UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A GEOSPATIAL FRAMEWORK FOR MONITORING AND ASSESSING DESERTIFICATION IN KEBBI STATE, NIGERIA

MUHAMMADU MANSUR ALIERO

FH 2018 12

DEVELOPMENT OF A GEOSPATIAL FRAMEWORK FOR MONITORING AND ASSESSING DESERTIFICATION IN KEBBI STATE, NIGERIA

BY

MUHAMMADU MANSUR ALIERO

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

May 2018

DEDICATION

This project work was dedicated to my family and beloved ones.

Abstract of thesis presented to the Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF A GEOSPATIAL FRAMEWORK FOR MONITORING AND ASSESSING DESERTIFICATION IN KEBBI STATE, NIGERIA

By

MUHAMMADU MANSUR ALIERO

May 2018

Chairman : Mohd Hasmadi Ismail, PhD
Faculty : Forestry

Terrestrial degradation nowadays presents one of the devastating environmental problems of the earth caused by natural as well as man-made factors. According to UNCCD, almost one-third of the world agricultural land is facing a degradation phenomenon. Desertification phenomenon is threatening Kebbi state with huge drawback relating to the diminishing of ecosystem services and negative socioeconomic impact on community livelihood. However, the extent, trends and severity of desertification in Kebbi state has neither fully recognised, nor the rate of its development is accurately documented. Subsequently, the primary aim of the study is to develop a geospatial framework to monitor and assess land degradation in the area with specific emphasis on quantifying land cover (LC) change and vegetation depletion from 1986-2016, modelling the LC change for the year 2026 and characterising desertification sensitivity in the area.

Remotely sensed data were classified into five thematic LC classes namely dense vegetation (DV), shrubs land (SL), farmland (FL), bare/grassland (BGL) and water body (WB). The Driver-Pressure-State-Impact-Response (DPSIR) framework was used for better understanding of the drivers, the state of the environmental condition, the causes and the impact of the LC changes. Modelling the future (2016-2026) LC of the area was conducted using the CA-Markov model. Desertification sensitivity of the area was assessed using Mediterranean Desertification and Land Use-Environmental Sensitivity Area Index (MEDALUS-EASI) methodology.

The analysis of LC change from 1986-2016, indicates a gradual decrease of DV by about 61%, the downturn in the SL by about 25.7%. BGL has increased by about 18.2% while FL increases by 35.9%. WB remains unchanged. The drivers of the change are mainly the demand for farming land as the population increases as well as socio-economic stresses.

The pressures of the change include expansion of farming land and the use of wood as fuelwood, construction material and other domestic use. The state of the condition indicates a decline in vegetated and shrubland, however; farming land and bare grassland are increasing. The impacts include severe land degradation, soil erosion, the decline in the provision of ecosystem goods and services and biodiversity loss. The responses include afforestation programs by government and Non-Governmental Organisations (NGO's) however, communities and individuals organise an annual tree planting campaign. The future LC prediction (2026) illustrates that FL and DV may probably increase while SL and BGL may probably decline. WB may decrease slightly. The spatial assessment of desertification sensitivity of the area indicates that 36% of the area is not affected. 17%, 30%, 15 % fall within a low, moderately and sensitive categories respectively. Only 1% of the area is highly sensitive to desertification. The impact of the different quality index to the desertification in the area show that climatic indices have a high impact on desertification in the area (r^2=0.64) followed by soil indices (r^2=0.47) and human indicators to desertification (r^2=0.45). Vegetation indices have the least impact to the desertification in the area with (r^2=0.38).

It is recommended that Governmental and NGO's should make an essential strategic plan for the continued in-depth assessment and monitoring of land degradation using advanced tools. Adaptation and mitigation measures such as agroforestry system of farming, robust afforestation and land restoration activities need to be strengthened. Environmental education needs to be integrated into both primary and post-primary teaching curricula to enhance environmental awareness. There is also the need to improve the livelihood of the rural people by providing alternative income and domestic energy sources since they depend heavily on natural resources for sustenance. The novelty of the study laid on the integration of remote sensing and GIS, the MEDALUS-EASI and the DPSIR frameworks for developing a unique and explanatory platform for modelling LC cover trend and magnitude of land degradation in the area.

Abstrak tesis yang dikemukakan kepada Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN RANGKA KERJA GEOSPASIAL BAGI PEMANTAUAN DAN MENILAI KEMISKINAN TANAH DI KEBBI NEGERI, NIGERIA

Oleh

MUHAMMADU MANSUR ALIERO

Mei 2018

Pengerusi : Mohd Hasmadi Ismail, PhD
Fakulti : Perhutanan

Degradasi terrestrial pada masa kini merupakan salah satu masalah alam sekitar yang dahsyat di bumi yang disebabkan oleh faktor semula jadi dan buatan manusia. Menurut UNCCD, hampir sepertiga tanah pertanian di dunia menghadapi fenomena degradasi. Negeri Kebbi di Nigeria terancam dengan fenomena desertifikasi dengan kelemahan yang besar berkaitan dengan penurunan perkhidmatan ekosistem dan kesan sosioekonomi yang negatif terhadap kehidupan masyarakat. Walau bagaimanapun, sejauh mana pola, dan keparahan desertifikasi di negari Kebbi tidak dapat dipastikan sepenuhnya atau kadar perkembangannya secara tepat tidak didokumenkan. Matlamat utama kajian ini adalah untuk membangunkan rangka kerja geospatial untuk memantau dan menilai kemerosotan tanah di kawasan tersebut dengan penekanan khusus untuk mengire perubahan tanah (LC) dan penurunan kawason tumbuhan dari 1986-2016, memodelkan perubahan LC pada tahun 2026 dan mencirikan sensitiviti desertifikasi di kawasan tersebut.

Data pendiriaan jauh diklasifikasikan kepada lima kelas LC bertema iaitu tumbuh-tumbuhan padat (DV), pokok renek / kawasan binaan (SB), tanah ladang (FL), kosong / padang rumput (BGL) dan badan air (WB). Rangka Kerja Kerangka-Impak-Kemajuan-Negeri-Dampak (DPSIR) digunakan untuk pemahaman yang lebih baik tentang pemandu, keadaan keadaan alam sekitar, sebab-sebab dan kesan perubahan LC. Pemodelan masa hadapan (2016-2026) LC kawasan itu telah dijalankan menggunakan model CA-Markov. Sensitiviti desertifikasi kawasan itu dinilai dengan menggunakan kaedah Indeks Kawasan Kepekaan Bumi (MEDALUS-EASI) yang digunakan oleh Desertification Mediterranean dan Penggunaan Tanah-Kepekaan Alam Sekitar.

