AFRICAN CLIMATE CHANGE FELLOWSHIP PROGRAM (ACCFP)

Patterns of Terrestrial Ecological Imprints and Feedbacks and their Implications on Climate Change Adaptation in the Wooded Savannah of Nigeria

FINAL TECHNICAL REPORT

Submitted by:

MAYOWA JOHNSON FASONA
Department of Geography, University of Lagos
Akoka-Yaba, Lagos, Nigeria

September 2010

ACCFP Fellow – Final Technical Report

1. Personal Information:

1.1. Fellow's Full Name: FASONA, MAYOWA JOHNSON

1.2. Fellowship Type: Postdoctoral

1.3 **Fellowship Project Title**: *Patterns of Terrestrial Ecological Imprints and Feedbacks and their Implications on Climate Change Adaptation in the Wooded Savannah of Nigeria*

1.4 Host Institution: CSAG, UCT, Cape Town, South Africa

1.5 Home Institution: University of Lagos, Akoka-Yaba, Lagos, Nigeria

1.6 Host Institution Supervisors: Prof Bruce Hewitson & Dr Mark Tadross

1.7 Home Institution Supervisor: Dr Ademola Omojola

1.8 Fellowship period: 12 August 2009 to 15 August 2010

1.9 Report Date: 30 September 2010

ABSTRACT

Background

Significant climate change expected over the 21st century will affect ecosystems, natural resource systems and rural livelihoods especially in dry and semi-dry environments where large population depends on natural resource stock. Restored and well managed, but climate-sensitive natural resource systems can become human shock absorbers, targets for climate change mitigation, and fulcrum for adaptation strategies. Climate and landcover interaction is a two way feedback. Understanding the implication of this feedback for climate change adaptation requires detailed and local knowledge. A degree of localised eco-geographical factors create eco-climatic complex which often vary by season and area and controls the local climate in the wooded savannah of Nigeria. This study demonstrates that integrated remote sensing and GIS models have the potential to compliment regional climate models to analyze climate-landcover relations and feedback at high spatial resolution.

Methodology

The eco-geographic variables were integrated within a GIS and statistically analysed using principal component analysis (PCA). The result was profiled for association and feedbacks between climate and the variables and to also determine the principal controlling factors of the local climate in both present and future scenario. Classified landcover image maps derived from Landsat data for 1986, 2000 and 2006 formed the base landcover data. Change drivers developed by integration of Markov probabilities matrix, transition areas and conditional probability for landcover classes with suitability maps for landcover categories computed from rainfall, maximum temperature and local eco-geographic factors were also used to simulate future landcover from 2006 to 2046 under present and future climate scenarios using Idrisi's dynamic CA_Markov model.

Results

The results suggest a local climate system driven mainly by the coupling between terrain (with associated vegetal cover), rainfall and temperature in all seasons. Under present climate, this eco-climatic complex predominates around the southeast-northwest corridor in all seasons except June-July-August (JJA). The system spatially reverses to the southeast-northeast corridor in JJA, which also coincides with the period of the West African monsoon. The southeast-northeast corridor especially across the Niger receives maximum rainfall. This pattern is projected to continue in future scenario. However, the spatial influence of the climate-orographic complex will diminish around the northwest, while the system will weaken with rainfall becoming less significant in the system in JJA. The pattern of rural settlements and rural landuse suggests that livelihood systems of the local population are directly connected to this local eco-climatic complex. This complex is also the single source of all major drainage of the entire western Nigeria. Recovery from the droughts of the 1970s and 1980s was suggested by increased canopy ecosystems and significant decrease in shrub/grassland, bare surface and fire scar. Under present climate scenario urban lands is projected to progressively increase by about 270% from 577km^2 in 2006 to 2136km^2 representing 5.4% of total landcover in 2046. A corresponding increase in area under cultivation is also projected with a peak of about 12% of total landcover in 2016 (from 8% in 2006) and stabilizes around 10% from 2026 to 2046. The largest growth of settlements and cultivated lands is projected for the areas around the northwest-southeast corridor especially the headwaters of Ogun river (*Oke-ogun*) areas. Although total forest area is expected to decline by about 378km^2 between 2006 and 2046, its overall coverage as percent of total landcover is projected to increase to 18% in 2016 and stabilizes around 15% from 2025 to 2046. The strongest transition gain of 110% over 2006 coverage is expected from shrub and grassland. Projection based on future climate suggests significant decline in the coverage of the two canopy ecosystems – forest and woodland- from 2016 to 2046. Galleria forest - a signature of the upper Guinea and Sudan savannah - is projected to dominate presently forested landscapes. Shrub and grassland will be much more widespread. A shift in rural settlement and agrarian landuse is also expected with more settlements and cultivated lands emerging around the middle areas especially at fringe of the protected area. Aggressive vegetation and albedo enhancement and ecotourism are tipped as viable climate change mitigation options. Adaptation strategies will benefit from existing project platforms that address local natural resource systems, rural livelihoods, resource conflicts, and community driven development.

The work is summarised in two yet to be published papers:

Paper I: *Principal components of local forcing of mesoscale climate in the wooded savannah of Nigeria*

Paper II: *Terrestrial ecology response to climate change and implications for adaptation in the wooded Savannah of Nigeria*

Paper I: Principal components of local forcing of mesoscale climate in the wooded savannah of Nigeria

Mayowa Fasona[1], Mark Tadross[2], Babatunde Abiodun[2] and Ademola Omojola[1]

[1]Department of Geography, University of Lagos, Akoka-Yaba 101017, Lagos, Nigeria

[2]Climate Systems Analysis Group, Environmental and Geographical Science Department, University of Cape Town, South Africa

Abstract

Significant climate change expected over the 21st century will affect ecosystems and access to natural resources especially arable lands and water in arid and semi-arid environments. Restored and well managed, but climate-sensitive natural resource systems can become human shock absorbers, targets for climate change mitigation, and fulcrum for adaptation strategies. This study demonstrates how a degree of localised eco-geographical factors, some of which vary by season and areas, control the local climate in the semi-dry wooded savannah of Nigeria.

The eco-geographic variables were integrated within a GIS and statistically analysed using principal component analysis (PCA). The result was profiled for association and feedbacks between climate and the eco-geographic variables and to also determine the principal controlling factors of the local climate in both present and future scenario. The results suggest a local climate system driven mainly by the coupling between terrain, rainfall and temperature in all seasons. This climate-orographic complex predominates around the southeastt-northwest corridor in all seasons except June-July-August (JJA). The system spatially reverses to the southeast-northeast corridor in JJA, which also coincides with the arrival of the West African monsoon. The southeast-northeast corridor thus receives maximum rainfall. This pattern is projected to continue in future scenario. However, the spatial influence of the climate-orographic complex will diminish around the northwest, while the system will weaken with rainfall becoming less significant in the system in JJA. The pattern of rural settlements and rural landuse suggests that livelihood systems of the local populations are directly connected to the local climate-orographic complex. This eco-climatic asset is also the single source of all major drainage of the entire western Nigeria.

Key words: climate change, eco-geographic factors, PCA, eco-climatic asset, adaptation, Savannah

1 Introduction

Climate change is expected to have significant impact on the environment and ecosystems and natural resource-dependent and low adaptive capacity sub-Saharan African countries will be most severely affected (Muller, 2009). The arid and semi-arid environments of West Africa will be especially affected because they are projected to get drier in future scenario. They also harbour large population which accelerates land transformation and makes resource competition and conflict fiercer. Rapid transition from one land-cover to another may enable the continued provision of some ecosystem services including provision of food and fibre, but it can significantly compromise other services including climate regulation, soil fertility and watershed protection (Kuemmerle *et al*. 2009). Change in land that leads to reduction or loss of surface vegetative cover can impact water supply by altering hydrological processes (Neely *et al*. 2009, Lin *et al*. 2007, Hoffmann & Jones 2000, Stohlgren *et al.* 1998) which increases the severity and extent of degradation and further reduces land resilience to drought and adverse conditions.

Forests are a significant terrestrial sink of global carbon (Pielke Sr. *et al*. 2007). Terrestrial ecosystems drive most of year-to-year variations in atmospheric CO_2 (Cao, et al. 2002) and as much as 35% of the human-induced CO_2 equivalents in the atmosphere today can be traced to the totality of land-use and cover changes (Turner II *et al*. 2007). In addition to their mitigation potential vegetative cover plays a significant role in human and environmental health.

The historical interaction between climate and ecosystems needs to be further understood in the context of today's need for climate mitigation and adaptation measures. Ecosystems influence climate through multiple pathways, primarily by changing the energy, water, and greenhouse-gas balance of the atmosphere (Chapin *et al*. 2008). In dry and semi-dry environments where agriculture is predominantly rainfed, a decline in precipitation occasioned by a change in land-use and land-cover (LULC) may also have considerable ecological and economic consequences (Hoffmann & Jones 2000, Omotosho & Abiodun, 2007). Sub-Saharan Africa (SSA) has been projected to get drier in future scenario. Current temperatures are predicted to increase in the order of 1.4 to 5.8°C by 2100 (Solomon *et al*. 2007) depending on the emission scenario. Rainfall is also projected to become more erratic in space and time distribution as already noted in sub-Saharan West Africa (SSWA) (Abiodun *et al*. 2008, Afiesimama *et al.* 2006, Nicholson 2000), and on average only 3.7 % of the total agricultural land is irrigated in the entire SSA (Muller 2009). The water footprint is definitely going to be important in defining future trajectory of agricultural lands, and the challenge will overwhelm the current traditional agriculture and water management practices.

While it is true that the synoptic-scale forcing will have some influence on local climate, there is also a degree of local forcing that will vary by region and by season (Hewitson & Crane 2006). Topography, land-water boundary and LULC are examples of local forcing with strong influence on local climate and the degree to some of these can feedback to impact local climate represents an element of uncertainty in the climate projections just as green-house gasses emission (Hewitson & Crane 2006). Global and regional climate models provide good insights into climate-terrestrial feedbacks at global and regional scale and the dynamic interaction between land surface and atmospheric processes which drive global and regional climates. However, the responses are of limited duration and their relatively coarse (geographically speaking) parameterisations often mask large differentials especially in local forcings including terrain, landcover, agricultural practices, energy policies and socio-economic orientations (UNFCCC, 2007). Hence details about local scale circulation features induced by landscape heterogeneity (Pielke Sr et al. 2007, Stohlgren et al. 1998) and local processes which are important for location-specific, place based decisions support for ecosystems management and climate change adaptation are effectively eliminated. Many impact applications require the equivalent of point climate observation and are highly sensitive to fine scale climate variations that are parameterised in coarse scale models. This is especially true for regions of complex topography, coastal or island locations, and regions of highly heterogeneous land-cover (Wilby, et al. 2004). Many areas in Africa are recognized as having climates that are among the most variable in the world on seasonal and decadal time scales (UNFCCC, 2007). Understanding the role of such local-scale forcings is important for the West African savannah with large footprint of small-holder rainfed agriculture, where the mesoscale processes produce over 75% of rainfall (Omotosho and Abiodun, 2007) and the knowledge on climate change in government polices and among the teeming population is still limited.

In this study we present evidence that remote sensing and geographic information systems with capability to generate and integrate data across multiple geographic scales have the potential to compliment climate models at local scale by providing an understanding of the potentials of eco-geographic forcings to influence the local climate.

2 Material and Methods

2.1 Regional setting

The case study area is roughly defined by Lat. 8^0 to $9^0 15^1$ and Lon. $3^0 50^1$ to $5^0 50^1$ covering about 40,000km^2 in west-central Nigeria including part of the States of Kwara, Niger, Oyo, Osun, Ekiti and Kogi and extends to the boundary with Benin Republic in the west (Fig 1). It falls within the wooded Savannah, which approximates the transitional zone between the southern rainforest and the tropical guinea savannah with a vegetation type that composed of a mixture of trees and grasses (Hoffmann & Jackson 2000). The wooded savannah also typifies the area referred to as derived savannah (Adejuwon 2006) and part of the southern guinea, a zone of moist peri-forest mixed with a savannah of anthropic degradation and patchy landscape (Bucini & Lambin 2002, Hoffmann & Jackson 2000*)*. The area is covered mainly by undifferentiated basement complex, recent alluvium along the floodplain and Nupe sandstone formations to the north-eastern axis. Soils consist of deep well drained sandy loam soils and poorly drained sandy clay loam subsoil along the Niger floodplain.

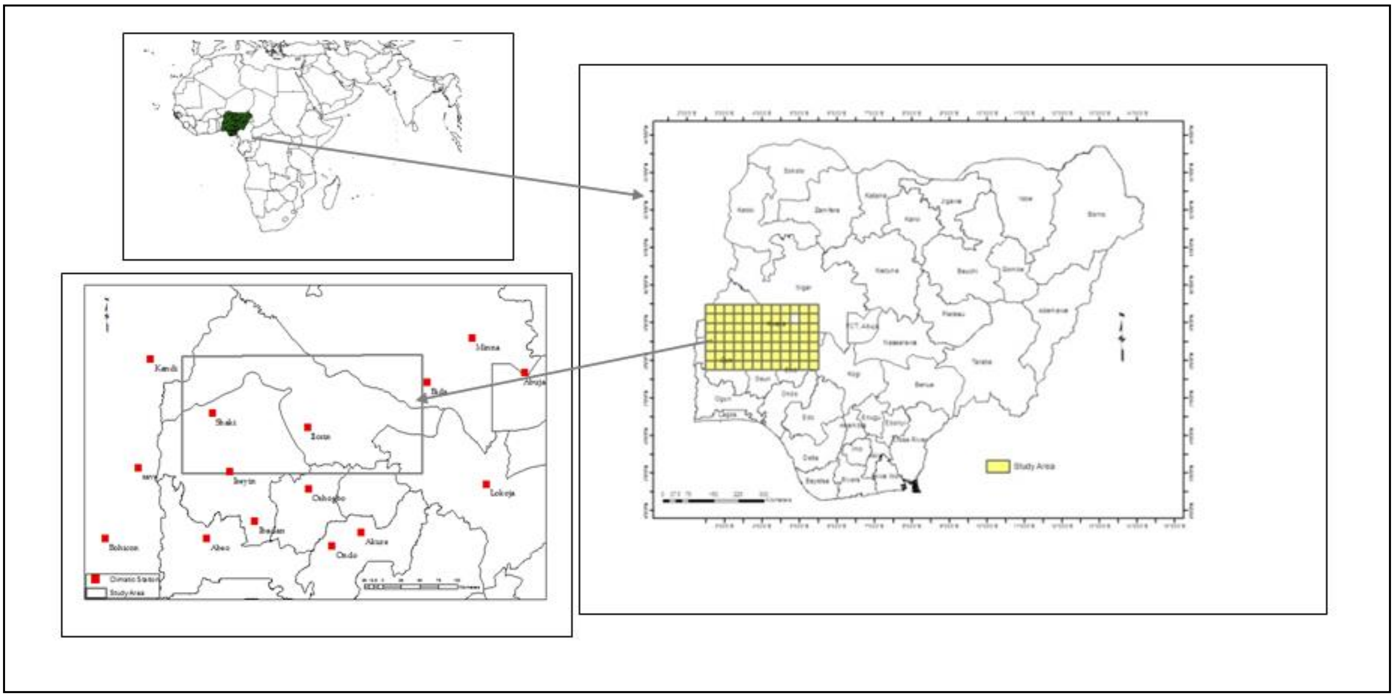

Fig 1: Study area and observation stations

It is characterized by *a* sub-humid Koppen's *Aw* (Kottek *et al*. 2006) climate with annual rainfall between 900mm and 1300mm. It shares the double maximum rainfall pattern (with peaks in June/July and September) with the southern rainforest but with highest monthly rainfall of about 220mm occurring in September. Maximum temperature range is between 28 and 36^{0}c with February/March being the hottest months. Rainfall is perhaps the most important climatic characteristic which determines the rhythm of human activity in the Nigerian Savannah. Change in rainfall quantity and regime is a strong index of climatic variability and a critical limiting factor to human survival. The onset and cessation of the rains are controlled by what Nicholson

(2009) has now described as the rain-belt movement produced by a large core of ascent lying between the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ). This rainbelt movement also corresponds to the southern track of African Easterly Waves (AEW) that distributes the rainfall. The mesoscale processes still predominate and providing over 75% of rainfall in the region (Omotosho & Abiodun 2007) with the sea surface temperature and land-sea thermal contrast responsible for inter-annual variability in rainfall onset and retreat dates (Odekunle *et al*. 2005).

The Nigerian Savannah is a densely populated area with strong poverty-environment linkages. With an average population density of about 160 (which is by far higher in urban areas), survival for large rural population depends on small-holder rain-fed agriculture (Afiesimama *et al*. 2006, Fasona et al. 2007, Odekunle *et al*. 2005), the natural capital thus contributes significantly to human well-being and the wealth of nation (UNDP-UNEP 2009). The wooded savannah in particular is becoming a zone of intense land-use pressure. Humans have increased the frequency of fire and burning now typically occurs at intervals especially at dry periods. Forest land conversion to agriculture and pasture and incursions into marginal lands is rapid and harvesting of trees for fuel wood and charcoal is an important livelihood activity reducing tree density (Kneely *et al* 2009) and decimating woodlands (Akinbami *et al.* 2003). It is a delicate ecological zone between the drier savannahs of the north and the moist tropical rainforest of the south. It is an important zone for root, tuber and cereal (mainly maize and sorghum) cultivation. Because of its large pasture undergrowth, the area has in recent years been targeted as an important extensive grazing area by migrating pastoralists from the Sudan and Sahelian zones especially in dry periods and this has increased the frequency of land resource conflict (Fasona & Omojola 2005, Obioha 2008) with farmers widely experiencing material and farm income losses and cattle rearers' encroachment on peasant farms now becoming a major impediment to increased cassava cultivation (Adisa And Adekunle 2010).

2.2 Data and data sources

2.2.1 NDVI

Dekad 2 Long Term Mean seasonal normalised difference vegetation index (NDVI) for January (representing mid December-January-February), April (for mid March-April-May), July (for mid June-July-August) and October(for mid September-October-November) were accessed from the archive of the Famine Early Warning Systems Network (FEWS-NET) African Data Dissemination Service (http://earlywarning.usgs.gov/adds/imgdatas2.php?imgtype=nd&extent=w). The NDVI were calculated from data for the period 1982 to 2008. This NDVI (described as NDVI-g) dataset is inter-calibrated with SPOT Vegetation NDVI, and uses NOAA-17 data since January 2004 and the NOAA-17 NDVI data have also been inter-calibrated with NOAA-16 and previous NDVI products (Tucker *et al*. 2005, Pinzon *et al*. 2004, Pinzon 2002, Anyamba & Tucker 2005)
The pixel size for all spatial extent of the NDVI data is 8km in both X and Y directions and original projection was Albers Equal Area Conic and Clarke 1866 spheroid. This was re-projected to UTM-31 projection on WGS84 spheroid to match other datasets. The NDVI is derived from data collected by National Oceanic and Atmospheric Administration (NOAA) satellites, and processed by the Global Inventory Monitoring and Modelling Studies group (GIMMS) at the National Aeronautical and Space Administration (NASA). The NOAA-Advanced Very High Resolution Radiometer (AVHRR) collects the data that are used to produce NDVI. The NDVI is calculated from two channels of the AVHRR sensor, the near-infrared (NIR) and visible (VIS) wavelengths, using the following algorithm:

NDVI = (NIR - VIS)/(NIR + VIS) ------------(i)

The NDVI provides a measure of the amount and vigour of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigour and amounts of vegetation. The close coupling between rainfall and the growth of vegetation has made it possible to utilize NDVI data as proxy for the land surface response to precipitation variability (Anyamba & Tucker 2005, Neigh *et al*. 2008,) and vegetation biophysical properties (Stow *et al*. 2004).

2.2.2 Terrain

Terrain data was generated from the 3 arc-second STRM data from the Shuttle Radar Topography Mission (SRTM). The STRM data, an international project spearheaded by the National Geospatial-Intelligence Agency (NGA), NASA, the Italian Space Agency (ASI) and the German Aerospace Centre (DLR), was obtained using specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. The WRS-2 scenes *SRTM_ffB03*, p190r054 and p190r054 was downloaded from the archive of the global landcover facility - GLCF - (http://www.landcover.org/data/srtm/). Terrain derivatives including elevation, slope, and aspect were generated from this data and integrated with other datasets for the analysis.

2.3.3 Climate

Daily observed rainfall and maximum temperature (for between 25 and 50 years depending on length of observation records) for 12 climatic stations around the study area was sourced from the Nigerian Meteorological Agency (Fig 1). To ensure a representative interpolation data for 3 nearer stations in Benin Republic were accessed from the data portal of the Climate Systems Analysis Group (CSAG), University of Cape Town (www.csag.uct.ac.za).Statistical downscaling of the daily rainfall and maximum temperature data was also performed by the CSAG by matching global circulation model (GCM) data with self organised map (SOM) characterisation of atmospheric states forced by the SRES A2 emissions scenario (Hewitson & Crane 2006). The driving GCMs for the downscaling are from the Coupled Model Intercomparison Project phase 3 (CMIP3) archive.

Empirical downscaling is a widely used technique for exploring the regional and local-scale response to global climate change as simulated by comparatively low-resolution global climate models (Hewitson & Crane 2006). Climate data downscaling represents the cross-scale relationships between the larger scale circulation (from the GCMs) and local climate responses. It is based on the premise that the local-scale climate is in some measure a response to the larger, synoptic-scale forcing (Wilby *et al*. 2004). Observational data are used to derive a relationship between the synoptic-scale and local climates, and that relationship is used with comparable resolution fields of a GCM to generate information on the local climate consistent with the GCM forcing (Hewitson & Crane 2006, Wilby *et al.* 2004). Empirical downscaling is important for generating regional and local scale scenarios of future climate to make climate change information available for impacts and vulnerability assessments, policy formulation, and climate change adaptation at regional and local scales.

The statistical downscaling process, apart from reproducing the observation data, yields present and both near-future (2046-2065) and far-future (2081-2100) climate projections for 10 different

GCMs and NCEP reanalysis. Studies that compare climate model output often use ensemble sets of all the models. Cook & Vizy (2006) have analysed 18 coupled GCM outputs (including the 10+NCEP downscale GCM model outputs from CSAG) at the process level and concluded that the MRI CGCM 2.3.2 (with pressure at the top of the atmospheric model of 0.4hpa, and the horizontal and vertical resolution at top of T42 (~2.8°x2.8^0), L30, developed by the Meteorological Research Institute, Japan) provided the most reliable simulation of the twenty-first century climate over West Africa (COOK & VIZY 2006). We therefore employ MRI CGCM 2.3.2 model to describe the future climate over the study area. A comparison of the model output with observation data and NCEP reanalysis shows significantly agreement in spatial and temporal pattern of rainfall and temperature.

2.2.4 Other datasets

Other datasets accessed and included in the integrated analysis include soil data from the 1:650,000 digital Soils map of Nigeria produced by the Soils Survey Division of the Nigeria's Ministry of Agriculture and Natural Resources. Protect areas were digitised from existing 1:250,000 Vegetation and Land-Use maps produced in 1995/96 by the Forestry Mapping, Evaluation and Coordination Unit and forested areas and disturbance index maps were interpreted from Landsat Geocover imageries downloaded from archive of the Global landcover Facility, www.landcover.org .

The 2006 population census by Local Government Area (LGA) was accessed from the data archive of the Nigerian National Bureau of Statistics (http://www.nigerianstat.gov.ng/nbsapps/Connections/Pop2006.pdf). In addition existing topographic maps and administrative records were accessed for data on place names and LGA boundaries.

2.3 PCA analysis

The procedure adopted for data integration and analysis for principal component analysis (PCA) is shown on Fig.2. The seasonal NDVI data with a spatial resolution of 8km produced around 798 points (Fig 3). This was adopted as the frame for extracting point values from all the other datasets (maps) across the space. The point values extracted from each map was digitally written into the attribute file of the seasonal NDVI data.

