GEOSPATIAL APPROACH USING SOCIO-ECONOMIC AND PROJECTED CLIMATE CHANGE INFORMATION FOR MODELLING URBAN GROWTH

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To my parents.

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ABSTRACT

Urban growth and climate change are two interwoven phenomena that are becoming global environmental issues. Using Niger Delta of Nigeria as a case study, this research investigated the historical and future patterns of urban growth using geospatial-based modelling approach. Specific objectives were to: (i) examine the climate change pattern and predict its impact on urban growth modelling; (ii) investigate the historical pattern of urban growth; (iii) embrace some selected parameters from United Nations Sustainable Development Goals (UN SDGs) and examine their impacts on future urban growth prediction; (iv) verify whether planning has controlled urban land use sprawl in the study area; and (v) propose standard operating procedure for urban sprawl in the area. A MAGICC model, developed by the Inter-Governmental Panel on Climate Change (IPCC), was used to predict future precipitation under RCP 4.5 and RCP 8.5 emission scenarios, which was utilized to evaluate the impact of climate change on the study area from 2016 to 2100. Observed precipitation records from 1972 to 2015 were analysed, and 2012 was selected as a water year, based on depth and frequency of rainfall. A relationship model derived using logistic regression from the observed precipitation and river width from Landsat imageries of 2012 was used to project the monthly river width variations over the projected climate change, considering the two emission scenarios. The areas that are prone to flooding were determined based on the projected precipitation anomalies and a suitability map was developed to accommodate the impact of climate change in the projection of future urban growth. Urban landscape changes between 1985 and 2015 were also analysed, which revealed a rapid urban growth in the region. A Cellular Automata/Markov Chain (CA-Markov) model was used to project the year 2030 land cover of the region considering two scenarios; normal projection without any constraint, and using some designed constraints (forest reserves, population and economy) based on some selected UN SDGs criteria and climate change. On validation, overall simulation accuracies of 89.25% and 91.22% were achieved based on scenarios one and two, respectively. The projection using the first scenario resulted to net loss and gains of -7.37%, 11.84% and 50.88%, while that of second scenario produced net loss and gains of -4.72%, 7.43% and 48.37% in forest, farmland and built-up area between 2015 and 2030, respectively. The difference between the two scenarios showed that the UN SDGs have great influence on the urban growth prediction and strict adherence to the selected UN SDGs criteria can reduce tropical deforestation, and at the same time serve as resilience to climate change in the region.

