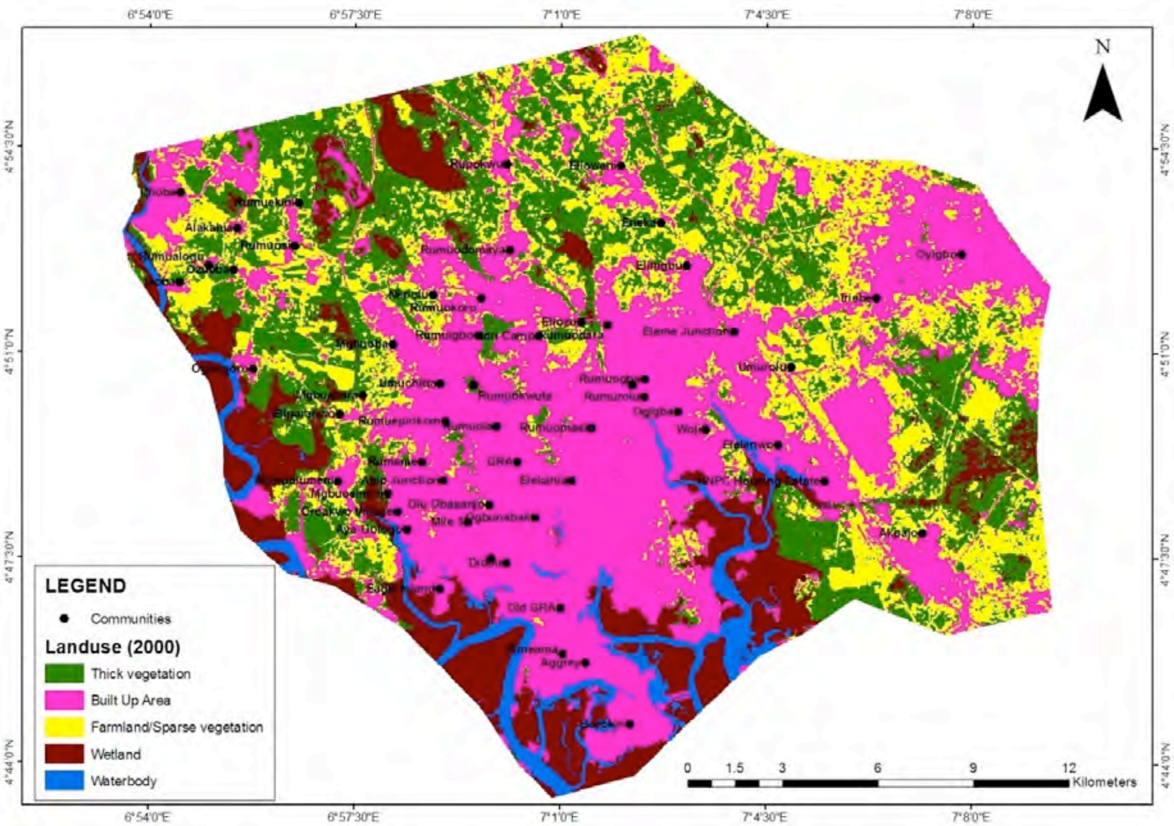
APPENDICES



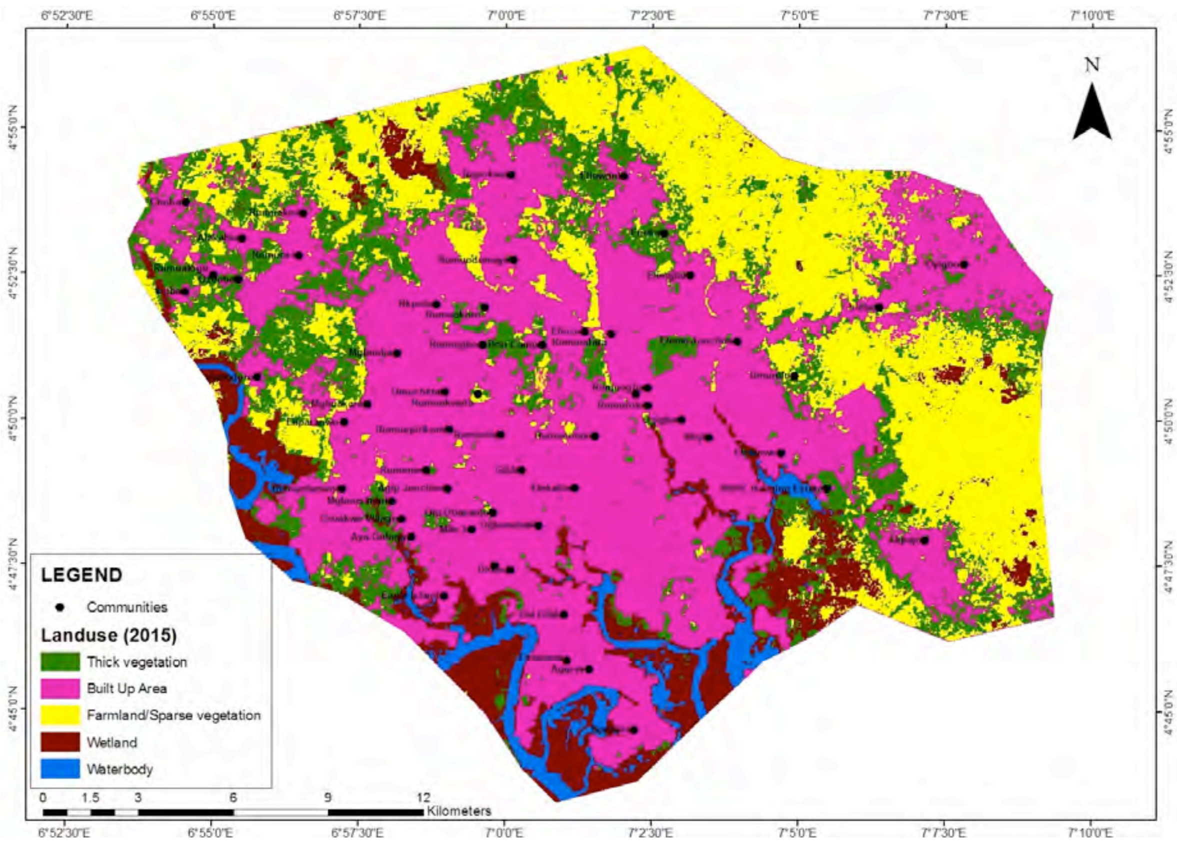
Appendix 1: Port Harcourt Metropolis