Analisis perubahan LC dari tahun 1986-2016, menunjukkan pengurangan DV secara perlahan kira-kira 61%, kemerosotan SL sebanyak 25.7%. BGL telah meningkat sebanyak 18.2% manakala FL meningkat sebanyak 35.9%. WB kekal tidak berubah. Pemacu perubahan ini terutamanya permintaan terhadap tanah pertanian sebagai peningkatan penduduk serta tekanan sosio-ekonomi. Tekanan kepada perubahan termasuk pengembangan tanah pertanian dan penggunaan kayu sebagai bahan bakar, bahan binaan dan kegunaan domestik yang lain. Keadaan ini menunjukkan penurunan kepada kawasan tumbuh-tumbuhan dan tanah rimba, bagaimanapun; tanah pertanian dan padang rumput kosong semakin meningkat. Impak termasuk kemerosotan tanah yang teruk, hakisan tanah, kemerosotan kepada perkhidmatan barangan dan perkhidmatan ekosistem dan kehilangan biodiversiti. Tindak balas yang di lakukan termasuk program penanaman semula hutan oleh kerajaan dan Pertubuhan Bukan Kerajaan (NGO) walau bagaimanapun, komuniti dan individu turut menganjurkan kempen penanaman pokok secara tahunan. Ramalan masa depan LC (2026) menggambarkan bahawa FL dan DV mungkin akan meningkat sementara SL dan BGL mungkin mungkin menurun. WB boleh berkurangan sedikit. Penilaian spacial sensitiviti desertifikasi kawasan menunjukkan bahawa 36% kawasan tidak terjejas. 17%, 30%, 15% jatuh dalam kategori rendah, sederhana dan sensitif masing-masing. Hanya 1% kawasan yang sangat sensitif terhadap desertificasi. Impak dari indeks kualiti yang berbeza kepada desertifikasi di kawasan tersebut menunjukkan bahawa indeks iklim mempunyai kesan yang tinggi terhadap penurunan di kawasan tersebut ($r^2 = 0.64$) diikuti dengan indeks tanah ($r^2 = 0.47$) dan penunjuk manusia ke arah desertification (r^2=0.45). Indeks tumbuh-tumbuhan mempunyai kesan paling kurang kepada desertifikasi di kawasan tersebut dengan (r^2=0.38).

Adalah disyorkan bahawa, Kerajaan dan NGO perlu membuat pelan strategik yang perlu untuk penilaian dan pemantauan degradasi tanah secara mendalam dengan menggunakan alat canggih. Langkah-langkah adaptasi dan mitigasi seperti sistem perhutanan tani pertanian, penanaman semula hutan dan aktiviti pemulihan tanah perlu di perbanyakan. Pendidikan alam sekitar perlu disepadukan dalam kurikulum pengajaran rendah dan menengah untuk meningkatkan kesedaran alam sekitar. Terdapat juga keperluan untuk meningkatkan kehidupan penduduk luar bandar dengan menyediakan pendapatan alternatif dan sumber tenaga dalam negeri kerana mereka sangat bergantung kepada sumber semula jadi untuk hidup. Kajian baru ini terletak pada pengintegrasian penginderaan jarak jauh dan GIS, MEDALUS-EASI dan rangka kerja DPSIR untuk menyediakan platform yang unik dan jelas bagi pemodelan pola litupan LC dan magnitud degradasi tanah di kawasan tersebut.

ACKNOWLEDGEMENTS

All praise is to Allah (SWT), the creator of humanity and the solicitor of the universe. May peace and blessings of Allah be upon to our beloved prophet Muhammad (SAW), his companions, households and all the believers of Islam (Ameen).

I wish to first express my sincere appreciation to my able supervisor Associate professor Dr Mohd Hasmadi Ismail for his constant encouragement and guidance throughout this research work.

I will also like to express my gratitude to members of the supervisory committee Associate Professor (Dr.) Mohamad Azani Alias and Dr Alias Mohd Sood for their guidance, support and encouragement.

I as well want to thank the Tertiary Education Trust Funds (TETFund) of Nigeria through Kebbi state university of Science and technology, Aliero for funding this research work.

I am very grateful to the families of Late Alhaji Adamu Suleiman Aliero especially Muhammad Adamu Aliero and Abubakar Abba A. Aliero; my family members for their ever tied support and encouragement.

I also want to appreciate the effort of the United States Geological Survey (USGS), European Space Agency (ESA), National Statistics Bureau of Nigeria (NSB) as well as all the relevant Agencies for providing the data freely available for a project of this kind.

Worth mentioning are my colleagues Iqbal Putut, Umar Lawal, Juan Doksi, Muhammad Ado, Murtala Dangulla, Shaila to mention but a few, for their contribution to the success of this study.

I certify that a Thesis Examination Committee has met on 28 May 2018 to conduct the final examination of Muhammadu Mansur Aliero, on his thesis entitled "Development of a geospatial framework for monitoring and assessing land degradation in Kebbi State, Nigeria" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Pakhriazad Hassan Zaki, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Helmi Zulhaidi Mohd. Shafri, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohammad Firuz B. Ramli, PhD
Associate Professor
Faculty of Environmental Science
Universiti Putra Malaysia
(Internal Examiner)

Itaya Tamaki, PhD
Associate Professor
Laboratory of Forest Operation and Systems
Graduate School of BioResource
Mie University, Japan
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: …………………...

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Hasmadi Ismail, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Mohamad Azani Alias, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Alias Mohd Sood, PhD
Senior Lecturer
Faculty of Forestry
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No: Muhammadu Mansur Aliero, GS44395

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Ecosystem pattern changes over time, depending mainly on the environmental, social, economic and natural forces acting upon them. Understanding the nature of these changes is essential not only to enhance proper planning, management and guideline on the use of land resources but also to adapt and mitigate the adverse changes. Forest ecosystem plays an essential role not only in the provision of goods and services but also in the global carbon cycles (Kumar et al., 2010), however, are in a state of permanent flux at a variety of spatial and temporal scales. The causes of these changes can be natural as well as anthropogenic or may be a combination of the two (Khaine, & Woo, 2014).

Natural disturbance events such as wildfire, disease outbreaks, windstorms, hurricanes, floods, and droughts are expected to increase in frequency and magnitude, which will impose significant consequences to forest ecosystem dynamics (Virginia et al., 2001). Long-term changes in climatic variables such as temperature, drought and precipitation dramatically alter the conditions of vegetation growth. Human-induced changes related to deforestation, unsustainable land use, overgrazing, illegal bush burning, fuelwood extraction are believed to have caused significant adverse changes in the forest ecosystem. These changes in the forest interacting with air quality fluctuations, may substantially alter forest productivity, stand density as well as sequestration of carbon in both vegetation and soils (Matyssek et al., 2012); the net effect of these is forest degradation.