ABSTRAK

Pertumbuhan bandar dan perubahan iklim adalah dua fenomena yang dijalin menjadi isu global alam sekitar. Menggunakan Niger Delta Nigeria sebagai kajian kes, kajian ini mengkaji corak sejarah dan masa depan pertumbuhan bandar menggunakan pendekatan permodelan berdasarkan metrik spatial. Objektif khusus kajian ini adalah untuk: (i) mengkaji corak perubahan iklim dan meramalkan impaknya terhadap pemodelan pertumbuhan bandar; (ii) mengkaji corak sejarah pertumbuhan bandar; (iii) menilai beberapa parameter terpilih dari Matlamat Pembangunan Lestari Pertubuhan Bangsa-Bangsa Bersatu (UN SDGs) dan mengkaji kesannya terhadap ramalan pertumbuhan bandar akan datang; (iv) mengesahkan sama ada perancangan telah menguasai penggunaan tanah di kawasan kajian; dan (v) mencadangkan prosedur operasi standard untuk kawasan bandar di kawasan tersebut. Model MAGICC, yang dibangunkan oleh Panel Antara Kerajaan mengenai Perubahan Iklim (IPCC), digunakan untuk meramalkan pemendakan akan datang di bawah senario pelepasan RCP 4.5 dan RCP 8.5, yang digunakan untuk menilai kesan perubahan iklim di kawasan kajian dari tahun 2016 hingga 2100. Rekod pemendakan yang diperhatikan dari 1972 hingga 2015 dianalisis, dan 2012 dipilih sebagai tahun air, berdasarkan kedalaman dan kekerapan hujan. Model regresi linier yang diperoleh menggunakan regresi logistik daripada hujan yang dilihat dan lebar sungai dari imaginasi Landsat 2012 digunakan untuk melaksanakan variasi lebar sungai bulanan terhadap perubahan iklim yang diunjurkan, dengan mempertimbangkan kedua-dua senario pelepasan. Kawasan yang terdedah kepada banjir ditentukan berdasarkan ramalan hujan dan peta kesesuaian dibangunkan untuk menampung impak perubahan iklim dalam unjuran pertumbuhan bandar akan datang. Perubahan landskap bandar antara 1985 dan 2015 juga dianalisis, yang menunjukkan pertumbuhan pesat bandar di rantau ini Model Rantaian Automata / Markov (CA-Markov) selular digunakan untuk melaksanakan penutupan tanah tahun 2030 di rantau ini berdasarkan dua senario; unjuran normal tanpa sebarang kekangan, dan menggunakan beberapa kekangan yang direka (rizab hutan, penduduk dan ekonomi) berdasarkan beberapa kriteria dan perubahan iklim PBB yang dipilih. Berdasarkan dapatan, ketepatan simulasi keseluruhan 89.25% dan 91.22% telah dicapai berdasarkan senario satu dan dua. Unjuran menggunakan senario pertama menghasilkan kerugian bersih dan keuntungan sebanyak -7.37%, 11.84% dan 50.88%, manakala senario kedua menghasilkan kerugian bersih dan keuntungan sebanyak -4.72%, 7.43% dan 48.37% dalam hutan, kawasan antara 2015 dan 2030, masing-masing. Perbezaan antara kedua-dua senario menunjukkan bahawa SDG PBB mempunyai pengaruh yang besar terhadap ramalan pertumbuhan bandar dan pematuhan ketat terhadap kriteria SDG PBB yang terpilih dapat mengurangkan penebangan hutan tropika, dan pada masa yang sama berfungsi sebagai daya tahan terhadap perubahan iklim di rantau ini.

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LIST OF ABBREVIATIONS

ABM	-	Agent-Based Model
ANN	-	Artificial Neural Networks
AR3	-	Third Assessment Report of the Intergovernmental Panel on Climate Change
AR4	-	Forth Assessment Report of the Intergovernmental Panel on Climate Change
CA	-	Cellular Automata
CA-Markov	-	Cellular Automata/Markov Chain
CA'	-	Class Area
CLUES	-	Catchment Land Use for Environmental Sustainability
CONTAG	-	Contagion
DEM	-	Digital Elevation Model
DN	-	Digital Number
ED	-	Edge Density
ENN_MN	-	Mean Euclidian Nearest Neighbor Distance
EROS	-	Earth Resource Observation and Science
ESRI	-	Environmental Systems Research Institute
ETM+	-	Enhanced Thematic Mapper Plus
FOA	-	Food and Agriculture Organization of the United Nations
FRAC_AM	-	Area Weighted Mean Patch Fractal Dimension
GCP	-	Ground Control Point
GDP	-	Gross Domestic Product
GFM	-	Gravitational Field Model
GIS	-	Geographic Information System
GLOVIS	-	Global Visualization Viewer
GPS	-	Global Positioning System

IDW	-	Inverse Distance Weighting
IMO	-	International Maritime Organization
IOC	-	International Olympic Committee
IPCC	-	Intergovernmental Panel on Climate Change
IR	-	Infrared
KIA	-	Kappa Index of Agreement
LC	-	Land Cover
LU	-	Land Use
LPI	-	Largest Patch Index
MAGICC	-	Model for the Assessment of Greenhouse-gas Induced Climate Change
MCE	-	Multi-Criteria Evaluation
MLP	-	Multi-Layer Perception
MLP-Markov	-	Multi-Layer Perception-Markov Chain
NCDC	-	National Climatic Data Centre
NCEI	-	National Centre for Environmental Information
NIMET	-	Nigerian Meteorological Agency
NIR	-	Near Infrared
NNBS	-	Nigerian National Bureau of Statistics
NOAA	-	National Oceanic and Administration
NPC	-	National Population Commission of Nigeria
NP	-	Number of Patches
OLI	-	Operational Land Imager
OWG	-	Open Working Group
P-Chrome		Panchromatic
PRB	-	Population Reference Bureau
REDD+	-	Reducing Emission from Deforestation and Forest Degradation in Under Developing Countries
RMSE	-	Root Mean Squired Error
SD	-	System Dynamics
SD-CA	-	System Dynamics and Cellular Automata
SD-CLUES	-	System Dynamics and Catchment Land Use for Environmental Sustainability