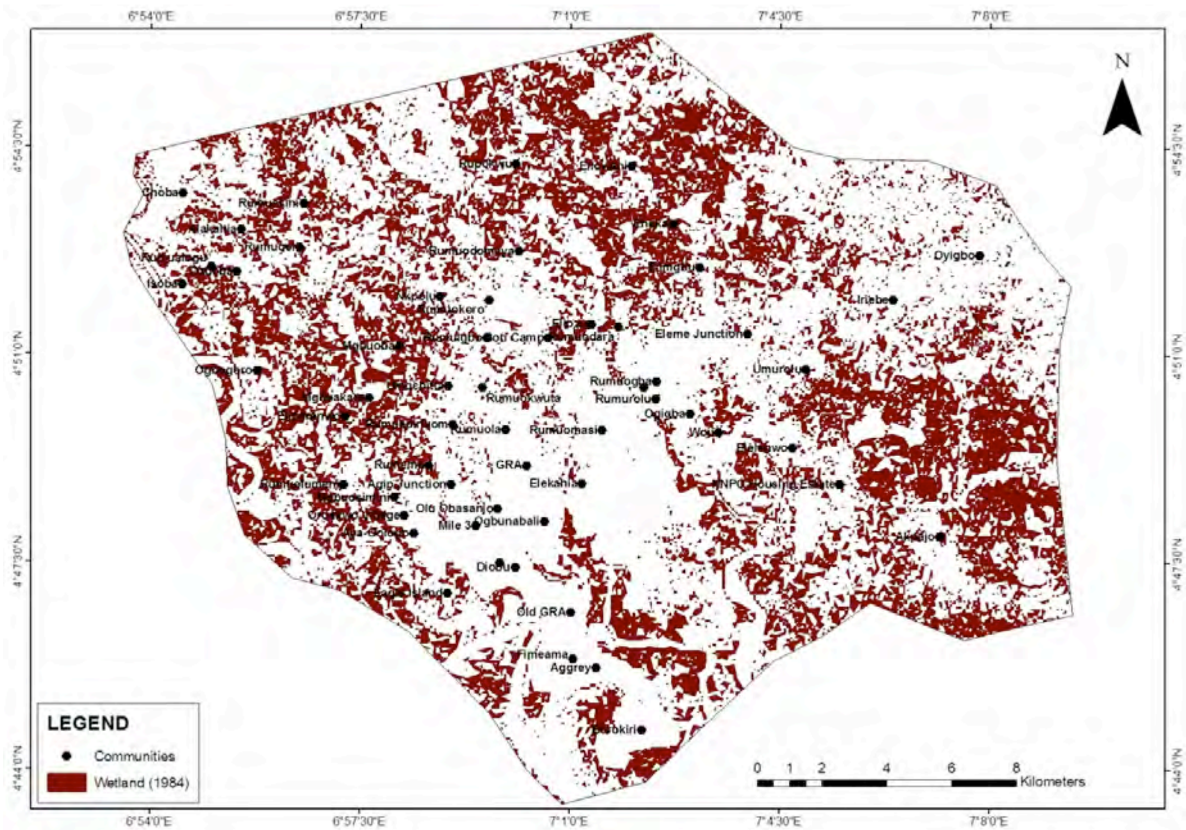
Appendix 2: Land use/Land cover pattern of Port Harcourt Metropolis in 1984