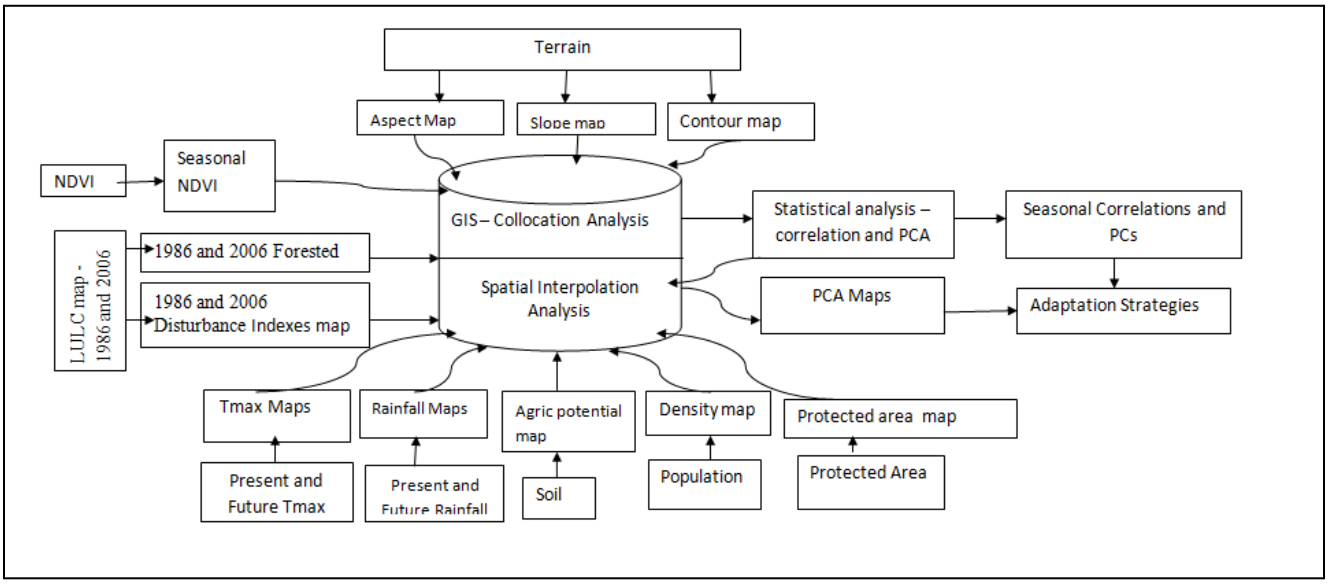

Fig 2: The framework for integration of eco-geographic variables for PCA

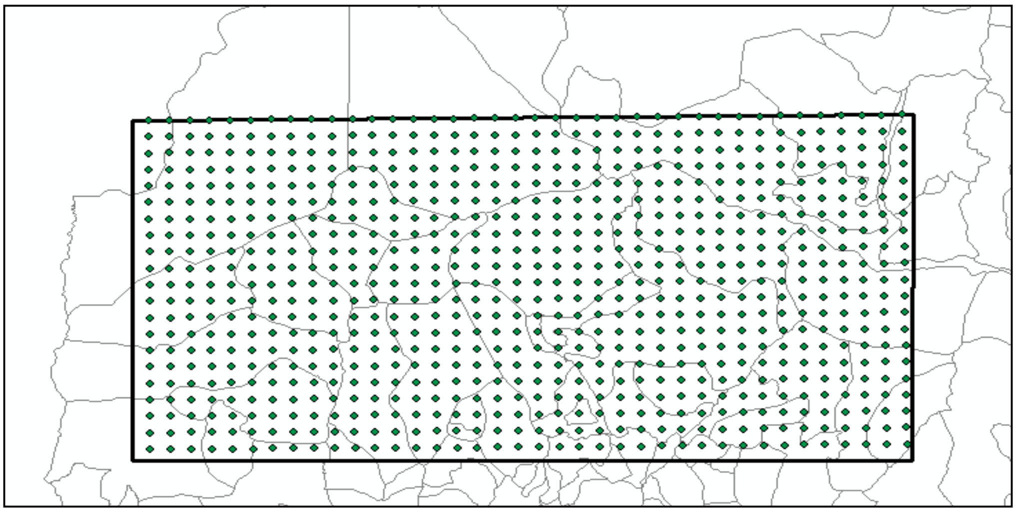

Fig 3: The 8km grid collocation plane

This procedure produced an extended collocated attribute data for the seasonal NDVI data. These extended attribute data files were exported to STATISTICA 9.0 software (Stat Soft Inc.2009) where the data were subjected to PCA. The correlation matrix option was chosen to produce standardised PCA. The Eigenvalues (variances extracted by the factors) cut-off was set at 1, and in addition, the slope of the scree plot was also considered and used as basis to solve the 'number of factors to retain' problem and to eliminate inconsequential principal components. While the summaries produced were further analysed to determine the controlling systems. The factor coordinates of all cases was also exported back into GIS. Using the inverse distance weights (IDW) spatial interpolation algorithm with Arcview GIS, PCA surfaces were produced to capture the spatial pattern and variability of several principal components across space.

Principal Component Analysis (PCA) is a powerful technique for analysing variability over space and time (Eastman 2009). It is a multivariate statistics that transforms series of variables into a set of components that are orthogonal in both time and space and are ordered in terms of the amount of variance they explain from the series. It is primarily an exploratory tool that is remarkably effective in organizing the underlying sources of variability in data. Efficient computation of PCA is actually done with matrix algebra and starts with a matrix of inter-correlations. This produces standardised PCA since correlations express the covariance between variables standardised by their variances (Eastman 2009). Data reduction is achieved by finding linear combinations (principal components) of the original variables, which account for as much of the original total variance as possible. The successive linear combinations are extracted in such a way that they are uncorrelated with each other and account for successive smaller amounts of total variance (Statheropoulos *et al*. 1998).
Principal Components are expressed by the following equation:

$$PC_i = a_{1i}V_1 + a_{2i}V_2 + \dots\dots\dots + a_{ni}V_n \text{-----------------------} (ii)$$

Where PC_i is principal component i and a_{1i} is the loading (correlation coefficient) of the original variable V_1 (Statheropoulos ET AL. 1998).

PCA has been used to study variability in data with climatic and ecological significance including air pollution (Paterson *et al*. 1999, Statheropoulos *et al*. 1998), biological diversity

(Moore *et al*.2002, Engler *et al*. 2004), groundwater and geochemical data (Love *et al*.2004, Reimann *et al*. 2002) and also used with geographic information systems (GIS) for mapping heavy metal sources in soil (Facchinelli *et al*.2000).

3 Results and discussions

3.1 Spatial pattern of present and future rainfall and temperature

Rainfall generally decreases from the south-eastern highlands to the northwest and northeast corners for both present and future climates. Positive rainfall anomalies for the present climate are recorded in the southeast corner extending from Isanlu area to Ogbomosho area in southwest. Normal rainfall anomalies are rerecorded in other areas (Fig 4a).

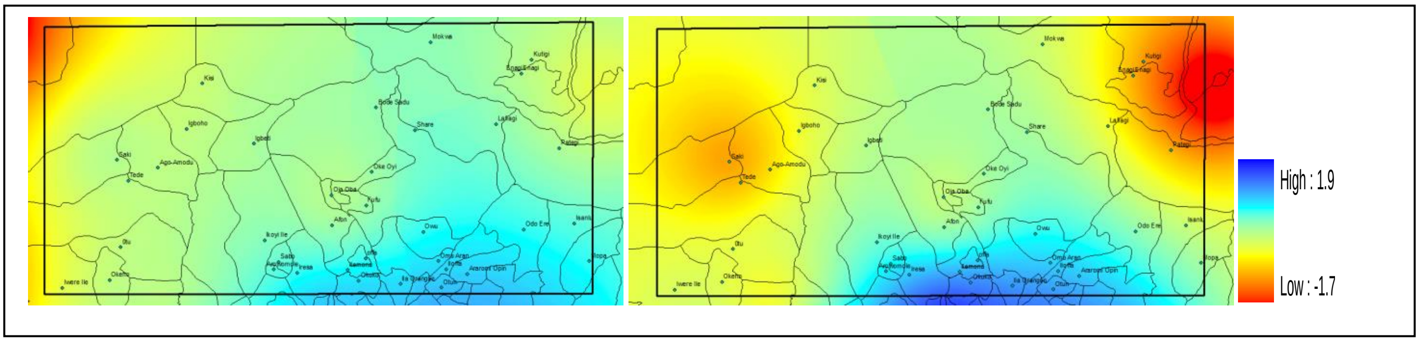

Fig 4: Pattern of rainfall anomalies (a) present (b) future climates

The future climate however shows that areas of positive anomalies are becoming localised at the south-eastern corner closer to the southern rainforest with complex topography. Some areas around the northeast corner (Kutigi-Bida axis) will in future experience strong negative rainfall anomalies. The Oke-ogun areas (around Shaki, Tede, Ago Amodu and Igboho) in central-west axis are also projected to experience considerable reduction in rainfall in future scenario (Fig 4b). The pattern exhibited by rainfall anomaly follows the general land-cover pattern. Forest and woodlands areas appear to associate with positive rainfall anomalies while shrub and grasslands exhibit negative rainfall anomalies.

Tmax anomalies for present climate tend to increase from west to east in a north-south corridor fashion. The negative Tmax anomalies generally extend through a corridor that stretches from Ila-orangun and Otun areas in southeast to Oke ogun areas in the central-west (Fig 5a). Higher elevation may have been responsible for lower Tmax around these areas. The northeast corner extending from the Niger floodplain to Kutigi-Enagi-Bida axis recorded positive Tmax anomalies.

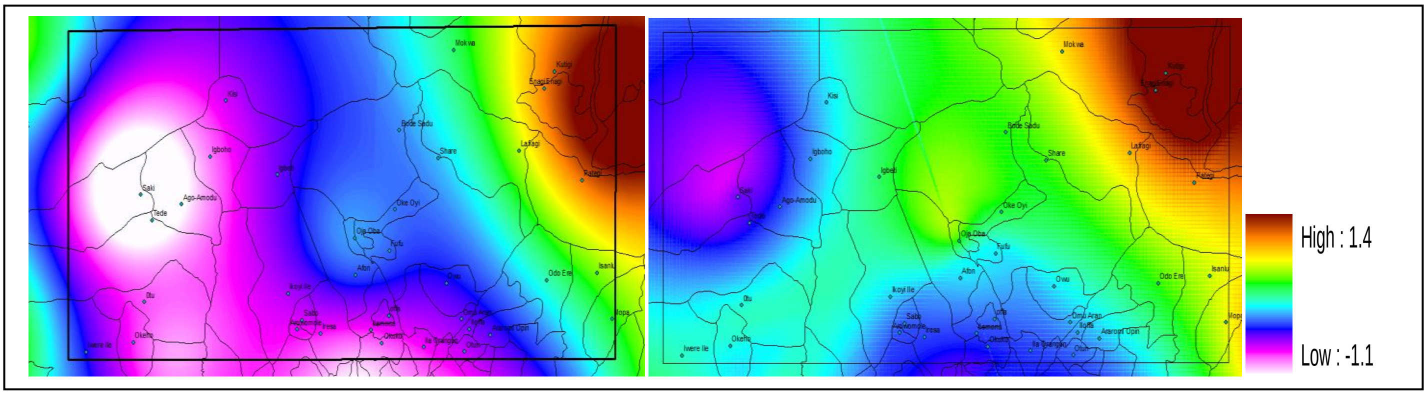

Fig 5: Pattern of Tmax anomalies (a) present (b) future climates

Fig 5b strongly suggests that this pattern will change in future scenario when warming increases in most parts of the area. This is expected to change the existing anomaly corridor patterns and a new corridor of high to normal will extend from the southwest corner (part of Okeogun) to northeast axis. This emerging pattern of Tmax anomalies can also be linked to local desertification expected in the area (Abiodun *et al* 2009). The influence of terrain is also expected to continue to influence Tmax in parts of 'Okeogun' areas especially Shaki axis, while temperature continues to increase in the inland basin covering the Niger and Kaduna basins around the northeast corner.

3.2 Pattern of feedbacks between climate and eco-geographic factors

The pattern of feedbacks between climatic elements and eco-geographical variables in terrestrial ecology is important for planning adaptation to climate change at local and regional levels. Some eco-geographic variables including NDVI are critical for determining climate-ecology relations and feedbacks at local levels. The regional climate of West Africa is controlled to an appreciable degree by the mesoscale convective systems (MCS), a coupled system of local processes including the influence of terrain, land-cover and moisture gradient. The seasonal correlations across space between rainfall and Tmax on one hand, and NDVI and elevation on the other are shown on Tables 1a and 1b respectively for present and future climates.

Table 1: Correlation of climate and eco-geographic variables for present climate

Variables	Season	NDVI	Elevation	Rain_	Tmax_
NDVI	DJF		-0.161	-0.184	0.298
	MAM		0.563	0.530	-0.382
	JJA		-0.073	0.347	0.250
	SON		0.261	0.023	-0.089
Elevation	DJF			0.678	-0.774
	MAM			0.499	-0.670
	JJA			-0.624	-0.641
	SON			0.151	-0.666
Rain_	DJF				-0.777
	MAM				-0.733
	JJA				0.759
	SON				-0.096

All correlations significant at the 0.01 level (2-tailed).

Table 2: Correlations of climate and eco-geographic variables for future climate (**2046-2065)**

Variables	Season	Elevation	Rain_	Tmax_
Elevation	DJF		0.739	-0.761
	MAM		0.620	-0.739
	JJA		0.034	-0.683
	SON		0.389	-0.756
Rain_	DJF			-0.887
	MAM			-0.658
	JJA			0.351
	SON			-0.431

All correlations significant at the 0.01 level (2-tailed).

NDVI is a good proxy for identifying land surface response to climate (ANYAMBA & TUCKER 2005, STOW, *et al*. 2004). There is a strong positive association of NDVI with elevation ($r=0.56$ $p<0.01$) and rainfall ($r= 0.53$ $p<0.01$) in March-April-May (MAM). MAM represents the onset of rains when the wooded recovers after the dry season of December-January-February (DJF). The more rainfall experienced during this period the greener the area. Elevated areas normally have the chances of receiving early rainfall due to strong effect of MSC which requires the force provided by elevation to produce rain. This also explains why highlands around the area of study are wetter than the surrounding areas.

This well known effect of terrain on climate is also demonstrated by positive correlation of elevation with rainfall and negative correlation with temperature (in all seasons) except in June-July-August (JJA) when the pervading system is reversed with rainfall showing strong negative correlation with elevation ($r=-0.62$, $p<0.01$) and strong positive correlation with Tmax ($r=0.76$ $p<0.01$). This strongly suggests the dominance of the West African monsoon system in JJA. Normally, the MCS requires a local forcing such as higher altitude to provide the force required to gathered moisture to reach saturation and condensation stages and then produce rain. However, in JJA because of the influence of the monsoon system which predominates at this period, the influence of MCS and the local forcings are weakened because the whole atmosphere is saturated. Hence, less rainfall is produced by the local systems at higher altitudes.

The monsoon system is essentially driven by land-ocean pressure differential being driven by heating on the land. The sun is overhead on the tropic of cancer in June (boreal summer) and overhead around the West Africa savannah in July –August on its way back to the equator which it reaches in September. The savannah thus receives direct insolation, leading to low pressure on land. This low pressure on land drives the monsoon from the ocean to the land to produce rainfall, hence the positive correlation between rainfall and temperature. This is especially significant because it represents a reversal of the existing system dominated by MSC and allows areas the inland basins of the savannah to experience maximum rainfall. The system is reversed again in September-October-November and this appears to be responsible for the strongly delineated double maximum rainfall received in the southeast-northwest corridor.

This strong association of rainfall and temperature with terrain in DJF, MAM and SON is expected to continue in future scenario. However, the no correlation ($r=0.03$, $p<0.01$) and weak positive ($r=0.35$, $p<0.01$) association between rainfall and temperature respectively with terrain in JJA suggest that the coupling between rainfall, temperature and terrain will become weaker in future scenario. This will have serious possible implications for rainfall (and by extension, livelihoods) in the inland basins around the northeast corner which rely on the reversal of the system in JJA. This is also consistent with rainfall and temperature anomalies which show future hotspot of dryness resulting from rising temperature and declining rainfall.

3.3 Analysis of the controlling systems

Apart from large scale processes that influence the pattern of climate, the climate is also conditioned by several meso and local scale factors. Some of these required fine scale resolution that cannot be captured by several global and regional land surface models. Although GIS has no capability to generate complex feedbacks between ecology and several parameters of climate, it provides the capability to integrate data on different local to regional scale parameters. In this study, 18 variables (15 for future climate) were generated, integrated and analysed. The objective is to identify those factors coupled into a system that has considerable impacts on the local climate. Table 3 shows the rotated (varimax with Kaiser normalization) results of component matrix generated through correlation matrix for the present climate.

Six principal components which have eigenvalues of above 1 and explain 65.6% of the total variance between the data was extracted. The first principal components define the climate-orographic complex and explain 20% of the total variance. It accounts for the coupled system between elevation, temperature and rainfall. Elevation is inversely related to temperature and directly related to rainfall. It also reinforced the assumption that mesoscale processes which relies on orographic forces controls that local climate. The second, third and fourth principal components show inter-correlations between the same set of variables i.e. rainfall, vegetation index and forested areas respectively. Principal components five and six, though explain only 7% and 6% of variance respectively, combine factors such as aspect, forested area, slope and soil potential for agriculture which are important for the ecological systems and use of the land.

Table 3: Extracted principal components for present climate

	Component					
Variables	1	2	3	4	5	6
Aspect	.129	-.116	.220	-.138	.621	-.287
Slope	-.075	.156	.236	.274	.014	-.534
Elevation	-.818	-.018	.292	.063	.059	.060
Population density	-.168	.234	-.062	.289	-.062	.312
Soil potential for agric	.099	.081	.320	.130	.119	.663
Distance to water	-.076	-.023	.111	.534	-.017	.154
Protected areas	.175	.215	-.292	.503	-.135	-.001
NDVI for 1986	-.210	-.001	.770	.156	-.059	-.026
NDVI for 2006	-.096	.156	.756	-.195	.018	.041
Average Tmax for 1986	.958	.033	-.045	.050	.028	.057
Average Tmax for 2006	.961	-.037	-.049	.087	-.007	.054
Average rainfall for 1986	.125	.931	.008	-.005	-.024	-.019
Average rainfall for 2006	-.650	.690	.069	-.045	.056	-.013
Disturbance index for 1986	-.162	-.063	-.030	.097	.760	.292
Disturbance index for 2006	.055	-.200	.126	.642	.215	-.117
Forested areas in 1986	.001	-.090	.465	-.176	-.660	-.019
Forested areas in 2006	-.121	-.058	.393	-.681	-.070	.136
Long-term mean rainfall	-.048	.915	.097	.007	-.080	.035

Table 4 Extracted principal components for future climate (2046-2065)

	Component					
Variables	1	2	3	4	5	6
Aspect	-0.035	-0.094	0.431	0.383	0.052	0.387
Slope	0.133	-0.150	-0.199	-0.208	-0.031	0.756
Elevation	0.823	-0.157	0.192	-0.197	-0.120	0.007
Population Density	0.151	-0.285	-0.286	-0.049	-0.197	-0.446
Soil potential for agriculture	-0.005	-0.085	0.010	0.172	-0.848	0.022
Distance to water	-0.029	-0.387	-0.016	-0.376	-0.317	-0.008
Protected area	-0.241	-0.406	-0.504	-0.085	0.108	-0.039
Disturbance index for 1986	0.100	-0.535	0.438	0.421	-0.152	-0.077
Disturbance index for 2006	-0.182	-0.523	0.217	-0.372	-0.110	0.173
Forest area in 1986	0.112	0.640	-0.086	-0.482	-0.267	0.058
Forest area in 2006	0.295	0.654	0.288	0.157	-0.243	0.005
Long term average rainfall	0.746	-0.025	-0.518	0.294	-0.035	0.108
Monthly average rainfall	0.746	-0.026	-0.518	0.294	-0.034	0.107
Long term average Tmax	-0.867	0.114	-0.292	0.207	-0.169	0.093
Mean monthly Tmax	-0.867	0.104	-0.283	0.209	-0.172	0.096

For the future climate, 6 principal components accounted for 69% of the total variance. The coupled climate-orographic complex still remains the controlling system (Table 4) and accounts for about 24% of the total variance. The second principal component only establishes inter-relationship between forested areas at two different periods and the third principal component establishes the direct positive feedback between rainfall and protected areas.

3.4 Spatial pattern of the controlling systems

The dominance of 'climate-terrain' complex on the local climate system is unassailable in both present and projected future climates. In both cases, elevation exerts positive influence on rainfall and negative influence on temperature. This pattern dominates the southeast to northwest corridor and more pronounced south of Ilorin and '*Okeogun*' areas especially around Shaki. The seasonal analysis indicate that this pattern predominates for present and future climates in DJF (Fig 6a&b), MAM (Fig 7a&b), SON (Fig 9a&b) and for the annual average (Fig 10a&b). The system is reversed in the monsoon season of JJA (Fig 8a&b) and the inland basins across the Niger (areas around Lafiagi, Patigi, Kutigi and Bida corridor in the northeast) experience higher rainfall and cooler temperature. Onset of rains in the southeast-northwest corridor is around mid-March to April and most of the early rains are from mesoscale processes, thus giving the area a double peak rainfall in June and September. Incidentally, the agricultural land-use around southeast-northwest corridor is dominated by rainfed small-holder root, tuber and cereal cultivation which is conditioned by the relative suitability of the area in terms of optimum rainfall and lower temperature that reduces water loss. On the other hand, onset of rains in the inland basins across the Niger is around the month of May which coincides with the approach of the West African monsoon. Peak rainfall is received in August, a month which marked '*the little-dry season'* in the northwest-southeast corridor. These systems feedbacks also contrast with the general notion that regular rainfall gradient that decreases with latitude characterises the Nigerian savannah.

The spatial pattern is projected to continue in future climate but with diminishing influence. While the system is expected to become pronounced in the highland areas located at the edge of the rainforest zone in the southeast corner, the influence around the northwest corridor especially in '*Okeogun*' around Shaki area will diminish. This will have severe implication for large rural population that depend on the system for livelihood. The expected upturn of the system in JJA will also become severely weakened in future scenario (Fig 8b) because rainfall will no longer be significant in the system. What is likely to be experienced is cool temperature pervading the inland basins across the Niger (Kutigi-Bida axis) without significant rainfall. This will also pose serious implications for rural livelihoods in the northeast inland basins that rely on the up-turn of the system in JJA to optimize their peasant agriculture.

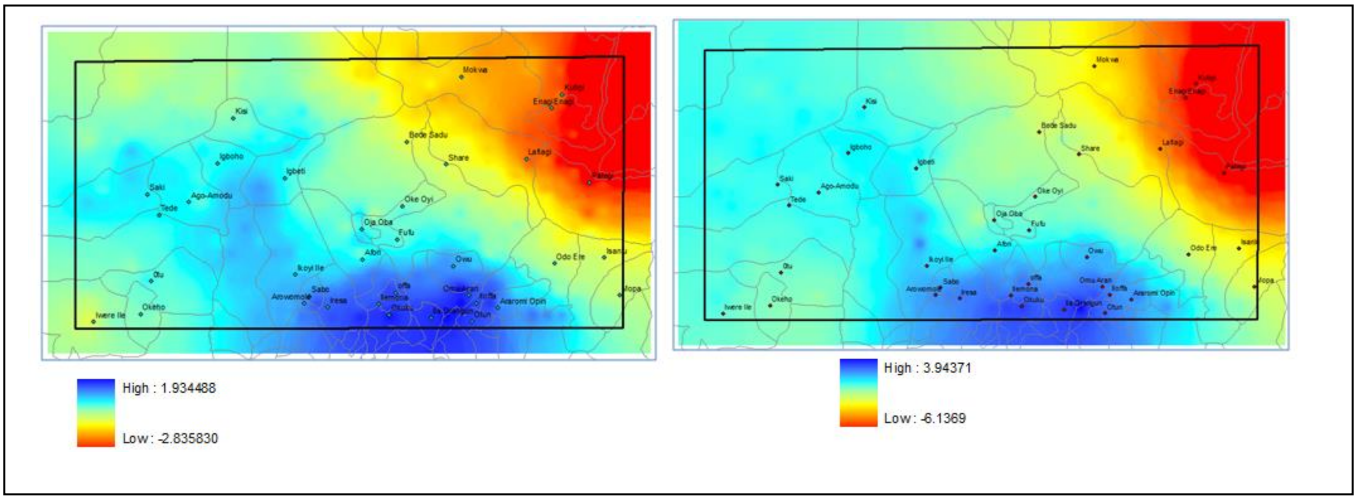

Fig 6: DJF: Elevation varies directly with Rainfall and Inversely with Tmax in (a) present and (b) future climates

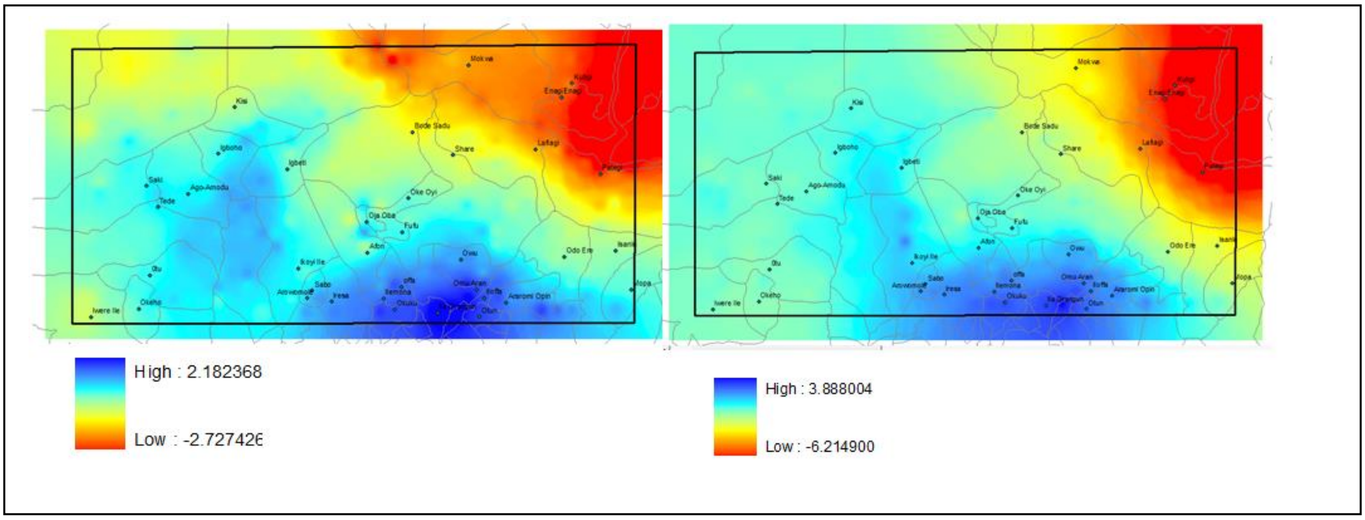

Fig 7: MAM: Rainfall and Tmax vary inversely with Elevation for (a) present (and also with NDVI) and (b) future

