Investigating Potential Feedbacks of Smallholder Farmers' Reactionary Climate Adaptation on Vegetation Cover Dynamics in Keffi, Nigeria (1999-2018)

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Dekan: Prof. Dr. Georg Rümpker

Gutachter: Prof. Dr. Jürgen Runge, Prof Dr. Jürgen Wunderlich

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Abbreviations

AFLOU	Agriculture, Forestry and Other Land use
ANPP	Above Ground Net Primary Production
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
AVHRR	Advanced Very High-Resolution Radiometer
BFAST	Breaks for Additive Season and Trend
CDKN	Climate Development Knowledge Network
CIDA	Canadian International Development Agency
CO2	Carbon dioxide
COP	Conference of Parties to the UNFCC
CRU	Climatic Research Unit
cumNDVI	Cumulative NDVI
DPSIR	Drivers, Pressures, State, Impact, Response
EEA	European Environment Agency
EMS	Electromagnetic Spectrum
ETM	Enhanced Thematic Mapper
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
fPAR	Fraction of Photosynthetic Radiation
GDP	Gross Domestic Products
GEF	Global Environmental Facility
GIMMS3g	Global Inventory Monitoring and Modelling System-3rd generation (NDVI)
GNDVI	Green Normalized Difference Vegetation Index
GNSPI	Geostatistical Neighbourhood Similar Pixel Interpolator
GPS	Global Positioning System
GRADE	Goethe Research Academy for Early Career Researchers GRADE
Ha	Hectare
ICs	International Ground Stations
IFFP	Ford Foundation International Fellowships Program
INDCs	Intended Nationally Determined Contributions

IPCC	International Panel on Climate Change
Km	Kilometre
L1TP	Level 1 Precision and Terrain-Corrected
LAI	Leaf Area Index
LGAC	Landsat Global Archive Consolidation
LiDAR	Light Detection and Ranging
LLHM	Local Linear Histogram Matching
LUI	Land Use Intensity
MNL	Multinomial Logistic Model
NBS	Nigeria National Bureau of Statistics
NDVI	Normalized Difference Vegetation Index
NEST	Nigerian Environmental Study/Action Team
NIMET	Nigeria Meteorological Agency
NIR	Near Infrared
NPC	National Population Commission
NPP	Net Primary Production
NPP	Net Primary Production
NSPI	Neighbourhood Similar Pixel Interpolator
OECD	Organization for Economic Co-operation and Development
OLI/TIRS	Operational Land Imager and Thermal Infrared Sensor
Pg/C/Year	Petagrams of carbon per Year
PH	Power of Hydrogen
PMT	Protection Motivation Theory
PP	Projected Population
RESTREND	Residual Trends
RUE	Rainfall Use Efficiency
S-BiK-F	Senckenberg Biodiversität und Klima- Forschungszentrum (BiK-F)
SIDA	Swedish International Development Agency
SLC-Off	Scan Line Corrector off
SSA	Sub-Saharan Africa
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework of Climate Convention

USGS	United States Geological Service
VAST	Vegetation, Assets, States and Transitions
VSI	Vegetation Spectral Index
WLR	Weighted Linear Regression
WMO	World Meteorological Organization

Table of Contents

List of Figures

List of Tables

Abstract

As a cognitively-mediated response, autonomous adaptation at farm-gate levels constitutes reactionary actions by farmers against climate impacts. These actions are shaped by interacting factors such as household characteristics, livelihood scope and resources. It is driven by the goal of adapting cultivated farmlands to climate and for sustaining crop yields. Thus, interest in balancing adaptation goals with protection of vegetation conditions is less of a priority. Lack of research interest in understanding the gap between objectives of reactionary adaptation and protection of surface conditions (vegetation canopies) is a gap in research. In many studies, farm-gate level adaptation is described as a set of zero-feedback actions in response to climate impacts. This perception conceals the stress and impact-engendering attribute of reactionary adaptation. Inspired towards addressing this conceptual gap; this study investigates impact of farmers' reactionary adaptation on vegetation cover in Keffi, Nasarawa, Nigeria. A twenty-year time-series NDVI and rainfall datasets are linearly regressed to examine the extent of NDVI-rainfall sensitivity. A weak linear relationship between NDVI and rainfall in Keffi for the period, 1999-2018 is observed. At a regression slope of 0.001, R squared, R2=0.129 (implying that only about 13% of the variability in NDVI in Keffi are explained by rainfall amount) and a bivariate regression coefficient, r=0.359; statistical evidence shows that rainfall amount are not significant predictors of NDVI in Keffi. In investigating the possible interference of non-rainfall factors on vegetation productivity (NDVI) in Keffi; a residual trend (RESTREND) analysis was carried out. Regression of residuals from NDVI-Rainfall linear regression produced a R=0.192 with a negative and downwards slope. The downward character of the RESTREND slope is suggestive of non-rainfall factors contained in the residuals. In validating the RESTREND analysis, a comparative analysis between observed and predicted NDVI derived from a reference NDVI value of 0.46 was carried out. The NDVI value of 0.46, is empirically assumed to be average NDVI value expected at a minimum rainfall amount of 850mm/year reported in tropical Savanna ecosystems. Using this empirical relationship, NDVI values were predicted for Keffi. Even at higher rainfall amounts≈1340mm/year, amounts were unable to produce corresponding higher NDVI values; rather a more plausible correlation between reference-derived predicted NDVI values and rainfall was obtained. A further analysis with predicted NDVI values, based on 1999 NDVI value in Keffi returned higher NDVI units than observed NDVI values. This strengthens the attribution of the possible interference of rainfall-NDVI sensitivity by non-rainfall factors like human activities on vegetation productivity. Surface soil analysis to exclude potential impacts of soil nutrients and moisture deficiency on vegetation productivity, showed that soil had insignificant effect on vegetation dynamics. Further inferential analysis, using the inter-annual NDVI and the reclassified bi-decadal NDVI maps showed that spatial vegetation distribution in Keffi were driven by farmers inter-annual rotational cultivation footprints than rainfall variability. With a three-class categorization, "gain, loss and significant loss", the spatial distribution of vegetation in Keffi between (1999-2008) and (2009-2018) was assessed. Temporal condition (stressed and healthy) across the three classes supports the attribution of farmers' reactionary adaptation and cultivation practices on the dynamic spatial vegetation distribution. Between 1999 -2018, an increase in areas with significant vegetation loss (42%), so with a decrease of -25% in areas with healthy vegetation was observed. The character of vegetation cover across the two decadal time slices, reflects landuse intensity and unsustainable farming practices. Preferences for modification of cultivation practices and changes in seed by farmers exerts positive feedbacks on vegetation cover. Higher statistical measures, 38.4% (yearly cropping) and 44% (shifting cultivation with less fallow periods) were observed in the chi-square analysis. These measures were higher than 2.0% relating to shifting cultivation with more fallow periods. While 11.6% farmers noted cultural practices as reasons for preferred cultivation methods, 48.4% farmers attributed climate as reason behind cultivation modification. This was higher than 24.4% who linked issues of tenure rights to cultivation practices. With preferences for yield- breaching strategies, the non-receding cultivation and shorter fallow practices in Keffi triggers feedback on vegetation dynamics. Evidence from this study shows that the NDVI-rainfall functional sensitivity in Keffi is plausibly dampened by effects of reactionary farm-gate level adaptation practices.

Keywords: Climate, Reactionary, Human-cognition, Adaptation, NDVI, Smallholder Farmers, Vegetation Cover Dynamics, Nigeria, Keffi, Feedbacks.

1 Introduction

1.1 Smallholder Farmers' Autonomous Adaptation at Farm-Gate level and Potential Impacts on Vegetation

Small scale farming at farm-gate level has been identified as one of the socio-economic sectors that will experience incremental impacts due to the exposure of its system's attribute to the risks associated with shifts in the averages of climate variables. Subsistence farming practiced on small farm hectares and holdings are sectors managed by limited sized labour and highly dependent on average climatic conditions. Lacking in technological and mechanized capabilities, small scale farming as described in Harvey et al. (2014, p 20130089) and Jayne et al. (2010, pp 1384–1398), are fragile sectors with high vulnerability to climate risks. Some studies have documented that the projected scale of future impacts of local and regional climate change on small scale farming in Africa will be high especially in regions with very low development indices. Persisting institutional, economic and technological challenges confronting rural societies in tropical African countries, coupled with the widening deficit in physical infrastructure are factors that will interact with climatic and non-climatic risks with impacts on the agricultural sector. According Graff et al. (2006, pp 1430–1445) the lack of or low penetration of technologies capable of supporting mechanized farming as well as poor policy environment capable of incentivizing off-farm economic activities increases the risks index of climate change on subsistence farming. Much of these policy gaps are in the agricultural and market sectors.

In Nigeria, impacts of these institutional and policy gaps affect subsistence agricultural due to limited institutional incentives. At the rural level, these gaps are expected to interact with both changing climatic variables (rainfall and temperature) and household conditions to exacerbate impacts. In a country with over 80% of its population engaging in small scale farming Mgbenka et al. (2016, pp 43–54), the impacts of climate risks on small scale farming systems in Nigeria is estimated to be complex. This is so because of the characteristics of the sector. Small scale farming is characterized as a sector whose functional attributes are highly sensitive to climate variables Harvey et al. (2014, p 20130089). In Nigeria, the small scale agricultural sector is also a sector managed by resource-poor individuals whose main objective of farming is principally for household consumption and meeting daily subsistence needs Badiru (2010). According to the fifth assessment of the intergovernmental panel on climate change (IPCC), (AR5, 2013); small scale agriculture fundamentally underpins three key objectives. These three objectives include securing of household incomes, sustaining of social cohesions and supporting livelihood means. In the last three decades, the management of small-scale farming under new realities of constrained climate has gained both policy and research attention. This is against the backdrop of the impacts of climate change on small farm systems in terms of its biophysical and functional attributes (AR5,2013). Climate change is expected to affect the small-scale farm sectors with respect to its vulnerable arising from the interaction of a mixed of factors including globalization with climate risks.

The scientific and policy attention given small scale farm holdings is in part due to the character of small-scale farms. The scope, region of operation and the dependence of small-scale farms rainfall and temperature characterizes this sector. In terms of scope, small scale farming is cultivated on small hectares of farmland and is managed with family-oriented labour. The scope of its operation is also restricted to ensuring food supplies and subsistence household needs. In terms of geographical region, the defining physical geography and environmental conditions also characterizes small scale farming. In terms of the geographical conditions, climate-related conditions of long drought periods, high temperature and frequent storms in most tropical African regions (AR5, 2013) affect small scale agriculture. Small scale agriculture has been described in (AR4, 2007) as highly sensitive to impacts of climate change and in Sultan et al. (2013, p 14040), it is due to the character of precipitation events (drought or floods). Thus, the characteristic elements of small-scale farming in poor developing economies is expected to interact with existing inequalities, poverty and associated institutional limitations to exacerbate socio-economic impacts Olsson et al. (2014).

From a regional perspective, the institutional arrangements and governance systems also impacts the performance of small-scale farming systems. In Barrett et al. (2001, pp 497–502), impacts of weak institutional systems on small scale farming such as lack of robust extension services and incentives for supporting large scale agriculture has also been accounted for. Across Nigeria, other institutional issues include land tenureholdership. Land tenureholdership affects the duration and size of land hectares which farmers are entitled to. Land tenure titles in Nigeria are fluid and transitory and with its inherent uncertainty which limits the scope of small farm systems within subsistence farm systems.

The interaction of the different elements that characterises small scale agricultural systems thus deepens the system's biophysical vulnerability as well as the social vulnerability of small farm holders. It also limits the abilities of smallholder farmers to undertake more sustainable adaptation options including off-farm adaptation strategies. In Keffi, Nasarawa state, there is growing documentation on the impacts of climate variability on cultivated farmlands Salau et al. (2012, pp 199–211), Labaris (2012, pp 68–74) . There exists also reports and research publications on small holder farmers perception of changing climate in Keffi and the adjoining localities in studies such as Falaki et al. (2013, pp 133–140). Farmers' efforts at managing climate risks and protecting cultivated farmlands from climate change impacts have also been documented in Othniel & Resurreccion (2013, pp 341–364) Managing climate risks implies evolving adaptation and coping measures; which entails adjustments in management practices in other to safeguard performances of crops. However, studies on adaptation to climate change in Keffi have largely focused on trends in adaptation among small scale farmers, preferred adaptation strategies as well as challenges to adaptation in Keffi. Adaptation in major rural farming settlements is fast becoming a set of cultural practices by farmers in responding to climate change. In Keffi, new ways of sustaining crop performances under sets of constrained climatic conditions have evolved and through development policies, these incremental and transformative practices are growing in acceptance.

From a human geography perspective, adaptation to environmental impacts is an inherent social action; and human history is replete with the evolution of fit-for-purpose adaptation strategies. This understanding is highlighted in Pitman (2005, pp 137–148). According to the study, adaptation efforts by the human society interfaces with elements of human geography. However, while incremental and transformative adjustments to the impacts of climate change has been embraced as a corresponding social action, little attention has been given to the impacts of autonomous climate adaptation which in most cases are carried out reactively. So has little research interest been made on the impact of reactionary autonomous adaptation on the biophysical conditions of land surfaces and vegetation canopy cover. While adaptation is desirable, the lack of consideration by all actors including small holder farmers, policy makers and adaptation research scientists on the potential of autonomous climate adaptation on land surface conditions is of curious interests. This study therefore seeks to go beyond the routine adaptation research at farm gate levels and the necessity thereof into investigating whether or not autonomous adaptation at farm-gate levels carried out reactionarily could potentially affect land biophysical properties. This study seeks to further deepen the interlinkages between physical and human geography.

1.2 Motivation for the Research

The motivation for this study arises from the research interest in understanding climate adaptation at farm-gate levels within the influence of other externalities (economic and socio-political pressures) as well as investigate the feedback loop of such adaptation process on vegetation canopy conditions. As a locality sandwiched between Abuja, the federal capital of Nigeria in the west, Plateau state in the east and Benue in the south, Keffi, as one of the thirteen local government areas in Nasarawa state, Nigeria faces multiple development and environmental challenges. Keffi is particularly affected by the synergistic impacts of persisting socio-political and economic challenges confronting neighbouring localities like Mararaba, Greater Karu, New Nyanya, Ado, Masaka and One-man village. The rapidly growing population of these areas coupled with vehicular congestion, poor town and housing planning in these surrounding localities have been identified as major drivers of the urban expansion into Keffi. This has been reported in Isma'il et al. (2015, pp 45–57). Unsustainable urban growth, expansion of human settlements into primary vegetated areas and population dynamics is altering the human and physical geography in Keffi.

It has been documented in some studies that vegetation conditions in Keffi is undergoing changes in the aereal coverage and canopy density. Most of the associated causes has been due primarily to socio-economic pressures both from the quest for new arable land for small scale agriculture and for housing development Rikko (2013). This new environmental and development reality and the factors driving it has been reported in Habila (2018). The urban sprawl along Greater Karu Urban Area (Gkua) and Keffi in Nasarawa state as mentioned in Rikko (2013) has also led to the shrinking of primary vegetation cover. In recent years, road congestion along the Abuja-Keffi corridor reported in Biliyamin and Abosede (2012) has aggravated land use challenges in Keffi necessitating both the expansion of human footprints on native vegetation and changes in land use and land use cover management. Aggravating this spatial planning challenge is the uncoordinated peri-urban planning in Keffi which as documented in Mahmud & Achide (2012, pp 129–134) is responsible for dwindling vegetated land coverage. For example, a study by (Alwadood et al., 2016) it was observed that between 2001 and 2007, Keffi witnessed growth a 58.71% growth in built-up settlements sprawl with a 2.21% corresponding increase from 9.13% in 2007 to 22.36% in 2013.

Besides the impacts of inefficient land use planning and urban sprawl in Keffi, the pressure on landuse from agricultural practices particularly subsistence farming has reported in Salau & Attah (2012, pp 17–29). The study reported that rural dwellers in the three major peri-urban areas in Nasarawa state (Keffi, Akwanga and Lafia) indicated that the main motivation behind urban agriculture was to achieve additional household income, household food security and new employment streams. Urban agriculture is now a new phenomenon aggravating the challenge of multiple land uses in Keffi and a major driver of declining natural vegetation covers.

Interacting with poor spatial planning and population dynamics is the unsustainable management of agricultural systems by subsistent farmers in Keffi. In recent years, the management of cultivated farmlands have evolved under both impacts of climate change, poor town planning and new armed conflicts by Hausa-Fulani Herdsmen on farming communities. Although a country-wide development challenge particularly in the northern and north -central parts of Nigeria, armed conflicts between nomadic Fulani herdsmen and peasant farmers in Nasarawa state has increased. This, according to the federal government of Nigeria is due to resource competition for pasture and arable land exacerbated by changing rainfall variability. This climate-driven resource conflict between local subsistent farmers in Keffi and Fulani herdsmen has been reviewed in Okoli & Atelhe (2014, pp 76–88) and Girei et al. (2017). Findings and arguments contained in these publications corroborates local newspaper reports on the climate change dimension of armed conflicts between Nomads and smallholder farmers in Nasarawa and other Northern states in Nigeria. Thus, there exists in Keffi and other adjoining localities in Nasarawa state a multi-faceted development challenge. To smallholder farmers in Keffi, these multi-faceted challenges is of greater concern to their natural resource-dependent livelihoods due to the role in driving the decline of arable land areas. In addition to driving the decline in aereal extent of arable land, the socio-political dimension from the standpoint of land tenure rights also impacts on the issue of sustainable land management. So are the qualitative and quantitative attributes of land surface conditions under new vulnerabilities from these socio-economic and institutional challenges.

Examining the synergistic role of these challenges within the context of growing climate change risks and the character of farm-gate level adaptation in Keffi from the perspective of impacts on land surface conditions underpins the motivation of this study. Smallholder farmers in Keffi as in anywhere else, intuitively carry out different modifications in cultivation practices and farmland management decisions in responding to the impacts of climate change. These coping and adaptation decisions are inevitable human responses as risks from variations in climatic means interact with fragile rural livelihoods to further exacerbate the biophysical vulnerability of these livelihoods systems and the social vulnerability of the managers of these systems. The synergistic influence also exerts additive impacts on the land surface biophysical conditions including vegetation canopy conditions. Natural vegetation canopy conditions are dynamic and undergo changes in the functional (physiological) and structural attributes when exposed to disturbances and stress regimes. Spanning anthropogenic and environmental factors, the conditions of vegetation covers can undergo transition in states (from undisturbed to disturbed states) when altered by actions from these factors Thackway and Lesslie (2006, S53-S62). Vegetation dynamics has been widely studied in terms of the impacts of abiotic and biotic factors on shifts in specie composition, structure and functionality. In Pickett et al. (2005, pp 172–198), Verbesselt et al. (2006, pp 399–414), Tessema et al. (2011, pp 662–670) and Ma et al. (2013, pp 97–115) are some of the studies that have provided accounts on the temporal vegetation dynamics with respect to shifts in the structural and functional attributes. . In other research endeavours, where vegetation monitoring and land surface mapping is the main objective, the impact-engendering potential of only certain anthropogenic activities such as land use changes, infrastructural development impacts, irrigation and mining have frequently been cited as human activities with potential impacts on land surface conditions and vegetation canopy structures.

Similar to the narrow problem framing and consideration of only certain human activities as anthropogenic in character in vegetation mapping and monitoring studies; research interests in climate change impacts at farm-gate levels have been largely focused on farmers' adaptation strategies, farmers' perception of climate change, knowledge and information capacities. A review of relevant studies with geographical focus on tropical ecoregions in sub-Saharan Africa has further shown the preponderance of these themes as problem statements in adaptation research. Studies like Gbetibouo et al. (2010, pp 217–234); Shikuku et al. (2017, pp 234–245), and Zamasiya et al. (2017, pp 233–239) are examples. In Keffi, research interests on climate change at farm-gate level also follows the traditional research pattern with problem statement framing revolving around farmers' perception of climate change. In Nigeria, scholars with interests in climate change research within the agricultural sector in the northern-central and northern parts of the country have also followed the conventional problem statement framing pattern. Scientific interests in climate adaptation at farm gate levels and the related socio-cultural transformation associated with farmers' adaptation responses has dominated the climate research landscape. Studies like Labaris (2012, pp 68–74), Falaki et al. (2011, pp 49–62), Salau et al. (2012, pp 199–211) , Bello et al. (2013, p 107) and Othniel & Resurreccion (2013, pp 341–364) are some of the empirical studies that have provided new knowledge into the process of climate adaptation in the agricultural sector in Keffi and other localities in Nasarawa state.

The preponderance and limited interests on farmers' perception, knowledge and behaviours within the context of climate adaptation has created a missing link in both adaptation research and vegetation mapping studies. The drawback of this missing link is that it has eluded the interlinkages between human and physical geography which strengthens associated socio-ecological concept. It has also limited further scholarly deepening of climate adaptation research not only in conceptual terms but also in implied development terms. Autonomous climate adaptation process is a social action initiated on land surfaces. It is not only a stand-alone social action in itself but a reactive action influenced by many factors such as governance, socio-economic capabilities and prevailing cultural regimes. It is also an action intended for and influenced by household considerations. Thus, at farm-gate levels, autonomous climate adaptation is an action embedded in household and economic considerations with influence from institutional and socio-political factors. This makes its complex interlinkages with socio-economic and environmental variables as well as institutional governance arrangements relevant for studying its anthropogenic attributes. Autonomous climate adaptation at farm-gate levels are institutionally-constrained actions that influences the ways in which adaptation strategies are implemented. It shapes the tools, adaptation decisions as well as how the response and resource efficacy are evaluated. Due to the complex inter-linkage, autonomous climate adaptation constitutes anthropogenic activities that could potentially impact land surface conditions. This gap in knowledge in adaptation research and the potential feedback of on vegetation cover dynamics from a socio-ecological point of view constitutes the missing link which this study seeks to establish.

1.3 Significance of the Study

This study is relevant to the body of science and to the deepening of climate adaptation science research in three ways. First, it reviews the limiting and narrow framing problem statements of vegetation monitoring studies to climate change and to only certain anthropogenic activities. It highlights that certain subtle social responses like climate change adaptation can potentially impact vegetation canopy conditions and functional states. In expatiating the impact-engendering attribute of farm gate level adaptation, this study argues that interacting influences from socio-political, demographic and socio-economic development challenges acts as institutional constraints to sustainable adaptation decisions. Against the backdrop of resource-constrained climate adaptation process in the agricultural sector, the commonly held perception of autonomous adaptation as an idealized response measure to impacts of climate change is re-examined. Arguing from the context of the coupled human-environment system with attributes of a closed system; it is plausible to expect positive feedback loops when a component of one system interacts with the interacting system. This system analogy can be applied to autonomous and reactionary climate adaptation at farm-gate levels on vegetation covers. However, narratives on climate adaptation in the agricultural and land use sectors both in scientific studies and policy discourse addresses autonomous climate adaptation at fine-grain levels obfuscates the potential of feedbacks from a coupled human-environment point of view. Farmers’ adaptation to climate impact particularly at the farm-gate levels has been widely studied but less attention has been given to the potential impact of these reactionary-oriented adaptation actions on vegetation cover dynamics.

This study examines the nature, scope of autonomous climate adaptation as well as the underlying socio-economic factors influencing farmers’ adaptation decisions at farm-gate levels. Through a discursive analysis of relevant concepts of rural livelihoods and land use intensity, this study in addition to investigating the potential feedback of farmers’ adaptation on plant assemblage; also interrogates the commonly held episteme of which activities are anthropogenic in nature. This study argues that current and commonly applied intellectual understanding of anthropogenic activity is limited. Arguments using typologies of adaptation provided in other studies and associated consequences of unregulated, autonomous climate adaptation is utilized in interrogating the dominantly held episteme of what constitutes anthropogenic. The weakness and bias in the dominantly held epistemology of only certain activities qualifying as anthropogenic activities is provided. The study reveals the limiting role of such commonly held episteme in contributing to the exclusion of other subtle human activities such as autonomous adaptation. The study therefore contextualizes farm-gate level adaptation as an anthropogenic activity and brings to the fore the impact-engendering potential of autonomous climate adaptation actions. The nexus between human and physical geography is also explored using spatial and vertical hierarchies in social organisations which shapes human resource capabilities. Vertical differentiation in social organizations constitutes some form of limitations to more precautionary and sustainable autonomous adaptation due to the differential capabilities or its lack thereof. In conditions of lack and access to resources and lack of institutional incentives, sustainable adaptation choices requiring long term planning and investment are unrealizable by rural farmers. This influences farmers’ preference for short term and quick fix adaptation strategies. Involving most often than not, intense and unsustainable use of land, quick fix and reactionary adaptation strategies have potential impacts either directly or indirectly on the environment. With vertical differentiation in social organizations with regards to human capabilities determining the scope, character and degree of human-environment interaction, reactionary and autonomous adaptation at farm gate levels have the potential of engendering feedbacks on the biophysical properties of land. Studies have shown that non-receding human trampling on land and vegetation cover can potentially cause shifts in the quantitative and qualitative physiological processes.

1.4 Research Hypothesis: Vegetation Cover Dynamics and Anthropogenic Regimes

Impacts of human footprints on vegetation cover has been widely studied with anthropogenic activities in the land use sector framed as causative factors in the quantitative and qualitative mapping of the extent of human modification of vegetation. Common research interests in these studies often revolves around investigating parameters like vegetation physiological condition states, species composition, plant phenology and changes in vegetation structural forms in relation to human disturbances. Although other subtle human activities with the potential of altering vegetation cover dynamics have been under-investigated or less considered in vegetation mapping studies; the common objective of assessing vegetation response to human disturbances has been upheld. To support the development of a hypothesis for this study, a brief overview of the scientific understanding of physiological functioning of vegetation is offered. According to Lesslie et al. (2010), vegetation are in an optimal growth condition when a balance between the functional and structural states as well as physiological processes are maintained. However, the optimum growth condition of vegetation can be altered under disturbances or stress from abiotic in Akula and Ravishankar (2011, pp 1720–1731), biotic agents or environmental factors as reported in Short and Wyllie-Echeverria (1996, pp 17–27). Vegetation condition states can also be modified through human disturbances and other non-human factors as mentioned in Monz (2002, pp 207–217) irrespective of the duration of disturbance whether abruptly or through time. In response to external stress, Thackway & Lesslie (2008, pp 572–590) identifies vegetation dynamics, shifts in succession and fragmentation processes, alteration in the functional and structural patterns of vegetation as some of the indicator events. The author also notes that changes in the regenerative capacity and gradual change in vegetation condition states as manifestations of disturbance on assemblage plant life forms. In this study, vegetation cover dynamics is utilized as an indicative process in studying vegetation cover response to climate adaptation-related disturbances in Keffi.

Vegetation cover dynamics according to Pickett et al. (2005, pp 172–198) implies changes in the three-dimensional structure of plant covers and the species composition of plant assemblage. It also implies changes in initial biological conditions due to the disruption of the substrate upon which vegetation grows Pickett et al. (2005) and in the removal of vegetation cover. According to Pickett et al. (2005, pp 172–198), vegetation dynamics can be triggered by biological conditions, or by “new sites” (modified land surfaces) or vegetation structures caused by disturbances or differences in available species. In Thackway & Specht (2015, pp 136–152), vegetation dynamics is implicit in the variation of vegetation conditions states. However, both studies, Thackway & Specht (2015, pp 136–152) and Pickett et al. (2005, pp 172–198) while upholding the concept of change in condition states, relates vegetation dynamics with changes through time. Other studies like Sellers (1985, pp 1335–1372) and Tessema et al. (2011, pp 662–670) assess vegetation dynamics using changes in biomass (an indicator related to variations in the physiological states of plants). In these studies, changes in herbaceous biomass were correlated to changes in vegetation structure and soil due to grazing activities in the semi-arid Savanna of Ethiopia.

Under normal environmental conditions, studies have shown that vegetation functional and structural variables are in equilibrium guaranteeing maximum photosynthesis Betts et al. (1997a, p 796). Where the structural-functional balance is impaired, physiological state is also affected with consequences on dynamic shifts in vegetation cover and green distribution as noted in Tessema et al. (2011, pp 662–670). A study by Betts et al. (1997b, p 796) expatiates the scientific knowledge on the role of “steady state conditions” as well as an enabling environmental condition in supporting physiological processes in vegetation. However, plant physiological processes are linearly linked with structural organs and plants performances. This knowledge is based on the scientific evidence of the link between vegetation physiological functioning and structural organs (leaf morphology, canopy composition, height and growth form) and its implication in overall vegetation growth conditions. Lesslie et al. (2010) noted an equilibrium between structural organs, species composition, functional quantities as well as the regenerative capacity of vegetation is important in maintaining balanced physiological states in vegetation. This view is also shared by Migliavacca et al. (2017, pp 1078–1091) and Gamon et al. (1995, pp 28–41). At the process level, canopy structures have been found to be relevant for both the infiltration of precipitation, carbon dioxide fertilization and also for the absorption and utilization of fPAR. Corroborating this, Pearcy et al. (2000, pp 137–160), Sassenrath-Cole (1995, pp 55–72) and Gamon et al. (1995, pp 28–41) explained that vegetation physiological functioning and by implication, vegetation dynamics is determined to a large extent by four measures of canopy structure. These four indices of canopy structures include biomass, leaf Area Index, chlorophyll concentration and foliar nitrogen concentrations. Studies by Drake et al. (2002, pp 305–319) where a high correlation coefficient (R2=0.94) between biomass and average forest canopy characteristics under the sensitivity of LiDAR was observed also supports this evidence. Norman & Campbell (1989, pp 301–325) also summarized the canopy-radiation interface in a plant-environment context strengthening knowledge of impairment in radiation absorption in plants due to modification of structural organs. Similarly, (Sellers 1985), in a study comparing vegetation physiological performances under stress and non-stress scenarios, demonstrated that canopy structures impaired under conditions of stress loses plant capacity to absorb photosynthetic active radiation thereby undermining plant physiological functioning.

Stress or disturbance regimes can impair plants optimal physiological conditions through shifts in the structural-functional equilibrium states. The effect of stress (biotic, abiotic, human or environmental) on vegetation cover dynamics have been widely studied so is the mechanisms by which stress affects plants. Pickett et al. (2005, pp 172–198) notes that disturbance largely affects the structure of vegetation, the condition of the substrate upon which vegetation grows, the degree to which biomass is removed as well as the resources that remains after vegetation condition state is transformed. According to Pickett et al. (2005, pp 172–198) disturbances could come from intense events like tornadoes and floods, less intense events (soil disturbances) as well as from human activities including post-agricultural activities and human-dominated landscapes. In the context of vegetation dynamics or other response trajectory of vegetation in response to disturbances or stress factors; the research value of these disturbance regimes is crucial because of the intensity, degree and frequency of disturbance on plants assemblage. Understanding the concept of stress is helpful in building up a study hypothesis that supports the framing of the problem statement.

Conceptually, Lichtenthaler (1996, pp 4–14) defines stress in plants as any unfavourable condition that hinders plant metabolic activities and also affects plants growth and development. However, from a physiological viewpoint, Larcher (2003) refers to stress in plants as impacts on plant physiology following exposure to unfavourable conditions. The definition provided by Larcher (2003) and Lichtenthaler (1996, pp 4–14) shows differential emphasis on the concept of stress in plants. While, Larcher (2003) highlights the concept of intensity (increasing pressures), impacts (destabilization of functions), response and regeneration (normalization and or improved resistance) and end-phase (in extreme cases); Lichtenthaler (1996, pp 4–14) emphasizes on applied force in describing factors that can predispose plants to stress. While preferences of and usages of conceptual terms differs across studies, the scientific understanding remains the same and does not in any way obfuscate the role of stress regimes on vegetation cover and physiological condition states. Stress in plants have the capacity to cause alteration in plant growth response including variations in cell metabolism. As reviewed in studies by Dirmeyer (1994, pp 1463–1483) and Lichtenthaler (1996, pp 4–14), stress or disturbance factors has the ability to impair canopy structures, cell metabolism, reduce physiological functioning and also affect plant growth and vitality. In most of these studies, exogenous stress has been identified as the major causes of shifts or absolute impairment in plants functional states. Also, in Sellers (1985, pp 1335–1372), stress was found to reduce canopy structural capacity to absorb photo-synthetically active radiation (fPAR) with consequences on photosynthesis. Kancheva & Georgiev (2012) in an assessment study of crops under influence of different environmental and human pressures established a statistical relationship between stress factors and plant spectral indices. Quantifying the impact of plants exposure to stress in vegetation mapping studies, derives relevance when these disturbance factors are assessed in terms of their sources, magnitude, intensity, degree as well as the duration of exposure. Thus, intensity (increasing pressure in magnitude and in return time) and the character of stress offers exploratory basis in understanding how disturbance regimes affects vegetation covers both linearly and non-linearly. Hierarchical destabilization of structural features of plants have been discussed in Pickett et al. (2005, pp 172–198), where the author notes that vertical destabilization occurs from canopy structural arrangements through to functional imbalances.

In this study, focus is on human-related stress (reactionary farm-gate level adaptation practices) on vegetation cover and by implication structural-functional performances. Continuous human activities on land surfaces exerts stress through trampling effects on vegetation covers and foliar organs. Human activities (mechanical stress) particularly in the agricultural and landuse sectors manifests as trampling effects, directly damaging vegetation with direct implications on plants morphological structures and cellular functioning. As defoliation occurs instantly upon trampling, Sun and Liddle (1993, pp 497–510) notes that loss of nutrients and reduction in surface for photosynthesis are affected. Sun and Liddle (1993, pp 497–510) noted that human activities exerted limitation on chlorophyll content and fPAR[1] as 87.5% of the densely tourist patches were made up of stressed vegetation that performed poorly physiologically. Human-related stress regimes have direct contacts with plants structural organs as mentioned in Norman & Campbell (1989, pp 301–325) with consequences on spectral absorptive capacity of plants through damage on optical apparatuses.

Empirical evidence from studies like Cole (1995, pp 203–214), where vegetation responses under intensive experimental trampling in eighteen different vegetation types were studied corroborates this scientific understanding. Results from the study showed that vegetation responses to trampling were linear and that responses depended on the intensity of human disturbances as well as the vegetation type. Although, Cole (1995, pp 203–214) showed that vegetation response under human trampling impacts was more pronounced within shorter periods after the trampling but effects decreased with time as species resilience and diversity tolerance increased. In Monz (2002, pp 207–217), it was shown that human trampling affected vegetation heights, species diversity and richness. In Vrieling et al. (2011, pp 455–477), changes in African farmlands under different farming systems and climatic conditions were characterized and a positive correlation between trends in cumulative NDVI (cumNDVI) and differential land use across Senegal and Southern Sudan was found. This scientific understanding provides a premise for the study hypotheses seeking to investigate whether reactionary adaptation practices by smallholder farmers in Keffi could potentially affect vegetation cover dynamics.

1.5 Research Goal, Objectives, Hypotheses and Research Question

The aim of this study is to examine potential impact of farmers' reactionary adaptation behaviours on vegetation cover dynamics in Keffi.

Goal of Research: To investigate the potential feedbacks of reactionary adaptation by smallholder farmers in Keffi on vegetation cover dynamics.

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[1] fPAR is photosynthetically active radiation. It is the fraction of incoming solar energy that is effectively used for photosynthesis in plants.

Objective 1: To generate and inferentially analyse NDVI values in Keffi between 1999-2018.

Objective 2: To disentangle signals of climate adaptation-driven farming practices from inter-annual rainfall variability on vegetation conditions in Keffi.

Objective 3: To analyse surface soil for the control of impact of soil nutrients and moisture deficiency on vegetation cover dynamics in Keffi

Hypothesis 1 (Null): Climate adaptation-driven cultivation practices in Keffi does not have the potential of triggering changes in vegetation cover.

Hypothesis 1 (Alternative): Climate adaptation-driven cultivation practices in Keffi does have the potential of triggering changes in vegetation cover.

Hypothesis 2 (Null): Smallholders' livelihood circumstances in Keffi have no influence on their preferred climate adaptation strategies.

Hypothesis 2 (Alternative): Smallholder farmers' livelihood circumstances in Keffi have no influence on their preferred climate adaptation strategies.

Research Question: To what extent are variations in inter-annual NDVI values associated with climate variability relative to agricultural land use-related practices in Keffi?

1.6 Overall Context of the Research and Problem Statement

This section is dedicated to providing the background information underpinning the research idea. It provides the thematic scope from which the problem statement is framed. An overview of the challenge of climate change, the knowledge underpinning the physical science basis of climate change and its regional disparities is provided. A narrative on the impacts of climate change on natural and social systems is also provided with the intention of deepening contextual clarity.

1.7 Overview of Climate Change and Associated Impacts on Natural and Social Systems

The scientific knowledge of the physical science basis of the Earth-Climate system and current lived realities points the fact that earth climate has changed. Changes in the above-surface mean temperature and sea level rise as documented in Barros et al. (2014), growing levels of species extinction and range shifts reported in Chen et al. (2011, pp 1024–1026) and Walther et al. (2002, p 389) as ecological responses to climate change; all point to marked changes in the climate beyond normal internal climate variability. Alteration in hydrological fluxes reported in Vitousek et al. (1997, pp 494–499), the occurrence of extremes such as floods and droughts mentioned in Easterling et al. (2000, pp 2068–2074) are all part of the observed changes linked to marked shifts in the Earth-climate system.

In Myhre et al. (2013, pp 658–740) and Barros et al. (2014), changes in the climate system have been linked primarily to greenhouse gas emissions which Stern (2007) notes are mainly rooted in human consumption and production levels. These greenhouse gases are often associated with current development patterns and rising levels or industrialization. According to Stern (2007), human production and consumption systems are main anthropogenic forcing which also accounts for the variations of the overall Earth-Climate energy budget. This, Stern (2007) argues is connected primarily to the unsustainable development patterns undertaken by the human society to meet socio-economic needs with direct consequences on the levels and concentrations of atmospheric carbon dioxide and other greenhouse gases. According to Stern (2007), the influence of anthropogenic emissions on the Earth-climate system depends to a large extent on the carbon stock in the atmosphere, the carbon cycle, the Earth's absorptive capacity and related feedback processes.

In other studies, changes in the Earth-Climate system have been attributed to two major drivers: human and natural drivers which Stott et al. (2010, pp 192–211) notes contributes to the shift or alteration in the energy balance of the Earth-Climate System. These two major drivers influences climate through their impact on the energy balance of the climate system. Although shifts in the radiant energy where imbalances of incoming and out-going energy are also prominent in triggering changes in the total energy balance of the climate system due to the high radiative factor of 0.12 [0.06 to 2.4Wm^{-2}] associated with solar radiation variation. Although low compared to the radiative forcing exerted by greenhouse gases 1.65 [1.49 to 1.83 Wm^{-2}] and even lower that the radiative forcing due to stratospheric ozone gases 0.35 [0.25 to 0.65Wm^{-2}] as mentioned in Myhre et al. (2013, pp 658–740); the radiative forcing of solar irradiance is a principal factor in the internal shift in the climate system. Further scientific understanding has further shown that not only are variations in solar radiation responsible for imbalances in climate system energy budget but also are changes in atmospheric composition, quantity of greenhouse gases and changes in land surface biophysical properties as mentioned in Stocker et al. (2013). Interests in the radiative forcing of drivers in the context of climate change is due to the measure of the size of influence and impact which an agent can exert on the climate system through alteration of its energy budget. These alterations in the net energy balance of the climate system as noted in Pachauri et al. (2014) is associated with positive feedback processes with attendant risks on natural and social systems.

Of all the drivers of climate change, anthropogenic activities have been identified as the principal driver of energy shifts in the climate system due to its large radiative forcing. Myhre et al. (2013, pp 658–740) notes that the size of radiative forcing on the climate system due to atmospheric greenhouse gases is accounted for by increases in emissions from production systems, aerosols, the use of ozone-forming chemicals and changes in land surface albedo. Of these greenhouse gases, Stocker et al. (2013) notes that carbon dioxide is the most significant earth warming gas with its atmospheric abundance rising exponentially relative to pre-industrial times as reported. Activities in the energy, industrial as well as the agriculture, forestry and other land use (hereafter called AFLOU) sectors were identified in Pachauri et al. (2014) as the main sources of greenhouse gas emissions contributing about 78% of total global GHG emission in The contribution of the AFLOU sector to climate change has also been documented in Smith et al. (2014) where changes in land use management practices and the removal of vegetation cover were linked to shifts in land albedo and evapotranspiration with overall consequences according to Pielke et al. (2002, pp 1705–1719) on local climate.

Present and future changes in the Earth-Climate system according to Settele et al. (2015) and Shaver et al. (2000, pp 871–882) will impact biophysical variables of terrestrial and aquatic ecosystems although studies have shown that more pronounced effects will be felt over terrestrial ecosystems than in aquatic ecosystems according to Field et al. (2014). The reason for more pronounced effects on terrestrial biosphere as reported in Hall et al. (1988, pp 3–22) is due to the structure, function and composition of terrestrial biosphere including vegetation cover and their interaction with the lower atmosphere where as reported in Arneth et al. (2010, pp 525–532) are more pronounced. According to Hall et al. (1988, pp 3–22), the three feedback loops (the atmosphere and terrestrial biogeochemical fluxes; vegetation structure, hydrological cycles and climate as well soil conditions) and their rates of cycling have the potential of reinforcing stronger impacts on the terrestrial biosphere. This understanding has also been mentioned in Nikolov et al. (1995, pp 205–235).

Following impacts of climate change on structural and functional attributes of biophysical parameters of land surfaces; physiological conditions of vegetation will be affected. Example, Goward & Prince (1995, pp 549–564) mentioned that climate change will affect vegetation growth, function and health as well as the capacity of vegetation to uptake rising greenhouse gases and the rate of uptake. Due to the complexity of coupled human-natural-climate system cited in Ruddiman (2013, pp 45–68) and Liu et al. (2007, pp 1513–1516), anthropogenic-driven changes in the climate system has been reported on natural systems. Current and anticipated future changes in the climate system has been documented on having impacts on natural systems including water cycle and quality, soil, air quality Jacob & Winner (2009, pp 51–63); Paavola & Adger (2006, pp 594–609) as well as biodiversity and landscapes as mentioned in Pereira et al. (2010, pp 1496–1501) In Barros et al. (2014). Some of the cited vulnerable natural systems to changes in climate system includes coral reefs, glaciers, mangroves, tropical forests, native grasslands and biodiversity. Growing concerns however have been on the impacts of climate change on terrestrial ecosystems, integrated ecological services and social systems within the terrestrial ecosystem. Terrestrial ecosystem, particularly land surface and the economy of the human society it supports is continually at risk of a changing climate. Although, a post-perturbation recovery in the climate system can support ecological processes, residual impacts associated with shifts in climatic variables will constitute risks to land-based human activities. According to (Settele et al. 2015), human activities on land including grazing, agriculture and settlements will continue to be at risks under climate change even under new equilibrium of the climate. In (Cowling et al. 2009), (Melillo et al. 1993; Shaver et al. 2000, pp. 871–882); different aspects of the terrestrial ecosystem structure and resources that are susceptible to climate change risks have been documented. For example, Melillo et al. (1993, pp 234–240) studied the effect of global climate change on net primary production and found that the doubling of carbon dioxide and climate change were the significant primary limiting factors of net primary production in the tropics while temperature effect on nitrogen was the limiting factor in temperate regions. Overall, water, energy, food, carbon regulation and cultural aesthetics as reported in Burton et al. (2002, pp 145–159) are resources and systems that will be impacted by changes in the present and future climate regimes. Such impacts will be driven by the tight coupling of the natural and social systems to the climate system and will increase the propensity of the vulnerability of these systems to changes in climate. Fischer et al. (2002) elaborated on these vulnerabilities in the light of a changing climate mentioning diminished capacity and loss of potential for production by environmental systems. The author also mentioned increased gender inequalities, unbalanced population dynamics and weakening of economic systems as related impacts of climate changes. At a broader scale, impacts of climate change transcend all human development sectors including human settlements, infrastructure, public utility services, human livelihoods and food production systems. Rosenzweig and Parry (1994, pp 133–138) assessed the potential impacts of climate change on world food supply and found out that although doubling of carbon-dioxide may not likely contribute to significant reductions in global food supplies; there are plausibility that changes in climate system will burden climate-sensitive systems such as agriculture. Subsequently, economies with large reliance on climate-sensitive sectors such as developing countries will bear the highest brunt of changes in the climate system. According to Rosenzweig and Parry (1994, pp 133–138), farmers' self-adaptation agency in these countries will have little or no impacts on mitigating risks due to the additive impacts of interacting local conditions with changing climate systems. Of all development sectors, human settlements and food production systems will be highly susceptible to climate risks and impacts with regional disparities in socio-economic and governance systems playing major roles in shaping vulnerability indices of regions. Under conditions of more than two degrees centigrade (2^0C) temperature warming above pre-industrial levels; tropical developing countries will experience pronounced impacts of climate change including food shortages which Niang et al. (2014, pp 1–51) and Cooper et al. (2008, pp 24–35) have observed is due largely to the continent's dependence on rain-fed agriculture. This over-dependence intensifies the vulnerability of population with climate-sensitive livelihoods to impacts of climate change. Vulnerability here refers to the tendency of a system to be adversely affected upon exposure to unfavourable conditions including climate change as mentioned in IPCC AR5 report Annex II (2013, pp 117–130).

Food production systems both large-scale agriculture and small farm holdings have been identified as one of social sectors with high sensitivity to the risks of variances in the mean energy balance of earth-climate system. In the following studies, Calzadilla et al. (2013, pp 150–165), Lema & Majule (2009, pp 206–218), Morton (2007, pp 19680–19685); impacts of climate change on food production systems have been discussed. In Parry (2007) and Lobell et al. (2011), changes in crop production and yields under different emission scenarios were estimated and results showed that climate scenarios with increased surface temperature exhibited the greatest decreases in food production both at regional and global levels. Using a panel analysis model, Schlenker & Lobell (2010, p 14010) showed that most crops in Sub-Saharan Africa will suffer significant yield decreases under constraint climate conditions with the following estimated mean changes -22%, (maize) -17% (Sorghum), -17% (Millet), -18% (groundnut) and -8% for cassava. Schlenker & Lobell (2010, p 14010) also noted that across all the scenarios examined, there was a 96% probability that damages to crop production in sub-Saharan Africa exceeded 7% and 5% that damage to agricultural food production exceeded 27%. In Smith et al. (2014), the potential impact of climate change on soil organic carbon through warming have also been documented. Other studies includes Gaiser et al. (2011, pp 1120–1130); Thornton & Herrero (2015, p 830).

1.8 Regional Disparities of Current and Projected Climate Impacts within Africa

Impacts of climate change are characteristically dissimilar upon exposed units and systems and these disparities are rooted within the defining environmental, geographical, institutional and socio-economic conditions of regions and localities with recent studies showing that variations in climatic mean across regions are responsible for the differences in regional climate impacts. In the tropical and semi-tropical regions, Barros et al. (2014) and Watson et al. (1998) documented observable marked variations in climatic and meteorological events between these regions. For example, while decadal climate modelling studies on patterns of anthropogenic climate change across Africa showed increased warming trend across the continent, there were tangible regional variations in the manifestation of climate risks. Pachauri et al. (2014) noted that warming in Africa has increased more during the last 50-100 years relative to pre-industrial periods due to the rise in near surface temperatures and mean annual temperature. These regional disparities have also been validated by regional climate models and with the trajectory of present and current emission scenarios; temperature rise in Africa is expected to exceed global temperature and in addition Barros et al. (2014) reports is expected to occur one to two years earlier. While greater increases in annual minimum temperatures in North Africa have been observed; mean annual temperature in West African region, according to Pachauri et al. (2014); is rather estimated to increase rapidly exceeding global average temperature. Both Barros et al. (2014) and Pachauri et al. (2014) also described the Sahel and tropical West Africa as hotspots for climate change with projected reductions in rainfall levels at the end of 21st century. Across West Africa as with southern parts of Africa, delays in the onset of rainfall but wetter rainfall seasons at the end of 21st century has been reported in Barros et al. (2014). Overall, increases in the number of warmer days, more intense wet seasons, severe droughts and increases in the number of days of extreme events have also been documented in Abrams et al. (2017), Nicholson (2001, pp 123–144); Zinyengere et al. (2014, pp 1–10) .

These current and projected trends of climate change impacts over tropical countries have been found to interact with the intensification of cultural livelihoods like farming and the fragile over-exploited ecosystems in these regions. Reported consequences include the deepening of ecological and human system vulnerabilities in these regions. In Lema & Majule (2009, pp 206–218), these vulnerabilities are already occurring. In Busby et al. (2014, pp 51–67), similar knowledge has been corroborated and factors such as low resilience, weak adaptive capacity of the human systems and poor governance institutions have been noted as having the potential to interact with large exposure to climate change to increase risks factors. Following this understanding, South Sudan, Madagascar, Morocco, Northern Nigeria as well as the coastal areas of Egypt and Nigeria have been identified as climate risk prone areas in Busby et al. (2014, pp 51–67). In addition to social factors, the complex topography of Africa has also been mentioned in Pachauri et al. (2014) as having the potential of contributing to the severity of climate risks in the region including extreme weather events. The regional scale atmospheric processes, the relatively small internal climate variability, El-Nino events as well as underlying socio-political realities have been identified as factors that accounts for the high vulnerability of Africa to climate impacts.

In Pachauri et al. (2014), climate impacts on natural and social systems in tropical developing countries will also be exacerbated on account of other drivers like population growth, uneven demographics and the poor technological infiltration to support more sustainable adaptation programmes. For the resource-constraint population, factors such as low socio-economic profiles, fragile rural commerce and inadequate infrastructure to support improvements in economic conditions are some of the factors according to Adger & Kelly (1999, pp 253–266); Barros et al. (2014); Busby et al. (2014, pp 51–67); Gbetibouo & Ringler (2009) that will deepen the vulnerability of income-poor families in rural and peri-urban areas of tropical developing countries.

For managers of subsistence-oriented livelihoods like small-scale farming, Niang et al. (2014, pp 1–51) mentions that the impacts of climate change on local farming systems will constitute enormous challenges to already burdened populations. This knowledge frame have been Morton (2007, pp 19680–19685) and Altieri & Koohafkan (2008); Bryan et al. (2013, pp 26–35). Thus, subsistence-oriented farmers in tropical developing regions continue to remain highly susceptible to climate change impacts due to geographical and socio-political conditions. These climate realities and associated impacts in Nasarawa state as reported in a few cited studies have also been observed in Keffi, a locality in Nasarawa state, Nigeria. Studies have indicated that there have been observable changes in key climate variables like rainfall and temperature. Research and development attention has been given to rainfall variability in Keffi. The timing, character and onset of rainfall in the last decade in Keffi and its impacts on rain-fed agriculture have been documented in studies such as Falaki et al. (2011, pp 49–62), Luka & Yahaya (2012, pp 134–143) and Salau et al. (2012, pp 199–211). In some of these studies, the response pattern and perception index of smallholder farmers in Keffi to the rainfall variability have also been documented in the aforementioned studies.

Scholarly and development interests on the predisposing conditions which not only increases the susceptibility but also deepens the vulnerability of human and natural systems in Keffi and other adjoining localities in Nasarawa state have also been of research interests. While studies such as Falaki et al. (2011, pp 49–62) and Labaris (2012, pp 68–74) have addressed questions of farmers' response to climate change as well as farmers' perception to local climate variability respectively; investigating farmers reactionary adaptation behaviours in Keffi under constraints of local socio-economic and institutional conditions have not been done. This study aims not just at filling this gap in research but also in investigating the potential positive feedback loop on vegetation covers in Keffi under reactionary adaptation by smallholder farmers in Keffi. This research interest is inspired by the observation that literature on farmers' adaptation behaviours at farm-gate levels have routinely supported and idealized the need for individuals to carry out autonomous adaptation, with emphasis on opportunities for humans. Attention and interest in the environment component of autonomous climate adaptation at farm-gate and individual level within the context of a coupled human-environment system have rarely been raised. Understanding how local socio-economic conditions interacts with changing climatic variables.

1.9 Keffi: Geography, Cultural and Socio-Economic Contexts

1.9.1 Overview of the Geography (Soil, Vegetation and Climate) in Keffi

Keffi local government area which is located at latitude 8.8471 and Longitude 7.8775 is the smallest locality in Nasarawa state, Nigeria. Keffi is approximately 50km from Abuja and has a land area of about 154km2 as measured using the measure tool in Arc Map 10.7. Although some studies, such as Binbol & Marcus (2010) have reported that Keffi lies measures between 140km2 and 150km2 in land area, this disparity is due to topography between the south and Northern parts of Keffi. In terms of its bordering location, Keffi in Nasarawa state relative to other states are; Kaduna to the north, Kogi state to the west, Plateau state to the east and Taraba and Benue states to the South. In terms of proximate localities, Keffi is bounded by Karu Local Government Area to the West, Nasarawa to the South, kokona Local Government Area to the East as mentioned in Mahmud & Achide (2012, pp 129–134) and Ekwe et al. (2014, pp 56–62).

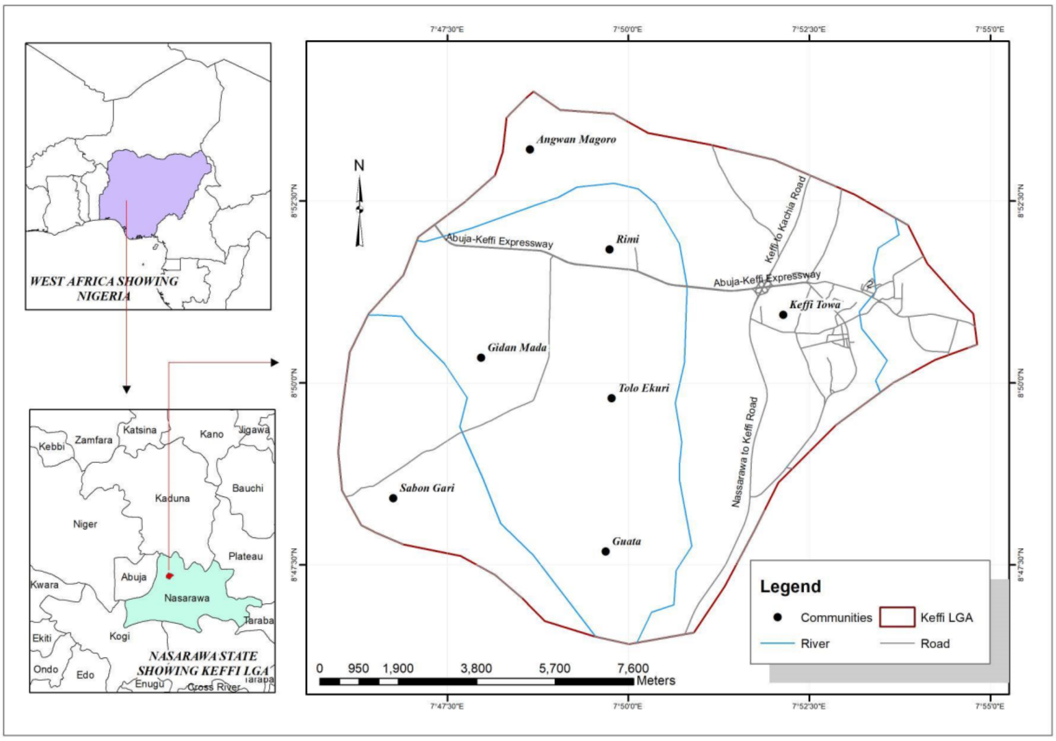

Figure 1: Map of Keffi showing selected localities surveyed during field survey

The topography of Keffi is characterised by a relief that is sloppy with undulating hills in the north and fairly flood plain terrains and lowlands. Modest variations in topography exists in Keffi. For example, within two (2) miles, there is an approximate 113 meters to 114 meters change in topography and 281 meters change within ten (10) miles. These slight variations in topography has however contributed to the differences in published studies regarding the topography of Keffi. For example, Mahmud & Achide (2012, pp 129–134) noted that the topography of Keffi is between 290 meters towards the north-east and 340 meters towards the south-east of the local government area. In Abdullahi et al. (2019, pp 1–16), the average topography of Keffi is 400 meters above sea level. For this study, the topographic information for Keffi was retrieved from the Landsat Shuttle Radar Topographic Mission Digital Elevation Model (hereafter, SRTM) at the United States Geological Survey website (hereafter USGS). The analysed digital elevation data showed that Keffi has a gradient topography of between 263 and 400 meters above the sea level (see figure 2). In comparison to adjoining localities like Nasarawa Egon and Akwanga which are rocky and hilly, Keffi is has a moderately flat topography.

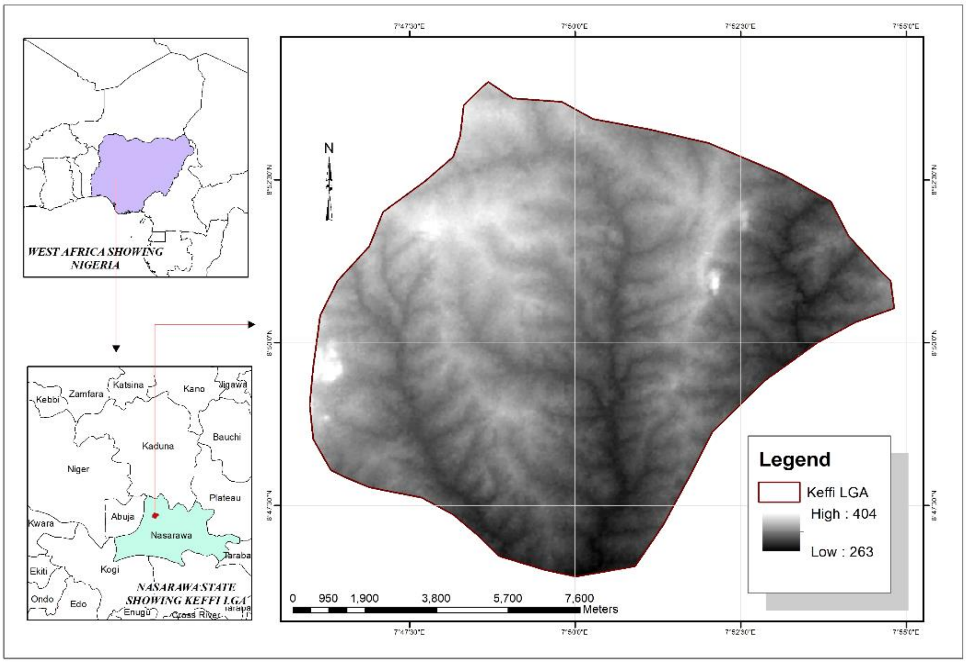

Figure 2: Digital Elevation Model (STRM) of keffi. Source: United States Geological Survey

1.9.2 Soil in Keffi

Due to their clay activity, structure, aluminium (Al) and iron (Fe) chemistry, soils in Keffi falls under the Lithisols (revised FAO nomenclature are Leptosols and in the USDA sub-group, Lithic; Ferralsols in USDA) and Oxisols (in FAO; Alfisols in USDA Nomenclature) as mentioned in Bouwman (1990,pp 33–59). According to Mahmud & Achide (2012, pp 129–134), Binbol & Marcus (2010), the tropical ferrigenous Oxisols and Alfisols soils in Keffi and other localities in Nasarawa are due to the presence of igneous and metamorphic rocks derived from cretaceous sandstones, iron and silt stones. In figure 3(B), soils obtained in Keffi in 2016 are represented. They are shallow deep, well-drained sandy and sandy loamy soils (Fig. 3A).

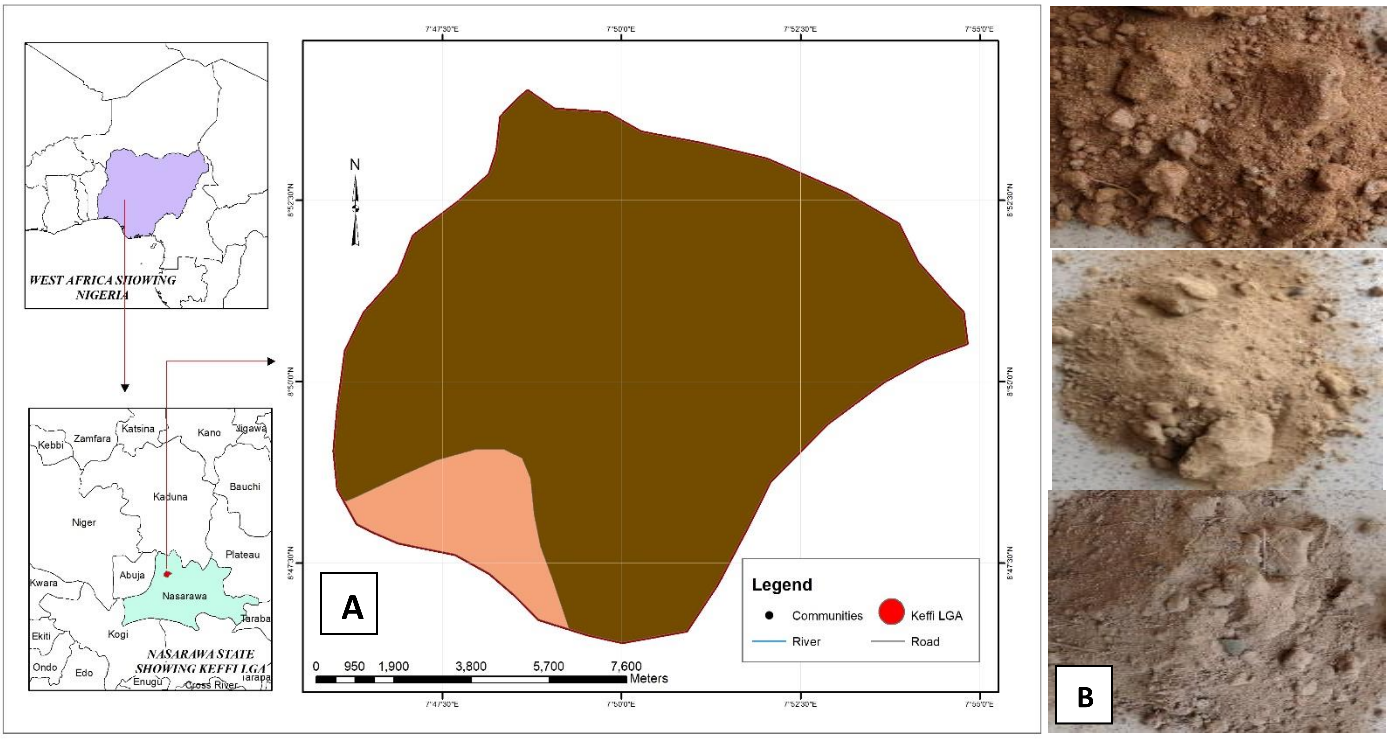

*Figure 3: Digital representation of Soil Type in Keffi (**A**). (Source:GeoNetwork) and soil samples collected during field trip in Keffi in 2016 (**B**)*

According to Nachtergaele (2010) and Bouwman (1990, pp 33–59), these soils have continuous gravely materials and rocks within the top soil (10-20cm). Found in tropical sub-humid, Savanna regions like within mean annual rainfall between 1000mm to 12000mm and mean annual temperature of 25 degrees centigrade; (Jones & Wild 1975) mentioned that these soils have low water holding capacity, low to moderate organic matter content, low clay content at the top soil but high clay activity. This accounts for their well-drained nature as shown in figure 3. Nachtergaele (2010) also notes that Oxisols and Alfisols have low structural stability. These soils are lateritic in nature and loamy with low to medium productivity. In Bouwman (1990, pp 33–59) and Montgomery (1988, pp 11–18), it has been reported that due to the low reserves of weatherable minerals in these soils, Oxisols and Alfisols have low nutrient availability and low organic matter on the top soil due erodibility during cultivation and harvesting.

Due to the average soil conditions in Keffi, arable farming is enhanced with synthetic nitrogen fertilizers making subsistent farming predominantly practiced. According to Joshua et al. (2013, pp 14–23) and Binbol & Marcus (2010), Keffi is one of the important agricultural zones in Nasarawa state with intensive crop cultivation and mixed farming (crop cultivation and livestock grazing) as the main livelihood means. In Panagos et al. (2011, pp 434–443), . low productivity of soil in Keffi and other parts of Nasarawa state has been mentioned.

1.9.3 Vegetation in Keffi

Vegetation in Keffi comprises of woody and exotic grass species. According to the classification by the Food and Agriculture Organization (hereafter FAO), the major classes of vegetation in Keffi are mosaic cropland and closed to open cropland. Apart from the bare land and artificial built up areas, a more detailed geoprocessing with Arcmap 10.7 shows four additional classes of vegetation in Keffi. The other four vegetation classes are open broadleaved deciduous woodlands/forest, mosaic forest or shrubland/grassland, lichen and mosses (figure 4). These classes belong to the northern and southern guinea Savannah vegetation type with a mixture of woodlands and shrub/grassland.