Forest degradation as a prelude to land degradation in some areas is a crucial phenomenon, and as such, monitoring of forest cover trends and functions offers essential information to support policies and decisions guideline in order to conserve, protect and sustainably manage the forests, particularly in the tropics where forests are diminishing at a speedy rate. Effective monitoring systems are required for efficient and updated information about the land resources trends. Detecting and analysing the pattern of these trends is an essential step, and the results may serve as a necessary input for forecasting, planning and decision-making processes to moderate the adverse effects of land degradation.

Land degradation is defined as a process of gradual or permanent loss of land productivity mainly due to anthropoid activities, or from the disparity between land quality and the intensity of land use. Land degradation became problematical in the sense that it affects all the global regions, not only the drylands and developing countries, with about one-third of the world farming land classified as either extremely or reasonably degraded (UNCCD, 2014).

Land degradation turns out to be critical, mainly when associated with extreme climatic conditions, together with specific patterns of drought and human-induced changes may transform into an irremediable form of environmental land degradation that is desertification.

Desertification in its simplest and operational definition by (UNCCD) to mean land degradation occurring in arid, semi-arid and dry sub-humid regions, caused by numerous factors put together as climatic and anthropogenic events. Desertification is getting popular by its extreme destructive effects not only on the environmental biodiversity, but a severe economic, social, and geopolitical consequence. The extent to which the phenomenon is spreading attracts the attention of not only politician and land managers, but also scientific and research communities at the different strategic level of actions with the aim of monitoring, assessing and evaluating desertification for better understanding before taking any crucial decision on the prevention, mitigation and adaptation measures.

Methodologies and frameworks were developed and applied to qualitatively and quantitatively monitor, assess and evaluate the extent and severity of desertification using various conceptions and definitions. However, are commonly based on essential indicators that attempt to simplify the reality of the complicated process of desertification, however, are found to be useful in enlightening information either qualitative or quantitative about the phenomenon which is sometimes difficult to measure.

Geospatial technological tool such as remote sensing (RS) and geographic information system (GIS) has advanced and present the most effective and efficient tool for analyzing environmental trends as demonstrated by many researchers (Aguilar et al., 2016; Hadeel, et al., 2009; Lu et al., 2005; Santini, 2005; Jensen 2005) in various field of studies. However, geographic information system, in particular, allows for the modelling of multiple factors or variables that are considered to have influenced a particular environmental problem and allow for the presentation of the modelled phenomenon in an explicit and spatial pattern.

The Medalus-ESAI stand for Mediterranean desertification and land use-Environmental Sensitive Area Index. It is a GIS-based environmental modelling approach that allows for cross-analyses and elaborations of the variable targeting particular aspects of desertification and their assessment concerning their spatial distribution. It is developed by (Kosmas et al., 1999) based on four group of several biophysical and human-induced variables, designated as soil (texture, rock fragments, drainage, parent material and depth), climate (aspects, rainfall and aridity,), vegetation (vegetation cover, resistance to aridity, fire risk and erosion protection) and management practices or human factors (pastures and forest areas, land use intensity, managerial policies). The basic premise here is that each triggering variable of land degradation will be allotted a threshold value based on the relevant starring role played in the land degradation process in a given land.

One of the outstanding features of MEDALUS-ESAI is its flexibility and allows modification of parameters by the local conditions and the availability of datasets.

The DPSIR framework was first coined in the year 1993 as Pressure-State-Response (PSR) by the Organization for Economic Cooperation and Development (OECD)(OECD, 1993) It was revised in the year 1999 as Driver-Pressure-State-Impact-Response (DPSIR) by the European Environment Agency (EEA). The framework was designed to be used for the environmentalists for identifying, analysing and evaluating complex environmental problems and has since been widely renowned by various scholars in numerous research disciplines not only for its advantages and suitability but also applicable to all kinds of environmental problems (Sermin et al., 2016).

The framework tends to describe the essential factors that act as the driving forces as well as their underpinning pressures that affect the state of the condition of a particular environment. It as well helps to assess the impact of the situation in the society and the responded by the government or society through different initiatives (activities or planning) to reduce the negative or to encourage the positive impacts to the environment.

1.2 Problem statement

Desertification phenomenon was discovered more than a century, however, has never been as critical as it is at present. It is known for its extreme destructive effects not only on the environmental biodiversity, but a severe economic, social, and geopolitical consequence (UNCCD, 2013; Ayuba, 2016; Thelma, 2015). Desertification, intensified by climate change, presently presents one of the ultimate environmental issues (UNCCD, 2007); it is hazardous to natural resources with negative implication on food security, poverty and political stability (M. Sivakumar & Stefanski, 2007). It was projected that millions of hectares of land are annually degraded; currently, more than 2 billion people are directly or indirectly affected globally by land degradation and distressing more than 33% of the earth´s land surface (UNCCD, 2014).

Despite the increasing global concerns from the observed impacts of desertification, the possible reliable assessments of the extent and nature of the land degradation and the rate at which it is increasing or diminishing at global, national and regional scale are limited (Santini, 2005). Moreover, there is still a paucity of available data on the extent, trends and severity of land degradation in the drylands (UNCCD, 2009; UN-REDD, 2013).

In northern Nigeria, desertification and droughts constitute the severe ecological problem with mortifying economic effect to the nation (Medugu et al., 2011).

It is presently estimated that Nigeria is losing some 351,000 square kilometres to the desert, representing 40% of its total land mass (Ayuba, 2016); at a rapid rate of about 600m annually southward (Olagunju, 2015). The effect is tremendous to the extent that, dunes buried villages and the major access roads in the extreme northern parts of Kebbi, Sokoto, Katsina, Borno, Jigawa, and the Yobe States (Medugu et al., 2011). This has resulted in the forced migration of the affected human and livestock populations southward to pressure point buffer states of Abuja FCT, Kwara, Taraba, Plateau, Kaduna and Niger states (Ayuba, 2016). Despite the fact that desertification is crucial, its extent and severity in Nigeria have not updated since the Dregne (1983)'s world desertification map which is still being used as a reference (Medugu, 2011).

Kebbi state is threatened with desertification phenomenon; the causes include rapid population growth, deforestation, mainly for fuelwood and construction purpose, climate variability, unsustainable land use and grazing as well as extreme poverty level and natural resource dependency. The issue is associated with severe land degradation resulting linked with an alarming rate of rapid desert encroachment southward. The situation has a vast drawback related to the diminishing of ecosystem services and negative socioeconomic impact on community livelihood.

Regardless of the adverse impact posed to the environment, the extent, trends and severity of desertification in Kebbi state has neither fully recognised, nor the rate of its development was accurately documented. Subsequently, there is an urgent need for geospatial monitoring and assessment of desertification sensitivity using biophysical (soil, climatic and vegetation) and anthropogenic indicators, because it established that the unsustainable management of these indicators had done more harm to the environment in addition to climate variability in the area.