SDGs	-	Sustainable Development Goals
SHEB	-	Spatially Heterogeneous Expert Based
SLUETH	-	Slope, Land use, Exclusion, Urban extent, Transportation and Hillshade
SOP	-	Standard Operating Procedure
St-Markov	-	Stochastic process and Markov chain
SWIR	-	Short-Wave Infrared
TM	-	Thematic Mapper
TIR	-	Thermal Infrared
UNDP	-	United Nations Development Programme
UNESCO	-	United Nations Educational, Scientific and Cultural Organization
UNFCCC	-	United Nations Framework Convention on Climate Change
UN-Habitat	-	United Nations Human Settlements Programme
UN SDGs	-	United Nations Sustainable Development Goals
USGS	-	United States Geological Survey
UTM	-	Universal Transverse Mercator
WLC	-	Weighted Linear Combination
WRF	-	Weather Research and Forecasting

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CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Human activities in pursuance for development are leading to continuous degradation of the physical environment, which in turn posturing dangers to the present and future habitations. Fast populace development and urbanization are of awesome worry to the sustainability of urban areas (Babanyara *et al.*, 2010); accordingly, the more individuals on the earth, the more prominent the effect on the earth and weights on the resources.

Both developed and developing worlds are witnessing urbanization progression (Al-shalabi *et al.*, 2013). However, fast urbanization, particularly the unauthorized urban land extension, and related issues like neediness, joblessness, poor sterile condition and natural corruption remain a testing issue in most developing nations(Basnet, 2011; Hove *et al.*, 2013; Owoeye and Ogundiran, 2014). Today, a larger number of individuals live in urban territories than provincial zones. As indicated by United Nations (2014b), just 746 million individuals (30% of the total populace) were urbanites in 1950 however in 2014, 3.9 billion individuals (54%, which is the greater part of the populace) were urbanites, jammed into around 3% of the landmass and it is normal that by 2050, 6.4 billion individuals (66% of the populace) will be urbanites (Figure 1.1). It additionally declared that this continuous increment of the urban populace and the diminishing of the country populace will prompt sustained urbanization. Despite the fact that urbanization is the way to modernization and in addition financial development and advancement, it likewise has backlashes on the livelihoods and the environment (Wei and Ye, 2014).