Climate variations in Keffi influences to a large extent vegetation condition, composition and distribution. Farming, livestock rearing, mining and the expansion of human settlements have interacted with the effects of climate with marked dynamics in the vegetation composition and density. It is also to a larger extent also being influenced by the interplay of historical and cultural identity. The invasion, conquest and subsequent settlement of the Fulani tribe in Keffi has impacted vegetation in Keffi due to pressure from livestock rearing and grazing. In the densely populated Gbagyi minority settlements, where small scale farming is the main stay of the people, shifting cultivation and other forms of farming systems have also had impacts on vegetation distribution. As mentioned in Okoli & Atelhe (2014, pp 76–88), the expanding agrarian frontier in Keffi due to high unemployment among the youths from Abuja and other neighbouring localities have increased the competition for an already scare land resource. This has exerted negative impacts on vegetation conditions particularly canopy density distribution. Like in other parts of Nigeria, human pursuit for subsistent livelihoods, social inequalities and economic disempowerment have driven vegetation dynamics in Nasarawa as a whole. In a study by Mahmud & Achide 2012, pp. 129–134, vegetation cover declined from 11.75% in 1999 to 7.34% in 2007. The character (occurrence and amount) of rainfall in Keffi also impacts vegetation. In Keffi, vegetation is characterized by closed to open shrub lands. The most abundant woody species found here Drypetes Floribunda, Entoda Abyssinica and Vitex doniana (Binbol & Marcus 2010). Some of these natural woody species in Keffi are now undergoing threat of extinction due to human influences. In Keffi and adjoining localities, fuel wood and charcoal extraction have been reported in (assessment of charcoal) as the second most major human activity in Keffi that has contributed to marked shifts in vegetation canopy cover. The study noted that an estimated 0.038 hectare of Savannah woodland in Doma, one of the local government areas in Nasarawa state were exploited to produce 15-kilogramme capacity bag of charcoal.

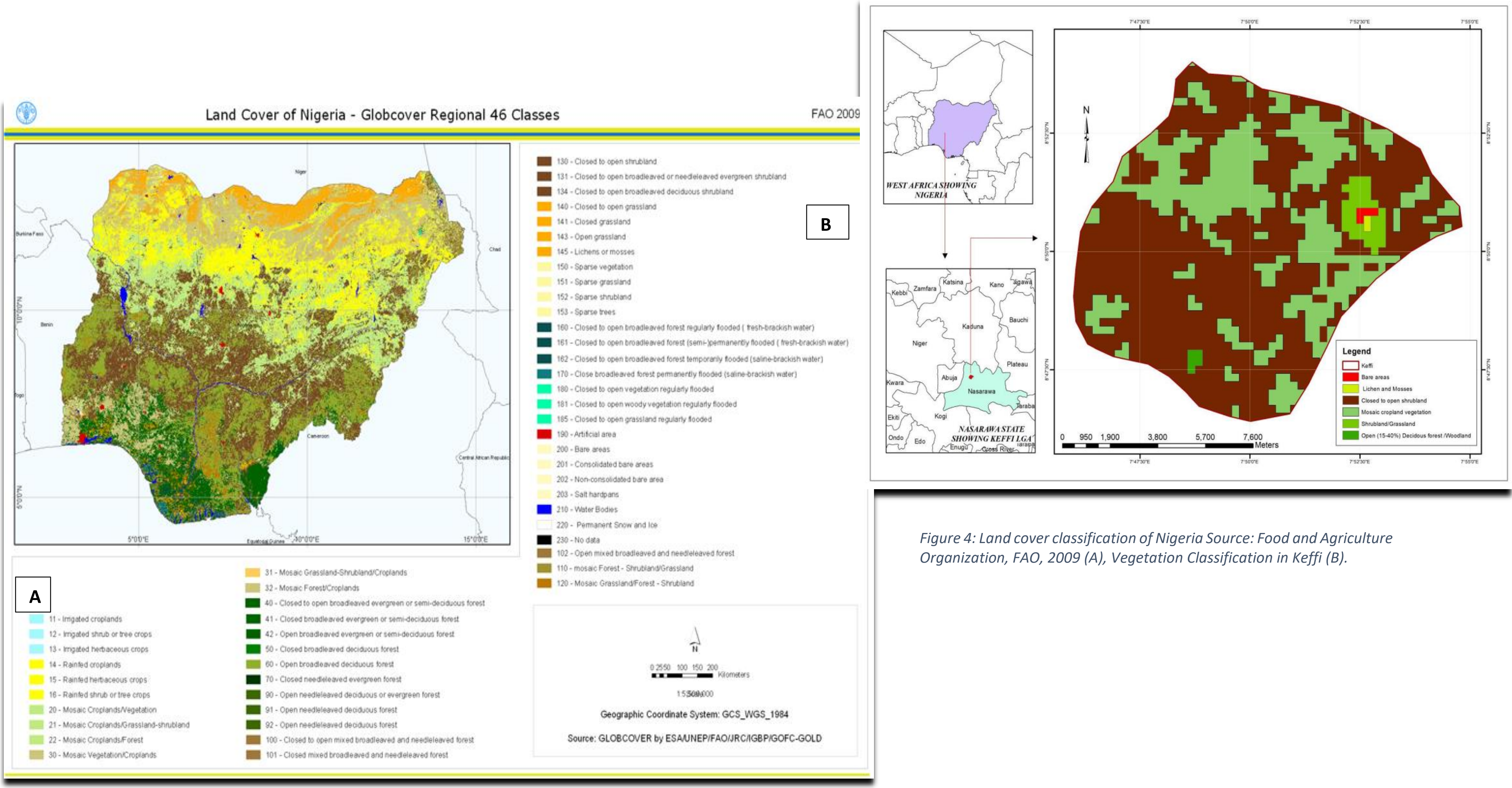

Figure 4: Land cover classification of Nigeria Source: Food and Agriculture Organization, FAO, 2009 (A), Vegetation Classification in Keffi (B).

Further descriptions of the vegetation cover in Keffi is mentioned in Ekwe et al. (2014, pp 56–62) where the vegetation in Keffi is described as a derivative of the tropical Northern Guinea forest and woodland. Much of this vegetation have now replaced a larger percentage of native vegetation in Keffi due to forest clearing for human settlement and agriculture as well as wood harvesting for energy purposes. According to Akwa et al. (2007, pp 2–3) vegetation in is covered with tall trees and thick grasses which characterizes the southern guinea Savanna vegetation type. In Keffi, as it is in other adjoining localities, the vegetation is characterized according to Ekwe et al. (2014, pp 56–62), by interspersion of fringing woodlands and forest gallery. Composed of isolated trees and sparse grasses species like hyparrhernia, ceressiformse and monocymbium (Omale ; vegetation in Keffi is covered mainly cropland (42%), shrubs (21%), grassland (19%), and trees (18%).

Native vegetation in Keffi as noted in Mahmud & Achide (2012, pp 129–134), have also been impacted resulting in declining vegetation areal coverage. This has been attributed to increasing conversion of land cover to agricultural areas which Nuhu & Ahmed (2013, p 607) notes occupies 140.69km2 as against 14.98km2 of uncultivated area and 14.12km2 of built up area and 64.64km2 natural vegetation. Partly also, the dwindling vegetated land coverage has also been attributed to distorted peri-urban planning, a rise in urban agriculture in Keffi and expanding housing settlements. For example, a study by (Alwadood et al., 2016) investigating the physical growth and built-up settlements along the Abuja-Keffi road, observed that between 2001 and 2007, Keffi witnessed growth a 58.71% growth in built-up settlements sprawl with a 2.21% corresponding to an increase from 9.13% in 2007 to 22.36% in 2013. Challenges of unplanned and unregulated built-up areas in peri-urban Keffi as well as Nasarawa state as a whole has been documented in a peer-reviewed paper by Ibrahim Usman Jubrin (reference listed in internet resources). In this publication, it was noted that between mid-2012 and 2013, Keffi with a land area of 154 km2 had 326 buildings per square meter compared to 353 buildings per square meter in Karu covering 650km2 and 279 buildings per square meter in Lafia covering 406km2. This has accelerated fierce competition for arable land and increased the intensification of crop cultivation by smallholder farmers. Similarly, (Mahmud & Achide 2012) also observed the urban sprawl challenges in Keffi which the author noted has implications for crop cultivation due to the shrinking of arable land areas.

Land use / Land Cover Estimates and its Environs Using GIS and Remote Sensing data from 1999-2007				
	Landsat ETM 1999		**Nigeria Sat – 1 2007**	
	Area (km2)	Percentage	Area (km2)	Percentage
Bare Surface	8.09	5.61	4.70	3.28
Built Up Area	13.38	9.59	26.25	18.30
Cultivated Lands	90.87	63.06	85.84	59.72
Rooted Out Crops	3.08	2.14	3.57	2.49
Vegetation	16.92	11.75	10.53	7.34
Wetlands	11.59	8.05	12.60	8.78
	143.93	100.0	13.49	100.0
****National Centre for Remote Sensing and GIS Jos/Field Work 2009				

Table 1: 1999-2007 land use cover assessment of Keffi and adjoining localities. Source: (Mahmud & Achide 2012, pp. 129–134)

1.9.4 Cultural and Socio-Political Background of Keffi

Like most other localities in Nasarawa state, Keffi has its cultural, political and socio-economic profile rooted in historical background. The historical background shapes the political, religious, cultural, socio-economic and demographic profile of the present day Keffi locality. The incessant emirate and conquest raids by the Fulani Nomads from Zaria and other Northern states like Sokoto in Nigeria towards the end of the 18th century and beginning of the nineteenth century led to the establishment of Keffi by Abdu Zanga (also known as Abdullahi)[2]. The eastern and western territories of the Panda kingdom (now present day Lafia and Abuja respectively) as well as the Kwotto territory to which Keffi initially belonged; were the predominant tribes of the southern and western parts of present day Nasarawa state. These western and southern territories were before the invasion, conquest and subsequent settlements of the Fulani Nomads, the most politically influential tribes in the Panda kingdom as mentioned in Wilson-Haffenden (1967). Keffi, after the intervention of the British Colonial masters led by Lord Frederick Lugard; emerged as one of the Muslim populated localities in the aftermath of the protracted slave-raid, hostile strife and head hunting by the Fulani Nomads according to historical notes in Wilson-Haffenden (1967) and Falola and Paddock (2012). Apart from the slave raids and colonial conquests by the Fulani Nomads during the dry seasons, the cooperative labour and trade between the Bassa, Gbagyi and Afowas of the Niger-Benue River as mentioned in Mejida (2016, pp 61–79) also contributed to the emergence of towns like Keffi, Abuja, Toto and Umaisha. Keffi is inhabited by the Hausas, Fulanis, Gbagyi and Bassa as the major indigenous tribes.

Although administered politically under democratic governance structure of the Nigerian state, the role and recognition of the emirate council institutions still influences the daily socio-political lives in Keffi. The Emirate council is the traditional administrative structure which unites major Hausa-Fulani tribes in the locality. The emirate council is made up of the Emir, as the head and other district chiefs who support the day-to-day local governance of the people. The slave trading and head-hunting occupation of the Fulani Nomads in the late 18th and early 19th centuries in Keffi has contributed in large to shaping the rural economy, culture and religion in Keffi. The co-habitation of the Hausa-Fulani in Keffi after the era of slave trade and strife has made Keffi and other parts of Nasarawa state, an agricultural zone with livestock rearing and crop cultivation as the most important socio-economic activities.

While the Fulani Nomads are particularly known for livestock rearing in cattle and sheep; the Hausa communities including the Gbagyi tribes are known for subsistence farming, crafts and household livestock rearing in pigs and poultry. The socio-economic and cultural significance of cattle and sheep to the Fulani tribes in Keffi is of comparable economic significance of subsistence crop cultivation of the non-Fulani tribes. Although in recent years, illegal mining, crafts and other artisanal preoccupations have gradually made their ways into the socio-economic profile of Keffi; livestock farming, and crop cultivation remain the main livelihood bases in Keffi. This is agricultural-based livelihoods are the main activities that characterizes both the rural economy and household structures in Keffi. Demographics and household characteristics in Keffi through the influence of religion (Islam) is also shaped by history of slave trading by Fulani as well as inter-culturality through cooperative trades among tribes in the Niger-Benue valleys. Larger families are common cultural characteristics in Keffi with its preference being justified as important source of labour for livestock rearing and crop cultivation. Commonly cultivated crops in Keffi are cotton, yam, groundnut, rice, maize, cassava, guinea corn, millet, sweet potatoes and sorghum. Keffi provides livelihood benefits to the estimated 107,528 people particularly subsistent farmers and those in the informal sectors (as projected for the period 2008-2011 by the NPC). The expanding frontiers of intensive crop cultivation and livestock rearing leaves the rural parts of Keffi with deeper footprints of human activities relative to a densely populated but low agricultural centre and peri-urban area of Keffi. While widespread and intensive mixed farming are carried out in the rural areas of Keffi, the heterogeneously oriented peri-urban area of Keffi boost of local public institutions, informal service-providing economic and mining activities. This explains the dichotomous commerce and economy in Keffi. Rural agriculture as livelihood mean is not only intensively practiced in rural settlements in Keffi, they are also culturally

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[2] https://muzzammilwrites.wordpress.com/2017/11/22/tribes-and-culture-the-ancient-city-of-Keffi-nasarawa-state/

embedded in the social fabrics of the locality as observed in Labaris (2012, pp 68–74) and Luka & Yahaya (2012, pp 134–143).

1.9.5 Land use and Socio-Economic Profile of Keffi

The land use change in Keffi is similar to that of the entire country, Nigeria. It is shaped by predominant livelihoods which is rooted in cultural and ethnicity. Crop cultivation as a sedentary livelihood is the most practiced in Keffi and thus the predominant land use type. In a study by (Salau et al. 2012), mixed farming accounted for 58.89%, 27.78% for crop cultivation and 13.33% for livestock grazing. Corroborated by (Chunwate, Banki Thomas, et al,2019), vegetation cover decreased from 25% in 1986 to 12% in 2014 with a corresponding increase in cultivated lands from 56% in 1986 to 67% in 2014. Cropping footprints are thus deeper in Keffi than grazing activities as Nomads move around and feed their livestock on host communities. However, mixed farming of subsistence scale is wide-spread and many rural dwellers in Keffi as in other localities in Nasarawa derive their livelihoods from subsistence farming. This, to a large extent is associated with the history and influence of the incessant conquest and invasions by the Nomadic Fulani herdsmen during the 18th century along the Niger-Benue axis. Apart from livestock rearing and crop production, aquaculture is also an integral part of the rural economy in Keffi. Studies like Abari et al. (2015, pp 78–85) have provided useful knowledge on the aquaculture economy in localities in Nasarawa state. Livestock farming in Keffi as mentioned in Ayoade et al. (2009, pp 31–40), Yakubu et al. (2019, pp 1497–1506) are the second most subscribed livelihood means in Keffi commonly practised by the Fulani and Hausa ethnic groups.

Crop production, aquaculture and crop sales and vendoring are practiced by the non-Fulani ethnic groups in Keffi which include the Gbagyi, Eggons, Hausas and Yoruba-speaking tribes in Keffi. Although widespread agricultural practices in Keffi have both a cultural and historical undertone, the proximity of Keffi to Abuja also influences the agriculture-based rural economy in Keffi. Household income and rural economy in Keffi is driven by mixed farming. With higher prospects of high household incomes from crop production, the cultivation of staple crops such as maize, cowpea, sorghum, cassava, potatoes, millet, yams and rice continue to increase. This makes rural economic diversification in Keffi a challenge particularly with non-enabling institutional conditions and lack of technological infrastructure. The over-dependence on agriculture in Keffi and the associated challenge with rural diversification both in income and crop varieties have been addressed in studies like Ibrahim et al. (2009) which argues that rural diversification would offer new sustainable strategies for raising household incomes.

The other commonly practised rural livelihoods in Keffi apart from cattle rearing and crop cultivation are artisanal mining and craft making. Artisanal mining has also become an integral livelihood venture in Keffi although in small scale and in most cases unregulated by the government. This is because Keffi is home to rich mineral resources and precious stones as reported in Yaro & Ebuga (2013, pp 1–5) and Akwa et al. (2007, pp 2–3) include coal, gypsum, clay, lead, talc and gemstones. This is why Nasarawa state is called the *home of solid minerals*. Small scale mining in Keffi is a growing source of living among the youths because of its potential in reducing poverty and hunger as well as providing non-formalized employment in Keffi as mentioned in Oramah et al. (2015, pp 694–703). However as in other surrounding localities in Nasarawa state, small scale artisanal mining in Keffi is non-formalized, non-regulated and carried out in the most unsustainable practices.

Despite its rich mineral endowment, the rising per-capita income poverty in Keffi and Nasarawa state as a whole has not been abated. According to the Nigeria National Bureau of Statistics (NBS), the state has experienced a rising per capita poverty index from 66.1 % in 2003-2004 to 78.4% in 2009-2010. The socio-economic characteristics of Keffi have also been identified as a contributing factor to wide-spread inequalities and income poverty. For example, Otuka (2011) in a study aimed at assessing the link between poverty and child labour in Nasarawa state using (i) total income levels of parents and (ii) child economic supportive scale; showed that a statistical significant correlation between poverty and child labour existed in Keffi. Per capita access to development infrastructure relative to the growing population reviewed by Adefila (2012, p 60) shows that socio-economic infrastructure necessary to support rural commerce and economic growth are grossly inadequate. Infrastructural inadequacy are some of the factors retarding rural commerce and growth according to Umaru & Tende (2013, p 1583).

Nigeria Poverty Profile						
Household Assessment of Livelihood: Subjective Poverty Measurement						
Household Assessment Household Assessment of Livelihood: Subjective Poverty Measurement						
Sector	Very Poor	Poor	Moderate	Fairly Rich	Rich	Total
Urban	6.1	30.1	56.2	6.3	1.2	100.0
Rural	11.6	41.9	41.2	4.5	0.8	100.0
Total	9.5	37.2	37.2	5.2	0.9	100.0
North-Central						
Benue	12.6	50.4	50.4	3.8	0.5	100.0
Kogi	5.8	32.2	32.2	2.9	0.4	100.0
Kwara	3.8	36.6	36.6	2.4	0.2	100.0
Nasarawa	7.0	26.9	26.9	5.9	0.2	100.0
Niger	6.9	25.1	25.1	7.7	0.7	100.0
Plateau	7.6	31.1	31.1	4.0	1.4	100.0
Federal Capital Territory	3.3	39.0	39.0	1.3	0.8	100.0
Total	7.3	35.1	35.1	4.2	0.6	100.0

Table 2: Nigeria Poverty Profile. Source: Nigeria National Bureau of Statistics

This has triggered not only the expansion of all forms of agricultural activities but as also led to the intensification of mixed farming in Keffi. This is particularly common in the rural parts of Keffi because of the deep-seated social inequalities and limited opportunities for rural commercial activities which leave rural dwellers living on the brink of both incomes, situational and absolute poverty. This lived reality has been reported in Ibrahim & Umar (2008, pp 11–21) where it was noted that demographic factors including level of education of heads of households, limited non-farm income streams and household size were major determinants of poverty in Nasarawa state. Ibrahim & Umar (2008, pp 11–21) also documented common coping strategies in Nasarawa state and its adjoining localities to include reduction in meal quantities, skipping meals and engaging in wage labour. With uneven yet densely populated rural settlements criss-crossing the local government area, a distribution of land use and land cover change pressures from socio-economic activities have affected land surface conditions and vegetation cover conditions. In addition to the social inequalities in Keffi and other parts of Nasarawa state, environmental factors contributed to the limited opportunities for socio-economic improvements and income stability.

1.9.6 Local Climatic Conditions in Keffi

Keffi is within the Aw zone of the Köppen climate classification system as it is an ecoregion within the tropical wet and dry climate. The Köppen climate classification is a system derived from the empirical relationship between key climatic variables and vegetation. As mentioned in Chen and Chen (2013, pp 69–79) , the Köppen climate classification system is used to map the geographic distribution of long term mean climatic metrics with related vegetation conditions. The radiation geometry together with other factors like marked diurnal and local processes in the tropics influences the local climate in the core Northern and also in the north-central parts of Nigeria where Keffi is located. This radiation geometry together with large amounts of water vapour and latent heat transported by the meridional circulation are concentrated in the equatorial zones and in a study by Hastenrath (2015, pp 170–176), this accounts not only for the high temperatures but also for the marked climate variability in regions with humid tropical climatic zones.

There are two distinct climatic seasons in Keffi, dry season which spans from the end October (as the onset of the dry season) to March and wet season which begins from April to September as documented in Labaris (2012, pp 68–74) and Akwa et al. (2007, pp 2–3). However, further distinctions have been made by Mahmud & Achide (2012, pp 129–134) into three seasons: warm rainy (May-October), cold dry (November-February) and hot dry (March-April), Apart from the effect of the different seasonal classification, elevation-influenced differences between the north and the south of Keffi has also contributed slight discrepancies in published temperatures and rainfall values in Keffi

1.9.6.1 Temperature in Keffi

The mean surface temperature in Keffi is affected a number of factors and influences including time of the day (night and daytime temperature) and elevation. Towards the northern and north-eastern part of Keffi, higher temperature values are observed due to the increase in altitude and increase in solar incidence than there are in the South. Secondly, variations in mean surface temperature in Keffi is also accounted for by seasonal changes. This variation in temperature values in Keffi across seasons has also been reported in the seasonal weather report by NIMET. In the 2012 NIMET report, the mean annual cold season temperature ranged between 20^0C-22^0C while the hot season temperature lies between 36^0C and 38^0C. According to the 2012 NIMET report, temperature values in Keffi within the last 30 years did not deviate significantly apart from 2005 and 2015 which were the years with extremely high temperatures. According to data from other relevant studies in Keffi and Nasarawa, such as Binbol & Marcus (2010); average surface air temperature ranges between 26^0C and 38^0C due to effect of seasonal changes.

For this study, observations of the mean annual surface temperature for the temporal window, 1999–2018 were inferred through two sources; instrumental source from NIMET and gridded interpolated data from the climatic research unit (CRU), University of East Anglia. Instrumental data from NIMET for the study temporal window (1999 -2018) showed that the minimum annual mean surface temperature in Keffi was 33.4^0C and the maximum stood at 34.2^0C. The interpolated area-weighted derived monthly mean temperature values at 0.5^0 resolution from the version CRU TS v.4.02 datasets showed that the mean annual temperature value for the period, 1999 and 2018 was 26.7^0C Harris et al. (2014, pp 623–642). The consideration of the interpolated CRU temperature values in this study was aimed at validating observations by instrumental data and in weighting the standard deviation from the annual mean temperature. In table 5, the bi-decadal time-sliced observations for the periods 1975 – 1995 and 1996 – 2017 shows that mean annual temperature in Keffi was 25.6^0C and 26.1^0C respectively.

1.9.6.2 Rainfall in Keffi

Average annual rainfall amount in Keffi during the rainy season is reported to range between 800mm/year-1600mm/year with the highest in August (1560mm/year) according to Agidi et al. (2018, pp 1–21). The lowest rainfall amount is about 328mm towards the end of the rainy season. The same study notes that rainfall is unpredictable in character and indices (distribution, amount, frequency and timing) with high unpredictability observable at the start than the cessation of rains. In a study by Orinmogunje et al. (2009, pp452-465), unpredictability however has little impact on the cessation trend of rainfall in Keffi. Inter-annual variations and associated unpredictability rather influences monthly and seasonal averages. For example, the 2012 NIMET seasonal report noted that mean annual rainfall amount in Keffi was between 1024mm/year and 1290mm/year for years (2000-2009). NIMET again documented, a 8-year mean rainfall amount (between 2011 and 2018) at 1153mm/year with an average growing season of 207 days and average rainfall season length of 204.6 days. In this study, the analysed NIMET instrumental dataset for the period 1999-2018 used, shows that average rainfall amount in Keffi during the rainy season is 1088mm/year. Decadal variability in rainfall in studies like Ijioma et al.(2011,pp 228-236) shows that rainfall amount is decreasing and also over the entire country at a rate of 78.4mm/decade .

1.9.7 Impacts of Changes in Climate on Farm-based Livelihoods in Keffi

Significant local and regional variability in rainfall and temperature over Keffi and other parts of Nigeria has been reported and associated impacts on agro-meteorological systems have been well studied. These observations have been documented in the Nigeria's intended nationally determined contributions (INDC) based on B1 and A2[1] emission scenarios. The INDC is both a political and a scientific strategy document, submitted by the Nigeria government during the Conference of Parties (COP 21) in 2015 in which Nigeria communicated her commitment towards reducing greenhouse gases at a sector-wide scale. With rainfall being the most important agro-metrological factor for agriculture across Nigeria, the observed variation in rainfall amounts and timing has implications for crop yield with subsistence farming most vulnerable. In Keffi, as it is in other localities in Nigeria, agriculture is entirely dependent on rainfall. Thus, key rainfall indices like start of rainfall, duration, amount, frequency of occurrence, cessation of rainfall events as well as rainfall distribution plays an important role particularly in small scale agriculture. Rainfall distribution in the far north and north-central states in Nigeria is more variable in comparison to observation in the South.

The Impacts of observed changes in local climate over Keffi and other localities in Nasarawa state have been documented in the following studies; Falaki et al. (2011, pp 49–62); Labaris (2012, pp 68–74); Salau et al. (2012, pp 199–211). For example, inter-annual rainfall variability over Nasarawa state was associated with significant inter-annual variability in the amount of rainfall since 1990s. Although rural dwellers particularly farmers in Keffi hold very strong perceptions about observed variations in temperature and rainfall in Keffi, greater concerns about inter-annual rainfall changes have been expressed during the field surveys in 2016 and 2017. This widespread knowledge has triggered research interest in studying perception indicators and understanding both farmers' knowledge of their local environment and their adaptation strategies. Luka & Yahaya (2012, pp 134–143), Falaki et al. (2011, pp 49–62) are some of the published studies that have investigated the impacts of climate change on farm-based livelihoods in Keffi and other localities in Nasarawa state.

Respondents in the farming locations who were interviewed maintained that the less predictable and near-extreme nature of rainfall in Keffi affected farm-based livelihoods and other value chain informal economy associated with the performance of farm-based livelihoods. Rains in Keffi starts from either April or May every year with very extreme rainfall events which resulted in floods and run offs. The average rainfall season length in Keffi is 204.6 days. With the average growing season of 207 days (approximately six months), the extreme and early cessation of rainfall in Keffi impacts crop cultivation and yield. In Agidi et al. (2018, pp 1–21), the impact of late onset, early cessation and shorter length of growing season rainfall averages in terms of its effectiveness in Keffi has been reported. High daytime temperatures in Keffi also affects rural economic activities including subsistence agricultural and mining activities. Farmers who were interviewed noted that within the last five years, they were recording poor yields from crop wilting associated with high daytime temperature.

Farmers in Keffi also mentioned that they had suffered even more losses due to tramping from livestock grazing. The interacting impacts of high temperature and low soil moisture resulting from surface water runoff impacts not only crop yields but also livestock through dwindling pastures. This has increased the nomadic nature of livestock grazing in Keffi with livestock grazing on cultivated farmlands of host communities. This strengthens the argument about the role of climate change in farmers-herders protracted conflict in Keffi. With more than 70% of rural livelihoods connected to subsistent farming, climate change has according to Salau & Attah (2012, pp 17–29), engendered significant negative impact on household decisions including the socio-economic profiles of farming households in Keffi. Changes in the local climatic conditions in Keffi has also affected other forms of livelihood activities like aquaculture particularly where indigenous technology in water harvesting are limited. Associated livelihood means within the value chain like sales of seedlings, crop produce, farm labour hires and tenure rents have also been impacted by climate change. In Keffi, climate impact is also linked not only to the over-dependence on rain-fed agriculture but also to low opportunities for livelihood diversification.

Climate impacts on farming livelihoods in Keffi are in two folds. First, the impact temperature and rainfall variability on crop growth, harvestable yield and on livestock. Second is the implication of these sector changes on the socio-economic situation of farmers and their household decisions. Crop plants require optimum conditions of temperature, soil conditions, carbon dioxide and water to grow. At the leaf and plant level, crop plants show physiological response to the presence or absence of these conditions. With most crop plants in Keffi, being C4 plants (sugar cane, sorghum, millet and maize), and C3 plants (rice, wheats, potatoes, cassava, yams and soybeans), variability in surface temperature affects CO_2 fertilization in crop plants according to Rötter and van de Geijn (1999, pp 651–681). Farmers who cultivate annual and even those who cultivate perennial crops in Keffi suffer from the impacts of shortened growth period due to increase in diurnal temperatures. Higher temperatures in Keffi are also responsible for higher radiation levels and water use demands by plants. The shortening of rainfall periods and increase in daytime temperature has contributed to the shortening of growing seasons in Keffi. Although, temperature requirements differ for crop plants like wheats, rice and maize, higher temperatures for the phenological development of some crop plants should be at a fairly-acceptable levels for optimum growth conditions to be established. Farmers also complained about the impact of temperature on the cultivation of non-seasonal crops within the planting and growing seasons. As annual rainfall in Keffi varies in amount and timing, crop plants in Keffi suffer from poor distribution of rainfall, reduced soil moisture level caused by run -offs and inefficient nutrient cycling in soil. In certain years, when unusually high amounts of rainfall occur in Keffi, farmers noted that there were crop failures due to excessive soil moisture.

Decreasing pasture for livestock in Keffi has contributed to a large extent to the conflict between Gbagyi farmers and Fulani herdsmen not only in Keffi but also in many parts of northern Nigeria. The climate-driven resource conflict between local subsistent farmers in Keffi and Fulani herdsmen has been reviewed in Okoli & Atelhe (2014, pp 76–88) and Girei et al. (2017). Findings and arguments contained in these publications corroborates local newspaper reports on the climate change dimension of the herders-farmers conflicts in Nasarawa and other Northern states in Nigeria where pasture density is low. In figure 5, a photonews from a Nigerian daily newspaper, Premium Times provides a pictorial information on the unregulated grazing of livestocks on managed small scale farm holdings in Keffi.

Figure 5: Photo of Cattles grazing in Keffi. Source: a photonews from a Nigerian daily newspaper, Premium Times Newspaper

These climate-related impacts have contributed to a larger extent to the weakening of climate-dependent rural livelihoods such as subsistence farming. Observed impacts of climate change on managed farmlands in Keffi and adjoining localities have shaped the evolution of farmland management practices by smallholder farmers. The evolving crop cultivation and farm management practices in Keffi has been more about the frequency of the use of arable land than about the modification of cultural farming practices. Changes in both the frequency of land use and cultivation practices by smallholder farmers in Keffi shaped, not only by climate impacts but also by defining institutional realities have contributed to behavioural responses. These behavioural responses are more reactionary self-help than precautionary measures aimed at protecting and safeguarding livelihood systems. Reactionary autonomous climate adaptation has been undertaken by local farmers in Keffi and other localities in Nasarawa state in response to the potential threats of climate risks on farm-based livelihoods.

Figure 6: Gbagyi farmers in Doma, a locality near Keffi town, managing cultivated farmlands, Accessible at ttps://climate.earthjournalism.net/2015/12/08/gbagyi-women-on-the-frontlines-in-nigerias-fight-against-climate-change/

1.9.8 Understanding Smallholder Farmers' Vulnerability to Climate Change in Keffi

The interactions of poor socio-economic conditions, a bulging demography, weak institutional structures and altered environmental conditions in Keffi presents a complex interwoven challenge of development and ecological concerns in Keffi. Aggravated by the deficit of development infrastructure and good governance to support the organization of non-farm income-generating activities outside; livelihoods of farmers in Keffi and other surrounding localities have been affected. This situation increases both the vulnerability of smallholder farmers and their farm assets to climate variability and associated risks. An understanding of the synergistic impacts of institutional, environmental, household characteristics on the degree of vulnerability of rural agricultural assets requires extensive discourse on some relevant concepts and terms. The terms, smallholder farmers and rural livelihoods and the accompanying discursive analysis follow after the exposition on vulnerability.

1.9.9 Vulnerability and conceptual Relevance to Subsistence Farm Livelihoods

First, attempt at expanding the concept of vulnerability is made. As a term used frequently in characterizing the susceptibility of social and natural systems to impacts from shifts in environmental conditions (including climate change), vulnerability has evolved in conceptual nuances and in research application. In Füssel & Klein (2006, pp 301–329), the evolution of the concept of vulnerability is associated with the characterization of the progressive inclusion of the non-climatic determinants of vulnerability to climate change. The study describes that some of those non-climatic determinants include adaptive capacity. In the Merriam Webster English dictionary, vulnerability implies the capacity to be harmed or wounded. In its more conceptual usage, vulnerability encompasses sensitivity and the capacity to be affected by hazards reported in Adger & Kelly (1999, pp 253–266). In the 5th Assessment report of the International Panel on Climate Change (AR5,2013) glossary of terms, vulnerability is defined as the degree to which a system is susceptible to and is unable to cope with adverse effects of climate change including climate variability is implied in advancing the argument.

Vulnerability, in the context of climate change and risk assessment is related to the resilience index or measure of resilience after exposure to climate risks or other natural hazards. In the hazard school of thought, vulnerability is defined in (IPENZ, 1983) as a condition or situation which has the potential to create harm to people, property, or the environment. In all referenced definitions, the term, vulnerability according to Füssel & Klein (2006, pp 301–329) is associated with elements of resilience, susceptibility, risks, exposure and adaptability. In its broader conceptual frame, vulnerability, in addition to associated elements already mentioned also includes the inherent capacity or capability of the exposed system to cope or recover after exposure. Thus, vulnerability of a system is determined not only by its exposure or sensitivity to source of hazard but also its ability to recover after impact. This understanding has been extensively expressed in 5th assessment IPCC report, (IPCC AR5 2013).

In Brooks (2003, pp 1–16), a clear distinction between biophysical and social vulnerability is provided. The distinction attempts a conceptual linkage between risks (or hazards), the two forms of vulnerability (*biophysical*-inherent system characteristics and *social* (pre-disposing conditions) and adaptive capacity. It attempts this distinction in the framework of climate adaptation. In Brooks (2003, pp 1–16), socio-economic conditions are the inherent (biophysical characteristics of an exposed system) characteristics of the social system. These socio-economic conditions determine social vulnerability of human systems to climate change. Although a general understanding of the term vulnerability encompasses system exposure to hazard or a source of harm, Brooks (2003, pp 1–16) distinguishes vulnerability into two broader frames: biophysical vulnerability which deals directly with the physical harm contingent upon the inherent biophysical characteristics of the system. The study also identifies the source of hazard causing the harm and the amount of damage experienced by the system. In this case, the vulnerability of human systems according to Brooks (2003, pp 1–16) is determined by the nature of hazard, frequency and rate of exposure and the extent of exposure to the hazard. Thus, the biophysical vulnerability aspect is concerned principally with the outcome associated with a certain nature of the hazard. In the next major characterization by Brooks (2003, pp 1–16), the author aligns with Allen et al. (2002) idea of vulnerability as relating to the state or condition state of a system that is being exposed to a hazardous situation. Smit & Wandel (2006, pp 282–292) advances the elements of vulnerability drawing the dimensions of exposure and sensitivity of exposed systems to impacts of climate or other hazards which the author argues are determined by social and environmental factors. In Smit & Wandel (2006, pp 282–292), vulnerability also implies the capability to cope or adjust upon exposure, which are however shaped by the combination of political, social and economic forces. Thus, factors (both natural hazards and anthropogenic disturbances) determines exposure and sensitivity of human and social systems. The interaction of the factors of susceptibility and the degree of exposure determines the ability of affected systems to recover and reassume a condition that supports and sustain performance.

The discourse of inherent characteristics is upheld in Allen et al. (2002), where the author emphasizes on the state of internal variables or inherent characteristics of a system (whether human or natural) prior to exposure to hazard and after exposure. This condition is determined, according to Allen et al. (2002) by the structural variables in addition to the inherent factors already mentioned by Brooks (2003, pp 1–16). However, in addition to these elements, social factors have also been recognized in either attenuating or amplifying the degree of system vulnerability. In human systems, these intrinsic characteristics in the view of Allen et al. (2002) are more associated with the socio-economic conditions and level of access to resources, assets and capitals that can support access to resources needed to increase resilience capacity. Resilience here implies the ability of a system to recover impacts associated with exposure to hazards.

To a larger extent, social elements of vulnerability determines the outcome or degree of impact following exposure to hazardous event. Hence, the totality of all the factors including inherent systems variables and social condition states (in terms of human systems) determine the outcome of a hazardous event as well as the resilience capacity. These socio-economic variables relate more often to those that empower or disempower people in organizing responses or strengthening their capacities in coping or adapting to impacts of hazards. In the context of smallholder farmers, these social variables relate more to social inequalities including worsening states of poverty which together constitutes the social vulnerability component of human systems to climate hazards. Social vulnerability increases *system sensitivity* to risks from hazards as noted in Smit & Wandel (2006, pp 282–292) and interacts with other dimensions of vulnerability like biophysical vulnerability to affect the degree of resilience.

In Olsson et al. (2014), these social components of vulnerability links directly with rural livelihoods. Rural livelihood is used here to espouse the socio-economic conditions of poor subsistence farmers in rural communities such as Keffi. The characterizing socio-economic conditions of smallholder farmers in Keffi and the size of their farm livelihoods constitutes those system variables that not only increase their sensitivity to climate impacts but also motivate farmers towards certain adaptation pathways. Thus, the social component of vulnerability and its interlinkage between climate-sensitive livelihoods and associated climate risks supports the study's attempt at investigating how these complex sets of interactions drive reactionary climate adaptation at local levels. With the challenge of harnessing financial and social resources for robust economic activities, these interactions places smallholder farmers in rural communities at disadvantaged positions and weakens their resilience capacities as noted in Brown et al. (2009); Vermeulen et al. (2012, pp 136–144) and Gbetibouo & Ringler (2009), Angelsen et al. (2014, S12-S28); Bebbington (1999, pp 2021–2044); Chambers & Conway (1992). In this study, theoretical frames of social inequalities and poverty which are utilized in characterizing challenges faced by smallholder farmers in Keffi are nested under social vulnerability. This social vulnerability element shapes capabilities of smallholder farmers in pursuing investment–demanding and more sustainable adaptation measures with longer-term planning horizons. Rather subsistence farmers undertake shorter-term adaptation strategies requiring fewer financial resources and investments. In Keffi, such short-term reactions under certain constraining conditions includes continuous crop cultivation with shorter fallow periods (non-receding use of farmlands). In Liu et al. (2007, pp 1513–1516), such land use practices have been reported as having the potential of triggering positive natural-social system feedback. Feedback lopes are associated with system interactions and this, Kolasa & Pickett (1989, pp 8837–8841) observes are inherent properties of closed systems. The understanding offers a premise for the human-environment (vegetation dynamics) interaction and resultant feedback which is hypothesized in this study.

1.10 Rural Livelihoods

Scholarly works on the conceptual framework of vulnerability has shown that vulnerability goes beyond being just a label as Luna (2009, pp 121–139) puts it but a layer of dimensions and socio-economic elements. The discourse of rural livelihoods in this study thus supports Luna (2009, pp 121–139) argument in terms of farm-based rural livelihoods as a layer of vulnerability. It provides a strong linkage between smallholder farmers, poverty and vulnerability. The propensity of being vulnerable is associated with the degree of exposure, the susceptibility of the biophysical attributes of the system, system resilience and sensitivity. In the human society, particularly in resource-limited societies, these vulnerability elements are in parts linked with rural livelihoods. The concept of rural livelihoods in this study is therefore intended to describe the role of rural livelihoods in exacerbating the vulnerability of smallholder farmers to the risks and impacts of climate change. Rural livelihoods are not only used to show the limit or resource deficiency but rather in the broader context of deficits in institutional organization of development opportunities that can offer non-farm opportunities to rural dwellers.

Since its first introduction by Scoones (1998), rural livelihoods concept has been relevant in the discourse of survival and capabilities. The means to secure a form of survival means (livelihood) and the capability to organize such survival means; including access to assets and resources needed to do so, sums up the term, livelihood. With the inclusion of the term rural, the concept of livelihood takes up a geographical character describing the smallest spatial unit. It also lends credence of its use in the description of certain forms of survival means predominantly practised in local and resource-poor societies. In Ellis (2000), the concept of rural livelihoods is related to a constellation of economic activities that relates to crop cultivation, production and livestock grazing. In subsistence poor and marginalized groups in developing Africa and Asian countries where institutional support is limited, agriculture-based activities are usually major rural livelihood sources.

In Chambers & Conway (1992) where more explicit scholarly explanation is provided; livelihoods implies human capabilities, assets, resources and activities required for and as a means of living. Rural livelihoods are organized and managed towards a goal–income generation and subsistence living. At the farm gate level, on-farm incomes thereof are the main purpose of farming livelihood. Thus, to a farming population, on-farm livelihood is essential to securing sustainable incomes for household need and food security. This therefore establishes the relevance of farm-based livelihoods in rural economy. Olsson et al. (2014) mentions that in local communities, organizing economic livelihoods depends on access to natural, human, physical, financial capital as well as the social relations needed by humans to draw on and transform resources into production systems Olsson et al. (2014). A slightly different conceptual definition is provided by Ellis (2000) where rural livelihoods are described as " means of organizing a living comprising of not only assets (natural, human, financial and social capitals) but also activities and access thereof. The study mentions that access to these assets are and can be mediated by institutions and social relations arguing that the combination of access to resources determines the scope of means of living procured by an individual or the household.

Another important attribute of livelihood is that sources of livelihoods are either supported or limited by social, institutional and technological factors which either constitutes constraints or enablers. Some of the constraints or multiple stressors capable of affecting rural livelihoods include according to (Morton 2007); market shocks, poverty, land tenure, regulatory regimes of regional, global markets and protectionist policies in developed countries. Additionally, given the differences in capabilities in accessing resources and assets (which determine livelihood options); institutional incentives play a key role. Where such institutional incentives are lacking and livelihood strategies are limited; Olsson et al. (2014) argues that conditions of poverty can be deepened. In Harvey et al. (2014, p 20130089), this linkage has been upheld where livelihood conditions and high levels of poverty in Madagascar were underlying factors responsible for increased vulnerability of smallholder farmers to climate risks.

Across all the definitions provided, capability is strongly emphasized. Capability in terms of assets and resources where capability refers to the ability to realize potential as mentioned in Chambers & Conway (1992). In Olsson et al. (2014), capability entails access to assets and capitals. In Bebbington (1999, pp 2021–2044) and Barrett et al. (2001, pp 315–331) additional nuances have been provided. In Ellis (2000) capability implies the availability of options. Options are an essential analytical element in the conceptual framework of livelihoods (particularly in rural livelihoods) as the availability or lack thereof; implies the increase in the vulnerability of a source or system of livelihoods to institutional and environmental risks. At the farm gate level, the main sources or systems of rural livelihood are rain-fed agricultural systems. Smallholder farmers depend on small farm holdings for the organization of means of survival and income-generating activities. As mentioned in Olsson et al. (2014), the social and economic integrity of a household is not only measured by the size and viability of the farm holdings but also by its resilience in the face of climate risks.

Recognizing the overall objective of small farm holdings in rural localities, as centering around subsistence living; expanding, the concept of rural livelihoods is relevant in expanding the conceptual framework of vulnerability. Farm-based rural livelihoods are not only vulnerable under exposure to climate change but also under conditions of weak governance structures that are incapable of providing institutional incentives to support diversification or rural livelihoods or enterprises. Such conditions predispose farm-based livelihoods to climatic and non-climatic hazards and deepens vulnerability of such socio-economic systems. In predominant agriculture and rural settlements, where assets for income-procurement and livelihoods are based on natural resources (Rigg 2006); the risk from climate change including extreme weather events on farm assets will be high. In Adger et al. (2003, pp 179–195), the vulnerability of farm-based livelihoods to climate risks and other interacting stressors has also been linked to smallholder farmers' inability to spread risks due to limited financial and non-financial resources. In other studies, such as Webb et al. (2017, pp 450–459), the role of land degradation in deepening vulnerability of farm-based livelihoods as well as the reduction of farmers' adaptive capacities have been mentioned. In DeFries et al. (2004, pp 249–257), similar understanding has been upheld where the study showed increase in vulnerability index of farm-based livelihoods to climatic and non-climatic stressors due to farmers' inability to spread risks due to limited financial and non-financial resources. In other studies, such as Webb et al. (2017, pp 450–459), the role of land degradation in deepening vulnerability of farm-based livelihoods as well as the reduction of farmers' adaptive capacities have been mentioned.

1.11 Smallholder Farmers in Keffi

According to Morton (2007, pp 19680–19685), the term smallholder farmers refers to rural producers predominantly in tropical developing countries whose source of farm labour capital are immediate family members with the major purpose of farm investment being for social fulfilment, wellbeing, food and income security. In Ellis (2000), smallholder farmers are those who depend on farm livelihoods to generate incomes to meet the welfare needs and material demands of the family. They are managers of land-based production systems from which both kind and cash outputs are derived. Ellis (1993), defines smallholder farmers as managers of households which derive their livelihoods mainly but not exclusively from smallholding agriculture and who mainly use family labour for farm production. Cooper et al. (2008, pp 24–35) describes these categories of farmers manage and depend on rain-fed agriculture for basic subsistence living. They are also characterized by their partial engagements in input and output markets and are both producers and consumers of agricultural goods.

According to Harvey et al. (2014, p 20130089), they are subsistent farmers who constitute about 73% of the population in sub-Saharan Africa and operate very complex, diverse and risk-prone systems of rain-fed agriculture. In addition to managing these risk–prone livelihood systems, these subsistence farmers are exposed to socially-imposed limitations such as inequalities, poverty and other forms of social deprivations. They are characterized by their vulnerability to shocks in the event of natural hazards and economic instabilities due to their over-dependence on rain-fed agriculture and as mentioned in Harvey et al. (2014, p 20130089), their limited abilities to cope. These characteristics of small holder farmers does not diminish their strategic relevance in the global food production systems as those according to Harvey et al. (2014, p 20130089), that will determine the fate of food security worldwide. Following the climate-dependence nature of a greater percentage of global food production systems particularly those located in the tropical developing countries; Morton (2007, pp 19680–19685) notes that smallholder farmers' face growing risks. Apart from the sensitivity of the small-scale food production systems to climatic variables, other risks to which farmers are exposed are largely determined by factors including constraining socio-economic conditions and the geographical location of these food production systems. In a review on the extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar, Harvey et al. (2014, p 20130089) further characterised smallholder farmers in terms of their population relative to size of other livelihood sectors. The study also characterized smallholder farmers' vulnerability in terms of their limited resources and access to capitals arguing that these limitations further exposes them to other multiple risks.

Following from this characterization, Harvey et al. (2014, p 20130089) therefore describes smallholder farmers as population of on-farm managers who are unable to cope or recover from shocks particularly those shocks that undermines their household food and income security. To smallholder farmers, food and income security for the sustenance of household and social needs are thus the central to their livelihoods. Consequently, there is a strong coupling between climate change, rural farm livelihoods and smallholders' population. Harvey et al. (2014, p 20130089) thus draws a linkage between livelihoods, smallholder farmers and food security. Farmers in Keffi fit the description of smallholder farmers as mentioned in this essay due to goal of crop cultivation by farmers in Keffi which is to ensure food security at household levels. In the following , Falaki et al. (2011, pp 49–62), Luka & Yahaya (2012, pp 134–143) and Salau et al. (2012, pp 199–211), the socio-cultural and institutional factors shaping small farm holdings in Keffi are discussed. Small scale agricultural sector in Keffi, Nasarawa state is the largest employer of labour. Sharing similar characteristics of agricultural sector at the national level, small scale agriculture in Keffi supports the livelihoods of more than three-quarters of the rural population in Keffi Ibrahim and Onuk (2009, pp 49–54), a shared commonality with the scenario at the national level which Hazell and Diao (2005, p 23) corroborates. As an economic sector, where holders manage between three to five hectares of land according to a World Bank report[3], with little or no agricultural incentives; smallholder farmers in Keffi are limited to subsistence farming. Apart from the minimal farm sizes owned by rural farmers in Keffi (less than 4 hectares), small scale farming in Keffi is shaped by constraints connecting with diversification into non-farm economic activities. It is also influenced by the socio-cultural and political backgrounds. Smallholder farming is an economic activity engaged mainly by tribes belonging to the Kwararafa cultural group.

The other cultural group is the Hausa-Fulani group. Small farm holdings are therefore major sources of household incomes and food security. Tribes in Keffi who undertake farming do so out of long cultural history and also due to the limited opportunities in exploring off-farm livelihood opportunities. Although, diversification into non-farm sources of incomes on the basis of smaller farm sizes and low incomes are usually desired by known farming tribes in Keffi, the opportunity to diversify have been constrained by financial risks, uncertainty and lack of information. Through crop cultivation and other forms of mixed agriculture, smallholder farmers in Keffi ensure food supplies at household levels, procure and sustain household incomes. However, accomplishing this in recent times due to climate risks, limited agricultural incentives such as credit facilities, fertilizers and information has been difficult as reported in Badiru (2010) and Salau et al. (2013, pp 113–121). They are also limited by lack of technologies as observed in Mustapha et al. (2012), supportive policy environment in Olomola (2013) and markets for their agricultural produce. These factors limit optimal agricultural productivity and also restricts the scope of farming beyond subsistence purposes. Under constrained climate, performances of these subsistence are impacted

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[3] World bank report accessible at http://documents.worldbank.org/curated/en/316661513583254475/National-survey-and-segmentation-of-smallholder-households-in-Nigeria-understanding-their-demand-for-financial-agricultural-and-digital-solutions

2 State-of-the-Art

2.1 The contribution of the study to Science

The discourse of climate change and the adaptation to its impacts in Nigeria have remained in certain traditional frame of discourse. These frames of discourse which includes but not limited to farmers' perception of climate change, determinants of climate adaptation, challenges constraining adaptation and the role of smart agriculture in minimising impacts have become frequently used frames. These traditional discursive frames transcend boundaries of empirical studies, development programming and policy intervention. Recognized as a complimentary action to mitigation in the fight against climate change particularly in the agriculture and forestry sectors, climate adaptation has been of increasing research and policy interests. First, because of its interventionist value and also due to the characteristics of the segment of population which are most likely to be impacted due to their existing vulnerabilities. Empirical studies and development policy engagements have often addressed climate change adaptation from these frequently used discourse frames. In Nigeria, this pattern and interest is not different as research endeavours national policies emphasize adaptation issues more than the reduction of emissions.

The engagement with climate adaptation issues in Nigeria along these discourse frames can be well understood due to the peculiarity of the Nigerian socio-economic and development conditions. The 2019 United Nations Development Programme (UNDP) Human Development Report, (UNDP, HDR 2019) reported that the human development assessment showed Nigeria ranked 158 (very low) in the world with a 56.6% of its population largely deprived. The UNDP, HDR 2019 report also noted that 46.0% of the Nigeria population live below the national poverty line while 53.5% of Nigerians lived below 1.90 $ per day. These statistics have also been corroborated in the 2019 Poverty and Inequality Report by the Nigeria National Bureau of Statistics which reported that 82.9 million of the Nigeria population corresponding to 40% lived below the poverty line (measured in less than 1.90$ daily). Out of this 40%, 52.1% are rural poor while 18.0% accounts for the urban poor[4]. This implies that the percentage of the poor (40%) in Nigeria compete for scarce land resource for agricultural-based livelihoods. Following that agriculture and other climate-sensitive livelihood bases have been identified as socio-economic sectors with a high vulnerability; research and policy interests in climate adaptation in Nigeria tends to focus more on its value as an intervention and response strategy to the impacts of climate change.

Climate change research interest in Nigeria particularly in the agricultural and forestry sectors have often discussed themes such as perception Salau et al. (2012, pp 199–211), determinants of adaptation options in Othniel & Resurreccion (2013, pp 341–364), Yila and Resurreccion (2013) ; constraints of adaptation in Abraham and Fonta (2018, p 11). Other studies such as Terdoo and Adekola (2014, pp 1180–1191) discussed the role of smart agriculture in combating climate change-driven desertification in rural Nigeria. Frequently addressed themes within the climate adaptation framework in Nigeria also includes common adaptation strategies by farmers Othniel & Resurreccion (2013, pp 341–364). The human and social element of climate adaptation has thus become prominent both in climate adaptation research as well as in policy and programme considerations. This interest in the human and social dimension of climate adaptation in Nigeria has diminished the physical geography dimension of climate change including land surface biophysical conditions.

In this chapter, a new conceptual and analytical insight into farm-gate level autonomous adaptation in rural settlements in Nigeria is presented with the intention to deepening the discourse of climate change adaptation in Nigeria beyond commonly addressed themes. The non-human (physical) geography aspect

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[4] (NBS, 2019 Poverty & Inequality Report accessible at file:///C:/Users/ensikan/Downloads/2019%20POVERY%20AND%20INEQUALITY%20IN%20NIGERIA.pdf)

of climate adaptation is highlighted drawing attention to the interactive feedback effects between social and ecological systems within a climate adaptations system. Beyond the Nigerian context and peculiarity of adaptation research interests, this chapter also highlights the contribution of this study to the body of science. It does this by with three main arguments.

First, it highlights gaps in relation to climate adaptation research relating to current trends in adaptation research whereby greater attention dedicated to the human (social) component of adaptation than the environment or ecological component. Given that adaptation to climate change takes places within the coupled human-environment system with a closed system attribute; both feedbacks and interactions from components from both interacting systems are inevitable. In widely-cited works like Adger et al. (2005, pp 77–86) and Adger et al. (2009, pp 335–354), focus has been given to the assessment of human adaptation practices in terms of its efficiency, effectiveness as well as certain limitations to effective adaptation. In the AR5,2013, working group II, IPCC report, contributions on impacts, vulnerability and adaptation to climate change has been more on sectoral and regional assessments with attention given to increasing human capacity for both resilience and adaptation. The human component of climate adaptation has thus assumed prominence in adaptation science research even as research interest has expanded to financial cost implication of adaptation actions as mentioned in Fankhauser (2010, pp 23–30) and Cartwright et al. (2013, pp 139–156). Besides the diminished relevance given to the environmental component of human adaptation system in the adaptation science research landscape; research interests on climate change in Keffi has been restricted at understanding farmers' perception to climate change.

In addressing these research gaps, this study proposes three arguments namely the epistemological bias around the concept of anthropogenic activities arguing that autonomous climate adaptation has an anthropogenic potential. It attempts to clarify how the human (social) component of autonomous adaptation and the management of it can impact the interacting environment. This, it does by introducing the spatial element of autonomous climate adaptation as it relates both to the vertically determined social scale (resource-determining) and the geographical extent (local level). With the scale dimension of climate adaptation, the argument in this paper attempts to provide understanding on the role of size of social organizations and vertical hierarchies in socio-economic capacities in limiting the scope and extents of climate adaptation options particularly at individual and farm-gate levels. The role of differential human capacities, unequal access to assets and financial incentives all of which not only shapes the nature and scope of livelihood means but also interacts with elements of human cognitive processes in influencing adaptation at farm-gate levels. It deepens the human cognitive element in climate adaptation actions already carried in other studies such as Grothmann & Patt (2005, pp 199–213); Truelove et al. (2015, pp 85–97) with the introduction of the positive feedbacks. The concept of feedback considered in this study is contextualized within condition of sustained exposure to non-receding and intensive cultivation.

Since autonomous adaptation is a set of social actions, it links more to changes in behaviours that supports shifts in the management of systems in ways that adapts these systems to impacts of climate change. Within this understanding, this study introduces protection motivation theory (PMT) to demonstrate how farmers undertake reactionary climate adaptation and the factors that drive their protective actions. One of those factors identified is the level and robustness of subsistence as a factor that either increase or reduces individuals' urge to act or that characterizes the reactionary nature of autonomous level climate adaptation. Using the concept of rural livelihoods, this study characterizes the socio-economic conditions of rural farmers in Keffi which is an integral element in the protection motivation theory. Given that climate adaptation actions interact with the environment, the land use intensity concept (LUI) is also used in this study to show how autonomous and reactionary climate adaptation by peasant farmers can potentially interact with the functional and structural attributes of land surface including vegetation covers.

2.2 Discursive Elements of the Research Frame of Argument

2.2.1 Epistemological Bias in the Conceptual Framing of Anthropogenic Activities

The introduction of epistemology in this study is to demonstrate a new understanding that would support a conceptual departure from the acceptance of only deliberate and planned human activities aimed at realizing development priorities exclusively as anthropogenic activities. Given its role in the communication, internalization and the acceptance of knowledge; the potential of extant understanding in influencing the acceptance of new knowledge frames can potentially lead to epistemological bias. Epistemological bias also affects how extant knowledge frames are applied in research and development over time. The sustenance of extant knowledge frames to the exclusion of new ideas and knowledge constitutes epistemological biases. From this understanding, this study argues that epistemological bias to some extent accounts for the exclusion of climate change adaptation from conceptual frames of anthropogenic activity.

Epistemology is concerned with the knowledge generation process (the method, theoretical and philosophical underpinnings of knowledge generation), the social communication of generated knowledge and its acceptance (belief). This definition is expressed in Kelly et al. (2012, pp 281–291) and how the study exposes the influence of different learning theories on science education. Thus, the main argument in Kelly et al. (2012, pp 281–291) is on the conception and generation of knowledge on learning theories. This implies how generated knowledge are transmitted and claimed and how this influences science education. Kelly et al. (2012, pp 281–291) argues that the philosophical and political elements associated with the origin, scope, nature and limitation of knowledge production (epistemology) influences the ways in which different learning theories are formed including disciplinary perspectives, social perspectives and learner's own belief system.

As argued in Siegel (1980, pp 297–321), the way in which knowledge is generated, the philosophical, political and sociological factors shaping the hypothesis of research from which knowledge is generated all reside within the realm of epistemology. Epistemology shapes the theory from which a research expedition is motivated, how the methodological framework is organized and how the results are validated Siegel (1980, pp 297–321). Thus, epistemology has a strategic role in knowledge generation, application, its social acceptance and the way in which it is used in framing problem statements of studies. That is why it assumes a central role in the scientific teaching, research and learning Thompson et al. (2000, pp 45–62). Its role in communication as shared in Thompson et al. (2000, pp 45–62) is also corroborated by Kelly et al. (2012, pp 281–291) who notes that disciplinary theories and perspectives shaped by political, philosophical and sociological views underpins epistemological framing in science. Epistemological biases and its obfuscating or exclusionary influence in scientific studies has been discussed in Katzav (2014, pp 228–238). Katzav (2014, pp 228–238) demonstrated this using the argument on the reliance on the outputs of global climate models by the International Panel on Climate Change (IPCC) in establishing technical and non-technical acceptance of climate model and in the advocacy for its consensus with existing non-scientific knowledge frames. This, Katzav (2014, pp 228–238) argues is somewhat counter-productive to scientific knowledge. Katzav (2014, pp 228–238) notes that this epistemological bias weakens the need for rigorous assessment of global climate models and the projected estimates generated by these models. Drawing from Katzav (2014, pp 228–238) viewpoint and the other scholarly arguments about the limitation of epistemology in the social communication and in the development of learning theories describes the gap inherent in the epistemological framing of certain knowledge frames and concepts. This study takes a que from other scholarly perspectives on the limitation of epistemology in knowledge generation and addresses this limitation with its argument about climate adaptation as an anthropogenic activity. The long-held perspective and knowledge frame of anthropogenic activities or events to the exclusion of other subtle human activities with anthropogenic attributes is addressed in this research.

2.2.1.1 The carriage of Anthropogenic Activities in Other Studies

In Lichtenthaler (1996, pp 4–14), a distinction between natural and anthropogenic activities is provided. Human activities such as the application of herbicides, pesticides, human-induced occurrence of air pollution, acid rain, fertilizer application, increased carbon dioxide and heavy metals are considered in (Lichtenthaler 1996) as anthropogenic activities. This classification suggests that anthropogenic activities are those deliberate socio-economic or development activities by the humans with the potential of engendering impacts on the environment. For example, the use of herbicides and pesticides or application of fertilizer is associated with human efforts at crop management with the ultimate goal of maximizing crop yields. he occurrence of acid rain, air pollutants, acid PH, excessive loading of heavy metals on land and water bodies are all consequences of human deliberate or planned activities for industrial or socio-economic goals.

Natural Stress Factors	Anthropogenic Stress Factors
High Irradiance (Photoinhibition, Photooxidation) Heat (Increased Temperature) Low Temperature (chilling) Sudden and Late Frost Water Shortage (Desiccation Problems) Natural Mineral Deficiency (e.g Nitrogen shortage) Long Rainy periods Insects Viral, Fungal and Bacterial Pathogens	Ozone (O_3) and Photochemical smog Herbicides, Pesticides and Fungicides Air Pollutants e.g SO2, NO, NO2, NOx Formations of Highly Reactive Oxygen Species (O_2 radicals O_2- and OH, H_2O_2) Photooxidants (e.g peroxyacylnitrates Acid Rain, Acid Fog, Acid Morning Dew Acid PH of soil and water Mineral Deficiency of the soil, often induced by acid rain (shortage of the basic cations K, Mg, Ca, often Mn and sometimes Zn) Over-supply of Nitrogen (dry and wet NO_3-deposition) Heavy Metal Load (Lead, Cadmium etc) Over-production of NH_4^+ in breeding stations (uncoupling of electron transport) Increased UV-radiation (UV-B and UV-A) Increased CO2 level and Global Climate Change

Table 3: Categorization of natural and anthropogenic stress factors. Source: (Lichtenthaler 1996)

In Western (2001, pp 5458–5465), the creation of open fields, construction of shelters and settlements and domestication of species as intentional human activities are listed as anthropogenic activities having the potential of impacting terrestrial Biosphere. Wuyts et al. (2017, p 15519) studied the effect of feedback of fire as human impact (anthropogenic activity) on forest bio-stability in the tropics. Dahlberg (2000, pp 19–40) studied the impact of livestock grazing and wood harvesting for fuel and construction of houses on the specie composition, population structure and plants productivity from the prism of anthropogenic activities. Claudio (2018) contributed to the discourse by characterizing mass population displacement as an anthropogenic activity within the Refugee camps in South Sudan as impact-engendering. Like Claudio (2018), Barbier et al. (2006, pp 537–547) also studied changing vegetation pattern properties under influence of activities carried out by internally displaced populations. This gap in the conceptualization of events deemed to be anthropogenic is obvious in the agriculture, forestry and other land use sector (AFOLU) sector where extensive human activities. In the AFLOU sector, human activities like livestock grazing, fuel wood harvesting, crop cultivation, domestication of species, irrigation, pasture and fire management are commonly reported. Studies like Scharsich et al. (2017, pp 278–286) and Wessels et al. (2004, pp 47–67) where activities such as over-grazing, wood harvesting, crop cultivation and pasture management under different states of land ownership were framed as problem statement and their impacts on the environment quantified are worth mentioning.

In Stellmes et al. (2013, pp 685–702), population loss due to migration and increase in human population density were framed as anthropogenic activities. The impacts of these activities studied in Stellmes et al. (2013, pp 685–702) were the increase or decrease in biomass. Barbier et al. (2006, pp 537–547) attributed the spatial periodicity of vegetation patterns in the semi-arid regions to human-managed grazing and wood cutting. In a similar study by Röder et al. (2008a, pp 2863–2875), anthropogenic disturbance was described in terms of livestock grazing where spatio-temporal trends derived from per pixel analysis reflected patterns of livestock distribution and ranging intensification. Permatasari et al. (2016, pp 27–35) highlighted two activities: industrial expansion and agriculture and the transition from agriculture to industries in Jombang Regency, Indonesia as anthropogenic disturbances for which the author applied the Break for Additive Season and Trend (BFAST) model in analysing the changing patterns in the vegetation phenology in the area.

The scope and type of human activities investigated in this research indicate the trend of the epistemological framework. Human activities such as climate adaptation is not considered even when the autonomous adaptation is capable of interacting with biophysical variables of land surfaces including vegetation. With Ellis & Ramankutty (2008, pp 439–447) argument on tools and technologies as elements implicit in the impact-triggering nature of anthropogenic activities; reactionary climate adaptation by farmers are capable of engendering impacts on the environment. To this end, the study argues that subtle human activities capable of triggering impacts on land surfaces such as farm-gate level climate adaptation which have hitherto been excluded from anthropogenic activities should also be considered as such.

2.2.1.2 Impact-engendering Attribute of Adaptation from Human-Environment Perspective

According to Kennish (1991), anthropogenic activities are those actions defined as environmentally external events derived from purposeful human activities with potential impacts on ecological system. In the 4th Assessment Report of the Intergovernmental panel on Climate Change, (AR4, 2007); anthropogenic activities are defined as activities coming from or being produced by humans mentioned in Parry (2007). The European Environment Agency (EEA) defines anthropogenic effects or activities as those processes, objects, materials derived from humans as against those occurring in the natural environment without human influence. Thackway & Lesslie (2008, pp 572–590) defines anthropogenic effects as those impacts arising from the application of artificial technology and energy subsidies. These knowledge frames reveal four dimensions that can be used to characterize anthropogenic activities. First, the human -environment dimension with larger influence of human actions. Second, the interference of non-natural objects, processes and events that are external to natural environment. Third, the purpose and objective of human actions or activities (either towards realizing development or socio-economic gains) which influences to some extent, the degree and frequency of use of environmental resources including land. Fourth, the use of tools and technologies in realizing these social objectives. From a broader perspective, the integration of these four dimensions supports the argument about epistemological bias in the perception of certain human activities as anthropogenic to the exclusion of other subtle human events. It also validates the categorization of autonomous climate adaptation at farm-gate level as anthropogenic activities. As a response-driven action mediated by the need to protect socio-economic assets, climate adaptation does not only involve dynamic systems including human and environmental systems Liu et al. (2007, pp 1513–1516) but also possesses certain social attributes. It is this coupling of the human and environmental systems that supports the argument of autonomous climate adaptation as an anthropogenic activity.

Adaptation to climate change is a social action undertaken by human agency as a response to climate change impact in other to safeguard systems of productions and subsistence. As noted in (Parry 2007), climate adaptation is an action carried out by human systems to adjust or fit processes, practices and structures to set of altered external circumstances upon exposure to climatic stimuli. It is aimed at building resilience of systems under exposure to the risks of climate change in ways that seek to sustain production capacity levels and system performance. Climate adaptation is shaped by social needs and constrained by institutional and social limitations that act to reinforce social inequalities. These factors with the potential of weakening the adaptive capacities or reducing the opportunities for non-farm adaptation options as noted in Noble et al. (2014, pp 833–868) increases the reactionary approach of adaptation.