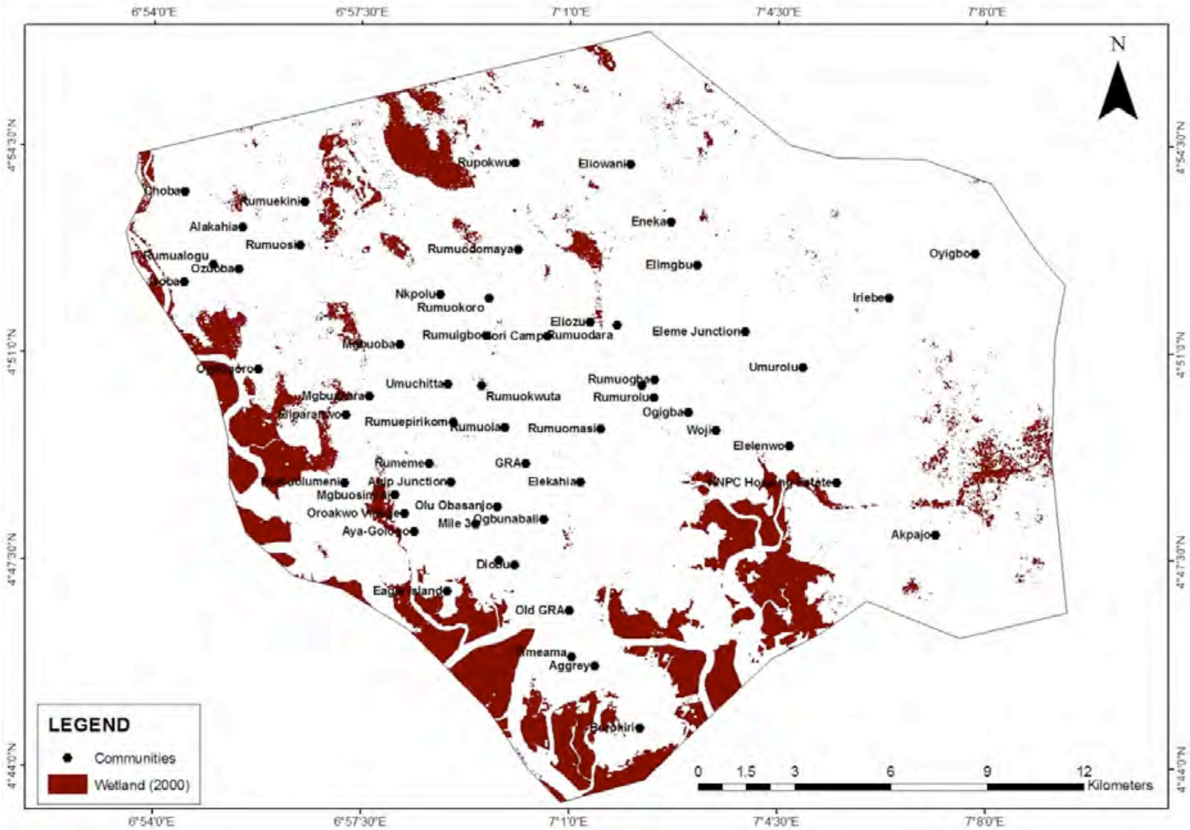
Appendix 3: Land use/Land cover pattern of Port Harcourt Metropolis in 2000