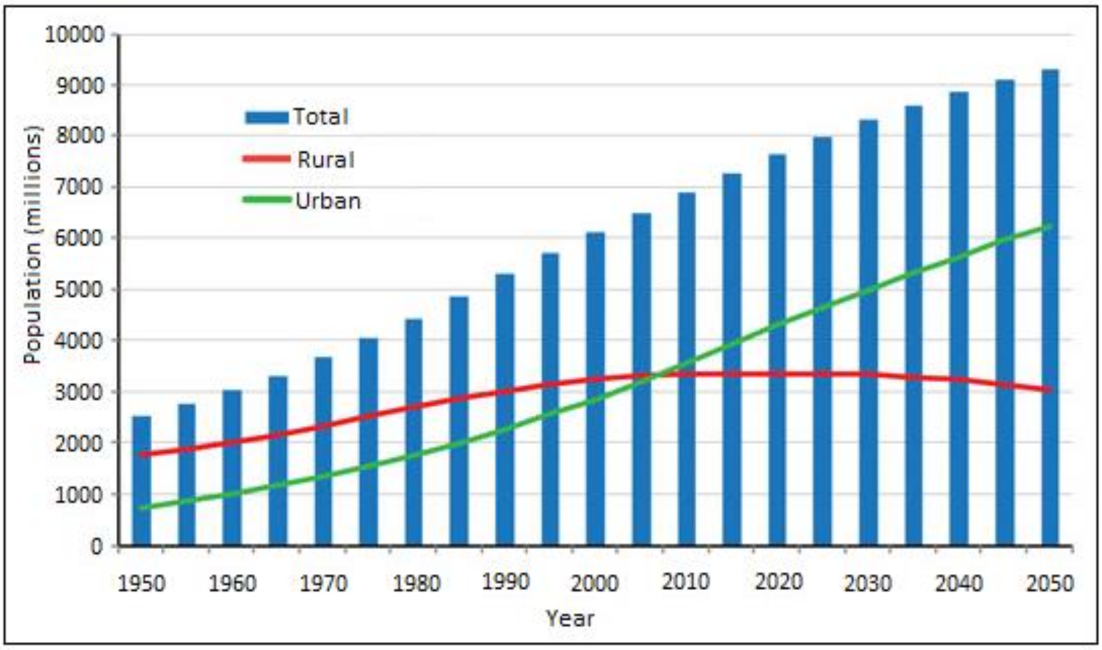

Figure 1.1: The world's urban and rural population, 1950-2050

Source: World Urbanization Prospects, the 2014 Revision (United Nations, 2014b)

Quick urban development unremarkably happens to the detriment of prime agrarian land, by changing the regular habitat and open spaces to urban use, which impacts worldwide ecological change (Al-shalabi, *et al.*, 2013; Deng *et al.*, 2010). Melillo *et al.* (2014) thought about human activities as the remote reason for the ascent in the atmospheric carbon dioxide, which has awesome repercussions on biodiversity, nourishment security, human wellbeing, and water quality as it adjusts the biochemical cycles and, in the meantime, prompts environmental change. In this way, the indirect impact of urban growth on the environment should be considered by researchers and decision makers since it has an immediate and significant effect on mankind.

Land use change has turned into a key worldwide natural issue and one of the critical areas in urban researches (Subedi *et al.*, 2013; Triantakonstantis and Mountrakis, 2012). Urbanization has been perceived as one of the primary causes of land use change since the beginning of human development (Babanyara, *et al.*, 2010; Deka *et al.*, 2011). With the quick advancement of urbanization, it turn out to be exceptionally important to comprehend landscape patterns and how it changes because of human activities for appropriate land and natural resource administration (Prakasam, 2010).

Looking at how urban growth is rising as a key part of worldwide ecological change, there is critical need to see how urban regions advance and in addition the magnitude and direction to which they may expand in the future. The most straightforward approach to accomplish this in a given region is to compare spatially at different time span what happened in the region by utilizing spatial change detection strategy, which is a methods for finding out land use changes by observation at different epochs (Adejoke *et al.*, 2014; Ahmed and Ahmed, 2012; Ozturk, 2015; Vaz and Arsanjani, 2015).

Despite the fact that only 3% of the global landmass is possessed by the urban areas, urbanization remains the main reason for alteration to the landscape as it modifies the physical condition and also the biodiversity composition of the ecosystems (Townroe and Callaghan, 2014). Thus, how ecosystems are touched by urbanization especially as far as climate change, biodiversity and ecological debasement has been recognized as a vital issue to be considered in future researches concerning urban growth (Vaz and Arsanjani, 2015).

Being the home of the biggest piece of the total populace, it is in the urban areas that the effect of climate change is probably going to be the most intense. Additionally, this is more evident in developing nations where security of land tenure might be poor and where a large number of urban occupants live in low quality homes on unauthorized or subdivided land with next to zero assurance against climate related catastrophe occasions (Boateng *et al.*, 2014).

Today, the impression of humankind on present and future forms of urban land use dynamics is poor and fragmentized. This might be ascribed to an uneven spreading of urban land use researches over the globe (Dadras *et al.*, 2014a). Also, absence of comprehension about past urban land use changes with respect to climate change might be considered as one of the elements that farthest point our capacity to recognize locales in danger for urban development. Therefore, it becomes imperative to know the historical and future growth patterns of cities with respect to climate change and other socio-economic variables such as population growth and gross domestic product (GDP) as this will facilitate the realization of the United Nations Sustainable Development Goals 11 and 15 "Make cities and human settlements inclusive, safe, resilient and sustainable" and "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt/reverse land degradation and biodiversity loss", respectively.