First, it is important to understand the risks (climate stress and other multiple interacting risks) to which peasant farmers in rural communities are vulnerable to and how these interacting circumstances influences farmers' adaptation choice and behaviours. In terms of climate risks, Smith et al. (2000, pp 223–251), notes that these risks precipitated by changes in the shape of distribution of climatic variables (variance) or shift in the mean values of climatic variables (Smit, Burton et al. 2000). These shifts in mean climatic conditions and variances trigger complex positive feedback processes as well as shifts in the earth's energy balance. With interactions of climate stimuli with other non-climatic constraints which Parry (2007) and Smith & Lenhart (1996, pp 193–201) term as intervening factors, the degree of climate risks are higher thereby exacerbating impacts on both human and environmental systems. This deepens vulnerability and drives reactionary and unplanned adaptation at farm-gate and individual levels.

At the farm level, farmers are confronted by a myriad of reinforcing institutional and socio-economic challenges which limits their capabilities towards diversifying means of income-generating sources apart from climate sensitive, rain-fed agriculture. Under these circumstances, the smallholder farmer executes adaptation actions (more often than not reactively than planned) in response to the combined stress of climatic stimuli and limiting Livelihood conditions. Thus, these actions are more often than not self-help actions under circumstances described earlier. Such autonomous adaptation actions plausibly have the potential of engendering positive feedbacks on land surface since it interacts with biophysical variables of land. These climate adaptation actions thus aligns therefore with Kennish (1991) definition of anthropogenic activities. Further argument on the potential of autonomous adaptation actions exerting anthropogenic impacts is premised on Albuquerque et al. (2017a) viewpoint. In Albuquerque et al. (2017b), the study posits that behaviours of non-plant species including humans within their immediate environments determines the nature and extent of interaction between them and the receiving environment. Thus, these interactions ultimately shape the resultant impacts on the environment.

Although Albuquerque et al. (2017b) argued from an ecological point of view, with an objective of advocating for a shift in previously-held knowledge of humans as exogenous to the environment; the understanding supports human-environment interactions. It also permits the attribution of impacts resulting to the outcomes of these interactions. Albuquerque et al. (2017b) further justifies the interaction between humans and non-humans with their immediate environment from a behavioural dimension. In a social system, the pursuit of social and economic gains shapes human behaviours with these behaviours being exercised in an in-situ condition. Characterizing human socio-economic behaviours and actions as endogenous, Albuquerque et al. (2017b) argues that such in-situ socio-economic actions by the human society (including autonomous climate adaptation) have the potential of engendering impacts on the environment. As actions procured by humans with available tools and resources; these actions have impact-engendering attributes. At the individual fine grain level, climate adaptation is often carried out without recourse to potential impacts on land surface conditions as long as adapted systems are safeguarded, and short-term benefits of adaptation objectives realized. The purpose of autonomous adaptation, the use of land surface-impairing tools by farmers, the frequency and reactionary nature of adaptation actions by subsistent farmers characterizes adaptation as an anthropogenic activity. The way autonomous climate adaptation is carried out compares to the objective and manner in which other anthropogenic activities are undertaken, thus providing a justifiable premise of characterizing it as one.

This study therefore defines anthropogenic activity a set of activities motivated by socio-economic goals or towards the protection of system attributes of value and which has the capacity of altering equilibrium states of systems through shifts in structures, processes and functions.

2.2.1.3 Farm-gate Level Autonomous Adaptation as an Anthropogenic Activity

The application of agricultural land use intensity in this research is to contextualize crop cultivation intensity and other reactionary climate adaptation as an agricultural land use Intensity activity. It is aimed at examining the potential impacts of agriculture on vegetation cover greenness and dynamics against the backdrop of the understanding provided by Matson et al. (1997, pp 504–509). In Matson et al. (1997, pp 504–509), agricultural intensity is extended to include the use of fertilizers, irrigation and the modification of cropping practices to support high-yielding crops varieties. Agricultural land use intensification (LUI) according to Kerr & Cihlar (2003, pp 161–172) refers to the increased exploitation of land resources through the use of unsustainable tools and practices without a receding period to derive socio-economic benefits. This, Kerr & Cihlar (2003, pp 161–172) notes can exert pressures on the balanced states of the environment; a knowledge which Lesslie et al. (2010) shares.

The frequency of the use of land and the application of local technological tools in the exploitation of resources has been reviewed in published articles like Dietz (2002, pp 3–15) and Hendrickx et al. (2007, pp 340–351). Land use intensification is usually related to economic pursuits and is not limited to a certain type of land use although more often than not, it receives increased attention in the agricultural, forestry and other land use sector (AFLOU). Land-use intensification by Boserup (1965) was originally propounded from the perspective of agricultural intensification where the cropping frequency in agricultural landscapes provided a frame for understanding land use intensity. Boserup (1965) also included the intensification of inputs and frequency of use of agricultural lands in deepening the concept of land use intensity. Decades later, Erb et al. (2013, pp 464–470) then extended the concept by introducing, types of inputs used in exploiting and managing agricultural lands in broaden both the concept and the understanding. Kerr & Cihlar (2003, pp 161–172) and Haberl (2015, pp 424–431) also supported the knowledge from Erb et al. (2013, pp 464–470).

Land use intensity is characterized by cropping intensity, a function of frequency in a given crop field per yearly basis as mentioned in Erb et al. (2013, pp 464–470). Erb et al. (2013, pp 464–470) advanced the land use intensity concept by proposing a land-based production system where three sets of indicators were applied in understanding what processes, actions and results could better explain land use intensification. In Land-based production system, Erb et al. (2013, pp 464–470) proposed three parameters: input intensification, output intensification and changes in land surface biophysical variables. To Erb et al. (2013, pp 464–470), input intensification related to the forms, types and methods of farm inputs as well as the frequency of land exploitation with these inputs. On the other hand, Yan et al. (2017, pp 387–402) also approached the concept of land use intensity by introducing the dimension of the degree or extent of disturbance on land surfaces. Yan et al. (2017, pp 387–402) advanced the discourse beyond intensification of use in terms of inputs and frequency to the inefficiency of inputs being used and the potential impact of these unsustainable inputs on land surface conditions and vegetation dynamics.

Land use intensity is characterized by cropping intensity and the associated frequency in a given crop field per yearly basis as mentioned in Erb et al. (2013, pp 464–470). Erb et al. (2013, pp 464–470) advanced the land use intensity concept by proposing a land-based production system where three sets of parameters are applied in understanding the types of processes, actions and results that could better explain land use intensification. In land-based production system, Erb et al. (2013, pp 464–470) proposed three parameters: input intensification, output intensification and changes in land surface biophysical variables. In Erb et al. (2013, pp 464–470), input intensification relates to the forms, types and methods of farm inputs as well as the frequency of land exploitation with these inputs. However, in Yan et al. (2017, pp 387–402), land use intensification or intensity is expanded to include the dimension of the degree or extent of disturbance on land surfaces. Yan et al. (2017, pp 387–402) advanced the discourse of land use intensity beyond frequency, input and output intensification to the inefficiency of inputs being used. Yan et al. (2017, pp 387–402) also deepened the discourse with the potential impact of the use of unsustainable inputs on land surface conditions.

Over time, interests in agricultural land use intensity and its potential impacts on land surface conditions including vegetation dynamics have grown with studies like Persson et al. (2010, pp 169–176), Marchant et al. (2018, pp 322–378) and Baessler & Klotz (2006, pp 43–50) deepening the discourse. Agricultural intensification is a novel stress or disturbances effect and can exert cascading impacts on plants from structural organs through species to functional traits. Claessens et al. (2009, pp 157–170), Dumanski & Pieri (2000, pp 93–102), Persson et al. (2010, pp 169–176) and McIntyre & Lavorel (2007, pp 11–21) mentions that it also has the potential of jeopardizing plants radiation absorption capabilities. This view have been further deepened in Norman & Campbell (1989, pp 301–325) where human disturbances were found to have direct contacts with plants structural organs impacting spectral absorptive capacity of plants through damage on optical apparatuses. From a morphological dimension, a link between modified or damaged vegetation structural organs, disturbance events and plants functional-structural response is explained. In Hendrickx et al. (2007, pp 340–351), impacts of land use intensification on agricultural landscapes have been reported albeit on specie richness between communal landscapes. Numata et al. (2007, pp 159–172) investigated the impact of Land use intensity by grazing on pasture biophysical properties and found that intensive grazing affected pasture biophysical properties significantly in comparison to land use age and soil order. Similarly, da C Jesus et al. (2009, p 1004) demonstrated how intensive agricultural practices by indigenous people in the Amazon impacted the structure and composition of Amazon soil bacteria communities. So did Dupouey et al. (2002, pp 2978–2984) also show the after-effects of agricultural activities around the AD 50-250 in Northern France on specie richness and plant communities which the study noted varied along land-use intensity gradients.

The intensive use of land by humans constitutes trampling effects on vegetation cover and foliar organs with a response-triggering effect. For example, in (Cole 1995), vegetation responses under intensive trampling in eighteen different vegetation types were studied. Results from these studies showed that vegetation responses to trampling was linear and that response depended on the intensity of human disturbances as well as the vegetation type. Also, (Monz 2002) showed that human intensive use of land surfaces (which constituted trampling disturbance) affected vegetation height, species diversity and richness. Burden & Randerson (1972, pp 439–457) also indicated that human trampling impacts arising from different land use types and land use management had the potential of triggering vegetation response such as edaphic and floristic effects. Burden & Randerson (1972, pp 439–457) furthermore noted that the noted that the magnitude of such responses depended linearly on the intensity of trampling effect. Changes in species quantities (Grime 1973), succession phenomena and reduction in plant productivity (Goldsmith 1974) all cited in (Liddle 1975) demonstrated vegetation response to human disturbances. (Liddle 1975, pp. 251–255) mentioned that plants primary productivity was an important measure of plants tolerance to human trampling through intensive land use.

According to Gamon et al. (1995, pp 28–41), vegetation canopy structural organs and foliar density have direct linkage with plant optical characteristics which plays a critical role in the absorption of energy in the visible portion of the electromagnetic spectrum. This is because the portion of the photosynthetically active radiation, fPAR useful for photosynthesis is intercepted by vegetation canopy structure with the leaf area index (LAI) playing a role in the absorption mechanism as mentioned in Gates et al. (1965, pp 11–20). Without solar energy absorption which is facilitated by plant canopy structural organs, Gates et al. (1965, pp 11–20) notes that physiological processes like photosynthesis is limited in plants. This implies that vegetation cover greenness depends not only on key climatic variables like rainfall but also on vegetation sites in terms of structure and the biochemical contents (chlorophyll) Kumar & Silva (1973, pp 2950–2954); Walter-Shea & Norman (1991, pp 229–251). In Gates et al. (1965, pp 11–20) and (Kumar & Silva 1973), vegetation physiology is also determined by air-cell wall-protoplasm-chloroplast interfaces.

2.2.1.4 Potential Impacts of Human-Environment Interaction on Vegetation Cover

Human-environment interactions and the ensuing system coupling is central in ecological and landscape studies. This is so because of the role and potential influence of humans in altering balanced state of the environment. Human influence on the environment has been widely studied and analyzed from the perspective of landscape functions and also from a socio-ecological view. In studies such as Bellot et al. (2007, pp 412–422) and Gurjazkaite et al. (2018, pp 143–155) have investigated the signals of human activities on the environment. In other studies, human influence on the bio-stability of forests cover was studied and results showed that human influences could quantitatively and qualitatively alter the composition and structure of forest cover. In Thackway & Freudenberger (2016, p 40), the study highlighted the impact of human signals on the transitional states of vegetation cover in Australia. Following the scientific understanding from these studies, this research thus situates farm-gate level autonomous coping and adaptation actions within the coupled human-environment system. The coupled human-environment system supports the rationalization of the role of socio-economic factors in human actions on the environment. It highlights how these interactions impact from an in-situ point of view, land biophysical variables. Since reactionary climate adaptation in rural communities is often characterized by unsustainable use of land resources; land use intensity concept is thus relevant here. The spatial (scale) dimension of human appropriation of land and other environmental resources is also used to validate the argument. While vertical social differentiation of resource capabilities impacts the scope and nature of autonomous climate adaptation at the farm-gate level, capability-determined adaptation strategies potentially interacts with biophysical variables of land. Thus, the contextualization of farm-gate level adaptation within the human-environment coupled system.

2.2.2 Protection-motivated Adaptation Actions and Potential Feedbacks on Vegetation

The second argument is on the potential of autonomous adaptation to interact with land surface biophysical variables. Human cognitive actions are inherent human psychological attributes which shapes behaviours, decision-making processes and ultimately actions. The concept of human cognition in the discourse of human reactions and response in the face of threats and risks has assumed relevance in hazard and environmental risks studies. In all actions executed by humans including those actions with anthropogenic potential; human cognition is a central consideration since it links to behaviours, motivation, intentions and actions. The objective to protect oneself or systems of socio-economic production from harm does not only involve elaborate decision-making process but also a set of response efficacy and resource capabilities analysis.

Protection Motivation Theory (PMT) explains human behavioural adaptation or response in the face of potential or real risks. Since its postulation in 1975 by Rogers (1975, pp 93–114), the protection motivation theory has been successfully applied in environmental studies such as Vaughan (1993, p 74), Floyd et al. (2000, pp 407–429), Wandersman & Hallman (1993, p 681), Mulilis & Lippa (1990, pp 619–638). Recently, it has been extended to climate change studies Grothmann & Patt (2005, pp 199–213). The PMT is used to understand how humans react in the face of threats and risks. It characterizes a framework of human decision-making processes illustrating not only the sequence of intended protective actions but also the situational analysis framework. The PMT analyses how people behave, think, act and cope in the face of risks and threats. PMT was originally postulated by Rogers (1975, pp 93–114) upon the expectancy-value theory to study human protective behaviours in the face of health risks and the cognition process involved in seeking safety or safeguarding well-being. Following its successful application in explaining protective behaviours in health issues, PMT has been applied in understanding what drives or informs protection or coping actions under different circumstances and conditions. The PMT theory having been reviewed by Prentice-Dunn & Rogers (1986, pp 153–161) now integrates components of self-efficacy and rewards of preferred protective actions. It also integrates element of self-and response efficacy assessment as well as cost analysis of initiating a coping action. A combination of these elements stimulates self-help actions.

The concept of PMT stands valid under the circumstances of reactionary response by smallholder farmers acting to protect and safeguard their rain-fed livelihood assets. Confronted by a web of other intervening social and institutional factors, subsistence farmers autonomously react to adapt. Such reactionary behavioural actions by rural farmers are often premised on a judgement towards actions to sustaining sources of survival base. This judgement is a decision-making process involving comparison of alternatives prior to adopting a preferred adaptation strategy. Protective behaviours are rooted in cognitive processes which favour quick outcomes and less planning horizon that long-term planning. Grothmann & Patt (2005, pp 199–213) and Prentice-Dunn & Rogers (1986, pp 153–161) described stimuli as threats or risks in the PMT framework. The perception of threats and potential risks inspires the appraisal of perceived threats as well as the perceived ability to respond to these threats. Risk and response appraisals are important elements in organizing protective responses. It involves the assessment of self and resource efficacy (measured by the availability of resources and in the efficacy of preferred action). According to Grothmann & Patt (2005, pp 199–213), self-efficacy has a greater influence not only on the decision to protect oneself from harm but also on the perceived practical course of action. Self-efficacy determines according to Grothmann & Patt (2005, pp 199–213), coping actions and also increases the probability to motivate system protective measures.

Upon the successful application of the concept of protection motivation theory in beyond traditional disciplines of health sciences, Grothmann & Patt (2005, pp 199–213) applied PMT in climate adaptation science research. Grothmann & Patt (2005, pp 199–213) expanded and adapted the concept of protection motivation theory in espousing private proactive adaptation to climate change. The argument was to demonstrate the central role of human cognition in the facilitation of adaptation actions. Autonomous climate adaptation bears all the attributes of cognition which includes:–perception, behaviours, evaluation, motivation, decision and ultimately actions. Grothmann & Patt (2005, pp 199–213) argued that upon risk and response efficacy assessments as well as the appraisal of perceived capacity to perform actions; those exposed to climate risks institute reactionary actions. Grothmann & Patt (2005, pp 199–213) strengthens the application of PMT in climate adaptation research with emphasis on risk perception and perceived adaptive capability arguing that these considerations inspire not only the need for those under exposure to act but also in the preference of certain coping actions to others.

Other studies that incorporated PMT in understanding the dynamics of farmers' adaptation strategies include Le et al. (2012, pp 83–96). In the study, the author, noted that farmers are likely to pursue adaptation intentions when they perceive higher risks of climate change and greater effectiveness of preferred adaptation strategy. Le et al. (2012, pp 83–96) also mentioned that adaptation intention increases in conditions of decreased opportunities for institutional support or in conditions of lack of enhanced physical and entrepreneurial infrastructure to support the diversification of livelihood means. Similarly, Truelove et al. (2015, pp 85–97) also showed that farmers' conviction in the execution of preferred adaptation option (self-efficacy) significantly influenced farmers' adaptation behaviours more than demographic and other psychological variables such as risk perception.

However, most of these studies have failed to consider the potential consequences or positive feedbacks that are implicit in these protective measures. In this study, the human cognition (PMT theory) has been expanded to include feedbacks following reactionary adaptation actions. Feedbacks have not been mentioned since the original postulation of PMT by (Rogers 1975) and through the lifecycle application of the theory across other disciplinary frames like environmental, climate and disaster reduction contexts. Although Risbey et al. (1999, pp 137–165) mentioned feedbacks in public adaptation process, the role which the author ascribed to feedbacks was as one of the essential steps in the flowchart in organizing public adaptation process. The feedback in climate change adaptation by Risbey et al. (1999, pp 137–165) was incorporated to support the monitoring of selected adaptation options to ascertain their effectiveness and this was at the institutional level not fine-grain level. It assumes a more procedural effectiveness role. Also in Le et al. (2012, pp 83–96), feedback in land use-environment system was highlighted to demonstrate how environmental feedback could potentially re-shape future land-use decisions at household levels. Kandlikar & Risbey (2000, pp 529–539) In Risbey et al. (1999, pp 137–165), feedbacks have been mentioned in the context of monitoring outcomes of adaptation decisions and in assessing whether outcomes are within range of expectations. The relevance of feedback as used in these studies are for the selection of alternative land use pathways based on new complexities on land surface conditions. Thus, the conceptual relevance of feedbacks in adaptation decisions cited in Le et al. (2012, pp 83–96) which is more on evaluating risks in adaptation decisions is unconnected to the conceptual thinking of this study.

In this study, the integration of feedback in PMT theory is to assess the potential impact of reactionary climate adaptation on land biophysical conditions including vegetation cover. This is so given the dynamic coupling between human and environment systems (socio-ecological systems). The introduction of feedbacks into the PMT is justified on the basis of the interaction of the inherent components of human and physical environment systems in an in-situ condition as mentioned in Albuquerque et al. (2017a). Kolasa & Pickett (1989, pp 8837–8841) argues that interacting systems in closed loop systems are bound to trigger feedbacks, an understanding shared by Åström & Murray (2007). According to Kolasa & Pickett (1989, pp 8837–8841), feedbacks cannot exist in isolation and must not necessarily occur from inherent actions, stress events but from physical perturbations or application of an external force on a medium. Any system with internal components in a coupled state exhibits characteristic behaviours in such a way, that impact on one system components triggers effect in another system component in a circular manner as mentioned in Kolasa & Pickett (1989, pp 8837–8841). The integration of feedback loop in this study is to compensate for the human-environment perspective gaps in previous studies on socio-cognition element of climate adaptation.

2.2.2.1 Adapted Protection Motivation Framework with Potential Feedback Loop

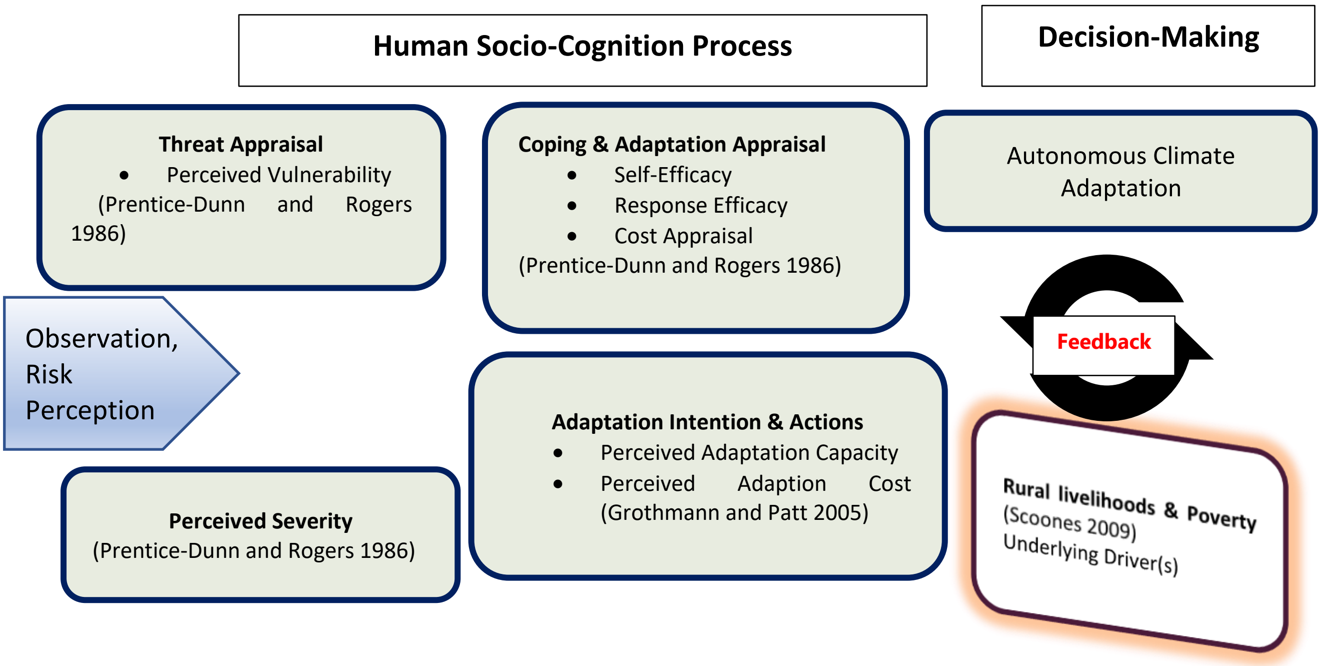


Figure 7: Flowchart showing human socio-cognition process as the basis of autonomous adaptation decisions at farm-gate levels

2.3 Scale Dimension of Autonomous Farm Gate Level Climate Adaptation

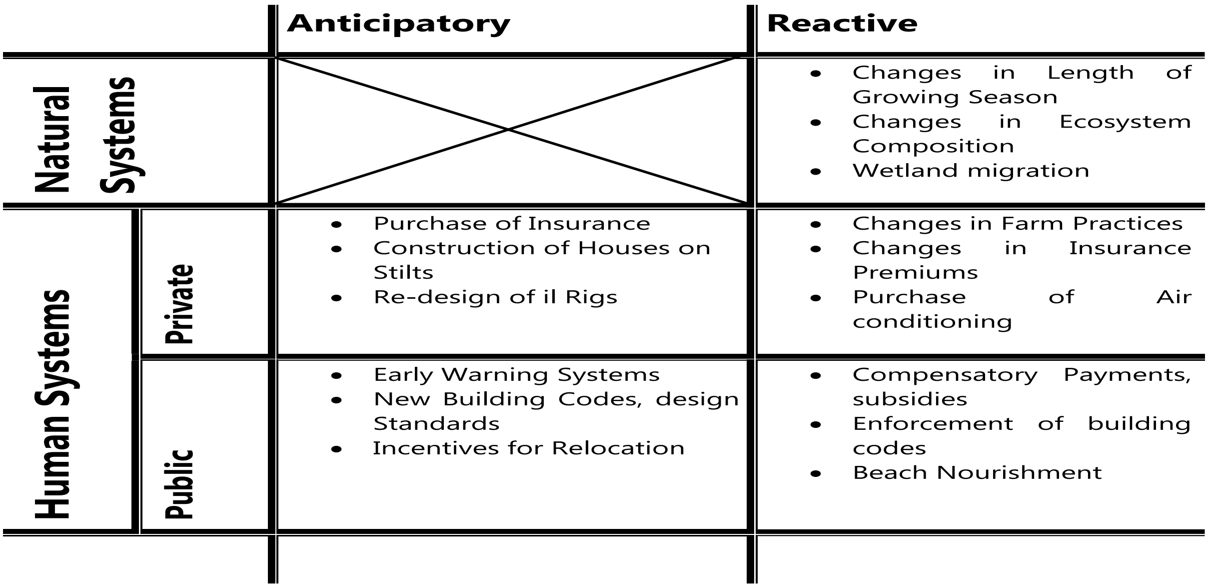
Deepening coupled human-environment system concept in understanding how autonomous climate adaptation at farm-gate levels can interfere with biophysical properties of land surfaces is explained with the scale dimension of adaptation actions. The scale element here is aimed at broadening the discourse on the role of scale (both in terms of social and spatial) and the interaction of these scale quantities both from a capacity and impact point of view. It is also intended to show that both the interaction between spatial extent of climate change impacts and resource-differentiated social groups impacts the architecture of autonomous climate adaptation at local levels. This spatial scale and scope has been discussed in Risbey et al. (1999, pp 137–165). Vertical differentiation of resources and extent of social capabilities have direct implications in climate actions and associated outcomes. In this study, two types of spatial scales; spatial (phenomena) and socially-constructed spatial scale (quantity) are considered to support the difference between institutional-type adaptation and individual-type adaptation to climate change. It contributes to the understanding of the role of resource capability on adaptation choices and its linear relationship with environmental variables through the human-environment interface.

According to Howitt (1998, pp 49–58) and Howitt (2002, pp 299–313), spatial or phenomena scale refers to the size at which human or geographic structures or process exists referring explicitly to geographical processes or events. On the other hand, spatial or phenomena scale advanced by Neumann (2009, pp 398–406), Marston et al. (2005, pp 416–432), Jonas (2006, pp 399–406) and Gibson et al. (2000, pp 217–239) include social scale. Social scale here , as explained by Brenner (2004, pp 447–488) in Marston et al. (2005, pp 416–432) refers to the 'vertical' differentiation in which social relations are embedded within a hierarchical scaffolding of nested territorial units. These territorial units stretch from the global, the supra-national, and the national downwards to the regional, the metropolitan, the urban, the local to the individual. Differentiation connotes separation, demarcation and distinction; thus, the concept of scale provides clarity on the differences in size and magnitude. When applied in terms of social organization or social elements, scale refers to the size of resources and capacity to act. This definition shares two important keywords in the definition of scale provided by Wilson & Wilson (1945). In Wilson & Wilson (1945), scale from a human geography dimension is a variable used for describing not only the size and nature of a social organization but also for distinguishing the characteristics of different societies. It was Wilson & Wilson (1945) ideas that introduced the premise for the use of scale in describing the limit of social organization like poor communities or households; and how this resource limitation can mediate negatively, human-environment interactions particularly at local scale (spatial) with positive feedbacks.

The term "limit" in scale concept is synonymous with the word restriction or borderline. Limit signifies level-bounded structures, process or extent of size of a feature class. It implies differentiation either spatially, socially or in terms of human capability. Vertical limit as used by Brenner (2004, pp 447–488) is synonymous with the words restriction or borderline. Limit signifies level-bounded structures, process, the extent or size of a system. In Blaikie & Brookfield (1987), it implies differentiation in terms of socio-economic capabilities and hierarchies. From the social point of view, social scales have more to do with individual capability to draw on resources and inputs as at when needed as well as the size of resources. Thus, it determines not only the capacity of an individual to act but also the scope and nature of such socio-economic-oriented actions. Brenner (2004, pp 447–488) ideas link both spatial and social capability boundaries. In Marston et al. (2005, pp 416–432), these boundaries and vertical differentiation comes through in terms of the limits imposed by institutional systems on the capability limits of social organizations (farming settlements) to produce, reproduce and consume. Brenner (2004, pp 447–488) ideas further supports Blaikie & Brookfield (1987) argument on the hierarchies of socio-economic organizations (example, person, household, village, region, state) as cited in Neumann (2009, pp 398–406). These knowledge frames apply to human geography and political ecology. The relevance of social scale concept in this study is highlight the how differences in capabilities, assets and resources determines hierarchy of social organisations and how this in turn shapes individual capability to respond to geographic phenomena (like climate change) across scales. Regarding autonomous adaptation to climate change, the scope and extent of selected or preferred adaptation actions are direct consequence of both size of social organization and available resources. This in turn determines the outcomes and the feedback on the interacting environmental medium.

The scale-oriented approach to climate change links not only to size of available resources but also draws on the political and institutional elements shaping autonomous adaptation at local levels. With opportunities for institutional and budgetary support, corporate organizations and governments can afford to carry out proactive, long term adaptation planning as against individuals or farmers without incentives. At the individual and farm-gate level, the degree of capability, measured by size of investment assets, access to social support and opportunity for alternative incomes Parry (2007). This influences on a larger extent, the way in which systems of production are adjusted following climate risks; with individuals with weaker socio-economic capabilities preferring adaptation strategies with short-term economic gains potential. Thus, resource and capability-based adaptation choices or strategies are determined by the level and size of social unit involved. The constraints of timely and adequate access to finances and other resources experienced by peasant farmers to initiate sustainable adaptation actions that recognize associated ecological concerns increases the likelihood for short-term reactionary adaptation choices.

Outcomes of such short-term approaches will be fundamentally different from outcomes of long-term, proactively planned and procedurally implemented adaptation measures. At the institutional level, climate adaptation entails more systemic planning involving multi-stakeholder dialogues, needs assessments, broader organizational administration and budgetary planning. It also includes the consideration of different long-term options, the methodical implementation of selected adaptation activities as well as the monitoring and review of actions. Such well-planned and well-managed climate adaptation are likely to be screened for potential impacts on the receiving natural environment and social systems. In contrast to institutional type adaptation, autonomous adaptation by poor farmers lacking enabling resources are more reactionary than planned. Such autonomous reactionary adaptation lacks elements of planning, risk identification and methodical implementation. The pressure to secure household needs as well as protect systems of production (small farms) drives not only reactionary climate adaptation actions but also non-receding pressure on vegetation. A schematic diagram depicting the conceptual understanding of the difference in different climate adaptation approaches (anticipatory versus reactive) as mentioned in the IPCC 2001 assessment report is shown in figure 8.



		Anticipatory	**Reactive**
Natural Systems			• Changes in Length of Growing Season • Changes in Ecosystem Composition • Wetland migration
Human Systems	**Private**	• Purchase of Insurance • Construction of Houses on Stilts • Re-design of il Rigs	• Changes in Farm Practices • Changes in Insurance Premiums • Purchase of Air conditioning
	Public	• Early Warning Systems • New Building Codes, design Standards • Incentives for Relocation	• Compensatory Payments, subsidies • Enforcement of building codes • Beach Nourishment

Figure 8: Pictorial representation of the differences between reactive and anticipatory climate adaptation. IPCC 2001 Report

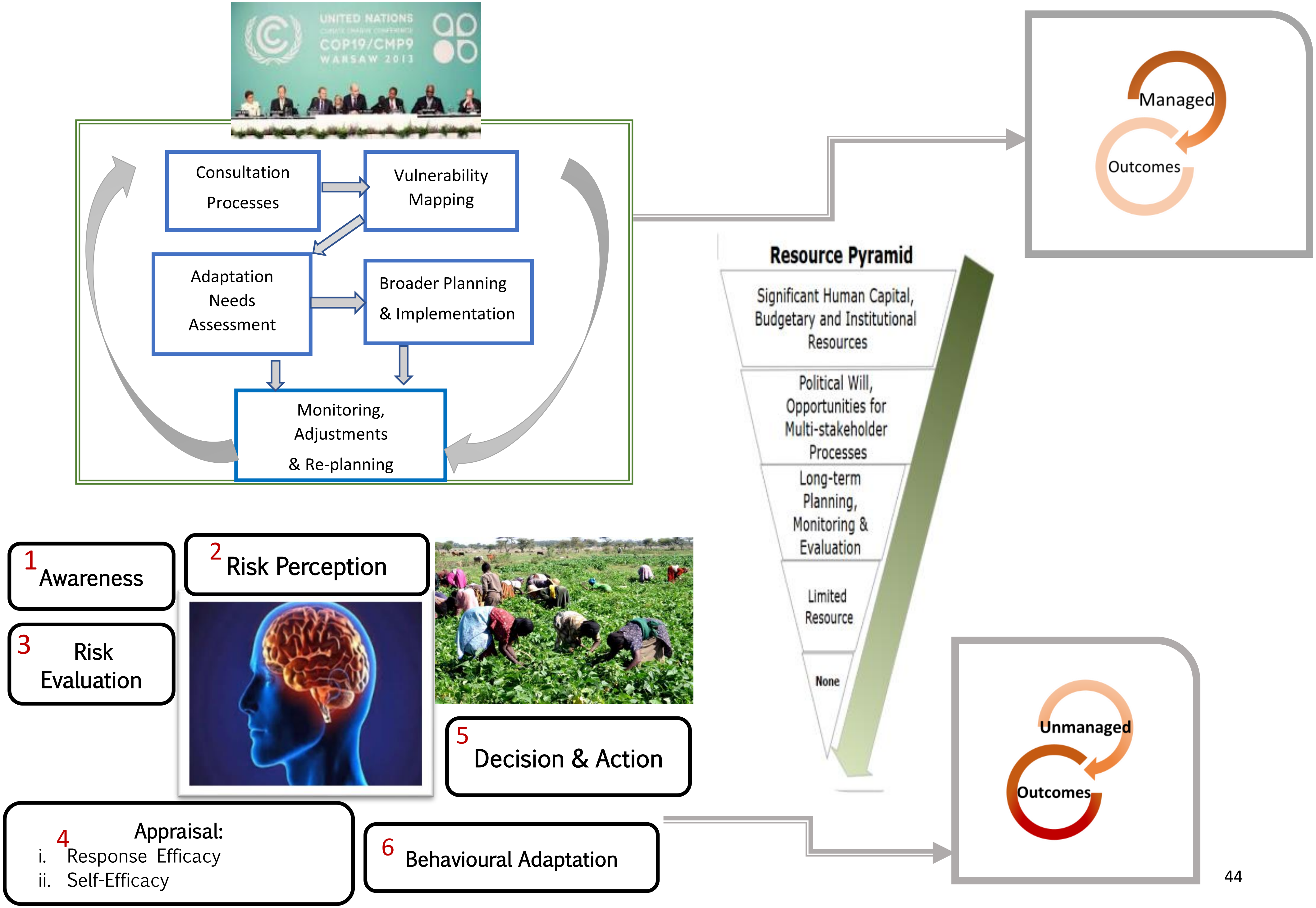


Figure 9: Schematic diagram depicting scale-oriented differences in approach to climate adaptation

2.4 Climate Adaptation, Typologies and Theoretical Framework

2.4.1 Climate Adaptation

Climate adaptation is a complementary set of response to mitigation aimed not only at adjusting systems to climate impacts but also at minimizing potential and real impacts of climate change. It is embraced across all levels, from individual to community to programmatic levels. According to the fourth IPCC report (AR5, 2013), climate adaptation is process of adjusting to actual or potential climate effects in order to moderate, avoid, or exploit benefits that may be associated with adaptation process itself or climate impacts. Climate adaptation can be autonomous or carried out as an integrated response at an institutional or programmatic level. Given that the human society undertakes adaptation actions with the primary goal of protecting the structural, functional and socio-economic attributes of livelihood systems against climate impacts, it is fundamentally rooted in social-oriented behaviours. Thus, associated adaptation strategies are implicit in the protective behaviours and cognitive processes of those whose livelihoods sources or attribute system of values are at risk due to a changing climate. Owing to its social and economic significance, its conceptual meaning varies both in research and in practice to the extent that its definition is determined by scope and its typologies.

Since its early emergence within the framework of global negotiations under the United Nations Framework Convention on Climate Change (UNFCCC); climate adaptation has assumed both policy and conceptual significance. In Schipper (2006, pp 82–92), it has been noted that, since the first mention of adaptation in the early 1990s, climate adaptation has been promoted not only as an integral policy response to climate impacts but also as a complimentary response to mitigation. The policy character and relevance of climate adaptation is evident in the organization of budgetary and institutional resources in developing programmes that seek to improve resilience of natural and social systems as mentioned in Cartwright et al. (2013, pp 139–156). Upon its adoption at the conference of parties (hereafter referred to as COP), COP 7 in 2001 in Marrakesh, adaptation has been targeted at addressing issues of financial and technical constraints faced by least developed and developing countries in executing mitigation actions as mentioned in Schipper (2006, pp 82–92). Adaptation to climate change also assumed significance in UNFCCC process due to the insufficiency of mitigation actions in addressing residual impacts and real-time climate change risks. This has been elaborated in Schipper (2006, pp 82–92). While climate mitigation is aimed at addressing the reduction in source and quantities of greenhouse gas emissions, adaptation was recommended for managing vulnerabilities, reducing systems’ susceptibility and strengthening resilience of exposed systems.

According to Schipper (2006, pp 82–92), climate adaptation is perceived as an instinctive human action which occur naturally in response to real and perceived threats to sources of economic livelihoods. It is seen as a cost-effective response strategy for managing climate impacts and reducing system’s vulnerability to climate risks. Following its minimal cost implications and the reactionary way in which it is undertaken. Adaptation has become prominent in global policy response to climate change due to the limited capacities of individuals in carrying out mitigation actions. In addition, the argument regarding impacts of the unabated occurrence of shifts in climatic variables, which are already affecting natural and social systems; a social response to cope and adapt climate impacts are inevitable. Like Schipper (2006, pp 82–92), Füssel & Klein (2006, pp 301–329) also corroborates this understanding. While mitigation measures were thought to engender slow-paced results due to the long-term planning horizon, investments in institutional and financial resources; adaptation strategies were considered short-term actions that could be undertaken tactically at the individual level and across different social groups. The reactionary ways in which climate adaptation is undertaken at the fine-grain, individual level independent of external support further underscores the argument that autonomous adaptation is an event tightly coupled to the socio-economic system of the human society.

These social and reactionary attributes of climate adaptation have influenced its definition. In Pielke (1998, pp 159–170), adaptation to climate change is described as a portfolio of responses towards minimizing the impact of climate change. In Smit et al. (1999, pp 199–213), adaptation is defined as the process involving the readjustments and modifications of systems' conditions in other to make them suitable for intended purpose under constrains of new climatic conditions. In Adger et al. (2005, pp 77–86) and Adger et al. (2003, pp 179–195), climate adaptation is defined more in terms of the enhancement of adaptive capacities of natural and systems to cope with anticipated and real-time climate risks. Adger et al. (2005, pp 77–86) further notes that the purpose of adaptation is to reduce severity, increase resilience and alter exposure of systems to climate change impacts. In Füssel & Klein (2006, pp 301–329), adaptation is espoused as a proactive step in managing or dealing with climate risks and impacts whereas in Pelling (2010), adaptation implies building resilience, transformation of systems and transition in scope and levels of practices. Barros et al. (2014) notes that adaptation implies responding or reorganizing affected systems in ways that supports such systems to maintain their essential functions, identities and structures including the capacity for learning and transformation. Smit et al. (1999, pp 199–213) also highlights both the process of adaptation and the conditions that are supportive of adaptation to climate change. In Smith et al. (2000, pp 223–251), this definition is expanded to include modifications in management strategies of natural and social systems towards positioning them for actual or expected climatic conditions. Across all definitions, it is deducible that the main objective of climate adaptation is for reducing climate risks on socio-economic and cultural systems.

2.4.2 Scope and Typologies of Climate Adaptation

Adaptation to climate change differ in approach, scope and resources deployed. This difference in approach is driven in most by the interacting socio-economic and political factors. In Le et al. (2012, pp 83–96), some of these socio-economic factors includes household and land-use decisions. The degree to which these factors determine adaptation type and scope is related to an interaction of factors. Approaches to climate adaptation can be institutional, managerial or behavioural according to Krupnik & Ray (2007, pp 2946–2957) and Smith et al. (2000, pp 223–251).   This constitutes the typologies of adaptation which are not only determined by the function of planning and implementation horizons but also by capabilities and assessable resources. At institutional level, climate adaptation actions are administrative, technical and engineering strategies while adaptation at individual levels are behaviourally-oriented lacking in long-term planning, impact screening and organization. They are more about developing frameworks, implementing adaptation decisions and strengthening institutional capacities to support implementation of adaptation programmes. These types of adaptation measures are programme-type involving resource needs assessment and logistical planning. In Smith et al. (2000, pp 223–251) and Dess and Lumpkin (2005, pp 1–32), such actions are described as anticipatory and proactive with technological, financial instruments and programmatic tools to support adaptation activities. Given the way in which institutional-type adaptation are planned, potential activities stand a high chance of being screened for its potential impact on the environment or positive feedbacks on the ecological system.

Adaptation actions occurs at different scales from fine grain (individual) through community level, to broader institutional and programme levels. However, adaptation differ in scope and typologies across scales. Scales here is determined by the socio-economic capability of the individuals undertaking autonomous adaptation actions. The social element of climate adaptation including the disproportionate size of resources as used in Agrawal (2010, pp 173–178) determines the planning horizons, the strategies, and the goal of adaptation. This disproportionateness influences the extent to which livelihoods considerations outweighs other long-term objectives of adaptation. At the fine grain level, strategies supporting the quick realization of short-term gains of fulfilling household needs are favoured to longer- term, planning and cost-intensive approaches. Such considerations underpinned particularly by dissimilarities in socio-economic capabilities apart from influencing adaptation strategies contributes to the differences in outcomes of adaptation actions. That means that screened adaptation strategies, selected after potential impact assessment will likely result in better managed outcomes than reactionary adaptation strategies adopted autonomously at farm gate levels by subsistent farmers.

The availability of institutional support (agricultural incentives, finances, and credits) and the ability to access, and draw on them when needed shapes to a greater extent, the way individuals adapt to climate change. So does social and institutional limitations impact the capacities of individuals in resource-poor communities in engaging in more systematic and sustainable climate adaptation activities. Rather, it supports, according to Douxchamps et al. (2016, pp 1305–1317), shorter-term coping and reactionary adaptation actions seeking to protect sources of household incomes. This understanding has been corroborated in Adger et al. (2003, pp 179–195), Agrawal (2010, pp 173–178) and Bradshaw et al. (2004, pp 119–141). Besides the issue of limited resource capability, Challinor et al. (2007, pp 381–399) and Thornton et al. (2011, pp 117–136) also note that slow infiltration of technological solutions and absence of infrastructure that could support livelihood diversification, also incentivizes autonomous and self-help adaptation measures which are reactionary than planned.

At the fine grain level (individual), adaptation to climate change is motivated towards the assessment of climate risk and impacts. Risk in this context implies the potential of an unfavourable consequence affecting assets of high value with uncertainty in outcomes according to Niang et al. (2014). Although risk is an important element of adaptation, the perception and evaluation of risk in adaptation decisions seems more critical in the decision making at individual and autonomous level than at institutional level. At farm gate levels, where institutional resources, finances and social capitals are either lacking or limited, judgement on risk management are important consideration of self-help adaptation actions.

Thus, adaptation to climate change at the individual level is more behavioural and driven by the motivation to protect socio-economic systems of livelihood value based on risk perception. This understanding aligns with Smith & Lenhart (1996, pp 193–201) viewpoint which explains that behavioural adaptation are connected with changes in the way economic systems are managed in other to reduce system sensitivity to climate risks. Risk perception drives behavioural-based actions, which in the context of individual adaptation describes how human agency organizes reactionary solutions in response to climate impacts. Behavioural approach to climate adaptation has at its core, emphasis on the preservation of socio-economic attributes of exposed systems as highlighted in Stehr & Storch (1995, pp 99–105).

Within a behavioural context, affected individuals, in addition to modifying their behaviours and decisions towards managing altered states of production systems, also re-position, such climate-impacted systems. For example, managers of rangelands motivated towards protecting rangeland from climate impacts and conserving them for livestock grazing, engage in proactive monitoring and adaptive management practices Mccollum et al. (2017, e01264). Subsistence-oriented farmers change planting decisions and dates according to Labaris (2012, pp 68–74), modify cultivation practices including changes in crop varieties. Other commonly cited strategies carried out by subsistence farmers include as reported in Eitzinger et al. (2014, pp 161–176) includes investing in irrigation as well as the adoption of early maturing and drought-resistant crops mentioned in Wall and Smit (2005, pp 113–123). Agro-forestry management practices have been also cited in Luedeling et al. (2014, pp 1–7) and Mbow et al. (2014, pp 8–14). Although these strategies differ in the mode of execution, research has shown they are rooted in human cognitive actions and behaviours oriented towards the protection of livelihoods from climate impacts.

The perception of climate-related risk on farm assets, the ability to carry out preferred strategies and the efficacy of these preferred strategies drive the cognitive process and reactionary actions with regards to climate adaptation at farm-gate levels. In the planning, implementation methods and horizons, these autonomous adaptation strategies differ from institutional-level type climate adaptation and lacks to a greater extent, considerations for land surface variables and vegetation canopy conditions. Aligning to the understanding in Smith et al. (2000); Klein & Tol (1997), autonomous adaptation measures at individual levels are less tactical in approach with protective actions undertaken with or without planning or impact assessments. Thus, autonomous climate adaptation can be described as a disturbance event within coupled human-ecological systems. The reactionary nature of autonomous climate adaptation and its lack of consideration for the potential feedback loop within the human-physical environment system is what this study is focused on hypothesizing and investigating.

2.4.3 Theoretical Framework

The theoretical framework of the study is adapted from a conceptual analysis provided by Smit et al. (2000, pp 223–251). This anatomical analysis by Smit et al. (2000, pp 223–251) is used to deepen the discourse on farm-gate level autonomous adaptation actions. The analysis is adapted in this research to provide better clarification on the factors and conditions influencing farmers' autonomous climate decisions at farm-gate levels. It is also intended to understand how such conditions and livelihood circumstances shape reactionary coping strategies and adaptation behaviours. The inter-connectedness of impacts of small holder farmers' adaptation behaviours and the receiving environment is also provided. The anatomy of climate adaptation as adapted in this study recognizes smallholder farmers as the initiators of adaptation actions, farm-based livelihoods as the attribute system of value and small farm systems as the exposed units of adaptation. This theoretical framework however addresses in its limited scope, adaptation actions which takes place at farm-gate levels.

The susceptibility of farm-based livelihoods to climate risks are higher in poor rural settlements particularly in the tropical regions where shifts in the mean climatic conditions exerts significant impacts on climate-dependent livelihoods. The dependence of such rural livelihoods like small-scale farming to optimal climatic conditions as mentioned in Niang et al. (2014), describes the livelihood-climate-impact interactions. Following this interaction, smallholder farmers are compelled to adjust livelihood practices and means, to either cope temporarily or adapt to these impacts on a long term. Such coping or adaptation strategies usually involves the adjustment in behaviours of managers of production systems, changes in methods of production as well as the management of such systems. The vulnerability of farm-based livelihoods to climate risks and reactionary adaptation by smallholder farmers to these risks is representative of a system configuration. This system configuration can be described with these elements: the smallholder farmers whose socio-economic goal is impacted by climate risks (initiator of adaptation), cultivated farmlands (as the attribute system of value). Changes in climatic conditions whether as stand-alone factor or in combination with other non-climatic stressors constitutes the hazard or source of hazard.

The fourth element is the duration of exposure and impacts (temporal window). The consideration of these four elements lends credence to the anatomy of climate adaptation propounded by Smith et al. (2000, pp 223–251). This analytical element of Smith et al. (2000, pp 223–251) forms the basis of the study's theoretical framework. Smith et al. (2000, pp 223–251) espouses the process, the objective, the initiator of adaptation and the system attribute of value for which an adaptation action is sought. To provide better understanding of the anatomical analysis of Smith et al. (2000, pp 223–251) and its contextual application for this research, a brief exposition of the typologies and scope of climate adaptation is provided. The theoretical framework of this study is premised on the anatomy of adaptation by Smith et al. (2000, pp 223–251).

The anatomical analysis by Smith et al. (2000, pp 223–251) describes the elements of adaptation which includes, the process of adaptation (how climate adaptation is exercised), the facilitators of adaptation actions (actors) and the vulnerable system (exposed system unit of adaptation). System in the anatomical framework of climate adaptation as espoused by Smith et al. (2000, pp 223–251) is used to describe the characteristic of a system unit of adaptation. System analysis in adaptation according to Smith et al. (2000, pp 223–251), includes features such as scale (extent and scope of adaptation) by which the system unit of adaptation is operationalized. It also includes the type of adaptation process (ecological, economic, social or political). System unit of adaptation also includes the vulnerability and susceptibility characteristics of both the initiator of adaptation actions and the exposed system unit. To provide a discursive frame for the theoretical framework of the study, the three elements of Smith et al. (2000, pp 223–251) anatomical framework of climate adaptation are discussed in the order presented.

- Exposed system unit of adaptation, (Small Farm Holdings)
- Vulnerability of smallholder farmers (initiator(s) of adaptation actions)
- Vulnerability of small farm livelihoods (attribute system of value)

2.4.3.1 Small Farm Holdings (Exposed System Unit of Adaptation)

Rain-fed agricultural activities in rural communities comprising mainly of small farm holdings are according to Cooper et al. (2008, pp 24–35), the dominant sources of staple foods for the majority of the rural poor particularly in sub-Saharan Africa (SSA). In resource-poor communities, small farm holdings provide assets, food security and means of subsistence to a large percentage of rural and peri-urban population. This makes small farm holdings not only relevant in the realisation of household and subsistent needs but also to the improvement of rural economy as mentioned in Ali and Thorbecke (2000, pp 9–40), Hilson (2009, pp 1–5) and Rebelo et al. (2010, pp 557–572). Given the socio-political nature of land, land resources are thus crucial in the organization of small farm holdings and also in the way farmlands are managed under threats of social and environmental threats.

Due to its coupling and sensitivity to key climatic variables like rainfall, temperature and humidity; rain-fed agricultural systems are highly susceptible to climate risks. The impacts of such susceptibility on managed crop systems are of significance to the physical environment and to the livelihood base of small farm holders. In the context of the theoretical framework of this study, small farm holdings are the exposed system unit of adaptation. Small farm holdings, in addition to the initiators of the adaptation actions (smallholder farmers) and the attribute system of value (livelihoods obtained from small farms) constitute the anatomical framework of climate adaptation propounded by Smith et al. (2000, pp 223–251). The socio-economic relevance of cultivated farmlands makes it therefore the attribute system of value.

The socio-economic importance of small farmlands is enhanced with the optimal balances in the biophysical quantities of land surfaces and the photosynthetic performances of vegetation canopies. Imbalances or variations in land surface biophysical properties and impairment in photosynthetic potential of vegetation canopy has direct implications for land productivity and by extension for those livelihoods tied to land. In Friedl et al. (1995, pp 233–246), the inter-linkage between biophysical properties of land and its productivity has been demonstrated where impacts of variations in leaf area index (LAI) on the fraction of absorbed photosynthetically active radiation (FPAR), and the normalized difference vegetation index (NDVI) were investigated. The susceptibility of biophysical attributes of land under exposure to climate change supports the characterization of small farmland systems as the exposed system units within Smith et al. (2000, pp 223–251) conceptual framework. In predominant rural settlements where small-scale agricultural are major livelihood bases, optimal conditions of farmland surface conditions are important in the sustenance of farm-based livelihoods. However, farmlands and associated biophysical properties of land surfaces are potentially susceptible to both biotic and abiotic factors such as variability in the means of climatic conditions.

In resource poor communities and rural farm settlements, the susceptibility of land surface conditions as an issue of concern, is influenced by the extent to the biophysical variables of these farmland conditions are integral parts of the optimum condition necessary to support farmland-based livelihoods. This also shapes the behavioural management of land use and the utility pressure under which farmlands are subjected to. In predominant farming areas, the use of farmland are influenced by farmers' socio-economic considerations which determines the frequency, management and extent of use. Farmland use and management patterns are also in the institutional factors enabling or limiting the management of farmlands. Some of these institutional factors include land tenure rights. In rural communities of tropical and sub-tropical countries, the access to land right starts with the possession of a land right as mentioned in Sjaastad & Bromley (1997, pp 549–562). Sjaastad & Bromley (1997, pp 549–562) notes that tenure rights and the associated entitlements to it, determines not only access to arable land but also the duration, extent, size of economic activities permitted to be undertaken on such piece of land and its overall use.

Tenure rights also influences farmers' land use behaviours and practices with direct implications on land surface conditions. Tenure land rights also influences the frequency of crop cultivation and land fallow practice management. Under fluid tenure rights in local farming settlements, the intensification of farm land use has been identified in studies like in Sjöstedt (2011, pp 133–140). Where intensive demand for land resource in pursuit of the sustenance of on-farm livelihoods takes place under conditions of land insecurity; the potential of biophysical variables of land surfaces to be impaired are high. Potential impacts may involve the alteration of key biophysical and geophysical parameters (albedo) as well as processes (evapotranspiration) Coudert et al. (2008, pp 872–887); DeFries et al. (2002, pp 438–458) and Hall et al. (1988, pp 3–22). Intensification of farmland use in rural areas of resource-poor communities includes not only unsustainable cultivation practices but also the use of crude tools. Ellis & Ramankutty (2008, pp 439–447) corroborates this by identifying the use of crude tools and unsustainable local technologies as contributing to impacts on land surfaces. Land tenure rights also influences the way in which adaptation strategies are organized and the scope of such adaptation measures. Behavioural adaptation by small farm holders are frequently carried out under situations of limited farmland resource and fluidity of land tenure rights. Changes in cultivation practices and management decisions may also include shorter fallow periods and the non-receding (yearly mono & mixed cultivation) use of land for crop cultivation and livestock rearing.

Some studies have examined these types of practices by small scale farmers and their potential impacts on vegetation cover conditions and dynamics. For example, Stampfli et al. (2018, pp 2021–2034) noted the synergistic impact of land-use intensification and climate change on grassland vegetation composition and plant functional diversity. Similarly, Dietz (2002, pp 3–15) in a study to assess vegetation diversity within farmlands as well as determine the impact of land use type and distance of farmlands from border structures observed that land-use intensity influenced to a larger extent vegetation diversity within agro-ecosystems. Wessels et al. (2011, pp 19–29) also investigated the differences in woody vegetation structure across three land use types (communal rangelands, communal cultivated fields and public protected areas. The study found that tree canopy cover and heights differed across the three sites with more reduced total woody cover identified in areas under heavy communal usage. So did, Tesfaye et al. (2014), Ahmed et al. (2015, pp 26–37) and Landmann & Dubovyk (2014, pp 76–82) also found differences in the structural composition of woody vegetation across different ecological sites. So did Baessler & Klotz (2006, pp 43–50), Beurs & Henebry (2004, pp 497–509), Giannecchini et al. (2007, pp 26–42), Long et al. (2007, pp 141–153), Zechmeister et al. (2003, pp 165–177) and Dumanski & Pieri (2000, pp 93–102) all established an empirical relationship between land use intensity and vegetation structural and functional dynamics. These studies as well as Thackway & Lesslie (2008, pp 572–590) and Thackway & Specht (2015, pp 136–152) contribute to the strengthening of empirical knowledge of the effects of land-use management on land surface biophysical variables.

Evidence from some of the cited studies supports the argument about the susceptibility of intensely-cultivated farmlands to changes in land surface condition as well as shifts in vegetation photosynthetic states. This understanding regarding the dynamics of functional, structural and compositional states of land surfaces and the role of disturbances on land surfaces have been cited in Cowling et al. (2009, pp 287–299) and Garnier et al. (2007, pp 967–985). The process-quantities-function-composition balance of land surface properties that supports land productivity also includes the biotic abundance, its composition and species diversity. In McIntyre & Lavorel (2007, pp 11–21) and Rapport et al. (1985, pp 617–640), impacts of intensive land use by smallholder farmers on the land productivity conditions is also indirectly related to shifts in species diversity. Shifts in biotic abundance, composition and species diversity as mentioned in Hansen et al. (2001, pp 765–779) can potentially undermine and destabilize the productivity performances of land surface conditions.

Land surfaces and its biophysical properties undergo transition in states and various degrees of alteration under stress from landuse. Such stress as noted in Lesslie et al. (2010), Pickett et al. (2005, pp 172–198) and Beurs & Henebry (2004, pp 497–509); Sellers (1985, pp 1335–1372); Zhao et al. (2013, pp 2087–2095) also includes the non-receding and unregulated use of land by smallholder farmers or under large mechanized agricultural programmes. These land-related disturbances triggers variations in the process-quantities-function-composition balance of land surface were human, abiotic and environmental elements are major constituents. Thus, disturbed land surfaces under unsustainable farming practices is capable of triggering cascading changes from plant species, compositional structure and richness, biomass production rates and nutrient cycling. This is because equilibrium between biotic and abiotic components of the environment also have direct effects on land surface variables. Furthermore, the coupling of land surfaces to the climate through energy (nitrogen and carbon) and biogeochemical fluxes as mentioned in Bonan (1995, pp 57–73) and Schimel (1995, pp 77–91) also increases the susceptibility of land surfaces to shifts in biophysical states.

Thus, deficits in moisture or energy between land and climate under internal variability will potentially increase the sensitivity of land surface structural and functional shifts and in extreme cases as mentioned in Webb et al. (2017, pp 450–459), to land degradation For example, soil moisture deficit can interfere with the normal transpiration and physiological process of plants with reinforcing feedbacks on the land biophysical variables and productivity. This explains the potential vulnerability of land-based production systems (farmlands) under reinforcing effects of climate change and anthropogenic disturbances. This abiotic-biotic-stress-functional-land surface response forms the scientific basis for the attribution of unsustainable land management practices to the vulnerability of farmlands (as exposed system units of adaptation) under constrained climatic conditions.

2.4.3.2 Initiators of Adaptation Action (Smallholder Farmers)

The initiators of farm-gate level adaptation are generally small-scale holder farmers. They are farmers whose livelihoods and household subsistence depend on outputs of small-scale crop cultivation. In Morton (2007, pp 19680–19685), small farm holdings of subsistent farmers are described as complex, diverse and risk-prone systems due to their dependence on climatic factors such as rainfall. Non-climatic factors such as size of assets of small farm holders also characterizes small farm holdings and this has been observed in Cousins (2010, pp 102–127). The farm assets of small-scale farm holders are further characterized by the purpose of farming, investment size, availability of farm labour and accruable net farm incomes. Due to the limited investment capabilities of small-scale farmers in expanding the scope and size of their agricultural enterprises, small farm holdings are integrated investments serving many social and economic objectives of the poor rural dwellers managing them.

In terms of the role and impact of environmental factors on small-scale farm systems, crop productivity and performance are highly sensitive to shifts in rainfall and temperature. Thus, in scenarios of variations in key climatic variables, cultivated crops are exposed to threats from imbalances in environmental conditions. Also, due to the geographical location, smallholder farmers in developing countries are worst hit by climate impacts as reported in Morton (2007, pp 19680–19685). Apart from affecting crop productivity negatively in terms of shifts in mean climate balances, optimal environmental and climate conditions support crop growth and by implication, the livelihoods procured from such rainfall-dependent production systems.

The exposure of subsistent-oriented farm systems to impacts of climate variability reinforces the biophysical vulnerability of rainfall-dependent systems. Biophysical vulnerability is an element of the composite vulnerability of small-scale holder farmers. Biophysical vulnerability according to Brooks (2003, pp 1–16) reinforces the social vulnerability of small farm holders. Further deepening the climate vulnerability of small holder farmers in sub-tropical regions are poor conditions of soil and land degradation as mentioned in Bojö (1996, pp 161–173). This view is corroborated in Deressa et al. (2009, pp 248–255) although the study views shifts in the variance in mean of the climate system as a more significant factor that shapes small farmers' vulnerability. The impact significance and index of climate change is due to the character of climatic change which is particularly about decadal timescales changes. This timescale of change, Vincent (2004) notes is incremental.

The constituting element of small-scale holder farmers is socio-economic vulnerability. Social vulnerability of subsistent farmers is connected with poor conditions of livelihoods, lack of or limited access to resources and capital, and all conditions which exacerbates their levels of social inequality and poverty. The interactions of these conditions determines as noted in Busby et al. (2014, pp 51–67) and Thornton et al. (2006), influence the extent to which small-scale farmers and farm-based livelihood systems are affected. Much of the vulnerability of farm-based subsistent livelihoods are due to poor household conditions of small-scale farmers as well as their limited access to institutional incentives. This understanding has been elaborated in studies such as (Harvey, et al. 2014), where it has been noted that livelihood conditions and high levels of poverty in Madagascar contributes more in deepening the vulnerability of small farm holdings to climate change risks. Niang et al. (2014), therefore highlights that these social and institutional factors that constitutes social vulnerability of small farm livelihoods under constrained climates.

Socially-imposed limitations such as extreme deprivations and the transition between levels of poverty, do not only impacts the performance of crop production systems of small scale farmers, it affects the management of these systems and according to Olsson et al. (2014) also strips farmers of their capabilities at safeguarding farm-based livelihoods under new climate risks In (Tschakert 2007), other factors like rural unemployment and inadequate infrastructure have been identified as undermining the adaptive capacities of farmers. These scenarios are similar to the lived experiences in Keffi where social deprivation and other forms of social inequalities predispose farmers to biophysical vulnerability arising from changes in the climate. In Luka and Yahaya (2012a, pp 1520–5509), farmers' proclivity towards indigenous soil management practices in connection with climate impacts on food production systems were due to socially and economically-induced constraints. Other relevant studies such as Umaru & Tende (2013, p 1583), Otuka (2011); Salau et al. (2012, pp 199–211), also identified the role of poverty in weakening small holder farmers' capacities in the effective management of rain-fed farming systems as well as in sustainable adaptation practices.

Under these circumstances, smallholder farmers are compelled towards adjusting cultivation practices and management decisions in order to adapt to climate impacts or take advantage of the associated opportunities. Small holder farmers thus initiate different patterns of preferred coping and adaptation strategies within the remit of their capabilities and the potential efficacy of selected actions. At farm-gate levels, under socio-economic constraints and limited capacities, adaptation strategies are autonomous, based on individual decisions and reactionary than proactive in nature.

2.4.3.3 Attribute System of Value (Farm-based Livelihoods)

The attribute system of value of a natural or socio-economic system and its significance as espoused in Smith et al. (2000, pp 223–251) constitutes a major part of the consideration that incentivizes individuals to undertake adaptation actions. The value or composite values (social, economic, cultural, knowledge) derived from a socio-economic or natural system influences the decision to act to safeguard such systems from impacts of climate adaptation. The attribute system of value of a "system" is the totality of the inherent features of a system with their characteristic physical, chemical, biological elements which contributes to the socio-economic and cultural value of the system. Livelihoods derived from small scale farming is the attribute system of value in this context. The attribute system of value of farm-based livelihoods and other rural livelihood means therefore play central roles in the sustenance of household needs. This is of great importance to managers of these livelihoods as well as of those who depend on them for survival. This attribute system of value has been acknowledged in Füssel (2007, pp 155–167), as one of the four key characteristics that succinctly describes the vulnerability of system under the adaptation conceptual framework. The other key characteristics includes system of analysis, hazard, and temporal reference.

Livelihoods and the means thereof play a critical role in the lives of individuals and communities particularly in resource-poor communities. Defined in Chambers & Conway (1992) as comprising the capabilities, assets (including both materials and social resources) and activities for a means of living; livelihoods are central to the daily management of household needs. In rural areas, livelihoods are largely natural resource-based and depend on optimal environmental conditions to function. That means that natural resource -based livelihoods interact with environmental variables. The role of livelihoods in the socio-economic development of rural and peri-urban dwellers is not only important for subsistence support but the sustainable management of these natural based livelihood sources are critical for household economic decisions. Thus, small farming-oriented livelihoods are of greater socio-economic importance to poor households as they are organized and shaped within extents of natural resource endowments and family circumstances as mentioned in Dixon et al. (2001).

In Dixon et al. (2001), it is reported that livelihoods in rural areas are largely linked to small scale farming and livestock management and this corroborates with the ideas in Chambers & Conway (1992), which observed that livelihoods takes a more subsistence nuance in rural settings than it does in urban settings. Small scale farming and livestock rearing are preferred livelihood practices in rural settings because of the unregulated access to natural resources and ease to procuring unpaid labour mainly from family members. However, these rural farm-based livelihoods are farming size, restricted scope mainly due to the lack of capital assets and capabilities for organizing mechanized agricultural systems and off-farm livelihoods. Small-scale rural livelihoods are therefore critical to the management of hunger and the upkeep of household subsistence. This has been corroborated in Tschirley & Benfica (2001, pp 333–358), where natural-based livelihoods are primarily aimed at overcoming household poverty and supporting immediate socio-economic needs. The convenience and self-efficacy associated with the organization of small-scale farming following the availability of land, family labour and indigenous knowledge makes small-scale farming widely practiced. The lack of institutional-related issues including lack of technological and incentives to promote other off-farm activities, further strengthens the livelihood value of small farm-based livelihoods according to Scoones & Wolmer (2003, pp 1–14).