The capability of modern geospatial technologies is believed to play a critical role; and its integration with the conventional inventories using advance methodological frameworks (DPSIR and ESAI) can facilitate quantitative evaluation and provide a baseline for monitoring the extent, severity and the trend of desertification in the area.

1.3 Objective of the study

The primary objective of the research is to develop a geospatial framework for monitoring and assessing land degradation in Kebbi State, Nigeria.

The specific objectives are:

1. To quantify land cover change and vegetation depletion between 1986 to 2016.
2. To model a land cover change for the year 2026.
3. To characterise desertification sensitivity in the area.

1.4 Research justification

Desertification, deforestation, land degradation and climate change are nowadays the most common critical environmental problems globally. In particular, land degradation and desertification have vast negative consequence not only to the environment but also socio-economic as well as to the general livelihood of the society, especially in the dry land.

These problems include poverty, social conflict and forced migration, to mention but a few. Addressing these critical issues requires information on the extent and severity of land degradation process and pattern of land cover change as well as their impact on the society.

This study “development of a geospatial framework for monitoring and assessing desertification process in Kebbi State, Nigeria” is of very significant in the following context. The long-term spatial-temporal evaluation of land cover changes and vegetation depletion aspect of this study is of immense benefit as it will provide necessary information about the trends of land cover and vegetation depletion in the area for thirty years (30), from (1986-2016). The thematic land cover maps for the studied area would be available for the year 1986, 1996, 2006 and 2016 which will be very useful both by the government, non-government organisations, civil society for proper planning of sustainable management.

The study however, employ the use of socio-demographic information to examine land cover change and vegetation depletion using the components of DPSIR framework as it provides a linkage between the underlying factors acting as driving forces of the change and underpinning pressures and their impacts posed to the environment as well as the response (remediation) actions either by the government or the society through different initiatives (activities or planning) to reduce the menace to the environment. This will augment a better understanding of the land cover change trend.

The land cover prediction part of the study will provide the thematic future land cover maps (scenario) for 2026; this will give an insight on what the future probably holds about the current land resource use. This will serve as a guide to relevant authorities in economic, social as well as environmental planning.

The desertification sensitivity of the area was also assessed using soil, climate, vegetation and anthropogenic factors; this is very crucial especially now that it has become a global concern. The desertification sensitivity map of the area is made available for the year 2016; this will be very beneficial both by the government, non-government organisations as well as civil society for proper planning and sustainable environmental management.

Finally, information obtained from this study can serve as a reference point for desertification monitoring and management in the study area. These may, however, help the environmentalists, researchers or land resources managers in their various activities.

1.5 Scope and limitations

This study focused mainly on the integration of remote sensing and conventional socio-economic survey dataset using MEDALUS-ESAI and DPSIR framework for long-term monitoring and evaluation of land cover change and vegetation depletion, prediction of the future land cover and spatial assessment of desertification sensitivity in the semi-arid region (Kebbi state) Nigeria.

The long-term spatial-temporal evaluation of land cover changes and vegetation depletion encompasses the analysis of the trends of land cover and Vegetation indices of the study area for thirty years (30). From (1986-2016) with available Landsat data for the year 1986, 1996, 2006 and 2016 using ten (10) years interval (1986-1996, 1996-2006 and 2006-2016), while the land cover prediction for the year 2026 is accomplished using the CA-Markov prediction model with the same data.

The desertification sensitivity of the study area was assessed by using MEDALUS-ESAI index with soil (organic matter, texture, porosity, bulk density and slope), climate (potential evapotranspiration, temperature, aspect and aridity), vegetation (vegetation cover and stand density) and anthropogenic (population density, farming intensity, grazing density and fuelwood usage) indicators.

The research was initially planned to cover the whole Kebbi state as a study site with a land mass of about 36,000Km^2 but, later cascade down to a mere half of the site (18,000Km^2) due to time, financial and workforce constraint. Lack of or paucity of literature about the issue under investigation (Land degradation) that explicitly relate to the study site is as well also a limiting factor too.

Another critical issue is a land degradation variables selection; though many factors contribute to land degradation, only biophysical (soil, climate and vegetation) and anthropogenic factors were considered, based on their availability at the study site.

1.6 Research framework

This study conceptualised that desertification is increasing rapidly mainly due to natural and diverse anthropogenic factors (both land use factors and socioeconomic factors), and land degradation has exacerbated the issue.

Currently, there is an urgent need to monitor and assess desertification in the area critically with the geospatial tool using biophysical (soil, climatic and vegetation) and anthropogenic indicators, because it established that the unsustainable management of these indicators had done more harm to the environment. The planned conceptual framework is shown in Figure 1.

Historical satellite data were used to monitor and detect a land cover change in the area, field survey data used to identify factors of the changes and its impacts while biophysical (soil, climatic and vegetation) and anthropogenic indicators were used to assess the current extent of desertification in the area. This will be very beneficial both by the government, non-government organisations as well as civil society in proper planning for adaptation, mitigation and sustainable land restoration.

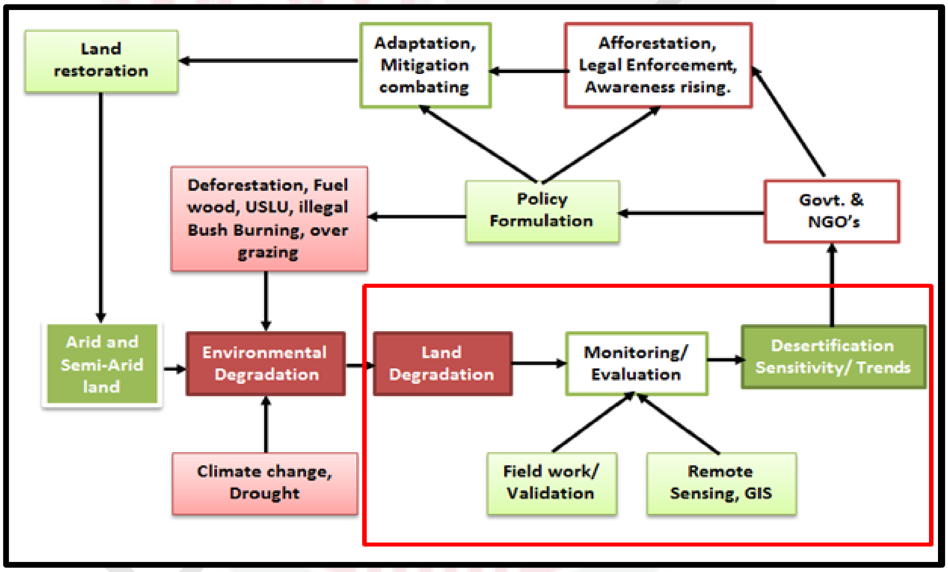

Figure 1.1: Conceptual framework of the study

REFERENCES

Abdi, O. A., Glover, E. K., & Luukkanen, O. (2013). Causes and Impacts of Land Degradation and Desertification: Case Study of the Sudan. *International Journal of Agriculture and Forestry*, *3* (2), 40–51.