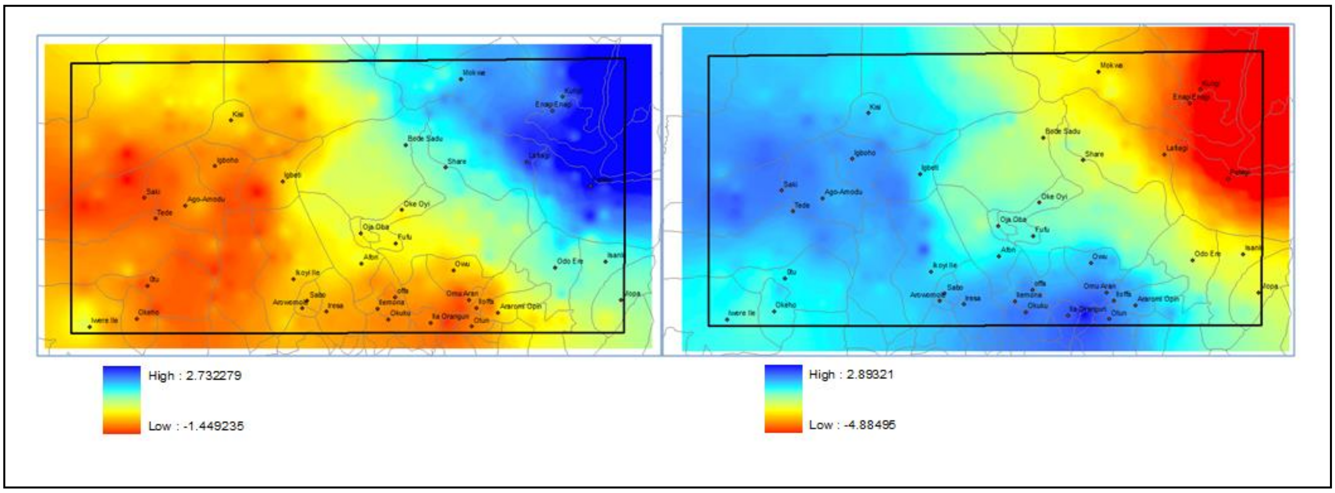

Fig 8: JJA: Rainfall and Tmax varies inversely with Elevation in (a) present climate, and (b) future climate -rainfall no longer significant

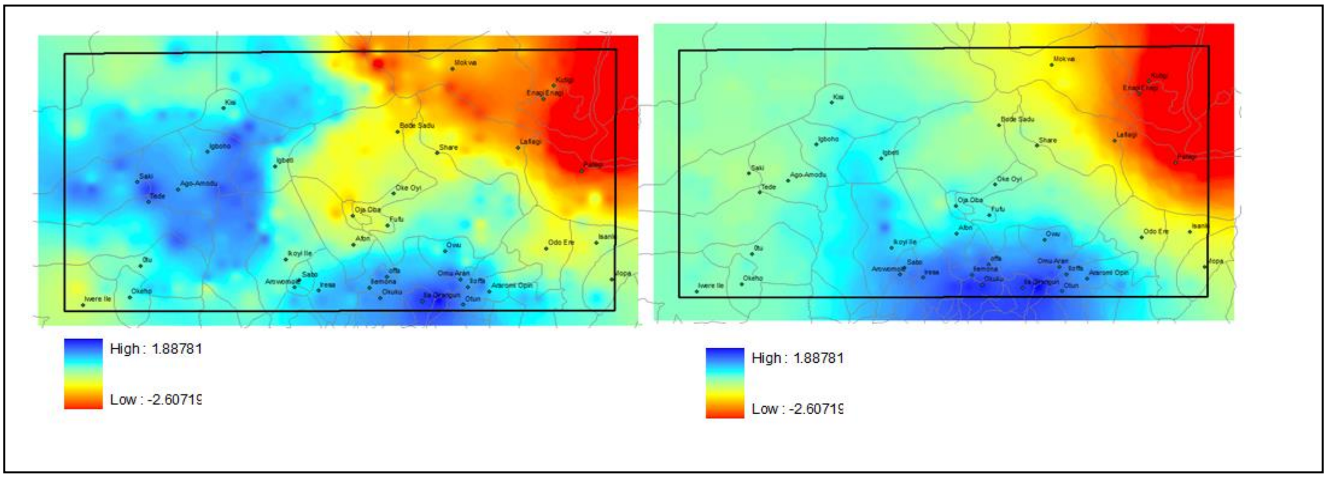

Fig 9: SON: Elevation Varies inversely with Tmax only in (a) present climate, and (b) also directly with rain in future climate

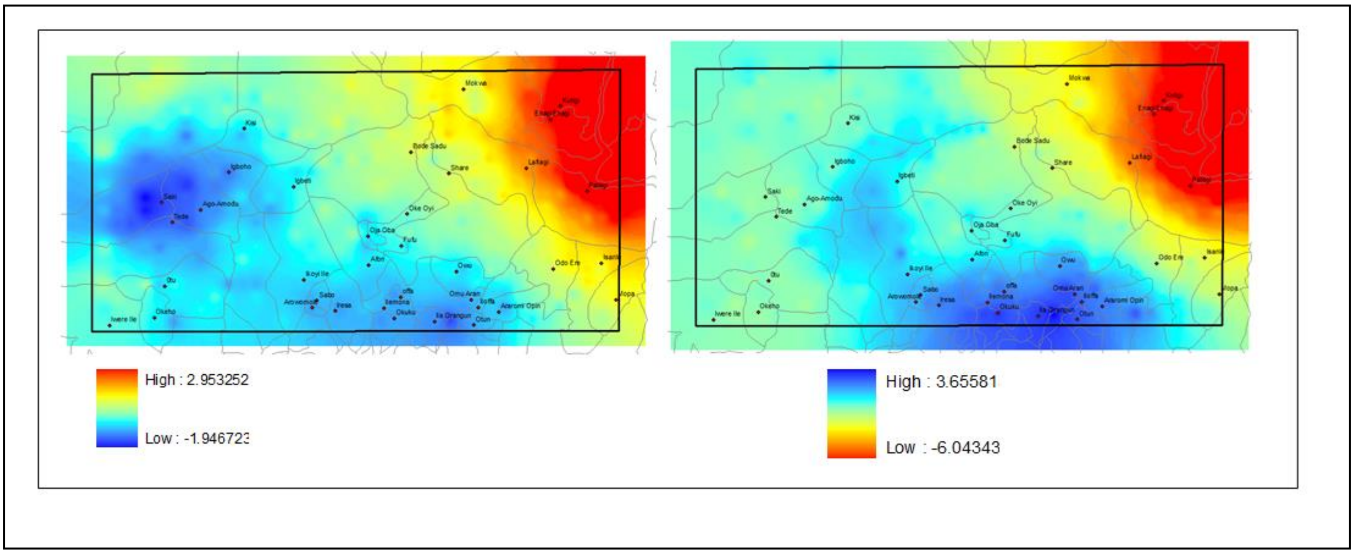

Fig 10: The annual average: Rain and Tmax sensitivity to terrain (a) Present climate (-Elevation, -rain, +Tmax) (b) future climate (+Elevation, +rain, -Tmax)

The pattern of terrain influence on local climate was also compared with the present pattern of rural settlements and drainage. The distribution of rural settlements across space is clustered (average nearest neighbour index: = 0.58 and Z score = -39.21 Std ($p<0.01$)). These settlements are clustered around the areas where the terrain positively influences the climate (Fig 11a) for most seasons. This suggests a strong feedback between the rural livelihood systems and the local climate.

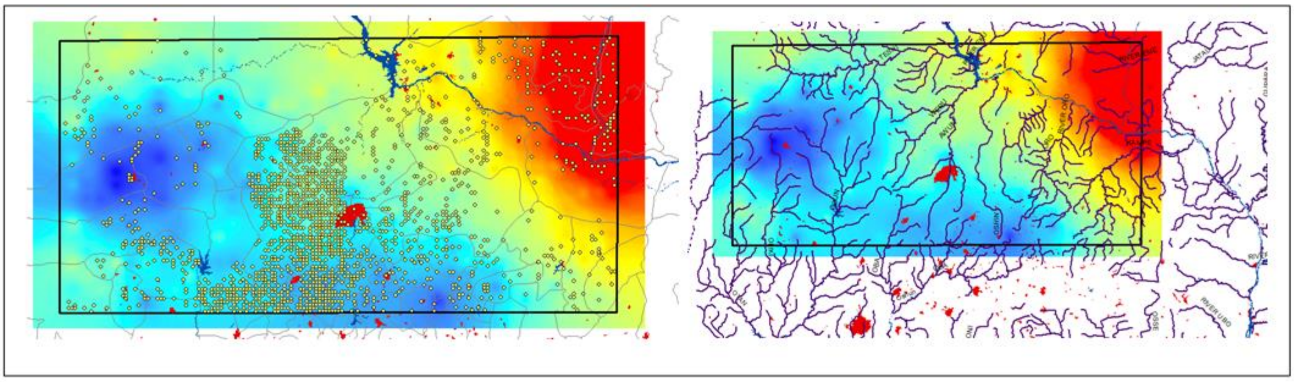

Fig 11: (a) Clustered settlement influenced by the systems (b) the drainage system

This suggests that the ‘favourable’ climate of the southeast-northwest corridor has long been recognised by the local population as an eco-climatic asset on which their livelihood (mainly rainfed peasant agriculture) depends. It also underscores the importance of incorporating indigenous knowledge into climate change mitigation and adaptation planning. The integration of the local climate system map with the draining pattern (Fig 11b) also reveals that the eco-climatic assets found around the southeast-northwest corridor is the single source for all major drainage systems of the entire western Nigeria. It produces important river catchment including the Okpara, Oyan, Ogun, Oba and Oshun that drain a combined large catchment into the Atlantic ocean and produce water supply for agriculture (though limited irrigation is actually carried out) as well as industrial and municipal water supply for large urban agglomerations including Lagos, Ibadan, Abeokuta, Oshogbo, Ogbomosho, Oyo, Iwo, and several medium and small urban and thousands of villages. The eco-climatic complex also produces drainage systems that drain rivers such as Teshi, Awun, Asa, Ero, and Kampe Rivers into the Niger River. This strongly suggest this local climate system is a natural resource system that is critically important for survival of neighbouring population, and also of several millions of people that indirectly depend on the provisioning services from this eco-climatic resource.

3.5 Climate change adaptation

While climate change mitigation may range from local, regional to global, climate change adaptation is a local issue. Adaptation is place-based and sometimes contextual and requires place-specific strategies. Place-based analyses provide more complete understanding of the local peculiarities and intrinsic qualities of places which are fundamental for planning effective adaptation strategies. It is clear that climate change has the potential to negatively alter socio-ecological balance. An effect on ecosystems which support livelihood of millions of population exposes them to other composite externalities including poor resilience to environmental risk and shocks, poor health and economic under-development. Climate change has the potential to deepen the dynamic and context specific poverty-environment linkages, reflecting geographic location, scale and economic, social and cultural characteristics of individuals and households and social groups (UNDP-UNEP, 2009). Climate sensitive but well managed natural resource systems provide sustainable livelihoods. But when they are poorly managed, they exacerbate climate change impacts. According to Mueller (2009), significant climate change that will affect ecosystems and access to natural resources such as fertile land and water is expected over the

21st century. Regions with low adaptive capacity due to poverty, lack of infrastructure, services, and appropriate governance will be most severely affected.

Substantial change in climate is expected in the Savannah. Although temperature is not expected to increase substantially, reduction in rainfall is expected to be significant. The present and future pattern of rainfall and temperature anomalies show that the distribution of stressors across space is non-uniform which also means different adaptation strategies may be necessary for different group of communities and social groups. More importantly, the results have shown the feedbacks and relations between the eco-geographic variables and climate. The connection between the pattern of location of rural communities across space and eco-climatic corridors created by the controlling system is very clear. It can be deduced from this that livelihood systems around the area is directly connected to this eco-climatic corridor. In essence, the terrain system modifies the local climate to produce favourable condition that supports peasant rainfed agriculture for most seasons. This also distinguishes peasant agriculture practices between the southeast-northwest corridor and northeast inland basins. Communities around the northeast axis rely on the upturning of the system in JJA to get a more favourable condition for rainfed agriculture. This partly explains why flood plain agriculture and small scale irrigation farming is also common around the northeast inland basins than the southeast-northwest axis. In either case, the eco-climatic resource complex propagated this system that controls the local climate.

The fact that the climatic-orographic complex areas also create an important divide that produces the drainage basins of the entire western Nigeria underscores the importance of this natural resource system. It is the live-wire of the entire region and any ecological breakdown resulting from climate change will be disastrous, first, for human livelihoods in the area, and second, for water availability in the entire southwest Nigeria. However, the future scenario projections indicate that the systems will likely be weakened which may result in ecological breakdown and the water footprint may become the footprint for fierce resource competition in future. Hence mitigation strategies are required to prevent such a state.

Aggressive vegetation and albedo enhancement strategies are primary form of climate change mitigation. Extensive reforestation efforts hold the potential to restore moisture and energy balances to pre-disturbance levels over a time scale measured in decades rather than in centuries (Stone Jr. 2009). The possibility of compensating developing countries for reduced emissions from deforestation and forest degradation (REDD) was proposed by the governments of Papua New Guinea and Costa Rica at the 11th Conference of Parties (COP) of the United Nations Framework on Climate Change (UNFCCC) in 2005 (Sazaki & Putz 2009). As the roles of tropical forests in sustainable development and global warming become increasingly apparent, progress is being made towards including REDD in the post-Kyoto Protocol climate change agreements. REDD is attractive because it explicitly recognizes the value of natural forests and because the associated costs for project developers are expected to be low. The eco-climatic resource of the area under study together with the catchments constitutes an important climate sensitive natural resource system that needs to be protected. It can therefore benefit from the REDD, carbon trading initiatives and other clean development mechanisms (CDM) project. This area is very attractive and such a project will maintain the ecological integrity of the area, prevent the existing highland forests and woodlands from deforestation and unsustainable land use practices, and also ensures that the local forcings responsible for producing the favourable climate are continually activated to produce the much required water footprint as we have it now. Less than 10% of the area is currently protected, and encroachments and fire scars are visible even within the protected areas. Ecotourism is also a good climate mitigation strategy to protect the forest and woodlands in such a high density agrarian landscape.

Mainstreaming climate change and natural resource management into development planning is critical to garner support for climate change awareness, education, mitigation and adaptation at local levels because it affects livelihood, health, and the way of life of the people at this level. A number of potential best management practices for land use planning and design could be implemented to mitigate impacts resulting from changes in climate and LULC. This includes reforestation, restoration of abandoned lands and riparian corridors, and low impact development techniques for residential housings. Land based mitigation may provide the most viable mechanism for addressing the likely shortfall between the emissions reductions required to avert catastrophic warming and the emissions reductions achievable through the international political process. Large scale reforestation programs, if recognized through international agreements to generate benefits in the form of climate regulation, could attract significant international investment. The availability of remote sensing tools to monitor compliance with land-based mitigation agreements may render this approach more easily enforceable than carbon reduction agreements (Stone Jr. 2009).

The climate change projection for the area of study suggests that the double peak rainfall pattern will collapse and be replaced with a July mono rainfall peak. In addition, the onset of the rains will come earlier than present and cease later than present. This definitely means a shift of the growing season. Yam, Cassava, Maize and sorghum are staples grown extensively in the wooded savannah. The implication of this for adaptation is that the dual growing season for maize, early and late season, may cease. Instead because of elongated growing season, it may be advantageous to grow maize for most parts of the year except in July when rainfall is at peak. However, for root crops especially yam which requires appreciable rainfall at the early stage, the planting season may have to be shifted back to February instead of the present March-April to take advantage of the early rainy season. For cassava, the new situation may be providing all season advantage for growing cassava.

It also mean that some varieties of root, tuber and cereals that are suitable for drier upper latitudes (in the upper guinea and Sudan savannah) may now become suitable in the wooded savannah. This also suggests that the local population will have to be receptive and try new crops which hitherto were not grown in the area. Results from land-use change modelling carried out for the area (not shown in this paper) also suggests that rural settlements will likely grow along the ‘favourable-climate’ corridor which basically aligns with the southeast-northwest corridor. Since migration too has been described as a form of adaptation to changing climate, we can expect more influx into the area around Shaki, Igboho, Tede and the border with Benin Republic as a response to unfavourable climate in the northeast axis.

Finally, the floodplain of the Niger still presents a buffer that is yet to be fully explored at present. Less that 20% of agricultural potential of the floodplain is currently realised. If the experience of the Nile Valley in Egypt and other drier areas such as Isreal is anything to learn from, the Niger flood-plain may become a fulcrum and bastion of climate change mitigation in the area in future. Irrigation and water management techniques will also need to be optimised. Currently, many big dams are constructed without any evidence of the water being used for large scale agriculture. The current footprints of agricultural land-use show about 95% of agrarian land is devoted to small-holder peasant farms. As an adaptation option to optimize land resource productivity and use, the present peasant small size holdings may be replaced by commercial and collective farms in future.

4 Conclusions

We have attempted to unravel the controlling factors of the local climate using the PCA in this study. The performance of the PCA confirms the results from the correlation analysis and suggests a local climate system being controlled by the terrain influence, a strong factor of the mesoscale convective systems. The spatial variability in the pattern of influence shows its implications on human activity including agriculture and other livelihood systems. The pattern of rural settlements suggests population with livelihood tied to the eco-climatic resource complex. While the trend is expected to continue into the future, the spatial influence is expected to severely diminish and areas around *Okeogun* that presently supports a large population and viable rural livelihood with rainfed agriculture may be seriously affected.

The areas of strong positive climate-orographic feedback corridor also correspond to an important divide which is the source of the major drainages of western Nigeria. Such an important natural resource system needs be treasured and targeted as fulcrum of climate change mitigation to avert future disaster. Some place specific adaptation strategies including shift in planting and growing season, new varieties of crops, rural-rural migrations and sustainable exploitation of agricultural potentials of the Niger floodplain have also been suggested. Future survival of the population may depend on how much of workable strategies for climate change mitigation and adaptation are put in place. The next key challenge for this study, therefore, is to design appropriate doable climate change mitigation and adaptation projects across the study area.

Acknowledgment

This research was carried out under the African Climate Change Fellowship Programme (ACCFP). The ACCFP is supported by a grant from the Climate Change Adaptation in Africa (CCAA) funded jointly by the International Development Research Centre (IDRC) of Canada and the UK's Department of International Development (DFID). The International START Secretariat is the implementing agency in collaboration with the Institute of Resource Assessment (IRA) of the University of Dar es Salaam and the African Academic of Sciences (AAS).

References

Abiodun, B.J., Pal, J.S., Afiesimama, E.A., Gutowski, W.J., & Adedoyin, A. (2008). Simulation of West African monsoon using RegCM3 Part II: impacts of deforestation and desertification. Theor. Appl. Climatol. 93: 245-261. doi 10.1007/s00704-0222-1

Adisa, S.R & Adekunle, O.A (2010). Farmer-Herdsmen Conflicts: A Factor Analysis of Socio-economic Conflict Variables among Arable Crop Farmers in North Central Nigeria. J Hum Ecol, 30(1): 1-9.

Afiesimama, E.A., Pal, J.S., Abiodun, B.J., Gutowski Jr, W.J., & Adedoyin, A, (2006). Simulation of West African monsoon using the RegCM3.Part I: Model validation and interannual variability. Theor. Appl. Climatol. 86, 23–37

Akinbami, J.F.K., Salami, A.T., & Siyanbola, W.O. (2003). An integrated strategy for sustainable forest–energy–environment interactions in Nigeria. Journal of Environmental Management 69, 115–128. doi:10.1016/S0301-4797(03)00083-5

Anyamba, A. & Tucker, C.J. (2005) Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. Journal of Arid Environments 63, 596–614. doi:10.1016/j.jaridenv.2005.03.007

Barbier, E.B & Thompson. J.R (1998) The Value of Water: Floodplain versus Large-Scale Irrigation Benefits in Northern Nigeria. Ambio, 27 (6), 434-440

Cao, M., Prince. S.D. & Shugart H. H. (2002) Increasing terrestrial carbon uptake from the 1980s to the 1990s with changes in climate and atmospheric CO2, Global Biogeochemical. Cycles, 16(4), 1069, doi:10.1029/2001GB001553

Chapin, F.S., Randerson, J.T, McGuire, D.A., Foley,J.A. & Field, C.B. (2008) Changing feedbacks in the climate–biosphere system. Frontiers in Ecology and the Environment: Vol. 6, 6, 313-320. doi: 10.1890/080005

Cook, K.H. and Vizy, E.K. (2006). Coupled Model simulation of the West African Moonsoon Systems: Twentieth-and Twenty-First Century Simultions. Journal of Climate 19, 3681-3703. American Meteorological Society.

Donoghue, D.N.M. (2002) Remote sensing: environmental change**.** Progress in Physical Geography 26 (1), 144–151.doi: 10.1191/0309133302pp329pr

Douglas o. Fuller, D.O & Ottke, C. (2002) Land cover, rainfall and land-surface albedo in West Africa**.** Climatic Change 54**,** 181–204

Engler, R., Guisan, A. & Rechsteiner, L (2004). An Improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41, 263–274.

Facchinelli,A., Sacchi E. & Mallen, L. (2001): Multivariate statistical and GIS-based approach to identify heavy metals in soils. Environmental Pollution 114:313-324. PII S0269 -7491 (00) 00243-8. Elsevier

Falkenmark, M., Rockstrom, J. & Kalberg, L. (2009). Present and future water requirements for feeding humanity. Food Security. 1(1): 59-70.

Fasona, M., Omojola, A., Adeaga, O. & Dabi, D (2007). Aspects of Climate Change and Resource Conflicts in the Nigeria Savannah. IPCC/TGICA Expert Meeting on Integrating Analysis of Regional Climate Change and Response Options, Nadi, Fiji Islands. Supporting Material prepared for consideration by the IPCC, p45-55. http://www.ipcc.ch/pdf/supporting-material/tgica_reg-meet-fiji-2007.pdf

Hewitson, B.C. & Crane, R.G. (2006). Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. Int. J. Climatol. 26: 1315–1337

Hoffmann, W.A.& Jackson, R.B. **(**2000) Vegetation–Climate Feedbacks in the Conversion of Tropical Savannah to Grassland**.** Journal of Climate, *13*, 1593-1602

Kuemmerle, T., Muller, D., Griffiths, P. & Rusu, M. (2009) Land use change in Southern Romania after the collapse of socialism. Reg Environ Change 9,1–12. doi: 10.1007/s10113-008-0050-z.

Lauwaet, D., van Lipzig, N.P.M. & De Ridder, E.K (2009) The effect of vegetation changes on precipitation and Mesoscale Convective Systems in the Sahel. Clim Dyn 33:521–534

Li, X.Y., MA, Y.J., Xu, H.Y., Wang, J.H & Zhang, D.S.(2009) Impact of Land Use And Land Cover Change on Environmental Degradation in Lake Qinghai Watershed, Northeast Qinghai-Tibet Plateau. Land Degrad. Develop. 20, 69–83. doi: 10.1002/ldr.885.

Love, D., Hallbauer, D., Amos, A., Hranova, R. (2004). Factor analysis as a tool in groundwater quality management: two southern African case studies. Physics and Chemistry of the Earth 29, 1135–1143. doi:10.1016/j.pce.2004.09.027

MacKellar,N.C., Tadross, M.A & Hewitson, B.C (2009) Effects of vegetation map change in MM5 simulations of southern Africa's summer climate**.** Int. J. Climatol. 29, 885–898 DOI: 10.1002/joc.1754

Moore, J.L., Manne, L., Brooks. T., Burgess, N.D., Davies, R, Rahbek, C., Williams, P. & Balmford, A (2002). The distribution of cultural and biological diversity in Africa. *Proc. R. Soc. Lond.* 269, 1645–1653. DOI 10.1098/rspb.2002.2075

Müller, Christoph.(2009). Climate change impact on Sub-Saharan Africa : an overview and analysis of scenarios and models Bonn : DIE, 2009 – (Discussion Paper / Deutsches Institut für Entwicklungspolitik 3/2009.

Neely, C., Bunning, S. & Wilkes**,** A. (2009) Review of evidence on drylands pastoral systems and climate change: Implications and opportunities for mitigation and adaptation. Land and Water Discussion Paper, FAO, Rome

Neigh, C.S.R., Tucker, C.J. & Townshend, J.R.G. (2008) North American vegetation dynamics observed with multi-resolution satellite data. Remote Sensing of Environment 112, 1749–1772. doi:10.1016/j.rse.2007.08.018

Nicholson, S. (2000) Land surface processes and Sahel climate. Reviews of Geophysics 38(1), 117-339. American Geophysical Union

Nicholson, S.E (2009): A revised picture of the structure of the ‘‘monsoon’’ and land ITCZ over West Africa. Clim Dyn (2009) 32:1155–1171.DOI 10.1007/s00382-008-0514-3

Obioha. E.E (2008) Climate Change, Population Drift and Violent Conflict over Land Resources in North-eastern Nigeria, J. Hum. Ecol., 23(4), 311-324

Odekunle, T.O., Balogun, E. E., & Ogunkoya, O.O (2005) On the prediction of rainfall onset and retreat dates in Nigeria. Theor. Appl. Climatol. 81, 101–112. DOI 10.1007/s00704-004-0108-x

Omotosho, J.B & Abiodun, J. (2007): A numerical study of moisture build-up and rainfall over West Africa. *Meteorol. Appl.* 14: 209–225. DOI: 10.1002/met.11

Paterson K.G., Sagady, J., Hooper, D., Bertman, S.B., Carrol, M.A. & Shepson., P.B (1999). Analysis of Air Quality Data Using Positive Matrix Factorization. Environ. Sci. Technol. 1999, 33, 635-641. 10.1021/es980605j. American Chemical Society.