Given that rural small farm livelihoods are natural resource-based and their functionality depending on optimal environmental conditions, they are sensitive to minor and major shifts in environmental conditions. Rigg (2006, pp 180–202) reported that given the tight coupling of small-scale farming with the key climatic variables like rainfall, temperature and humidity; rural farming are highly susceptible to impacts. Barros et al. (2014) also mentions that the quantitative and qualitative features of rural agriculture are potentially impacted in scenarios of extreme changes in climatic conditions. The livelihood-climate risk linkage has also been documented in Niang et al. (2014, pp 1–51) where crop performances were shown to depend weather and climatic conditions. Under conditions of climatic change, attribute system of values inherent in small farm agricultural systems are exposed as mentioned in Ouyang et al. (2017, pp 156–167). Studies assessing impacts of climate change to small-scale farming systems in sub-Saharan Africa like Blignaut et al. (2009, pp 61–68); Reid et al. (2007, pp 609–637); Zinyengere et al. (2014, pp 1–10) have also corroborated this understanding. The risks of environmental conditions on small farm systems are not limited to direct changes in key environmental variables, they are also indirectly connected; according to understanding from the studies; Easterling et al. (2000, pp 2068–2074); Feddema (1998), Fowler et al. (2007), Kandlikar & Risbey (2000, pp 529–539) and Kangalawe et al. (2017, pp 202–216) to environmental damages on physical infrastructure such as roads and irrigation facilities that supports agricultural-based livelihoods.

This understanding supports the discourse of rural livelihood within the context of vulnerability. It also raises the importance of the susceptibility of the attribute system of value of such livelihoods to climatic shifts. It brings to the fore the predisposing conditions under which an attribute system of value of a livelihood system can be endangered which is not limited only to the vulnerability of such livelihoods but also related the capacity of managers of such natural-based systems. The weak social and financial capital as well as the individual capacity of small-scale farmers is a critical determining factor which raises the susceptibility index of attribute systems of value of farm livelihoods. Similar views have been expressed in Adger (2006, pp 268–281), Schroth et al. (2016, pp 231–241); Thornton et al. (2014, pp 3313–3328) where it has been mentioned that farm-based rural livelihoods are more susceptible to climate change impacts where there are weak capacities of subsistent farmers in organizing cost-intensive and long term climate-proof strategies. This explains why the resilience of these systems is of importance to small scale farmers and livestock managers. The degree of to which small farm-based livelihoods can recover and sustain its productivity value after exposure to climate risks and other environmental impacts is critical. In Chambers & Conway (1992), this is further elaborated to include its potential in maintaining its production capability after exposure without undermining the natural resource base from which it is derived.

2.5 Integrated Conceptual Framework

The conceptual framework for this study is an adapted framework premised on the driver-pressure-states-impacts-responses framework (hereafter the DPSIR). The DPSIR framework developed by the organisation for economic co-operation and development (OECD) towards supporting the analysis of pressure-state-response of affected systems has been modified by the European Environmental Agency. This modification as elaborated by Niemeijer & de Groot (2008, pp 14–25) has resulted in a new driving forces-pressures-states-impacts-response framework. In this study, he DPSIR framework is the over-arching framework upon which other conceptual frames in this study are embedded. The DPSIR is a conceptual framework for studying casual factors, their interactions, impacts on system states as well as the responses. While it has more policy relevance, its conceptual value in supporting change detection objective within an anatomical framework of climate adaptation is of research significance.

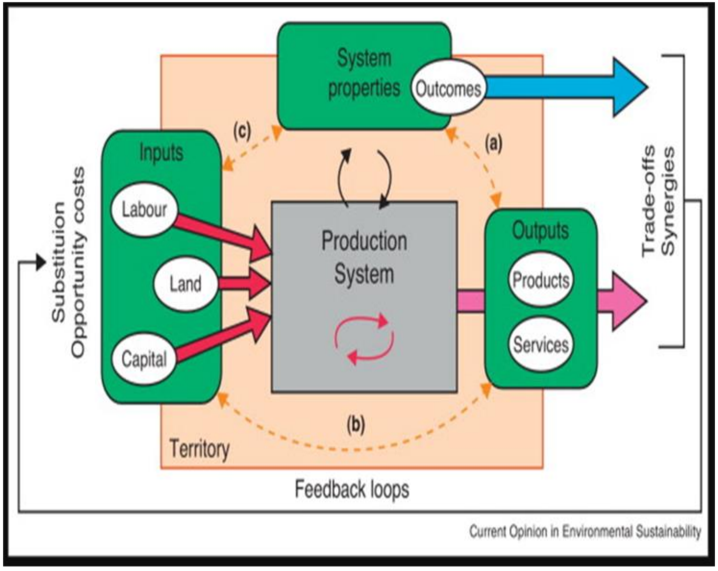
Other conceptual frames which supports the DPSIR framework includes the landuse intensity (LUI) by Boserup (1965) and Kerr & Cihlar (2003, pp 161–172). Land use intensity is applied in this study to describe the trampling effect of non-receding use of land by smallholder farmers under reactionary climate adaptation. Landuse intensity is used in characterizing farmers' land use practices as a disturbance regime with the potential of exerting stress on plants cover structural organs. The canopy-structural-functional linkage of vegetation cover dynamics by Migliavacca et al. (2017, pp 1078–1091) and Gamon et al. (1995, pp 28–41) from which the research hypothesis is derived is also applied. This canopy-structural-functional linkage is meant to elucidate functional and physiological response of vegetation cover to stress and trampling regimes.

The protection motivation model by Prentice-Dunn & Rogers (1986, pp 153–161) and Grothmann & Patt (2005, pp 199–213) are applied as a conceptual frame in understanding the cognitive processes that underpins farmers' adaptation decisions and the underlying drivers that shapes farm management practices. A modified climate adaptation by Smith et al. (2000, pp 223–251) provides clarity on the interaction between initiators of adaptation actions, the exposed system unit (managed farmlands) and the attribute of concerns (crop yields). Deepening the argument, is the concept of scale by Brenner (2004, pp 447–488) which describes the vertical differentiation of social classes based on resource availabilities and capabilities in organizing sustainable adaptation measures. The concept of scale by Brenner (2004, pp 447–488) is reinforced with Wilson & Wilson (1945) idea of scale as a limit of and to social organization.

Reactionary Adaptation by Farmers

(Land Use Intensification) (Erb, Haberl et al. 2013)

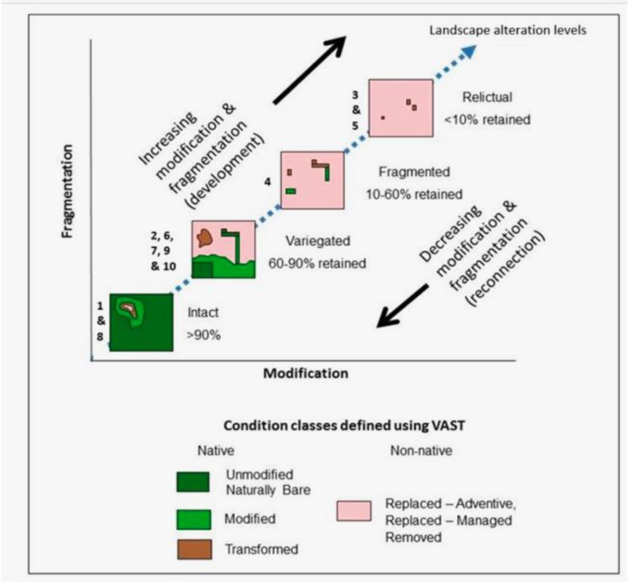
- Land Use and Cropping Intensity
- Changes in land Management Practices
- Changes in Crop varieties
- Changes in Cultivation Decisions



Stress and Feedback on Vegetation

(Thackway & Freudenberger 2016)

- Changes in vegetation aereal cover and Dynamics
- Shifts in Structural & Functional Traits



Protective Motivation Theory

(Rogers 1975), (Grothmann and Patt 2005)

Impacts on Livelihoods

Decline in Crop Yields
Modification of structural and Functional states of Land-based Production systems

Variable of Interest / System of Adaptation
(Smith, Burton et al. 2000)

•Agricultural Asset/ Land-based Rural livelihoods (Farmlands)

Predisposing Vulnerability Conditions (Non-Climatic Stressor)

(Chambers and Conway 1992), (Scoones 2009)

- Social Marginalization and Household Poverty
- Land Scarcity and tenure Rights insecurity
- Limited social and financial assets
- Weak and Near Absence of Institutional Support
- Household Characteristics

Major Stressor

- Climate Change
- Climate Stimuli

Figure 10: Integrated conceptual framework of the study

3 Research Methodology

3.1 Detecting Vegetation Cover Dynamics Using Vegetation Spectral Indices (VSIs)

Vegetation cover dynamics as mentioned in Kolasa & Pickett (1989, pp 8837–8841) are influenced by factors including biotic, abiotic and environmental factors. In part, are vegetation exposed to the interacting influences of both human disturbances and changes in climatic conditions. Under disturbances from anthropogenic activities and impacts of other abiotic events, vegetation dynamics undergoes variation in structural architecture, functional processes, rates and quantitative balances. These variations as symptomic signals are detectable with vegetation spectral indices derived from remotely sensed data. This symptomic approach therefore supports the detection of shifts in vegetation functional and structural conditions.

The plausibility of evidence associated with vegetation spectral index-based change detection studies like normalized difference vegetation index (hereafter NDVI) is based on the capability of NDVI differencing as a method to indicate plant condition states. Through assigning boundary values to different states of vegetative conditions, with zero (0) indicating bare land surfaces and +1 (forest covers); computed NDVI values have been used in detecting structural and functional (physiological) changes in vegetation states. The application of NDVI or other vegetation spectral indices is based on the scientific understanding that low NDVI signifies impaired plant physiology or weakened photosynthetic capacities.

3.1.1 The Underlying Science of Change Detection Capability of NDVI

The scientific mechanism which supports the use of NDVI in change detection studies as explained in these studies, Gates et al. (1965, pp 11–20), Nikolov et al. (1995, pp 205–235), Tucker et al. (1985, pp 233–249) Lakkaraju et al. (2010, pp 379–389) are based on the science of the spectral behaviours of plants. First propounded by Rouse Jr et al. (1973), mentioned in Tucker (1979, pp 127–150) and expatiated in Vina et al. (2004, pp 1139–1147), NDVI contains a measure of the amount of plants growing conditions. Expressed with the expression; NDVI indicates plant physiological states whether in the improved or declining conditions.

$$NDVI = (NIR - Red) / (NIR + Red)$$

The spectral behaviours of plants are principally related to the interaction between the chlorophyll content of plants and radiant energy from the sun. Gates et al. (1965, pp 11–20) notes that mature plants with maximum value of chlorophyll contents absorb light at the blue and red portions of the electromagnetic spectrum with a concomitant reduction in reflectance absorption in the infra-red region. Thus, deficiency in green pigmentations chlorophyll in plants can undermine solar radiation and affect known patterns of spectral responses in plants as mentioned in Gates et al. (1965, pp 11–20). Solar energy in the visible red spectral zone (400-700nm) have deeper penetrations than in the blue wavelength whereas chlorophyll show greater absorption in the red region of the electromagnetic spectrum. This explains the low reflectance of solar energy in the red wavelength.

Beyond its function in influencing spectral behaviour of plants, plants chlorophyll content also plays key role in the process of photosynthesis. Corroborating Gates et al. (1965, pp 11–20), Tanaka & Makino (2009, pp 681–683) reported the nexus between chlorophyll in plant photosynthesis as well as its role in the regulation of the cellular and enzymic activities of plants through the control of the redox state of plant cells. The production rates of above-ground biomass as noted in (Tanaka & Makino 2009) also correlate with photosynthetic rates. To a larger extent therefore, plants spectral behaviour is indicative of the overall conditions of plants.

In strengthening knowledge of the mechanistic evidence of chlorophyll in plant physiology, Gates et al. (1965, pp 11–20) compared the reflectance and transmittance of spectral properties of plants with different pigmentation. A red rose with high levels of carotene showing marked absorption in the green part of the visible spectrum whereas the magnolia blossom plant having little or no pigmentation showed absorption at the blue portion of the visible region of the electromagnetic spectrum. Darker coloured green leaves from matured plants showed stronger absorption in the visible region of the electromagnetic spectrum. This mechanistic process has provided the basis for linearly correlating canopy structural states with net primary production (NPP) and NDVI, thus demonstrating the significant linear relationship between NDVI and healthy plants. Plants characteristics such as morphology, taxonomic composition and functions also linearly interacts with plants physiological processes Mohanta et al. (2017, pp 58–73). Healthy vegetation or plants is represented by the intensity of greenness of plant leaves which is a direct indication of optimal photosynthetic processes. Thus, NDVI signals are sensitive to the presence, density and conditions of vegetation and thus correlates with Net Primary Production Herrmann et al. (2005, pp 394–404).

Photosynthesis in plants according to Gates et al. (1965, pp 11–20) occurs under conditions of sunlight and its derivative radiant energy which must be absorbed, transfer and transmitted. The important plant organ required in facilitating the transfer of radiant energy is plant leaf and its significance is associated with its morphological anatomy and chlorophyll-containing chloroplast organs. In the presence of water, carbon dioxide, mineral salts and other inorganic compounds, plants are able to sustain optimal physiological states and metabolize organic compounds through photosynthesis. Thus, healthy vegetation indicated by the darker green appearance of upper plant leaf surfaces is a robust parameter in detecting shifts in plants morphological and structural configuration. According to Tehrany et al. (2017, pp 12–23), NDVI is associated with components of vegetation conditions thus offering an empirical measure of past and current conditions of vegetation. It is within this framework that NDVI can be used in change detection studies. This scientific understanding supports the knowledge of the role of healthy leaf morphology in solar energy absorption and ultimately, plants physiological functioning.

Plants leaves also acts as an interface between the biosphere and the atmosphere. In the study by (Charney 1975), the direct relationship between vegetation and climate was observed through biophysical feedbacks of water and carbon fluxes between vegetation and the atmosphere. Given the coupling between healthy vegetation and climate processes, via evapotranspiration and exchanges of energy; the detection of variation in vegetation states was possible. This study raised interests in the application of NDVI differencing in the detection of dynamic states of vegetation. Charney (1975, pp 193–202) reported that variation in vegetation condition states were detected due to the influence of healthy vegetation (through shifts in surface albedo and radiative fluxes) on local climate conditions. This biogeochemical link between vegetation cover dynamics, surface albedo and climatic variables has also been corroborated by Hall et al. (1988, pp 3–22).

For example, Justice et al. (1985, pp 1271–1318) showed a close correlation between the phenologies of different vegetation cover types in tropical ecosystems and inter-annual variability of rainfall. Anyamba & Tucker (2005, pp 596–614) equally observed that below average NDVI values in the Sahelian vegetation corridor corresponded to the drought periods between 1982-1983 while above normal NDVI averages under wetter periods corresponding to 1994 -2003. Similar observations were reported in Goward & Prince (1995, pp 549–564). Camberlin et al (2007) in a study aimed at investigating the principal determinants of the relationship between NDVI and rainfall in tropical Africa showed that the largest correlation between NDVI and inter-annual rainfall (>0.60) were in open grass ecosystems, crop areas as well as water-limiting regions of the Sahel. Other studies include Ahmedou et al. (2008, pp 75–81), Hermance et al. (2016, pp 3293–3321), Georganos et al. (2017), Dardel et. al (2014, pp 350–364), Eklundh & Olsson (2003) and Brandt et al. (2014, pp 52–63) who all demonstrated the relationship between healthy vegetation and rainfall. Davenport & Nicholson (1993, pp 2369–2389) also reported a similar observation on environmental effect on vegetation growth. Studies by Malo and Nicholson (1990, pp 1–24) and Nicholson et al. (1990, pp 209–241) also explains the reinforcing influence of vegetation on climate and vice versa on vegetation dynamics. Studies like Davis et al. (2017, pp 76–85); Hermance et al. (2016, pp 3293–3321), Soudani et al. (2012, pp 234–245), Tian et al. (2016, pp 265–276); Tsai and Yang (2016, pp 1624–1639) Zewdie et al. (2017, pp 167–178) and Gandhi et al.

(2015, pp 1199–1210) have all provided empirical insights into the functionality of NDVI in monitoring vegetation dynamic states.

NDVI has also been applied in change detection, earth mapping and vegetation dynamic monitoring studies. This scientific application is justified by the potential of the range of NDVI values in supporting the monitoring of impacts of anthropogenic stress events and abiotic factors on native vegetation. Following this understanding, Lichtenthaler (1996, pp 4–14) assessed the impacts of environmental and human stress on the structural, compositional and spatial distribution of vegetation. In White (1979, pp 229–299) and Pickett et al. (2005, pp 172–198), shifts in species composition can also impact leaf-radiant energy-photosynthesis equilibrium with overall impact on plant health. Studies like Beuel et al. (2016, pp 684–692) and Albuquerque et al. (2017b) have all corroborated the anthropogenic impact of human activities in destabilizing plants structural-functional balance. For example, Dardel et. al (2014, pp 350–364), reported effects of human activities (pastoral management and farming) on vegetation cover through the application of NDVI and field observations. O'Connor & Roux (1995, pp 612–626) studied the differential impacts of sheep grazing and climate on vegetation in African Savanna. Bond et al. (2003, pp 79–91), Berglund (2003, pp 7–12), Josefsson et al. (2009, pp 1017–1036) and Zhang et al. (2001, pp 701–708) used NDVI in disentangling synergistic impacts of human activities and climate on vegetation dynamics. In Thackway & Specht (2015, pp 136–152) as well as in Kolasa & Pickett (1989, pp 8837–8841), intensive agricultural land use and extensive human domination of native vegetation landscapes were responsible for marked changes in the structural and composition of vegetation cover. Alves et al. (2015, p 329), Lenney et al. (1996, pp 8–20) and Yengoh et al. (2015) also used NDVI in detecting changes in land use.

In other studies, time series NDVI datasets were used in disentangling rainfall signals from anthropogenic impacts on vegetation covers. For example, Tian et al. (2015, pp 276–289) assessed the influence of both climate change and ecological restoration programs on spatio-temporal changes in vegetation cover in Mongolia. Similarly, O'Connor & Roux (1995, pp 612–626) observed that inter-annual rainfall drove changes in species composition and vegetation covers of perennial grass and shrubs at a shorter timescale in comparison to sheep grazing which impacted plants specie composition at longer terms. In Landmann & Dubovyk (2014, pp 76–82), apart from climate variation, unsustainable land use were also identified as major drivers of declining vegetation productivity and land degradation in East Africa. Evans & Geerken (2004, pp 535–554) and Wessels et al. (2004, pp 47–67) also detected and disentangled human-induced changes in vegetation dynamics using time series NDVI. These studies have strengthened the science of detection and attribution through the application of vegetation spectral indices in monitoring synergistic or stand-alone effects of climate, human and abiotic signals on vegetation dynamics.

3.1.2 A Review of Change Detection Approaches

Success in the application of NDVI (or other VSIs) in land surface condition monitoring and mapping of vegetation dynamics has been supported not only with remotely-sensed spatial datasets but also with appropriate methodological framework. Depending on the objective of the study, change detection methods such as bi-temporal Coppin et al. (2004, pp 1565–1596), temporal trajectory method as mentioned in Jianya et al. (2008, pp 757–762) have been used. However, some of these change detection methods have been associated with limitations and drawbacks. One of such drawback Lu et al. (2004, pp 2365–2401) notes is the inability of some change detection methods in showing the direction and magnitude of structural change. Other drawback mentioned is the use of thresholds in defining reference states which Lu et al. (2004, pp 2365–2401), notes are open to subjectivity and ambiguity. This view is also supported by Thackway & Lesslie (2008, pp 572–590) who argues that change detection in vegetation as a complex system with different transitional states, is characterized by dynamism and variability which can be triggered by different forms of disturbance regimes. Thus, transitional states of vegetation impacted by noise from other factors cannot be monitored objectively with two date classification method. This is due to the inability of a two-date classification system in providing a within-class change detection. Its limitation is also associated with its inability in linking as reported in Waylen et al. (2014, pp 4473–4497), emitted and reflected spectral values to biophysical processes. Temporal trajectory method, as mentioned in Coppin et al. (2004, pp 1565–1596) supports the detection of changes in objects of interests over an extended time. Coppin et al. (2004, pp 1565–1596) also notes that temporal trajectory allows for the detection of change through the identification of a departure of trend curve from the mean condition value regardless of the time scales.

Supporting the application of various change detection approach are remotely-sensed time series datasets. Differing in spatial and radiometric resolution, these datasets have been used in earth monitoring studies at different spatial scales. However, despite the coarse spatial detail of time series NDVI datasets from Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very-High-Resolution Radiometer (AVHRR); time series datasets have been utilized in change detection studies. With interest in overcoming limitations associated with bi-temporary and temporal trajectory approaches, other approach such as time-series trend analysis has been considered. The time series-based trend analysis has proven useful in the tracking of vegetation responses to both abiotic and anthropogenic perturbations. The use of time series datasets has not only supported trend analysis of vegetation index of interest, it has made the detection of directional change much easier and with less ambiguity. The change detection functionality of time series-based detection method has been proven in ecoregions of marked rainfall variability and reduction. The underlying knowledge of time series trend-based detection approach is that the departure from mean trend profile curve signals the varying condition states of vegetation or objects under investigation. Time series-based studies have also proven suitable for the detection of abrupt or trend shifts in vegetation functional states particularly in cultural landscapes where anthropogenic pressure is predominant and capable of affecting the process-functional states or structural-compositional states of vegetation.

With the increasing human influence on the ecosystem and growing interest in global change studies, advances and interests in the application of time series trend-based change detection approach has widened Gillanders et al. (2008, pp 503–528), Waylen et al. (2014, pp 4473–4497). Time series supported trend-based analysis have been used successfully in monitoring and in characterizing temporal changes on land surfaces. The following studies, Yang and Lo (2002, pp 1775–1798), Wessels et al. (2004, pp 47–67), Röder et al. (2008b, pp 2863–2875), del Barrio et al. (2010, pp 1817–1832), Jacquin et al. (2010, S3-S10), Verbesselt et al. (2010, pp 106–115), Guyon et al. (2011, pp 615–627), Pflugmacher et al. (2012, pp 146–165), have demonstrated the robust functionality of time-series trend-based detection method in characterizing changes in vegetation dynamics.

In the Sahel where annual rainfall amount is less than 1000mm/year, impact of the increasing the dominance of inter-annual rainfall variability as a major climatic characteristic of the ecoregion as noted in Dardel et. al (2014, pp 350–364) on vegetation cover has been detected with time-series based trend analysis. In Herrmann et al. (2005, pp 394–404), Prince et al. (1998, pp 359–374), Heumann et al. (2007, pp 385–392), Fensholt et al. (2013), Eklundh & Olsson (2003), time-series based trend analysis have also been successfully applied. Another strength derived from trend-based change detection approach is the possibility to decouple dual effects; example inter-annual rainfall variability from humans on NDVI values with further plausible attribution of observed change based on the character of trend slope(s) to certain factors.

3.1.3 Time Series-Based Trend Detection Method

Time series-based trend studies, particularly in rainfall-limiting regions like the Sahel often adopts ratio-based approach like the rain-use efficiency (hereafter RUE) methods in detecting impacts of inter-annual rainfall or other cultural perturbations on vegetation cover dynamics. RUE, a ratio of net primary production to rainfall (NPP/Inter-annual Rainfall) is used in characterising vegetation response to rainfall variability. Thus, RUE supports the use of linear regression models in detecting temporal shifts in rainfall and also in characterizing impacts on vegetation covers. RUE works on the assumption that a reduction in an estimated yearly biomass in drylands (4kg-dry matter/ha/year/mm rainfall) according to Higginbottom & Symeonakis (2014, pp 9552–

9575), signifies disruption of physiological states of plants influenced mainly through climate variability and anthropogenic perturbations. This implies that drylands incapable of producing about 4kg-dry matter/ha/year/mm rainfall had impaired physiological performances under the assumptions that environmental factors are held constant Fensholt & Rasmussen (2011, pp 438–451). Thus, studies aimed at investigating land degradation caused by other factors other than inter-annual rainfall variability utilize RUE due to its statistical relationship with rainfall variability. For example, Fensholt et al. (2013) showed the relationship between primary production and rainfall in the African Sahel using RUE.

While the application of RUE has been well adapted to vegetation monitoring in the Sahelian areas of Africa, the method has been fraught with data, ecological interpretation and methodological issues as mentioned in Prince et al. (1998, pp 359–374), Herrmann et al. (2005, pp 394–404) and Dardel et al. (2014, pp 3446–3474). One of the drawbacks of RUE in hypothesizing the linear relationship between Rainfall and NDVI is the dependence of its performance on a certain threshold of rainfall for greening to occur. For example, Herrmann et al. (2005, pp 394–404) noted that a linear relationship between rainfall and NDVI could only be obtained in areas where the annual rainfall average was below 1000mm/year (<1000mm/yr). Another theoretical issue with RUE is that scientific knowledge suggest that vegetation productivity does not only depend on rainfall as a growth factor but also on plant nutrients and soil conditions. In this regard, Dardel et. al (2014, pp 350–364) argues that there could be other sources of greening like nutrient availability, and improved land management practices that could impact vegetation physiology.

In ecological mapping and detection studies, RUE is applied on the assumption that there exists a proportionality between rainfall and net primary production. Within this context, it is assumed that the measure of NDVI must be proportional to the amount of rainfall within the growing season under consideration. However, some studies have argued that NDVI-Rainfall proportionality is only evident at the zero intercept on the regression line but Yengoh et al. (2015) argues that it is statistically unrealistic for NDVI to be at a zero intercept since NDVI values, even in bare soils cannot be zero. In situations, where conditions of proportionality (example in marked inter-annual variability) are not met, RUE becomes unsuitable for trend analysis outside rainfall-limited areas as reported in Dardel et al. (2014, pp 3446–3474). Secondly, the assumption of proportionality is most pronounced in semi-arid and arid regions and not in tropical Savanna where according to Dardel et al. (2014, pp 3446–3474) and re-emphasized in Yengoh et al. (2015) are defined by distinct rainy and dry seasons. In addition, the use of RUE outside the Sahel and semi-arid regions could potentially lead to ambiguous interpretation of the causes of greening or browning as mentioned in Olsson et al. (2005, pp 556–566) and Yengoh et al. (2015). In Fensholt et al. (2013, pp 664–686), the use of RUE has been advised with caution.

3.1.4 Residual Trend Analysis (RESTREND)

Following the limitations associated with RUE, time series-based trend methods with capability for characterizing trend slopes have been found useful in decoupling non-rainfall signals from impacts of rainfall variability on vegetation conditions (NDVI). In this study, residual trend analysis (RESTREND) method is used in investigating impacts of reactionary adaptation actions by farmers in Keffi on vegetation cover dynamics. Residuals are considered statistical deviations from the any normal linear regression model, hence its adaptability in NDVI-Rainfall linear model. As a parametric analytical method, the significance of the Pearson correlation value (p-value) as well as the character of the trend slope forms an important part of the interpretation of trend-based approach in decoupling human impacts on vegetation cover dynamics from rainfall variability.

RESTREND in change detection studies is concerned with analysis of standardized residuals from NDVI-rainfall linear regression. This is because residuals offers indication on the underlying abnormalities between the relationship between the independent (rainfall) and dependent variables (NDVI) as noted in Belloto & Sokolovski (1985, pp 295–303). Higginbottom & Symeonakis (2014, pp 9552–9575) documented the effectiveness of RESTREND in supporting the disentangling of impacts associated with rainfall variability on vegetation physiological performances from other underlying signals. This is because of its functionality in providing additional useful information on the timing of breakdown between NDVI-rainfall correlation beyond diagnostics functions. When the NDVI-Rainfall residuals (dependent variable) are regressed against time (year), the resulting trend slope allows for the detection and characterization of non-rainfall causes. The p-value as well as the character of the trend slope forms an important part of the interpretation RESTREND plots. RESTREND is used on the assumption that there is a linear relationship between inter-annual rainfall variability and NDVI. Residuals from NDVI-Rainfall linear model are likely to contain information which are not explained by rainfall as an independent factor thus providing a clue on the presence of non-rainfall factors. This underscores the application of residuals in vegetation and land surface monitoring studies in revealing the unexplained occurrences that might interfere with the linear relationship between rainfall and NDVI.

For example, Evans & Geerken (2004, pp 535–554) was able to identify degraded areas in dry-lands attributed to human-induced process by removing the influence of inter-annual rainfall variability. In detangling the impact of rainfall variability from the NDVI trend, the intercept NDVI values (that is the linearly regressed normalized NDVI) of each image pixel were subtracted from the observed NDVI value of the same pixel. The NDVI-rainfall residuals, *r* – time*, t plot* as mentioned in Evans & Geerken (2004, pp 535–554) resulted in trend slope whose character was indicative of poor vegetation cover health unassociated with rainfall but plausibly due to other external disturbances. Wessels et al. (2007, pp 271–297) combined the rain use efficiency (RUE) and RESTREND methods in decoupling human interferences from climate variability on land degradation in South Africa and found that the RESTREND method performed better. Eckert et al. (2015, pp 16–28) also detected anthropogenic influences on the spatial variation of vegetation productivity in Mongolia. The result of the time series regression analysis in Eckert et al. (2015, pp 16–28), indicated a correlation between negative trend slopes and areas under mining, urban expansion, deforestation and forest fires. Li et al. (2012, pp 969–982) also applied the RESTREND method in detecting human-induced vegetation changes of Xilingol grassland in Mongolia. The study observed negative trends between 1981-2006 within the study area which corresponded to the period of the active implementation of the Land Use Policy on household production responsibility systems in Mongolia. In Li et al. (2012, pp 969–982), livestock grazing was identified as a major driver of changes in vegetation cover dynamics between 1981-2006. Similarly, Burrell et al. (2017, pp 43–57) also used RESTREND in separating impacts of inter-annual rainfall variations from anthropogenic impacts on NDVI measurements.

3.2 Research Methodological Framework

In this study, a mixed research method is used following ques from relevant studies. In addition to ground truthing and statistical regression of remote-sensed and rainfall datasets, multinomial logistic model, MNL (a choice determinant model) was also incorporated in the methodological framework of this study. Studies like Brandt et al. (2014, pp 52–63) applied integrated research method in studying the spatio-temporal variation in vegetation cover in two Sahelian settlements. In Herrmann et al. (2014) also, field photography, local perceptions and botanical inventories were used in combination in assessing changes in the composition and abundance of woody vegetation in Central Senegal. Dimobe et al. (2015, pp 559–571) and Nicholson et al. (1998, pp 815–830) combined remote sensing and household datasets in analysing the impacts of climate and human pressure on vegetation cover. The research flowchart is given in figure 11.

Flowchart of Research Methodological Framework

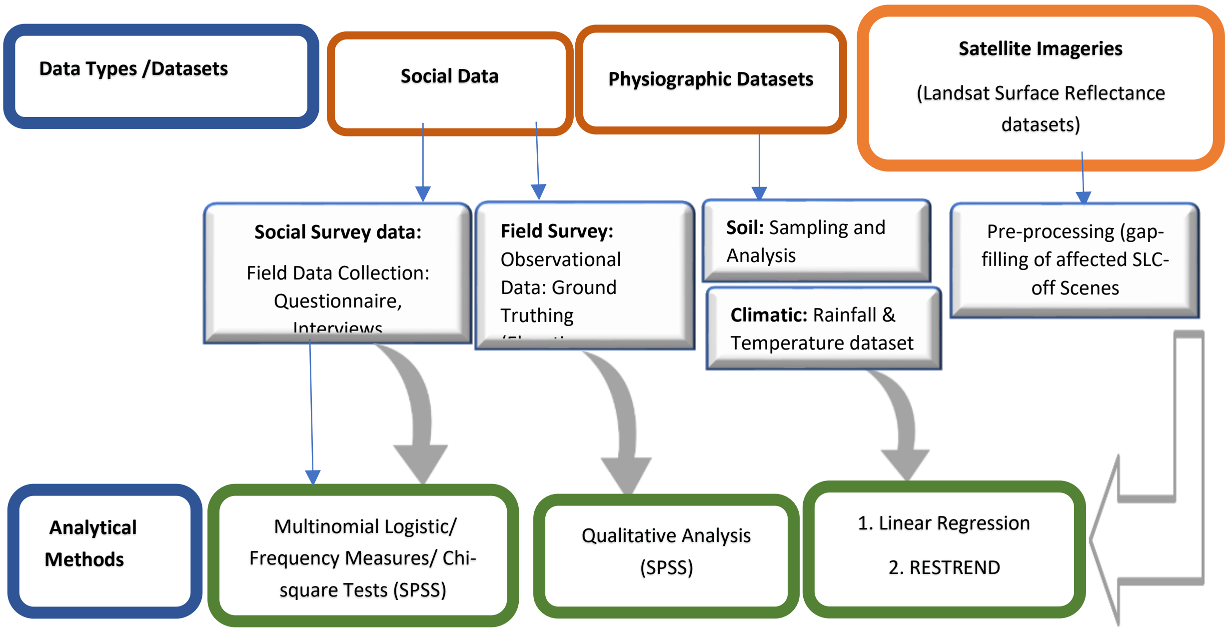


Figure 11: Flowchart for the research design including datasets and analytical approach

Several studies focusing on farmers' adaption strategies have often noted two overarching themes in climate adaptation research: farmers' perception and underlying drivers of farmers' adaptation decisions or choices. Perception and decision-making are themes that belong to human cognitive processes but are shaped by factors including individual capacity, access to institutional incentives, resource availability as well as the capacity to deploy these resources. Perception plays a key role in the way in which people approach climate adaptation actions, but perception lacks strong currency with scientific methodology. Understanding drivers of Adaptation decision at farm gate levels or underlying factors that influences adaptation choices and decision is very important.

Below et al. (2012, pp 223–235) mentioned that the consideration of these factors including household characteristics is useful for developing and analyzing vulnerability index of poor farmers. Below et al. (2012, pp 223–235) quantified determinants of farmers' adaptation choices by looking at the relationship between socio-economic characteristics (household attributes), farmers' adaptation behaviours and an activity-based Adaptation Index which the authors developed. Other studies that have addressed the underlying factors in adaptation decisions by small holder famers are Mertz et al. (2009), Gbetibouo et al. (2010, pp 217–234) and Bryan et al. (2009, pp 413–426). These studies have not only generated useful knowledge in this direction; they have also illuminated the degree of influence of one or more of these factors in influencing adaptation options. Institutional, household characteristics, demographic and socio-economic factors or issues have often been identified as significant determinants of adaptation preferred strategies at farm gate level. For example, while Mugi-Ngenga et al. (2016, pp 49–60) and Bryan et al. (2009, pp 413–426) documented the availability or absence of incentives including social and investment capabilities as factors determining adaptation choices in Kenya; Deressa et al. (2009, pp 248–255) listed demographic (head of household, age, gender), social (level of education, wealth status of head of household and institution (access to information, access to extension services) as major factors influencing adaptation choices in Ethiopia.

Where interplay of factors (institutional, socio-economic, governance and demography) exists, understanding the over-arching influence of one over the other is crucial in adaptation research. Hence to fully explore the interaction between the influences of these factors on adaptation responses at farm gate levels; modelling the impact probability of one driver or a combination of drivers on any preferred adaptation option is important. In realizing this, a choice model, multinomial logit model (MNL) was used in modelling the influence an explanatory variable (socio-economic factors) on preferred adaptation strategies. Arunrat et al. (2017, pp 672–685) also applied MNL in examining the influence of socio-economic factors on farmers' decision to adapt and observed that size of farm incomes, social capital and effective adaptation communication significantly influenced farmers' adaptation intention and decisions. Likewise did Zamasiya et al. (2017, pp 233–239) use MNL in determining factors that influenced farmers' adaptation intention and behaviours. Hassan & Nhemachena (2008, pp 83–104) and Fisher et al. (2015, pp 283–299) used multinomial Logistic Regression in identifying determinants in farmers adaptation strategies. Similar studies include Tazeze et al. (2012, pp 1–12) and Othniel & Resurreccion (2013, pp 341–364)

3.4 Research Design and Methods

The research design is a mixed design comprising of social research, quasi-experimental (field survey), quantitative methods of analysis and ground-truthing methods. Qualitative research methods included field surveys comprising of structured questionnaire administration and focus group interviews. Quantitative methods included data collection and statistical quantification of rainfall and NDVI datasets. Ground-truthing was undertaken to obtain visual and first-hand information for validating results from other research methods.

3.5 Data Analytical Methods

Analytical approaches used included statistical and inferential analysis. Statistical methods comprised of linear regression, residual analysis and choice modelling using multinomial logistic regression. Frequency counts and other summary statistical analyses were computed with variables of interests. Since most of the responses obtained in the structured questionnaire were categorical in nature with no ordered ranking, chi-square analytical test was used in comparing counts and test of independence or otherwise between selected categorical variables. Chi-square test of independence was also used in hypothesis testing. This is follows similar studies such as Diwediga et al. (2015, pp 132–143). Pre-statistical tests including the use of scatter plots (to investigate the existence of a linear relationship) and bivariate correlation for assessing the strength of correlation between NDVI and rainfall were undertaken. Associated tests of assumptions including the test of normality of distribution, homoscedasticity and linearity were also carried out. Correlations between NDVI and Rainfall values was inspected with the regression line of best fit as well as with the visual inspection of the direction of the trend line (positive linear relationship). The significance of the p-value was also considered in establishing the strength of the relationship between inter-annual rainfall and NDVI measures.

3.6 Data Types and Collection Methods

3.6.1 Social Data

Social data for this study included structured questionnaire, personal interviews and focal group discussions. Questions relating to socio-economic activities, household characteristics, cultivation practices and adaptation strategies made up a greater part of the questions obtained during the field survey. The target population comprised of rural farmers and crop vendors. A total of two hundred and fifty (250) valid responses were retrieved during the social survey against a total of 360 administered questionnaire. Fifty (50) questionnaire were returned uncompleted and sixty partially completed.

3.6.2 Sampling Frame

According to the 2006 population census, Keffi has a population density of 905.1 persons per one square kilometre with a growth projection of about 3.04% annually from 2006-2016. The target population in this study were primarily small holder farmers in the rural farming settlement of Keffi. Using a compass-oriented basis Franklin et al. (2003), densely-populated farming settlements were identified. These areas are shown on the map of Keffi in figure 39. An area sampling frame which supports a geographically unbiased survey and an equal sampling opportunity across the study area was adopted. The choice of geographic area sampling frame is, according to Franklin et al. (2003) to minimize sampling errors from sampling frame defects. Such errors include under-coverage, over coverage and duplication of sampling units. Within a geographical area survey approach, a compass-oriented method was adopted. A compass-oriented method is useful in developing a sampling frame particularly in unplanned settlement patterns and housing arrangement such as in Keffi. A similar method was used in Mahmud & Achide (2012, pp 129–134) where the study investigated patterns of urban sprawl in Keffi and its and its implication for development. A compass-oriented approach is also useful in aiding access to target population and for identifying sampling units. Within the geographic area sampling frame, seven settlements in the study area were selected from which the survey population was drawn. The surveyed settlements were Angwan Mangoro (North), Gidan Mada (North-West), Sabon Gari (South-West), Keffi town (North-East), Rimi (North-Central), Gauta (South), Tolo Ekuri (Central).

3.6.3 Sampling Method and Design

The sampling method employed for this study was chosen against consideration of some factors. Some of these factors included characteristics of the study area, the settlement patterns and the sampling frame adopted for the survey. Keffi has twenty human settlements under a well-defined administrative structure. However, due to logistical implications, about 38.8% (≈40%) of these settlements were selected for the study. A probability sampling design was used because of the choice of sampling frame (geographical area sampling). Geographical area sampling frame while convenient for studies of this nature, lacks structured means of contacting sampling units (such as a survey list). Due to this drawback, a systematic means of reaching survey population was utilized. A systematic sampling method which is carried out against a sampling interval requires a seamless random start as noted in Bhattacherjee (2012) and Franklin et al. (2003).

To calculate the sampling interval, the 2016 projected population of the National Population Commission for Keffi was used. The projected population estimate is given as 124,900. Using a set of parameters described below, the total number of eligible respondents were derived.

N2 – Actual estimated population size per settlement

PP_{2016} - 2016 Projected population by NPC

N - Cost-constrained estimated Population size per settlement

n – sample size

S- Estimated survey sample size

r- random number

k- sampling interval, between 1 and 60 Franklin et al. (2003)

$$\text{Thus } \mathbf{N2} = \frac{\text{Projected population by NPC, PP2016}}{\text{Number of settlements in Keffi}} = \frac{124{,}900}{20}$$

N2= 6,245 persons per settlement

In this study, 5% of N2, which is actual estimated number of persons per settlement, was considered in estimating **N** (Cost-constrained estimated Population size per settlement) as well as other associated operational constraints. Thus 5% of 6,245 accounted for 312 eligible respondents per settlement (N=312.25). An estimated sample size of n=52 persons per settlement (totalling 364 persons for the 7 selected settlements) was considered. In selecting sampling units (respondents); a systematic probability sampling with a sampling interval, ***k*** of 6 persons was used. The sampling interval, k was calculated from the equation, ***k*** = N/n (312.25 /52) = 6. That implied that upon the selection of a random number between 1 and 360, an interval of 6 houses was considered in the selection of sampling units.

3.7 Data Collection Instruments

3.7.1 Questionnaire

A trial field survey was first carried out to obtain a better understanding of the area, the people, culture and pattern of economic activities. This was done in order to support the development of a survey questionnaire with relevant questions. During the pilot survey, the first draft version of the questionnaire was administered on 5-interval randomly sampled houses. A total number of 105 respondents were reached on two different trial field visits. During the pilot field survey, personal interviews and focus group discussions were also undertaken. These personal interviews were exploratory in nature and was intended for fine-tuning the final questionnaire. The content and the structure of the questionnaire was designed with the consideration of the characteristics of potential respondents in mind particularly with regards to educational capabilities and the willingness of respondents to commit to longer interview process at the expense of their farm businesses. The questions were less complex, clear and written in simple English to aid translation into local dialects by local guides engaged to assist in the administration of questionnaire. The questions were short, closed categorical questions and probing in nature. Some of the questions were rating questions requiring yes or no answers. Due to the nature of socio-economic activities in Keffi, target respondents were hardly at home during the day due to farming activities. This necessitated multiple visits and questionnaire administration. The questionnaire administration was conducted in at least two visits in almost all the selected settlements. The outcome of the questionnaire administration is presented in the table 12. Fifty-five (55) questionnaire were designated for selected settlements. Between 29 and 46 questionnaires were fully administered per selected locality.

3.7.2 Field Observations

Field observations intended for mapping farming settlements in Keffi, collection of samples of interests for further analysis and questionnaire administration was carried out. Samples of interest including surface soil samples were also collected. With the use of a digital map sourced from the Nasarawa Geographic Information system, NAGIS, surveyed areas were identified and mapped out. A hand-held global positioning system receiver (GPS) was used for determining the positional accuracy, the sample area coordinates and the elevation.

3.8 Social Data Analysis

3.8.1 Summary Measures and Frequency Distributions

Descriptive and quantitative analyses were carried out with both Excel and SPSS statistical packages. The frequency counts, summary statistics and the statistical relationship as well as regression between selected variables were computed.

3.8.2 Statistical Modelling of Choices - Multinomial Logit Model

The multinomial logistic regression model (MNL) was applied in investigating driving factors influencing adaptation choices among smallholder farmers in Keffi. MNL model is a statistical model used in examining the effect of more than two predictor variables on multiple categorical responses as used in these studies Liu & Agresti (2005, pp 1–73), Agresti (1996) and Hedeker (2003, pp 1433–1446). Differing from the logistic model with more than just two outcomes (binary), MNL models the natural log (logit-transformed) probability of an observation belonging to a certain categorical member relative to the reference variable. The multinomial logistic model has been applied widely in choice determination studies in understanding the underlying factors (explanatory factors) influencing preference of one choice (dependent) over another Marcos & Baerenklau (2015, pp 203–215). This is because of the capability of the transformed logarithm odds associated with the outcome variables in describing the constant effect of a predictor variable(s) on the categorical outcome variables. The transformed logarithm odds of outcome variables are in a linear relationship between the predictor variable and its measure describes the constant effect of the predictor variable(s) on the outcome variable(s). With its algorithmic ability in overcoming the restrictiveness of probability measures, the logarithm odds of categorical outcome variables were used in calculating the probability of membership in a particular category relative to the baseline or reference variable. The multinomial logit model (MNL) supports null hypothesis 2 of the study which seeks to investigate whether there is a linear effect of explanatory variables (socio-economic variables) in influencing farmers' adaptation strategies and choices. Using the regression coefficient, the measure of the log odds and associated p-values; the constant effect sizes of selected independent variables (socio-economic factors) on farmers' adaptation preferences in Keffi were modelled. In this study, percentage of household needs financed with farm incomes (HouseFIN), alternative sources of incomes (AltSource) and Household characteristics like family size (FamPURP) were predictor variables. Represented with the equation below as mentioned in Williams (2017). The equation below described in Rodriguez (2001) explains

$$P(n_{i\text{-}m}) = \frac{\exp(Z_{ij})}{1 + \sum_{k=2}^{J} \exp(n_{ik})} \qquad \text{Rodriguez (2001)}$$

in terms of the probability of membership relative to the baseline category; the relationship between the independent and dependent variables where they are more than two responses. In terms of the log odds of the outcome variables, the equation;

$$n_{ij} = \log \pi_{ij} / \pi_{iJ} = \alpha j + x'i\beta j, \text{ Rodriguez (2001),}$$

where αj is the constant, n= the outcome variable(s), P= probability of n; βj, the vector of regression coefficient for parameter values, j =1,2…….., J-1.

MNL has been used in adaptation studies. Mugi-Ngenga et al. (2016, pp 49–60) used MNL in predicting economic drivers on adaptation decisions in Kenya, where on a gradient of low to high, the study showed that socio-economic factors were most significant in explaining adaptation decisions than demographic factors. Fanifosi & Amao (2000) also used MNL in assessing factors driving food insecurity and poverty status among farmers in Osun, South-West, Nigeria.

3.9 Satellite Imagery Processing and Analysis

Analysis-ready surface reflectance Landsat scenes over area corresponding to latitude: 8. 8471 and longitude: 7.8776 (Keffi) were assessed from earth explorer, courtesy, the United States Geological Survey (hereafter USGS). The Landsat archive, known for its data capture consistency, high temporal coverage (since 1972) and open source data policy Wulder et al. (2012, pp 2–10) supported the analysis of this research. A greater motivation for the use of Landsat scenes for this research is the validity of Landsat scenes currently archived in the Landsat Global Archive Coverage. According to documentation from Landsat web page, all products in the LGAC are precision and terrain-corrected data (L1TP) which has been inter-calibrated across sensors requiring no further geometric and radiometric corrections. Wulder et al. (2016, pp 271–283) noted that the LGAC has improved temporal and spatial coverage, improved depth and contains Level 1 Collection 1 (analysis-ready) products. Due to the challenge of sparse data collection over West Africa during the early years of Landsat, only 20 scenes were retrievable for this study. The constraints of sparse data over most parts of West Africa has been reported in Wulder et al. (2016, pp 271–283) where collection, processing and archival of imageries were done at international ground stations (ICs) over North and West Africa, due to the on-board technical storage problems in the early days. For example, only six (6) scenes Landsat 7 ETM+ surface reflectance images within the dry season were available on the Landsat Archive for the temporal period 1st January 1985 to 31st December 1998.

Following this, fourteen (14) Landsat 7 ETM+ surface reflectance (14) scenes dating from 1999 to 2012 and six (6) Landsat 8 OLI/ITIRS data from 2013–2018 were downloaded for the study. Landsat data for Keffi corresponded to Path 188 and Row 54. LT 7 ETM+ and Landsat 8 OLI/TIRS dry season (October to March) surface reflectance scenes with less than 10% scene and cloud covers from 1999 to 2018 were downloaded for this research. Apart from the scarcity of historical images over west and north Africa, only images from dry season scenes were preferred to avoid impact of between season phenological influences Verbesselt et al. (2010, pp 2970–2980). However, some of the downloaded scenes contained gaps due to the failure of the scan line corrector of the Landsat satellite from May 2003. This necessitated the filling of scan line corrector gaps. Confidence in gap-filled Landsat 7ETM+ images has supported its use in change detection studies. Since about 78% of the data quality in the SLC-off scenes are not affected by the SLC issue according to Chen et al. (2011, pp 1053–1064), gap-filling algorithms have been used to fill gaps in SLC off scenes. These gap-filled scenes produce high performance change detection and land cover classification results.

Year	Landsat_Datsets_Surface_Reflectance_Scenes	Year	Landsat_Datsets_Surface_Reflectance_Scenes
1999	LE07_L1TP_188054_19991113_20170216_01_T1	2009	LE07_L1TP_188054_20091226_20161216_01_T1
2000	LE07_L1TP_188054_20001217_20170208_01_T1	2010	LE07_L1TP_188054_20101229_20161211_01_T1
2001	LE07_L1TP_188054_20011102_20170202_01_T1	2011	LE07_L1TP_188054_20111130_20161205_01_T1
2002	LE07_L1TP_188054_20021121_20170127_01_T1	2012	LE07_L1TP_188054_20121202_20161127_01_T1
2003	LE07_L1TP_188054_20031124_20170123_01_T1	2013	LC08_L1TP_188054_20131111_20170428_01_T1
2004	LE07_L1TP_188054_20041212_20170117_01_T1	2014	LC08_L1TP_188054_20141130_20170417_01_T1
2005	LE07_L1TP_188054_20051215_20170111_01_T1	2015	LC08_L1TP_188054_20151117_20170402_01_T1
2006	LE07_L1TP_188054_20061116_20170107_01_T1	2016	LC08_L1TP_188054_20161221_20170405_01_T1
2007	LE07_L1TP_188054_20071221_20170101_01_T1	2017	LC08_L1TP_188054_20170106_20180527_01_T1
2008	LE07_L1TP_188054_20081121_20161224_01_T1	2018	LC08_L1TP_188054_20180109_20180119_01_T1

***L1TP - Landsat Collection 1 Level 1 Products with the highest data quality geometrically, radiometrically and topographically corrected using sufficient ground control points suitable for pixel-based time series analysis
***T1 – Tier 1 – Level of inventorization of acquired and processed Landsat data products
***LC= Landsat Collection

Table 4: Identification Numbers, IDS of downloaded Landsat scenes

Already radiometrically and geometrically corrected surface reflectance (SR) scenes were used in this study due to its robustness- as it contains actual surface physical properties of the object. Its low sun angle conditions were also considered. A range of methods including local linear histogram matching (LLHM) by the USGS; weighted linear regression (WLR), neighborhood similar pixel interpolator (NSPI), by Zhu et al. (2012, pp 49–60) and the geostatistical neighborhood similar interpolator, GNSPI mentioned in Chen et al. (2011, pp 1053–1064) have been used in gap-filling the SLC-off scenes. With the use of the neighborhood similar pixel interpolator (NSPI), Chen et al. (2011, pp 1053–1064) presented results from a comparative study between gap-filled simulated SLC-off data and SLC-on scenes. In this study, images filled with the NSPI were aesthetically and analytically comparable with the SLC-on data. The SLC-off interpolated values were accurate for use in change detection studies.

Algorithms for the interpolation of missing values from neighbouring pixels according to Chen et al. (2011, pp 1053–1064) are based on the assumption that pixels showing same spectral characteristics and the spectral difference(s) between dates observed in SLC-on scenes are also similar with spectral differences observed in SLC-off images. Viet et al. (2014) applied the local linear matching method to fill the gaps and the results of the change detection (land classification) showed results with high accuracy of 87.44% and kappa Coefficient of 0.86. Outcomes of the land cover classification under the West Africa Land Use and Land Cover trend project also validated the capability of SLC-off Landsat scenes in Earth monitoring. Tappan (2010) noted that the SLC-off images across the five (5) different sites under each category of land classes (agriculture, wetlands, Savanna, human settlements) indicated visible perturbations of land features comparable with original SLC-on scenes. Comparatively, the differences between the performance of SLC-off and original SLC-on scenes in the change detection across all the sites under review in Tappan (2010) showed not more than 1.5% disparity. Similarly, as mentioned in Rindfuss et al. (2004, pp 13976–13981) and mentioned in Wulder et al. (2008, pp 955–969); 63% of the global land area are composed of less than 1% base scenes and 5% filled SLC-off scenes. This reinforces the usefulness of SLC-off images in scientific analysis. A gap filling algorithm executable with ArcGIS and developed by (Bustillos 2012) was used in gap-filling the affected SLC-off surface Reflectance scenes. The flowchart of the gap fill algorithm is presented in figure 12.

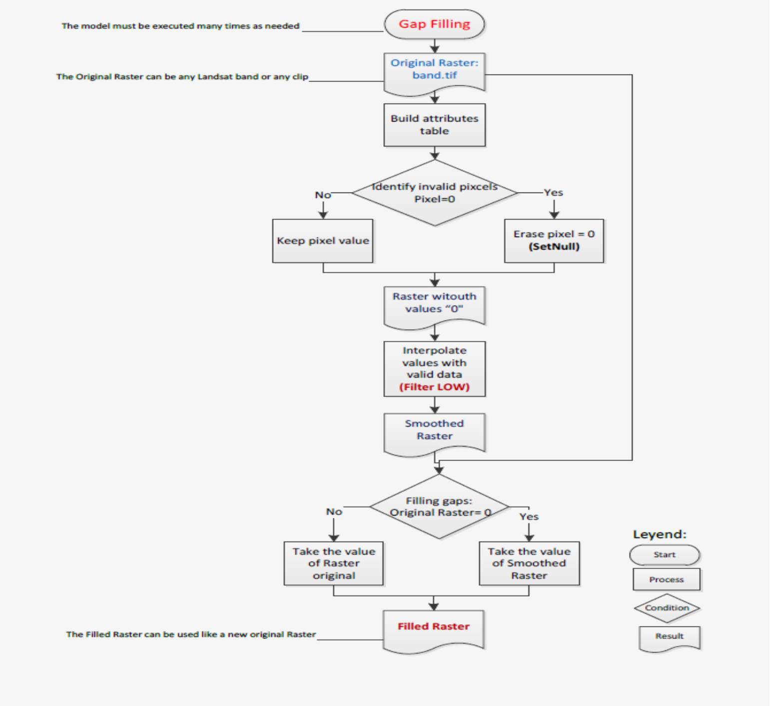


Figure 12: Flowchart of the gap fill algorithm used in the gap-filling of SLC off scenes. Source: (Bustillos 2012, pp 3-4)

The gap-fill method by (Bustillos 2012, pp 3-4) was chosen because of its practicability and ease of execution. The USGS recommended methods, the mosaicking method (Phase 1) and Local Linear Matching method (Phase 2) which runs by interpolation was not used for the gap-filling of these scenes due to some cited limitations of temporal variability between target and primary scenes in Zhang et al. (2007, pp 5103–5122), Romero-Sanchez et al. (2015, pp 2786–2799) and Chen et al. (2011, pp 1053–1064). Affected SLC-off Landsat scenes were gap–filled and sub-setted using Keffi boundary shape file. The sub-setting of the gap-filled SLC-off scenes was done to optimize the analysis of the scenes. The selected band (tiff.file) is used as the original Raster. The model works in two parts: Part 1 involves the creation of an attribute table for the identification and display of pixels with invalid values, zero. All invalid cells containing (null) value-pixels values are erased using the SetNull tool based on the algorithm. The second part is concerned with the filling of the gaps using the filter LOW tool, which operates on a nearest neighbourhood algorithm (Bustillos 2012 pp 3-4). The filter LOW is then used to create a smooth raster (one without null values) by interpolation with values from neigbouring pixels into the original raster file but preserving the pixel statistics Bustillos (2012, pp 3-4). Finally, null value pixels in the original raster (SLC-off) are interpolated with pixel values of the smoothed raster created by the LOW Filter. This process was repeated for individual .tiff files (each individual band) for all affected SLC-off scenes. Using ArcGIS 10.5 software, NDVI Maps were generated with filed .tiff files, so were NDVI values.

3.10 Physiographic Variables (Sampling and Analysis)

3.10.1 Soil Sampling and Analysis

Soil is the major source of nutrients for plants growths and imbalances in optimum averages of essential available soil nutrients can contribute additional stress on plant growth in linear and non-linear ways. Also, variations in microbial soil activities, soil moisture and level of P^H can also impact plants growth and by implication, vegetation canopy conditions. According to a Food and Agricultural report (FAO)[5], plants do well

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[5] A FAO soil analysis handbook assessable at http://www.fao.org/3/a-i0131e.pdf

in soils that are close to either side of neutrality. In a study Ernst (1996, pp 41–98), the characteristics and composition of vegetation were found to have direct relation with soil quality and health. Related studies by Wan et al. (2019) also showed the effect of soil properties such as the volume of coarse fragment on spatial distribution of vegetation. The impact of Soil P^H on plant growth investigated by Gentili et al. (2018, p 1335) showed that soil P^H affected the development of plant including leaves distribution with plants growing at soils P^H of 7 being shorter and slow leaves development than plants growing at soils P^H of 5. In terms of soil moisture, Tatian et al. (2010, pp 77–86) and Nave et al. (2017, pp 157–173) showed that low soil moisture can lead to decrease in plant growth, variation in leaf phenology and growth dynamics irrespective of the presence of plant nutrients.

To control the effect of the incapacity of soil to provide adequate amounts of nutrients to meet vegetation photosynthetic needs, an indicative nutrient inventory of essential soil nutrients, nitrogen, potassium and phosphorous was carried out. The role of soil in nutrient availability potentially impacts on vegetation structural and functional dynamics. The indicative moisture level and soil P^H was also carried out. Surface soil samples were collected in May 2016 and in March 2017. According to Landon (2014), simple soil nutrient and moisture inventory analyses are intended to control or exclude the effect of soil properties on plant growth and vegetation spatial distribution. It was thus important to carry out soil analysis to control for the effect of soil nutrient deficiency or quantitative imbalances in indicated soil properties.

3.10.1.1 Selection of Soil Sampling Locations and Sampling Design

Soil samples were collected from four locations in Keffi. These locations were NSUK (the Nasarawa state university in Keffi main town), Angwan Tanko (a settlement bordering the North East of Keffi and close to Angwan Jaba), Guata (in the south) and Angwan Jigwada (bordering the South West of Keffi). The choice of these locations was to ensure representation of soil fertility conditions in Keffi It was also done to minimize error in the quantitative observations of indicative soil fertility and moisture in Keffi. The geographical spread in the sample locations was in fulfilment of the simple random sampling approach which (Carter 1993) notes should be representative enough for nutrient inventory studies. While three of the sampled areas are largely farming settlements, the decision to include Keffi (where the Nasarawa state University is situated) was due to the expanding urban farming activities in Keffi centre.

3.10.1.2 Soil Sampling Design

Probability sampling design was used in the selection of sampling locations in Keffi as recommended in (Carter 1993). Probability design is a soil inventory sampling design and it is suited for simple inventory of soil available nutrients. Apart from facilitating the ease of access to sampling locations (the four selected locations), probability sampling was the most efficient method considered for representative sampling of soil in Keffi. Given that the purpose of soil sampling was not for comparative mensurative observations where categorization or characteristics of sampling points example landforms positions and textures play important roles for comparison of results (Carter 1993), probability sampling was used.

Soil samples were collected in through a simple random sampling method. This was done based on the scientific understanding in (Carter 1993), that soil analysis aimed at simple soil testing or the inventorization of indicative soil nutrient averages and properties can be sampled with probability sampling design. Secondly, due to the relatively flat topography of Keffi, a sampling consideration mentioned in (Tan 2005), simple random sampling method was preferred. A pre-visual survey was carried out in Keffi before sampling to identify localities with large farming settlements and locations with less farming footprints. Soil samples were collected from three localities with large farming settlements (Angwan Tanko, Guata and Angwan Jigwada). The area where the Nasarawa state university, Keffi (NSUK) is located was selected as another sampling location and was used as a control location in assessing the average values of soil nutrients, P^H and soil moisture within Keffi and the extent to which these values vary with regards to type of human activities.

3.10.1.3 Soil Sampling Procedure

In each sampling location, a sampling unit (a marked-out portion of a farmland) 100 meters in length and 50 meters in width was made using a tape. Selected units were in farmlands with similar cultivation practices. The relatively flat topography was also considered. A 100m diagonal transect within the marked-out portion was made. Two soil sampling points along the 100m transect were marked off. Transects were made at points far away from typical buildings as mentioned in Carter (1993). This is to control for the effect of disturbances on soil conditions from structural objects like houses.

A tape was used in measuring 50 meters distance along the diagonal transect. At each 50 meters distance, a sampling point was established. Two sampling points, one in the middle and one at the end of the diagonal transect were established. With a shovel as seen in figure 13, a V-shaped sampling depth measuring 15cm was dug. 15cm depth lies within the E, B and C zones of the soil profile (Tan 2005). This, according to (Tan 2005) is the horizon where leaching as well as accumulation of soil nutrients occurs. It is the horizon which determines the type of soil order formed and is the zone where average soil moisture content and soil nutrients are held Tan (2005).

Soil samples were excavated using a shovel and unwanted materials like stones, plant roots and animals were removed. Excavated soils from each 50 meters point were put in a bucket and evenly mixed. Mixing of excavated soils from both 50m sampling point was done three times for homogenous mixing. 100g of excavated soil was then placed in a sealable polythene bag to keep soil samples air-tight. Sealed soil samples were marked and labelled with the name of the locality. Separate hand-written information sheet containing time of collection, name of locality and date was also put inside the sample bag to enable easy identification in the laboratory. This same procedure was the standard procedure used in all four sampling locations during 2016 and 2017. The soil samples transported immediately to the laboratory (Sheda Science and Technology Complex, Abuja, Nigeria) for further analysis.