Adeel, Z., Safriel, U., Niemeijer, D., & White, R. (2005). *Ecosystems and Human Well-Being: Desertification Synthesis*. (J. Sarukhán & A. Whyte, Eds.). Washington, DC.: World Resources Institute.

Aguilar, F. J., Nemmaoui, A., Aguilar, M. A., Chourak, M., Zarhloule, Y., & García Lorca, A. M. (2016). A quantitative assessment of forest cover change in the moulouya river watershed (Morocco) by the integration of a subpixel-based and object-based analysis of Landsat data. *Forests*, *7* (1), 1–19.

Al-doski, J., Mansor, S., & Shafri, H. (2013). Change Detection Process and Techniques. *Civil and Environmental Research*, *3* (10), 37–46.

Alim, M., & Mumuli, S. O. (2010). *Practical guide for Land Degradation Monitoring*. FAO-SWALIM. Project Report No. L-20. Nairobi, Kenya.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*. Rome, Italy.

Ambursa, A. S. (2015). *Assessment of the indicators of desertification process in Kwari-kwasa Forest reserve in Kebbi state semi-arid zone of Nigeria.* Department of Forestry and Environment, Usmanu Danfodiyo University, Sokoto, Nigeria. (Unpublished).

Avdan, U., & Jovanovska, G. (2016). Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. *Journal of Sensors*, *2016*.

Ayuba, N. M. G. H. K. (2016). On major environmental problems of desertification in northern Nigeria with sustainable effort to managing it. *World Journal of Science, Technology and Sustainable Development*, *13* (1).

Azpurua and Ramos, (2010). A comparison of spatial interpolation methods for estimation of average electromagnetic field magnitude. *Progress in electromagnetics research m, vol. 14, 135-145.*

Basso, F., Bove, E., Dumontet, S., Ferrara, A., Pisante, M., Quaranta, G., & Taberner, M. (2000a). Evaluating environmental sensitivity at the basin scale through the use of geographic information systems and remotely sensed data : an example covering the Agri basin, Southern Italy 1, 19–35.

Basso, F., Bove, E., Dumontet, S., Ferrara, A., Pisante, M., Quaranta, G., & Taberner, M. (2000b). Evaluating environmental sensitivity at the basin scale through the use of geographic information systems and remotely sensed data: an example covering the Agri basin (Southern Italy)1. *Catena*, *40* (1), 19–35.

Benabderrahmane, M. C., & Chenchouni, H. (2010). Assessing Environmental Sensitivity Areas to Desertification in Eastern Algeria using Mediterranean Desertification and Land Use “MEDALUS” Model. *International Journal of Sustainable Water and Environmental Systems, 1* (1), 5–10.

Bennie, J., Hill, M. O., Baxter, R., & Huntley, B. (2006). Influence of slope and aspect on long-term vegetation change in British chalk grasslands. *Journal of Ecology*, *94* (2), 355–368.

Bennie, J., Huntley, B., Wiltshire, A., Hill, M. O., & Baxter, R. (2008). Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland. *Ecological Modelling*, *216* (1), 47–59.

Bensel, T. (2009). Fuelwood, deforestation, and land degradation: 10 years of evidence from Cebu province, the Philippines. *Land Degradation and Development*, *20* (November), 587–588.

Brabant, P. (2010). *A land degradation assessment and mapping method. A standard guideline proposal.* (R. Escadafal, Ed.), *Les dossiers thématiques du CSFD* (8th ed.). Montpellier, France: CSFD/Agropolis International.

Caspari, T., van Lynden, G., & Bai, Z. (2015). *Land Degradation Neutrality: An Evaluation of Methods*. (K. Ehlers, Ed.). Dessau-Roßlau, Germany: Umweltbundesamt. Retrieved from http://www.umweltbundesamt.de/publikationen/land-degradation-neutrality.

Chaudhari, P. R., Ahire, D. V, Ahire, V. D., Chkravarty, M., & Maity, S. (2013). Soil Bulk Density as related to Soil Texture, Organic Matter Content and available total Nutrients of Coimbatore Soil. *International Journal of Scientific and Research Publications, 3* (1), 2250–3153.

Chaves, A. (2008). Remote Sensing and GIS-Based Integrated Study and Analysis for Mangrove-Wetland Restoration in Ennore Creek, Chennai, South India. In *Proceeding of Taal2007: The 12th World lake Conference: 685-690* (pp. 685–690). Retrieved from http://moef.nic.in/modules/recent-initiatives/nlcp/D - Remote Security GIS Application/D-9.pdf.

Contador, L. J. F., Schnabel, S., Gutiérrez, G. A., & Fernández, M. P. (2009). Mapping sensitivity to land degradation in Extremadura. SN Spain. *Land Degradation and Development*, *20*, 129–144.

Coppin, Pol R. and Bauer, Marvin E. (1996), Digital change detection in forest ecosystems with remote sensing imagery, *Remote Sensing Reviews*, 13(3) 207-234.

Crosetto, M., Tarantola, S., & Saltelli, A. (2000). Sensitivity and uncertainty analysis in spatial modelling based on GIS. *Agriculture, Ecosystems & Environment*, *81* (1), 71–79.

Crowther, T. W., Glick, H. B., Covey, K. R., Bettigole, C., Maynard, D. S., Thomas, S. M., … Bradford, M. A. (2015). Mapping tree density at a global scale. *Nature*, *525* (7568), 201–205.

D’Odorico, P., Bhattachan, A., Davis, K. F., Ravi, S., & Runyan, C. W. (2013). Global desertification: Drivers and feedbacks. *Advances in Water Resources*, *51*, 326–344.

de Jong, R. (2012). *Analysis of vegetation-activity trends in a global land degradation framework*. Wageningen University, Netherlands.

DESIRE. (2008). *Manual for describing land degradation indicators*. Agricultural University of Athens. Retrieved from http://www.desire-his.eu.

Edith, S., & Weterings, R. (1999). *Environmental indicators : Typology and overview. European Environment Agency* (Vol. 25).

Elisabeta Oprisan. (2011). *Desertification: a visual synthesis*. (Y. Hori, C. Stuhlberger, & O. Simonett, Eds.). Bresson, France: Swiss Agency for Development and Cooporation.

Feizizadeh, B., Jankowski, P., & Blaschke, T. (2014). A GIS-based spatially-explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. *Computers and Geosciences, 64*, 81–95.

FGN. (2005). *Federal Ministry of Environment of Nigeria: National Action Programme To Combat Desertification*. Abuja, Nigeria. Retrieved from http://www.unccd.int/ActionProgrammes/nigeria-eng2001.pdf.