1.2 Problem Statement

Advances in space technology have eased the acquisition of data for different kinds of research. For instance, there are different methodologies now accessible to urban researches more specifically using geospatial-based approach through the combination of remote sensing and GIS. Remote sensing provides accurate, timely, reliable and periodic data, while GIS gives distinctive strategies for coordinating such information to speak to various situations that can be utilized for assessing urban growth. Cellular Automata (CA) has been extensively used for urban growth analysis but the use of emerging parameters such as climate change, forest reserves, population and economy to model urban growth as proposed by the United Nations Sustainable Development Goals 11 and 15 is quite unexplored. Although, understanding the extent of the urban growth and its effect are usually estimated using geospatial techniques, but considering how climate change is becoming a global issue, coupled with rapid development of cities, it is important to incorporate climate variability as a decision tool for urban development planning. In recent times, many researchers used remote sensing and GIS techniques to model urban growth and its impact on climate change, but without considering the impact that the climate change could have on the future urban growth. In other words, most previous researches focused mainly on predicting the future patterns of the urban growth, using geospatial data only, without taking the influence of climate change into account. Moreover, the use of economic factor like gross domestic product (GDP) and climatic variable like precipitation in projecting urban growth is relatively new. Therefore, the integration of geospatial, socio-economic and projected climate change information to predict future urban growth is paramount and this is also necessary towards realization of the United Nations Sustainable Development Goals. Besides, there is lack of standard operating procedures for urban growth in most of our urban settlements, especially in developing countries like Nigeria, and this is ignored by the previous researches.

Urban growth is considered as principal segment of worldwide ecological change. As the portions of cities (especially in developing countries) are growing outside of the legislative or development control framework, with practically no security against climate related catastrophe occasions, there is critical need to see how urban areas are evolving based on the present and future climate changes. Assessing the influence of climate change on urban growth is also paramount, which is ignored by the previous researches. As far as urban growth is concerned, climate change indicators such as excessive rainfall are of greater importance since more coastal cities are growing, hence vulnerable to impact of climate change such as flooding. Also, studies revealed that over two billion people (40% of the global population) dwell within 62 miles (100 kilometers) of the coast, increasing their vulnerability to storm surges and sea level rise (IOC/UNESCO, 2011).

Human anthropogenic activities, coupled with rapid population growth and development, are continuously altering the physical environment and the community composition of the ecosystem, especially as far as biodiversity and natural debasement. Urban growth and people concentration in the urban areas are of incredible worry to the sustainability of urban areas around the world. Literature revealed that only 30% of the world's population were urbanites in 1950, which rose to 54%, the greater part of the populace, in 2014 and it is anticipated that by 2050, 66% will be urbanites (United Nations, 2014b). Consequently, the more people trooping into an urban area, especially in poor countries with lack of proper planning and limited resources to meet their basic needs, the more noteworthy the effect on nature and weights on the resources, despite the fact that urbanization is the way to modernization and also monetary development and improvement. Since monitoring and predicting urban growth are among the vital information needed for long term planning, research in this area remains an on-going topic. This study therefore seeks to develop a methodology for modeling the pattern of urban growth with respect to climate change and socio-economic development, through the integration of projected precipitation, population and gross domestic product (GDP), and remotely sensed imageries towards realization of the United Nations Sustainable Development Goals in Niger Delta region of Nigeria.

1.3 Research Questions

The study is poised to answer the following questions:

i. How can climate change pattern and its impact on Niger Delta be predicted?

ii. How can remote sensing and GIS be used to analyse the historical patterns of urban growth in the Niger Delta?

iii. How can adherence to the United Nations Sustainable Development Goals affect future urban growth in the Niger Delta?

iv. Does spontaneous and unplanned urban land use sprawl happen around the Niger Delta?

v. How can remote sensing and GIS be used as assessment tool for land use development planning and control?

1.4 Objectives of the Study

The aim of this study is to investigate the patterns of urban growth using geospatial-based modelling approach by integrating geospatial, socio-economic and projected climate change information with a view to present a prototype approach. In order to achieve the aim, the following specific objectives were set:

i. To examine the climate change pattern and predict its impact on urban growth modelling with geospatial approach;

ii. To investigate the historical pattern of urban growth using some selected spatial metrics;

iii. To embrace some selected parameters from United Nations Sustainable Development Goals (UN SDGs) and examine their impacts on future urban growth prediction in the area;

iv. To use the outputs of the historical and future urban growth analyses to determine whether planning has controlled urban land use sprawl in the study are; and

v. To propose standard operating procedure for urban sprawl in the area.