3.10.1.4 Soil Sampling Units

Soil Sampling Location Information

Legend
Sampling Point(s)
▭

Sampling Unit
▭

Location: Gauta
Date: June 2017
Locality: Keffi
State: Nasarawa
Country: Nigeria
Photo Credit: Nsikan-George Emana

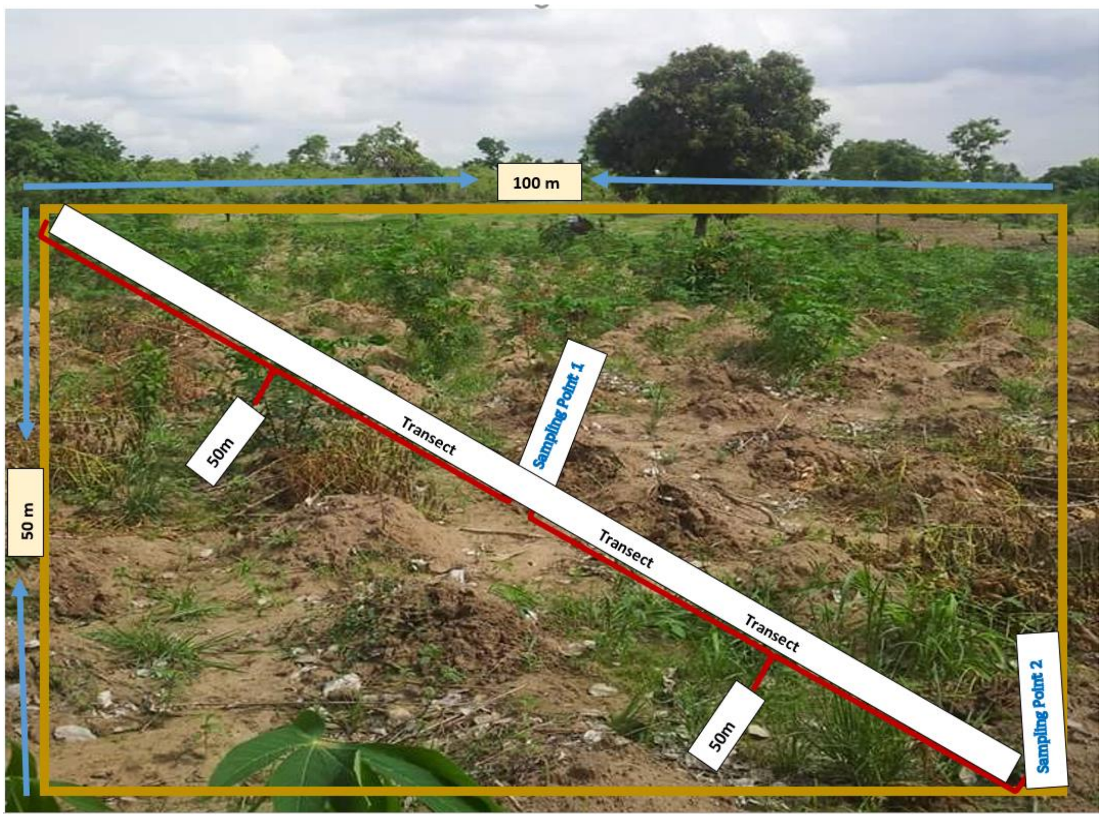
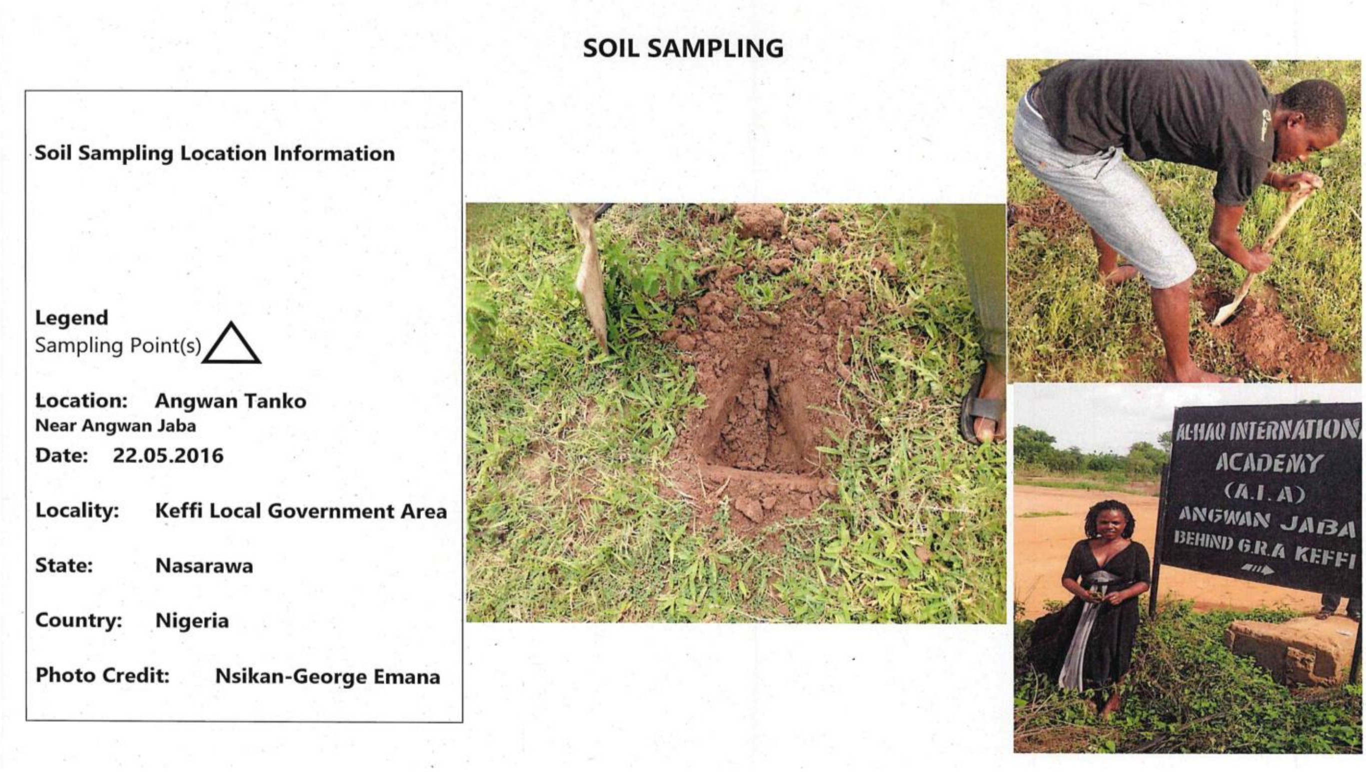


Figure 13: Soil Sampling Procedure in selected Locations in Keffi


SOIL SAMPLING

Soil Sampling Location Information

Legend
Sampling Point(s) △

Location: **Angwan Tanko**
Near Angwan Jaba
Date: **22.05.2016**

Locality: **Keffi Local Government Area**

State: **Nasarawa**

Country: **Nigeria**

Photo Credit: **Nsikan-George Emana**

Figure 14: Soil Sampling Unit

3.11 Climatic Data Analysis

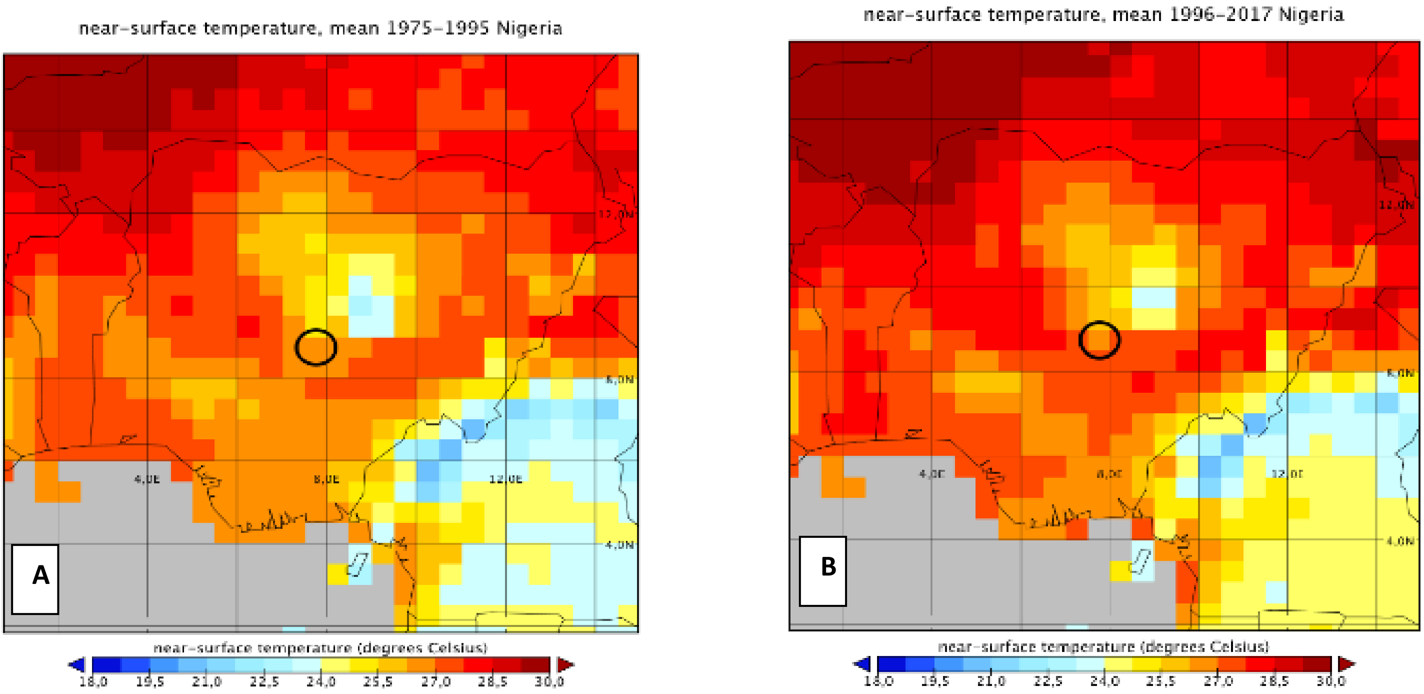
Real time rainfall and temperature observations were sourced from the Nigerian Meteorological Agency (NIMET). CRU interpolated datasets were only utilized for validating mean annual rainfall and temperature measurements. Only rainfall datasets were utilized in a linear regression analysis with observed NDVI measurements. Observed rainfall datasets for each year were smoothed out before being used in the analysis. Since dry season Landsat images between October and April were used, dry season rainfall observations were smoothed. Wet season rainfall averages were smoothed out to minimize impact on inter-annual rainfall mean.

3.11.1 Temperature Analysis

Annual averages derived from smoothing two seasonal observations were used for the linear regression. Annual temperature averages were only plotted for the visualization of the yearly character and trend of temperature measures in Keffi within the temporal window of 1999-2018. Studies on climate change impacts on small farms in Nasarawa such as Falaki et al. (2011, pp 49–62), Luka & Yahaya (2012b, pp 1520–5509), Salau et al. (2012, pp 199–211) and Ekwe et al. (2014, pp 56–62) also aggregated annual rainfall and temperature measurements. Version CRU TS v.4.02 gridded datasets from the climatic research unit (CRU), University of East Anglia obtained from https://crudata.uea.ac.uk/cru/data/hrg/ Harris et al. (2014, pp 623–642) was used. Interpolated area-weighted means-derived monthly temperature average at 0.5^0 resolution Harris et al. (2014, pp 623–642) showed that the mean surface sir temperature in Keffi ranges between 25.6^0C for first bi-decadal time slice, (1975-1995) and 26.1^0C for the 2nd bi-decadal (1996–2017) (table 5 & figure 15). Since CRU datasets are interpolated values, slight differences with instrumental measurements by NIMET exists. Instrumental temperature observations from the Nigerian Meteorological Agency (NIMET) were also used in validating CRU temperature measurements. The NIMET covering 1999-2018 shows that the minimum daytime temperature in Keffi was 33.4 degrees centigrade and the maximum of 34.2 degree centigrade.

Decadal time-sliced values for Temperature and Rainfall, Keffi (CRU Datasets)		
	Annual Mean Near-Surface Temperature	Annual Mean Rainfall
1975 - 1995	25.6^0C	1171.0 mm/ year
1996 - 2017	26.1^0C	1216.0 mm/year

Table 5: Two bi-decadal time-sliced mean annual temperature and precipitation datasets, Keffi; Source: Climatic Research Unit, UEA



near-surface temperature, mean 1975–1995 Nigeria

near-surface temperature, mean 1996–2017 Nigeria

Figure 15: Temperature Map of Nigeria showing in circled portions, mean annual temperature values in Keffi for two bi-decadal time slices (A: 1975-1995) (B: 1996-2017). Data Source: CRU, UEA, Norwich

3.11.2 Rainfall Analysis

Due to the influence of seasonal character (intense but shorter duration) of rainfall events in Keffi, a 12-month average was used for estimating the annual rainfall. Although the onset of rainfall in Keffi is between March and April, rainfall in Keffi are intense and frequent between May and October. This intense and short duration character of rainfall in Keffi, results in water run-offs during the rainfall season, accounting for reduced soil moisture. Data from the gridded interpolated datasets from CRU showed that within the intense months of rainfall events in Keffi (May-October), the average rainfall lies between 932.5mm/year and 1408.4mm/year (CRU). With the NIMET dataset, the rainfall average during the months of intense rainfall in Keffi lies between 835mm/year and 1197mm/year. Secondly the p-value, P=0.02 associated with the independent t-test between the 6-dry months average (July to December) and 12-monthly instrumental averages from NIMET, shows that the length or duration of rainfall in Keffi has little influence on the effectiveness of rainfall in Keffi. Against the significance level of α=0.5, the null hypothesis was rejected.

Duration of Rainfall in Keffi influences rainfall effectiveness,
Ho: $\text{Rainfall}_{\text{duration}} = \text{Rainfall}_{\text{Effectiveness}}$
Duration of Rainfall in Keffi does not influence rainfall effectiveness
H1: $\text{Rainfall}_{\text{duration}} \neq \text{Rainfall}_{\text{Effectiveness}}$

Corroborating the empirical finding in (Agidi et al. 2018), on impact of the character (late onset and early cessation) of rainfall than amount, on planting and growing seasons in Keffi, the p-value of the t-test, p=0.02 supports the use of 12-monthly mean in the NDVI-rainfall regression. Aggregating monthly observations also smoothed out outliers in both wet and dry seasons. Although instrumental data from NIMET were used for the NDVI-Rainfall regression, interpolated rainfall datasets from CRU were also used to assess the distribution and annual quantity of rainfall in Keffi as given by both data sources.

Mean Annual Rainfall Data, Keffi, (Instrumental Data, NIMET: 1999- 2018)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Rainfall (mm/year)
1999	1	0	54.2	100.3	124.6	224.6	102.3	301.7	317.3	115.1	0	0	1341
2000	0	0	0	72.0	111.2	172.3	132.7	304.6	119.2	59.0	0	0	971
2001	0	0	0	102.3	126.6	211.0	211.4	305.4	175.7	38.7	0	0	1171
2002	0	0	0	55.0	113.0	45.2	236.5	305.2	111.1	112.2	11.8	0	990
2003	0	15.8	0	108.5	112.6	128.1	231.5	221.5	249.2	84.9	18.1	0	1170
2004	0	0	9	108.8	113.0	128.5	242.3	257.1	155.3	66.6	0	0	1081
2005	0	0	52.7	43.2	129.7	102.3	208.3	303.4	112.4	119.3	0	0	1071
2006	0	0	25.7	31.9	204.7	110.3	304.3	161.9	211.4	41.1	0	0	1091
2007	0	0	20.5	68.5	134.4	215.3	224.3	212.9	183.5	210.2	0	0	1270
2008	0	0	11.2	31.8	151.5	202.4	171.3	210.5	103.4	56.9	0	2	941
2009	0	0	2	114.3	190.2	324.0	211.9	172.6	125.9	173.3	6.8	0	1321
2010	0	0	0	75.0	125.0	312.5	215.3	200.6	151.9	20.0	0	0	1100
2011	0	7.3	0	21.1	167.7	211.7	61.4	220.8	203.2	147.1	0	0	1040
2012	0	0	0	45.5	141.6	200.8	199.4	210.3	161.9	111.2	28.9	0	1100
2013	0	0	25.1	102.2	111.3	114.2	264.9	148.1	224.7	144.2	26.3	0	1161
2014	12	0	24.7	105.2	155.2	112.7	211.8	154.1	193.7	49.5	2.2	0	1021
2015	0	12.7	1	21.2	123.5	102.1	210.3	229.8	149.4	20.0	0	0	870
2016	0	2	2	76.7	138.2	185.2	223.8	156.0	159.6	80.0	7	0	1031
2017	1	2	16	40.8	165.0	155.0	184.0	183.1	155.2	110.9	8	0	1020
2018	1	7	10	49.1	165.5	160.0	225.9	126.0	178.0	82.0	13	0	1017

Table 6: Instrumental Annual Mean Rainfall Data for Keffi, Source: Nigerian Meteorological Agency

It was also important in ensuring that the instrumental values used for the regression could be comparable with CRU interpolated datasets and also that they could be used in assessing the distribution and annual quantity of rainfall in Keffi. Examining whether or not the variance (σ) of CRU dataset and that of NIMET (instrumental) datasets are equal, a hypothesis testing of the variance of both datasets as shown in the hypothesis testing expressions below was carried out.

Interpolated Annual Rainfall Mean,1999-2018 , mm/year (Climatic Research Unit, UK)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Rainfall (mm/year)
1999	0.5	2.5	7.6	51.6	122	203	208	236	231	231	1.9	0	1294
2000	0.2	0.1	6.4	31.5	183	214	208	286	254	129	0.4	0	1313
2001	1	2	23	78	146	179	226	243	236	107	4	0	1245
2002	1	2	23	78	146	179	226	243	236	107	4	0	1245
2003	1	2	23	78	146	179	226	243	236	107	4	0	1245
2004	1	2	23	78	146	179	226	243	236	107	4	0	1245
2005	1	2	23	78	146	179	226	243	236	107	4	0	1245
2006	1	2	23	78	146	179	226	243	236	107	4	0	1245
2007	1	2	23	78	146	179	226	243	236	107	4	0	1245
2008	0.1	0.2	2	55.4	168	152	262	225	254	143	0.4	0	1262
2009	0.1	2	23	78	146	179	253	436	268	84.7	0.4	0	1469
2010	0.1	2	2	62.7	152	120	266	243	200	152	13.2	0	1214
2011	0.1	1.6	2	33.6	161	84.4	204	158	236	107	4	0	991
2012	1	0.2	2	78	146	179	226	243	296	149	0.4	0	1321
2013	1	0.2	2	67.5	58.2	237	153	207	207	70.5	0.4	0	1004
2014	0.1	0.2	2	123	165	148	169	228	334	101	0.4	0	1270
2015	0.1	0.2	40	6.9	130	257	132	277	181	84.7	3.3	0	1112
2016	0.1	0.2	66.5	78	144	219	180	278	405	183	0.4	0	1554
2017	0.1	0.2	2	15.4	239	292	199	197	226	40.4	4	0	1214
2018	0.1	3.7	11.9	74.8	192	200	161	217	236	107	0.4	0	1204

Table 7: Interpolated values for mean annual rainfall in Keffi (1999-2018)

The F-value value of the two rainfall datasets is 1.0355 and the F-critical one–tail is 2.20329. The result showed that the variance (distance of a value from the mean) of CRU dataset is 15164.6 (with 20-year mean of 1246) and 14147.9 (with 20-year mean of 1088) for NIMET dataset.

$$H_0: \sigma_{CRU}^2 = \sigma_{NIMET}^2$$

$$H_1: \sigma_{CRU}^2 \neq \sigma_{NIMET}^2$$

To show how the two datasets performed in terms of assessing the distribution and annual quantity of rainfall in Keffi, the F-value associated with the two rainfall sources= 1.0355 and the F-critical value= 2.2033 were analysed. The F-value was not greater than the F-critical value, indicating that the null hypothesis test of equal variance of the two datasets holds. The independent t-test with a significant p-value, $p< 0.0003$ also suggests no statistically significant difference between the annual mean of the rainfall measures as accounted for by the two data sources. An inferential analysis of the climatic conditions over Keffi was carried out within a two-time slice of twenty years (bi-decadal) in each time slice, 1975–1995 and 1996–2017. The annual rainfall and surface temperature for the two decadal windows (1975-1995 and 1996-2017) were visualized using Panoply software which showed that for annual rainfall for the period (1975-1995) in Keffi was 1171mm/year and 1216mm/year for (1996-2017).

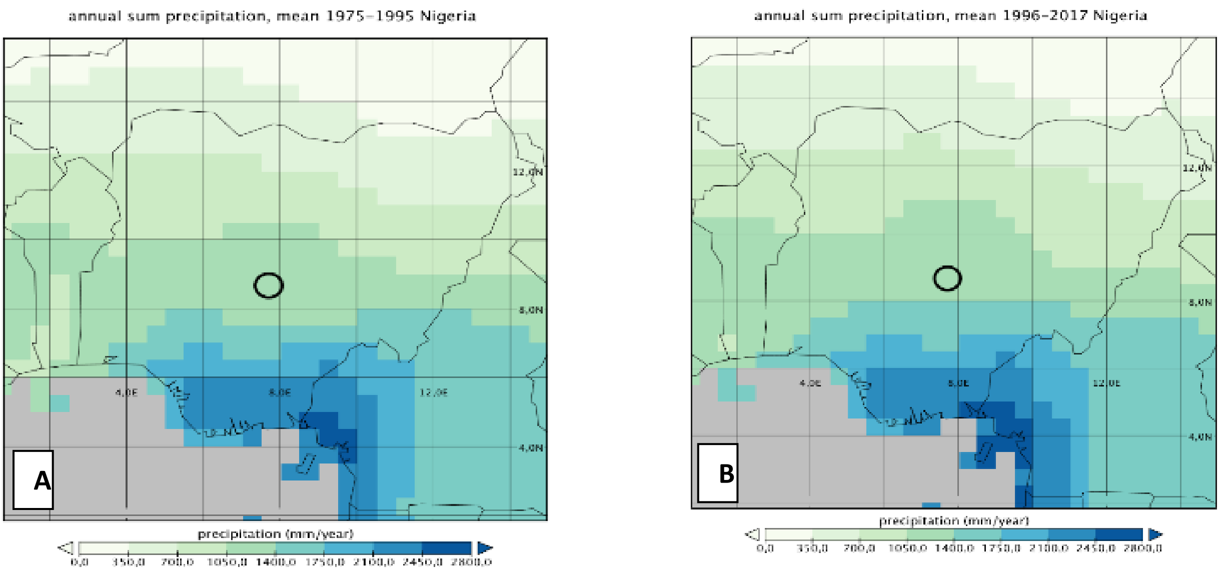


Figure 16: Rainfall map of Nigeria showing in circled portion, mean annual rainfall amount in Keffi for bi-decadal time slices (A: 1975-1995) (B: 1996-2017). Data Source: CRU, UEA, Norwich

3.12 Pre-statistical Analysis and Data Preparation

In disentangling the effect of anthropogenic events from inter-annual rainfall on vegetation dynamics, relevant studies like (Evans & Geerken 2004) and (Wessels et al. 2007) used statistical analytical measures including linear regression and residual analysis. In these studies, the correlation between NDVI and rainfall measurements was first investigated using linear regression analysis. Linear regression modelling has a significant predictive capability to show the casual relational effect between two continuous variables of interests. It also supports the prediction of a dependent variable following a unit increase in the independent variable. The resulting standardized residual observations from the NDVI-rainfall linear regression were subjected to trend analysis. Prior to regression analysis, NDVI and rainfall data were screened for fulfilment of statistical assumptions (presence of outliers, approximate normality distribution of data, detection of outlaying values, homoscedasticity) associated with linear regression analysis as mentioned in (Fernandez 1992), Razali & Wah (2011, pp 21–33). Studies such as Doane & Seward (2011) and Fernandez (1992, pp 297–300) have mentioned that the violation of basic regression assumptions can jeopardize statistical linear models and affect regression results. Other relevant statistical tests include correlation test for evaluating the strength of association between rainfall and NDVI. Inter-annual rainfall and NDVI mean values were then fitted into a linear regression model with a regression line. Similar to studies like Higginbottom & Symeonakis (2014, pp 9552–9575); residual (ZRESID) values from the rainfall-NDVI linear regression were plotted against time (Year).

4 Results and Discussions

Results from the study are presented under five sub-sections. These are social survey and ground truthing, NDVI data analysis, physiographic data analysis (soil and climatic data analysis), time-series based (RESTREND) decadal reclassification analysis. Each sub-section of the results obtained from climatic datasets analysis, soil, social survey and statistical analysis addresses the research objectives, study hypothesis, research questions and overall goal. These results are presented in different formats including charts, tabular summaries, and digital maps.

Results from the study strongly suggests that inter-annual variability in vegetation productivity (measured with NDVI) in Keffi is more associated with land use-related practices by farmers than with inter-annual rainfall variability. Cultivation practices and farmland management decisions during the temporal window of the study (1999-2018) have been modified by subsistent farmers in response to shifts in climatic conditions in Keffi. This understanding is supported by outcomes of social survey and questionnaire which shows that these climates impact-driven farming practices have potential impacts on rainfall-vegetation sensitivity. The weak correlation between NDVI and rainfall in Keffi signified by a regression coefficient of, (R=0.129) despite the high rainfall amounts in Keffi between (1999-2018) lends credence to the plausibility of other non-rainfall factors dampening NDVI sensitivity to rainfall.

Outcomes of the social survey indicates, to a larger extent that, changes in cultivation decisions and farmland management are influenced by a myriad of factors including household needs and subsistence decisions. Farmers with larger family sizes and whose livelihood sources were primarily small farm holdings without alternative means of off-farm livelihoods, adopted yearly continuous cultivation with less fallow system. Yearly cultivation on the same piece of land or on alternate farmlands in Keffi by subsistent farmers in Keffi was also influenced by the transitory nature of tenure rights and systems. In Keffi, small scale farmers autonomously reacted to impacts of climate change by changing cultivation practices and planting seasons and decisions. These farm-gate level adaptation strategies by farmers in Keffi (initiators of adaptation) are intended for the adjustments in cultivation practices in order to sustain the performance of farm-based livelihoods (attribute system of values) as an inherent economic variable of small scale farm holdings (exposed units) within the shortest possible time frame (temporal scale).

Given the unsustainable ways in which these farm-gate level adaptation strategies are carried out, they potentially constitute land use intensification with anthropogenic trampling effects on vegetation canopy structures. This non-receding use of land constitutes trampling effects on vegetation canopy with a potential implication of canopy morphological structures impairment. The direct implication from a scientific perspective is the potential alteration in the process and quantitative variables associated with photosynthetic performances of plants as mentioned in Gates et al. (1965, pp 11–20). The weak regression coefficient of the NDVI-rainfall linear regression as well as the downwards character of the RESTREND plot (residuals of NDVI-rainfall linear regression) plausibly suggests that climate change -driven changes in the use of farmland decisions, planting times and fallow management is potentially driving vegetation cover dynamics more than inter-annual rainfall amounts. Small scale farmers' adaptation behaviours in Keffi constitutes trampling effects on vegetation canopy structural and functional conditions, thereby weakening and interfering with the linear relationship between functional photosynthetic process and rainfall amounts.

In investigating the extent to which inter-annual NDVI variability in Keffi is affected by mean annual rainfall amount in comparison to adaptation-driven crop cultivation practices or vice-versa, results of NDVI reclassification between 1999 and 2018 for understanding vegetation dynamics in Keffi were and the residual trend plots were analysed. Outputs of the linear regression showed that rainfall was a weak predictor of NDVI in Keffi. Inter-annual mean rainfall amounts were in Keffi were unable to trigger corresponding NDVI units. Assessment of the character and shape of the residual trend (trend plot between residuals of NDVI-rainfall linear regression and years) slope showed that shifts in vegetation productivity in Keffi were not significantly explained by inter-annual rainfall variability but plausibly by other non-rainfall factors which masked and dampened NDVI-rainfall sensitivity.

Outcomes of field surveys and the statistical summaries from chi-square and frequency counts revealed farmers in Keffi preferred changing farm management decisions and cultivation practices in responding to climate impacts than venturing into off-farm livelihood activities. Shifting cultivation with less fallow periods was the most preferred by farmers in Keffi. For example, (38.4%) farmers preferred yearly mono-and mixed cropping as against (2%) who shifting cultivation with less more fallow periods. The highest statistics was recorded for farmers who practiced cultivation with less fallow periods in between (44.0%). In terms of coping and adaptation strategies, 54.80% preferred changing crop cultivation practices and farm management decisions as an adaptation option, a statistic higher than 25.20% (who preferred changing crop varieties) and 20% (farmers who would rather diversify means of livelihoods (figure 56). The high preference for changing crop varieties or modifying cultivation practices by farmers in Keffi is connected in part to the lack of right policy environment and resources to support new livelihood means.

Although some respondents (farmers and crop vendors) showed interests in pursuing non-farm livelihoods activities or more sustainable adaptation option, they were however unable to implement desired off-farm economic activities due to social capability and asset limitations. With the limited livelihood choices faced by farmers in Keffi, preferences for changing crop varieties, practicing shorter fallow system or inter-annual cropping were common farmland management methods in Keffi. These management methods have the potential of exerting trampling effects on land surfaces and vegetation canopy structures. Thus, vegetation in Keffi are exposed to cultivation-related disturbances and stress.

Increasing intensity and frequency of unsustainable farming practices can potentially impair spectral absorptive capacity of plants through damage on optical apparatuses and human disturbances are capable of constituting stress regimes. They have also been found to have direct effects on plants structural organs such as leaf area index. Empirical evidence has found that these impacts become more pronounced under conditions of interactions between changing environmental conditions and anthropogenic activities. Human-related disturbances shave been identified apart from inter-annual rainfall variability, as a significant factor that can affect vegetation cover dynamics in Savanna ecosystems. Relating this scientific understanding to this study, observed low NDVI values in Keffi despite high inter-annual rainfall amounts can be plausibly attributed to weak vegetation canopy conditions under constant trampling effects from short fallow system and inter-annual cultivation.

4.1 Objective 1: To generate and inferentially analyse NDVI values in Keffi (1999-2018)

Real time rainfall observations for Keffi from the Nigerian Meteorological (NIMET) for the 20-year period (1999-2018) were regressed against annual NDVI values computed from Landsat scenes. Since selected Landsat scenes were seasonal (dry season), observed annual rainfall values were smoothed. The annual average was derived from smoothing six-monthly rainfall observations (January to June; July to December of each year). The two 6-monthly averages were summed up into annual value. The smoothed out inter-annual averages presented in table 6. NDVI values derived from Landsat Enhanced Thematic Mapper (LE 7ETM+) and Operational Land Imager (LE 8 OLI.) and computed with Arc Map 10.5. The computed NDVI values for the temporal period (1999 -2018) are presented in table 8.

Year	Observed Inter-annual Rainfall Average (mm/year) (source: NIMET)	Observed Inter-Annual NDVI Average
1999	1340	0.4371
2000	971	0.3281
2001	1171	0.4183
2002	990	0.3951
2003	1170	0.3761
2004	1081	0.3460
2005	1071	0.3405
2006	1091	0.3892
2007	1270	0.3585
2008	941	0.3708
2009	1321	0.3491
2010	1100	0.3411
2011	1040	0.3713
2012	1100	0.3798
2013	1161	0.3942
2014	1021	0.3756
2015	870	0.3748
2016	1031	0.3155
2017	1021	0.3095
2018	1017	0.2795

Table 8: Showing computed NDVI inter-annual values (1999 - 2018) and corresponding NDVI values

From the results presented in table 9, there is a noticeable variation in the inter-annual NDVI values between 1999 and 2018 over Keffi. The minimum annual NDVI value corresponding to 0.2795 is recorded against the year 2018 while the maximum NDVI value of 0.4371 was obtained for the year 1999. The 20-year 1999-2018) mean value is 0.3625. The excel-computed standard deviation relative to the mean is 0.0366 implying that NDVI values were not too spread out away from the 20 year mean value of 0.3625. The median NDVI value was 0.37 implying that a greater size of the NDVI dataset centrally tended towards 0.37 which was a more representative NDVI value that could be used in describing the conditions of vegetation cover health over Keffi.

To support the understanding of the average vegetation condition in Keffi between the research period (1999-2018) and an inferential analysis of the sensitivity of vegetation to mean rainfall values in Keffi, the temporal window was split into two-time frames; 1999-2008 and 2009–2018. Between the first timeframe, 1999 -2008, the minimum NDVI is 0.328, maximum NDVI value=0.4371, average$_{10\ \text{year}}$ NDVI=0.3761 and the standard deviation =0.0347. In the second decadal time period, 2009 – 2018; the minimum NDVI value was 0.2795, maximum, 0.3942; the 10-year average was 0.3761 and the standard deviation of the inter-annual NDVI values for this time 0.0329. The average NDVI value between 1999 and 2008 is 0.376 whereas the average NDVI value for the period 2009 and 2018 is 0.349. Optimal physiological performance of vegetation cover in Keffi was noticed during the first decadal time slice (1999 -2008) than the second decadal (2009-2018) time-slice. This variation in inter-annual NDVI averages between the two-time frames is suggestive of attenuation in the photosynthetic performance of vegetation conditions. A tabular presentation of the statistical values associated with observed NDVI and rainfall datasets is given in table 8.

Tabular Summaries of Observed Variables (NDVI, Temperature and Rainfall) in Keffi (1999 -2018)				
Variables				
Observed Mean NDVI	**Minimum Value**	**Maximum Value**	**Average**	**Standard Deviation**
20 years	0,2795	0,4371	0,3625	0,0376
1st Ten Years	0,3281	0,4371	0,3761	0,0347
2nd Ten years	0,2795	0,3942	0,3761	0,0329
Annual Mean Rainfall	**Minimum Value**	**Maximum Value**	**Average**	**Standard Deviation**
20 years	870	1340	1088	122
1st Ten Years	940	1340	1109	129
2nd Ten years	870	1320	1068	116
Annual Mean Temperature	**Minimum Value**	**Maximum Value**	**Average**	**Standard Deviation**
20 years	33,4	34,6	34,22	0,3422
1st Ten Years	33,4	34,4	34,04	0,3596
2nd Ten years	34	34,6	34,39	0,2234

Table 9: Tabular summaries of Observed measures of NDVI, temperature and rainfall in Keffi (1999 - 2018)

For the study period under consideration, the distribution of the NDVI values showed that 25% of the derived NDVI values fell within the range of ±0.3406, 50% within the range of ±0.3710 and 75% of the NDVI values were within the range of ±0.3868.

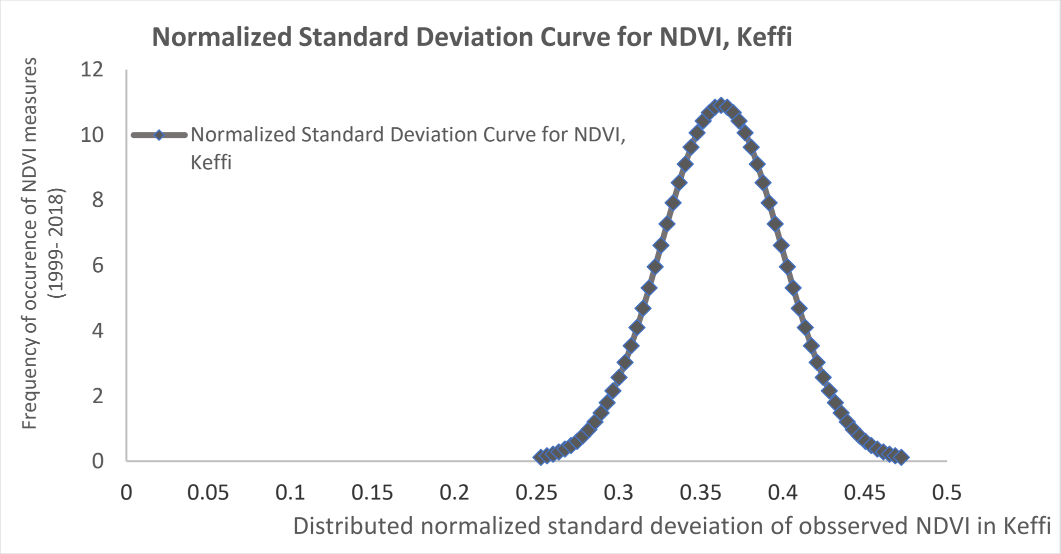


Figure 17: Normalized Standard Deviation Curve for NDVI, Keffi

A plot of the distributed normalized standard deviation of observed NDVI values presented in figure 16 also supports the inferential spread of NDVI values between 1999 -2018 in Keffi. The plot shows that observed NDVI values were two standard deviations (2σ±mean) with 0.2795 and 0.4371 as statistically significant data points. In figure 18, a trend plot of inter-annual NDVI variability is provided. The moving average trend line depicts the fluctuations of observed NDVI (vegetation greenness) between years in Keffi. A sharp decline between 1999 and 2000 is observed. Between the 2001 to 2005, a steady decline in the vegetation productivity over Keffi is observed. The observed inter-annual NDVI values from 2001 steeps further and recovers in 2006. The vegetation condition indicated by observed NDVI values recovers slightly between 2011 and 2013. A reoccurrence of steep in NDVI is observed from 2014 up till 2018. Very low values are observed between 2016 and 2018.

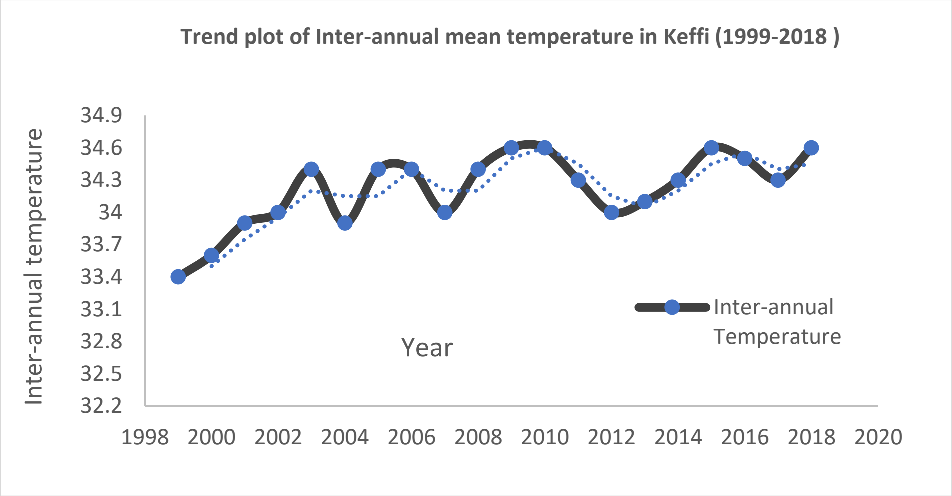


Figure 18: Plot of Inter-annual mean temperature in Keffi (1999-2018

The character of the inter-annual NDVI fluctuations over Keffi within the 20-year time frame suggests interferences in rainfall-NDVI sensitivity in Keffi. This is because the mean annual rainfall at more than 800mm/year in Keffi is within a range capable of triggering higher amounts of NDVI values. A plot showing temperature trend in Keffi is shown in figure 17.

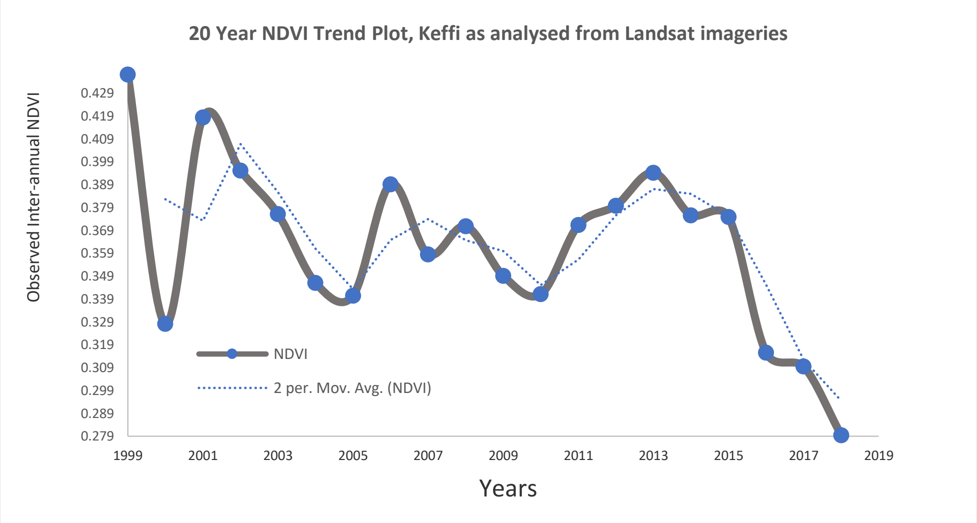


Figure 19: Twenty Year NDVI Trend Plot, Keffi as analysed from Landsat imageries

Trend series analysis of the inter-annual temperature over Keffi from 1999 to 2018, shows more of an upward trend than a downward trend. The lowest temperature between 1999 and 2018 is 33.4 degree Celsius observed in Keffi and a maximum temperature of 34.6 degree Celsius. The observed character of the climatic condition in Keffi with a steady increase in inter-annual temperature and fluctuating between years rainfall predisposes cultivated farmlands to vulnerability to climate risks.

An inter-comparison plot between NDVI and rainfall in figure 20 supports the inference that although a linear relationship between inter-annual rainfall amounts and NDVI does exists; the correlation coefficient, R= 0.359 suggests that a unit increase in rainfall amount in Keffi is only capable of producing 0.359 units in NDVI. This represents the effect size of inter-annual rainfall on NDVI in Keffi. Following Cohen (1992, pp 98–101) ranking, this effect size is not large. As would be expected in tropical Savanna ecoregions, where vegetation covers and rainfall amounts determine to a large extent, vegetation physiological performances; rainfall amounts in Keffi did not stimulate higher NDVI values. This raises plausibility of the interference of other “masked factors” impacting vegetation greenness and distribution in Keffi.

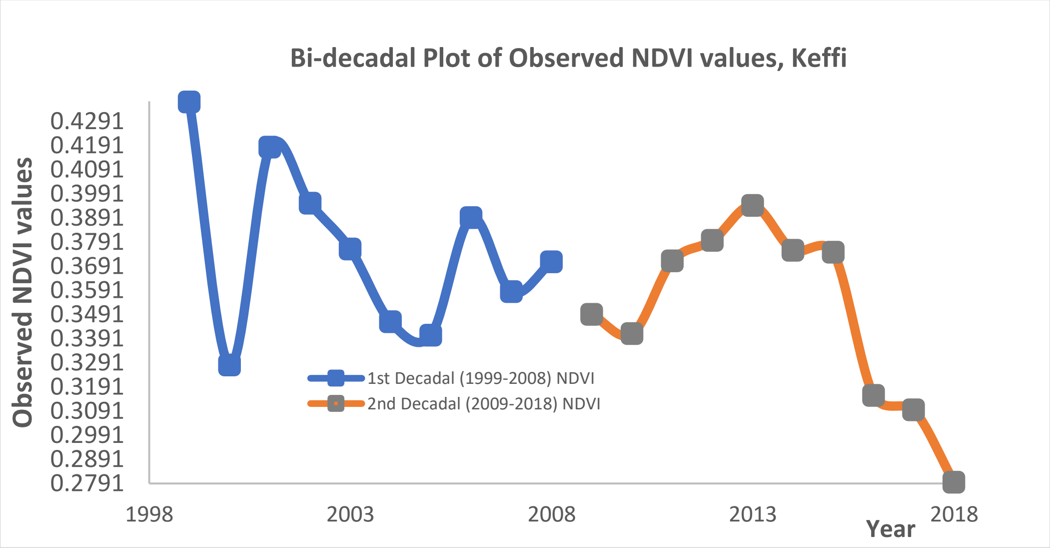


Figure 20: Bi-decadal Plot of Observed NDVI values for the temporal window of 1999 -2018

Further inferential analysis between inter-annual rainfall and NDVI amount with split time frames (1999 -2008) and (2009 -2018) showed that while there was a slight recovery between 2010 and 2013, a steep decline in NDVI values was between 2015 to 2018. The character of the observed inter-annual NDVI over Keffi has a more fluctuating pattern and is uncorrelated with the amount of rainfall. The weak recovery between 2010 and 2015 from the steep decline between 2001 and 2005 drops 2015 and 2018. This is indicative of the potential impacts of non-rainfall factors on vegetation cover conditions in Keffi.

A statistical analysis of the inter-comparison plot of rainfall and observed mean NDVI in Keffi as shown in figure 21 indicates the insensitivity of NDVI to rainfall amounts in Keffi. NDVI values decrease significantly even during peak rainfall seasons as seen in the graph. Although, there is a tight coupling between rainfall and NDVI in 1999, weak correlations between NDVI was obvious in subsequent years. This weak correlation and insensitivity between rainfall amounts and NDVI values in Keffi can plausibly associated with land management practices in predominant farming settlements in Keffi.

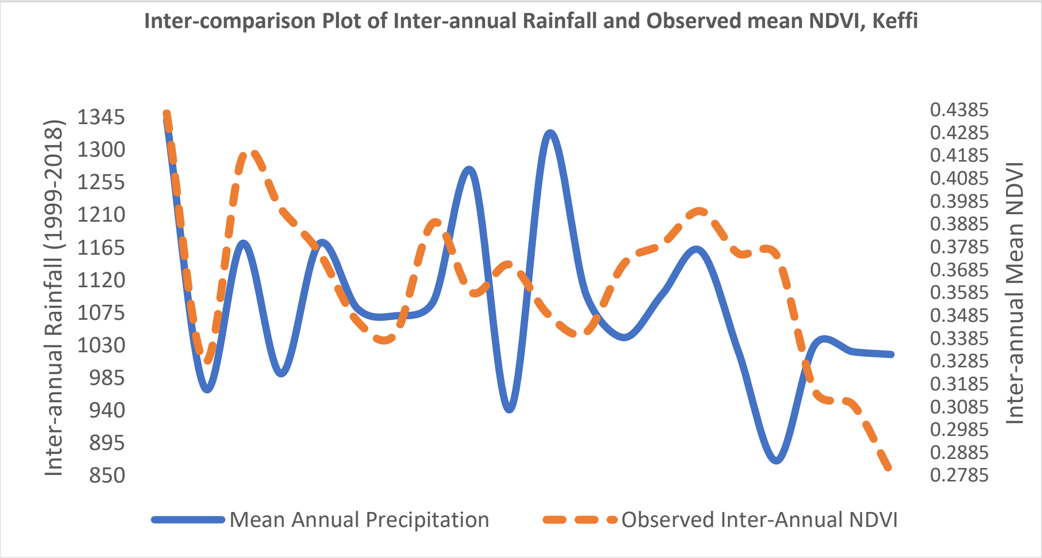


Figure 21: Inter-comparison Plot of Inter-annual Rainfall and Observed mean NDVI, Keffi

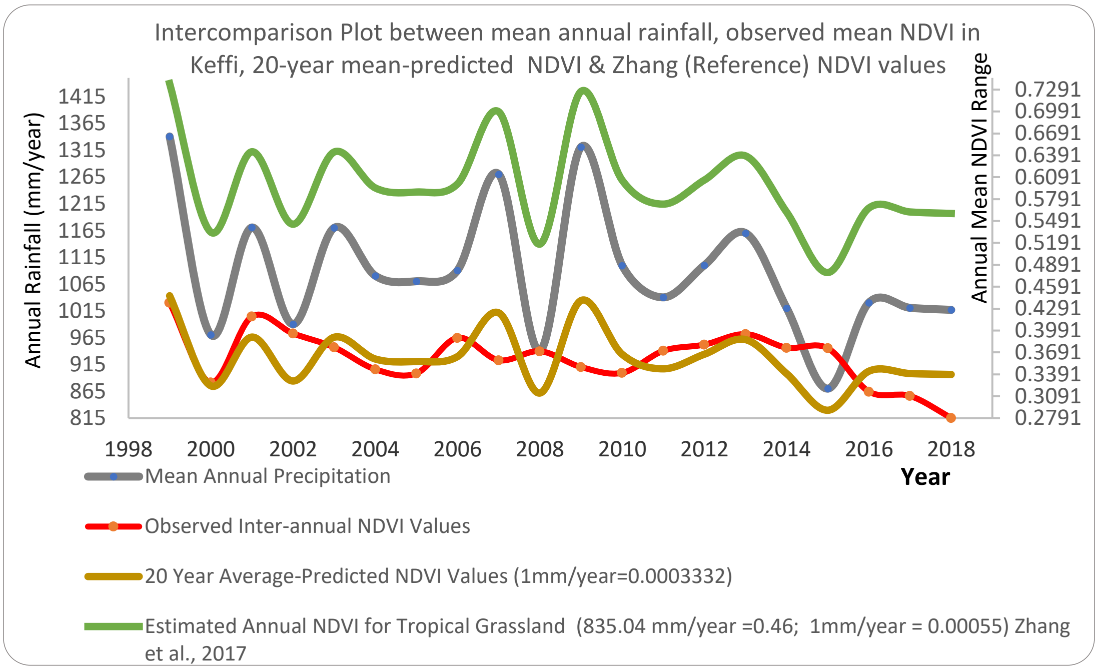


Figure 22: Inter-comparison Plot between mean annual rainfall, observed mean NDVI in Keffi, 20-year mean-predicted NDVI & Zhang (Reference) NDVI values

4.2 Objective 2: To disentangle impacts of adaptation-driven farming practices from inter-annual rainfall variability on vegetation conditions in Keffi.

Rainfall is a limiting factor for vegetation growth and productivity performance. This implies that as rainfall varies, net primary production according to Bamba et al. (2015, p 367) will vary too. Although this coupling is mostly pronounced in rainfall-limited which Nicholson et al. (1998, pp 815–830), Herrmann et al. (2005, pp 394–404) notes are common in the Sahel and arid area; the coupling reported in Fay et al. (2003, pp 245–251) and Harper et al. (2005, pp 322–334) also holds true for grassland Savannas and herbaceous scrublands. However, in altered anthromes (biomes with deep anthropogenic activities) particularly in cultural settlements with intense exploitation of resources and deep footprints of farming activities; linearity of vegetation to rainfall amounts and variation (timing and duration) of rainfall event can be interrupted by land use activities.

In addressing objective 2, a relationship between NDVI and rainfall is hypothesized as follows:

H_0: NDVI values are significantly associated with rainfall amounts in Keffi, **H_o: rainfall = NDVI**
H_1: NDVI values are not significantly associated with rainfall amounts in Keffi, **H_1: rainfall ≠ NDVI**

The set of null and alternative hypotheses is intended to investigate the degree of correlation or linearity of NDVI (vegetation productivity) with rainfall amounts over Keffi. Given the Savanna vegetation cover in Keffi, it is expected that the dense canopy cover structures provided by shrubs and grasses should be capable of triggering high NDVI due to moisture retention capability and photosynthetic sites offered by broad leaf area index. The set of hypotheses are thus based on the scientific understanding highlighted in Camberlin et al. (2007, pp 199–216). The null hypothesis, H_0 is premised on the assumptions that large rainfall amounts in the presence of dense vegetation sites should trigger higher amounts of NDVI. The alternative hypothesis, H_1 is intended to refute the null hypothesis and examine whether there is a breakdown of the assumed and hypothesised NDVI -rainfall correlation. Proving either of the hypothesis requires examining any linearity in relationship between rainfall and NDVI. To achieve a linear regression, NDVI and rainfall datasets were screened for basic statistical tests to ensure that all datasets meet certain assumptions such as normality distribution, linearity and correlation tests. These tests preceded the linear regression modelling.

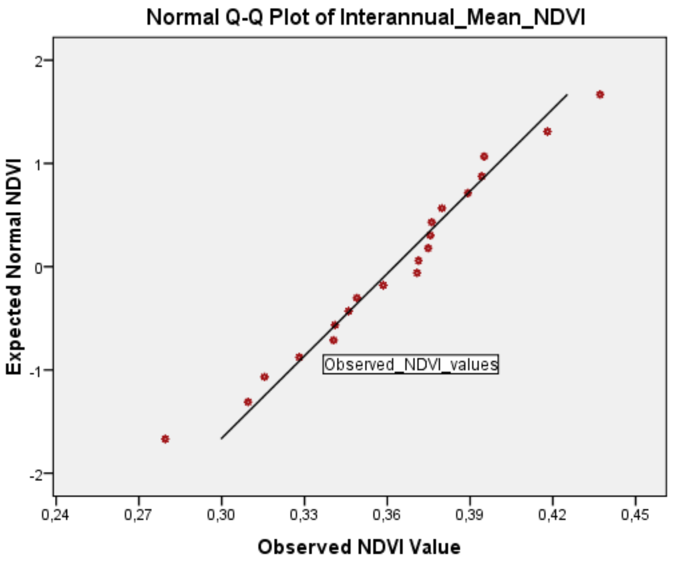


Figure 23: SPSS output of Histogram showing Normal Q-Q plot of observed NDVI values

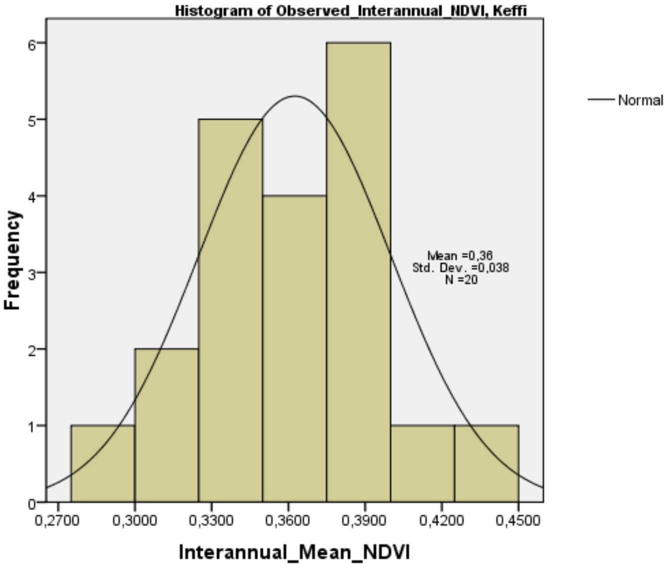


Figure 24: SPSS output of Histogram showing approximate normal distribution of observed NDVI values

4.2.1 Parametric Assumption Test of Normal Distribution of Rainfall values

Inter-annual rainfall datasets were screened for normality distribution and outliers. The computed inter-annual rainfall datasets showed no outlaying values. The normality test for rainfall datasets turned in a Skewness value of 0.956 falling within the accepted range of -1.96 and +1.96. The Kurtosis z-value for the rainfall measures was 0.069 and this was similar to the skewness value. Kurtosis z-value and the skewness value were all within the accepted range of -1.96 and +1.96 (Shapiro & Wilk 1965). Visual inspections of the associated histogram, Q-Q and Box plots (figure 23) also suggests the approximate normality distribution of the twenty years rainfall datasets over Keffi.

4.2.2 Parametric Assumption Test of Normal Distribution of NDVI Values

For NDVI values, a Shapiro Wilks test which returned a p-value of 0.931 >p >0.05, a skewness value of -0.6992 and a kurtosis z-value of -0.2813 for the normality test (figure 24). These measures as noted in Shapiro and Wilk (1965, pp 591–611) indicates that the data are approximately normally distributed. Shapiro and Francia (1972, pp 215–216) corroborated that datasets which fall within a -1.96 and +1.96 range, are approximately normally distributed. The Shapiro Wilk test p-value at p>0.931 >0.05 was significant enough to support the acceptance of the null hypothesis associated with the Shapiro normality Wilk test.

A visual inspection of the histogram, normal Q-Q plot, box plot in figure 23 showed that the annual NDVI datasets were approximately distributed with the data points clustering around the reference line. The bell shape of the histogram in figure 24 shows an agreement with the Normal Q-Q plot.

4.2.3 Parametric Test of Linearity between NDVI and Rainfall datasets

A simple scatter plot aimed at visually examining the existence or otherwise of a linear relationship between NDVI and rainfall was plotted. A positive linear relationship was established with an upward regression line at total. However, the linear relationship between rainfall amounts and NDVI values as represented by the R-square, R^2 was weak at R^2=0.129. This indicated that the relationship between rainfall and vegetation productivity (with NDVI as the quantification parameter) were not strongly coupled inter-annually. The variance is wide.

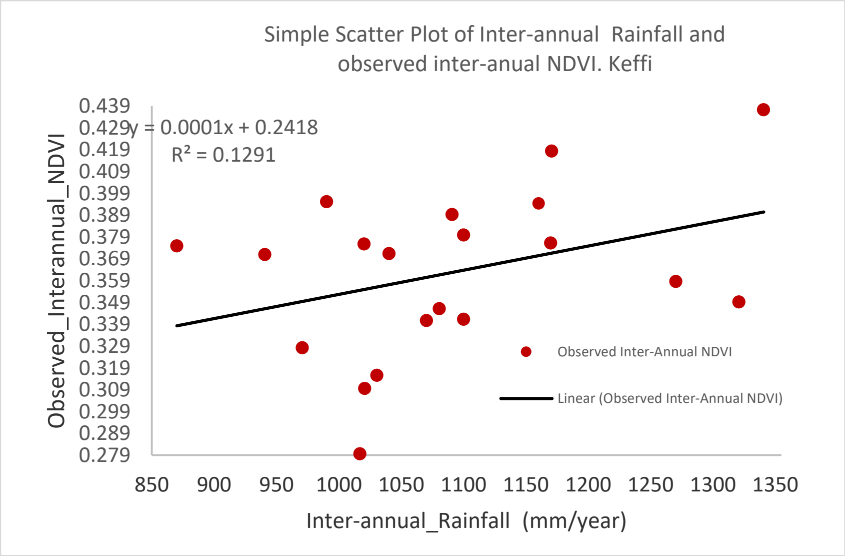


Figure 25: Simple Scatter Plot of Inter-annual rainfall and inter-annual NDVI values, Keffi

Information obtained with the regression coefficient, R^2 corresponded to the size of the correlation coefficient, r=0.359 which was obtained in the bivariate correlation test. A bivariate analysis examining the strength of correlation between inter-annual mean NDVI and rainfall amounts in Keffi returned a correlation coefficient of r=0.359 indicative of the effect size of rainfall on NDVI over Keffi. Although positive, the correlation coefficient measuring the effect size of inter-annual rainfall on vegetation condition health in Keffi was not statistically significant. While the weak correlation coefficient, *r* could be explained by factors such as sample size; the low NDVI values obtained during peak rainfall times in Keffi suggests the plausibility of intervening factors masking NDVI-rainfall sensitivity. According to (Cohen 1992), for a statistical power of any significance requiring an effect size of α =0.01, the sample size (N) should be 41 and α =0.05 for sample size of N=28. It could also be explained by the insignificance of rainfall as a predictor of vegetation greenness (NDVI) in Keffi. For example, in the year 2009, rainfall amount of 1320mm/year produced 0.3491 units of NDVI, an amount far less than 0.4371 units of NDVI produced in 1999 with almost the same amount of rainfall. In year 2000, 0.3281 units of NDVI was produced at a rainfall amount of 970mm/year. In year 2015, a 100mm/year less amount of rainfall (870mm/year) produced more units of NDVI than in the year 2000.

A linear regression analysis between observed NDVI and rainfall datasets in Keffi returned the following statistics: a regression coefficient, r= 0.359, R^2 =0.129, adjusted, R^2 = 0.80, F-change value of 2.663, a Pearson value P>0.120>0.05, a Durban Watson statistic of 1,329 and an unstandardized beta value of 0.000 for mean rainfall amount. Statistics for the standardized predicted NDVI values and standardized residuals were also obtained. The standardized predicted NDVI and the standardized residuals were -1.793 and -2.080 respectively. These values did not exceed neither -3.29 nor +3.29. The standard error of the estimate (SEE) at 0.03607 implied that observed NDVI values were less spread out from the mean NDVI value of 0.0376. The F-change statistics=2.663 and the p-value associated with the F-change statistics, p>0.120>0.05 showed that rainfall as a predictor in the regression model did not perform better. This suggested a weak statistical relationship between rainfall amount and NDVI in Keffi showing that rainfall amounts were not significantly correlated the NDVI or vegetation productivity in Keffi. The Durban Watson statistics at 1,329 was neither less than 1 nor greater than 3 and this showed the independence of observations. The slope of the regression model, β= 0.0001 which means that for every 1 (one) unit increase in rainfall amount in Keffi, 0.0001 units NDVI would be produced. This showed that rainfall is a weak predictor of NDVI in Keffi even under suitable conditions of high rainfall amounts and dense vegetation sites. The R-square, indicated that only about (0.129 ≈13) 13% of the variability in NDVI in Keffi were accounted for by the inter-annual rainfall amount. The proportion of variability of inter-annual NDVI is in agreement with the low proportion of NDVI produced by a unit increase in rainfall amount in Keffi.

Although empirical knowledge from other relevant studies such as Fuller & Prince (1996, pp 69–96) attempts to explain the influence of timescales on the NDVI-rainfall relationship in the Savanna, the rainfall–NDVI inter-annual correlation analysis in Keffi suggest otherwise. The plausibility of tight coupling between rainfall amounts and NDVI has been emphasized in Davenport & Nicholson (1993, pp 2369–2389). The study noted that rainfall is a limiting factor to vegetation growth in the tropic although the linearity is more pronounced under conditions of minimal rainfall amounts and longer timing durations such as in the Sahel and semi-arid regions. This observation is also corroborated by Dardel et. al (2014, pp 350–364) and Camberlin et al. (2007, pp 199–216).

Camberlin et al. (2007, pp 199–216) also observed that vegetation cover type also determines NDVI-rainfall coupling. In the study, open grass and croplands vegetation cover type were strongly coupled with vegetation physiological performances relative to rainfall amounts. In summary, the outcome of the linear regression showed that inter-annual NDVI values in Keffi were weakly associated with inter-annual rainfall amounts despite the Savanna ecosystem type. In the presence of ≥ 600mm/year rainfall amounts and dense vegetation sites ecosystem such as the northern guinea Savanna in Keffi; a concomitant increase in NDVI values should be expected. Where these conditions are unattainable, there exists justification to further investigate possible interferences between NDVI-rainfall sensitivity.

Taking a cue from relevant studies where impacts of non-rainfall factors on vegetation dynamics were separated from rainfall signals, standardized residuals from the NDVI-Rainfall regression were plotted against years (20 years). Standardized residual from the NDVI-inter-annual rainfall average linear regression returned a negative slope trend plot as shown in figure 26.

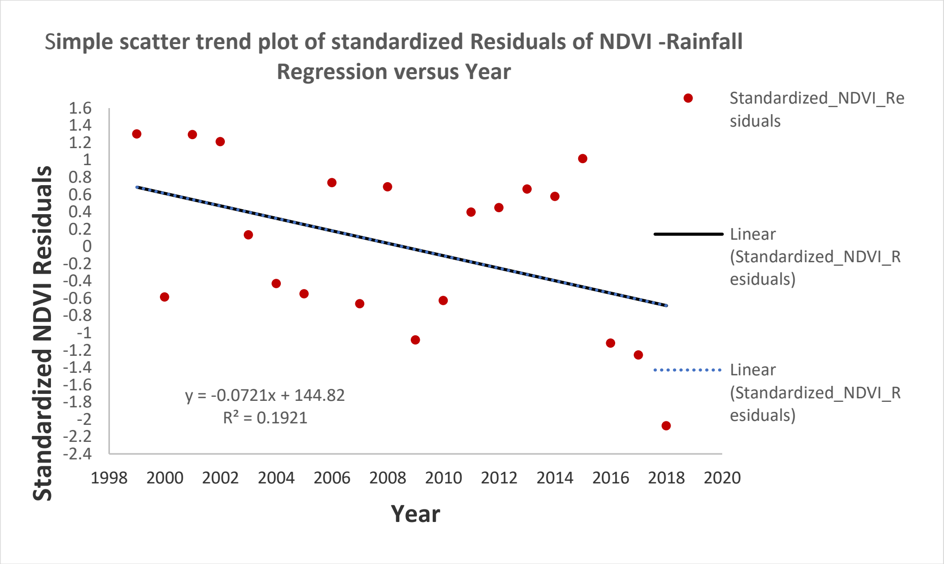
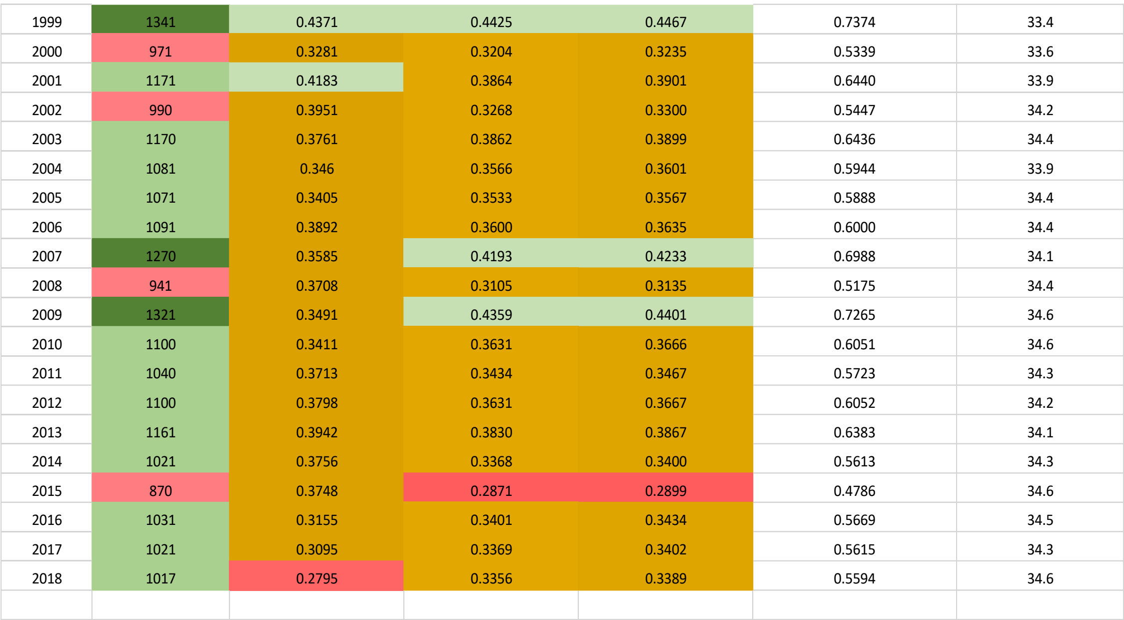


Figure 26: Simple scatter trend plot of standardized Residuals of NDVI -Rainfall Regression versus Year

The regression coefficient associated with the NDVI-rainfall residual RESTREND plot was $R^2 = 0.1921 \approx 19\%$. This is the estimated effect size of rainfall on NDVI values in Keffi. Similar to the regression coefficient associated with NDVI-rainfall linear regression plot, the regression coefficient, R^2 was low. In a study by (Evans & Geerken 2004), a downward and negative trend slope in a residual plot is indicative of a breakdown in the relationship between inter-annual rainfall amount and NDVI values presumably caused by “masked factors” like human influences. With the negative and downward directional slope of NDVI-rainfall residual trend plot, it is indicative that rainfall-NDVI sensitivity was dampened presumably by other factors contained in the residuals. Other studies which utilized the RESTREND plot in detecting influence of masked factors on rainfall -NDVI linearity such as (Wessels et al. 2007), (Zhai et al. 2015, pp. 2926–2941) and (Li et al. 2012, pp. 969–982); identified and successfully separated human influences from rainfall on vegetation dynamics.



1999	1341	0.4371	0.4425	0.4467	0.7374	33.4
2000	971	0.3281	0.3204	0.3235	0.5339	33.6
2001	1171	0.4183	0.3864	0.3901	0.6440	33.9
2002	990	0.3951	0.3268	0.3300	0.5447	34.2
2003	1170	0.3761	0.3862	0.3899	0.6436	34.4
2004	1081	0.346	0.3566	0.3601	0.5944	33.9
2005	1071	0.3405	0.3533	0.3567	0.5888	34.4
2006	1091	0.3892	0.3600	0.3635	0.6000	34.4
2007	1270	0.3585	0.4193	0.4233	0.6988	34.1
2008	941	0.3708	0.3105	0.3135	0.5175	34.4
2009	1321	0.3491	0.4359	0.4401	0.7265	34.6
2010	1100	0.3411	0.3631	0.3666	0.6051	34.6
2011	1040	0.3713	0.3434	0.3467	0.5723	34.3
2012	1100	0.3798	0.3631	0.3667	0.6052	34.2
2013	1161	0.3942	0.3830	0.3867	0.6383	34.1
2014	1021	0.3756	0.3368	0.3400	0.5613	34.3
2015	870	0.3748	0.2871	0.2899	0.4786	34.6
2016	1031	0.3155	0.3401	0.3434	0.5669	34.5
2017	1021	0.3095	0.3369	0.3402	0.5615	34.3
2018	1017	0.2795	0.3356	0.3389	0.5594	34.6

Table 10: Excel- predicted NDVI value against Zhang et al. (2017), 1999 Reference year and 20-Year NDVI Average of 0.3625

In validating outputs of the RESTREND plot, a contextual anomaly analysis was also carried out. In doing this, a reference NDVI value adapted from a study by Zhang et al. (2017, pp 2318–2324) was used in evaluating observed NDVI values for Keffi. In Zhang et al. (2017, pp 2318–2324), an NDVI value of 0.46 is descriptive of normal vegetation physiological process in tropical grassland Savanna at a rainfall value of 835.0 mm/year. On this assumption, a mathematical relationship of; (1 mm/year= X_{NDVI} =0.00055 units) was derived. This implies that for one unit increase in rainfall amount in tropical Savanna region, a corresponding predicted NDVI value of 0.00055 units were expected. The 0.00055 units per 1mm/year rainfall was used as a basis in predicting 20 years inter-annual NDVI values in Keffi. The excel-predicted NDVI values returned higher NDVI values than the observed NDVI values in Keffi (see table 10). An inter-comparison graph derived from excel-predicted NDVI values based on 0.46 NDVI/835mm/year rainfall in Zhang et al. (2017, pp 2318–2324) were higher than observed NDVI values in Keffi. This indicated that rainfall-vegetation physiological relationship in Keffi was interrupted by non-rainfall factors.