FGN. (2012). Great Green Wall for the Sahara and Sahel Initiative: National Strategic Action Plan.

FGN. (2015). *Federal Government of Nigeria: National Human Development Report: Human Security and Human Development in Nigeria*. Abuja, Nigeria.

FGN. (2016). *Federal Republic of Nigeria: IFAD Country Programme Evaluation*. Abuja, Nigeria. Retrieved from https://www.ifad.org/documents/10180.

Fisher-Giorlando, M. (1992). Sampling in a Suitcase : Multistage Cluster Made Easy Sampling. *Teaching Sociology*, *20* (4), 285–287.

Fu, P., & Weng, Q. (2016). A time series analysis of urbanization induced land use and land cover change and its impact on land surface temperature with Landsat imagery. *Remote Sensing of Environment, 175* (January), 205–214.

Gari, S. R., Newton, A., & Icely, J. D. (2015). A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. *Ocean and Coastal Management*, *103,* 63–77.

Garnero and Godone, (2013). Comparisons between different interpolation techniques. The international archives of the photogrammetry, remote sensing and spatial information sciences, volume xl-5/w3, the role of Geomatics in hydrogeological risk, 27 – 28 February 2013, Padua, Italy.

Haase, D., & Nuissl, H. (2007). Does urban sprawl drive changes in the water balance and policy?. The case of Leipzig (Germany) 1870-2003. *Landscape and Urban Planning*, *80* (1–2), 1–13.

Hadeel, A. S., Jabbar, M. T., & Chen, X. (2009). Application of remote sensing and GIS to the study of land use/cover change and urbanization expansion in Basrah province, Southern Iraq. *Geo-Spatial Information Science*, *12* (2), 135–141.

Hadeel, A. S., Jabbar, M. T., & Chen, X. (2011). Remote sensing and GIS application in the detection of environmental degradation indicators. *Geo-Spatial Information Science*, *14* (1), 39–47.

Hamby, D. M. (1994). A review of techniques for parameter sensitivity analysis of environmental models. *Environmental Monitoring and Assessment*, *3* (2), 135–154.

Hargreaves, G. H., & Allen, R. G. (2003). History and evaluation of Hargreaves evapotranspiration equation. *Journal of Irrigation and Drainage Engineering-Asce*, *129* (1), 53–63.

Hasmadi, M. (2010). Determining and Mapping of Vegetation using GIS and Phytosociological Approach in Mount Tahan, Malaysia. *Journal of Agricultural Science*, *2* (2), 80–89.

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*, *10*, 4–10.

Hessel, R., Reed, M. S., Geeson, N., Ritsema, C. J., van Lynden, G., Karavitis, C. A., Witsenburg, K. (2014). From Framework to Action: The DESIRE Approach to Combat Desertification. *Environmental Management*, *54* (5), 935–950.

Hills, R. G. (2006). Model Validation: Model Parameter and Measurement Uncertainty. *Journal of Heat Transfer*, *128* (4), 339.

Hostert, P., Roder, A., Jarmer, T., Udelhoven, T., & Hill, J. (2001). The potential of remote sensing and GIS for desertification monitoring and assessment. *Annals of Arid Zone*, *40* (2), 103–140.

Idris Medugu, N., Rafee Majid, M., & Johar, F. (2011). Drought and desertification management in arid and semi-arid zones of Northern Nigeria. *Management of Environmental Quality: An International Journal*, *22* (5), 595–611.

Idris Medugu, N., Rafee Majid, M., Johar, F., & Choji, I. D. (2010). The role of afforestation programme in combating desertification in Nigeria. *International Journal of Climate Change Strategies and Management*, *2* (1), 35–47.

Illo, A. I., Ango, A. K., Usman, H., & Aminu, Z. (2015). Role of International Fund for Agricultural Development-Community Based Agricultural and Rural Development Programme (IFAD-CBARDP) in Improving the Livelihood of Rural Women: A Case Study of Aliero Local Government Area, Kebbi State, Nigeria. *Nigerian Journal of Basic and Applied Science*, *23* (1), 23–30.

Izzo, M., Araujo, N., Aucelli, P. P. C. C., Maratea, A., & Sánchez, A. (2013). Land sensitivity to desertification in the Dominican Republic: An adaptation of the ESA methodology. *Land Degradation and Development*, *24* (5), 486–498.

John R. Jensen. (2005). *Introduction to Digital Image Processing, A Remote Sensing Perspective*. (Third edit.). Upper Saddle River, NY.: Pearson Prentice Hall.

Kairis, O., Kosmas, C., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., … Ziogas, A. (2013). Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Types of Degradation, Causes, and Implications for Management. *Environmental Management*, *54* (5), 971–982.

Kamal, M. I., & Sulaiman, I. M. (2015). A review of Afforestation Efforts in Nigeria. *International Journal of Advanced Research*, *4* (12).

Kapalanga, T. S. (2008). *A Review of Land Degradation Assessment Methods*. Land Restoration Training Programme. Agricultural University of Iceland.

Kayte, J., Kayte, S., Bhable, S., Maher, R., & Deshmukh, R. R. (2015). Modification and Climate Change Analysis of surrounding Environment using Remote Sensing and Geographical Information System. *IOSR Journal of Computer Engineering Ver. I*, *17* (6), 2278–661.

Khaine, I., & Woo, S. Y. (2014). An overview of interrelationship between climate change and forests. *Forest Science and Technology*, *11* (1), 11–18.

Kosmas, C., Kairis, O., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., … Ziogas, A. (2013). Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Methodological Approach. *Environmental Management*, *54* (5), 951–970.

Kosmas, C., Kirkby, M., & Geeson, N. (1999). *Medalus Project: Mediterranean Desertification and Land Use. Manual on Key Indicators of Desertification and Mapping Environmentally Sensitive Areas*. Luxembourg. Retrieved from http://www.medalus.demon.co.uk/.

Kravchenko A. and Bullock D.G., (1999) A comparative study of interpolation methods for mapping soil properties. Agronomy Journal 91: 393,400.

Krejcie, R. V, & Morgan, D. W. (1970). Determining Sample Size for Research Activities. *Educational and Psychological Measurement*, *30* (1), 607–610.

Kumar, P., Rani, M., Pandey, P. C., Majumdar, A., & Nathawat, M. S. (2010). Monitoring of deforestation and forest degradation using remote sensing and GIS: A case study of Ranchi in Jharkhand (India). *Report and Opinion*, *2* (4), 55–67.

Kundu, A., Patel, N. R., Saha, S. K., & Dutta, D. (2015). Monitoring the extent of desertification processes in western Rajasthan (India) using geo-information science. *Arabian Journal of Geosciences*, *8* (8), 5727–5737.