Pielke Sr. R.A., Adegoke, J., Beltran-Przekurat, A., Hiemstra, C.A., Lin, J., Nair, U.S., Niyogi, D. & Nobis, E (2007) An overview of regional land-use and land-cover impacts on rainfall. Tellus 59B (3), 587-601.doi:10.1111/j.1600-0889.2007.0025.x

Pinzon J., Brown M.E., Tucker C.J. (2004). Satellite time series correction of orbital drift artifacts using empirical mode decomposition. Hilbert-Huang Transform: Introduction and Applications. N. Huang: Chapter 10, Part II. Applications

Pinzon, J. 2002. Using HHT to successfully uncouple seasonal and interannual components in remotely sensed data. SCI 2002. Conference Proceedings Jul 14-18. Orlando, Florida

Pontius Jr.R.G. & Schneider, L.C (2001) Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems and Environment 85, 239–248

Reimanna, C., Filzmoserb,C., & Garrett, R.G (2002). Factor analysis applied to regional geochemical data: problems and possibilities. Applied Geochemistry 17 185–206. PII: S0883-2927(01)00066-X. Elsevier

Sasaki, N. & Putz, F.E. (2009) Critical need for new definitions of “forest” and “forest degradation” in global climate change agreements. Conservation Letters XX**,** 1–7. doi: 10.1111/j.1755-263X.2009.00067.x

Sertel,E., Robock, A & Ormecia, C (2009) Impacts of land cover data quality on regional climate simulations. *Int. J. Climatol.* DOI: 10.1002/joc.2036.

Solomon S, Qin D, Manning M, Alley R.B, Berntsen T, Bindoff N.L, Chen Z, Chidthaisong A, Gregory J.M, Hegerl G.C, Heimann M, Hewitson B, Hoskins B.J, Joos F, Jouzel J, Kattsov V, Lohmann U, Matsuno T, Molina M, Nicholls N, Overpeck J, Raga G, Ramaswamy V, Ren J, Rusticucci M, Somerville R, Stocker T.F, Whetton P, Wood R.A, Wratt D (2007): Technical Summary. In: Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averyt K.B, Tignor M, Miller H.L (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working

Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Statheropoulos, M., Vassiliadis, N. & Pappa, A. (1998). Principal component and canonical correlation analysis for examining air pollution and meteorological data. Atmospheric Environment 32 (6)1087-1095.

Stéphenne, N.& Lambin, E.F. (2001) A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU). Agriculture, Ecosystems and Environment 85, 145–161

Stohlren T.J., Chase T.N., Pielke Snr, R.A., Kittel, T.G.F. & Baron, J.S (1998) Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. Global Change Biology 4, 495-504

Stone, Jr B. (2009) Land Use as Climate Change Mitigation. Environ. Sci. Technol. 43, 9052–9056. doi: 10.1021/es902150g

Stow, D.A., Hope, A., McGuire, D., Verbyla, D., Gamon, J., Huemmrich, F., Houston, S., Racine,C., Sturm, M., Tape,K., Hinzman L., (Professor of Water Resources), Yoshikawa,K., Tweedie,C., Noyle,B., Silapaswan,C., Douglas,D., Griffith, B., Jia,G., Epstein,H., Walker, D., Daeschner,S., Petersen,A., Zhou,L.& Myneni, R. (2004). Remote sensing of vegetation and land-cover change in Arctic Tundra Ecosystems. Remote Sensing of Environment 89, 281–308. doi:10.1016/j.rse.2003.10.018

Tucker C.J., J.E. Pinzón, M.E. Brown, D. Slayback, E.W. Pak, R. Mahoney, E. Vermote, and N. El Saleous, 2005. "An Extended AVHRR 8-km NDVI Data Set Compatible with MODIS and SPOT Vegetation NDVI Data." International Journal of Remote Sensing 26(20): 4485-4498.

Turner II, B.L., Lambin, E .F.& Reenberg, A. (2007) The emergence of land change science for global environmental change and sustainability. PNAS. Vol. 104 (52), 20666–20671, doi_10.1073_pnas.0704119104.

UNDP-UNEP (2009): *Mainstreaming Poverty-Environment Linkages into Development Planning: A Handbook for Practitioners* available online at www.unpei.org

Verburg, P.H., Eickhout, B. & Meij, H (2007) A multi-scale, multi-model approach for analyzing the future dynamics of European land use. Ann Reg Sci. doi 10.1007/s00168-007-0136-4.

Verburg, P.H., Schulp, C.J.E., Witte, N & Veldkamp, A (2006) Downscaling of land use change scenarios to assess the dynamics of European landscapes. Agriculture, Ecosystems and Environment 114, 39 - 56. doi: 1 0.1016/j .agee.2005.11.024

Weng, Q (2002) Land use change analysis in the Zhujiang Delta of China using Satellite remote sensing, GIS and stochastic modelling. Journal of Environmental Management 64, 273–284 doi:10.1006/jema.2001.0509.

Wenshi Lin, Lu Zhang, Dongsheng Du, Limin Yang, Hui Lin, Yuanzhi Zhang , Jiangnan Li (2009): Quantification of land use/land cover changes in Pearl River Delta and its impact on regional climate in summer using numerical modelling. Reg Environ Change (2009) 9:75–82. doi 10.1007/s10113-008-0057-5

Wilby R.L., Charles S.P., Zorita E., Timbal B., Whetton P., and Mearns L.O. (2004). Guidelines for use of climate scenarios developed from statistical downscaling methods. TGICA. IPCC Supporting Materials. http://www.ipcc-data.org/guidelines/dgm_no2_v1_09_2004.pdf

Lin, Y.P., Hong, N,M., Wu, P.J., Wu, C.F & Verburg, P.H (2007) Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. Landscape and Urban Planning 80, 111–126.

Paper II: Terrestrial ecology response to climate change and implications for adaptation in the wooded Savannah of Nigeria

Mayowa Fasona[1*], Mark Tadross[2] & Ademola Omojola[1]

[1] Laboratory for Remote Sensing & GIS, Department of Geography, University of Lagos, Nigeria
[2]Climate Systems Analysis Group, Environmental & Geographical Sciences Dept, University of Cape Town, South Africa

*Corresponding author: mfasona@unilag.edu.ng, / mfasona@yahoo.com

Abstract
Climate change as one of today's greatest human security challenges is expected to have significant impact on natural resource systems and rural livelihoods in dry and semi-dry environments where large population depends on natural resource stock. Climate and landcover interaction is a two way feedback. Understanding the implication of this feedback for climate change adaptation requires detailed and local knowledge. Several studies in land surface climatology have attempted to simulate landcover impact on climate, but only few have attempted to study climate feedback on landcover. Integrated remote sensing and GIS models have the potential to compliment regional climate models to analyze climate-landcover relations at high spatial resolution.

This study presents evidence that climatic elements and local forcing have the potential to influence future pattern of landcover over time and space. Classified landcover image maps derived from Landsat data for 1986, 2000 and 2006 formed the base landcover data. Change drivers developed by integration of Markov probabilities matrix, transition areas and conditional probability for landcover classes with suitability maps of rainfall, maximum temperature and local eco-geographic drivers were used to simulate future landcover from 2006 to 2046 using Idrisi's dynamic CA_Markov model under present and future climate scenarios.

Recovery from the droughts of the 1970s and 1980s was suggested by increased canopy ecosystems and significant decrease in shrub/grassland, bare surface and fire scar. Under present climate scenario urban lands is projected to progressively increase by about 270% from about 577km^2 in 2006 to 2136km^2 representing 5.4% of total landcover in 2046. A corresponding increase in area under cultivation is also projected with a peak of about 12% of total landcover in 2016 (from 8% in 2006) which stabilizes around 10% from 2026 to 2046. The largest growth of settlements and cultivated lands is projected for the areas around the northwest-southeast corridor especially the headwaters of Ogun river (*Oke-ogun*) areas. Although total forest area is expected to decline by about 378km^2 between 2006 and 2046, its overall coverage as percent of total landcover is projected to increase to 18% in 2016 and stabilizes around 15% from 2025 to 2046. The strongest transition gain of 110% over 2006 coverage is expected from shrub and grassland. Projection based on future climate suggests significant decline in the coverage of the two canopy ecosystems – forest and woodland- and some others from 2016 to 2046. Galleria forest - a signature of the upper Guinea and Sudan savannah - is projected to dominate presently forested landscapes. Shrub and grassland will be much more widespread. A shift in rural settlement and agrarian landuse is also expected with more settlements and cultivated lands emerging around the middle areas especially at precinct of the protected area. Aggressive vegetation and albedo enhancement and ecotourism are tipped as viable climate change mitigation options. Adaptation strategies will benefit from existing project platforms that address local natural resource systems, rural livelihoods, resource conflicts, and community driven development.

Keywords: climate, landcover change, CA-Markov, factor maps, change drivers, mitigation, adaptation, savannah, Nigeria

1. Introduction

Climate change has been described as one of the greatest threats facing future societies (Martens *et al*.2009) with expected significant impact on the natural resource systems. Regions such as sub-Saharan Africa that are highly dependent on natural resources and also possess low adaptive capacity due to poverty, lack of infrastructure, services, and appropriate governance will be most severely affected (Muller, 2009). The dry and semi-dry environments of West Africa will be especially affected because they are projected to get drier in future scenario and they harbour large population which will make resource competition and conflict fiercer.

Landuse and cover change (LUCC) is an index of ecosystems perturbation and significant regional natural and anthropogenic disturbance to the environment in space and time. LUCC change is central to global change processes and has strong influence on socio-ecological processes including carbon sequestration and intake, biogeochemical flows, soil fertility, land-atmosphere interaction, net primary production, heterotrophic respiration, supply of ecosystems good and services, and human-environmental interactions (Verburg *et al*. 2002, Verburg *et al.* 2000, Desanker *et al*. 1997, Li *et al*. 2009, Neigh *et al*. 2008, Cao & Prince, 2002). Landcover is a primary site for exchange of water, energy, and momentum between land and atmosphere (Hoffman & Jackson, 2000). It also gives clue to changes in other biophysical systems and processes that keep the biosphere alive. Globally, Landcover change (including land degradation and deforestation) is expected to account for about 18 percent of Co_2 equivalent emissions (Neely *et al*. 2009) and changes in climate and landuse/landcover (LULC) have the potential to create major changes in land surface temperature, watershed runoff, and ecosystem productivity. Accurate quantification of terrestrial ecosystem carbon fluxes is a fundamental need for realistic projection of atmospheric Co_2 concentrations and climate change (Cao & Prince, 2002). Changes in land and ecosystems and their implications for global environmental change and sustainability are therefore important challenge for human-environmental systems (Turner II *et al*. 2007).

Rapid transition from one landcover to another can enable continued provision of some ecosystem services including provision of food and fibre. It can also significantly compromise other services such as climate regulation, soil fertility and watershed protection (Kuemmerle, *et al.* 2009). Change in land that leads to reduction or loss of surface vegetative cover can impact water supply by altering hydrological processes (Neely *et al*. 2009, Lin *et al*. 2007, Hoffmann & Jones 2000, Stohlgren et al. 1998) which increase severity and extent of degradation and reduce land resilience to drought and adverse conditions. Forests are a significant terrestrial sink of global carbon (Pielke Sr *et al*. 2007). Terrestrial ecosystems drive most of year-to-year variations in atmospheric Co_2 (Cao & Prince, 2002) and as much as 35% of the human-induced Co_2 equivalents in the atmosphere today can be traced to the totality of LULC changes (Turner II *et al.* 2007). In addition to their mitigation potential vegetative cover play a significant role in human and environmental health. Nothing possibly suggests the impact of climate change on the environment and livelihoods than the imprints created by human attempts to grapple with the impacts of diminishing land resources occasioned by climate change. Regulating LUCC to compliment greenhouse gas (GHG) emission reduction presents a potential for mitigating climate change (Stone Jnr 2009).

2. Background

The historical interaction between climate and ecosystems needs be understood in the context of today’s need for climate mitigation and adaptation measures. Ecosystems influence climate through multiple pathways, primarily by changing the energy, water, and greenhouse-gas balance of the atmosphere (Chapin *et al*. 2008). While land cover change may have positively influenced the pre-industrial climate (Solomon *et al*. 2007), increase in temperature and decline in rainfall that characterise today's climate is projected to have very strong negative impacts on terrestrial ecosystems. Climate may become a dominant driver of ecosystems change and biodiversity loss in future (Leary *et al.* 2007). In dry and semi-dry environments where agriculture is predominantly rainfed, a decline in precipitation occasioned by a change in landuse and cover may also have considerable ecological and economic consequences (Hoffmann & Jones 2000, Omotosho & Abiodun, 2007). Sub-Saharan Africa (SSA) has been projected to get drier in future scenario. Current temperatures are predicted to increase in the order of 1.4 to 5.8°C by 2100 (Solomon, *et al.* 2007) depending on the emission scenario. Rainfall is also projected to become more erratic in space and time distribution as already noted in West Africa (Abiodun *et al*. 2008, Afiesimama *et al*. 2006, Nicholson, 2000) where agriculture is predominantly rainfed. The water footprint is definitely going to be important in defining future trajectory of agricultural lands, and the challenge will overwhelm the current traditional agriculture and water management practices. Landcover change and conversions is expected to play significant role in future climate of West Africa (WA) where large population relies on dry and semi-dry land agriculture. Competing demands among various landuses including cropland, forestry, rangeland, agrofuels, and urban in the face of climate change and variability has already increased the dimensions of human security (Neely *et al.* 2009, Fasona & Omojola, 2005).

Although the impact and contribution of LULC as a climate forcing is recognised (Solomon *et al.* 2007), it is still not generally seen in international climate assessments as having a role on precipitation that is at least as large as caused by the radiative effects of human addition of added well-mixed greenhouse gases (Pielke Sr *et al*. 2007). Current evidence also suggests that landuse is playing a measurable and significant role in ongoing climate change at multiple geographic scales and through a set of mechanisms independent of greenhouse gases (GHG) emissions (Stone Jnr, 2009). Long-term climate patterns have control on vegetation type and canopy structure. The potential linkage between vegetation and climate is becoming better established in land surface climatology. Sensitivity experiments using simple extreme scenarios for effect of tropical deforestation and complete removal or drastic change from one vegetal cover to another (e.g. from forest to grassland) using general circulation models (GCMs) give valuable insights into the dynamics of land–atmosphere interaction (McKellar *et al*. 2009). In addition, some dynamic regional climate models now have land surface model with more complex spatial patterns of vegetation change that is within the range of observed land-surface alteration as component of their parameterization schemes. This latter group has been used to carry out regional climate experiments that have provided useful insights into potential feedbacks between vegetation and temperature, rainfall, wind, albedo, cloud formation, enhanced shortwave radiative forcing, moisture fluxes, surface roughness, etc (Fuller & Ottke 2002, Pielke Sr *et al*. 2007, Taylor *et al*. 2002, Abiodun *et al*. 2008; Afiesimama, *et al*. 2006, Wang & Eltahir 2000; MacKellar *et al.* 2009; Hoffmann & Jackson 2000, Stohlgren *et al*. 1998, Nicholson, 2000, Lin *et al*. 2009, Sertel *et al*. 2009). The degree to which landcover change in particular can feedback to impact local climate still represents an element of uncertainty in the climate projections (Hewitson and Crane 2006).

While the GCMs and RCMs have provided good insights into climate-landcover feedbacks at regional scale, their spatially-coarse landcover parameterisations often mask large differentials in actual characteristics of landcover types. Details about mesoscale circulation features induced by landscape heterogeneity (Pielke Sr *et al.* 2007, Stohlgren *et al*. 1998) and local processes which are important for location-specific, place based decisions on issues such as ecosystems management and climate change adaptation are effectively eliminated. Many impact applications require the equivalent of point climate observation and are highly sensitive to fine scale climate variations that are parameterised in coarse scale in climate models. This is especially true of regions with complex landuse and heterogeneous landcover, topography and island locations (Wilby, *et al*. 2004, Hewitson and Crane 2006). There is also evidence that climate also induces changes in vegetation cover and composition which needs to be monitored at different spatial scales (Stow, *et al*. 2004, Turner II *et al* 2007) in the face of global change challenges. Dynamic simulation of climate-vegetation projection over a long range require a good understanding of the major human causes of land-use changes in different geographical and historical contexts as well as an understanding of how climate variability affects both landuse and landcover (Stephenne and Lambin, 2002).

Climate-landcover interaction is a two way feedback. Understanding the real implication of vegetation-climate feedbacks in tropical Savannah requires detailed and local knowledge in several areas (Hoffmann & Jones, 2000). Just as landcover alters climate, changes rainfall and temperature also alter the distribution of landcover across space and time. While reduction in rainfall coupled with rise in temperature influence the presence and distribution of specific ecosystems and species (German Advisory Council on Climate Change, 2008, Solomon, et al. 2007), changes on a broader scale such as transition of woodlands or deciduous forests to grasslands and pastures is expected especially under poor soil management and unsustainable land practices. In some cases, spatial reorganization of agricultural lands to take advantage of 'suitable' lands with corresponding reorganisation in the pattern of agrarian settlements is also expected especially in rural environments with rapid population growth. Climate model is not end in itself; it needs be connected to other environmental and social-ecological dimensions on ground. Land change models developed by integration of remote sensing and geographic information systems provide extended potential to compliment climate models to provide insight into impact of climate on landcover at fine spatial resolution. In this study we present evidence that climatic elements combined with local eco-geographic forcings have the potential to influence the future pattern of landuse and cover, define trajectory of future agriculture and locational pattern of agrarian communities in the wooded savannah of Nigeria

3. Material and Methods

3.1 Regional setting

The case study area is roughly defined by Lat. 8^0 to $9^0 15^1$ and Lon. $3^0 50^1$ to $5^0 50^1$ covering about 40,000km^2 in west-central Nigeria including part of the States of Kwara, Niger, Oyo, Osun, Ekiti and Kogi and extends to the boundary with Benin Republic in the west (Fig 1). It falls within the wooded Savannah, which approximates the transitional zone between the southern rainforest and the tropical guinea savannah with a vegetation type that composed of a mixture of trees and grasses (Hoffmann & Jackson 2000). The wooded savannah also typifies the area referred to as derived savannah (Adejuwon 2006) and part of the southern guinea, a zone of moist peri-forest mixed with a savannah of anthropic degradation and patchy landscape (Bucini & Lambin 2002, Hoffmann & Jackson 2000*)*. The area is covered mainly by undifferentiated basement complex, recent alluvium along the floodplain and Nupe sandstone formations to the north-eastern axis. Soils consist of deep well drained sandy loam soils and poorly drained sandy clay loam subsoil along the Niger floodplain.

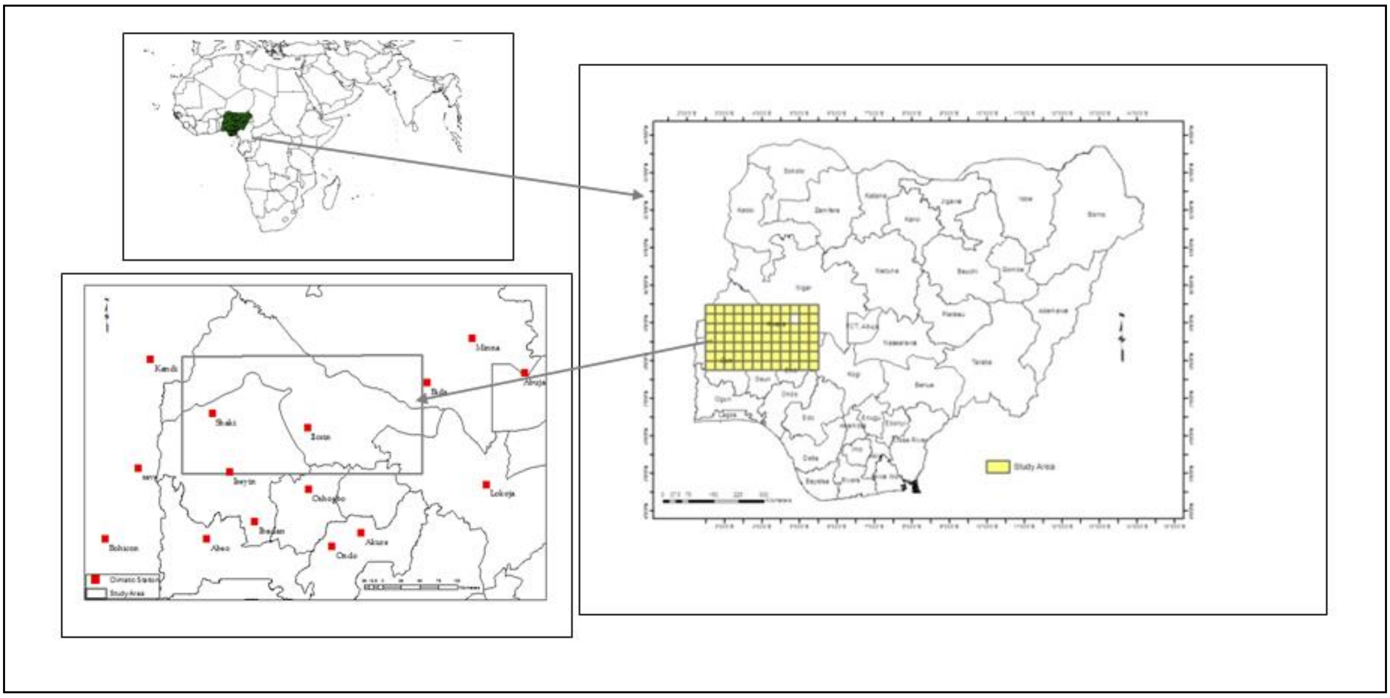

Fig 1: Study area with climatic stations

It is characterized by *a* sub-humid Koppen's *Aw* (Kottek *et al*. 2006) climate with annual rainfall between 900mm and 1300mm. It shares the double maximum rainfall pattern (with peaks in June/July and September) with the southern rainforest but with highest monthly rainfall of about 220mm occurring in September. Maximum temperature range is between 28 and 36^0c with February/March being the hottest months. Rainfall is perhaps the most important climatic characteristic which determines the rhythm of human activity in the Nigerian Savannah. Change in rainfall quantity and regime is a strong index of climatic variability and a critical limiting factor to human survival. The onset and cessation of the rains are controlled by what Nicholson (2009) has now described as the rain-belt movement produced by a large core of ascent lying between the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ). This rain-belt movement also corresponds to the southern track of African Easterly Waves (AEW) that distributes the rainfall. The mesoscale processes still predominate and providing over 75% of rainfall in the region (Omotosho & Abiodun 2007) with the sea surface temperature and land-sea thermal contrast responsible for inter-annual variability in rainfall onset and retreat dates (Odekunle *et al*. 2005). The development and prosperity of the region has been largely dependent on fluctuations in rainfall through the historical times. The prolonged Sahel drought of the 1970s to 1980s also seriously affected the area. Over the last several years, the wooded savannah has experienced an increase in rainfall comparable to the amounts in the decades prior to the onset of the drought (Anyamba & Tucker 2005). Some large and small scale water resource schemes with specific aim of diverting seasonal river flows for developmental purposes emerged after the droughts. However, there is a possibility, that the additional water need created by higher temperatures may not be met by the increase in rainfall. This means the area may get drier in future scenario and the water footprint will become critical for agriculture and human livelihood.

The Nigerian Savannah is a densely populated area with strong poverty-environment linkage. With an average population density of about 160 (which is by far higher in urban areas), survival for large rural population depends on small-holder rain-fed agriculture (Afiesimama *et al*. 2006, Fasona et al. 2007, Odekunle *et al*. 2005), the natural capital thus contributes significantly to human well-being and the wealth of nation (UNDP-UNEP 2009). The wooded savannah in particular is becoming a zone of intense land-use pressure. Humans have increased the frequency of fire and burning now typically occurs at intervals especially at dry periods. Forest land conversion to agriculture and pasture and incursions into marginal lands is rapid and harvesting of trees for fuel wood and charcoal is an important livelihood activity reducing tree density (Kneely *et al* 2009) and decimating woodlands (Akinbami *et al.* 2003). It is a delicate ecological zone between the drier savannahs of the north and the moist tropical rainforest of the south. It is an important zone for root, tuber and cereal (mainly maize and sorghum) cultivation. Because of its large pasture undergrowth, the area has in recent years been targeted as an important extensive grazing area by migrating pastoralists from the Sudan and Sahelian zones especially in dry periods and this has increased the frequency of land resource conflict (Fasona & Omojola 2005, Obioha 2008) with farmers widely experiencing material and farm income losses and cattle rearers' encroachment on peasant farms now becoming a major impediment to increased cassava cultivation (Adisa & Adekunle 2010).

3.2 Data and data sources

3.2.1 Image data

Six georeferenced and Orthorectified image scenes Landsat5 TM (p190r054 acquired 15 November 1986), Landsat4 TM (p191r054 acquired 27 December 1990), Landsat7 TM (p190r054 acquired 13 November 2000), Landsat7 TM (p191r054 acquired 06 February 2000), Landsat7 TM (p190r054 acquired 14 November 2006), and Landsat7 (p191r054 acquired 18 November 2005) from the Landsat Geocover datasets (www.landcover.org/data/) were downloaded. The image scenes were processed and used to derive LULC maps as input into the Cellular Automata-Markov (CA_MARKOV) land change model.