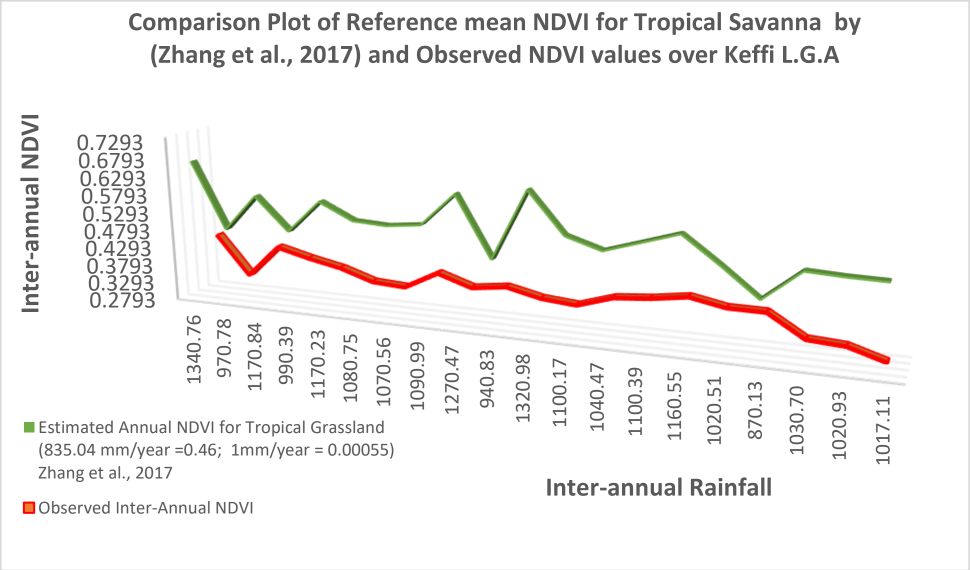


Figure 27: Comparison Plot of Reference mean NDVI for Tropical Savanna by (Zhang et al., 2017) and Observed NDVI values over Keffi L.G.A

Histogram plots in figure 28 and figure 29 were also used in inferential analysis. Frequency and cumulative percentages of inter-annual rainfall amounts and NDVI were computed for 1999 -2018. Between 1999 to 2018, the highest amount of rainfall at a cumulative percentage of 100% was 1105mm/year while the lowest amount of rainfall at a cumulative percentage of 0.00% was 870mm/year. This means that the average amount of rainfall in Keffi within 20 years was 1105mm/year. With this amount of rainfall, higher NDVI values would have been expected. The result in Zhang et al. (2017, pp 2318–2324) shows that higher amounts of NDVI in tropical Savanna are expected with higher rainfall amounts.

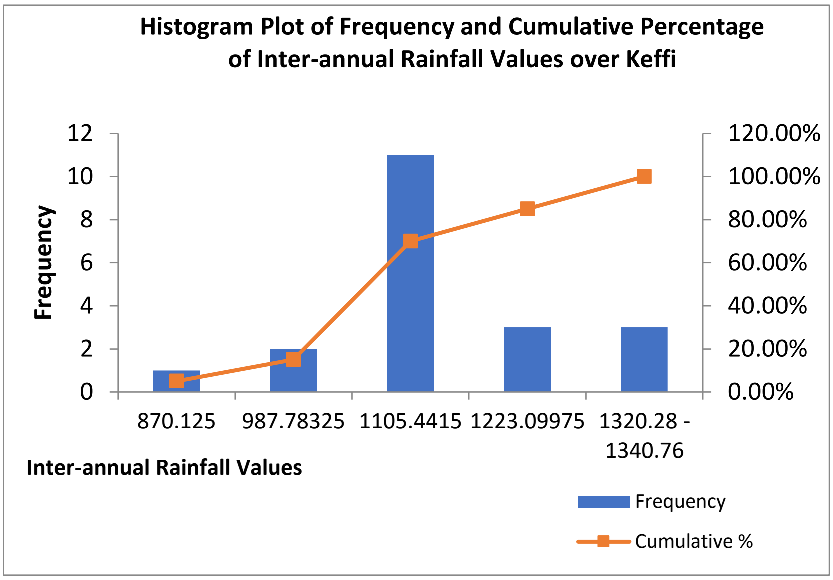


Figure 28: Histogram Plot of Frequency and Cumulative Percentage of Inter-annual Rainfall Values over Keffi

In figure 29, the NDVI value corresponding to a higher cumulative percentage is 0.3977 (100%) followed by 0.3583 which corresponds to 50% cumulative percentage. With a standard deviation of 0.0366 and a coefficient of variation, *CoV* of 0.1011; only 10.11% variation in NDVI values between 1999 -2018 was triggered by inter-annual rainfall amounts. This indicates a breakdown in rainfall-NDVI sensitivity. Observed NDVI values over Keffi showed that higher amounts of rainfall were not able to trigger larger proportion of NDVI values. This meant that either rainfall was a weak predictor or there were interferences from non-rainfall effects on NDVI in Keffi.

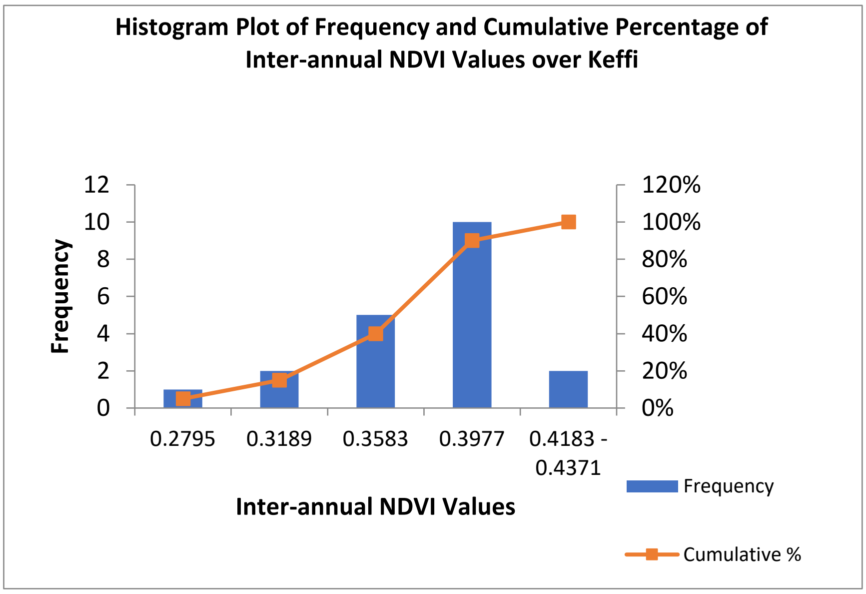


Figure 29: Histogram Plot of Frequency and Cumulative Percentage of Inter-annual Rainfall Values over Keffi

NDVI values in Keffi showed that 95% of the observed data were within the 2nd sigma rule (mean-2*σ, mean+2*σ) Rousseeuw & Hubert (2011, pp 73–79); that is between 0.2868 (minimum threshold) and 0.4332 (maximum threshold) except for (0.2795) in 2018. The 20-year average NDVI value is given at 0.3625 a low standard deviation of 0.0376. This means that inter-annual NDVI values in Keffi for the period between 1999-2018 were not significantly spread out from the mean NDVI value of 0.3625 even under conditions of higher rainfall amounts. That implies higher amounts of rainfall were incapable of causing higher photosynthetic performances in vegetation. The cumulative average of the lowest NDVI value, 0.2795 stood at 15.0% and the cumulative average of an NDVI value at 0.3189 was 40%. The cumulative percentage values indicate that the physiological performances of vegetation canopies in Keffi were incapable of exceeding 0.3977.

For example, in the year 2009, rainfall amount of 1320mm/year produced 0.3491 units of NDVI, an amount far less than 0.4371 units of NDVI produced in 1999 with almost the same amount of rainfall. In year 2000, 0.3281 units of NDVI was produced at a rainfall amount of 970mm/year. In year 2015, a 100mm/year less amount of rainfall (870mm/year) produced more units of NDVI than in the year 2000. In year 2001, the rainfall amount, 1171mm/year produced 0.4183 units of NDVI but the same amount of obtained in 2003 was unable to trigger corresponding units of NDVI. On the contrary, 1170mm/year in year 2003 produced 0.3761 units of NDVI, a difference of 0.0422. Also, years 2014 and 2017 which had equal amounts of rainfall, 1021mm/year produced distinctly different NDVI values (0.3786 and 0.3095) respectively. This non-linearity between high rainfall amounts in Keffi and vegetation physiological performance can be attributed to three plausible reasons. That rainfall in Keffi resulted in run-offs or were ineffective in triggering corresponding higher NDVI units or that vegetation photosynthetic conditions were impaired by non-rainfall signals like human land use management. The last inference stands plausible as vegetation productivity increases and decreases between years (see NDVI maps in Appendix II).

Scientific understandings as suggested from the results of related studies on the effects of physiographic factors such as soil types, climatic variables and extreme weather events like droughts on NDVI-rainfall sensitivity shows that the two major factors with significant influences on NDVI-rainfall relationship are land cover types and inter-annual variability in rainfall events (amount and timing). Related to inter-annual rainfall variability are inter-annual rainfall amounts and intervals between the timing of rainfall events. Other non-physiographic factors but with significant influence on NDVI-rainfall relationship are anthropogenic activities and fire. The following studies Camberlin et al. (2007, pp 199–216), Du et al. (2017, p 40092) and Sankaran et al. (2005, p 846) have associated low NDVI values to either marked variations in rainfall amounts or variation in timing – onset and cessation of rainfall events. Drawing from the observation by Camberlin et al. (2007) for example, which noted that NDVI-rainfall sensitivity in grassland Savanna which corresponded to high NDVI values under conditions of higher rainfall amounts were associated with dense vegetation sites (large canopy covers). The study observed that higher regression coefficient was derived at ecosystems with larger canopy cover due to the broader leaf area index.

The vegetation in Keffi is characterized with open grassland covers interspersed with cultivated crops. However, the norther guinea Savanna ecosystem type and high rainfall amounts in Keffi were unable to trigger higher NDVI values. Secondly, with the knowledge of the variability in the timing of rainfall events in Keffi (through responses from field survey and the seasonal climate reports from the Nigerian Meteorological Agency, NIMET) which indicated that many parts of Nigeria including Nasarawa state were experiencing variability in the timing of rainfall events; NDVI-rainfall relationship was nevertheless weak. Intervals between rainfall events according to Fay et al. (2000, pp 308–319) exerts significant effects on NDVI-rainfall relationship relative to rainfall amounts. Despite marked variability between rainfall events and higher rainfall amounts; NDVI values in Keffi were lower than expected. The low slope, *b=0.0001* from the NDVI-Rainfall linear regression analysis indicating that an average of 0.0001 change in NDVI would be expected at a one-unit increase in rainfall amount. According to Camberlin et al. (2007, pp 199–216), where NDVI sensitivity to rainfall is tightly coupled, leading to higher correlating NDVI values, larger regression slopes would be realized. This further reiterated the weak NDVI-rainfall sensitivity in Keffi. It also strengthened the plausibility of the influence of other masked factors in dampening NDVI-rainfall sensitivity in Keffi.

Other studies such as Dahlberg (2000, pp 19–40), Barbier et al. (2006, pp 537–547) and Camberlin et al. (2007, pp 199–216) have also generated empirical evidence showing the influence of non-rainfall factors such as anthropogenic activities on vegetation productivity. Due to the direct trampling effect from landuse activities particularly from subsistent farmers have on vegetation cover, Norman & Campbell (1989, pp 301–325) notes that plants structural organs are exposed and associated physiological functioning impacted. Land-use related trampling directly affects plants radiation absorption potential and structural apparatuses as mentioned in Claessens et al. (2009, pp 157–170) and Persson et al. (2010, pp 169–176). The linkage between damaged vegetation structural organs, functional variables and disturbance regimes has been expatiated by Gamon et al. (1995, pp 28–41). Gamon et al. (1995, pp 28–41) showed that vegetation canopy structural organs and foliar density have direct linkages with plant optical characteristics with the absorption of photosynthetically active radiation (fPAR) impaired. Thus, plants photosynthetic performances are weakened, and NDVI-rainfall sensitivity affected.

4.3 Objective 3: To analyse surface soil for the control of impact of soil nutrients and moisture deficiency on vegetation cover dynamics in Keffi.

Optimal conditions of vegetation canopies in part are dependent on soil conditions including soil chemical properties, nutrients, moisture, and soil P^H. Soil nutrients particularly nitrogen, potassium and phosphorous are critical for plant growth. However, these nutrients are sometimes depleted or unavailable for plants physiological processes. Depletion or unavailability of soil nutrients are common under conditions of unsustainable cultivation practices, harvesting and erosion. In farming localities such as Keffi, the availability of soil nutrients can be impacted by routine farming activities and unsustainable farmland management strategies. Although, this condition can be addressed with the addition of synthetic nitrogen fertilizers, the intensity and rate of cultivation and other farm-related activities can impact on indicative quantity of nitrogen in the soil. The soil analysis objective of this research was to provide an inventory of indicative quantities of soil nutrients, soil PH and soil water levels against the backdrop of support for plant growth. In this respect, soil analysis was carried out to ascertain whether the indicative quantities of key soil properties in Keffi could exert potential impact on the vegetation-soil linear relationship. It was also aimed at assessing the range of indicative values of soil nutrients and the extent to which these values differ from other related soil studies in Keffi. The soil evaluation of this study is therefore restricted to the scope of the inventorization of soil nutrients, P^H and moisture at soil surface level, 0 – 15 cm.

The soils in Keffi are mainly Oxisols and Alfisols, with Alfisols making up the greater proportion of the soil type Agbenin & Goladi (1998, pp 59–64) Møberg & Esu (1991, pp 113–129). Surface soil samples were analysed for indicative levels of soil nutrients (potassium, phosphorous and Nitrogen), soil moisture, and soil P^H. Soil sampling and analysis were carried out to control for the effect of imbalances in soil properties including chemical properties on vegetation functional conditions in Keffi. Four sampling sites were selected and sampled twice between 2016 and 2017. These four soil sample sites, Gauta (southern part), Angwan Jigwada (north-east), Angwan Tanko (close to Jaba locality in the Northern part of Keffi) and NSUK, farming settlements bordering the location of the Nasarawa state university, NSUK were selected to ensure a representative estimate of soil properties in Keffi. Results of the soil analysis showed that soil properties including available soil nutrients, as well as soil P^H were more related to common land use practices in Keffi which included subsistent farming with seasonal harvesting, livestock grazing, illegal mining and fallow corridors. The indicative soil nutrient levels were also plausibly related to the soil types in Keffi which Henao & Baanante (1999) mentioned have low nutrient levels due to their structure and cations activities.

The ability of soil to hold moisture is very important under conditions of inter-annual variability in rainfall amount and in the timing of rainfall events. Inter-annual rainfall amounts or marked variability in the interval between inter-annual rainfall events as mentioned in Fay et al. (2000, pp 308–319) are have been in most cases the defining factors of moisture availability in soils. This implies that soil moisture-interannual rainfall variability should be linearly correlated. An additional linear correlation to the soil moisture-interannual rainfall variability is also expected when plants photosynthesis is considered, and this is expected to be represented by a significant regression coefficient. This rainfall-soil moisture-vegetation linear relationship can only be significant where soil water-holding capacity is optimal and can effectively support nutrient transport, soil microbial activities and the solubility of plants nutrients. That means that soil moisture can impact rainfall-NDVI dynamics. This impact, according to Rodriguez-Iturbe et al. (2001) is largely felt in the case of marked variability in the timing of rainfall events as well as in its amounts. The amount of soil moisture determined by soil water holding capacity and the character of rainfall (variability in seasonal amounts and timing of events) are critical for plants growths. While soil structure and physical properties plays an important role in soil-plant growth relationship, Rodriguez-Iturbe et al. (2001, pp 695–705) notes that the implication of soil structure in terms of water holding capacity is very important.

Rodriguez-Iturbe et al. (2001, pp 695–705) notes that soil moisture holding capacity can exert more influence of soil on NDVI-rainfall relationship than with other soil properties. In acidic soils and soils with large water-retention capacity, Hsiao (1973, pp 519–570), notes that the influence of soil moisture retention capacity on vegetation dynamics-rainfall relationship can only be of significant impact where it exerts a dampening effect on rainfall variability (in terms of amount and timing) on NDVI. The rainfall-soil moisture retention on NDVI-rainfall correlation particularly in sub-tropical humid regions is therefore insignificant and may only affect the physiological functioning of plants under conditions of acute soil moisture reduction or an extended duration of soil moisture reduction as mentioned in Rodriguez-Iturbe et al. (2001, pp 695–705).

4.3.1 Available Soil Moisture

Soil moisture contents obtained across the sampled locations within the two sampling periods were 21.4% (NSUK, Keffi Town), 18.46% (Angwan Tanko), Angwan Jigwada (5.62%) and Gauta (4.01%). Although soil samples in Angwan Jigwada and Gauta were taken during the dry season which has implications on the level of soil moisture content; the low soil moisture obtained in these locations are associated with the textural structure of Alfisols. Low soil moisture levels in Keffi is also associated with the effect of culturally-oriented rural farming in Keffi involving short fallow cultivation and frequent harvesting. Low soil moistire levels in Keffi are also partially associated with run-offs in Keffi. Due to the texture of Alfisols soils which Batjes (1997) and Pathak et al. (2013, pp 12–21) notes are sandy or sandy loamy with low content of fine clay, low organic matter, irregular silt content and low structural stability; the amount of readily available water in the sub surfaces of Alfisols in comparison to other soils with more structural stability and cohesiveness are low and moderate. This linear relationship between soil textural cohesiveness and moisture-holding capacity, Pathak et al. (2013, pp 12–21) and Odunze et al. (1996) reported can contribute to the high runoff nature and low water holding capacity of Alfisols soils in humid tropical Savanna. Similar views on soil structural characteristics and water-holding capacity has been corroborated in Bouwman (1990) and (Landon 1984) which noted that low structural stability of Alfisols contributes to the inhibition of readily available water in the low tensions of soils.

(Landon 1984) mentioned that soils with up to 50% and 70% gravel constituents for example sandy loamy (SL) soils in tropical agroecological zones (between 40 and 70mm/m^{-1}) and loamy clay sandy(LCS) – (between 20mm and 40mm/m^{-1}) in contrast to associated indicative soil moisture range relative to soil textural properties, have medium to high water holding capacity.

The low soil moisture in Gauta and Angwan Jigwada can be attributed to the impact of yearly, non-receding land cultivation by farmers which has been mentioned in (Henao & Baanante 1999) and Voncir et al. (2006). The indicative soil moisture level in Keffi did not exert significant impacts on vegetation physiological performance. Soil played relatively minor or no impact on NDVI-rainfall sensitivity. This is in agreement with previous studies such as Camberlin et al. (2007, pp 199–216) with evidence of negligible influence of soil moisture and chemical properties on NDVI-rainfall relationship in ecoregions of humid tropical Africa. With the influence of soil moisture content on plant growth largely linked to nutrients transportation, and as a factor of rainfall amounts and occurrence; NDVI-rainfall relationship in Keffi ought to have been more correlated.

4.3.2 Available Phosphorous Concentration

The available phosphorous across the four sampling points and two sampling periods (2016 and 2017) were 1.82 mg/g (≈2ppm), 2.16 mg/g (≈2ppm), 0.523 mg/g (≈5ppm) and 0.887 mg/g (≈9ppm) with 0.3625 mg/g (≈4ppm) as mean. The lowest values were obtained at Angwan Jigwada (0.523 mg/g) and Gauta (0.887mg/g). Available Phosphorous at NSUK, Keffi Town and Angwan Tanko were not as low as recorded in Gauta and Angwan Jigwada (Table 8). (Møberg & Esu 1991) reported that available Phosphorous concentration for surface soils (0-20cm) around the Northern Guinea Savanna area of Nigeria were within the range of 3.6mg/g. In a study by Ibrahim et al. (2016), the available phosphorous concentration in the upper Northern Guinea Savanna ranged between 1.9mg/g and 5.1 mg/g. Lawal et al. (2013, pp 148–152) reported a range of between 14, 18 and 25 mg/g phosphorous within 0-20cm soil depth in the southern guinea Savanna. The disparity in the available phosphorous concentration in the southern and Guinea Savanna can be plausibly attributed to differences in soil conditions particularly the pH as mentioned in Landon (1984).

On one hand, these values in comparison with the general sufficiency range by (Landon 1984) and values documented in (Møberg & Esu 1991) are indicative of phosphorous deficiency as the estimated sufficiency range for phosphorous concentrations in sub-humid soils as noted by (Landon 1984) are <4ppm (low), 3-7ppm (middle) and > 8ppm (high). These low to moderate concentrations are associated with the soil type particularly Alfisols and Oxisols in West Africa with low nutrient reserves in Henao & Baanante (1999). Apart from the influence of soil type on available phosphorus, human activities like harvesting and soil pH can potentially affect phosphorous availability (Landon 1984). Drawing form this scientific understanding, the phosphorous ranges obtained in Keffi reflected a combined influence of human activity and type of soil. For example, at the city center, NSUK, there are more informal small entrepreneurial activities than farming activities hence the available Phosphorous concentration values were higher than Angwan Jigawa and Gauta where intensive farming is carried out. This variation according to type of land use has also been observed in (Henao & Baanante 1999) and Ibrahim et al. (2016).

			2016		
Sampling Area	Moisture Content %	Phosphorous (mg/g)	Potassium (mg/g)	Nitrogen (mg/g)	P^H
NSUK	21,41	2,16	34,88	18,8	7,04
Angwan Tanko (close to Jaba)	18,46	1,82	26,14	10,4	7,42
			2017		
Sampling Area	Moisture Content %	Phosphorous (mg/g)	Potassium (mg/g)	Nitrogen (mg/g)	P^H
Angwan Jigwada	19,62	0,523	0,229	0,84	7,56
Gauta	22,01	0,887	0,301	1,68	7,05

Table 11: Results of surface soil analysis showing indicative range of soil moisture and nutrients in Keffi

4.3.3 Available Potassium Concentration

Available Potassium concentration across sampled locations ranged between 0.2290mg/g (≈0.00587mEq) and 34.88mg/g (0.8944mEq) across the two years. (Møberg & Esu 1991) mentioned that for soil horizons of 15-30cm, the available Potassium concentration in Guinea Savanna of North-central Nigeria stood at about 0.41mEq). Lawal et al. (2013, pp 148–152) the measured potassium concentrations was within the range of 0.13 mEq/10g and 0.48 mEq/10g in Southern Guinea Savanna. In this study, and in comparison, to (Landon 2014) rating of :< 0.2 (low); 0.2 -0.5 (medium) and > 0.5 (high), the potassium concentration across all sampled locations were relatively high. These values were higher than the absolute estimated sufficiency levels for soils in sub-humid tropical regions and within the Guinea Savanna belt in Nigeria Landon (1984) and Montgomery (1988, pp 11–18).

4.3.4 Available Nitrogen Concentration

Available Nitrogen concentration levels ranged between 1.88% ≈18.8mg/g (in Keffi Town), 1.04% ≈10.4mg/g (in Angwan Tanko); 0.084% ≈0.84mg/g in Angwan Jigwada and 0.168% ≈1.68mg/g (Gauta). Havlin et al. (2005) noted that soil nitrogen in the range of 0.1 and 0.2 was documented as low; 0.2 and 0.5 as medium and greater than 0.5 was assumed optimal for plant growth. Although the Oxisols and Alfisols soils in Keffi (like other intensively-managed soils in Savanna ecosystem) have characteristically low to moderate supply of some essential plant nutrients as noted in Henao & Baanante (1999) and (Montgomery 1988); the available concentration of available soil Nitrogen in Keffi indicated the possibility of the effects of feedbacks between land use practices and organic matter content. Keffi, as in other adjoining settlements in Nasarawa state is largely agrarian and Nuhu & Ahmed (2013, p 607) notes that the common cultivation practices in these localities are unsustainable in approach. Such intensive-oriented agricultural practices have the potential impact on vegetation cover with consequences on soil organic matter and available nutrients. (Henao & Baanante 1999) also noted that low Nitrogen concentration were linked to low soil moisture and organic matter of the Alfisol soils in the sub-humid soils in Savanna ecosystems.

4.3.5 Soil pH:

The soil pH in Keffi across all sampled locations between 2016 and 2017 were between 7.1 and 7.5. This corresponds to a neutral soil pH. The values obtained from the soil sampling are in agreement with soil pH values obtained in other soil studies such as Lawal et al. (2013), Ibrahim et al. (2016) and Sharu et al. (2013, pp 137–147). Soil pH within the range of 5.5 -7.0 have been observed as favourable and optimal for plant growth and productivity Sims (1986, p 367) . Soil pH influences plants micronutrients source such as magnesium and zinc as well as their distribution. This in turn affected crop response to micronutrient fertilization. pH values obtained during the field study in Keffi were within the indicative sufficiency range for most crops and vegetation growth. In (Landon 1984), it has been noted that poor plants growth associated in parts, with poor soil fertility occur mostly in acidic soils. Low soil pH hinder the uptake of cations Jackson (1967, pp 43–124) as mentioned in Uexküll and Mutert (1995, pp 1–15). At higher soil pH values, 6.6> pH>7.5, Uexküll and Mutert (1995, pp 1–15) reported that organic matter and iron, Fe-oxide forms are more dominant implying high soil fertility and better plant performances than in acidic soils.

In terms of the effect of soil pH on the response of NDVI to inter-annual rainfall variability, soil pH range between 5.5> pH>7.0 for soils in tropical Africa show significant median r(0) relationship between vegetation productivity and inter-annual rainfall amounts as mentioned in Camberlin et al. (2007, pp 199–216). Overall, higher soil pH have minor impacts on rainfall-NDVI sensitivity. Camberlin et al. (2007, pp 199–216) also observed that only four soil types: arenoslos, vertisols and solonetz had high impact on the regression coefficient on NDVI-rainfall sensitivity. On the other hand, Camberlin et al. (2007, pp 199–216) also reported that where the presence of semi-arid conditions and open grassland covers are not able to trigger significant NDVI-rainfall sensitivity; only then in such conditions can rainfall-NDVI sensitivity be associated with soils types like gleysols, acrisols and ferrasols. With Leptosols (Oxisols and Alfisols) as the main soil types in Keffi and with neutral soil pH range of between 7.1 and 7.5; observed soil pH values in Keffi should have induced a more significant NDVI-rainfall sensitivity more than the observed NDVI values in Keffi.

4.4 Result of Social Survey and Field Observations

Outcome of Questionnaire Administration

Settlements	Elevation (meters)	Total Number of Questionnaire Allocated	Number of Questionnaire Not Completed	Number of Questionnaire Partially Completed	Number of Questionnaire completed	Percentage of Completed Questionnaire
Rimi (North)	354	54	18	4	32	59.25%
Angwan Mangoro (North West)	385	54	5	13	36	66.66%
Gauta (South)	256	54	11	8	35	64.81%
Tolo Ekuri (Center)	324	54	5	10	39	72.22%
Sabon Gari (South West)	298	54	7	14	33	61.11%
Keffi Town (North East) **	309	36	2	5	29	80.55%
Gidan Mada (West)	338	54	2	6	46	85.18%
Total		**360**	**50**	**60**	**250**	

**** Fewer number of questionnaire were administered in Keffi due to the heterogeneity of occupations**

Table 12: Table showing the distribution and completion of Questionnaire in Keffi

Social survey to identify farmers' preferred adaptation strategies and choice of cultivation practices in Keffi was carried out. Out of the 360 set of questionnaires administered during the field survey, 250 were duly completed, 50 were returned uncompleted and 60 were partially completed. A tabular representation of the summaries of the questionnaire survey is presented in table 12. Pictures taken during the survey are shown in figure 30 to figure 39.

Figure 30: Personal interview a subsistence farmer in Angwan Jaba, Keffi on her preferred cultivation methods

Personal interviews and focus group discussions were held as part of the field survey. Apart from administering the structured questionnaire, interactive discussions, personalized questions and inquiries were also sought from smallholder farmers and non-farming rural dwellers. This was done as a validation for responses from the questionnaires. While revealing the socio-economic conditions in Keffi, it also provided clarity to the reasons behind choice of adaptation options and how adaptation behaviours are shaped in Keffi, Nasarawa State. Photos showing meetings, activities, questionnaires administration, soil sampling and landscape observation are shown in figures 30 to figure 39. In figure 30, the representative of the village Head deliberates on a formal request submitted by the research team (myself and two local guides) on securing permission to carry out research in Angwan Jaba and adjoining areas. The meeting was attended by members of the village council and farmers' cooperatives

Figure 31: Two female farmers in Gauta respondimg to the questionnaire

In figure 31, two female farmers share their personal experiences on impacts of climate on crop yields and livelihoods as well as their approaches to adaptation.

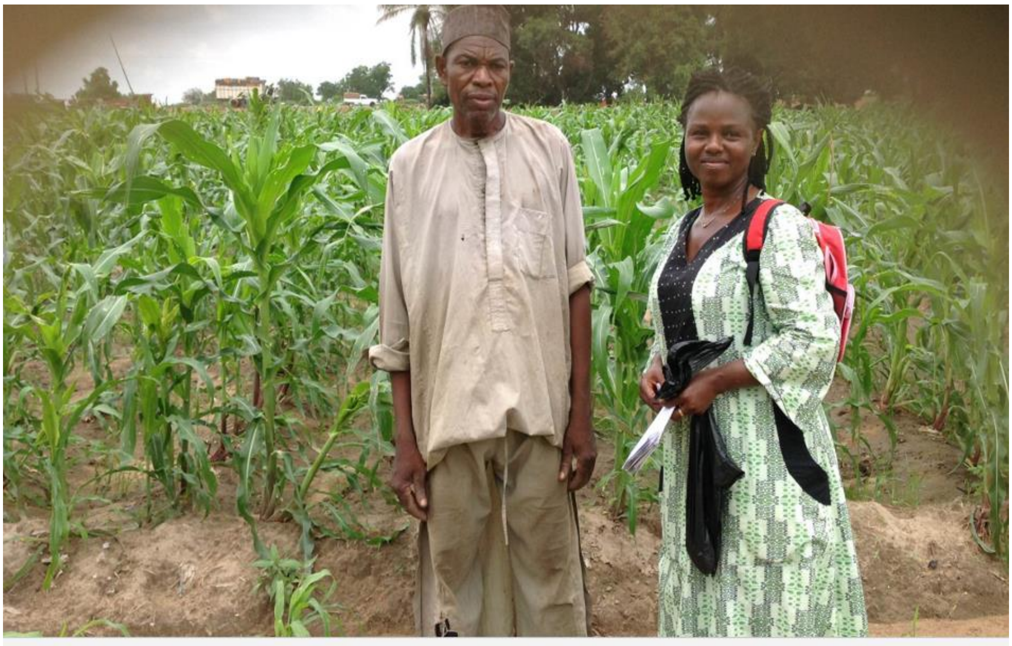


Figure 32: An Indigene farmer in Keffi responding to personal interviews on land tenureholdership in Keffi

In figure 32, an indigenous farmer describes impacts of climate variability on his corn field and the compounding challenges of lack of access to statutory land rights limiting his capability to spread risks. An excerpt of the interview is given below as well as the translation. *"Ina zama a nan, ni da iyali na. Ina noman masara, dankalin bakin mutum (dankali mai zaki - sweet potato) da kuma doya. Bani da wani sa'ana ko yanayin samun kudi sai gona. Kuma a anan Keffi kadai Na ke yi. ko wani shekara ina chanja shuki bisa ga lokacin gona. Ama ni da iyali na baza mu bar gonan nan Ba." -Respondent (local Farmer in Keffi). Translated as*: "I live here with my family and I grow corn, sweet potatoes and yam on this land. I have no other means of Livelihood in Keffi or elsewhere. Therefore, I only change the crops I cultivate yearly and as the weather changes, but I and my family cannot leave because we lack an alternative"

Figure 33: A typical farming settlement in rural Keffi with settlements clustered within farmlands.

As seen in figure 33, a larger percentage of farmlands are within rural settlements in Keffi. Due to the difficulties in obtaining permanent tenureholdership and land rights, associated in most parts with the politics of indigenes and settlers in Keffi and other parts of Nasarawa states, farmlands are clustered within settlements. This decision is influenced in part by understanding that close proximities to their cultivated farmlands is a secured way of sustaining title ownership of land. It is also, according to respondents during the field survey, a safeguard against trespassing by livestock rearers.

Figure 34: Hausa-Fulani women in Angwan Jaba selling freshly produced dairy products

The picture in figure 34 was taken in Angwan Jaba, a local settlement in Keffi. Nomadic Hausa-Fulani women are seen engaging in selling dairy products known in local Hausa language as *Fura de Nunu.* This informal enterprise is also an integral part of agricultural-oriented livelihood in Keffi. It is the backbone of the pastoral economy in Keffi managed by the Hausa and Fulani tribes. Livestock grazing is an additional land use pressure on vegetation covers in Keffi.

Figure 35: Picture showing a typical rural setting in Keffi showing the lack of physical infrastructure

Figure 36: Picture taken during soil and ground truthing survey near NSUK, Keffi

The adjoining farmlands and settlements bordering the department of geography, Nasarawa state university was one of the ground truthing and soil sampling sites. The picture was taken during one of the field visits. In figure 37, a landscape view of typical farmlands in Gauta (sorthern part of Keffi) is shown. The locality is a densely-populated farming settlement with mostly Gbagyi minorities. Due to limited land tenureholdership arising from transitory and family-oriented tenure rights, small holder farmers in Angwan Mangoro, a farming locality bordering Rimi, practice yearly mono and mixed cropping. These cultivation practices related in part to the economic pressure has impacts on vegetation and soil conditions in these localities in comparison to native vegetation cover in Keffi.

Figure 37: A farmland in Gauta (southern part of Keffi) showing sparse vegetation and loosened surface soil condition due to intensive cultivation and harvesting.

Figure 38: Landscape view of farmlands in Tolu Ekuri captured during the field survey shows the vegetation in Keffi

Figure 39: Farming frontier bordering in Keffi showing conditions of vegetation covers in two different years (2016 and 2017).

In figure 37, a landscape view of Gauta, south of Keffi assessed during the field survey is shown. Gauta is one of the densely populated farm settlements in Keffi. Given its proximate location to the major Keffi-Abuja road, expanded urbanization is penetrating into the interior areas of Gauta. Sprawling urbanization is shrinking arable farmlands triggering the growing replacement of natural vegetation with cultivated farmlands as smallholder farmers shifts the frontier of farming in Gauta in the search of land.

In figure 38, an extended farming frontier bordering Tolu Ekuri in Keffi, pictures of the spatial distribution of vegetation cover conditions. Picture (a) on the left-hand side was taken during the first field survey in May 2016 and the second picture (b) during the second field survey in March 2017. The short inter-annual fallow system by farmers in most parts of Keffi is obvious in these pictures. Due partly to the challenges of land tenureholdership coupled with socio-economic pressures in Keffi; crop cultivation as a mainstream for many rural dwellers and an alternative for holders of other vocation is expanding in intensity and scope. Increasing number of farmers are engaging in crop cultivation to bridge financial gaps and meet household food needs and given the competition over possession of community farmlands; many smallholder farmers and other seasonal and intermittent farmers in Keffi adopt short term fallow systems or continuous yearly mixed and mono cropping systems with extensive fertilizer application. Such cultivation approach has the potential of extorting stress on vegetation structure organs including foliar density as noted in Betts et al. (1997, p 796).

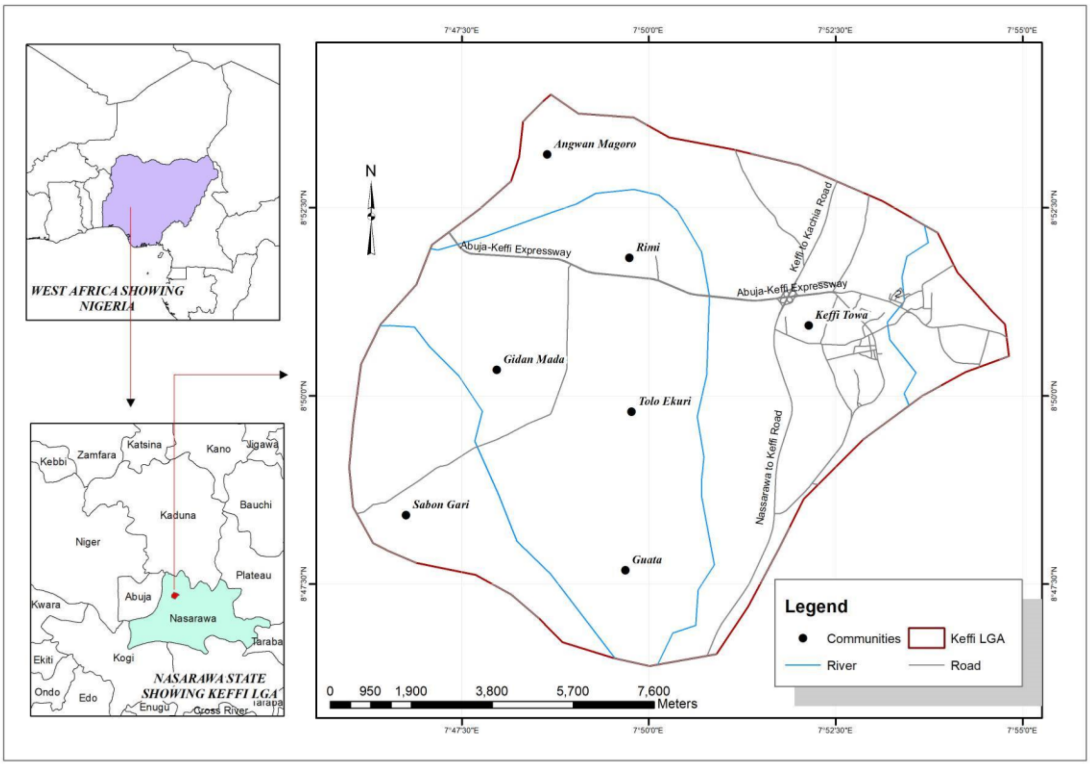


Figure 40: Farming Settlements in Keffi surveyed during the field work carried out in 2016 and 2017

In figure 40, the settlements surveyed during the field survey are shown. Questionnaire administration and focal group discussions were carried out in the communities indicated with black bullets in the map. The following settlements were surveyed, Angwan Mangoro (North), Gidan Mada (North-West), Sabon Gari (South-West), Keffi town (North-East), Rimi (North-Central), Gauta (South), Tolo Ekuri (Central).

4.5 Analysis of Results of Social Survey

4.5.1 Socio-Economic Themes (Occupation)

As derived from the statistical output, the total percentage of farmers in the sampled locations accounted for 84.4% (figure 40). Due to the link between farming and sales of crop produce as well as the transitory nature of livelihoods from farming to crop sales and vice-versa in Keffi; crop vendors were also interviewed. Crop vendors accounted for 15.6% translating to 39 frequency counts. Crop cultivation and sale of crop produce are predominant activities in Keffi. Similar observations have also been documented in Ibrahim & Umar (2008, pp 11–21). This statistic reveals the centrality of small-scale agriculture in the rural economy of Keffi.

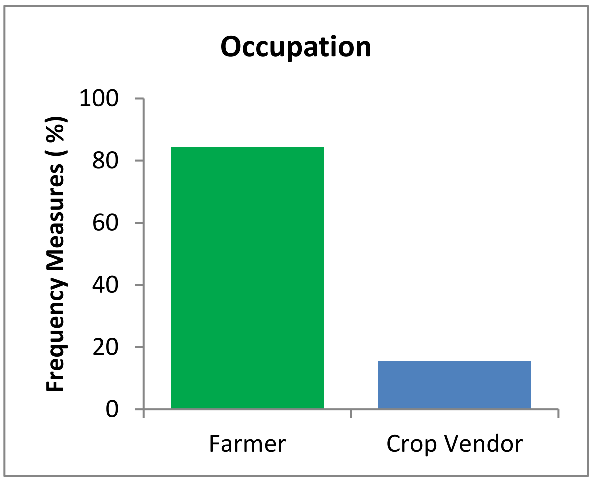


Figure 41: Frequency distribution of Subsistent farmers and crop vendors interviewed in Keffi during the field survey

As reported in Ibrahim & Umar (2008, pp 11–21), small scale farming does not only provide informal employment to over 80% of the population in Keffi ; it is also the source of substantial crop production. This accounts for the prevalence of its practice in rural communities in Keffi.

4.5.1.2 Size of Household

The bar chart in figure 42 shows the frequency counts and cumulative percentage of household size across the categories. Category 2 representing size of household of more than five members, but less than ten members accounted for 52.80%. This was significantly higher than those with family sizes in category 1 (less than five members=39.2%) and those in category 3 (8%).

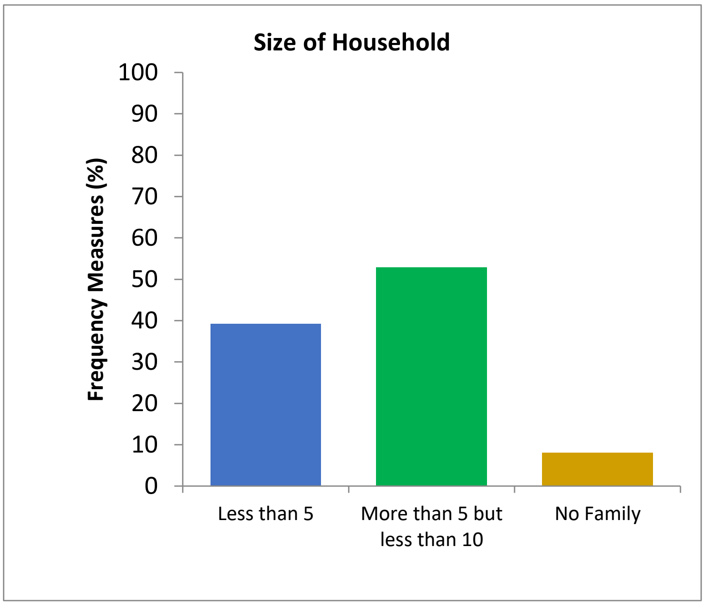


Figure 42: Statistical frequency counts and cumulative percentage of household size in Keffi

Given the strong cultural influence supporting male-dominated characteristics of the Nigerian society particularly in the Northern parts; high rates of reproduction and larger family sizes are accepted practices. The reasons are that larger family sizes provide labour for farm activities and the higher the number of children, the larger the socio-economic security for the future for the extended family and ageing family members.

4.5.1.3 Purpose of Farming

Smallholder farmers were also interviewed on the main purpose of agriculture or other land-based economic activities. This was important for understanding how this might influence the ways in which agricultural systems are managed in Keffi as well as how it determines cultivation decisions.

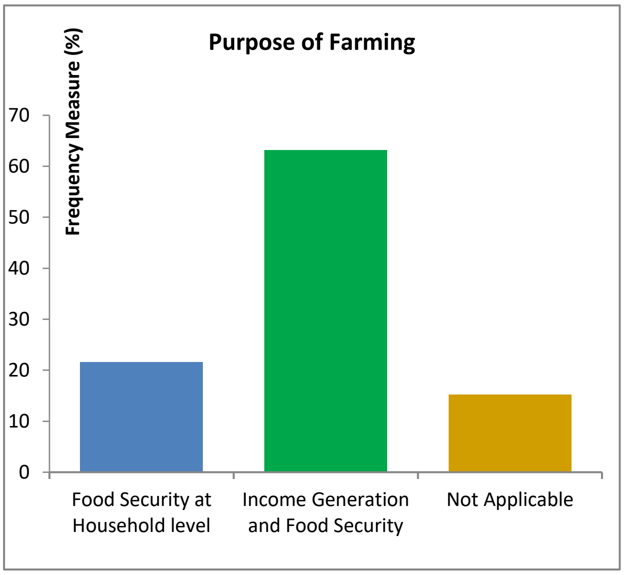


Figure 43: Statistical frequency counts and cumulative percentage on major reasons for farming

As indicated in the figure 43, 63.2% of respondents cultivated for the purposes of both food security and income generation. 21.6% cultivated for sole purpose of ensuring food security at household level. For non-farmers (crop vendors), responses from this group corresponded to 15.2% (non-applicable). Outputs of the frequency summary reveals that the primary objective of securing subsistence living and addressing basic household needs underscored the sole purpose of crop cultivation in Keffi in Labaris (2012, pp 68–74). Growing food insecurity among non-farming population in Nasarawa state has been reported in Simpa (2016, pp 108–116). The study reported that 43% of rural non-farming dwellers were food insecure. Besides achieving food security, generating household income was also a major motivation for farming in Keffi and adjoining localities. Salau & Attah (2012, pp 17–29) reported on urban farming in Nasarawa and mentioned that additional income accounted for (75.56%) and household feeding (55.56%) respectively in Keffi.

4.5.1.4 Alternative sources of Income

Respondents were asked whether or not they had other alternative sources of incomes besides crop cultivation or sales of crop produce. Figure 44 represents the frequency measures of the responses obtained from local residents on whether or not they had alternative sources of incomes. From the SPSS analysis, 72.0% reported having no alternative sources of income. However, 70 respondents (totalling 28.0%) indicated that they had alternative means of livelihoods. Non-farmers were also part of those who reported having alternative sources of income. In Keffi, small scale farming and petty trading enterprise makes up the larger proportion of the informal sector. The propensity towards small scale farming and livestock production is due to the lack of institutional environment and poor state of physical and social infrastructure to support diversification of means of livelihoods. This has been noted in Umaru & Tende (2013, p 1583)

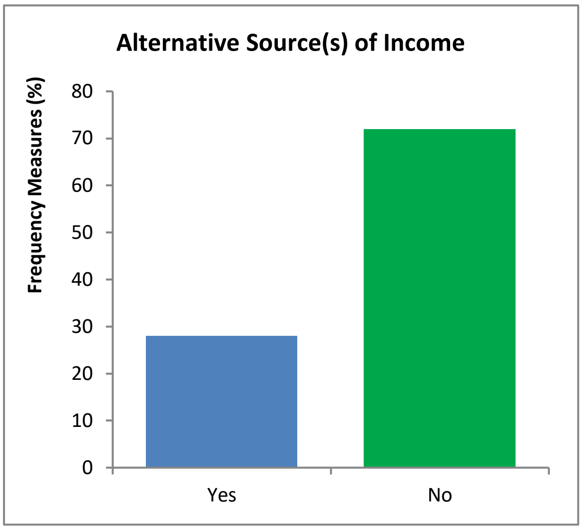


Figure 44: Statistical frequency counts and cumulative percentage on alternative source of Income within farming families

4.5.1.5 Financing of Household Needs

As part of the characterisation of the socio-economic conditions of farming settlements in Keffi, estimated size of average spending on household needs by farmers and crop vendors were undertaken. This was important due to its importance of farm incomes in household decisions (figure 45).

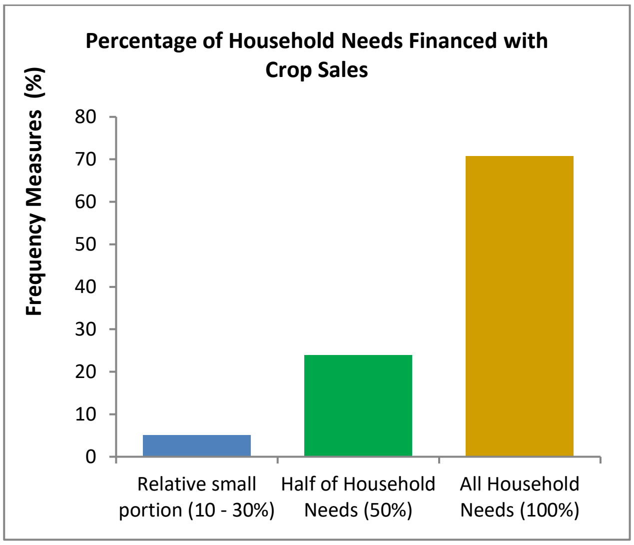


Figure 45: Statistical frequency counts and cumulative percentage on percentage of household Needs financed with crop incomes

Of all the 250 respondents, 5.2% had between 10%-30% of their household needs financed with incomes from crop sales, 24.0% had about 50% of their household needs financed through farm-based incomes and 70.8% had all (100%) of their household needs financed with incomes from sales of crop produce. This implied an over-reliance on local agricultural systems for meeting daily household needs and other social demands. The absence of technology as mentioned in Umaru & Tende (2013, p 1583) and lack of institutional incentives to provide the investment climate for diversification to non-farm opportunities increases the tendency to over-rely on agriculture. This observation was reiterated by local farmers during the field survey in Keffi. This also contributed to the expansion of human footprints in hitherto landscapes housing primary vegetation in Keffi.

4.5.1.6 Access to Government Incentives and Institutional Support

An enabling institutional environment derived from a sound agricultural policy has been argued in relevant studies as a necessary pre-requisite for optimal food production. In Fulginiti et al. (2004, pp 169–180) this has been assessed as one of the conditions that preceded the high food production during the green revolution. Thus, Fulginiti et al. (2004, pp 169–180) argues that agricultural practices in sub-Saharan Africa are likely to remain at the subsistence level due to a lack of sound and incentivising institutional conditions which the study argues eludes smallholder farmers. In figure 46, 20.4% respondents responded in the affirmative implying access to government incentives and other institutional support. On the contrary, 79.6% reported not receiving or benefitting from any support from the government.

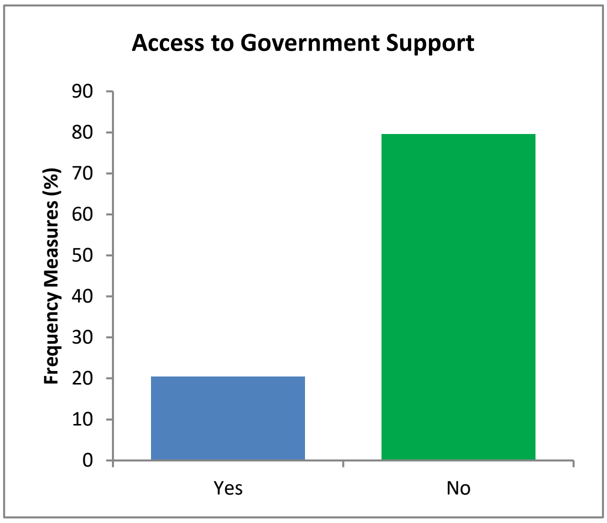


Figure 46: Statistical frequency counts and cumulative percentage on access to government support and institutional incentives

4.5.1.7 Perception Theme

Respondents' views on changes in crop yields, climatic conditions, living standards and distribution of healthy vegetation were sought. So was respondents' perception on standard of living.

4.5.1.8 Farmers Perception of Standard of Living

In figure 47, 56.8% indicated that the standards of living in Keffi was very low. This was higher than 29.6% of response corresponding to 74 counts who indicated that standard of living was low. 13.6% alluded to moderate standard of living. No value was recorded for high standard of living.

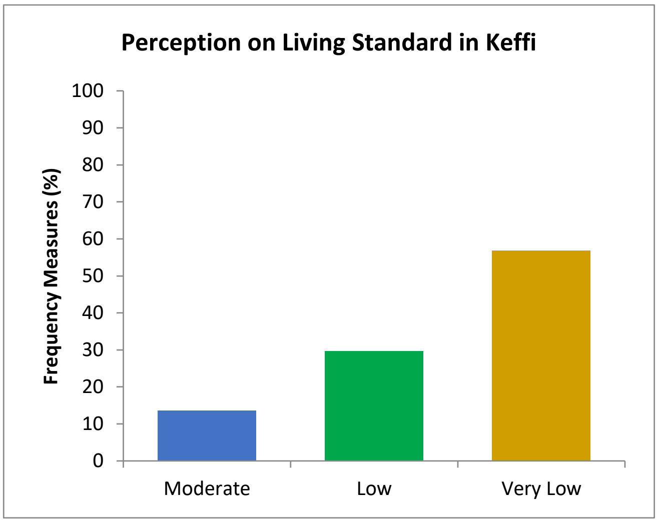


Figure 47: Statistical frequency counts and cumulative percentage on percentage on standard of living in rural Keffi

4.5.1.9 Farmers' Perception of Changes in Vegetation Cover

Personal views about changes in vegetation cover in Keffi were also sought from respondents. As graphically represented in figure 48, 26.4% were indifferent regarding whether or not there was any noticeable decline in healthy vegetation coverage. While 11.2% said there were no detectable changes in vegetation aereal coverage, 62.4% said there were detectable variations in vegetation cover in Keffi. Respondents attributed the shrinking areas covered with healthy vegetation more to rapid urban expansion in Keffi than to increase in areas occupied with cultivated farmlands.

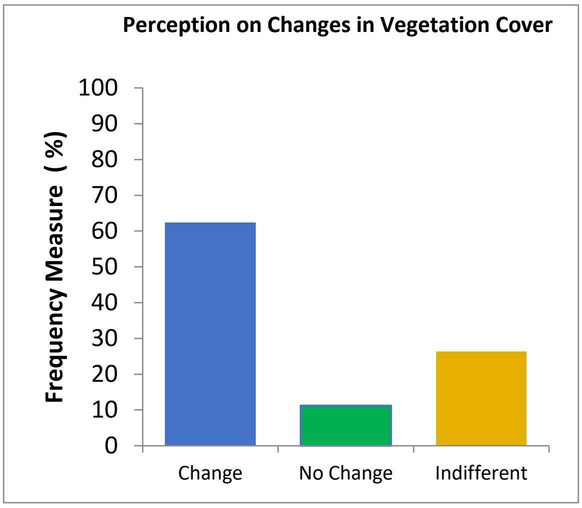


Figure 48: Statistical frequency counts and cumulative percentage on individual perception on changes in vegetation cover in Keffi

4.5.1.10 Farmers Perception of changes in Climatic Conditions

Respondents' perception about climate and weather-related phenomena were also sought. Similar studies in Keffi and adjoining areas in Nasarawa state have also documented farmers' perception and awareness or indifference with perception of shifts in climate conditions. In Luka & Yahaya (2012, pp 134–143), awareness of climate change among Sesame farmers in Nasarawa state and farmers' adaptation strategies have been reported. Bello et al. (2013, p 107) also documented that farmers' perception in Keffi and other adjoining localities in Nasarawa state were shaped not only by daily experiences but also by information from radio as well as from agricultural extension workers. Perception also came through personal observation of irregularities in rainfall events in Keffi.

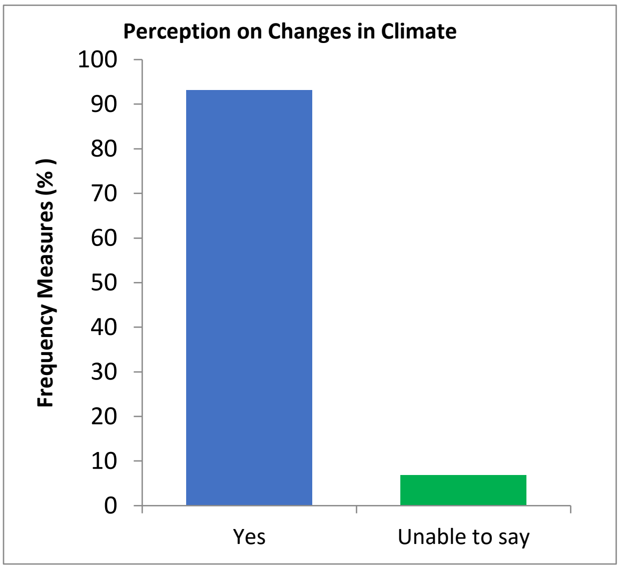


Figure 49: Statistical frequency counts and cumulative percentage on individual perception of changes in local climate conditions

As depicted in figure 49, a total of 93.2% respondents noted there were changes in local climate and daily weather conditions between the last five to ten years. 6.8 % were unable to permissibly recollect. This reflected high awareness of changes in seasonal and long-term climate conditions in Keffi.

4.5.1.11 Farmers Perception of Changes in Crop Yields

While 17 respondents (6.8%) in figure 49 said there were no visible changes in crop yields, 80%, affirmed there was a visible decline in crop yield in Keffi. 13.2% who were indifferent were crop vendors.

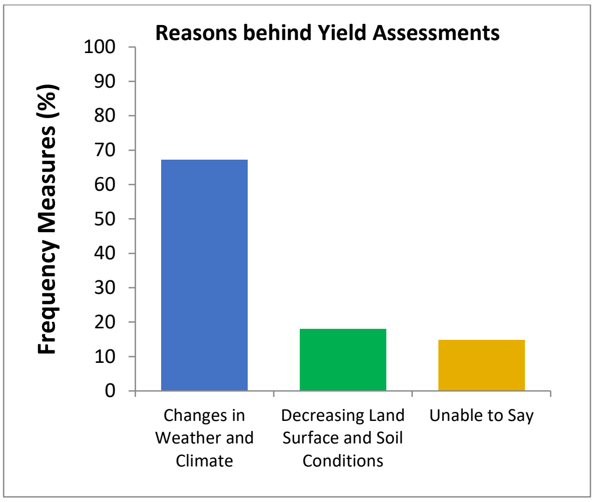


Figure 50: Statistical frequency counts and cumulative percentage on percentage on crop yields

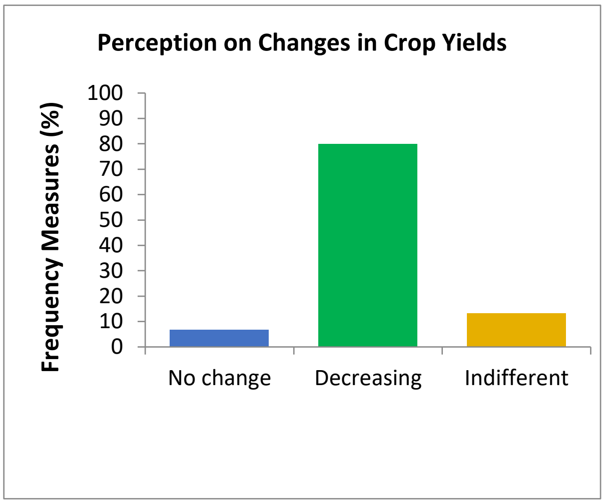


Figure 51: Statistical frequency counts and cumulative percentage on perceptions behind yield assessment

Understanding whether or not, there is an association between farmers' perception of crop yields in Keffi and the reasons behind such observations was important. The SPSS results showed that 67.2% of farmers who perceived there was a decrease in crop yields attributed it to changes in weather and climate. In figure 50, 18.0% attributed crop yield decline to deteriorating soil conditions. 14.80% of respondents were rather indifferent. Similar observation has been mentioned in Salau et al. (2012, pp 199–211) where low crop yields were reported among sesame seed cultivators.

4.5.1.12 Common Cultivation Practices in Keffi

Respondents were also asked to select from a list of categorized possibilities, the reason(s) behind different choices of crop cultivation and farm management practices. As seen in figure 52, 44.0% indicated preferences for shifting cultivation with less fallow periods as a farming technique. 2.0% (corresponding to 5 counts) allowed more fallow periods in between farming seasons, 38.4% practiced yearly mono and mixed cropping while 15.60% corresponding to crop vendors found it non-applicable.

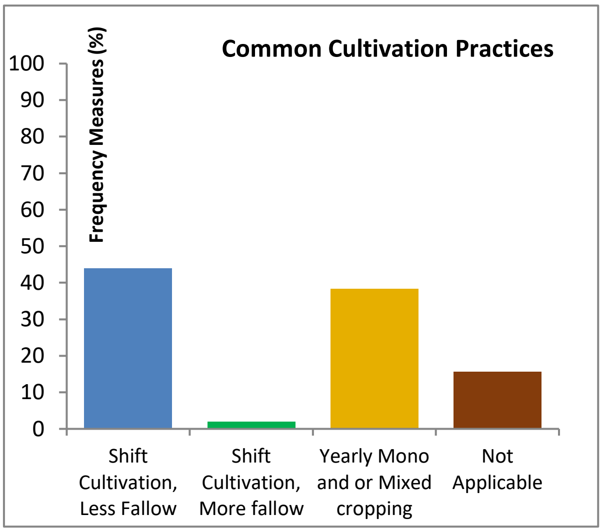


Figure 52: Statistical frequency counts and cumulative percentage on common cultivation practices in Keffi

4.5.1.13 Factors Influencing Changes in Cultivation Practices

With Keffi as an agrarian settlement, crop cultivation and livestock rearing are entrenched cultural practices supporting a large number of peasant families. To a large extent, agricultural practices are shaped by both increasing pressures of household needs and the absence of opportunities for non-farm ventures. This contributes to the growing practice of modification of cultural cultivation methods under threats of climate change. It also contributes to the intensification of food and livestock production systems in Keffi. 40.0% of the respondents attributed changes in climate change as reason behind changes in cultivation and farm management decisions while 27.6% linked reasons to insecure tenure titles. 16.4% said they changed due to availability or otherwise of crop seedlings. Underlying reasons behind preferred farming technique(s) were also sought from respondents (figure 54).

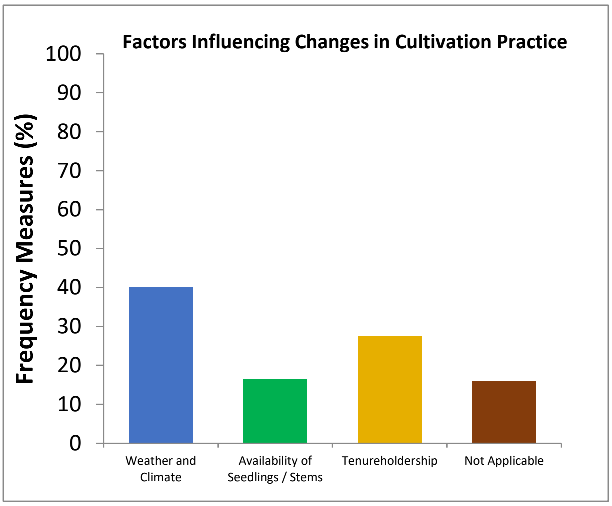


Figure 53: Statistical cumulative percentage on factors influencing changes in cultivation practices in Keffi.

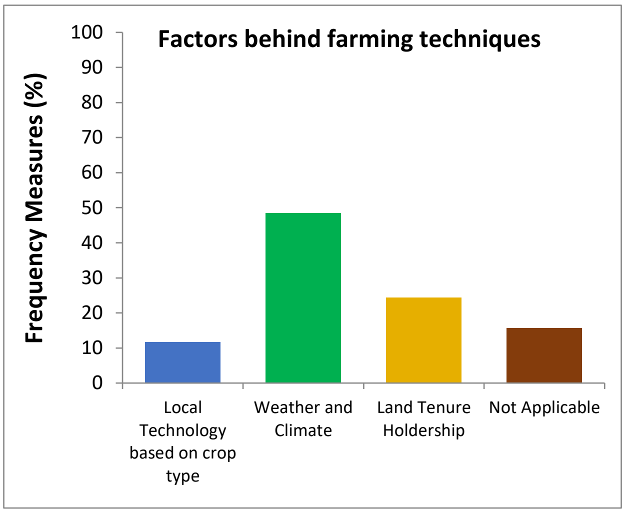


Figure 54: Statistical frequency counts and cumulative percentage on factors influencing farming techniques

In figure 53, 48.4% farmers attributed changes in weather and climate patterns as major reasons behind choice of farming technique and approach. While 11.6% adopted certain techniques at crop production based on common local technology and crop types; 24.4% of the interviewed respondents identified land tenure rights as shaping their decisions while 15.6% fond the question inapplicable.

4.5.1.14 Intensive Planting Season

Responses were also sought from respondents on preferred planting seasons and times. In Keffi, due to different choices of cultivated crops, planting seasons and times vary. In response to the corresponding question, farmers in surveyed settlements in Keffi indicated varying preferences for different planting seasons. Summary frequency measures shown in figure 55 showed that 49.20% of farmers preferred planting between November and February, while 35.20% within March and June (towards onset of the rains). 15.60% accounted for crop vendors respondents.

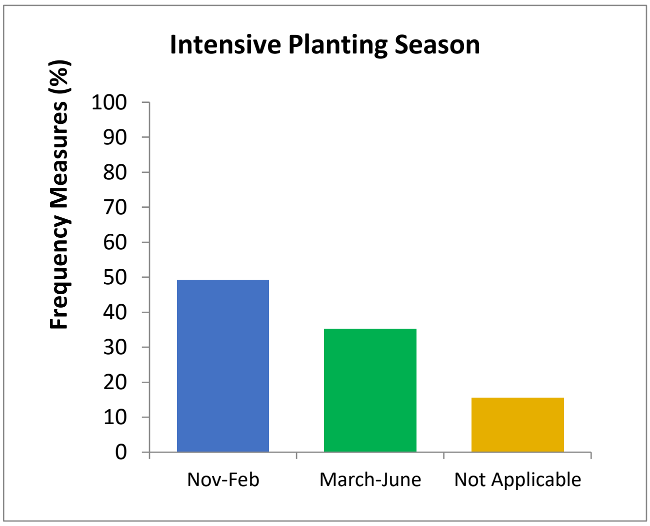


Figure 55: Statistical frequency counts and cumulative percentage on period of intensive planting season in Keffi

4.5.1.15 Coping and Adaptation Preferences

With regards to preferred adaptation options, 54.8% farmers preferred changing crop cultivation practices, a higher statistic than farmers who chose changing crop varieties (25.20%). 20.0% of the respondents elected to diversifying livelihood sources as a coping measure to climate impacts. In Bello et al. (2013, p 107); Labaris (2012, pp 68–74) and Salau et al. (2012, pp 199–211), farmers' adaptation behaviours in Keffi have also been reported. Some of the measures in these studies includes selection of drought and pest-resistant crop varieties, changing planting dates and adopting early harvesting periods for certain crop types. Cultivation of annual crops was also reported as an adaptation option.