Kunle, K., & Abubakar, N. M. (2017). Assessment of the ifad-cbardp activities towards poverty alleviation in Kebbi state, Nigeria. *International Journal of Advanced Research in Public Policy, Social Development and Enterprise Studies*, *2* (1), 47–58.

Ladisa, G., Todorovic, M., & Trisorio Liuzzi, G. (2012). A GIS-based approach for desertification risk assessment in Apulia region, SE Italy. *Physics and Chemistry of the Earth*, *49*, 103–113.

Lambin, E. F. (1997). Modelling and monitoring land-cover change processes in tropical regions. *Progress in Physical Geography*, *21,3*, 375–393.

Li, J., & Heap, A. D. (2011). A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. *Ecological Informatics*, *6* (3–4), 228–241.

Lu, D., Mausel, P., Batistella, M., & Moran, E. (2005). Land-cover binary change detection methods for use in the moist tropical region of the Amazon: a comparative study. *International Journal of Remote Sensing*, *26* (1), 101–114.

Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing*, *25* (12), 2365–2407.

Lunetta, R. S., Knight, J. F., Ediriwickrema, J., Lyon, J. G., & Worthy, L. D. (2006). Land-cover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment*, *105* (2), 142–154.

Matyssek, R., Wieser, G., Calfapietra, C., De Vries, W., Dizengremel, P., Ernst, D., … Paoletti, E. (2012). Forests under climate change and air pollution: Gaps in understanding and future directions for research. *Environmental Pollution*, *160* (1), 57–65.

Mensah, F., Adanu, S. K., & Adanu, D. K. (2015). Remote Sensing and GIS Based Assessment of Land Degradation and Implications for Ghana's Ecological Zones. *Environmental Practice*, *17*, 3–15.

Mohamed, E. S. (2013). Spatial assessment of desertification in north Sinai using modified MEDALUS model. *Arabian Journal of Geosciences*, *6* (12), 4647–4659.

Mortimore, M., & Turner, B. (2005). Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification? *Journal of Arid Environments*, *63* (3), 567–595.

N. M. G. H. K. Ayuba. (2016). On major environmental problem of desertification in northern Nigeria with sustainable efforts to managing it. *World Journal of Science, Technology and Sustainable Development*, *1 3*(1).

NBS. (2012). *Federal Republic of Nigeria: Annual Abstract of Statistics*. *Annual Abstract of Statistics*, Abuja, Nigeria. Retrieved from www.nigerianstat.gov.ng.

Nkonya, E., Gerber, N., Baumgartner, P., Braun, J. Von, Pinto, A. De, Graw, V., … Walter, T. (2011). *The Economics of Desertification, Land Degradation, and Drought Toward an Integrated Global Assessment*. *SSRN eLibrary* (Vol. 37). Bonn, Germany: Zentrum für Entwicklungsforschung (ZEF) Center for Development Research.

Nwokocha, C. (2015). Effect of Desertification on Environmental. *Arabian Journal of Business and Management Review (Nigerian Chapter)*, *3* (6), 7–13.

OECD. (1993). *OECD core set of indicators for environmental performance reviews: A synthesis report by the group on the state of the environment*. *Organisation for Economic Co-operation and Development* (Vol. 83). Paris. Retrieved from http://enrin.grida.no/htmls/armenia/soe2000/eng/oecdind.pdf.

Ogungbenro, S. B., & Morakinyo, T. E. (2014). Rainfall distribution and change detection across climatic zones in Nigeria. *Weather and Climate Extremes*, *5* (1), 1–6.

Oladipo, E. O. (1993). A comprehensive approach to drought and desertification in northern Nigeria. *Natural Hazards*, *8* (3), 235–261.

Olagunju, T. E. (2015). Drought, Desertification and the Nigerian Environment: A review. *Journal of Ecology and the Natural Environment*, *7* (10), 256–262.

Palmer, B. J., Hill, T. R., McGregor, G. K., & Paterson, A. W. (2011). An assessment of coastal development and land use change using the DPSIR framework: Case studies from the eastern cape, South Africa. *Coastal Management*, *39* (2), 158–174.

Parker, D. C., Manson, S. M., Janssen, M., Hoffmann, M. J., & Deadman, P. J. (2003). Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers*, *93* (2), 314–337.

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K.-N., & Smith, C. J. (2016). DPSIR—Two Decades of Trying to Develop a Unifying Framework for Marine Environmental Management? *Frontiers in Marine Science*, *3* (September), 1–14.

Pianosi, F., Beven, K., Freer, J., Hall, J. W., Rougier, J., Stephenson, D. B., & Wagener, T. (2016). Sensitivity analysis of environmental models: A systematic review with practical workflow. *Environmental Modelling and Software*, *79*, 214–232.

Pimentel, D. (2006). Soil erosion: A food and environmental threat. *Environment, Development and Sustainability*, *8* (1), 119–137.

Pullanikkatil, D., Palamuleni, L., & Ruhiiga, T. (2016). Assessment of land use change in Likangala River catchment, Malawi: A remote sensing and DPSIR approach. *Applied Geography*, *71* (6), 9–23.

Rahman, S., Faisal, B., Rahman, M., & Taher, T. (2016). Analysis of VIA and EbA in a River Bank Erosion Prone Area of Bangladesh Applying DPSIR Framework. *Climate*, *4* (4), 52.

Raul, P.-H., & Koohafkan, P. (2004). *Methodological Framework for Land Degradation Assessment in Drylands. Food and Agriculture Organization of the United Nations, Land and Water Development Division*. Rome, Italy.

Romijn, E., Lantican, C.B, Herold, M., Lindquist, E., Ochieng, R., Wijaya, A., Murdiyarso, D., Verchot, L. (2015). Assessing change in national forest monitoring capacities of 99 tropical countries. *Forest Ecology and Management, In press*, 109–123.

Ross S. Lunetta, Joseph F. Knight, Jayantha Ediriwickrema, John G. Lyon, L. Dorsey Worthy (2006), Land-cover change detection using multi-temporal MODIS NDVI data, *Remote Sensing of Environment*, 105 (2006) 142-154.

Roxo, M. J., Casimiro, P. C., & Sousa, T. M. (2007). *What is desertification?* Retrieved fromhttp://www.kcl.ac.uk/kis/schools/hums/geog/desertlinks/index.htm

Safriel, U. (2009). Deserts and desertification: challenges but also opportunities. *Land Degradation and Development*, *20*, 587–588.

Salvati, L., Ferrara, C., & Corona, P. (2015). Indirect validation of the Environmental Sensitive Area Index using soil degradation indicators: A country-scale approach. *Ecological Indicators*, *57*, 360–365.

Sameen, M. I., Ahmed, M., & Kubaisy, A. (2014). Automatic Surface Temperature Mapping in ArcGIS using Landsat-8 TIRS and ENVI Tools Case Study : Al Habbaniyah Lake. *Journal of Environment and Earth Science*, *4* (12), 12–18.