3.2.2 Terrain

Terrain derivatives including slope, aspect and spot heights were generated from the 3 arc-second elevation data from the Shuttle Radar Topography Mission (SRTM) from the GLCF archive (http://www.landcover.org/data/srtm/). The STRM data, an international project spearheaded by the National Geospatial-Intelligence Agency (NGIA), National Aeronautics and Space Administration (NASA), Italian Space Agency (ASI) and the German Aerospace Center (DLR) was obtained using specially modified radar system onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. The WRS-2 scenes SRTM_ffB03, p190r054 and p190r054 were used seamlessly with the Landsat Geocover datasets.

3.2.3 Climate and climate data downscaling

Daily observed rainfall and maximum temperature (for between 25 and 50 years depending on length of observation records) for 12 climatic stations around the study area (Fig 1) was sourced from the Nigerian Meteorological Agency. To ensure a representative interpolation data for 3 nearer stations in Benin Republic were accessed from the data portal of the Climate Systems Analysis Group (CSAG), University of Cape Town (www.csag.uct.ac.za). Downscaling of rainfall and maximum temperature data was performed in CSAG. Statistical downscaling technique which match global circulation model (GCM) data with self organised map (SOM) characterisation of atmospheric states forced by SRES A2 emissions scenario (Hewitson and Crane, 2006) was used. The driving GCMs for the downscaling are from the Coupled Model

Intercomparison Project phase 3 (CMIP3) archive (see http://www-pcmdi.llnl.gov/projects/cmip/Table.php). Empirical downscaling is a widely used technique for exploring the regional and local-scale response to global climate change as simulated by comparatively low-resolution global climate models (Hewitson and Crane, 2006).

Climate data downscaling represents the cross-scale relationships between the larger scale circulation (from the GCMs) and local climate responses. It is based on the premise that the local-scale climate is in some measure a response to the larger, synoptic-scale forcing (Wilby *et al*. 2004). Observational data are used to derive a relationship between the synoptic-scale and local climates, and that relationship can then be used with comparable resolution fields of a GCM to generate information on the local climate consistent with the GCM forcing (Hewitson & Crane, 2006, Wilby *et al.* 2004). Empirical downscaling is important for generating regional and local scale scenarios of future climate to make climate change information available for impacts and vulnerability assessments, policy formulation, and climate change adaptation at regional and local scales. It has the advantage to downscale to point scales – a scale that matches the observational data characteristics that the impacts community are commonly used to. Downscaled projections of climate data also provide regional detail that is consistent with the actual spatial gradients over the region.

The downscaling process, apart from reproducing the observation data, yields present and both near-future (2046-2065) and far-future (2081-2100) climate projections for 10 different GCMs and NCEP reanalysis. Model output comparison studies often use statistical approach and sometimes combine integrations from different models to form large ensemble sets. Cook and Vizy (2006) have evaluated 18 coupled GCM outputs (including the 10+NCEP GCM downscaling model output from CSAG) at the process level to diagnose only those models that are best suited for capturing the West African monsoon climate and its variability. The MRI CGCM 2.3.2 (developed by the Meteorological Research Institute, Japan) was found to provide the most reliable simulation of the twenty-first century climate over West Africa (Cook & Vizy, 2006). It has a pressure at the top of the atmospheric model of 0.4hpa, and the horizontal and vertical resolution at top is T42 (~2.8°x2.8^0), L30 (Muller, 2009, Cook & Vizy, 2006). The broad variety of climate projections, considering all models and driving scenarios, cannot possibly be considered in its full breadth in smaller impact research projects (Muller 2009). And since inter-comparability of models output is secondary to this study, the MRI CGCM 2.3.2 was adopted for describing the future climate of the study area.

3.2.4 Other datasets

Other datasets accessed and included in the integrated analysis include soil data from the 1:650,000 digital Soils map of Nigeria produced by the Soils Survey Division of the Ministry of Agric and Natural Resources, Abuja. Data on forest reserve/protected areas was derived from the 1:250,000 Vegetation and Land use maps produced in 1995/96 by the Forestry Resources Mapping, Evaluation and Coordination Unit (FORMECU) of the Ministry of Agric and Natural Resources, Abuja. Population census figures linked to Local Government Area (LGA) levels was accessed from the data archive of the Nigerian National Bureau of Statistics (http://www.nigerianstat.gov.ng/nbsapps/Connections/Pop2006.pdf). Other government administrative data sources were accessed for data on place names and information on rural development projects.

3.3 Procedure

3.3.1 Framework

The basic scientific explanation is inductive approach proceeding from aggregation of particular spatial datasets to generate integrated results. These results become input a higher order analysis (Fig 2). The framework consists of acquisition and processing of 3 groups of datasets: land surface, climate, and ancillary datasets required for building factor maps and change drivers.

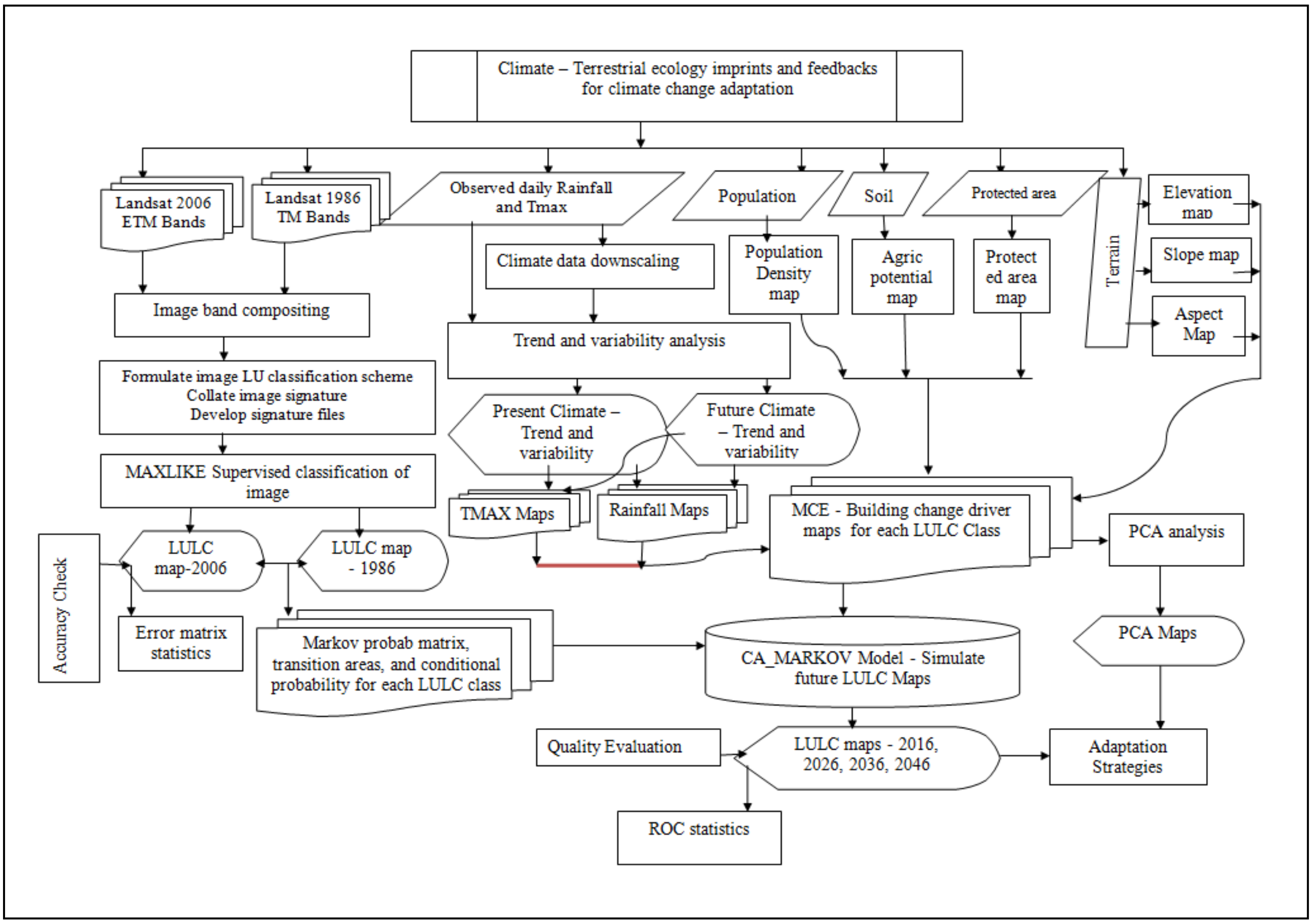

Fig 2: Study framework

The Landsat images were subjected to band compositing in Idrisi Taiga 15.04. A landcover classification schema (derived from the USGS land classification scheme (Anderson *et al*. 1976) was developed through a rigorous process that combines collation of landcover signatures during field reconnaissance, accumulation of spectral signatures from composited imageries to ensure inter-image consistency, and analysis of landcover classification used for the FORMECU 1:250,000 vegetation maps. To build training data for supervised classification, signatures were collated for 25 classes. The training sites were well defined with large sample sizes and maximum likelihood (MAXLIKE) algorithm was adopted. MAXLIKE is a hard classifier which yields decision about identity of each pixel based on probability density function associated with a particular training site signature. Pixels are assigned to the most likely class based on a comparison of the posterior probability that it belongs to each of the signatures being considered (Eastman, 2009, Weng, 2002). Subsequent refinement of the classification outputs for consistency and representation enables the reduction of the classes from 25 to 13 used in the final maps. Accuracy check was done and the classification output was subjected to Markovian probability estimator to generate conditional probabilities for prediction of future landcover change. Observed and downscaled rainfall and maximum temperature values were analysed for seasonal trends and variability. Present and future rainfall and temperature surfaces (maps) were generated and used as factor input into the suitability (change driver) maps. Factor maps for soil agricultural potentials, protected area, and population density were generated. Terrain derivatives including spot height and contour maps, slope, and aspect maps were also included. These maps were integrated with the climate maps and subjected to multi-criteria analysis to build change drivers as input into the CA-Markov model.

3.3.2 Model description and experimental set-up

Land change models are complex, owing to their coupling of human and environmental dynamics and to their need to be spatially explicit (Turner II *et al*. 2007). One basic assumption is to regard LULC change as a stochastic process and different LULC categories as the states of the chain (Weng 2002). Markov-type models constitute some of the historically most common methods of predicting change among various categorical states. The CA_Markov is spatially explicit, allows any number of categories, and can simulate the transition from any category to any other category (Eastman, 2009) which means it can theoretically model a wider variety of simultaneous processes. It is an agent based predictive land change model which essentially combines Markov conditional probabilities and transition areas for each LULC category with suitability map for each category to predict future LULC. Models of LULC change vary enormously in terms of assumptions concerning number of possible categories, types of category transitions, spatial dependency, feedbacks, cross-scale linkages and data requirements. An understanding of the major human causes of LULC changes and how climate variability affects LULC change is also important (Stephenne & Lambin, 2002). The selection of assumed predictor variables also relies on prevailing assumptions and theories on change drivers and knowledge of the local conditions (Verburg *et al*., 2002, Hagget & Chorley, 1967). Some of which may concern highly complex behaviours such as interactions among agents (Pontius & Malanson, 2005, Cabral & Zamyatin, 2006*)*. CA_Markov deals with complications associated with competition in land change among different pixels by implementing a multiple objective land allocation (MOLA) algorithm. The spatial explicity property enables the model to predict the quantity and location of each category using suitability map for each transition that it extrapolates. At every time step, CA_Markov determines the number of pixels that must undergo each transition, then selects the pixels, according the largest suitability for the particular transition (Pontius & Malanson 2005, Eastman 2009).

The Markovian process is a first order process (Lambin 1997) in which the state of a system at time 2 (t_2) can be predicted by the state of the system at time 1 (t_1) given a matrix of probabilities from each cover class to every other cover class. LULC change and land degradation in dry and sub-humid areas of Africa tend to be compatible with this first order dependency because of heterogeneous cover classes and complex landuse systems. As input the Markovian process, the CA_Markov takes two landcover maps (from time t_1 and t_2) and generate as outputs: a transition probability matrix, a transition areas matrix, and a set of conditional probability maps, one for each landcover class. The Cellular Automata (CA) component of the model allows the transition probabilities of one pixel to be, not only a function of the previous state, but also of the state of the local neighbourhood i.e. neighbouring pixels. It also helps during iteration in filtering process that reduces the suitability of land away from existing areas of that type. The CA component thus provides the model with some explanatory power. The net result is that landcover changes develop as growth process in areas of high suitability proximate to existing areas (Eastman, 2009, Pontius & Malanson, 2005, Pontius & Schneider, 2001, Hall *et al*. 1995). The landcover maps derived from Landsat Geocover imageries for 1986 and 2006 were used as input into the CA_Markov model. From these, the Markov sub-model generates a transition probability matrix (Table 1) a transition areas matrix (Table 2) and a set a set of conditional probability maps (Fig 3), one for each landcover category.

Table 1: Markov transition areas (2006-2016)

	Expected to transit to:												
Cells in:	Cl. 1	Cl. 2	Cl. 3	Cl. 4	Cl. 5	Cl. 6	Cl. 7	Cl. 8	Cl. 9	Cl. 10	Cl. 11	Cl. 12	Cl. 13
Cl.1	412197	0	0	29487	21319	70898	69041	19035	455	10927	0	1932	3520
Cl.2	33566	6867953	1542517	3577644	161390	772124	453499	225647	6100	89181	5173	67745	417602
Cl.3	0	2016641	4187767	527590	0	0	68510	41609	16036	15814	0	0	52755
Cl.4	78082	377739	568246	928927	207497	1000239	1648636	666773	20218	184211	3144	0	50799
Cl.4	516	669197	12782	0	267582	8926	445616	407181	20483	0	836	0	0
Cl.6	117679	332526	0	547471	207336	979483	1073897	199037	0	112605	1299	9503	34544
Cl.7	19450	3147379	737274	302468	378903	406440	1963685	411171	0	61273	281	0	0
Cl.8	13386	492219	0	268058	371871	201793	902825	221195	2523	22749	0	0	0
Cl.9	132	0	0	7703	23486	0	0	2533	272542	2686	0	0	760
Cl.10	15516	19253	43252	81266	16312	117840	120237	84259	1723	32823	1316	119	9385
Cl.11	594	0	0	3569	3918	411	0	1270	2745	0	284	0	0
Cl.12	453	7790	21851	8577	1376	7493	7106	6869	448	1516	88	0	302
Cl.3	27575	108379	0	142219	15126	72402	0	35452	573	1805	0	16989	41535

Table 2: Markov conditional probability matrix (2006 to 2016)

	Probability of change to:												
Given	Cl. 1	Cl. 2	Cl. 3	Cl. 4	Cl. 5	Cl. 6	Cl. 7	Cl. 8	Cl. 9	Cl. 10	Cl. 11	Cl. 12	Cl. 13
Class1	0.6453	0	0	0.0462	0.0334	0.111	0.1081	0.0298	0.0007	0.0171	0	0.003	0.006
Class2	0.0024	0.483	0.1085	0.2516	0.0113	0.0543	0.0319	0.0159	0.0004	0.0063	0.0004	0.0048	0.029
Class3	0	0.291	0.6046	0.0762	0	0	0.0099	0.006	0.0023	0.0023	0	0	0.008
Class4	0.0136	0.066	0.0991	0.162	0.0362	0.1744	0.2875	0.1163	0.0035	0.0321	0.0005	0	0.009
Class4	0.0003	0.365	0.007	0	0.146	0.0049	0.2431	0.2221	0.0112	0	0.0005	0	0
Class6	0.0325	0.092	0	0.1514	0.0573	0.2709	0.297	0.0551	0	0.0311	0.0004	0.0026	0.01
Class7	0.0026	0.424	0.0993	0.0407	0.051	0.0547	0.2644	0.0554	0	0.0082	0	0	0
Class8	0.0054	0.197	0	0.1074	0.1489	0.0808	0.3616	0.0886	0.001	0.0091	0	0	0
Class9	0.0004	0	0	0.0249	0.0758	0	0	0.0082	0.8796	0.0087	0	0	0.003
Class10	0.0286	0.035	0.0796	0.1496	0.03	0.2169	0.2213	0.1551	0.0032	0.0604	0.0024	0.0002	0.017
Class11	0.0464	0	0	0.279	0.3063	0.0321	0	0.0993	0.2146	0	0.0222	0	0
Class12	0.0071	0.122	0.3421	0.1343	0.0215	0.1173	0.1113	0.1075	0.007	0.0237	0.0014	0	0.005
Class13	0.0597	0.235	0	0.3078	0.0327	0.1567	0	0.0767	0.0012	0.0039	0	0.0368	0.09

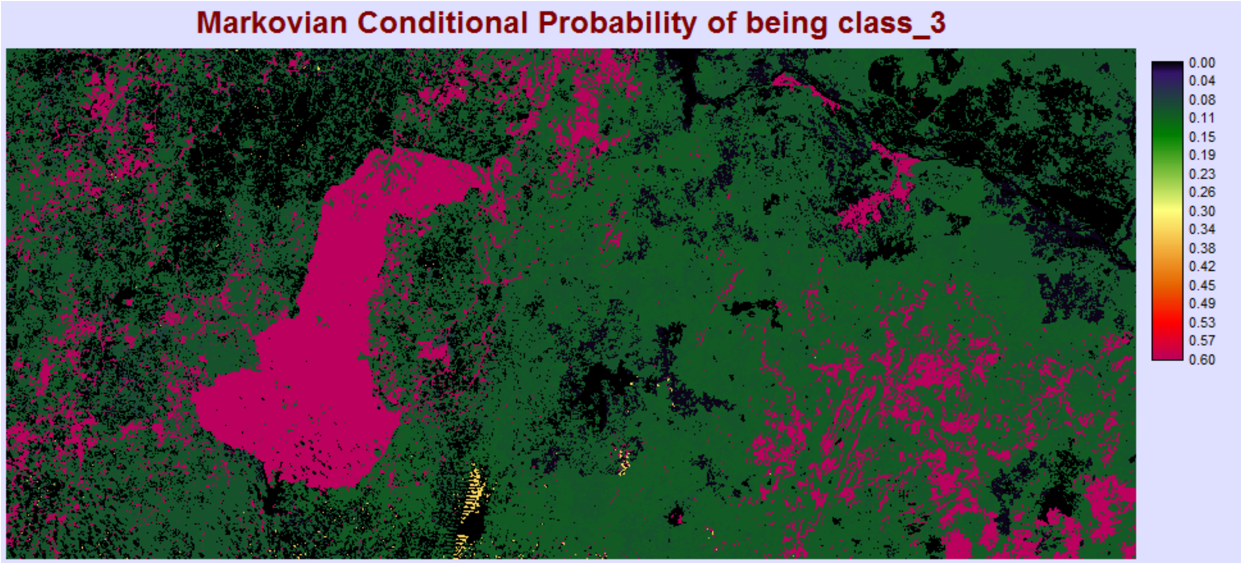

Fig 3: Markovian conditional probability of being class 3 (forest)

3.3.3. Preparation of suitability maps

The processes described here involve conversion, transformation and integration of several raster and vector data layers. Hence, we used tools from both Idrisi Taiga 15.04 and ArcView9.2 to achieve this. The suitability maps (one for each LULC category) were generated using the MCE module of Idrisi Taiga 15.04. These suitability maps are integration of the driver maps generated from the climate and other datasets which were prepared within ArcView GIS. Each data layer was standardised and converted into the integer format acceptable to the MCE module. The drivers maps (factor maps) defined as criteria in the MCE are divided into factors and constraints. Factors are generally continuous in nature (such as the slope, elevation, rainfall) and indicate the relative suitability of certain areas. Total weight point for all the factors must equal 1. Constraints are Boolean (0 or 1) and include criteria such as distance to water body, soil potential for agriculture. They serve to exclude certain areas from consideration. Factors and constraints were combined in the MCE module using weighted linear combination (WLC) which combines the weighted factors and constraints. It allows for trade-off between factors and average risk. The higher the factor weights the more its influence on the final suitability map.

Of the initial 13 criteria defined, 5 was eliminated for collinearity and only 8 was used to generate final suitability maps for the 13 LULC categories (Table 3, Fig 4a&b).

Table 3: Criteria for generating suitability maps in MCE

Code	LULC Class	Factors and score	Constraints
1	Urban	Elevation (0.6)+ slope (0.4)	distance to water body and protected areas
2	woodland	Mean annual rainfall (0.6)+ mean maximum temperature (0.4)	soil potential for agric
3	forest	Mean annual rainfall (0.4)+ mean maximum temperature (0.4) + Elevation (0.2)	soil potential for agric
4	Shrub/grassland	Aspect (0.6)+ mean maximum temperature(0.4)	
5	wetland	Aspect (0.4)+ Mean annual rainfall (0.6)	mean maximum temperature
6	cultivation/commercial agric	Mean annual rainfall (0.6)+ mean maximum temperature (0.4)	soil potential for agric
7	farmland/fallow/grazing area	Mean annual rainfall (0.6)+ mean maximum temperature (0.4)	distance to water body

8	Floodplain agric	Mean annual rainfall (1)	soil potential for agric
9	water	Mean annual rainfall (1)	mean maximum temperature
10	Bare surface	mean maximum temperature (0.4)+Elevation (0.4)+ aspect (0.2)	distance to water body
11	Alluvial	Mean annual rainfall (1)	slope
12	Burnt surface	Mean maximum temperature (1)	distance to water body
13	cloud/shadow	Mean annual rainfall (1)	

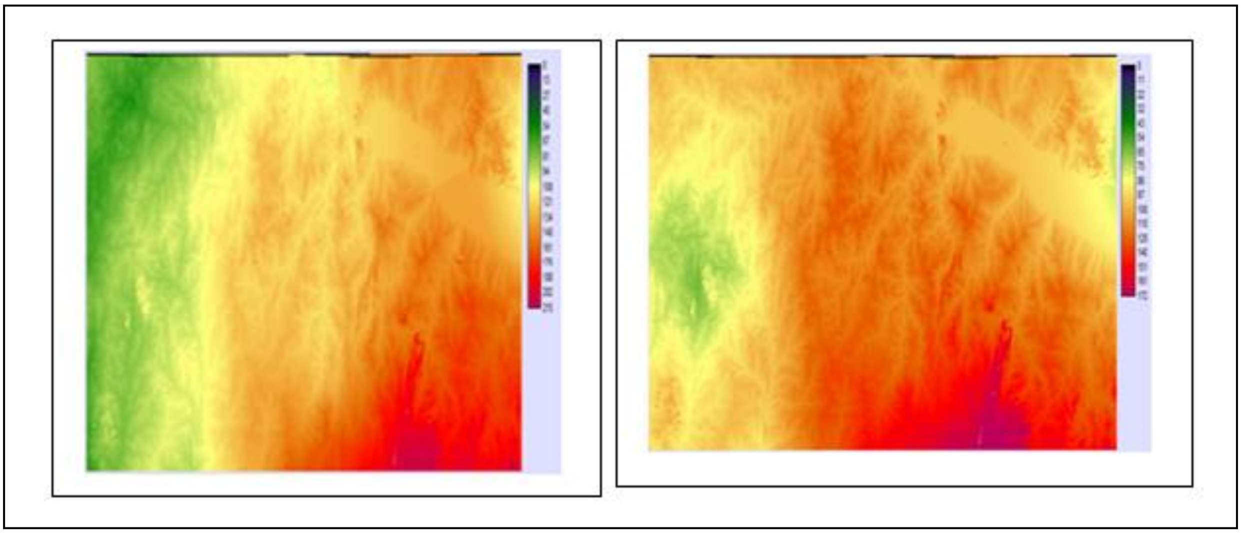

Fig 4a: Suitability map for Class 3 (forest) under present (left) and future (right) climate

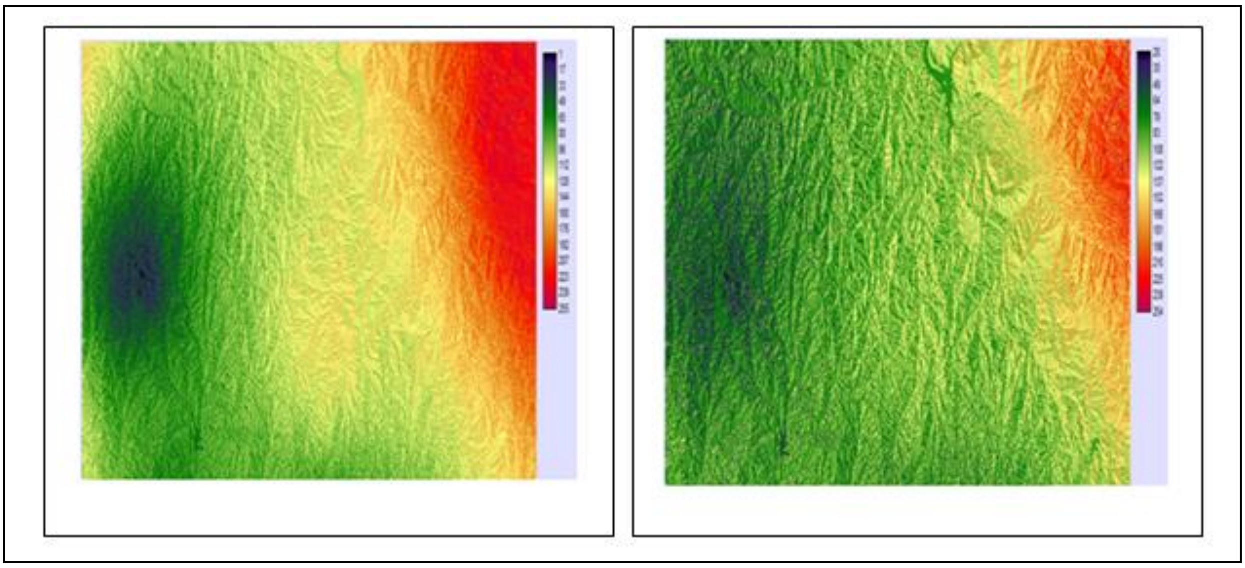

Fig 4b: Suitability map for Class 4 (shrub/grassland) under present (L) and future (R) climate

All the suitability images were combined into one image collection which becomes the transition suitability image collection that was combined with the basis landcover and transition file areas to project future landcover.