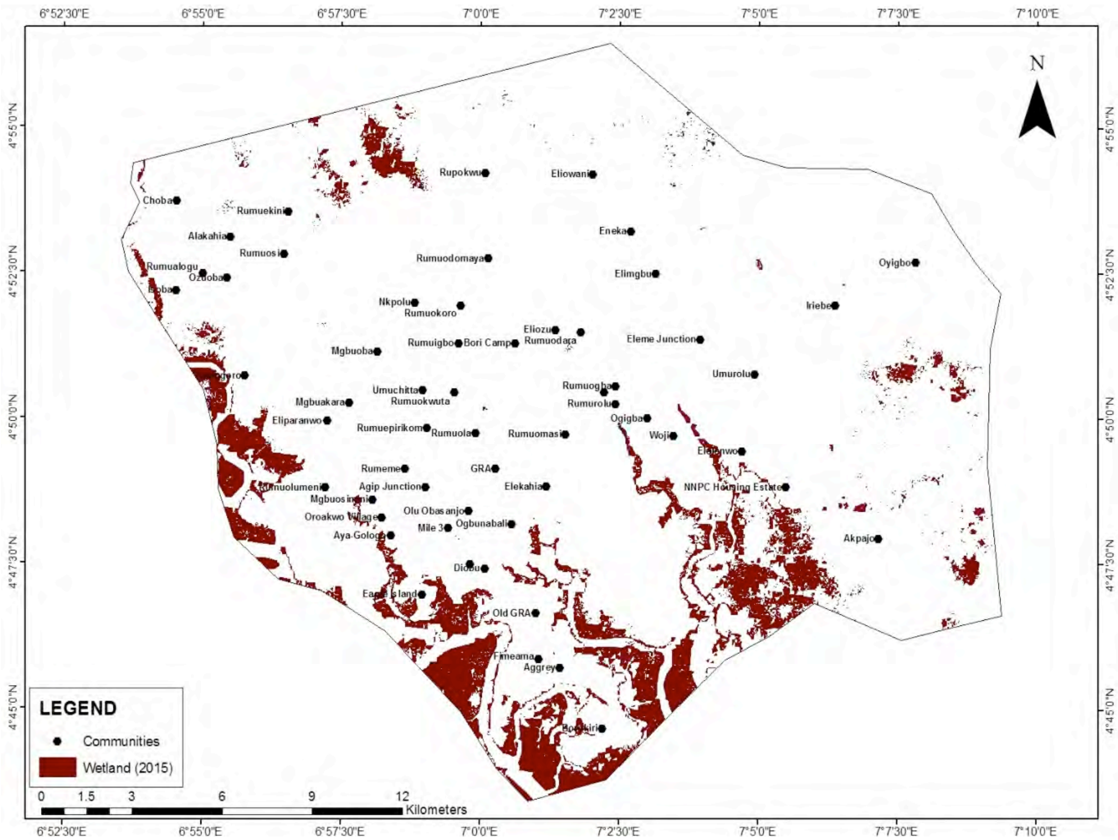
Appendix 4: Land use/Land cover pattern of Port Harcourt Metropolis in 2015



Appendix 5: Spatial extent of wetlands in Port Harcourt Metropolis in 1984



Appendix 6: Spatial extent of wetlands in Port Harcourt Metropolis in 2000



Appendix 7: Spatial extent of wetlands in Port Harcourt Metropolis in 2015