Sang, L., Zhang, C., Yang, J., Zhu, D., & Yun, W. (2011). Simulation of land use spatial pattern of towns and villages based on CA-Markov model. *Mathematical and Computer Modelling*, *54* (3–4), 938–943.

Santini, M. (2005). *A new GIS-based spatial modelling approach for desertification risk assessment in the Mediterranean area. An Italian case study: Sardinia Island*. Univerita Tuscia. Retrieved from http://dspace.unitus.it/bitstream /2067/2043/1/msantini_tesid.pdf.

Sarmin, N. S., Mohd Hasmadi, I., Pakhriazad, H. Z., & Khairil, W. A. (2016). The DPSIR framework for causes analysis of mangrove deforestation in Johor, Malaysia. *Environmental Nanotechnology, Monitoring and Management*, *6* (3), 214–218.

Sedgwick, P. (2015). Multistage sampling. *BMJ (Online)*, *351*, 1–2.

Shuaibu, R. B. (2015). Women's involvement in forestry practices as livelihood options in igalamela /odolu local government area, Kogi state, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, *1*(1), 13–22.

Singh, A. (1989). Review Article Digital change detection techniques using remotely-sensed data. *International Journal of Remote Sensing*, *10* (6), 989–1003.

Sivakumar, M., & Stefanski, R. (2007). *Climate and Land Degradation. Environmental Science and Engineering Subseries*. New York: Springer BerlinHeidelberg.

Sivakumar, M. V. K. (2007). Interactions between climate and desertification. *Agricultural and Forest Meteorology*, *142* (2–4), 143–155.

Sutherland, R. A. (1998). Loss-on-ignition estimates of organic matter and relationships to organic carbon in fluvial bed sediments. *Hydrobiologia*, *389*, 153–167.

Symeonakis, E., Karathanasis, N., Koukoulas, S., & Panagopoulos, G. (2016). Monitoring Sensitivity to Land Degradation and Desertification with the Environmentally Sensitive Area Index: The Case of Lesvos Island. *Land Degradation and Development*, *27* (6), 1562–1573.

Taghipour-javi, S., Fazeli, A., & Kazemi, B. (2016). A case study of desertification hazard mapping using the MEDALUS (ESAs) methodology in southwest Iran. *Journal of Natural Resources and Development*, *6*, 1–8.

Thelma, M. N. (2015). Desertification in northern Nigeria : Causes and implications for national food security. *Peak Journal of Social Science and Humanities*, *3* (2), 22–31.

Thomas, P. H., & Elias, S. (2014). Assessing land degradation and desertification using vegetation index data: Current frameworks and future directions. *Remote Sensing*, *6* (10), 9552–9575.

Trabucco, A., & Zomer, R. (2009). Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Databas. CGIAR Consortium for Spatial Information. Retrieved from http://www.csi.cgiar.org.

UN-REDD Programme. (2013). *National Forest Monitoring Systems: Monitoring and Measurement, Reporting and Verification (M & MRV) in the context of REDD+ Activities*. Geneva, Switzerland: FAO. Retrieved from www.fao.org/ publications.

UNCCD. (2007). Climate change and desertification: Thematic fact sheet series. Bonn, Germany.

UNCCD. (2009). *Climate change in the African drylands: Options and opportunities for adaptation and mitigation*. Nairobi, Kenya. Retrieved from www.undp.org/drylands.

UNCCD. (2010). *Comprehensive Communication Strategy*. *Drylands: Global Assests*. Bonn, Germany. Retrieved from http://www.unccd.int/Lists/SiteDocumentLibrary /convention/css.pdf.

UNCCD. (2014). *Desertification: The Invisible Frontline*. *United Nations Convention to Combat Desertification* (Second Edi). Bonn, Germany. Retrieved from www.unccd.int.

UNDP. (2016). *Human Development Report 2016: Human Development Report 2016 Human Development for Everyone Briefing note for countries on the 2016 Human Development Repor, Nigeria*. Retrieved from http://hdr.undp.org/en/2016-report.

UNEP. (2007). *Fourth Global Environment Outlook: Environment for development*. *United Nations Environment Programme (UNEP).* Nairobi, Kenya.

Usman S, Sani Noma S, K. A. (2016). Dynamic surface soil components of land and vegetation types in Kebbi State Nigeria. *Eurasian Journal of Soil Science*, *5* (2), 113–120.

Vani, K., Ramalingam, M., Ramakrishnan, S. S., Ramalakshmi, M. P. M., & Muneeswaran, M. (2015). Assessment of Environmentally Sensitive Area and Desertification Severity using GIS for an Indian Region - Virudhunagar District, Tamil Nadu. *Indian Journal of Geo-Marine Sciences*, *44* (November), 1734–1741.

Virginia H. Dale, Linda a. Joyce, Steve Mcnulty, Ronald P. Neilson, Matthew P. Ayres, Michael D. Flannigan, Paul J. Hanson, Lloyd C. Irland, Ariel E. Lugo, Chris J. Peterson, Daniel Simberloff, Frederick J. Swanson, Brian J. Stocks, and B. M. W. (2001). Predicting species invasions using ecological niche modelling: new approaches from bioinformatics attack a pressing problem. *BioScience*, *51* (5), 363–371.

Vogt, J. V., Safriel, U., Maltitz, G. Von, Sokona, Y., Zougmore, R., Bastin, G., & Hill, J. (2011). Monitoring and assessment of land degradation and desertification : Towards new conceptual and integrated approaches. *Land Degradation & Development*, *22*, 150–165.

Vorovencii, I. (2015). Assessing and monitoring the risk of desertification in Dobrogea, Romania, using Landsat data and decision tree classifier. *Environmental Monitoring and Assessment*, *187* (4), 204.

Wrigh, A. L., Wang, Y., & Reddy, K. R. (2008). Loss-on-Ignition Method to Assess Soil Organic Carbon in Calcareous Loss-on-Ignition Method to Assess Soil Organic Carbon in Calcareous Everglades Wetlands. *Communications in Soil Science and Plant Analysis*, *39* (19–20), 3074–3083.

Xu, D., Kang, X., Qiu, D., Zhuang, D., & Pan, J. (2009). Quantitative assessment of desertification using Landsat data on a regional scale - a case study in the Ordos Plateau, China. *Sensors*, *9* (3), 1738–1753.

Yao X, Fu B, Lu Y, Sun F, Wang S, et al. (2013) Comparison of Four Spatial Interpolation Methods for Estimating Soil Moisture in a Complex Terrain Catchment. PLoS ONE 8(1): e54660.

Zhou, Q., Li, B., & Chen, Y. (2011). Remote sensing change detection and process analysis of long-term land use change and human impacts. *Ambio*, *40*(7), 807–818.