3.3.4 Model simulation

Each model run uses the suitabilities image collection with the basis landcover map (2006), Markov transition areas files and conditional probability matrices to generate a map of simulated future change, placing simulated change in cells that have the largest suitability values. If the suitability map were perfect, the order of the suitability values would match the order in which humans change the landscape, with the largest suitability values being changed first (Hall *et al.* 1995, Pontius & Schneider 2001).

Model runs were carried out for 4 scenarios: 2006 to 2016 with 10 iterations (1 year time-step), 2006 to 2026 with 20 iterations (1 year time step), 2006 to 2036 with 15 iterations (2 year time step) and 2006 to 2046 with 20 iterations (2 year time step). The use of 2-year time step for 2036 and 2046 is to reduce the computation time. To attempt a validation we used the 1986 and 2000 landcover map as basis and an additional run from 2000 to 2006 with 12 iterations (6 month time step) was also performed. The standard 5by5 contiguity filter was used. Contiguity filters normally down-weights the suitabilities of pixels far from existing areas of that class (as of that iteration) such that preference is given to contiguous suitable areas. The net effect is that to be a likely choice for landcover conversion, the pixel must be both inherently suitable and near to existing areas of that class. CA_MARKOV automatically normalizes the filter kernel to force the values to sum to 1. This filter is passed over a Boolean image for each class from the current landcover image within each iteration. Following this a value of 0.1111 is added to the filtered results to produce a set of weight images. These are multiplied by the original suitability maps to down-weight suitabilities distant from existing areas of each class. The results are then stretched back to a byte (0-255) range. The net effect is that down-weighted suitabilities never exceed a down-weighting in excess of 90% of their original value. This ensures that suitable areas can be found if none are available in proximate areas.

Within each time step, each landcover is considered in turn as a host category. All other land cover classes act as claimant classes and compete for land (only within the host class) using the multi-objective land allocation procedure. The area requirements for each claimant class within each host are equal to the total established by the transition areas file divided by the number of iterations. Whereas the demand for land by different landcover categories (i.e. transition areas and probabilities) determines the overall competitive capacity of each landcover type, the location suitability is a major determinant of the competitive capacity of each landcover types at a specific location (Verburg *et al*. 2007). We simulated the pattern of future landcover under both present and future climate scenario by carrying out two sets of simulation. The first set was done using the present climate (rainfall and maximum temperature) as a driver input into the MCE suitability images, while the second used the future climate. That means we hold other drivers as constant and change the climate drivers. This also means that same Markov conditional probabilities and transition areas were used.

4. Results

4.1 Interpreted LULC Change

Landuse and cover complexity and heterogeneity, strong resilience and rapid transition of land system as a result of human activity and natural changes are a part of the dynamics of the wooded savannah ecosystems. Footprints of small-holder, non-continuous rainfed agriculture dominates the landscape. A piece of land area serves different uses depending on people's decision and the season. Non-regulation or lack of control on landuse is a significant contributor to land resource conflict among social groups especially pastoralists and sedentary cultivators. Rainfall is a strong determinant of the rhythm of activities on land. Abandoned fields and fallow used for grazing in dry season may become small-holder farms in wet season. There is a strong association between the present productive capacity of land and the livelihood it supports. Hence, a dry year is a pointer to food shortage in the next year, while a prolonged drought such as experienced from 1970 to 1977 which also extended to 1981-1983 can spell disaster.

Table 4: LULC Matrix 1986-2006

Class	URB	WDL	FR	SHG	WTL	CUT	FMF	FPA	WTR	BRS	AL	BSF	CLD	area_86
Urban	151.3	13.6	1.0	22.3	14.2	40.3	50.2	14.7	0.6	6.1	0.0	0.9	2.1	317.4
woodland	63.3	3152.8	1001.9	1669.8	166.5	562.8	666.7	261.5	14.7	76.7	2.7	29.3	182.8	7851.6
forest	15.0	1670.0	2505.2	588.9	44.6	98.2	239.0	99.3	20.2	28.8	0.4	2.8	59.5	5371.8
Shrub/grassland	21.9	220.3	144.0	190.4	54.7	180.9	321.1	119.1	5.8	31.2	0.5	0.3	11.8	1302.1
wetland	8.5	765.1	108.4	124.9	217.6	73.7	452.1	317.5	24.8	5.2	0.8	0.0	1.5	2100.0
cultivation/commercial agric	144.6	799.9	101.3	638.9	245.2	871.9	1168.1	274.0	3.6	109.4	1.5	9.6	42.9	4411.1
farmland/fallow/grazing area	85.7	5057.7	1577.1	1199.2	584.4	844.0	2747.9	695.6	7.5	124.7	1.9	6.8	65.7	12998.1
Floodplain agric	15.5	437.3	46.3	198.6	178.0	140.3	485.3	132.3	4.2	17.7	0.1	0.3	3.6	1659.2
water	0.4	4.6	1.1	8.3	20.9	1.6	2.7	5.4	170.6	2.4	0.0	0.0	0.7	218.6
Bare surface	29.8	149.6	96.4	145.4	42.1	172.5	224.3	118.2	4.5	41.3	1.5	0.8	14.1	1040.4
Alluvial	0.7	0.1	0.2	3.1	3.5	0.8	0.9	1.5	3.4	0.0	0.2	0.0	0.0	14.3
Burnt surface	24.9	467.1	647.6	311.4	68.3	231.9	305.8	189.5	18.3	43.0	2.0	1.3	17.8	2329.0
cloud/shadow	13.4	60.1	3.5	59.7	9.8	35.1	21.5	18.4	0.7	2.5	0.0	5.4	13.3	243.4
area_2006	574.9	12798.1	6234.0	5161.1	1649.8	3253.8	6685.5	2247.0	278.9	489.0	11.5	57.5	415.9	**39856.9**

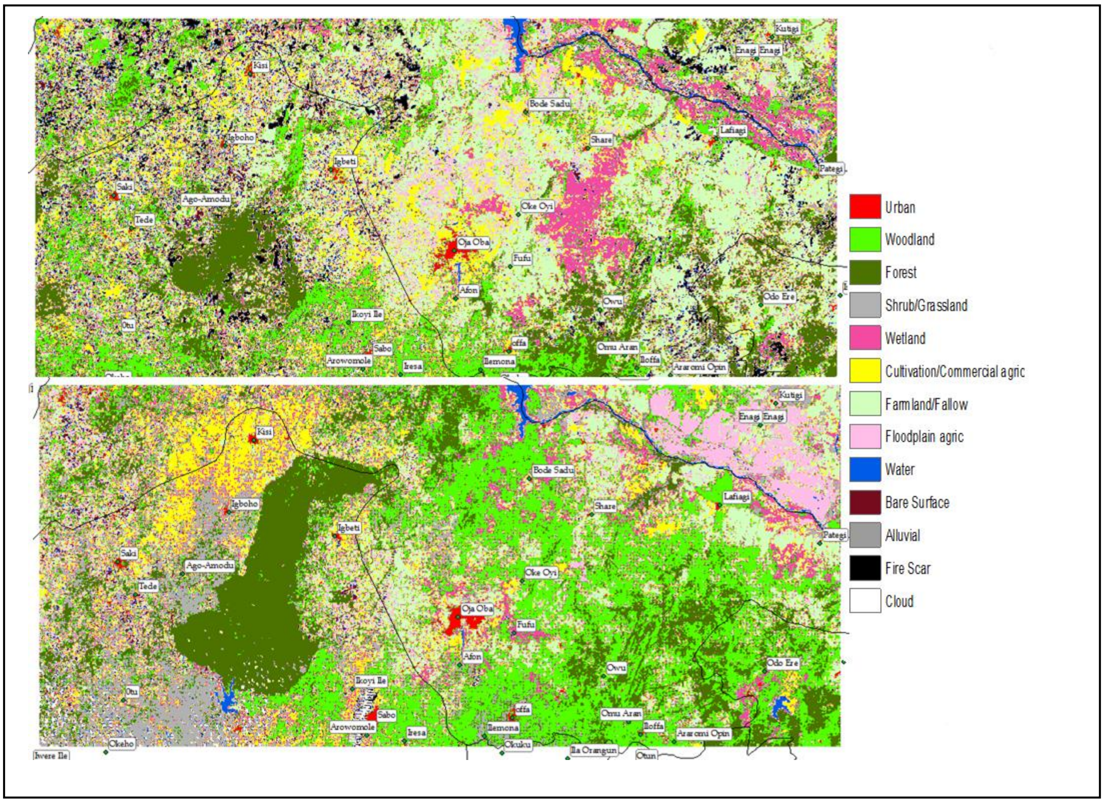

Fig 5: Interpreted LULC: in (U) 1986, and (D) 2006

A comparison of the LULC maps for 1986 and 2006 suggests significant recovery in landcover from the droughts that ravaged the area from around 1971 to 1977 and 1981 to 1983 when the rainfall recorded was far below normal. The two major canopy ecosystems – forest and woodland- increased considerably in 2006 (Table 4, Fig.5). Shrub/grassland, bare surface and burnt surface (fire scar) that are landcover categories which are strong pointers to ecosystem disturbance, land degradation and aridity recorded significant decrease in 2006. These are consistent with the findings of Lauwaet *et al.* (2009), Stow *et al.* (2004), and Nicholson (2000) on the West Africa Sahel region – a tag often wrongly used to combine both the Savannah and Sahel ecologies of West Africa. The assumption of improvement in canopy ecosystems is also supported by visible evidence of forest management including forest protection/forest reserve found in the middle axis to protect the headwaters of Ogun River. While human settlement or built up areas increased by about 81%, areas under present cultivation actually decreased by about a quarter, and fallow area (also used for grazing) by about 48%. Area of water bodies increased as a result of increase in water management through impoundment (dams and reservoir construction). This appears to be a direct response to counter the effects of the drought of previous decades and increase water availability for agriculture and urban use.

The effect of the droughts of previous decades is clear from the difference in the fig 5. Many fire scars or burnt areas are visible around the western parts, especially in the northwest axis in the 1986 map. The forested areas are also localised mainly around high altitude or difficult terrain. The wetlands are also clearly mapped because of reduced vegetal cover. Farmlands are also found closer to human settlements and around the floodplains. The 2006 map spatially shows the extent of vegetal recovery with more forests and woodlands emerging especially around the southeast to middle axis. Evidence of improved forest management is visible from the large track the contiguous '*Upper Ogun'* and *'Oyo Ile'* forest reserves. The two collectively formed what is now referred to as the *'Old Oyo'* national park.

From available records, quite a number of forest stands were designated as forest reserves across the study area. However, preserving these forests from deforestation and degradation to sustain their ecosystems function and services is still a big challenge. Efforts to improve water management through impoundments and dam designated for conjunctive uses are also visible on the 2006 map. Several dams the largest of them being the *Ikere* gorge dam ($65km^2$) on the southwest flank and *Omi* dam ($36km^2$) on the south-east were constructed to improve water for both domestic and agricultural uses. Increase in number and extent of built up areas is also is clear while large area of farmland can be seen in areas around *Kis*hi, *Igboho* and *Shaki* (in the western axis) due to improved rainfall. However some dry area mapped as shrub/grassland is also present south of the 'Ikere' gorge dam.

4.2 Projected LULC

4.2.1 Projected LULC under present climate

Table 5 compares the coverage of each landcover categories as percentage of total area in 1986 and 2006 with their expected (projected) coverage from 2016 to 2046 under the present climate scenario. Human settlements are projected to consistently increase by 270% from rising from about $577km^2$ in 2006 to $2136km^2$ or 5.4% of total landcover in 2046. This is logical because population rise through natural change and, expectedly, migration of people from less productive rural marginal lands to favourable areas. The latter is expected to be a significant process triggered by climate change in the wooded savannah. An increase in area under cultivation is correspondingly expected to occur simultaneously with increase in built up areas. Area under cultivation is projected to peak at about 12% in 2016 (from 8% in 2006) and then stabilizes around 10% from 2026 to 2046. Unutilized farmland and fallow land is projected to continue to decline with increase in area under cultivation at any given time. Fallow land is projected to decline by 2046 to only 60% of its 2006 coverage. The major canopy ecosystems -forest and woodland - are very sensitive to change in climate parameters especially rainfall as can be inferred from their change suitabilities.

Table 5: LULC Projections (2006-2046) in percent under present climate scenario

SN	LULC Class	**Mapped 1986**	**Mapped 2006**	**2016**	**2026**	**2036**	**2046**
1	Urban	0.80	1.45	2.82	3.93	4.82	5.36
2	woodland	19.70	32.11	20.68	26.93	23.09	22.62
3	forest	13.48	15.63	18.36	15.12	15.06	14.68
4	Shrub/grassland	3.27	12.95	21.55	26.74	27.21	27.20
5	wetland	5.27	4.14	2.55	1.64	1.89	1.50
6	cultivation/commercial agric	11.07	8.16	12.34	9.84	10.17	10.44
7	farmland/fallow/grazing area	32.61	16.79	8.21	4.80	6.89	6.79
8	Floodplain agric	4.16	5.63	6.81	4.38	3.51	3.61
9	water	0.55	0.70	1.23	1.67	2.07	2.45
10	Bare surface	2.61	1.23	1.01	1.33	1.53	1.59
11	Alluvial	0.04	0.03	0.02	0.01	0.02	0.01
12	Burnt surface/fire scar	5.84	0.15	0.67	0.49	0.46	0.52
13	cloud/shadow	0.61	1.04	3.74	3.13	3.27	3.22

Although total forest area is expected to decline by about 378km^2 between 2006 and 2046, its overall coverage as percent of total landcover is projected to increase to 18% in 2016 and then remain stable at around 15% from 2025 to 2046. Woodland is projected to cover over 20% of the area throughout the period, although in absolute term, only 70% of woodland mapped in 2006 is projected to remain in 2046. Some transition from woodland and fallow land into forest is projected and forest protection and management is expected to continue to be a core issue for climate change and ecosystems management. The area covered by forest and woodland constitutes a critical eco-climatic resource that controls the local climate. A drastic decline in the canopy ecosystems is expected to negatively impact the local climate and associated rural livelihoods. The strongest transition gain is expected from shrub/grassland category which is expected to increase by about 110% over the coverage in 2006. This translates into a gain of around 5600km^2 that is projected to come mainly from transition of woodland and abandoned farmlands and fallow lands into this category. This huge transition underscores the importance of climate change in increasing land degradation and desertification process in the savannah.

Under the present climate scenario, wetland is projected to consistently decline from about 1650km^2 in 2006 to less than 600km^2 in 2046. Area covered by water body is also projected to consistently increase as the settlements increase. This is logical because more water management projects including dams and reservoirs are likely to emerge in the near-future to continue to provide water for agriculture and human use in the face of increase demand and declining rainfall. Floodplain agriculture is expected to reach its peak covering about 7% of total area by year 2016 and then decline and stabilizes at around 4%.

The spatial pattern of projected LULC changes depicted on Figs 6a-b presents more interesting scenario. The key element in CA_Markov model is that LULC will grow along areas of high suitabilities based on the driving factors used to generate the suitability maps.

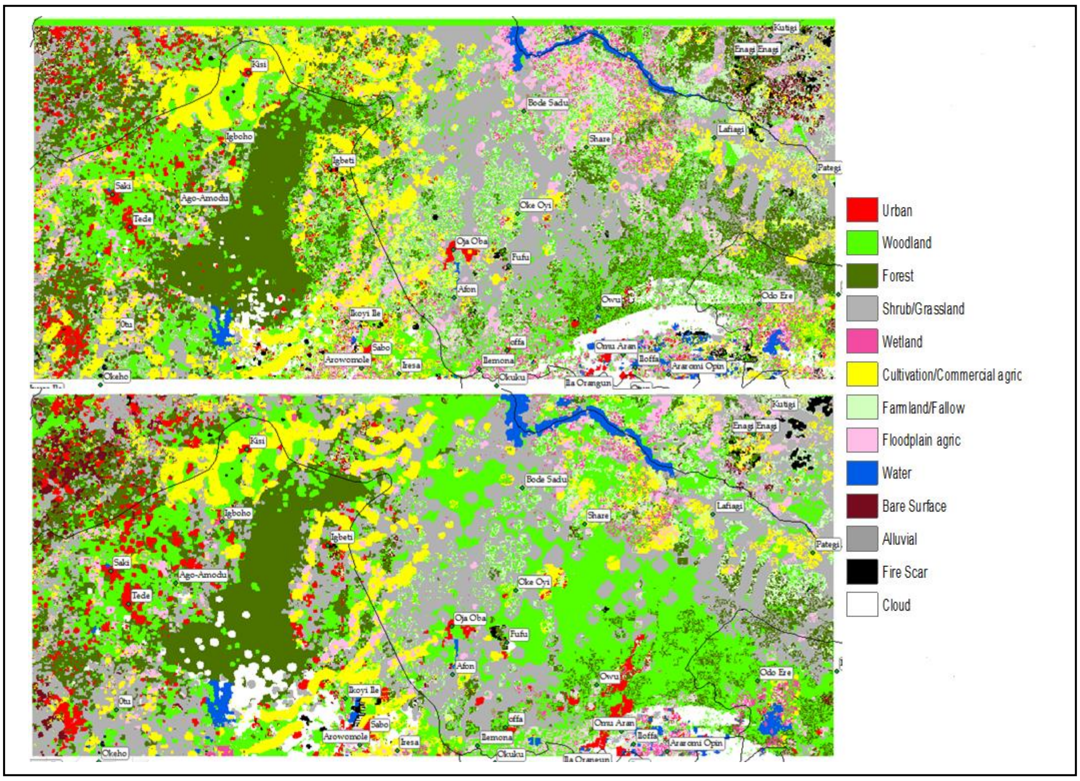

Fig 6a: Projected LULC under present climate scenario in (U) 2016 and (D) 2026

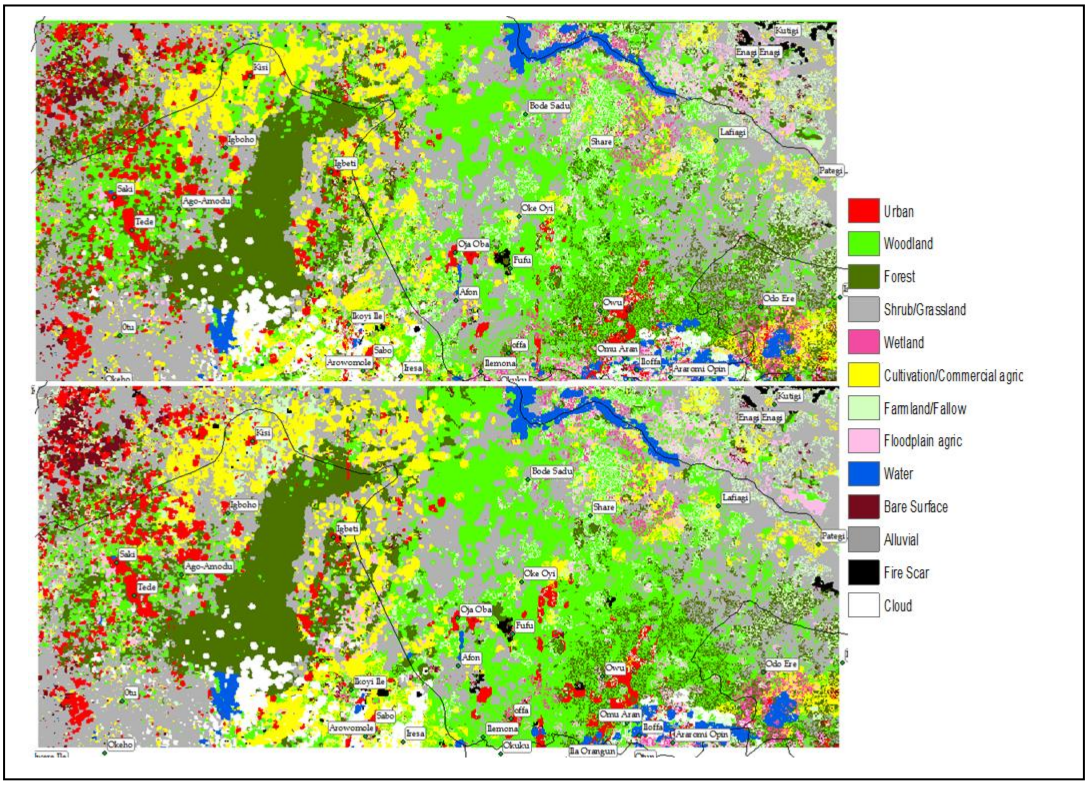

Fig 6b: Projected LULC under present climate scenario in (U) 2036, and (D) 2046

This is consistent with natural process of growth of LULC and the prevailing landscape pattern i.e. the spatial organization of the different landcover categories. Any drastic deviation from this pattern will likely be the result of spontaneous human action or natural catastrophe with small chance occurrence which, normally, is not included in the model.

The present climate trend for the wooded savannah shows warming trend for temperature and no clear trend for rainfall. From this we can assume that while rainfall pattern is expected to remain the same, temperature will rise. This means desiccation will increase. The projected LULC for 2016 to 2046 (Fig 6a-b) indicate increase in areas covered by shrub/grassland in some pocket areas around the northeast, central and southwest axis. These are mainly former farmland and fallow lands now transiting into shrub/grasslands. The forest complex of Old Oyo national park is project to remain, while mosaic of forest and woodland are expected to dominate areas around the southeast corridor. In all the four scenarios, built-up area is projected to continue to increase. Significantly, the largest growth and expansion of built-up land is expected around the northwest-southwest corridor. In response to increase in settlements, more cultivated lands are also projected to emerge in these areas. This is an indication of the connection between agriculture and settlement systems in rural landuse. In reality, the northwest-southwest corridor has in recent years experienced persistent resource conflict between and among social groups that operate in the wooded savannah. The areas in the upper reaches of Ogun river i.e. '*Oke-ogun'* (the local name for this area) which encompasses settlements around Iwajowa, Kajola, Itesiwaju, Atisbo, Shaki west, Shaki east, Olorunsogo, Orelope, and Irepo Local Government Areas (LGAs) in Oyo State, and parts of Baruten and Kaima LGAs in Kwara State has in recent times been experiencing resource conflicts especially between migrating pastoralists and sedentary cultivators. Evidences also suggest that population in the area has been increasing mainly as a result of rural to rural migration because of perceived favourable climate around this area.

4.2.2 Project LULC under future Climate

The percentage coverage of each LULC categories under future climate scenario (2046-2065 under SRES A2) is shown on Table 6 and Fig 7.