1.5 Scope of the Study

The following are the scope of the study:

1. The use of CA-Markov model, a blend of Cellular Automata and Markov Chain, to embrace some emerging parameters such as climate change, forest reserves, population and economy as proposed by the United Nations Sustainable Development Goals 11 and 15 and examine their impacts on future urban growth prediction was harnessed. The reason for the selection of the CA-Markov model was because of its capabilities as a hybrid land cover prediction model that adds spatial contiguity element and noesis of the likely spatial distribution of transitions to Markov chain analysis by the combined strength of traditional form of Cellular Automata, Markov Chain, Multi-Criteria and Multi-Objective Land Allocation procedures.

2. The data need of the study include: Multitemporal Landsat satellite images of four different epochs (1985, 2000, 2012 and 2015); Topographic maps;

Master plan; Digital Elevation Model (DEM) data; climate variability (precipitation) data; socio-economic data (population and GDP growth). The data were sourced from relevant government agencies and internet websites. More subtle elements will be given in Chapter 3 on data acquisition, pre-processing and preparation.

3. Different software packages were used at different processing stages. For instance, ArcGIS 10.3, ENVI 5.1 and IDRISI Selva were used for image correction/enhancement and assessment of their results, image classification and accuracy assessment, and production of suitability maps. The ArcGIS was also used for geographic database creation, map production and presentation, while FRAGSTATS 4.2 was utilized for the analysis of historical urban landscape's changes. For Markov chain analysis and modelling, prediction of land cover and spatial modelling, IDRISI software was employed. The choice of these software packages was on the ground of their availability and wide range of processing algorithms with high-quality performance.

1.6 Significance of the Study

Indeed, attempts have been made, within the last few decades, to model urban growth by using geospatial data only without taking the influence of climate change into account. This study therefore seeks to extend the knowledge of the capabilities of Remote Sensing and GIS through utilization of geospatial, socio-economic and predicted climate change information for developing a methodology that could be used for urban growth prediction. This is to improve urban growth prediction and physical development planning. It can also support decision making process for physical planning. Moreover, the proposed approach requires only geospatial, socio-economic and climatic data, most of which can be acquired from open sources which makes it a possible candidate of choice for planners and decision makers who usually prefer simple diagnostic techniques that require minimum data input.

The proposed approach demonstrates how adherence to the United Nations Sustainable Development Goals 11and 15 “Make cities and human settlements inclusive, safe, resilient and sustainable” and “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt/reverse land degradation and biodiversity loss” can help in realizing a sustainable urban development by 2030. The approach can also be beneficial for the purpose of decision making and physical planning based on the following instances; (i) it can serve as a powerful tool for predicting urban growth from spatial and temporal perspectives, (ii) it can be handy in many instances especially in countries/areas that have the problem of unplanned urban development and lack of data, and (iii) it can also be straight forward, in terms of operation, and easy going as it requires only geospatial, socio-economic and climatic data, most of which can be acquired from open sources.

1.7 Structure of the Thesis

The research comprised five chapters: Chapter 1 discloses the background to the study and gives the issues articulation, research questions, objectives, scope and significance of the study. Chapter 2 reviews issues like: some scientific views on climate change including its major causes and how it affects the urban environment; the state of the earth concerning spatial metrics together with their strength and limitation in assessing the spatial patterns of urban growth; as well as some chosen hypothetical points of view/past observational inquiries about in the field of urban growth, together with their strengths and limitations. Chapter 3 discusses the study area and the strategy to be adopted in achieving the aim of the study, which will include data requirements, sources and methods of collection as well as data pre-processing, preparation and manipulation. Chapter 4 presents the results of the performed analyses and full discussions on the research findings. Chapter 5 proposed standard operating procedures for urban growth in the study area. Chapter 6 concludes the major findings of the research in line with the research objectives and proffered some recommends for future studies.

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