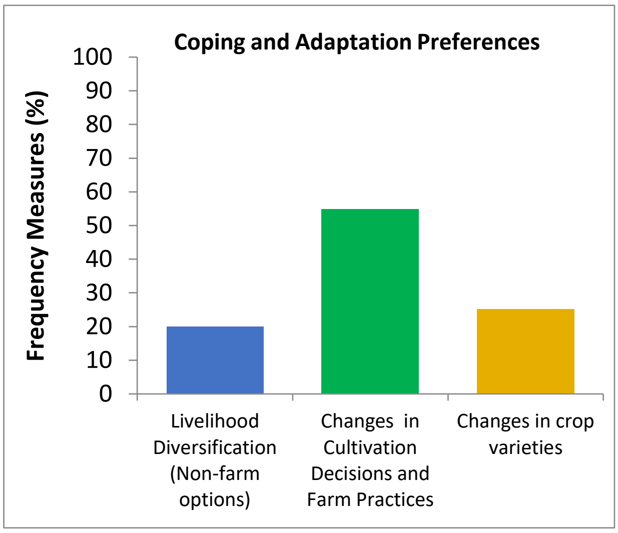


Figure 56: Statistical frequency counts and cumulative percentage on farmers' preferred adaptation and coping strategies

4.6 Hypothesis (H1): Adaptation-driven cultivation practices in Keffi do not have the potential of triggering changes in vegetation cover.

In addition to the RESTREND analysis and Zhang et al. (2017) reference-based comparative analysis in figure 27 and table 10; outputs of SPSS analysis were also used in inferentially assessing signals of human activities on vegetation cover dynamics. Farmers were interviewed on their preferred cultivation and adaptation strategies as well as reasons for selected practices. In all the surveyed areas in Keffi, statistical outputs of SPSS analysis as well as interview content analysis showed that modified farming methods and practices were evolving in Keffi under pressures like climate change and shrinking arable land areas due to sprawling urbanization in Keffi. In refuting or accepting the hypothesis, crop cultivation and farm management practices were evaluated and the extent to which underlying factors drove changes in these landuse practices was investigated. Local farming practices and autonomous adaptation strategies by smallholder farmers in resource-limited rural communities are more often than not actions characterized by intense and non-receding landuse practices. Given the fact that these adaptation practices are lacking in technological and institutional supports; farm-gate level adaptation practices are unsustainable and potentially constitute disturbance events on land surface phenology. With the exposure of vegetation covers to intensive farm use and management practices, there is the potential of autonomous farm-gate level adaptation practices impacting structural variables of vegetation.

Figure 52 shows that 44.0% of farmers practiced shifting cultivation with less fallow periods and 38.40% of small holder farmers in the area practiced yearly mono or mixed cropping. This was higher than 2.0% who practiced shifting cultivation with more fallow periods. In terms of preferred adaptation strategies, 54.80% smallholder farmers chose to change cultivation practices, and this was statistically higher than 20.00% of farmers who would rather diversify livelihoods means and 25.20% of small holder farmers in

Keffi who elected to change crop varieties. The introduction of household characteristics and economic variables as explanatory variables was aimed at examining the influence of socio-economic pressures on crop cultivation practices in Keffi and the degree to which these changes influence farmers' behaviours. The p-value associated with the frequency of farmers who elected changing crop cultivation practices under the potential influences of economic pressures was significant at P<0.000<0.001.

4.6.1 Purpose of Farming versus Changes in Cultivation Practices

In understanding the role of household characteristics and needs in shaping cultivation and adaptation decisions, a cross tabulation between purpose of farming and changes in cultivation was generated.

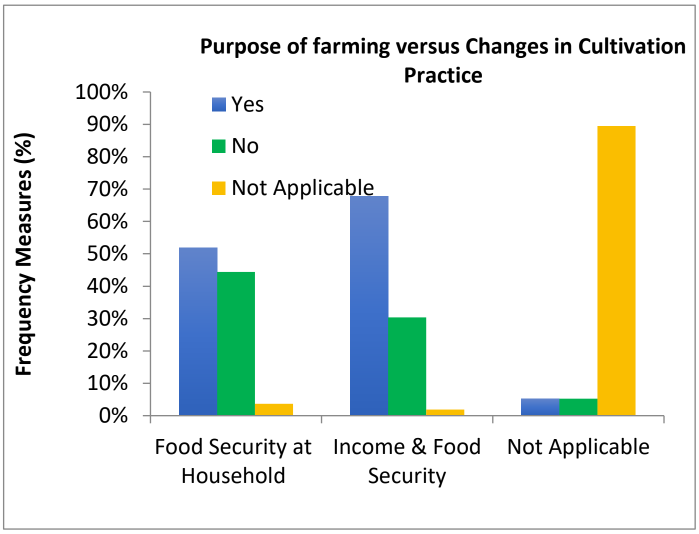


Figure 57: Cross tabulation on correlation between farming purpose and changes in cultivation practices under climate constraints

The graphical output of the crosstab analysis presented in figure 57 showed that farmers who modified cultivation methods were higher in both categories of farming purpose (food-secure and both income and food). At a p-value of p<0.000<0.01, 67.72% of smallholder farmers in Keffi who cultivated both for food and secured incomes changed their cultivation practices as against 30.38% in the same category. A higher statistic was also recorded for farming respondents who whose main purpose of farming was to ensure food security at household levels with 51.85% affirming shifts in approach to local farming practices due to climate change. This was statistically higher than 44.44% in the same food-secure only category.

4.6.1.1 Purpose of farming versus changes in cultivation practice (non-farm income sources as control variable)

Observing whether the lack of non-farm livelihoods exerted additional pressure on farmers in Keffi to the extent of driving changes in approach and decisions towards the management of cultivated land; alternative source of incomes was added as a control layer. Results from the crosstab in (Fig 53, 54, 57) showed that economic pressures played a significant role in farmers' behaviours regarding both the management of agricultural assets and climate adaptation practices. 72.22% of food secure-only farmers without alternative sources of incomes modified their cultivation practices as against 27.78% in the same category who had other non-farm means of livelihoods. Similarly, 79.75% of dual-purpose farmers without alternative sources of incomes also changed farm management practices, a statistic higher than 20.25% of farmers who did not change but in the same category. Overall, across the categories of those who changed their approaches in managing cultivated farmlands; statistics were higher than farmers who did not modify cropping methods including inter-annual mono and mixed cropping on same or proximate farmlands. This is represented graphically in figure 58.

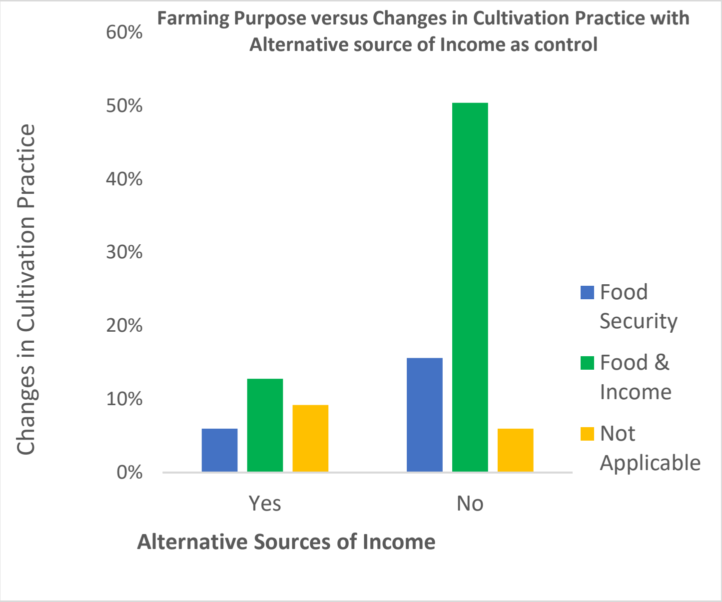


Figure 58: Cross tabulation on 3 variables: farming purpose, alternative source of income and changes in cultivation

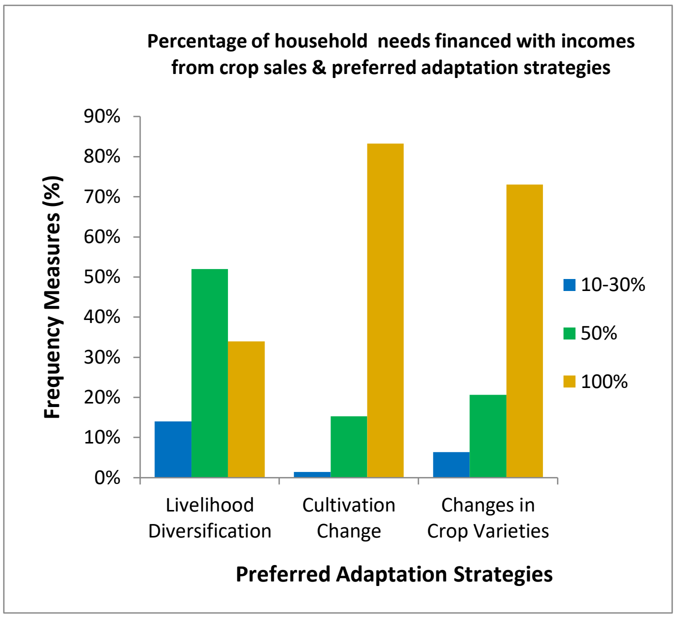


Figure 59: Cross tabulation on percentage of household needs financed with crop sales and preferred adaptation strategy

Change in Cultivation	FarmPurp			
AltSource	Food Security	Food & Income	Not Applicable	Gesamtergebnis
Yes	27.78%	20.25%	60.53%	28.00%
No	72.22%	79.75%	39.47%	72.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 13 : Pivot table showing statistical outcomes on the relationship between purpose of farming and changes in cultivation practices by farmers in Keffi

4.7 Hypothesis 2: Smallholder farmers' livelihood circumstances in Keffi have no influence on their preferred climate adaptation strategies.

The significance level associated with the statistical outputs with household characteristics and socio-economic explanatory variables was high. In figure 59, 50.40% of farmers in category [FarmPurp 2] - dual purpose farmers who did not have alternative sources of income changed their cultivation practices. The observed statistics was higher than farmers in the same category (15.60%) who without alternative sources of off-farm income changed their cultivation practices. Frequency statistics for farmers who changed their cultivation practices was higher in the category of those without alternative sources of incomes than farmers with additional non-farm means of livelihoods. In terms of the household financing, the statistics associated with farmers with different sizes of household needs financed wholly or partially with income from crop sales varied.

Smallholder farmers who financed their household needs with 100% and who preferred to change their farm management and crop cultivation practices were 83.21%. This statistic was relative to other adaptation options (diversification to non-farm livelihoods and changes in crop varieties). 83.21% was higher than 15.33% of farmers who only addressed about 50% of their household needs with crop incomes. Farmers whose one third (10-30%) of their household needs were supported with farm income and who preferred changing cultivation practice accounted for only 1.46%. Comparatively, the cross tabulation showed that changes in crop varieties followed modification in cropping practices. 73.02% of farmers covering 100% of their socio-economic needs with farm produce preferred changing crop varieties to changing cultivation practice. The statistic associated with changing crop varieties, 73.02% was higher than 20.63% (those who covered only half of their needs with incomes from farm sales) and 6.35% (those who covered between 10 -30% of their needs with incomes from farm sales)

Further chi-square test analysis to investigate whether or not there is discerning relationship between socio-economic explanatory variables and preferred adaptation decisions revealed a strong association. 67.72% of farmer respondents in Keffi cultivating crops for dual purposes of food security at household incomes indicated that they had changed cultivation methods and farm management decisions. This was higher than 51.85% of household food-security only farmers who. Both single-purpose (44.44%) and dual-purpose (30.38%) farmers who indicated not changing their farming methods recorded statistics that were lower than farmers in the same categories who modified their cultivation practices. Besides the statistical measures (48.40%) associated with climate-related reasons for influencing farming techniques in Keffi; land tenure insecurity was identified for influencing cultivation and adaptation practices in Keffi.

24.40% respondents accounted for farmers whose farming techniques were shaped by land tenure rights. Insecurity of land tenure in Keffi also impacted other adaptation choices.

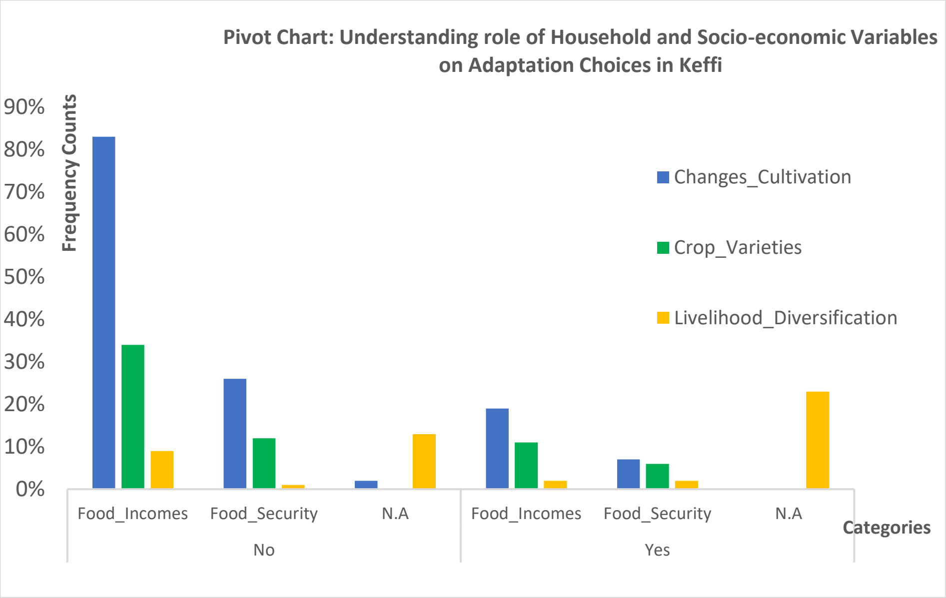


Figure 60: Pivot Chart showing statistical effect of socio-economic variables on preferred adaptation choice

Understanding the extent to which socio-economic and household characteristics variables influence farmers' adaptation choice was also investigated. The pivot chart in figure 61 showed the influence of farming purpose and size of household finance on adaptation choice. Farmers who lacked alternative means livelihoods and who cultivated largely for food security and household incomes accounted for 83% of those who changed cultivation methods. This was higher than 34% of farmers in the same category (FarmPurp). Respondents who did not engage in subsistence farming (crop vendors) indicated preference for diversification of livelihood options in the face of changes in local climatic conditions.

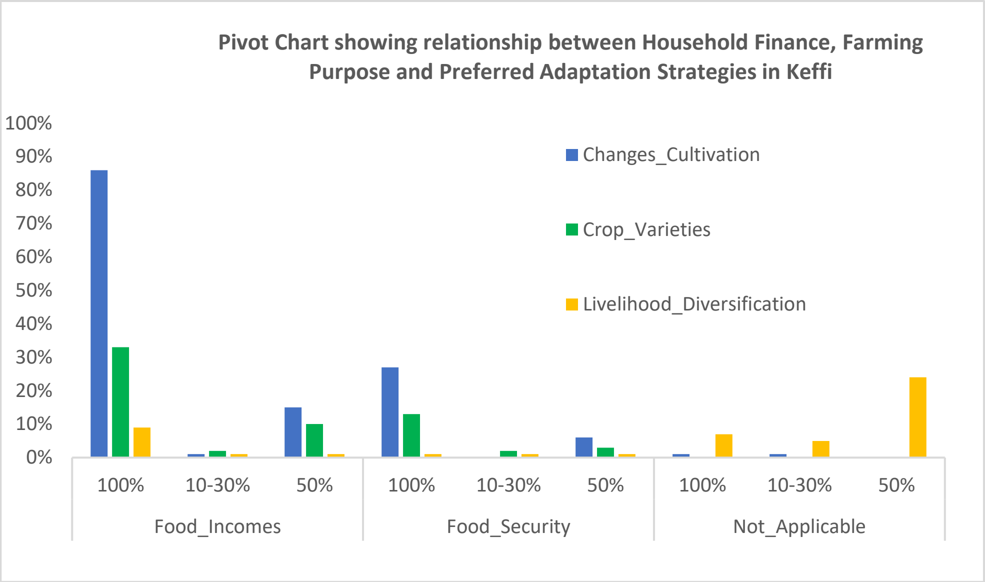


Figure 61: Pivot Chart showing statistical relationship between size of household finance, farming purpose and preferred adaptation strategy.

The proportion of farm income utilized for meeting household needs in relation to how this affected adaptation strategies was also examined. With the purpose of farming as a control variable, the pivot chart in figure 61 revealed that the preference for changes in cultivation practice relative to other adaptation options were higher. 86% farmers who cultivated for both income and food supplies and who addressed 100% of their household needs with incomes from crop sales preferred changing cultivation practices compared to 27% in the same (100% household needs). In comparison to farmers whose half (50%) of their household needs were financed with farm sales; the statistics was higher.

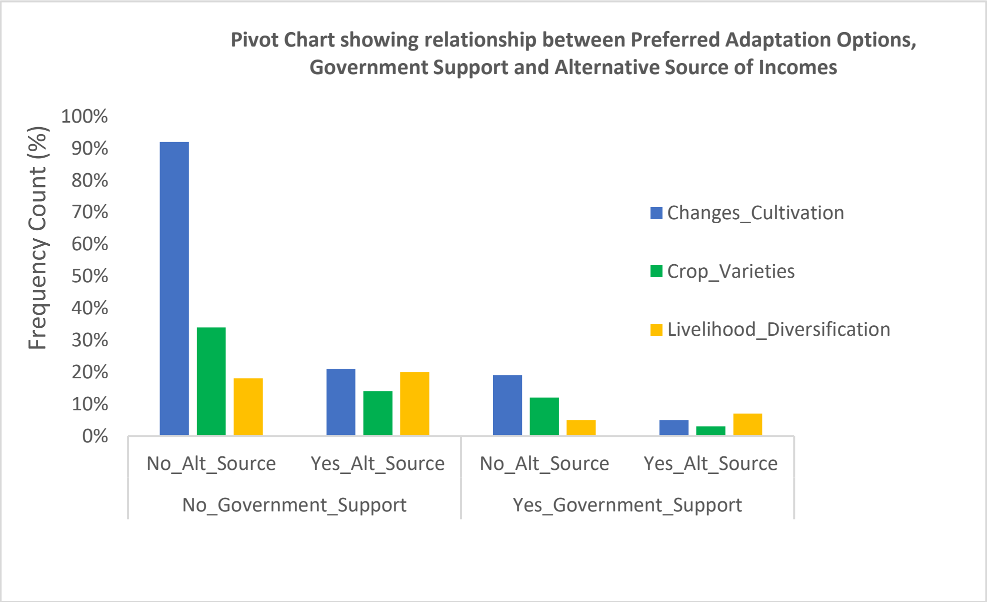


Figure 62: Pivot Chart showing Preferred Adaptation Options, Government Support and Alternative Source of Incomes

Lack or the incapability in accessing institutional incentives from the government was also investigated. The pivot chart in figure 62, shows that absence of incentives like credit schemes and fertilizers underpinned farmers' preference for adaptation strategies deemed efficacious in the short term.

4.8 Outputs of Multinomial Logistic Modelling (Understanding factors influencing adaptation choices)

The MNL outputs were also applied in validating outputs of pivot tables and chi-square test results. From the MNL outputs obtained, the probability of farmers in the category, [FarmPurp1– food security only purpose farmers] preferring livelihood diversification to changes in farming practices (the Reference category) was (-4,962) less implying less likelihood for diversification of livelihoods. For farmers in [FarmPurp2– both food security and income-generation purpose farmers], the probability associated with changing crop varieties relative to the reference category was 4,714 times higher. Smallholder farmers rather than diversify to non-farm livelihoods preferred changing cultivation practices which was considered more practicable against the backdrop of a lack of enabling environment including lack of access to incentives and infrastructure.

Besides, the effect of weak institutional conditions, transitory land tenure rights also influenced farmers adaptation practices in Keffi. An example is the opinion expressed by indigenous farmer and mentioned in Page 77 where the farmer expressed fear of moving away from Keffi due to the uncertainty in tenureholdership rights. Adaptation behaviours by poor farmers are also linked to challenges with land tenure rights. Tenure impermanence and transitory rights influences significantly cultivation decisions at rural communities. Similar observation has been mentioned in Sjaastad & Bromley (1997). Beside the challenge of tenure impermanence, the short-term goal of deriving household food security increases the preference by farmers in Keffi for altering cultivation practices. The practice is particularly common in poor localities where farm-based livelihoods are intricately linked to household decisions and explains why modification of cultivation practices and farmland management decisions were most preferred. As against other adaptation strategies such as changes in livestock management in Bryan et al. (2009); tree planting in Thomas et al. (2007); changes in land management practices in Mongi et al. (2010); irrigation in Sanfo et al. (2017, pp 80–89) as well as agro-forestry and changes in planting dates; farmers in Keffi were limited to few options. In Keffi, limited access to factors of production and inadequate institutional support disincentivized to a greater extent, longer-term and more sustainable adaptation practices among smallholder farmers.

Preference for less cost-intensive adaptation practices have been mainly related to socio-economic and institutional constraints as well as income-size determined capabilities as noted in Fischer and Connor (2018). Farmers' limited resource capabilities and scare assets base influences farmers' choices for more sustainable adaptation strategies. For example, Arunrat et al. (2017, pp 672–685) found that size of farm incomes and social capital statistically influenced farmers' decision to adapt. So did the role of household characteristics and social capital on the farmers' adaptation behaviours in Zamasiya et al. (2017, pp 233–239). In a study by Le Dang et al. (2014, pp 531–548), besides the role of perception of higher climate risks on cultivated crops; challenging socio-economic situations also impacted adaptation decisions. Farmers' income levels mentioned in Ayansina & Adeogun (2017), size of household and education level of head of household reported in Bryan et al. (2013, pp 26–35); (Mulatu 2013) are some of the frequently cited factors which affects farmers' adaptation behaviours. Similar circumstances also hold true for Keffi. In Falaki et al. (2011, pp 49–62), Salau et al. (2012) and (Labaris 2012), smallholder farmers in Keffi and other adjoining localities in Nasarawa state at large preferred changes in cultivation practices as adaptation pathway. Although seldomly practiced, crop diversification and agro-forestry were other adaptation strategies in Keffi and other rural settlements in northern-central parts of Nigeria. Results from both the chi-square test and multinomial logistic regression and the p-value associated with them provides evidence to establish significant association between socio-economic explanatory variables and climate adaptation preferred strategies and cultivation methods in Keffi.

4.8.1 Percentage of Household Needs financed with Crop Incomes and Adaptation Choice

In figure 59, statistical outputs suggest a stronger correlation between the percentage of household needs financed with incomes from crop sales and preferred adaptation choices was detected. At a significant p-value of $p<0.000<0.001$; farmers whose total household needs (100%) were financed with incomes from crop sales were higher for the category, "changes in cultivation practices" followed by "changes in crop varieties". 83.21% of farmers who fulfilled about 100% of their household demands with incomes from crop sales modified cultivation methods and farm management practices. 73.02% of farmers in the same (100% financed) category preferred changing crop varieties. The statistics associated with those who fulfilled all their household needs with proceeds from crop sales were higher than those who only invested 10-30% and 50% of farm incomes towards addressing household needs.

Other explanatory variables such as percentage of household needs financed with crop sales were also analysed to identify whether or not there was any statistical association between the variables. At a p-value of $p<0.000<0.001$, a significant association between percentage of household [House FIN] needs financed with farm sales and adaptation strategy was established. So was a statistically significant Pearson correlation value at $p<0.000<0.001$ between percentage of farm sales income used in financing household needs and preferred adaptation measures. Across all common adaptation strategies in Keffi, changes in cultivation and farming methods had the highest statistical measures. For respondents who elected to diversify sources of incomes, a percentage of 52% was obtained for farmers who spent 50% of their incomes on financing household needs. This was higher than 34.0% in the category of (100% of household needs financed with crop sales) and higher than 14% for respondents who covered about 10 -30% portion of their household needs with sales of crop produce. Respondents who preferred changing cultivation practices or changes in crop varieties (or both) were those whose 100% household needs were not dependent on incomes generated from crop sales. 83.2% accounted for respondents who preferred changes in methods and techniques of annual crop cultivation, and this was higher than 73.0% of farmers and crop vendors who preferred changing crop varieties to other adaptation options.

For example, with a p-value of $p<0.000<0.001$, a pseudo R^2, $R^2=0.487$, a goodness of fit (GoF) p-value of $p>0.476>0.05$ and a classification strength of 72.0% cases; the two independent variables, farming purpose [FarmPurp] and alternative sources of income [AltSource] were found to exert significant impacts on farmers' adaptation choices (the response variables). Other adaptation options (livelihood diversification and changing of crop varieties) were evaluated against the reference category (changes in cultivation practice and farm management methods). For livelihood diversification, [FarmPurp 1] had a more significant overall effect on the outcomes with the probability of farmers in category, [FarmPurp 1] choosing this option compared to the reference category. Implying that farmers in category [FarmPurp 1-those who cultivated only for ensuring food security at household level] had -5,128 times less the probability of choosing the reference category relative to farmers in [FarmPurp 2- both income and food security purpose]. Farmers in category [FarmPurp 2] had -4,888 times less the probability of choosing livelihood diversification rather than the reference category (changes in cultivation practice). That means that farmers were less likely to choose livelihood diversification compared to the reference category. Respondents in category [FarmPurp 3] were not considered in the analysis as it was set to zero as a redundant variable. Similarly, the probability of smallholder farmers with alternative sources of income in Keffi choosing livelihood diversification rather than the reference category (changes in cultivation) was 0.845 implying 15.5% (1 - 0.845 = 15.5). This implied that the probability of farmers in category, [AltSource 2] choosing livelihood diversification rather than changes in cultivation decision was 15.5% less compared to farmers in [AltSource 1]. In terms of relative odds, (determined by the exponential of Beta, Exp Beta), the odds of farmers in category, [FarmPurp 2] selecting livelihood diversification as opposed to reference category was 0.008 (1-0.008 =99.2%) in comparison to farmers in [FarmPurp 3] which was set as the redundant group.

For the adaptation option, *changes in crop varieties*, the probability of farmers in [FarmPurp 1 -those who cultivated only for food security at household levels] changing crop varieties as opposed to the reference category (changes in cultivation practice) compared to farmers in [FarmPurp 3- the redundant group] was 16,097 times. It had a corresponding log odd of 97,888 odds. Likewise, the probability of farmers in [FarmPurp 2 - those who cultivated for both food and incomes]; changing crop varieties as opposed to changes in cultivation methods and land management techniques was 15,919 times. This corresponded to a relative log odd of 81,973≈82% with a higher odd indicating less likelihood of choosing crop varieties. Farmers with alternative sources of incomes, [AltSource 1] had 158.8% odds of being in the crop variety category than the reference category.

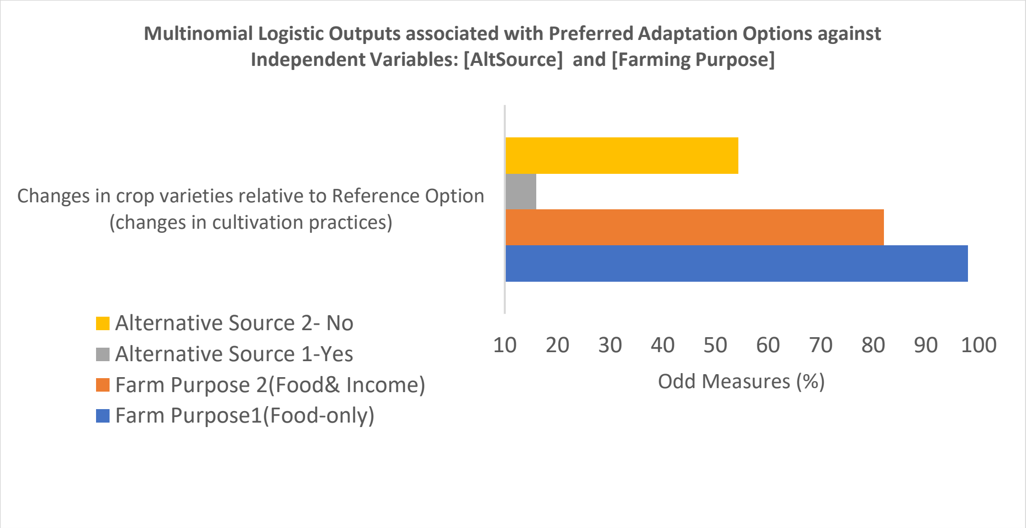


Figure 63: Statistical output associated with multinomial Logistic regression on adaptation option with two control variables

The effect associated with MNL on respondents in [HouseFIN1] and [FarmPurp] are described with the following statistics; $p<0.000<0.001$, the Nagelkerke Pseudo R^2 associated with the model, R=0.495; P-value of the goodness of fit was $p>0.052>0.05$. The model outputs were considered statistical given the proportion (69.6%) of the outcome variables it was able to classify. Farming purpose, [FarmPurp] performed better in the model in terms of the overall effect on the outcome variable than the percentage of household needs financed with crop sales in terms of the associated Pearson value, $p<0.000<0.001$. However, both explanatory variables were considered in the analysis. For the response variable*, livelihood diversification*, the relative probability of farmers in the category, [FarmPurp 1] choosing livelihood diversification as opposed to changes in cultivation decisions as an adaptation measure compared to farmers in [FarmPurp 3] was -4,962 times and an associated relative odd of (0.007) ≈99.3% odds implying less probabilities. For famers in [FarmPurp 2], the relative probability of diversifying livelihood sources under climate impacts were -4,714 times less. In relative odds, this translated to 0.009 ≈99.1% odds.

In assessing the influence of the independent variable, *percentage of household incomes*, [HouseFIN] on adaptation choice preference in Keffi, the probability and log odds ration were analysed. The MNL outputs showed that the probability of choosing livelihood diversification compared to the reference category (changes in cultivation and farming methods) by farmers in category [HouseFIN1 -farmers who had less than 30% of their household needs financed with crop sales income] was 1,930 times higher. In terms of odds ratio, this translated to 6.889 times the odds of a farmer in [HouseFIN1] selecting the changes in cultivation and farming methods (as the reference category) compared to livelihood diversification. The relative probability of farmers in [HouseFIN 2] choosing livelihood diversification was 0.638 (1-0.638=0.362) ≈36.2% while the relative odds of farmers in [HouseFIN2] choosing diversification of livelihood options was 1,894 times the odd.

For *changes in crop varieties,* as an adaptation option, the relative probability of farmers in category, [FarmPurp 1: those cultivated for only food security at household level] choosing changes in crop varieties as opposed to changes in cultivation practice (reference category) was 16,253 compared to famers in the redundant group [FarmPurp3]. Also, the probability of changing to new crop varieties instead of modifying land management practices was 16,097 times higher for farmers in [FarmPurp 2] than for farmers in [FarmPurp 3]. Farmers in [HouseFIN1] had 1, 609 times the probability of changing crop varieties rather than modifying their farm management decisions. That implied that the relative odd of farmers in this category choosing [changes in cultivation practices and land management methods] was 4,999 times≈499.9% higher compared to those in [HouseFIN 3]. The associated relative odds of farmers in [HouseFIN 2] selecting changes in crop varieties compared to the reference category was 1,608≈160.8%. The final model associated with household needs financed [HouseFIN 3-those whose 100% household needs were financed through crop sales] and alternative source of income [AltSource] as sets of explanatory variables showed an overall effect on the outcome variable. Although the pseudo R-square value, did not show good effect size with R=0.187; the p-value associated with the likelihood ratio test for the explanatory variable, [HouseFIN 3] was significant with p <0.000<0.001. The final model containing the explanatory variables classified 56.8% of the outcome variables and had a significant p value of p <0.000<0.001.

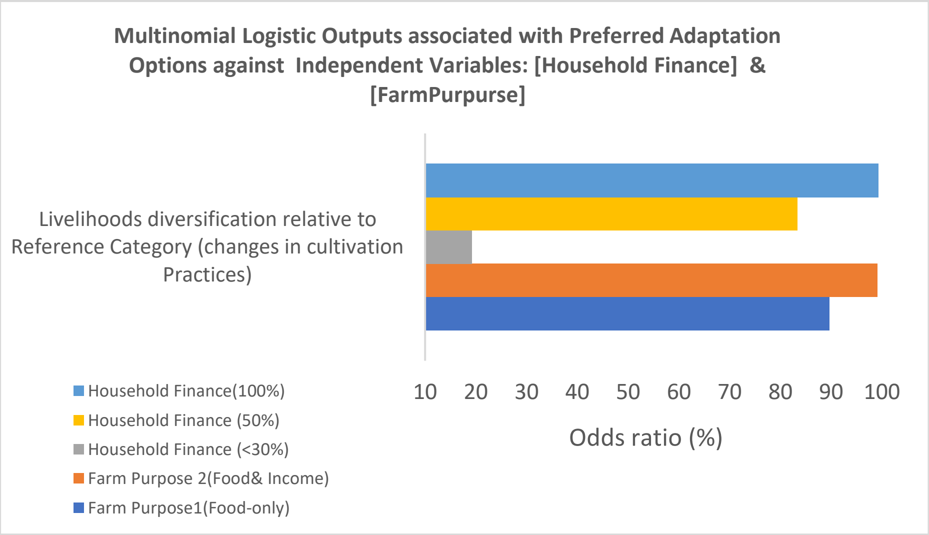


Figure 64: Statistical output associated with Preferred Adaptation Options against Independent Variables: [Household Finance] & [FarmPurpurse]

In assessing smallholder farmers' preference(s) for livelihood diversification, the model output indicated that the probability of farmers in category, [HouseFIN1] taking to livelihood diversification instead of changing crop cultivation practices was 2,820 times higher than those in [HouseFIN3]. The corresponding log odds was 16, 784 which showed that farmers in [HouseFIN1] were 16,784 times less likely to engage in the modification of farm and crop management methods than livelihood diversification in comparison to farmers in [HouseFIN3]. Farmers in [HouseFIN2- those whose only 50% household needs were financed through crop sales] had 1,839 the probability of choosing livelihood diversification rather than the reference category, "changes in crop management methods" and they were 6, 288 times less likely to adopt alternative livelihood sources than the reference category. The probability of farmers with alternative sources of income, [AltSource 1] diversify their sources of livelihoods as opposed to the reference variable was 0.542 (1- 0.542 = 0.458) ≈46%.

In terms of changes in crop varieties, the probability of farmers in category [HouseFIN1] to prefer changing crop varieties instead of the reference category was 1,488 times. The relative odd associated with this was 4,430 times which implied that the odds of farmers in this category cultivating new crop varieties instead of modifying their practices was 4,430 times higher compared farmers in [HouseFIN3]. Similarly, the probability of farmers in [HouseFIN2] electing to change crop variety in comparison to the modification of current crop planting methods and farm management decisions was 0.337 (1-0.337=0.663) ≈66.3%. The relative odd associated with farmers in the category [HouseFIN2] changing crop varieties rather than the reference category, *changes in land management practice and cultivation practice* was 1,400 times. The MNL outputs reflect farmers' coping and adaptation behaviours. Adaptation to climate change impacts by small holder farmers in Keffi as characterized by the multinomial logistic model regression analysis are shaped by certain factors including lack of incentives to support longer-term, well-planned sustainable adaptation practices including longer fallow periods in between cultivation cycles or agro-forestry measures. Other factors besides household characteristics and socio-economic conditions include formal land tenure rights. The cognitive related self-efficacy and strategy-efficacy influences on a greater extent, farmers' adaptation behaviours. In Keffi, reactionary adaptation actions are more common than well-screened and long-term adaptation practices because of the short-term gains associated with it.

A reactionary and cognitively based action is a judgement towards protecting oneself or sources of economic significance particularly those sustaining one's survival base. This judgement is a decision-making process which involves the comparison of alternative options prior to adopting a chosen adaptation pathway. In many poor communities, such decision-making processes are shaped by considerations of availability of assets and capabilities. Such decisions involve lots of trade-offs particularly at the farm-gate and individual levels as mentioned in Saaty (2008, pp 83–98). In terms of adaptation to climate change, preferred adaptation strategies are also determined by the confidence in one's ability to implement preferred strategies which are also contingent upon the availability of resources and in the efficacy of the preferred action. In Salau et al. (2012) and Bello et al. (2013), the drawback with off-farm sources of incomes or more sustainable adaptation measures in Keffi has been observed. Relating to the poor socio-economic conditions, absence of technology and derelict social and physical infrastructure (Umaru &Tende 2013) reported that there was lack of enabling environment for subsistent farmers to explore other off-farm opportunities.

In the bar chart in figure 63, farmers whose total household needs were addressed with 100% of income from farm sales, opted to for changing cultivation and farming practices. This is suggestive of the influence of socio-economic pressures on farmers in fulfilling their household needs and demands. In Sahn & Arulpragasam (1991) and Morton (2007), the dependence of rural dwellers on small-scale agriculture in the absence of off-farm activities have been reported. In like manner, the impact of poverty on deepening smallholder farmers' vulnerability to climate change mentioned in Lema & Majule (2009) has also been documented. While the SPSS outputs revealed a significant influence and inter-linkages between household decisions, socio-economic characteristics and agricultural management decisions; farmers' perception of inter-annual variability of climatic conditions also exerted an influence on preferred cultivation methods. Dual-purpose farmers who cultivated both for food sufficiency at household levels and income generation, were strongly motivated towards exploring means of sustaining crop yields under climate threats than in seeking non-farm alternatives. Field survey showed that subsistent-oriented farmers in Keffi were influenced by new lived experiences of climate variability in recent years which in parts drove changes in farmland management. Perception of the risks and potential threats from variations in climatic conditions in Keffi has in addition to the lack of adequate social incentives contributed to the expansion of frontiers of rural farmlands and in the sprawl of urban agricultural in Keffi. This has been reported in Salau & Attah (2012, pp 17–29). These synergistic pressures constitute the principal driver(s) of intensive and unsustainable crop cultivation in Keffi with shorter, non-receding and yearly cultivation with shorter fallows periods being the new norm.

In characterizing small holder farmers' crop cultivation and farm management practices in Keffi, the concept of land use intensity by Kerr & Cihlar (2003, pp 161–172) is applied. Within the frame of the use of land for subsistence farming, a set of interacting conditions including not just the socio-economic needs but also the factors and tools required for small scale farming are involved. These include, besides the types of local technologies applied, (Ellis and Ramankutty 2008); the intensification of farm inputs. Erb et al. (2013, pp 464–470) notes that the inefficiency of local tools and technologies used as well as the frequency of cultivation disturbances on land reported in Yan et al. (2017, pp 387–402) constitutes indicative impact parameters of subsistence farming disturbances on land biophysical properties (land use intensity). In this study, cropping intensity and the associated frequency of cropping activities in a given year on a given hectare constitutes landuse intensity. The three parameters, input and output intensification as well as changes in the biophysical variables of land mentioned in Erb et al. (2013, pp 464–470) is applied in characterizing land use intensification in Keffi. These three parameters when juxtaposed with the argument of impact-engendering potential of crude and inefficient farming tools in Yan et al. (2017, pp 387–402) which is further substantiated in Dietz (2002, pp 3–15) provides a contextual clarification on intensive land use as a disturbance regime. Reactionary climate adaptation by small holder farmers in Keffi is thus characterized as land-intensive activities. The application of crude tools and practices, the frequency of use land without a receding period to derive socio-economic benefits, a discourse deepened in Kerr & Cihlar (2003, pp 161–172) portends stress factors on vegetation covers. These conditions, Lesslie et al. (2010) notes has impairing effects on vegetation canopy structural and physiological attributes.

Relevant studies such as Stampfli et al. (2018, pp 2021–2034) have also highlighted the synergistic impact of land-use intensification and climate risks under severe environmental changes on grassland vegetation composition and plant functional diversity. Wessels et al. (2011, pp 19–29) found that tree canopy covers, and heights differed across three sites, with more reduced total woody cover identified in areas under heavy communal usage. Similarly, Dietz (2002, pp 3–15) in a study at assessing vegetation diversity within farmlands alongside determining the impact of landuse type and distance of farmlands from border structures; observed that land-use intensity influenced to a larger extent vegetation diversity within agro-ecosystems. Hibbard et al. (2017) reported that human disturbances on terrestrial land surfaces could potentially modify the structure, function and by extension the dynamics of vegetation cover. In Hendrickx et al. (2007, pp 340–351) impacts of agricultural landuse related intensification have been reported albeit on specie richness between communal landscapes. Numata et al. (2007, pp 314–327) investigated the impact of pasture grazing on biophysical properties and found that intensive grazing affected vegetation biophysical properties significantly in comparison to land use age and soil order. In Pickett et al. (2005, pp 172–198), evidence is being provided on impact of anthropogenic activities on vegetation dynamics.

The capability of anthropogenic activities particularly in the agriculture, forestry and other land use sectors (AFLOU) in inducing changes in biophysical land surface conditions, plants structural and species composition has also been documented in Pickett et al. (2005). This linear relationship (anthropogenic-plants-structural-physiological) is deepened with scientific understanding from Gates et al. (1965). In Gates et al. (1965), a strong relationship between leaf area index, canopy structure and NDVI was documented with broader area index leaves having maximum fPAR absorption than thinner leaves. Vegetation canopy structures (relating to abundance of plant forms, organs and inclination of Leaf Area Index) have direct implications on vegetation physiology and cover dynamics as noted in Migliavacca et al. (2017, pp 1078–1091). Unsustainable land-use practices which exposes vegetation covers and canopy structural organs to long-term perturbation by human activities has been attributed to low above ground biomass production in Hibbard et al. (2017).

In local farming settlements, deepened poverty, social exclusion, poor economic realities and governance deficit underpin to a greater extent the way land resources are used and managed. These conditions also influence farmers' autonomous adaptation behaviours. In Keffi, these conditions also play a critical role in shaping farmers adaptation and farm management behaviours which in turn impacts land surface conditions including vegetation covers (see NDVI maps in Appendix II). The inter-annual rotational character and footprints of short fallow and non-receding cultivation practices by small holder farmers in Keffi was observed in the spatial distribution of vegetation cover as displayed in NDVI maps between 1999-2018 (Appendix II). For example, in 1999, the condition state of vegetation cover in Keffi was photosynthetically optimal with most more than 80% land area covered with healthy vegetation. In the following year (2000), optimal conditions were replaced with stressed canopies with healthy vegetation occurring towards the southern areas. This suggests an interaction of both reduction in reduction in rainfall amount and farming practices (cultivation and harvesting). The NDVI in year 2000 was as low as 0.3281. In 2001, vegetation conditions showed significant improvements with an NDVI value of 0.4183 plausibly due to lesser footprint of farmers' activities. Subsistent farmers in Keffi practice fallow system though short (1-2 years) and this slows down vegetation regeneration.

Footprints of extending land use for realizing farming and other non-farming development activities in Keffi is also detected in the NDVI maps. In the years 2002 and 2003, despite the relative high amount of rainfall (1070mm/year and 1081mm/year) observed NDVI values at 0.3951 and 0.3761 respectively showed that the amount of rainfall was unable to stimulate vigorous canopy conditions. Human trampling connected with the non-receding farming and other cultural activities is plausibly associated with the weak rainfall-photosynthesis linear relationship. Within the years 2004 and 2005, the physiological conditions of surface canopies were low with NDVI values of 0.3460 and 0.3405. Very low vegetation conditions in Keffi were spatially observed expanding towards the north, south -east with north-east remaining non-dynamic with very low values. Keffi town is situated in the north eastern part with a higher population density and convergence of various land-based activities including increasing living settlements.

With the rainfall amount in 2007 at 1270mm/year, juxtaposed with Zhang et al. (2017) reference-based predicted NDVI value of 0.46, a more healthy vegetation state would have been expected. In contrast, low NDVI values (0.3585) showed intensive activities in most farming settlements across Keffi. There were however signs of recovery in the vegetation condition state in 2008 (with an NDVI value of 0.3708) in comparison to 2007. Curiously, this improvement occurred even with a low rainfall amount of 940mm/year in that year. Most parts of Keffi as seen in the 2007 NDVI map which had very low NDVI values translating to weak photosynthetic capacity (Appendix II) recovered in 2008. Although slight recovery in vegetation conditions was noticed in 2009 (Appendix II, NDVI: 0.3491) in central and north-western parts of Keffi, within the same areas (centre and north-west) which were covered with very low NDVI values in 2008; this was not linearly significant with the amount of rainfall recorded in that year (1321mm/year). In 2010, a 110mm/year rainfall amount was only able to trigger a NDVI value of 0.3411.

Outputs of a decadal-time slice NDVI reclassified map (figure 65) over the 20-year temporal window also support the attribution of farmers' inter-annual rotational cultivation and reactionary adaptation footprints on vegetation cover. For example, as shown in table 14, between (1999-2018), the percentage of the vegetation cover area corresponding to "gain" was decreased from 46,866km2 to 35,087km2. This corresponded to -25% change. Between the 1st decadal time –slice (1999 and 2008), the area corresponding to "vegetation cover loss" was 74,361km2 while in the second decadal time-slice, (2009-2018), an area of 72,686 km2 was under vegetation loss. Although, the change in the "loss" class was minimal, a marked difference was noticed in the two other classes, "gain" and "significant loss" during the second decadal time slice (2009 to 2018). The area witnessing "significant loss" increased from 32,136km2 to 45,589km2 between the two-time windows (1999-2008 and 2009-2018).

This corresponded to 42% change increase. Overall, in comparison to the percentage change associated with areas covered with healthy vegetation relative to areas covered with stressed vegetation; results showed that there was an increase in area under significant vegetation loss. Land areas with healthy vegetation decreased within the 20-year temporal window.

The character of the spatial distribution of vegetation across the three classes (gain, loss, significant loss) within 20-year window in Keffi can be plausibly attributed to inter-annual farmland management practices (crop fallowing systems) as well as other practices like seasonal harvesting. The signal and extent of change associated with land use type (mostly agriculture and livestock grazing) and land use cover types are expressed in both the NDVI maps (Appendix II) and the reclassified maps in figure 65. The yearly expansion of farming settlements and farmlands, rotational cultivation and seasonal impacts of livestock grazing are captured in these maps.

The influence of human activities on vegetation cover in Keffi has been corroborated in a study by (Mahmud & Achide 2012) on the tension between two land uses: urban sprawl and arable land for farming. Of all the land use covers identified in the study by (Mahmud & Achide 2012), cultivated land represented a larger portion of the total classified area in both anniversary years under consideration 1999 (90.87km2) and 2007 (85.84km2) in comparison to built-up areas which see a minimal increase of 18.30km2 in 2007 from 13.38km2 in 1999. Cultivated areas in Keffi was also larger than areas covered with healthy vegetation. The study also observed a marked decrease in the area covered with healthy vegetation between 1999 (16.92km2) and 2007 (10.53km2) corresponding to a 7.34% change. Results and inferences from this study suggesting anthropogenic pressures particularly from modification in farmland management and reactionary climate adaptation at farm gate levels in response to climate impacts is in agreement with study by (Mahmud & Achide 2012). Socio-economic and climate–driven factors are driving vegetation cover dynamics in Keffi. The reclassified NDVI map in figure 65 depicting the extent of temporal changes in condition state of vegetation cover in Keffi also showed the spatial character of vegetation cover across the three classes of change over time. Thus, farmers' cultivation methods and reactionary adaptation practices have the potential of triggering vegetation cover dynamics under influence of interacting factors on canopy structure and optical sites and variables for fPAR absorption.

Decadal_Time_Sliced_Vegetation_Cover_Change_Keffi

1st Decadal Time Sliced 1999-2008

Object_ID	Change_Count	Area_of_Change (m2)	Area_of_Change (km2)	Change_Description
1	46866	4.217.940	46,866	Gain
2	74360	6.692.400	74,361	Loss
3	32136	2.892.240	32,136	Significant Loss

2nd Decadal Time Sliced 2009 -2018

Object_ID	Change_Count	Area_of_Change (m2)	Area_of_Change (km2)	Change_Description
1	39071	3.157.830	35,087	Gain
2	83319	6.541.740	72,686	Loss
3	52587	4.103.010	45,589	Significant Loss

Vegetation_Dynamics_in_ Percentage_Change (2018 -1999)

Object_ID	Change_Description	Change_2008_1999_(km2)	Change_2018_2009_(km2)	%_Change
1	Gain	4.218	-12	-25%
2	Loss	6.692	-2	-2%
3	Significant Loss	2.892	13	42%

Area of Change = Change_Count x Pixel Size(m2)
Pixel Size = 90m2

Table 14: Decadal Time Sliced Analysis of Vegetation Cover Change in Keffi between 1999 and 2018.

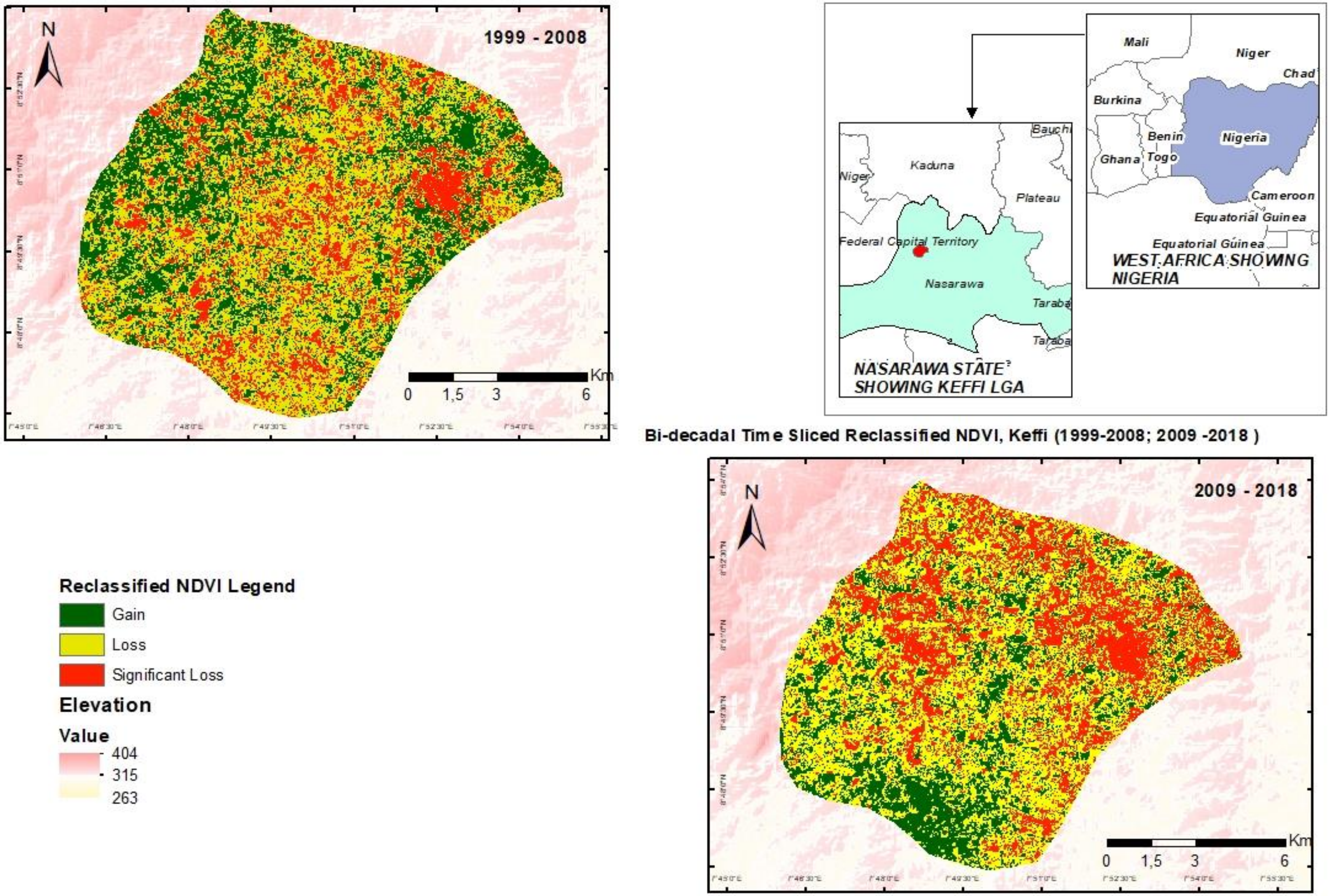


Figure 65: Bi-decadal Time Sliced Reclassified NDVI (1999-2008; 2009 -2018)

4.9 Research Question: To what extent are variations in inter-annual NDVI values associated with climate variability relative to agricultural land use practices in Keffi?

In addressing the research question, observed inter-annual mean values of rainfall were correlated against observed mean inter-annual NDVI values in Keffi. Both 1999-based reference mean (0.4371) predicted NDVI values and measured mean NDVI values from 1999 -2018 were also analysed against a reference NDVI value of 0.46 for tropical Savanna grassland at 835mm/year by Zhang et al. (2017, pp 2318–2324). As shown in table 6, the NIMET instrumental annual rainfall average in Keffi ranged between 850mm/year and 1340 mm/year. Although observed measurements of mean annual rainfall and temperature were obtained in Keffi, inter-annual temperature variations were not considered in the regression analysis. This is because the influence of temperature on vegetation dynamics have been found to more related to plant phenologies as well as ecological response to vegetation types than to biomass. For example, in Cleland et al. (2007, pp 357–365), variation in surface temperature were found to be more connected to range shifts and distribution of species. This understanding is also carried in Walther (2003, pp 169–185), where the impact of temperature on spring phenophases of plants had only indirect implications on vegetation phenological events. In tropical humid ecoregions, impacts of temperature on vegetation dynamics and sensitivity are non-significant in comparison to rainfall variability as reported in Spiekermann et al. (2015). Rather impacts of temperature on vegetation physiological functioning are more pronounced in the mid and high latitudes where vegetation growth is very sensitive to temperature change according to Wang et al. (2011, pp 1240–1245).

According to NIMET, the size of inter-annual mean rainfall amount in Keffi, is between 1024 mm/year and 1290mm/year. From 2011 to 2018, NIMET documented an 8-year mean rainfall amount over Keffi at 1153mm/year, an average growing season of 207 days and average rainfall season length of 204.6 days. In Joshua et al. (2013, pp 14–23) and Binbol & Marcus (2010), the mean annual rainfall in Keffi lies between 800mm/year and 1560mm/year and this is slightly influenced by the north-central highlands. Observed inter-annual rainfall amounts in Keffi from NIMET instrumental datasets (in table 6) showed that rainfall amounts ranged between 870mm/year and 1340mm/year. This real time rainfall measures indicates that a 20-year average of 1068mm/year could ideally produce about 0.42 units of NDVI in Keffi per Against the backdrop of vegetation monitoring studies in tropical Savanna, rainfall amount-NDVI correlation is weak, thus the high amounts of rainfall in Keffi is unable to produce linearly correlated measure of NDVI. According to evidence from relevant empirical studies in tropical Savanna grassland, higher performances of NDVI or biomass production is correlated with higher rainfall amounts where other environmental and non-environmental (man use of land) are in undisturbed states. Vegetation physiological performances (NDVI) or biomass in tropical Savanna are controlled by character of rainfall (annual mean rainfall amounts and timing patterns-*occurrence and cessations*), degree of human use of land and density of vegetation covers (density of vegetation sites). These three factors have been reported in other others like Camberlin et al. (2007, pp 199–216), Thackway & Lesslie (2008, pp 572–590) and Hermance et al. (2016, pp 3293–3321).

Higher annual mean rainfall amounts in tropical grassland Savanna with dense vegetation covers in ecoregions like Keffi ought to trigger higher measures of NDVI. However, this was not the case as observed in the inferential and regression analysis. Observed NDVI values in Keffi did not reflect the effect size expected of high inter-annual rainfall amounts. For example, in the year 2009, rainfall amount of 1321mm/year produced 0.3491 units of NDVI, an amount far less than 0.4371 units of NDVI produced in 1999 with almost the same amount of rainfall. In year 2000, 0.3281 units of NDVI was produced at a rainfall amount of 971mm/year. In year 2015, a 100mm/year less amount of rainfall (870mm/year), produced more units of NDVI, 0.3748 than in year 2000. Also, in year 2001, 1171mm/year produced 0.4183 units of NDVI but in year 2003, the same amount of rainfall should have produced corresponding units of NDVI. On the contrary, 1170mm/year rainfall in year 2003 produced 0.3761 units of NDVI, a difference of 0.0422. Also, years 2014 and 2017 which had equal amounts of rainfall, 1021mm/year produced distinctly different NDVI values (0.3786 and 0.3095) respectively.

Apart from the unpredictable character of mean annual rainfall amounts in Keffi (as derived both from NIMET and CRU), the quantity of rainfall in Keffi ought to have induced higher measures of NDVI. Seasonal reports from the Nigerian meteorological agency, NIMET have reported the unpredictability and inter-annual variations in the timing of rainfall events over Nasarawa state and other northern states in Nigeria including Keffi. This unpredictability with rainfall indices also affected rainfall seasonal trends in Keffi. However, cessations of rainfall events in Keffi have been reported to be more predictable. The effect of seasonal distribution of rainfall in Nasarawa has also been observed in the higher than normal rainfall amounts within very short periods in Keffi and also across other localities in the north-central part of Nigeria. While similar observations have been made in Agidi et al. (2018, pp 1–21), that is late onset and early cessation of rainfall, the interaction of local farmland management and precipitation ineffectiveness have contributed additional stress signals on vegetation.

In the context of linear correlation between vegetation physiology and rainfall, studies such as Fay et al. (2000, pp 308–319) has shown that variability in timing (cessation and occurrence) of rainfall had the potential of disrupting the relationship. In Agidi et al. (2018, pp 1–21) and Labaris (2012, pp 68–74) late onsets, early cessation and short duration of intense rainfall with larger run offs in Keffi and other localities in Nasarawa have been reported. During the social survey, small farmers noted recent increases in the frequency of occurrence shorter rainfalls amounts and associated uncertainties of occurrence. Farmers reported that rainfall variability in comparison to temperature had more impacts on their crops as this resulted in shorter lengths of planting and growing seasons.

However, the erratic nature of rainfall occurrence and the associated unpredictability of rainfall timing over the years in Keffi were not reflected in the 20 years inter-annual observations. Having persisted, the effect of the erratic timing of rainfall over Keffi ought to have produced a similar erratic trend and pattern of NDVI values within the corresponding temporal window under investigation. Such erratic patterns were not observed in the 20 years NDVI data sets. There were rather breaks in the NDVI trend as shown in figure 21. This non-linearity in the timing and breaks between rainfall and NDVI as well as well as between NDVI and rainfall measures suggest a likelihood of interference of non-rainfall factors on NDVI-rainfall linear sensitivity. The plausibility of the interference of non-rainfall factors on the physiological performance of vegetation in Keffi is further reinforced by the northern guinea vegetation type (open grass and crop land) being unable to trigger higher NDVI amounts.

The 1999 NDVI and rainfall values were used to mathematically derive predicted NDVI values. With the 1999 reference year measure, 1mm/year was equivalent to 0.00033 units of NDVI. In table 10, the 1999-predicted NDVI values are closely correlated with the amount of rainfall for each corresponding year in contrast to correlation with observed values. In the 1999-predicted values, lower rainfall amounts correlated to lower NDVI values and higher rainfall amounts correlated to higher NDVI values. In 2014 rainfall amounts (1021mm/year produced 0.3756) and 2017 (0.3095 from 1021mm/year) showed a more mathematical plausible correlation as shown in table 10.

From the real-time rainfall data obtained from NIMET, 1020 mm/year of rainfall in 2014 produced 0.3215 units of NDVI. In 2017, the same amount of rainfall yielded 0.2097 units of NDVI representing a weak coupling of NDVI-rainfall in Keffi for that year. The anomalous spatial distribution of observed inter-annual NDVI values aligns with the small regression slope as well as with the weak linear correlation coefficient. This weak statistical correlation between observed NDVI and inter-annual rainfall values can be plausibly attributed to some factors. First, the inability of rainfall amounts in Keffi to induce corresponding NDVI values could be attributed to the ineffectiveness of rainfall due to run-offs as mentioned in Agidi et al. (2018, pp 1–21). NDVI insensitivity to rainfall in Keffi could also be attributed to the impacts of non-rainfall signals like human land use management masking the correlation. The last inference stands plausible as vegetation productivity increases and decreases between years (see NDVI maps).

Assessing the extent to which variations in inter-annual NDVI quantities is associated with rainfall variability relative to land use-related practices in Keffi can be further assessed within the scientific understanding of the tight coupling of NDVI to certain vegetation sites and rainfall thresholds. In terms of vegetation, rainfall variability-NDVI sensitivity as reported in Camberlin et al. (2007) is pronounced in ecoregions where land covers are characterized with open grass, croplands or sparse trees. Also, certain rainfall thresholds affect rainfall-NDVI sensitivity. In Camberlin et al. (2007) and Du et al. (2017 p 40092), high rainfall-NDVI sensitivity were noticed in water-limiting areas with low rainfall thresholds (<300mm/year) to intermediate (200mm/year-600mm/year). Nicholson (2013) also documented similar observations in semi-arid and Sahelian regions. Corroborating documented observations are regression coefficients obtained in related studies. In Herrmann et al. (2005), r<0.01 and <0.05 were obtained; (r=0.78, p<0.01000) as noted in Anyamba & Tucker (2005, pp 596–614) ($r < -0.75$) ($r \approx 0.4$–0.6) and in (Fensholt et al. 2009). In sub-tropical humid ecoregions with moderate to higher rainfall thresholds, NDVI-rainfall sensitivity can also be impaired with impacts evidenced in insensitivity of photosynthetic quantities to higher rainfall amounts. This implies that higher rainfall amounts may not necessarily result in higher NDVI values. However, such relationship is more common in ecoregions with dense tree formations and not in open grass or croplands as mentioned in Camberlin et al. (2007). Open grass and croplands with sparse tree formations such as in Keffi are expected to show stronger coupling between rainfall amounts and vegetation productivity hence higher NDVI values. Following the observation in Camberlin et al. (2007), the vegetation cover type in Keffi is supportive of large productive sites which should ideally trigger higher units of NDVI under conditions of high rainfall amounts. In the context of the weak rainfall-NDVI relationship in Keffi, the plausibility of attributing the insensitivity of the two variables to the intervening impacts of non-rainfall factors (plausibly human agricultural footprints) is high.

As one of the major agricultural localities in Nasarawa state, intensive crop cultivation and livestock grazing are common in Keffi. Coupled with the raising level of food-poor and non-food poor population as documented in 2010 National Poverty Report (Nigerian Bureau of Statistics); there is a high per capita demand for farmlands for agriculture. The feedback associated with per capita demand for farmlands in Keffi is the non-receding and intensive use of land leading to impairment of biophysical land conditions. Under the condition of dwindling land areas in Keffi due to in parts to new realities of sprawling built-up areas in Nasarawa as reported in Mahmud & Achide (2012) and Nuhu & Ahmed (2013, p 607); the competition for arable land is exerting pressure on primary vegetation. In managing local livelihood challenges associated with scare arable land, rural dwellers in Keffi have resorted to new land management practices. These practices include but are not limited to yearly cultivation, short fallow, yearly mono and mixed cropping systems. Deepening the complexity, is the fluidity of land tenure titles, which villagers in Keffi has shaped the ways in which farming household approach agricultural livelihoods and landuse management practices. Following this, it is plausible to attribute interference in rainfall-productivity (NDVI) through modification of crop cultivation and pasture management practices in Keffi.

The chi-square test outputs also validated results of the MNL analysis and indicated that farmers in Keffi preferred to a larger extent, changes in cultivation practices as opposed to adopting other adaptation options such as livelihood diversification. Shifting cultivation with less fallow periods was the most preferred by farmers in Keffi. For example, (38.4%) farmers preferred yearly mono-and mixed cropping as against (2.0%) who shifting cultivation with less more fallow periods. The highest statistics was recorded for farmers who practiced cultivation with less fallow periods in between (44.0%). In terms of coping and adaptation strategies, 54.80% preferred changing crop cultivation practices and farm management decisions as an adaptation option, a statistic higher than 25.20% (who preferred changing crop varieties) and 20.0% (farmers who would rather diversify means of livelihoods (figure 56). The high preference for changing crop varieties or modifying cultivation practices by farmers in Keffi is connected in part with weak policy incentives worsened by poor physical infrastructure that could support non-farm livelihoods. Although some respondents showed interests in pursuing non-farm livelihoods activities or more sustainable adaptation option; they were however unable to implement these due to various limitations. With the limited livelihood choices faced by farmers in Keffi, preferences for changing crop varieties, practicing shorter fallow system or inter-annual cropping were common farmland management methods in Keffi. These management methods have the potential of exerting trampling effects on land surfaces and vegetation canopy structures. Thus, vegetation in Keffi are exposed to cultivation-related disturbances and stress.