Table 6: LULC Projections (2006-2046) in percent under future climate scenario

SN	LULC Class	**2016**	**2026**	**2036**	**2046**
1	Urban	2.84	3.93	4.85	5.36
2	woodland	15.26	16.57	16.74	19.41
3	forest	19.91	16.66	15.32	14.66
4	Shrub/grassland	19.33	26.30	26.85	27.16
5	wetland	2.71	1.61	2.12	1.67
6	cultivation/commercial agric	7.81	8.54	9.82	10.16
7	farmland/fallow/grazing area	21.49	16.57	13.20	10.20
8	Floodplain agric	3.86	3.24	3.69	3.60
9	water	1.21	1.64	2.07	2.42
10	Bare surface	1.07	1.32	1.54	1.59
11	Alluvial	0.02	0.01	0.01	0.01
12	Burnt surface	0.74	0.49	0.53	0.52
13	cloud/shadow	3.74	3.13	3.27	3.22

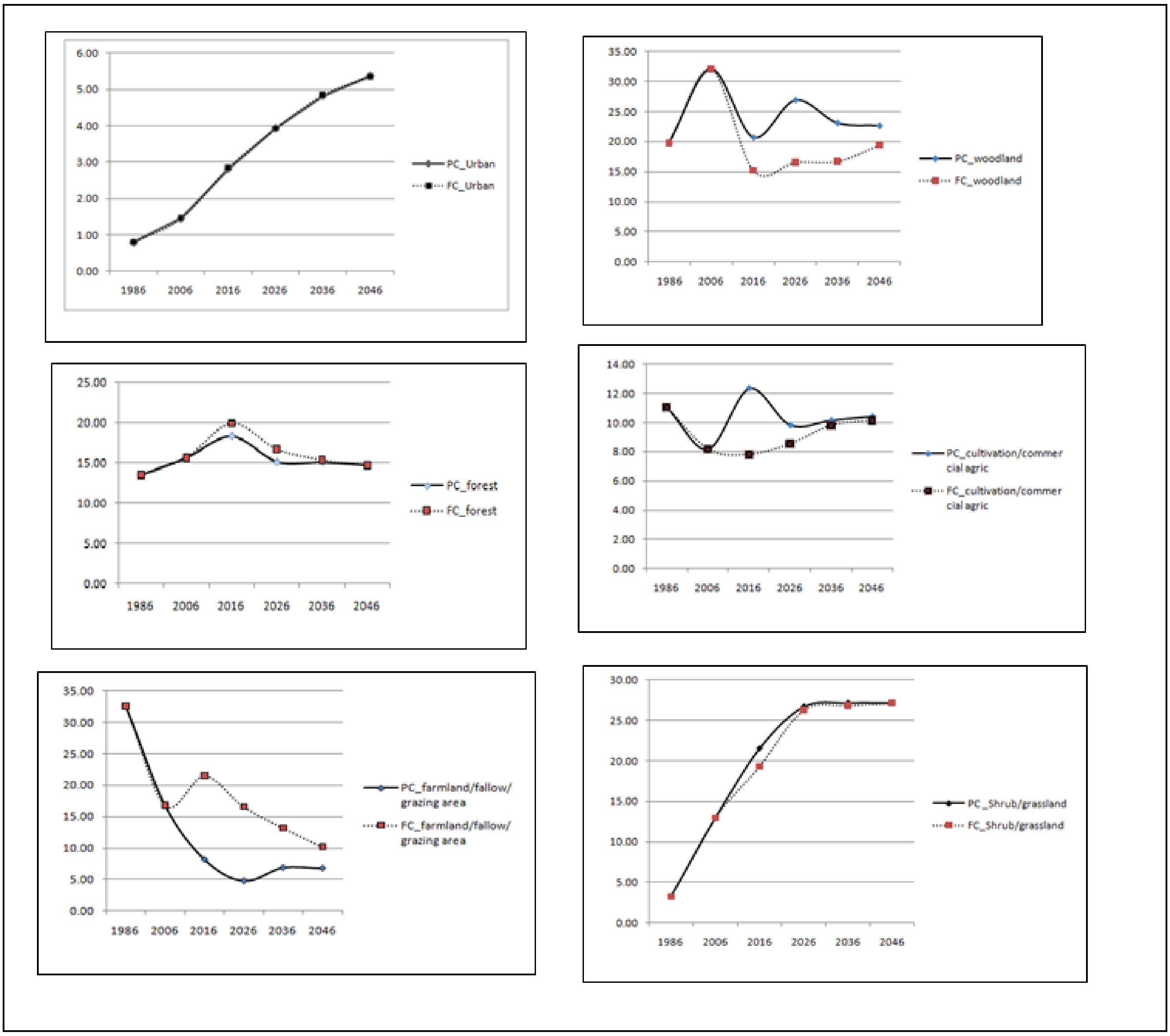

Fig 7: comparison of percent coverage of some LULC classes under present and future climate scenarios

The future climate scenario for the wooded savannah suggests a significant decline in rainfall (about 4mm per decade for mean monthly rainfall) and a rise in mean monthly maximum temperature that is lower than present (0.02^{o}c per decade for mean monthly Tmax). In comparison to the situation under present climate scenario, significant decline is projected in the coverage of the two major canopy ecosystems – forest and woodland- from 2016 to 2046. Moreover, the projected spatial pattern of the different LULC categories (Fig 8a-b) also differs from that of the present climate scenario.

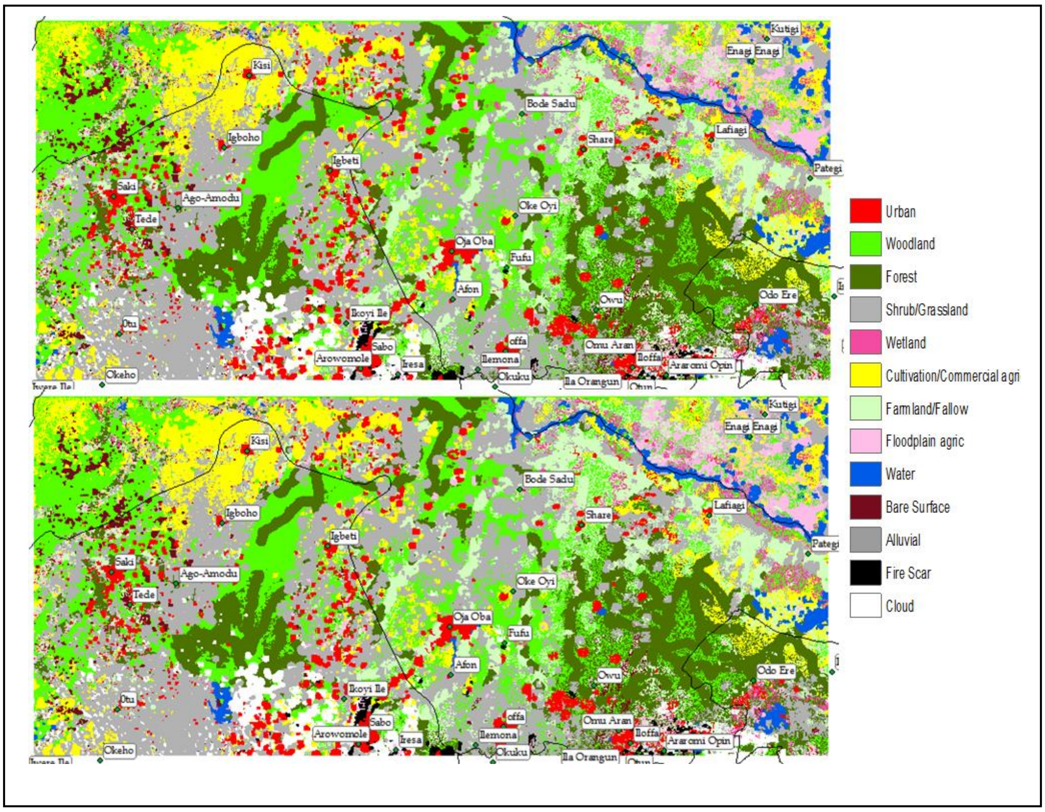

Fig 8a: Projected LULC under future climate scenario in (U) 2016, and (D) 2026

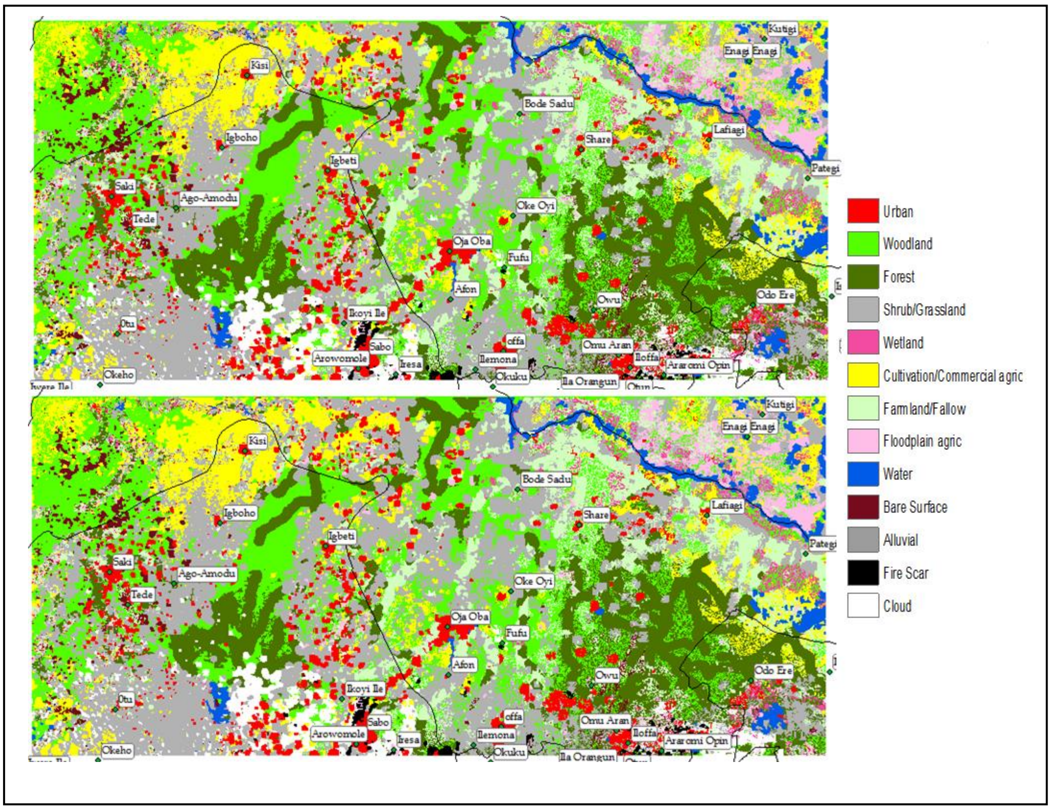

Fig 8b: Projected LULC under future climate scenario in (c) 2036, and (b) 2046

Galleria forests are projected to be the most significant forests, while shrub and grassland will be much more widespread. Galleria forest and widespread shrub and grassland are typical signature of the drier upper guinea and Sudan savannahs. In succinct terms, this suggests that under future climate scenario the wooded savannah will likely get drier and the vegetal signature which will change dramatically captures this. The spatial pattern of built-up lands suggest that more human settlements will likely emerge around the middle area mainly the Oyo, Ogbomosho, Ilorin, and Igbeti axis, than around Shaki axis projected by the present climate scenario. An explanation for this is that the spatial influence of the climate-orographic complex which controls the local climate will diminish and the local system will weaken with rainfall becoming less significant around the northwest including the '*Oke-ogun'* area under future climate scenario. This shift in settlement pattern is consistent with results of this eco-geographic influence on the local climate discussed in paper I.

5. Model validation and calibration

The validation method consists of two parts. The first aims to compute the index of agreement between the Markovian conditional probabilities and the simulated maps using the relative operating characteristics (ROC) statistics. The second is an attempt to simulate the map of a known period and compare same with satellite image derived map of the same period and then compute the kappa index (K). This means comparing a true ending time map with a simulated ending time map. How well is the category of interest concentrated at the locations of relatively high suitability for that category is answered by the ROC. ROC enables validation of a landuse model's ability to specify location, while maintaining the freedom from committing to a specific quantity of change. It is an index of agreement which measures similarity between the simulated change and real change and works exactly for two land cover categories (Pontius & Schneider, 2001**)**. In this case where there are more than two land-cover categories, ROC was created for each category by reclassifying the maps into the landcover class of interest versus other categories. This was done for all the categories. The ROC module in Idrisi examines the agreement between a Boolean map of one category and a suitability map for that category. The ROC was above 0.70 for all the 13 landcover. Since an ROC of 0.50 represents an agreement due to chance, it can be inferred that there is a good agreement between the simulated maps of the different categories and their suitability maps.

The VALIDATE module offers comprehensive statistical analysis that answers simultaneous questions about how well a pair of maps agree in terms of the quantity of cells in each category and in terms of the location of cells in each category (Eastman, 2009). In essence it gives insights into how well the comparison map agrees with the reference map. Attempt was made to simulate a 2006 map and compare with the true map. This was done by combining the 1986 map with another true map for 2000 as basis for landcover projection in the CA_Markov model. A 6 year simulation from 2000 to 2006 with 12 iteration (i.e. 6 month time step) was performed to simulate a map for 2006. The kappa index between the simulated and true map for 2006 was then computed. Fig 9 compares the two maps in terms of area extent of categories, and Fig 10 presents a visual comparison across space.

There seems to be confusion between woodland (in the real map) and shrub/grassland (in the simulated map) (Fig 9). The index of agreement was not at all fantastic. The overall Kappa between the real and simulated maps is 0.1099. The real maps of both 2000 and 2006 were also compared. The kappa was 0.0956. One possible reason for this low agreement may have been the lack of extensive and in-depth field validation of the maps (2000 and 2006) derived from satellite imageries. Another possible reason is the unavailability of imagery to derive an intermediate map for the decade 1990s. Hence the model might not have been able to capture the abrupt transition from the drought years of the 1970s/80s to the relatively wet years of the decade 2000s.

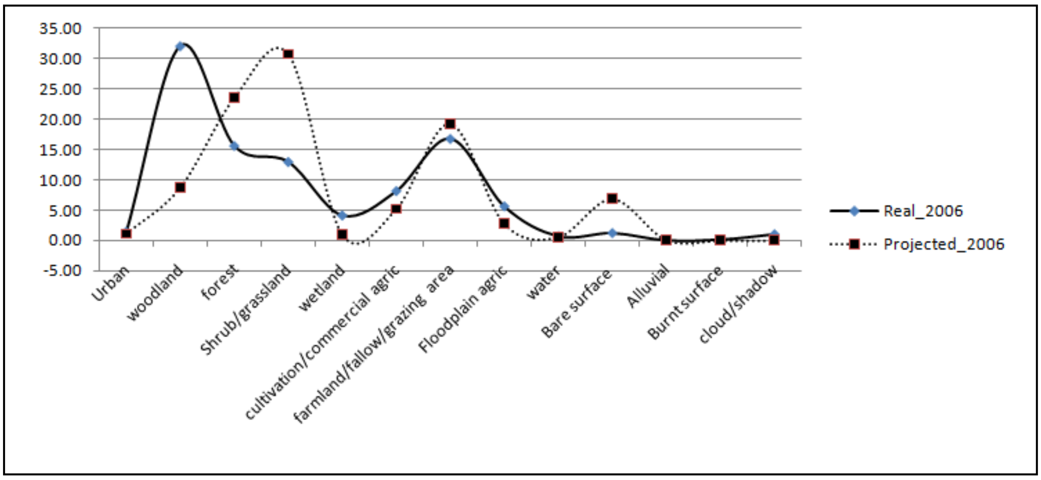

Fig 9: coverage (in percent) of LULC classes for real and simulated 2006 maps

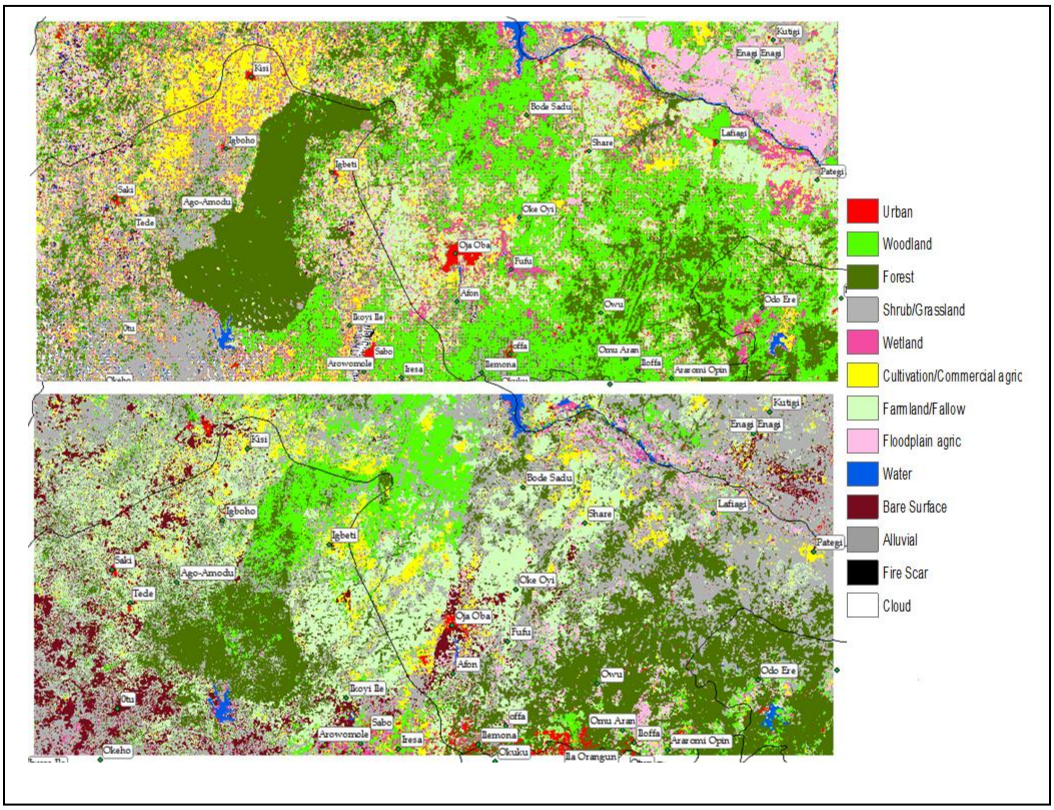

Fig 10: Comparison between the Real (up) and simulated (below) maps of 2006

The agreement in terms of quantity was better and almost equal for most of the classes. Fig 10 also shows that some of the spatial signature including the large track of protected old Oyo national park, cultivation around Kishi area in northwest, water impoundments in southwest and southeast, shrub/grassland in the southwest, the floodplain of the Niger around the northeast, and mosaic of forest and woodlands around the southeast are well captured.

Notwithstanding the uncertainty, this study is presented to elicit awareness and discussion support by stakeholders for climate change adaptation in the wooded savannah. Scenario such as this defines an outline of future development, a plausible future, a quantified description of a yet to-become reality which are often based on a combination of expert judgment, extrapolation of trends, local and regional comparisons, and model runs (Tol 1998). Uncertainly is also a common element in scenario building (Tol 1998; Smith & Hulme, 1998, Solomon et al. 2007).

6. Discussions

6.1 Description of ecosystems vulnerability and impacts

Administrative cum spatial-political framework in Nigeria consists of the Federal (central), State and Local Governments Areas (LGA), and electoral Wards. Ideally, the Ward should be targeted as the smallest spatial planning unit to elicit local level participation. But because spatial and socio-economic data are not often available, the LGA has become the basis for spatial and economic planning. There study area covers 43 LGAs either in part or whole which spread across 6 states (Ekiti-1, Kogi-4, Kwara-16, Niger-6, Osun-1, and Oyo-15). It is important to briefly describe land change scenario and by implication ecosystems vulnerability to climate on LGA basis. The study area is divided into west, central and east axis for discussion summary.

6.1.1 Western axis

The western axis which comprises of '*Oke-ogun'* area is consists the most agriculturally productive areas as suggested by the large extent of small-holder subsistence rainfed agriculture. The favourable climate produced for most seasons of the year by the eco-climatic complex (described in paper 1) appears to be the major factor responsible. Density of rural settlements is high in LGAs that include Itesiwaju, Atisbo, Shaki-west, and parts of Baruten. Future LULC projection under present climate scenario suggests that the fastest growth of settlements is expected in these areas. LGAs such as Shaki-east, Orelope and Irepo that currently have fewer settlements are expected to record high growth in rural communities in future. Area under cultivation will also correspondingly expand and a large area is expected to transit from fallow, cultivation and woodland into shrub/grassland especially in Kajola, Itesiwaju, Iwajowa, Atisbo, Orelope and Baruten LGAs. However, the eco-climatic complex that confers the present advantage will likely diminish under future climate scenario (paper1). This will make more areas transit into shrub/grassland and less settlement growth will be recorded.

6.1.2 Central axis

The extensive upper Ogun/Oyo Ile forest reserve complex (Old Oyo national park) shared by Atisbo, Shaki-east, Orelope, Irepo, Olorunsogo and Atiba LGAs separates the west from the central areas. The central area currently has the highest density of rural communities and the biggest urban areas including Ogbomosho, Ilorin and Offa. The area presently consists of large tracts of woodlands in Atiba, Ori-ire, Ogbomosho North and South, Surulere, Oyun, Ofa, Irepodun, Ilorin-east, Moro, and Kaiama LGAs. The river Moshi forest reserve which is part of the Kainji Lake National Park is located in Kaiama. But obviously, the ecosystem was not protected as suggested by mosaic of forest and woodland interspersed with cultivated lands which suggest high level of disturbance. The central area has the largest area of farmland/fallow land. LULC Projection under present climate suggests that more cultivated areas will emerge while large area of fallow land will likely transit into shrub/grassland. Forest areas in the river Moshi forest reserve in Kaiama LGA is expectedly to transit into woodlands which underscores persistence of disturbance expected through human activities.

However, under future climate scenario, because the influence of eco-climatic complex (paper 1) will likely weaken, the present settlements around Ogbomosho North and South, Ori-ire, Olorunsogo, and Moro at the edge of the park are expected to expand and increase rapidly than those of on the Oke-ogun area. Between the west and central area, south of the forest reserve complex is the Ikere Gorge Dam (about 65km^2) shared by Itesiwaju and Atiba LGAs. Image-derived maps and field visit show that this dam presently highly underutilized for agriculture.

6.1.3 Eastern axis

The eastern side has the lowest number and density of rural settlements. It consists of mosaic of forest and woodlands in highland areas around Isin, Oke-ero, Ifelodun, Ekiti, Yagba-West, Yagba-East, Ikole, Edu and Patigi LGAs. A large tract of floodplain agriculture lies around Mokwa and Edati on the Niger River floodplain. Tracts of cultivation and fallow lands are also found around Edu, Mokwa and Patigi. Between Kaiama and Mokwa is the Jebba hydro-electric power dam. The Omi dam (36km^2) also lies between Yagba East and West LGAs in Kogi State. Image-derived maps and field visits also show that the potentials of these dams for agriculture are not explored. Only little small-scale irrigation agriculture is found in most of the area except in few places around Mokwa, Edu and Patigi where some irrigated commercial fields are found. The Oro forest reserve in Ifelodun LGA, Kampe river forest reserve between Patigi and Yagba East LGA, Ebba river forest reserve between Yagba-East and Mopa-Muro LGAs, and the Niger River forest reserve that extends along the Niger River from Kaiama to Patigi are some of the ecological reserves established here. The state and level of disturbance of the ecosystems of these areas strongly suggests that the forest reserves are not being monitored.

LULC projection under present climate scenario suggests more settlement growth is expected especially in Isin-Irepodun-Ilorin axis. This is consistent with the spread of eco-climatic complex. The mosaic of forest and woodlands present are projected to become more disturbed, and large areas of shrub/grassland are expected around Patigi and Edu and also Mokwa and Edati across the Niger. A small area of fire scar/burnt area is also expected to emerge around Lavun LGA in Niger State. More flood plain agriculture is expected around the Niger alluvial floodplain. A new frontier of cultivated lands is expected to emerge around Yagba-East and West near the Omi dam. LULC projection under future climate scenario suggests forests in the eastern axis will be confined mainly to river valleys. In essence, it signifies the emergence of galleria forest –a signature of the upper guinea savannah. However, the absolute area covered by forest is projected to increase. This is consistent with the strong positive eco-climatic signals expected around the highland areas of Irepodun, Ifelodun, Isin, and Oke-ero under future climate. More lands will also transit into shrub/grasslands especially around Patigi, Edu and the LGAs across the Niger.

6.2 Implications for climate change mitigation and adaptation

6.2.1 Mitigation

The simulation results are not meant as predictions of future LULC, but projections based on the assumed climatic scenarios. According to Verburg *et al*. (2006), they represent a quantified visualization of the qualitative scenario descriptions. Such scenarios are important guide for land management, nature and biodiversity conservation, forest management, ecotourism, etc which are critical for climate change mitigation and adaptation. The irreversibility of critical processes including ecosystems degradation triggered by climate change and its implication for natural resource stock and socio-economic shock absorbers makes mitigation and adaption to climate change critical.

Landuse and cover changes that reduce canopy ecosystems increase surface albedo, reduce leaf area index (LAI), reduce infiltration, increase surface run-off, and impair nutrient cycling. Changes in LAI can significantly affect the regional and local climate especially rainfall by changing the moisture available for evaporation at the surface (Mackellar *et al.* 2009). This is particularly relevant in wooded savannah where a large proportion of annual rainfall is due to mesoscale processes that relies on local forcing especially terrain and vegetation to propagate. Reduced forest and woodland mean reduction in LAI with significant impact on the local forcings. It also means reduction in capacity ecosystems to sequester carbon. An increase in area covered by shrub/grassland and cultivated lands may also mean increased '*savannisation*' (Nobre & Borma, 2009), increased savannah fires and increased natural green house gas emission from soil and agricultural lands.

Some tracts of land had been gazetted as forest reserves since the 1950s in the study area. But it took the drought of the 1970s and 1980s to realise the real importance of catchment area protection against degradation. The area designated as upper Ogun, Oyo-Ile and river Moshi forest reserves cover about 6,000km^2. The two contiguous upper Ogun' and 'Oyo-Ile' which formed the Old Oyo national park since 1991 currently cover about 3,115km^2 . Obviously, the river Moshi forest reserve is not successful as noted earlier. The Oro forest reserve (about 921km^2) and Kampe forest reserve (580km^2) are other smaller protected areas. If all the forest reserves are to be truly protected, it will represent about 10,616km^2 or 26 percent of the study area. This mean a large part that constitutes vital catchments will still be open to degradation. Curiously, there appears to be a connection between possible forest degradation in the Old Oyo national park and the weakening of the eco-climatic complex in the adjacent *Oke-ogun* area under future climate scenario.

Landuse and cover change is a strong factor of catchment fluxes and hydrological regimes of rivers. There is a general belief that forest clearance and spread of cultivation increases rate of run-off and mobilization of sediment in catchments and sediment loads being discharged (Arthurton *et al*. 2008). The study area is the headwater for the all the major drainage found in western Nigeria. The rivers which include Ogun, Oshun, Oyan, Okpara, Asa, Katampe and Moshi drains a combine large catchment and provide municipal water supply in several major cities including Lagos, Ibadan, Abeokuta, Ijebu-Ode, Oshogbo, Iwo, Ede, Ejigbo, Oyo, Ogbomosho, Ilorin, Offa, and several hundreds of smaller settlements across western Nigeria. Hence, headwater and catchment deforestation which reduces rainfall will simultaneously precipitate water crisis in the entire western Nigeria.

Aggressive vegetation and albedo enhancement strategies as primary form of climate change mitigation appear to hold much promise here. Eco-tourism also appears a good climate mitigation strategy to protect the forest and woodlands in this high density agrarian landscape. Forest and woodland protection as climate change mitigation around the study area seems very attractive. A well packaged canopy enhancement and natural forest management through ecotourism under the Reduced Emission from Deforestation and land Degradation (REDD), Clean Development Mechanism (CDM) and Carbon Trading (CT) frameworks will likely be very appealing for funding under the adaptation funds such as the GEF Trust Fund and the Special Climate Change Fund (SCCF) -since the Kyoto protocol adaptation fund is not yet operational and Nigeria may not be qualified for the Least Developed Countries fund. There is a national park covering about 3000km^2 or 7.5% of the area. Other gazetted forest reserves are not monitored and maintained due to lack of resources. Hence, it is part of the mitigation strategy to strengthen the capacity to monitor and maintain existing reserves. They can also be extended especially in delicate ecosystems and those areas where forest has significant impact on the local climate. Such a project will also be attractive because there is yet no record of any REDD or CDM project instituted in Nigeria, nor are we aware of any record of mitigation/adaptation project in Nigeria that has benefited from any of the adaptation funds for ecosystems management. Local community reforestation and forest management and renewable grassland management for pastoralists are also viable mitigation/adaptation options. Ecotourism will also serve to diversify rural livelihood and reduce pressure on the natural environment.

6.2.2 Adaptation and its framework

Small-holder farmers, pastoralists, wood charcoal makers and sellers, commercial fire-wood gatherers, leave collectors, and other economically marginalised populations that depend on land resources to survive dominate the rural landscape. Women also form the largest percentage of people that depend on activities such as leaves collection for sale, charcoal merchandising, and a reasonable percentage of small-holder farmers. Food production is the primary source of food for the small scale farmers who paradoxically are most vulnerable to famine (Devereux, 2009).
The future landcover change scenario suggests possible increase in dry-lands which also mean the livelihoods of these vulnerable populations face a threat of decline or possible collapse. Rural livelihoods collapse will bring food insecurity and increase human insecurity. Appropriate, community-based and place-specific adaptation strategies built upon local peculiarities - social framework, natural resource stock and climate – is therefore important.

Climate adaptation, a continuous process of adjustment, is about reducing vulnerabilities and increasing resilience thereby reducing severity of climate impact. Integrated plans for the climate change challenge need to incorporate a wider range of mitigation, adaptation and vulnerability considerations (Martens *et al*. 2009) especially local development initiatives, plans, programmes, policies and indigenous climate and environmental knowledge base and coping mechanisms. Local coping strategies are an important element of planning for adaptation. Strategies and programmes that are more likely to succeed need to link with coordinated efforts aimed at poverty alleviation, enhancing food security and water availability, combating land degradation and reducing loss of biological diversity and ecosystem services, as well as improving adaptive capacity(UNFCCC, 2007). It must be science-based but community driven to ensure its sustainability and synergy for providing social safety nets for the most vulnerable.

Possible adaptation include shift in growing season for some crops, try new cultivars, crops and varieties especially those from the upper guinea ecology, rural-rural migration as projected by the land change model, Fadama and floodplain agriculture especially along the Niger floodplain, appropriate community-managed irrigation and water resources management, and possibility of collective or communal farms against the current small-holder individual farms. It will also include designation, equipping and maintenance of grazing reserves (with water points and irrigated grazing land) for the pastoralists. Climate change communication and confidence building between the farmers and pastoralists and among social groups is also necessary to reduce resource conflicts.

Each of State of Nigeria has separate ministries/or departments that are responsible for issues about natural resources, environment, agriculture and rural development and planning. In addition the LGAs also have departments/units responsible for local level planning, rural development, agriculture and health. These ministries, departments and units currently exist as autonomous and often operate with little inter-communication and most often without cooperation. Therefore, for climate change adaptation strategies in these areas to succeed, adaptation projects must be designed cross-cutting outside the government and then find a means to integrate several ministries, departments and units into such project. A survey of activities across the LGAs shows that the Local Empowerment and Environmental Management Project (LEEMP) and the FADAMA Project are two major local-level development frameworks that can be used as springboard for climate change adaptation.

The LEEMP has a nationwide scope and it is funded and supported by Global environmental Facility (GEF). It has several components such as the protected areas and biodiversity management with objectives *to improving protected area infrastructures and facilities, promote sound partnerships for effective protected area management, identify and promote incentives for wildlife and biodiversity conservation in the protected areas, creating alternative means of income generation activities to reduce pressure on the selected protected areas, provide technical assistance and capacity building for biodiversity and protected areas management in key public agencies and NGOs, and promote awareness of the benefits of conserving biodiversity and habitats* (Eze, 2008).

The poverty reduction and livelihood component has the objective of *promoting security and reducing poverty by empowering the poor, the communities and local government to take charge of their own development plans through the community driven development (CDD) principles*. *This implies empowering the poor to identify priority needs and to effectively organize themselves to partner with the local governments and other stakeholders to plan and implement actions to provide goods and services that meet their needs and immediate priorities. Specifically, the objectives of the project are to embark on demand driven micro-projects to enhance their well-being* (http://livingearthnigeria.org) .

The FADAMA project is a World Bank/IDA supported intuitive. The development objective is *to sustainably increase the incomes of farmers and other economic interest groups through a more diversified agricultural development program, including fadama users those who derive their livelihood through direct or indirect exploitation of the resources in the fadama aquifers found in Nigeria's major river systems as well as surface water irrigation perimeters*. This is to *be achieved through an integrated approach including provision of financial services, and grants for small-scale productive/economic infrastructure subprojects, training and skills development and increased diversification of agriculture. A second objective is reduction of natural resources access-based conflict, focusing on scarce land and water resources for fadama development. This is being pursued through the Local Development Planning (LDP) tool and other innovations to enhance inclusiveness, such as, better integration of individual private sector-oriented initiatives and social investments within the Community-Driven Development (CDD) harmonization policy framework, and vulnerable and other disadvantaged groups*.(Second National Fadama Development - Critical Ecosystems Management Project – Report No: AB1642, Third National Fadama Development Project (Fadama III: Integrated Safeguards Data Sheet - Report no: AC2414).

Fadama agriculture refers to small irrigation all year farming in areas of low depression or adjacent to streams/rivers (Mbanasor & Obioha, 2003, Adesoji *et al*. 2006). It can also be described as a form of adaptation response to climate change. Both the LEEMP and FADAMA projects address all the points required for ecosystems management, rural livelihoods, resource conflicts, and community driven development. But they fell short of including climate change impacts and responses. They therefore present ideal platform for mainstreaming climate change adaptation, piloting community adaptation initiatives, and implementing pilot adaptation measures. Integrating climate change adaptation into them will thus ensure a balance between peasant agriculture and ecosystems management to enhance carbon sequestration and promote positive feedback in the local climate system.

7. Conclusions

Climate change impacts, vulnerability and adaptation assessments need to generate outputs that are policy relevant. We recognise that to achieve this climate change data including future impacts and vulnerabilities needs to be integrated with socioeconomic data and analyses across a range of sectors, and the results must be tailored for policymakers and stakeholders (UNFCCC, 2007). Hence, a description of the aggregate vulnerabilities which combine environmental and social vulnerabilities to climate change at local level is important for determining and designing appropriate, place-specific, people-focused and participatory adaptation strategies that addresses these vulnerabilities. This should also include a review of current natural resource, poverty alleviation, water management, agricultural improvements, gender development and economic empowerment program currently being implemented. This has partially been achieved in this study. Socio-economic (income, livelihood, etc) and demographic (family size, dependency, social-safety nets, etc) data at appropriate spatial scale is not available to determine the level of vulnerability of households to climate change. This is a future research challenge. Communication and confidence building is also required to build common-purpose that stimulate knowledge base of communities to respond positively to changes. This aspect too requires further work.

The next phase of this work aims at designing pilot community-based adaptation and community-managed mitigation projects and strategies across the study area based on results and evidences from the present research. This we hope will receive local and national supports and international approvals. The present study will also be up-scaled by using information on multiple scenarios of landcover change from the present study for quantifying present and possible future carbon emission and sequestration scenarios from the study area. This we hope will present a classical benefit-cost analysis of local carbon fluxes in the area.

Acknowledgment

This research was carried out under the African Climate Change Fellowship Programme (ACCFP). The ACCFP is supported by a grant from the Climate Change Adaptation in Africa (CCAA) funded jointly by the International Development Research Centre (IDRC) of Canada and the UK's Department of International Development (DFID). The International START Secretariat is the implementing agency in collaboration with the Institute of Resource Assessment (IRA) of the University of Dar es Salaam and the African Academic of Sciences (AAS).

References

Abiodun, B.J., Pal, J.S., Afiesimama, E.A., Gutowski, W.J., & Adedoyin, A. (2008). Simulation of West African monsoon using RegCM3 Part II: impacts of deforestation and desertification. Theor. Appl. Climatol. 93: 245-261. doi 10.1007/s00704-0222-1

Adejuwon, J (2006): Food Security, Climate Variability and Climate Change in Sub Saharan West Africa. A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 23. The International START Secretariat, Washington. www.start.org

Adesoji, S.A, Farinde, A,J and Ajayi, A.O (2006): Determinants of training needs of Fadama farmers in Osun state of Nigeria and implication for extension workers. Journal of Applied Sciences. 6 (15) 3082-3088

Adisa, S.R & Adekunle, O.A (2010). Farmer-Herdsmen Conflicts: A Factor Analysis of Socio-economic Conflict Variables among Arable Crop Farmers in North Central Nigeria. J Hum Ecol, 30(1): 1-9.

Afiesimama, E.A., Pal, J.S., Abiodun, B.J., Gutowski Jr, W.J., & Adedoyin, A, (2006). Simulation of West African monsoon using the RegCM3.Part I: Model validation and interannual variability. Theor. Appl. Climatol. 86, 23–37

Akinbami, J.F.K., Salami, A.T., & Siyanbola, W.O. (2003). An integrated strategy for sustainable forest–energy–environment interactions in Nigeria. Journal of Environmental Management 69, 115–128. doi:10.1016/S0301-4797(03)00083-5

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E. (1976). A Land use and Land cover Classification System for use with Remote Sensor Data. *Geological Survey Professional Paper* 964, Washington D.C: USGS

Anyamba, A. & Tucker, C.J. (2005) Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. Journal of Arid Environments 63, 596–614. doi:10.1016/j.jaridenv.2005.03.007

Arthurton, R, Le Tissier, M. Snoussi, M, Kitheka, J, Shaghude, Y, Kane, A, Floser, G and Kremer, H (2008): Africat: LOICZ Global Chnage Assessment and Synthesis of river catchemenet-coastal sea interactions and human dimensions in Africa. LOICZ Report and Studies No 30.LOICZ IPO, Geesthacht, Germany.

Bucini, G and Lambin, E.F (2002): Fire impacts on vegetation in Central Africa: a remote-sensing-based statistical analysis. *Applied Geography 22 (2002) 27–48.* Elsevier Science Ltd

Cabral, P, and Zamyatin, A (2006) Three Land Change Models For Urban Dynamics Analysis In Sintra-Cascais Area. 1st EARSeL Workshop of the SIG Urban Remote Sensing Humboldt-Universität zu Berlin, 2-3 March 2006.

Cao, M., Prince. S.D. & Shugart H. H. (2002) Increasing terrestrial carbon uptake from the 1980s to the 1990s with changes in climate and atmospheric CO2, Global Biogeochemical. Cycles, 16(4), 1069, doi:10.1029/2001GB001553

Chapin, F.S., Randerson, J.T, McGuire, D.A., Foley,J.A. & Field, C.B. (2008) Changing feedbacks in the climate–biosphere system. Frontiers in Ecology and the Environment: Vol. 6, 6, 313-320. doi: 10.1890/080005

Cook, K.H. and Vizy, E.K. (2006). Coupled Model simulation of the West African Moonsoon Systems: Twentieth- and Twenty-First Century Simultions. Journal of Climate 19, 3681-3703. American Meteorological Society.

Desanker, P.V, Frost, P.G.H, Justice, C.O and Scholes, R.J (1997): The Miombo Network: Frameworks for a terrestrial transect study of land use and land cover change in the Miombo ecosystems of Central Africa. IGBP Report 41, 109p. www.geo.ucl.ac.be/LUCC/data/miombo

Devereux, S (2009): Why does famine persist in Africa. Food Sec. 1(1) p25-35. Springer. Doi 10.1007/s12571-008-0005-8

Eastman, JR (2009): Idrisi Taiga Guide to Image Processing, Clark Labs, Worcester, MA 01610-1477, USA
Eze, O.C (2008): A Case Study On Local Empowerment and Environmental Management Project (LEEMP) in Nigeria Protected Areas & Biodiversity Management Component. Sub-Regional Workshop for GEF Focal Points in West & Central Africa, Douala, Cameroon, 19 – 21 June, 2008

Fasona, M., Omojola, A., Adeaga, O. & Dabi, D (2007). Aspects of Climate Change and Resource Conflicts in the Nigeria Savannah. IPCC/TGICA Expert Meeting on Integrating Analysis of Regional Climate Change and Response Options, Nadi, Fiji Islands. Supporting Material prepared for consideration by the IPCC, p45-55. http://www.ipcc.ch/pdf/supporting-material/tgica_reg-meet-fiji-2007.pdf

Fasona, M.J and Omojola, A.S (2005): Climate Change, Human Security and Communal Clashes in Nigeria. Proceedings of International Workshop on Human Security and Climate Change, Holmen Fjord Hotel, Asker, near Oslo, 22–23 June 2005, www.gechs.org/activities/holmen/Fasona_Omojola.pdf.

Fuller, D.O And Ottke, C (2002): **Land Cover, Rainfall and Land-Surface albedo In West Africa.** *Climatic Change* **54:** 181–204, 2002. Kluwer Academic Publishers. Netherlands

German Advisory Council on Climate Change (2008): Climate Change as a security risk, Earthscan, U.K

Hagget, P., Chorley, R.J. (1967) Models, Paradigms and the new Geography. In R.J Chorley., P. Hagget (Ed), *Models in Geography*, (pp19-41). London: Methuen & Co Ltd.

Hall, C.A.S., Tian, H., Qi, Y., Pontius, G., and Cornell, J. (1995). Modelling Spatial and Temporal Patterns of Tropical Land Use Change. Journal of Biogeography, Vol. 22, No. 4/5, Terrestrial Ecosystem Interactions with Global Change, Volume 2 (Jul- Sep.1995), 753-757.

Hewitson, B.C. & Crane, R.G. (2006). Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. Int. J. Climatol. 26: 1315–1337

Hoffmann, W.A.& Jackson, R.B. **(**2000) Vegetation–Climate Feedbacks in the Conversion of Tropical Savannah to Grassland**.** Journal of Climate*, 13*, 1593-1602

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Ru, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15(3), 259-263.

Kuemmerle, T., Muller, D., Griffiths, P. & Rusu, M. (2009) Land use change in Southern Romania after the collapse of socialism. Reg Environ Change 9,1–12. doi: 10.1007/s10113-008-0050-z.

Lauwaet, D., van Lipzig, N.P.M. & De Ridder, E.K (2009) The effect of vegetation changes on precipitation and Mesoscale Convective Systems in the Sahel. Clim Dyn 33:521–534

Leary, N, Kulkarni, J and Sepit, C (2007): Assessment of Impacts and Adaptation to Climate Change**:** Final Report of the AIACC Project. A Global Environment Facility Enabling Activity in the Climate Change Focal Area Project No. GFL-2328-2724-4330

Li, X.Y., MA, Y.J., Xu, H.Y., Wang, J.H & Zhang, D.S.(2009) Impact of Land Use And Land Cover Change on Environmental Degradation in Lake Qinghai Watershed, Northeast Qinghai-Tibet Plateau. Land Degrad. Develop. 20, 69–83. doi: 10.1002/ldr.885.

MacKellar,N.C., Tadross, M.A & Hewitson, B.C (2009) Effects of vegetation map change in MM5 simulations of southern Africa's summer climate**.** Int. J. Climatol. 29, 885–898 DOI: 10.1002/joc.1754

Martens, P, McEnvoy D and Chang, C (2009): The climate change challenge: Linking vulnerability, adaptation and mitigation. Current Opinion in Environmental Sustainability, 1(1) p14-18. October 2009. Elsevier.

Mbanasor, J.A and Obioha, L.O (2003): Resource Productivity under Fadamas Cropping System in Umuahia North Local Government Area of Abia State, Nigeria. Tropical and Subtropical Agricultura 2 (2003): 81 – 86.

Müller, Christoph.(2009). Climate change impact on Sub-Saharan Africa : an overview and analysis of scenarios and models Bonn : DIE, 2009 – (Discussion Paper / Deutsches Institut für Entwicklungspolitik 3/2009.

Neely,C, Bunning, S and and Wilkes, A (ed, 2009): Review of evidence on drylands pastoral systems and climate change: Implications and opportunities for mitigation and adaptation. Land and Water Discussion Paper, Food And Agriculture Organization Of The United Nations, Rome

Neigh, C.S.R., Tucker, C.J. & Townshend, J.R.G. (2008) North American vegetation dynamics observed with multi-resolution satellite data. Remote Sensing of Environment 112, 1749–1772. doi:10.1016/j.rse.2007.08.018

Nicholson, S. (2000) Land surface processes and Sahel climate. Reviews of Geophysics 38(1), 117-339. American Geophysical Union

Nicholson, S.E (2009): A revised picture of the structure of the ‘‘monsoon’’ and land ITCZ over West Africa. Clim Dyn (2009) 32:1155–1171.DOI 10.1007/s00382-008-0514-3

Nobre, C.A and Borma, L.D (2009): Tipping points for the Amazon forest. Current Opinion in Environmental Sustainability, 1(1) p28-36. October 2009. Elsevier

Obioha. E.E (2008) Climate Change, Population Drift and Violent Conflict over Land Resources in North-eastern Nigeria, J. Hum. Ecol., 23(4), 311-324

Odekunle, T.O., Balogun, E. E., & Ogunkoya, O.O (2005) On the prediction of rainfall onset and retreat dates in Nigeria. Theor. Appl. Climatol. 81, 101–112. DOI 10.1007/s00704-004-0108-x

Omotosho, J.B & Abiodun, J. (2007): A numerical study of moisture build-up and rainfall over West Africa. *Meteorol. Appl.* 14: 209–225. DOI: 10.1002/met.11

Pielke Sr. R.A., Adegoke, J., Beltran-Przekurat, A., Hiemstra, C.A., Lin, J., Nair, U.S., Niyogi, D. & Nobis, E (2007) An overview of regional land-use and land-cover impacts on rainfall. Tellus 59B (3), 587-601.doi:10.1111/j.1600-0889.2007.0025.x

Pontius Jr, G.R., Malanson, J. (2005). Comparison of the structure and accuracy of two land change models. International Journal of Geographical Information Science, 19(2) 243- 265. doi: 10.1080/13658810410001713434

Pontius Jr.R.G. & Schneider, L.C (2001) Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems and Environment 85, 239–248

Sertel,E., Robock, A & Ormecia, C (2009) Impacts of land cover data quality on regional climate simulations. *Int. J. Climatol.* DOI: 10.1002/joc.2036.

Smith, J.B., Hulme, M. (1998). Climate Change Scenarios. In F. Jan., J.F Feenstra., I Burton., J.B Smith., R.S.J Tol. (Ed), *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies,* Version 2.0, UNEP/IVM Handbook

Solomon S, Qin D, Manning M, Alley R.B, Berntsen T, Bindoff N.L, Chen Z, Chidthaisong A, Gregory J.M, Hegerl G.C, Heimann M, Hewitson B, Hoskins B.J, Joos F, Jouzel J, Kattsov V, Lohmann U, Matsuno T, Molina M, Nicholls N, Overpeck J, Raga G, Ramaswamy V, Ren J, Rusticucci M, Somerville R, Stocker T.F, Whetton P, Wood R.A, Wratt D (2007): Technical Summary. In: Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averyt K.B, Tignor M, Miller H.L (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Stéphenne, N.& Lambin, E.F. (2001) A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU). Agriculture, Ecosystems and Environment 85, 145–161

Stohlren T.J., Chase T.N., Pielke Snr, R.A., Kittel, T.G.F. & Baron, J.S (1998) Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. Global Change Biology 4, 495-504

Stone, Jr B. (2009) Land Use as Climate Change Mitigation. Environ. Sci. Technol. 43, 9052–9056. doi: 10.1021/es902150g

Stow, D.A., Hope, A., McGuire, D., Verbyla, D., Gamon, J., Huemmrich, F., Houston, S., Racine,C., Sturm, M., Tape,K., Hinzman L., (Professor of Water Resources), Yoshikawa,K., Tweedie,C., Noyle,B., Silapaswan,C., Douglas,D., Griffith, B., Jia,G., Epstein,H., Walker, D., Daeschner,S., Petersen,A., Zhou,L.& Myneni, R. (2004). Remote sensing of vegetation and land-cover change in Arctic Tundra Ecosystems. Remote Sensing of Environment 89, 281–308. doi:10.1016/j.rse.2003.10.018

Taylor, C.M, Lambin, E.F, Stephenne, N, Harding, R.J and Essery, R.L (2002): The Influence of Land Use Change on Climate in the Sahel. J. Clim Vol 15 p3615-3629, American Meteorological Society.

Tol, R.S.J. (1998). Socio-economic Scenarios. In F. Jan., J.F Feenstra., I Burton., J.B Smith., R.S.J Tol. (Ed), *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*, Version 2.0, UNEP/IVM Handbook.

Turner II, B.L., Lambin, E .F.& Reenberg, A. (2007) The emergence of land change science for global environmental change and sustainability. PNAS. Vol. 104 (52), 20666–20671, doi_10.1073_pnas.0704119104
UNDP-UNEP (2009): *Mainstreaming Poverty-Environment Linkages into Development Planning: A Handbook for Practitioners* available online at www.unpei.org

United Nations Framework Convention on Climate Change (2007) Climate Change: Impacts, Vulnerabilities and Adaptation In Developing Countries. Climate Change Secretariat (UNFCCC), Bonn, Germany

Verburg, P.H., Chen, Y., Soepboer, W., Veldkamp, T.A. (2000). GIS-based modeling of human-environment interactions for natural resource management applications in Asia. Proceedings of the 4th International Conference on integrating GIS and Environmental Modelling: Problems, Prospect and Research Needs, Banff, Alberta, Canada.

Verburg, P.H., Eickhout, B. & Meij, H (2007) A multi-scale, multi-model approach for analyzing the future dynamics of European land use. Ann Reg Sci. doi 10.1007/s00168-007-0136-4.

Verburg, P.H., Schulp, C.J.E., Witte, N & Veldkamp, A (2006) Downscaling of land use change scenarios to assess the dynamics of European landscapes. Agriculture, Ecosystems and Environment 114, 39 - 56. doi: 1 0.1016/j .agee.2005.11.024

Verburg, P.H., Veldkamp, A., Espaldon, R.L., Mastura, S.S. (2002). Modeling the spatial dynamics of regional land use: the CLUE-S Model. *Environmental Management*, 30(3), 301-405.

Wang, G. L, and Eltahir, E. A. B (2000): Biosphere–atmosphere interactions over West Africa. II: Multiple climate equilibria. *Quart. J. Roy. Meteor. Soc.*, **126,** 1261–1280

Weng, Q (2002) Land use change analysis in the Zhujiang Delta of China using Satellite remote sensing, GIS and stochastic modelling. Journal of Environmental Management 64, 273–284 doi:10.1006/jema.2001.0509.

Wilby R.L., Charles S.P., Zorita E., Timbal B., Whetton P., and Mearns L.O. (2004). Guidelines for use of climate scenarios developed from statistical downscaling methods. TGICA. IPCC Supporting Materials. http://www.ipcc-data.org/guidelines/dgm_no2_v1_09_2004.pdf

Progress on Expected Outcomes

The work has been presented in the following workshops and conferences:

1. Patterns of Terrestrial ecological imprints and feedbacks and their implications for climate change adaptation in the wooded savannah of Nigeria. Climate Change Adaptation in Africa (CCAA) Advisory Board Roundtable, Cape Town, South Africa, November 2009
2. Climate Change, Terrestrial ecology imprints and adaptation options in the wooded Savannah of Nigeria. ICTP-AFRICA Conference on Developing Countries Vulnerability to Climate Change, Gaborone, Botswana, 2010
3. Patterns of Terrestrial ecological imprints and feedbacks and their implications for climate change adaptation in the wooded savannah of Nigeria. Departmental Seminar, CSAG, UCT, Cape Town, South Africa, May 2010
4. Climate change, Terrestrial ecology imprints and adaptation options in semi-dry environments – a case of the Nigerian Savannah. DFID DEWPOINT Pre-selection Presentation to attend the ICID+18 Conference, Niamey, Niger, June 2010
5. Climate Change, Terrestrial ecology imprints and adaptation options in the wooded Savannah of Nigeria, Departmental Seminar, Geography Department, University of Lagos, Nigeria, July 2010
6. Climate change, Terrestrial ecology imprints and adaptation options in semi-dry environments – a case of the Nigerian Savannah. ICID+18: Second International Conference on Climate, Sustainability and Development in Semi-arid Regions, Fortaleza, Ceara, Brazil. August 2010.
7. Urbanization and Landuse Change Response to Climate change in the Nigerian Savannah. Global Land Project Open Science Meeting. Arizona State University, Tempe, Arizona, USA. October 2010 (forthcoming).

Acknowledgement

I am grateful to the following for a successful fellowship:

- The funding and partner organisations – START, CCAA, IDRC, DFID, IRA and AAS
- The program staff at the START International Office in Washington, D.C – especially Dr. Hassan Virji, Charles ‘Skip’ Kauffman and indefatigable Clark Seipt
- Staff and Colleagues at CSAG, UCT, Cape Town for their cooperation and support
- University of Lagos for granting study leave to execute the fellowship