Human disturbances capable of constituting stress regimes have been found to have direct effects on plants structural organs such as leaf area index as reported in Norman & Campbell (1989, pp 301–325). Increasing intensity and frequency of unsustainable farming practices can potentially impair spectral absorptive capacity of plants through damage on optical apparatuses. Empirical evidence has found that these impacts become more pronounced under conditions of interactions between changing environmental conditions like climate and human activities. Anthropogenic activities have been identified as one of the major events apart from inter-annual rainfall variability that can affect vegetation cover dynamics (distribution and greenness) in Savanna ecosystems. Studies such as Spiekermann et al. (2015, pp 113–121) and Thackway & Specht (2015) are examples in this regard. For example, Spiekermann et al. (2015) observed a decrease in mean woody cover in the Seno plains of Mali and this was attributed to increase in cultivated land. In Vrieling et al. (2011, pp 455–477), changes in African farmlands under different farming systems and climatic conditions were characterized and significant positive correlation between cumulative NDVI trend and different land uses in both Senegal and southern Sudan were found. In Thackway & Specht (2015), human disturbances on vegetation dynamics were also reported under intensive use of land.

Relating this scientific understanding to this study, observed low NDVI values in Keffi despite high inter-annual rainfall amounts can be plausibly attributed to weak vegetation canopy conditions under constant trampling effects from short fallow system and inter-annual cultivation. This attribution is plausible based on the statistical and inferential analysis carried out in this study including, NDVI-rainfall residual trend plot as well as the visual assessment of the yearly NDVI and decadal reclassified NDVI maps. Visually assessing the residual trend (RESTREND) plot in figure 26, the downward and negative character of the trend slope is indicative of the influence of non-rainfall factors not captured in the regression model. Similar observations have been mentioned in Herrmann et al. (2005, pp 394–404), Evans & Geerken (2004, pp 535–554), Dieguez and Paruelo (2017). Li et al. (2012, pp 969–982) also noted that such masked non-rainfall factors describe the dampening influence of anthropogenic activities on NDVI-rainfall sensitivity due to its impairing effect on fPAR absorption in plants.

A visual assessment of the yearly NDVI maps from 1999 to 2018 (attached in Appendix II) supports the attribution of footprints of intensive farming practices in Keffi on vegetation cover dynamics. A weak photosynthetic performance in vegetation cover in Keffi particularly for the years 2005, 2007, 2008, 2010 and 2018 is observed and lending in argument of the role of farmers' inter-annual changes in land use patterns across Keffi. In the year 2000, the percentage area covered with low NDVI values was not only large but spatially expanding. From the north (Rimi and Angwan Mangoro) to the south (farming settlements in Gauta), criss-crossing the centre, Tolu Ekuri and towards the south-west, Sabon Gari, unhealthy vegetation states were observed in Keffi.

While land areas in the years 2002 and 2003 are seen covered with healthy vegetation (depicted with green and dark green colours), vegetation conditions degenerated in 2004 and 2005 with most areas in the south-eastern, north and north-west parts of Keffi being covered with pale green canopies. The expansion of areas with unhealthy vegetation covers as seen in NDVI map 2005 (Appendix II) supports a plausible inference of the synergistic impact of agricultural activities and variability in local climate conditions in Keffi on the quantitative balance of vegetation cover in Keffi. It is important to note that, marked as the hottest year on global instrumental records, Jones et al. (2006, pp 1–5), the impacts of the 2005 air surface temperature conditions in Nigeria which was accompanied by protracted periods of water stress had arguably influenced agricultural landuse management practices. This is plausibly related to the large distribution of low NDVI values for that year.

Visual outputs of a decadal-time slice re-classified NDVI map shown in figure 65 agrees with documented adaptation behaviours and land management practices of subsistent farmers in Keffi. Farmers' inter-annual rotational cultivation and reactionary adaptation footprints exerted impacts on the qualitative and quantitative physiological processes of vegetation cover in Keffi. The spatial character of vegetation cover dynamics and the extent of recovery by plants in Keffi were characterized by three classes; "vegetation gain", "vegetation loss" and "significant loss".

For example, as shown in table 14, between (1999-2018), the percentage of the vegetation cover area corresponding to "gain" was decreased from 46,866km2 to 35,087km2. This corresponded to -25% change. Between the 1st decadal time –slice (1999 and 2008), the area corresponding to "vegetation cover loss" was 74, 361km2 while in the second decadal time-slice, (2009-2018), an area of 72,686km2 was under vegetation loss. Although, the change in the "loss" class was minimal, a marked difference was noticed in the two other classes, "gain" and "significant loss" during the second decadal time slice (2009 to 2018). The area witnessing "significant loss" increased from 32,136km2 to 45,589km2 between the two-time windows (1999-2008 and 2009-2018). This corresponded to 42% change increase. Overall, in comparison to the percentage change associated with areas covered with healthy vegetation relative to areas covered with stressed vegetation; results showed that there was an increase in area under significant vegetation loss. Land areas with healthy vegetation decreased within the 20-year temporal window. The character of the spatial distribution of vegetation across the three classes (gain, loss, significant loss) within 20-year window in Keffi can be plausibly attributed to farmland management practices (crop fallowing systems) as well as other practices like seasonal harvesting.

During the first decadal time slice (1999 -2008), impacts of anthropogenic footprints in Keffi (due largely to cultural–based livelihoods like farming) is spatially observed across all areas. However, deeper footprints of human activities are concentrated in the central part of Keffi. The static character of the "vegetation loss" class as shown in figure 65 is in agreement of the increased concentration of socio-economic activities and housing settlements in Keffi town. This static nature representing Keffi town is also observable in the second decadal time slice. The urban sprawl which is witnessing both expansion of housing settlements and urban farming is responsible for the replacement of natural vegetation in Keffi town. Between 1999 and 2008, vegetation loss was spatially distributed with greater loss concentrating in the center and towards the south in Gauta and Sabon Gari. Although, significant vegetation losses were observable in most parts of Keffi, significant vegetation cover loss populated towards the north-east, south and south–east. Localities such as Rimi in the north, and other farming settlements in the west and north western parts of Keffi. Between 1999 and 2008, rural settlements extended beyond Keffi town, were still covered with healthy vegetation.

The dynamics of vegetation response to human activities in Keffi within the second decadal time slice, 2009 -2018, is seen in the reclassified NDVI map. The areas in the northern part of Keffi covered with green and healthy vegetation during the first decadal time slice (1999 -2018) is replaced with more red and yellow patches signifying both significant loss and loss respectively. The static nature of the vegetation condition in Keffi town is the same in the second decadal time slice. However, the red patches (significant loss) extended more from the north-east towards the core northern settlements. More areas in the west and central Keffi witnessed expansive loss of healthy vegetation as denoted by the spatial distribution of yellow patches. Intensive human footprints with its impacts contributing to significant loss of vegetation is observed western areas of Keffi. In the first decadal time slice (1999 - 2008), the northern and western parts of Keffi were covered with healthier vegetation and patches of areas with low vegetation cover. Within the 2009 and 2018, temporal window, a change in the spatial distribution of healthy condition of vegetation between the north and south is seen. A recovery of vegetation conditions in the south is observable whereas vegetation loss and significant loss moves northwards. This spatial displacement of health and unhealthy vegetation in Keffi between periods can be plausibly attributed to the rotational and inter-annual management of farmlands and expanding frontiers of other human activities in Keffi. Rural rain-fed agriculture as the mainstream anthropogenic activities in Keffi does indeed drive vegetation cover dynamics.

This inter-annual and inter-decadal variation in the land areas covered with healthy and or stressed vegetation cover is descriptive of the impacts of human activities on vegetation canopy structure conditions. NDVI map outputs from this research is therefore in agreement with other relevant studies which investigated vegetation cover dynamics in the Savanna. Evidence documented elsewhere showed that where mean rainfall amounts in a Savanna ecosystem are incapable of triggering corresponding amounts of vegetation productivity (NDVI); then there are plausibly other marked factors dampening the effect of rainfall on NDVI-rainfall sensitivity.

Thus, the attribution reactionary adaptation measures by farmers in Keffi to shifts in vegetation cover conditions in Keffi can be plausibly argued from the following observations:

- the static nature of very low NDVI values within Keffi peri-urban area (the smaller portion around the north-eastern part of Keffi with red colour) due to heterogenous character of land use types (pockets of small-scale artisanal mining, urban in-corridor farming, livestock grazing) and population growing population density .

- the gradual expansion of farming frontiers from the central and north-eastern parts of Keffi towards the north-western areas indicated by a pale-yellow and red colours.

- the marked decadal shift of and quantitative spatial distribution of healthy and unhealthy vegetation in the two decades (1999 -2008); (2009 -2018)

- the inter-annual dynamic pattern of spatial distribution of vegetation cover greenness between years

This provides a plausible basis for concluding that variations in inter-annual NDVI values in Keffi are more associated with vegetation conditions under new farmland management activities than climate variability. This pattern is explained by the abrupt character of inter-annual NDVI variation between 1999-2018 as well as the non-correlative proportions of NDVI units to corresponding rainfall amounts for each year. Also, inferential analysis using 1999 NDVI-based predicted values and observed inter-annual NDVI measurements (table 12) suggests that rainfall amounts in Keffi exerted minor influence on NDVI quantities. Similar correlational analysis with observed NDVI measurements in Keffi with predicted NDVI values from Zhang et al. (2017, pp 2318–2324) 0.46 units of NDVI to 1mm/year unit of rainfall pointed to similar inferential deductions. Quantities of NDVI units produced by observed rainfall amounts in Keffi were much lower than expected of vegetation sites such as in Keffi. Outputs from these inferential analyses therefore provides significant evidence to infer that non-rainfall variables plausibly impact of human footprints dampened the effect size of rainfall in Keffi. Both modified farm management techniques and reactionary adaptation measures by farmers in Keffi does have the potential of exerting trampling effects on photosynthetic sites of vegetation canopy. Thus, inter-annual variability in vegetation productivity (measured by NDVI) in Keffi is rather associated with land use-related practices by farmers than with inter-annual variability in rainfall amounts.

The study notes that human activities (particularly rain-fed agriculture) influences to a greater extent, vegetation cover dynamics as well as biomass production as rainfall amounts have little or no linear correlation with photosynthesis. To exclude effects of soil on vegetation conditions; surface soil samples were analysed and results showed that even with run off in Keffi, the indicative soil moisture quantity in Keffi (between 4.0% and 21.4%) did not impact moisture availability and soil nutrients transportation in the context of their roles in plant photosynthesis. The low soil moisture levels in Keffi is also associated with the effect of culturally-oriented rural farming in Keffi involving short fallow cultivation and frequent harvesting.

5 Conclusion

Results from the study strongly suggests that inter-annual variability in vegetation productivity (measured with NDVI) in Keffi is more associated with land use-related practices by small scale farmers than with inter-annual rainfall variability. Cultivation practices and farmland management decisions during the temporal window of the study (1999-2018) have been modified by subsistent farmers in response to shifts in climatic conditions in Keffi. This understanding is supported by outcomes of social survey including questionnaire responses which shows that farming practices in Keffi in the last decades have been more oriented towards the adjustment of farm livelihoods to the impacts of climate change. The signals from these culturally-modified farming practices and its impacts on rainfall-vegetation sensitivity are evident in the NDVI maps (Appendix II) and also in the character of the linear regression. The weak correlation between NDVI and rainfall in Keffi indicated by a regression coefficient of, (R^2=0.129) despite the high rainfall amounts in Keffi between (1999-2018) lends credence to the plausibility of other non-rainfall factors dampening NDVI sensitivity to rainfall. This can be understood from the scientific understanding of the effects of human trampling on vegetation canopy structures. Under common practices such as shorter fallow systems, yearly mono-and mixed cropping systems, the consistent use of synthetic additives like fertilizers and the periodic changes in crop varieties; surface conditions of farmlands and vegetation canopy covers in Keffi have been exposed to anthropogenic impacts.

These farm-gate level adaptation strategies by subsistent farmers in Keffi (initiators of adaptation) is intended for the adjustments in cultivation practices in order to sustain the performance of farm-based livelihoods (attribute system of values) as an inherent economic variable of small scale farm holdings (exposed units) within the shortest possible time frame (temporal scale). This understanding underpinned the theoretical framework adapted for this study. It makes up constituent part of the integrated conceptual framework of the research. The integrated conceptual framework adapted for this research provided a context for assessing commonly-held perceptions and scholarly carriage of autonomous adaptation. Autonomous adaptation has been held in its conceptual application in scholarly works as a zero-feedback and impact-proof social response to climate change impacts. Using farmers' reactionary adaptation practices in Keffi, this study explores the potential impact (cost) of autonomous adaptation at individual and farm-gate levels on vegetation cover dynamics.

Underpinned by the primary goal of adjusting farmland management decisions and adapting cultivated farmlands to climate change impacts for sustaining crop yields; farm-gate level adaptation strategies in Keffi are exercised through personal judgements of self- and response efficacies. Not only are the planning horizons for implementation of measures and tools determined by subsistent farmers in Keffi themselves; selected adaptation strategies are reactionary than precautionary in approach. Poor farming families and groups in Keffi are more concerned with meeting household needs and daily social responsibilities than any other consideration. Thus, the need to balance adaptation goals with wider considerations of protecting land surface conditions does not occur as a priority to small scale farmers. Rather the cognitive judgement of self-efficacy and response efficacy of preferred adaptation strategy and the realization of short-term gains influences unsustainable and reactionary adaptation behaviours by farmers in Keffi. Statistical analysis from multinomial logistic regression and personal interviews during the field surveys in Keffi pointed strongly to the fact that small holder farmers' adaptation behaviours in Keffi constituted trampling effects on vegetation canopy structural and functional conditions.

In investigating the extent to which inter-annual NDVI variability in Keffi is affected by rainfall amount in comparison to adaptation-driven farm management practices; results of NDVI reclassification between 1999 and 2018 (figure 65) were analysed. A residual trend analysis was also carried out to support understanding of whether or not there were factors masking NDVI-rainfall linear sensitivity.

Outputs of the linear regression showed that rainfall was a weak predictor of NDVI in Keffi. Inter-annual mean rainfall amounts were in Keffi were unable to trigger corresponding NDVI units. Assessment of the character and shape of the residual trend (trend plot between residuals of NDVI-rainfall linear regression and years) slope showed that shifts in vegetation productivity in Keffi were not significantly explained by inter-annual rainfall variability but plausibly by other non-rainfall factors which masked and dampened NDVI-rainfall sensitivity.

Also, an anomaly detection analysis was conducted using the 2nd sigma rule (mean-2*σ, mean+2*σ) on the observed NDVI values in Keffi with a 20 year mean NDVI value of 0.3625 and a standard deviation of 0.0376. NDVI values in Keffi showed that 95% of the observed data were within the 2nd sigma rule (mean-2*σ, mean+2*σ) that is between 0.2868 (minimum threshold) and 0.4332 (maximum threshold) except for (0.2795) in 2018. This implied that inter-annual NDVI values between 1999-2018 were not significantly spread out from the mean value, 0.3625 indicating that regardless of the amount of inter-annual rainfall, vegetation physiological conditions in Keffi revolved around the mean NDVI, 0.3625. Thus, higher amounts of rainfall were incapable of causing significant physiological performances in vegetation in Keffi. The cumulative average of the lowest NDVI value, 0.2795 is 15.0% and 0.3189 is 40%. The cumulative percentage values indicate that inter-annual NDVI values corresponding to vegetation physiological performances were incapable of exceeding 0.3977. Also, the standard deviation curve (figure 17) showed that most NDVI values were within low and medium NDVI range of 0.3 and 0.4.

An inferential analysis using predicted NDVI values based on 1999-based predicted NDVI values (0.00033 units at a corresponding rainfall amount of 1mm/year was carried out. Based on the 1999-predicted NDVI values, 0.3756 units of NDVI in 2014 were produced from 1021mm/year rainfall. In 2017, 0.3095 units of NDVI were produced from the same amount of rainfall, 1021mm/year. Higher measures of NDVI units were obtained with the 1999 reference year estimates in comparison to the observed NDVI values between 1999-2018 in Keffi. In comparison to the observed inter-annual NDVI values in Keffi, the 1999 reference year predicted values performed better than the observed measurements. This 1999-reference year predicted values showed a more mathematical plausible correlation with inter-annual rainfall amounts and were more representative of the physiological relationship between canopy structural organs. The pattern strongly suggests that observed inter-annual mean rainfall amounts in Keffi should have ideally produced higher amounts of NDVI values than what was obtained from Landsat images.

Further investigation of the functional relationship between canopy structural condition and photosynthetic rate was carried out. An analysis using a reference NDVI value of 0.46 at an annual rainfall value of 835.0 mm/year as reported in Zhang et al. (2017, pp 2318–2324) suggested from the comparative analysis with observed NDVI values in Keffi that vegetation productivity were not linearly correlated with inter-annual rainfall amounts. This suggested that observed rainfall measurements within the last two decades in Keffi (1999-2018) exerted minor influence on NDVI quantities. The most visible significant correlation between rainfall amounts and photosynthetic performance with regards to the observed NDVI values in Keffi are in the years 1999, 2001, 2002, 2006, 2015. Infact vegetation canopy conditions varied between years and non-linearly with rainfall amounts. This insignificant and non-linear correlation is plausibly related to the feedback signals of short fallow management and land use intensity.

Inferential assessment of the generated 20 years inter-annual NDVI maps suggested the impacts of inter-annual rotational footprints of farmers' cultivation activities in Keffi. This observation is supported by outcome of the ground-truthing study which links portions with very low values (red portions) in the NDVI map with densely populated farming settlements and built up areas in Keffi. This brownish coloured area remained static across all years while the remaining portions of the Keffi area showed dynamic distribution of vegetation cover greenness between years.

In other to control for the effect of surface soil moisture and nutrients on vegetation dynamics; results of surface soil analysis conducted between 2016 and 2017 showed that soil moisture level, soil types and nutrients had little or no effects on vegetation cover dynamic in Keffi. The indicative range or values of soil nutrients, pH and moisture related more to the soil types and cultural land practices in Keffi. Effects from soil moisture and nutrients on NDVI-rainfall sensitivity are more pronounced in soil types like Gleysols, Ferrosols and Acrisols soils or in acidic soils with pH values less than 5.0. In Keffi, the soil pH was 7.0 (neutral) and the soil types were of Leptosols group (Alfisols and Oxisols).

Outputs of the multinomial logistics regression model aimed at understanding both factors that influenced farmers' adaptation behaviours and preferred adaptation strategies showed that >70% of farmers preferred changing farmland management practices to other adaptation measures. This preference in part is shaped by socio-economic and institutional factors as explanatory variables. The lack of government support and development infrastructure to support diversification of rural livelihoods to non-farm options disincentivized to a larger extent consideration for sustainable adaptation practices such as longer fallow periods, irrigation and agro-forestry. A statistically significant association between socio-economic resources, capabilities, institutional incentives and preferred adaptation strategies was observed. This complex nexus can be linked to concept of scale (spatial and social) elements in autonomous climate adaptation. The size and level of social organization, the vertical hierarchical arrangements and differentiation of social organizations in terms of resources, assets and capabilities also plays an important role in adaptation decisions and behaviours. This is against the backdrop that smallholder farmers perceive modification of crop cultivation methods to other investment-intensive and longer-term adaptation measures as it offers a quick fix means of realizing incomes for household needs. Considering also the risks of insecure land tenure rights, small holder farmers in Keffi rather chose to modify crop cultivation practices or adopting shorter-term fallow practices than long-term options. Personal interviews with some local farmers in Keffi revealed that a considerable number of smallholder farmers preferred fertilizer-supported mono or mixed cropping on the same piece of land within proximate localities than migrate further away in search of new opportunities.

Preferences by smallholder farmers in Keffi to changes in farm management and cultivation methods against other adaptation measures also bears on human cognitive judgements which shapes decisions and protective behaviours. Smallholder farmers in Keffi exhibit protective behaviours in the face of impacts from climate change on cultivated farmlands after risk perception and appraisal as well as the appraisal of perceived solutions. Preferred adaptation measures in Keffi were deemed practicable and self-executable within limited resource means and assets by farmers. These considerations by smallholder farmers thus explain the reactionary approach to climate adaptation in Keffi characterized by intensive and non-receding use of farmlands. Such actions constitute stress regimes and exerts trampling impacts on plants. From a morphological point of view preferred climate adaptation strategies in Keffi potentially impacts energy-absorption sites in vegetation canopy and interferes with the rate and quality of photosynthetic processes.

To further investigate the extent to which rainfall relative to rural farming impacted vegetation conditions in Keffi, a bi-decadal reclassification was carried out to observe the character of vegetation cover change within 20 years' time. The spatial character of vegetation cover dynamics and the extent of recovery by plants in Keffi were characterized by three classes; "vegetation gain", "vegetation loss" and "significant loss". During the first decadal time slice (1999 -2008), impacts of anthropogenic footprints in Keffi (due largely to cultural–based livelihoods like farming) is spatially observed across all areas. However, deeper footprints of human activities are concentrated in the central part of Keffi. The static character of the "vegetation loss" class as shown in figure 65 is in agreement of the increased concentration of socio-economic activities and housing settlements in Keffi town. This static nature representing Keffi town is also observable in the second decadal time slice. The urban sprawl which is witnessing both expansion of housing settlements and urban farming is responsible for the replacement of natural vegetation in Keffi town. Between 1999 and 2008, vegetation loss was spatially distributed with greater loss concentrating in the center and towards the south in Gauta and Sabon Gari. Although, significant vegetation losses were observed in most parts of Keffi, significant vegetation cover loss populated towards the north-east, south and south–east. Localities such as Rimi in the north, and other farming settlements in the west and north western parts of Keffi. Between 1999 and 2008, rural settlements extended beyond Keffi town, were still covered with healthy vegetation.

The inter-annual variation of land surfaces in Keffi with a mix of healthy and stressed vegetation cover (or both) is descriptive of the impacts of human activities on vegetation canopy structure conditions. Agricultural intensification whether by routine application of fertilizer, or irrigation or the modification of cropping practices to support high yielding crops as mentioned in Matson et al. (1997) has a trampling effect on land surface conditions and vegetation covers. It impacts directly on vegetation canopies and plant morphological structures. NDVI map outputs in this research agree with other relevant studies which investigated vegetation cover dynamics in the Savanna. Evidence documented elsewhere showed that where mean rainfall amounts in a Savanna ecosystem are incapable of triggering corresponding amounts of vegetation productivity (NDVI); then there are plausibly other marked factors dampening the effect of rainfall on NDVI-rainfall sensitivity. In Keffi, observed NDVI values violated the assumption of proportionality between rainfall amounts and NDVI measurements in tropical Savanna ecoregions; although some studies have argued that marked proportionality is only pronounced in very low rainfall semi-arid and arid regions.

In ecoregions with distinct rainy and dry seasons such as tropical Savanna, a level of corresponding proportionality between NDVI measures and rainfall amounts is expected. Against the scientific understanding of the impact of variability in the occurrence of rainfall on NDVI cited in Fay et al. (2000, pp 308–319); similar conditions in Keffi (variability in occurrence and amounts) were unable to induce higher proportions of NDVI. Where mean rainfall amount in a Savanna ecoregion are found incapable of triggering corresponding proportions of vegetation productivity (NDVI); the interference from non-rainfall factors such as human intensive and unsustainable use of land could be a potential factor. As observed in this study, the pattern of inter-annual dynamic distribution of vegetation green cover over Keffi were more associated farmland use in Keffi than with rainfall amounts. This is strongly linked to the trampling impacts from intensive crop cultivation practices (anthropogenic) are capable of impairing fPAR absorption with consequences on plants physiological functioning.

From the results obtained in this study (statistical analysis of social, rainfall and NDVI values), there is a significant empirical evidence to support a sound inference on the inability of inter-annual rainfall amounts in Keffi to induce corresponding NDVI quantities. This therefore leads to a plausible argument that within the vegetation photosynthesis relationship, exists a counteracting signal associated with the dampening effects of intensive agricultural practices on energy-absorbing sites of vegetation canopies. The outcome of such interference is the reduced performance of photosynthesis in plants. In Keffi where rural livelihood activities are not only shaped by available resources, assets and capabilities but also by preferences for cultural livelihoods such as subsistence farming; autonomous responses to climate impacts inevitable. These reactions are also more reactionary than precautionary. In such cognitively-mediated reactions, balancing sustainable natural resource management and protection with short -term adaptation gains is at most non-realizable. Infact the former is less of a priority.

Research Summary

Contextual Overview and Goal of the Research

Autonomous climate adaptation at individual and farm-gate level is a cognitively mediated set of actions shaped by interacting factors such as household characteristics, resources availability and capabilities. It is underpinned by the primary goal of not only adapting cultivated farmlands to changes in climatic conditions but also of bridging gaps in crop yields. In rural communities where opportunities for alternative sources of livelihoods are limited due to lack of institutional support and deepened poverty; farm-gate level adaptation strategies are exercised through personal judgements of self- and response efficacies. Not only are the planning, implementation horizons and types of tools determined by farmers themselves; adopted strategies are reactionary than precautionary in approach. This makes the need for balancing adaptation goals with consideration for land surface conditions far less a priority to smallholder farmers. As a social action intended for the minimization of climate impacts on managed socio-economic systems, adaptation to climate impacts links directly to human perception, behaviours and decision-making; all of which are tied to the human cognitive processes. Autonomous adaptation at farm-gate level is rooted strongly in cognitive process of self and response efficacies. It is influenced by access to assets and capabilities in drawing up needed resources. A range of disincentivizing conditions exist at farm-gate level. This influences on a large extent autonomous adaptation behaviour of farmers and the spontaneity of the approach. In scientific research and development policy practice, autonomous farm-gate level adaptation is perceived differently as a zero-feedback, impact-proof response to impacts of climate change. This perception conceals the disturbance and impact-engendering potential of autonomous adaptation at farm-gate levels. This understanding underscore why less scholarly attention is being given to the potential Impacts or cost of autonomous climate adaptation on vegetation cover. This perception constitutes a gap in climate science adaptation research. In this study, this gap is being addressed with an argument centering on the epistemological bias in the definition of anthropogenic activities. Epistemological bias as argued in this study refers to the exclusion of subtle social actions as farm-gate level adaptation from the concept of anthropogenic events in scholarly works. This study addresses gaps in adaptation science research by identifying three issues: the epistemological bias in the definition of anthropogenic activities, the spatial dimension of climate adaptation and positive feedbacks of human-cognitive adaptation actions.

These three issues, in addition to the potential impact of autonomous adaptation are addressed in this research. Potential impacts of autonomous adaptation in this study is expressed in terms of impacts on land surface and vegetation cover conditions. This is different from the carriage of impacts or cost of adaptation in other studies, where it is expressed more in terms of monetary and resource implications. At the institutional level, some studies, example Cartwright et al. (2013, pp 139–156) have expressed the potential impact (cost) of climate adaptation in terms of investment size and governance commitments. Although Cartwright et al. (2013) raised the issue of implication at local administrative levels, the study addressed the financial implication of adaptation within the context of administrative costs in containing damages arising from the implementation of adaptation measures. Thus, implication or cost of climate adaptation actions in other studies have been more applied in terms of the budgetary implications involved in the implementation of adaptation measures relative to the size of investments and expected outcomes. Impact of climate adaptation irrespective of the scale (administrative or individual) or size of social organization has never been conceived in terms of potential positive feedbacks on vegetation cover dynamics. The under-estimation of potential impact of autonomous adaptation at farm-gate levels and the limitation of the concept of impact (cost) of adaptation to only investment or administrative implications; is addressed in this study. This study argues that autonomous and reactionary adaptation has the potential of interfering with patterns, processes and structures of land surface conditions including vegetation cover. This summarizes the impact-engendering attribute of autonomous adaptation and justifies this essay's argument of the gap in the exclusion from conceptual frame of anthropogenic activity in other studies.

In this research, potential cost or impact of reactionary adaptation by smallholder farmers on land vegetation cover dynamics in Keffi is investigated. The integrated conceptual framework adopted for the study allows for a better understanding of how farm-gate level adaptations can trigger vegetation cover dynamics. The concept also provides the interlinkage between different theoretical frameworks like disturbance regimes, plants physiological, protection motivation theory as well as the anatomy of adaptation. It clarifies concepts like rural livelihoods illuminating its role in autonomous adaptation. The socio-economic conditions and institutional limitations shaping rural livelihoods are also reviewed from which adaptation decisions and actions are explored. It examines the issues of poverty, social inequalities and limited access to institutional incentives providing linkages providing conceptual linkages of the role of these factors in limiting sustainable adaptation and more environmentally-aware options. It uses the concept of scale (both spatial and in terms of vertical hierarchy of social organizations) in clarifying the role which scale plays in determining the scope, type, degree and planning horizon of selected adaptation strategies. Apart from its role in influencing farmers' preferences and scope of adaptation; scale in this study is also used to show the degree and level of severity of climate impacts on resource-poor farming groups. Social deprivation and resource limitations links directly to restrictions experienced by poor farmers in procuring sustainable adaptation actions which can offer a balance between selected adaptation measures and vegetation conditions.

The study expatiates the concept of protective motivation theory (PMT), drawing linkages between human cognition, socio-economic limitations and decision-making. Such links influences adaptation behaviours. The elements of PMT including perception of risks and its severity, self and response efficacy are analysed. The deployment of these pre-decision evaluation processes in the integrated conceptual framework is justified. Drawing from this, the potential impact of autonomous adaptation actions at farm-gate levels on vegetation cover is investigated. This study argues that the carriage of anthropogenic activities in scientific research and development policy papers narrowly portrays anthropogenic activities as deliberate endeavours by humans intended for achieving socio-economic goals. This definition from an epistemological point of view is not only biased but exclusionary in ways that obscures other human activities with impact-engendering effects. The epistemology bias in the definition of anthropogenic activity is addressed in this research and a review of existing conceptual understanding of anthropogenic activity is proposed. This study thus proposes a new definition of anthropogenic activity. It defines anthropogenic activity as any set of events motivated by socio-economic goals or towards the protection of attributes values of managed systems with the potential of such events altering equilibrium states of structures and functions of interacting systems. The study thus contributes to climate adaptation science research with this new definition and with evidence showing influence of farmers' reactionary adaptation strategies on vegetation cover dynamics.

Research Goal: This main goal of this study is to investigate the impact of reactionary adaptation actions by smallholder farmers at farm-gate levels on vegetation cover dynamics. This research is motivated by an interest in interrogating existing knowledge frames and perception of autonomous adaptation as a net zero-feedback and impact-proof social action.

Research Methodology: The research methodological framework consisted of social surveys, ground truthing activities, remote sensing data analysis as well as analysis of physiographic data. Derived NDVI and rainfall datasets were subjected to statistical tests including simple scatter plot, normality test and regression modelling. Detecting signals of farmers' adaptation practices on vegetation cover dynamics in Keffi was realized through a combination of empirical procedures including residual trend (RESTREND) plot assessment and the analysis of anomalies in observed NDVI datasets in Keffi. This included inferential analysis using 1999 NDVI-reference predicted NDVI values as well as Zhang et al (2017)-based predicted values. The characterization of the slope of RESTREND plot (residuals from NDVI-rainfall regression versus time (years) also supported the disentangling of human footprints from inter-annual rainfall signals on vegetation cover. Visual assessments of inter-annual and decadal time-sliced reclassified NDVI maps were part of the inferential analysis. A multinomial logistic model (MNL) was used in understanding farmers' adaptation preferences and factors influencing these choices. Of the three adaptation options considered in this research, "changes in cultivation practices and farm management decisions" was held as the reference category against other adaptation options. The probability or odd ratios associated with other preferred adaptation options relative to the reference category was evaluated. Soil samples were also analysed for the purpose of controlling the effect of soil on vegetation cover dynamics, thus, a simple surface soil nutrient inventory analysis. Observed indicative range of soil nutrients and moisture in Keffi were assessed against the backdrop of outcomes of previous soil studies in Keffi. Ground-truthing activities including measuring elevation of selected soil sampling locations, picture-taking of farming settlements were part of the field survey. Apart from the administration of questionnaire and focal group discussions, personalized interviews on household characteristics were undertaken and considered in inferential interpretation of the statistical outputs.

Results and Discussions: The range of observed NDVI datasets for Keffi between 1999 and 2018 were within 0.2795 and 0.4371. The 20-year mean NDVI value was 0.3625 and the standard deviation, 0.0366. The minimum NDVI value for the 1st decadal time step was 0.3281 and the maximum value at 0.4371. The minimum NDVI value for the second decadal time step is 0.2795 and the maximum was 0.3942. The minimum rainfall amount over the period of 20 years in Keffi was 870 mm/year (2015) while the maximum rainfall amount within the temporal window was recorded at 1340 mm/year (1999). During the first ten years (1st decadal time step), the minimum rainfall value was 940 mm/year and maximum was 1340 mm/year. The minimum rainfall amount in the second decadal time was observed at 870 mm/year and maximum at 1320 mm/year. Apart from low rainfall amounts observed in 2002 (990 mm/year), 2008 (940 mm/year) and in 2015 (870mm/year); the annual rainfall amount in Keffi ranged between 1017mm/year (2018) and 1340 mm/year (1999). Although, the amount of annual rainfall in Keffi was moderate to high, the effect of rainfall was not reflected on vegetation. Observed NDVI values in Keffi were very low, low and moderate. This is below NDVI values expected for tropical Savanna ecoregion with an above 800mm/year rainfall. This empirical assessment by Zhang et al. (2017) suggests that at an annual rainfall quantity of 850mm/year, 0.46 units of NDVI should ideally be produced.

The observed statistical output of the NDVI-rainfall regression analysis returned the following values, regression coefficient R=0.359; R^2=0.129=0.13, adjusted R-squared, R=0.08, a p-value of P>0.120>0.05 associated with the F-Change statistics=2.663. An unstandardized Beta value associated with the Y-intercept, 0.0001 (slope) =0.0001 and the unstandardized Beta, B=0.242 associated with the constant were obtained. The regression coefficient denoting the strength of the linear relationship between NDVI and rainfall returned, R=0.359. The values showed that although there was a linear and positive relationship between NDVI and rainfall; the strength was weak. The R squared (R2) implied that only about 13% of the variability in NDVI was explained by variation in inter-annual rainfall. With P-value of P>0.120>0.05 and the associated F-Change statistics=2.663, it is indicative that inter-annual rainfall variability in Keffi had a weak predictive power on NDVI. At an intercept of 0.0001, an average of 0.0001 change in NDVI would be expected with a unit change in inter-annual rainfall. A bivariate analysis for examining the strength of correlation between mean NDVI values and rainfall returned a P-value of Pearson coefficient of P=0.359 ≈0.360. This was in agreement with outputs of the linear regression analysis. Results from the statistical analysis showed that the effect size of rainfall amounts on vegetation productivity in Keffi was small. The potential dampening of NDVI sensitivity to rainfall amounts by non-rainfall factors like human activities is plausible against the backdrop of the outputs of chi-square and multinomial logistic regression model. Soil analysis was interpreted within the context of inferential evidence from previous soil studies in Keffi. Results of surface soil analysis in this research showed that the impacts of soil nutrient and moisture levels and soil types on NDVI-rainfall sensitivity were insignificant or minor (if any). Pronounced soil signals on NDVI-rainfall sensitivity are more associated with soil types like Gleysols, Ferrasols and Acrisols or acidic soils with pH values less than 5.0. In Keffi, the soil pH was 7.0 and the soil types were of Leptosols group (Alfisols and Oxisols).

Following the outcome of the linear regression, suggestive of weak influence of rainfall amounts on NDVI in Keffi; a residual trend plot analysis was carried out. A trend between residuals from (NDVI-rainfall regression) against time (years) was plotted. The downward negative character of the RESTREND slope suggests that shifts in vegetation productivity in Keffi were not significantly explained by rainfall amounts. The character of the NDVI-rainfall residual versus time plot suggested the masking of rainfall influence on NDVI possibly by other non-rainfall factors contained in the residuals. To validate results from the RESTREND plot, a contextual anomaly detection analysis using a reference NDVI value of 0.46 at an annual rainfall of 835mm/year for tropical open grasslands reported in Zhang et al. 2017 was carried out. The predicted values using 0.46 units of NDVI at 1mm/year rainfall suggests that observed rainfall amounts in Keffi ought to have triggered more vegetation productivity. The assumption is plausible against the backdrop of evidence in Camberlin et al. (2007, pp 199–216) where large amounts of inter-annual rainfall in the Savanna corresponded to moderate (0.5) to high (0.7) NDVI values with significant regression coefficients of $R > 0.7$. However, the reverse was the case in this study as a deviation from other empirical studies was observed. A visual analysis and inference of NDVI maps also suggests the inter-annual rotational land fallow and post-fallow footprints of farmers' activities in Keffi. This observation is reinforced by the portions of the NDVI map with very low NDVI values which represents the built-up areas in Keffi. The portion with red colour patches in the NDVI maps (Appendix II) had the lowest NDVI value and in the north-eastern part of Keffi remained static across all years. This static portion is Keffi town itself which is characterized by heterogenous livelihood activities. The remaining portions of the Keffi area showed dynamic and quantitative distribution of vegetation greenness between years. Inferential analysis of the multinomial logistic model showed that more than 70% of smallholder farmers preferred changing crop cultivation and farm management practices as a response to climate change impacts. In addition to the chi-square test results, the MNL outputs also revealed farmers' preferred cultivation methods and adaptation behaviours. Farmers' cultivation practices and adaptation strategies in Keffi are more or less influenced by limited socio-economic capabilities and lack of institutional support which disincentives sustainable adaptation practices such as longer fallow periods, irrigation and agro-forestry. In this regard, farmers perceive modification of cultivation practices or application of fertilizer on the same piece of land as a quick fix at realizing pressing household needs as well as breaching crop yield gaps in the short term. The analysis showed that social inequalities affected farmers' access to resources for more sustainable adaptation practices.

Other factors include insecure land tenure to support longer-term approaches such as longer fallow periods in between cultivation cycles, irrigation and agro-forestry in Keffi. This means that farmers whose main purpose of farming is to secure both incomes and food supplies at household levels were less likely to adopt adaptation measures with longer time horizons. Reactionary adaptation by smallholder farmers is thus a judgement towards sustaining means of livelihoods and attributes system of value. It is not aimed at ensuring a balance between adaptation and protection of land surface conditions. The inter-linkage between human cognition which underlies human behaviours in the face of risks perception and appraisal is also demonstrated in reactionary adaptation actions. Thus, assessing land use intensity on account of yearly mono and mixed cropping by farmers, provides a contextual basis of the role of reactionary adaptation as anthropogenic stress with potential feedbacks. With vegetation covers under constant exposure; the potential of direct impacts on plants energy-absorbing variables is high. Thus, farmers' adaptation strategies have the potential of interfering with spectral absorptive capacities of plants. As observed in the study, the pattern of inter-annual distribution of vegetation green cover in Keffi relates more to farming activities than of inter-annual variability of rainfall amounts. The observed dynamic on vegetation cover distribution also aligns with views of farmers interviewed, most of whom indicated preferences for short inter-annual rotation of crop cultivation due to challenges of insecure land tenure rights and resources.

In investigating the extent to which vegetation covers in Keffi are impacted by rainfall relative to unsustainable farming practices, a bi-decadal NDVI reclassification was done to observe the character of vegetation cover change. The spatial character of vegetation cover dynamics and the extent of recovery by plants in Keffi were characterized by three classes; “vegetation gain”, “vegetation loss” and “significant loss”. Outputs of a decadal-time slice NDVI reclassification map over the 20-year temporal window also support the attribution of farmers’ inter-annual rotational cultivation and reactionary adaptation footprints on vegetation cover. Between (1999-2018), the area corresponding to “gain” equated to 4,218km2 corresponding to a -12km2 decrease. Within this period, 6,692km2 land area in Keffi was lost and 2,892km2 corresponded to the legend “significant loss”. Between 1999 and 2008, (1st decadal time–sliced), the area corresponding to “vegetation cover gain” was 46,866km2, and vegetation cover loss was 74,361km2. An area totalling 32,136km2 represented the proportion of vegetation cover which was significantly lost. A marked difference within the three classes was observed in the second decadal time slice. The area corresponding to vegetation gain reduced from 46,866km2 to 35,087km2 with a percentage change of -25%. Although, the classes corresponding to "minimal loss" in vegetation covers between 1999-2008 and 2009-2018, did not reflect marked vegetation cover dynamics; the areas classified as "significant loss" in Keffi increased from 32,136km2 to 45, 589km2 corresponded to 42% change increase. Changes in the areas covered with healthy vegetation covers, indicated as “vegetation gain” were negative. This implied an impairment in the quantitative and qualitative physiological processes of vegetation canopies in Keffi. A plausible attribution is either the stand alone or synergistic impacts of climate and anthropogenic activities (human trampling). The percentage change noticed in the “loss” class is greater than the percentage change (-25%) noticed in the “gain” class. The pattern of spatial distribution of vegetation cover across the three classes “vegetation gain”, “vegetation loss” and “significant loss” between the entire temporal scale (1999 and 2018) supports the attribution of low vegetation cover greenness in Keffi due to the short fallow, non-receding cultivation practices between planting seasons across farming settlements in Keffi. These inferences are therefore in agreement with other relevant studies which investigated vegetation cover dynamics under impacts of inter-annual rainfall variation in the Savanna. Evidence documented elsewhere showed that where mean rainfall amounts in a Savanna ecosystem are found incapable of triggering corresponding proportion of vegetation productivity (NDVI); then there are plausibly other masked factors (humans) responsible for dampening NDVI-rainfall sensitivity in Keffi.

Conclusion and Recommendation: Results from this research shows that reactionary adaptation practices particularly at farm-gate levels are largely mediated by a set of interacting cognitive factors. These factors are inter-linked to a large extent with household characteristics and socio-economic conditions which influences farmland management and adaptation strategies. More often than not, farm-gate level adaptation is reactionary in nature involving short fallow cropping systems and changes in crop varieties. Due to its tramping effects, reactionary and autonomous adaptation by smallholder farmers, exert direct impacts on the receiving vegetation covers. Intensive crop cultivation without receding time laps has the potential of not only damaging vegetation canopy structures but also interfering with photosynthetic rates and quantities. This is due to the effect of human trampling on energy-absorbing sites of plants. With regards to future research interest, seeking to replicate this investigation in other geographical regions, the following recommendations are offered. First, denser satellite images and rainfall datasets are recommended. The scarcity of Landsat images for Keffi restricted the analysis of longer time series. Another factor which needs to be addressed is the limitation in climate adaptation choices and the explanatory variables. Such considerations can support a more robust multinomial choice modelling.

Kontextueller Überblick und Forschungsziel

Autonome Klimaanpassung auf der Ebene landwirtschaftlicher Erzeuger ist ein kognitiv vermittelter Handlungsrahmen, der durch interagierende Faktoren wie Haushaltsmerkmale, Ressourcenverfügbarkeit und individuelle Möglichkeiten geprägt ist. Unterstützt wird diese durch das vorrangige Ziel, die Anbauflächen nicht nur an veränderte klimatische Bedingungen anzupassen, sondern auch Lücken im Ernteertrag zu schließen. In ländlichen Gemeinden, in denen die Möglichkeiten für alternative Lebensgrundlagen aufgrund fehlender institutioneller Unterstützung sowie durch Herausforderungen der Armut begrenzt sind, werden Anpassungsstrategien auf Ebene der landwirtschaftlichen Erzeuger durch persönliche Einschätzung der self- and response efficacies durchgeführt. Nicht nur der Planungs- und Umsetzungshorizont sowie die Umsetzungsinstrumente werden von den Landwirten selbst festgelegt, auch lokale Anpassungsstrategien sind reaktionär und nicht präventiv im Ansatz. Das heißt, es ist für Kleinbauern weitaus weniger wichtig, Anpassungsziele unter ökologischer Berücksichtigung der Bodenbeschaffenheit auszugleichen. Eher wirken die Anpassungsstrategien als soziale Maßnahmen zur Minimierung der Auswirkungen auf verwaltete sozioökonomische Systeme. Denn die Anpassung an Klimaauswirkungen hat direkten Bezug auf die menschliche Wahrnehmung, auf Verhaltensweisen und Entscheidungen, die alle durch kognitive Prozesse verbunden sind. Die autonome Anpassung auf lokaler Ebene ist stark im kognitiven Prozess der Selbst- und Reaktionswirksamkeitserwartung verwurzelt. Sie wird durch den Zugang zu Ressourcen und Fähigkeiten bei der Ressourcenbereitstellung beeinflusst und findet in der Regel unter bestimmten restriktiven Bedingungen wie sozialen Ungleichheiten und anderen Einschränkungen statt. Dies beeinflusst weitgehend das autonome Anpassungsverhalten der Bauern und die Spontaneität des Ansatzes.

In der wissenschaftlichen Forschung und der entwicklungspolitischen Praxis wird die autonome Anpassung auf Erzeugerebene anders wahrgenommen, nämlich als eine rückwirkungsfreie, wirkungsvolle soziale Reaktion auf die Auswirkungen des Klimawandels. Eine solche Betrachtung verbirgt das Störungs- und Wirkungspotential der autonomen Anpassung auf Erzeugerebene. Die hier vorgetragene Sichtweise unterstreicht, warum den potenziellen Auswirkungen oder Kosten einer autonomen Klimaanpassung der Pflanzendecke weniger wissenschaftliche Aufmerksamkeit geschenkt wird. Sie stellt eine Lücke in der klimawissenschaftlichen Anpassungsforschung dar. So wird in dieser Studie diese Lücke mit einem Fokus auf die epistemologische Verzerrung der Definition anthropogener Aktivitäten adressiert. Epistemologische Verzerrung/Bias, wie sie in dieser Studie verargumentiert wird, führt zum Ausschluss subtiler sozialer Aktionen als Anpassung auf Erzeugerebene an anthropogene Ereignisse in wissenschaftlichem diskurs Diese Studie adressiert Lücken innerhalb der Adaptionsforschung durch die Identifizierung von drei Themen: die epistemologische Verzerrung/Bias bei der Definition anthropogener Aktivitäten, die räumliche Dimension der Klimaanpassung und die positiven Rückwirkungen menschlich-kognitiver Anpassungsmaßnahmen.

Zusätzlich zu diesen drei Themen, werden die möglichen Auswirkungen der autonomen Anpassung in dieser Studie behandelt. Mögliche Auswirkungen autonomer Anpassung werden in dieser Studie in Form von Auswirkungen auf Landoberfläche und Vegetationsdecken ausgedrückt. Dies unterscheidet sich von der Vorgehensweise in anderen Studien, in denen die Auswirkungen oder Kosten der Klimaanpassung eher in monetärer und ressourcenbezogener Form ausgedrückt werden. Auf institutioneller Ebene zeigten einige Studien, wie beispielsweise Cartwright et al. (2013, S. 139-156), die potenziellen Auswirkungen (Kosten) der Klimaanpassung im Hinblick auf die Investitionsgröße und die Governance-Verpflichtungen auf. Obwohl Cartwright et al. (2013) Fragen nach der Implikation auf lokaler Verwaltungsebene aufwarfen, behandelte die Studie die finanziellen Auswirkungen, oder Kosten der Anpassung, im Zusammenhang mit den Verwaltungskosten zur Eindämmung von Schäden, die sich aus der Umsetzung von Anpassungsmaßnahmen ergeben. So wurden die Folgen von

Klimaanpassungsmaßnahmen in Studien stärker auf die budgetären Auswirkungen der Implementierung im Verhältnis zum Umfang der Investitionen und den erwarteten Ergebnissen angewandt. Bisher wurden klimaanapassungsbedingte Auswirkungen, unabhängig der Skalenebene (administrativ oder individuell) oder der Größe der sozialen Organisation, nicht in Hinblick auf potenzielle positive Rückkopplungen auf die Dynamik der Vegetationsdecke konzipiert. In dieser Studie werden Unterschätzungen der potenziellen Auswirkungen autonomer Anpassung adressiert. Der Fokus liegt hierbei auf dem Agrarsektor sowie auf der Begrenzung des Auswirkungskonzepts (Kosten) auf Investitionen und administrativen Implikationen. Außerdem wird argumentiert, dass die autonome Klimaanpassung im Agrarsektor das Potenzial hat, Muster, Prozesse und Strukturen der Landoberflächenbedingungen einschließlich der Vegetationsdecke zu beeinträchtigen. Dies fasst das impact-engendering Attribut der autonomen Anpassung und die Rechtfertigung des Arguments dieser Studie zusammen, dass die anthropogene Aktivität im konzeptionellen Rahmen ausgeschlossen ist.

Diese Studie untersucht potenzielle Kosten oder Auswirkungen der reaktionären Anpassung auf die Bodenbeschaffenheit und die Dynamik der Vegetationsdecke auf Basis von Anpassungspraktiken von Kleinbauern in Keffi, Nigeria. Der für die Studie gewählte integrierte konzeptionelle Rahmen ermöglicht ein besseres Verständnis dafür, wie autonome Anpassungsmaßnahmen auf individueller Ebene Auswirkungen auf die Vegetationsdeckendynamik auslösen können. Der Ansatz bietet auch die Verknüpfung zwischen verschiedenen theoretischen Rahmen wie Störregimen, Pflanzenphysiologie, Theorie der Schutzmotivation sowie Anatomie der Anpassung. Er klärt Konzepte wie ländliche Lebensgrundlagen auf und beleuchtet deren Rolle innerhalb autonomer Anpassung. Die sozioökonomischen Bedingungen und die institutionellen Beschränkungen, die die ländlichen Lebensgrundlagen prägen, werden ebenfalls untersucht und daraus Anpassungsentscheidungen und -Maßnahmen abgeleitet. Fragen der Armut, der sozialen Ungleichheiten und des begrenzten Zugangs zu Anreizen der Regierung werden ebenfalls untersucht um Verknüpfungen darüber herzustellen, wie diese Faktoren vorsorgliche und nachhaltigere Anpassungsmaßnahmen auf individueller Ebene verhindern. Das Skalenkonzept wird angewandt (sowohl räumlich als auch im Hinblick auf die vertikale Hierarchie der sozialen Organisationen) bei der Klärung der Rolle, die die Skala bei der Bestimmung von Umfang, Art, Grad und Planungshorizont der ausgewählten Anpassungsstrategien spielt. Die Rolle der Skala wird neben der Beeinflussung der Präferenz und des Umfangs von Anpassungsstrategien in der Studie ebenfalls dafür verwendet, um den Grad und die Schwere der Klimaauswirkungen auf arme und ressourcenarme Gemeinschaften oder soziale Gruppen aufzuzeigen. Soziale Benachteiligungen und Ressourcenbeschränkungen stehen in direktem Zusammenhang mit den Einschränkungen, die arme Landwirte bei der Beschaffung nachhaltiger Anpassungsmaßnahmen erfahren, die ein Gleichgewicht zwischen ausgewählten Anpassungsmaßnahmen und den Bodenverhältnissen herstellen.

Die Studie expliziert auch das Konzept der Protective Motivation Theory (PMT), indem sie Zusammenhänge zwischen der menschlichen Kognition und damit verbundenen sozioökonomischen Einschränkungen herstellt, die das menschliche Handeln auf lokaler Ebene bei der Beeinflussung des Anpassungsverhaltens charakterisieren. Die Elemente der Protective Motivation Theorie einschließlich der Wahrnehmung von Risiken und ihrer Schwere, Selbst- und Reaktionswirksamkeit werden analysiert. Der Einsatz dieser Bewertungsverfahren in der Vorentscheidungsphase im integrierten Rahmen wird gerechtfertigt. Ausgehend davon werden die potenziellen Auswirkungen autonomer Anpassungsmaßnahmen auf die Vegetationsdecke auf Erzeugerebene untersucht. Diese Studie argumentiert, dass der Einfluss anthropogener Aktivitäten im wissenschaftlichen und entwicklungspolitischen Diskurs als bewusste Bemühungen des Menschen zur Erreichung sozioökonomischer Ziele und damit zu eng darstellt. Diese Definition ist aus erkenntnistheoretischer Sicht nicht nur voreingenommen, sondern auch ausschließend, so dass andere menschliche Aktivitäten mit auswirkungserzeugenden Effekten überlagert werden. Die epistemologische Verzerrung/Voreingenommenheit/Bias in der Definition der anthropogenen Aktivität wird in dieser

Studie adressiert und eine Überprüfung des bestehenden konzeptionellen Verständnisses der anthropogenen Aktivität vorgeschlagen. Die Studie bietet damit einen neuen Definitionsrahmen, aus dem anthropogene Aktivitäten verstanden werden können. Dieser definiert anthropogenen Aktivität als jede Art von Aktivitäten, die durch sozioökonomische Ziele oder zum Schutz von Attributwerten von verwalteten Systemen motiviert sind und die die Fähigkeit haben, Gleichgewichtszustände von Strukturen, Prozessen und Funktionen interagierender Systemvariablen zu verändern. Mit dieser neuen Definition und mit Beweisen, die den Einfluss der reaktionären Anpassungsmaßnahmen der Landwirte auf die Dynamik der Vegetationsdecke aufzeigen, trägt diese Studie somit zur Klimaanpassungsforschung bei.

Forschungsziel

Das Hauptziel der Studie ist, die Auswirkungen reaktionärer Anpassungsmaßnahmen von Kleinbauern auf der Ebene der landwirtschaftlichen Erzeuger auf die Dynamik der Vegetationsdecke zu untersuchen. Die Forschung ist motiviert durch das Interesse, bestehende Wissensrahmen zu hinterfragen und die Wahrnehmung der autonomen Anpassung als ein Netto-Null-Feedback und wirkungsvolles soziales Handeln zu diskutieren.

Forschungsmethode

Der methodische Rahmen der Forschung bestand aus sozialen Umfragen und Ground Truthing [Aufnahme von Informationen direkt durch Geländeerkundung am Boden, die zur Analyse von Fernerkundungsdaten genutzt werden], Fernerkundungsdatenanalyse sowie der Analyse physiographischer Daten. Abgeleitete NDVI- und Niederschlagsdatensätze wurden statistischen Tests unterzogen, darunter einfaches Streudiagramm, Normalitätstest und Regressionsmodellierung. Die Erkennung von Signalen der Anpassungspraktiken der Landwirte an die Vegetationsdeckendynamik in Keffi wurde durch eine Kombination von empirischen Verfahren wie der Residuenanalyse (RESTREND) und Analyse von Ausreißern in den beobachteten NDVI-Werten in Keffi realisiert. Dies geschah unter Verwendung des 20-jährigen Jahresmittelwerts, des Varianzkoeffizienten sowie der 1. und 3. Sigma-Regeln der Anomalieerkennung. Die Charakterisierung der Steigung des RESTREND-Plots (Residuen der NDVI-Regenfallregression über die Zeit (Jahre)) unterstützte auch die entwirrend menschlicheren Fußabdrücke von zwischenjährlichen Niederschlagssignalen auf der Vegetationsdecke. Visuelle Bewertungen der generierten NDVI-Karten sowie eine Neuklassifizierung von NDVI-Karten in 10-Jahres-Abschnitte wurden ebenfalls durchgeführt. Ein multinomiales Logistikmodell (MNL) wurde verwendet, um die Anpassungspräferenzen der Landwirte zu analysieren. Von den drei in dieser Studie betrachteten Anpassungsoptionen wurde „Änderungen der Anbaupraktiken und Entscheidungen der Betriebsführung“ als Referenzkategorie gegenüber anderen Anpassungsoptionen angesehen. Die Wahrscheinlichkeit von oder ungeraden Verhältnissen, die mit anderen bevorzugten Anpassungsoptionen (Änderungen im Anbau anderer Pflanzensorten oder Diversifizierung der Lebensgrundlagen) im Verhältnis zur Referenzkategorie verbunden sind, wurde bewertet. Außerdem wurden Bodenproben analysiert, um den Einfluss des Bodens auf die Vegetationsdeckendynamik zu kontrollieren (es handelte sich hierbei lediglich um eine Bodennährstoffinventaranalyse). Indikativ beobachtete Bandbreiten von Bodennährstoffen und Feuchtigkeit wurden vor dem Hintergrund der Ergebnisse früherer Bodenstudien im Forschungsgebiet Keffi bewertet. Ground truthing beinhaltete Höhenmessungen ausgewählter Bodenprobenahmestellen, visuelle Beurteilungen des Gebietes, das Fotografieren von Landschaften, die die flächenmäßige Verteilung der Vegetation zeigen sowie Umfragen. Neben der Durchführung von Fragebögen und persönlichen Interviews wurden auch Gruppendiskussionen durchgeführt, um persönliche Erfahrungen mit den sozioökonomischen Bedingungen in Keffi zu sammeln. Diese personalisierten Ansichten wurden bei der Inferenzinterpretation der statistischen Datenanalyse berücksichtigt.

Ergebnisse und Diskussion

Der Bereich des beobachteten NDVI-Datensatzes für Keffi im Zeitraum von 1999 und 2018 lag zwischen 0,2795 und 0,4371. Der mittlere NDVI-Wert innerhalb einer Zeitspanne von 20 Jahren betrug 0,3625 und die Standardabweichung 0,0366 (0,3625+/-0,0366). Der minimale NDVI-Wert für den ersten Dekadenabschnitt betrug 0,3281 und der maximale Wert 0,4371. Der minimale NDVI-Wert für den zweiten Dekadenabschnitt betrug 0,2795 und der maximale 0,3942. Die minimale Niederschlagsmenge über einen Zeitraum von 20 Jahren betrug 870 mm/Jahr (2015), während die maximale Niederschlagsmenge innerhalb dieses Zeitfensters mit 1340 mm/Jahr (1999) erfasst wurde. In den ersten zehn Jahren (1. Dekadenabschnitt) betrug der minimale Niederschlagswert 940 mm/Jahr und der maximale 1340 mm/Jahr. Die minimale Niederschlagsmenge in der zweiten Dekade wurde bei 870 mm/Jahr und maximal bei 1320 mm/Jahr beobachtet. Abgesehen von den geringen Niederschlagsmengen, die 2002 (990 mm/Jahr), 2008 (940 mm/Jahr) und 2015 (870 mm/Jahr) beobachtet wurden, lag die jährliche Niederschlagsmenge in Keffi zwischen 1017 mm/Jahr (2018) und 1340 mm/Jahr (1999). Obwohl die jährliche Niederschlagsmenge in Keffi moderat bis hoch war, spiegelte sich der Effekt der Niederschläge nicht in den NDVI-Werten wider. Die beobachteten NDVI-Werte in Keffi waren niedrig bis moderat und lagen unter den für die tropische Ökoregion Savanne mit über 800 mm/Jahr erwarteten NDVI-Werten. Der Referenz-NDVI-Wert liegt bei 0,46 bei einer Niederschlagsmenge von 850 mm/Jahr, wie in Zhang et al. vorhergesagt (2017, S. 2318-2324).

Die NDVI-Regenfall-Regressionsanalyse lieferte folgende Werte: Regressionskoeffizient R=0,359; R^2=0,129=0,13, korrigiertes R^2=0,08, eine Signifikanz von p>0,120, mit dem dazugehörigen F--Wert von 2,663. Ein nicht standardisierter Beta-Wert, der dem Y-Achsenabschnitt zugeordnet ist 0,0001 und der nicht standardisierte B=0,242, der der Konstante zugeordnet ist, wurden erhalten. Der Regressionskoeffizient, der die Stärke der linearen Beziehung zwischen NDVI und Regenfall widergibt, wurde mit R=0,359 zurückgegeben. Die Werte zeigteneinen schwachen positiven linearen Zusammenhang zwischen NDVI und Niederschlag. Das R-Quadrat (R^2) deutete an, dass nur etwa 13% der Variabilität des NDVI durch die Variation der zwischenjährlichen Niederschläge erklärt wurde. Mit einem p-Wert von p>0,120 (und somit über dem Schwellenwert von p>0,05) und der zugehörigen F-Statistik=2,663 ist es indikativ, dass die zwischenjährliche Niederschlagsvariabilität in Keffi eine schwache Vorhersagekraft auf den NDVI hatte. Bei einem Schnittpunkt mit der y-Achse von 0,0001mm-year würde eine Änderung einer Einheit der jährlichen Niederschläge zu einer durchschnittlichen Änderung des NDVI von 0,0001 führen. Entsprechend wird bei 0 mm pro Jahr Niederschlag ein durchschnittlicher konstanter NDVI-Wert von 0,242 vorhergesagt/angenommen. Eine bivariate Analyse zur Untersuchung der Stärke der Korrelation zwischen mittleren NDVI-Werten und Niederschlägen ergab einen p-Wert von p=0,359 ≈0.360, welches in Übereinstimmung mit den Ergebnissen der Regressionsanalyse stand. Aus diesen statistischen Analysen lässt sich schließen, dass die jährlichen NDVI-Werte in Keffi nicht durch die jährlichen Niederschlagsmengen beeinflusst wurden. Die Bodenprobenanalyse wurde im Rahmen von Ergebnissen und Rückschlussfolgerungen aus früheren Bodenanalysen in Keffi durchgeführt. Die Ergebnisse der Oberflächenbodenanalyse in dieser Studie zeigten, dass die Auswirkungen von Bodennährstoff- und Feuchtigkeitsgehalt sowie Bodentypen auf die Empfindlichkeit von NDVI-Niederschlägen nicht signifikant oder geringfügig (falls vorhanden) waren. Signifikante Bodensignale auf die NDVI-Regenempfindlichkeit sind eher mit Bodentypen wie Gleye, Ferralsol und Acrisol oder sauren Böden mit pH-Werten unter 5,0 verbunden. In Keffi war der Boden pH-neutral und gehörte zur Leptosolgruppe (Alfisol und Oxisol), wie in Camberlin et al. erwähnt (2007, ss.199-216). Eine Residuenanalyse ergab einen schwachen linearen Zusammenhang zwischen der Niederschlagsmenge und dem NDVI während eine Bodenanalyse zeigte, dass die Bodenbedeckung in Keffi (Savannenlandschaft, offene Ackerfläche) keinen Einfluss auf die NDVI-Regenempfindlichkeit ausübt. Ein Trend-Plot der Residuen (der NDVI-Niederschlagsregression) gegen die Zeit (Jahre), die durch den Charakter und die Form des RESTREND- Anstiegs beschrieben wird; zeigte, dass

Veränderungen in der Vegetationsproduktivität in Keffi nicht signifikant durch die Variabilität der jährlichen Niederschläge erklärt wurden. Der Charakter des Modells deutete auf weitere Faktoren, die durch die Residuen erklärt werden, hin. Zur Validierung des RESTREND-Plots wurde eine kontextuelle Anomalie-Erkennungsanalyse mit einem Referenz-NDVI-Wert von 0,46 bei einer jährlichen Niederschlagsmenge von 835 mm/Jahr für tropische offene Graslandschaften gemäß Zhang et al. 2017 durchgeführt. Die vorhergesagten Werte unter Verwendung von 0,46 NDVI-Einheiten bei 1 mm/Jahr Niederschlag deuten darauf hin, dass beobachtete Niederschlagsmengen in Keffi eine höhere Vegetationsproduktivität hätten auslösen müssen. Diese Annahme ist plausibel vor dem Hintergrund der Studie von Camberlin et al. (2007, S. 199-216), die zeigte dass moderate bis hohe Mengen an jährlichen Niederschlägen in der Savanne in mittleren (0,5) bis hohen (0,7) NDVI-Werten mit signifikanten Regressionskoeffizienten von r > 0,7 resultieren. In dieser Studie ist jedoch das Gegenteil der Fall, da eine Abweichung von der Annahme beobachtet wurde.

Eine visuelle Bewertung der generierten NDVI-Karten zeigte auch die zwischenährlichen Rotationsfußabdrücke der landwirtschaftlichen Anbauaktivitäten in Keffi, die den beobachteten NDVI-Werten zwischen 1999-2018 entsprachen. Diese Beobachtung wird durch die Anteile der NDVI-Karte mit sehr niedrigen NDVI-Werten verstärkt, die den bebauten (peri-urbanen) Teil von Keffi darstellen. Dieser in den NDVI-Karten (siehe Anhang II) braun dargestellte Teil von Keffi hatte den niedrigsten NDVI-Wert und blieb über alle Jahre statisch. Die restlichen Teile des Keffi-Gebietes zeigten eine dynamische Verteilung der grünen Vegetationsdecke über die Jahre. Die Schlussfolgerungsanalyse des multinomialen Logistikmodells (MNL) ergab, dass mehr als 70% der Kleinbauern es vorzogen, den Anbau und die Betriebsführung als Reaktion auf die Auswirkungen des Klimawandels zu ändern. Zusätzlich zu den Ergebnissen des Chi-Quadrat-Tests zeigten die MNL-Ergebnisse auch die bevorzugten Anbaumethoden und Anpassungsverhalten der Landwirte. Die Anbaumethoden und Anpassungsentscheidungen der Landwirte in Keffi werden mehr oder weniger von begrenzten sozioökonomischen Ressourcen und einer schwachen institutionellen Unterstützung beeinflusst, die nachhaltige Anpassungspraktiken wie längere Brache und Agroforstwirtschaft verhindern. In diesem Zusammenhang empfanden die Landwirte die Änderung der Anbaupraktiken als eine schnelle Lösung, um kurzfristig dringende Haushaltsbedürfnisse zu befriedigen und Ertragslücken zu schließen. Die Analyse ergab auch, dass sich die sozialen Ungleichheiten in größerem Maße auf den Zugang zu Ressourcen und Werkzeugen für ausgewählte Anpassungspraktiken der Landwirte auswirkten. Weitere Faktoren sind unsicherer Landbesitz zur Unterstützung längerfristiger Ansätze wie längere Stillstandszeiten zwischen den Anbauzyklen, Bewässerung und Agroforstwirtschaft in Keffi. Die reaktionäre Anpassung der Kleinbauern ist daher ein Urteil über die Erhaltung der Lebensgrundlagen und der Attribute des Wertesystems. Dies bedeutet, dass Landwirte, deren Hauptzweck es ist, sowohl das Einkommen als auch die Nahrungsmittelversorgung auf Haushaltsebene zu sichern, weniger wahrscheinlich Anpassungsmaßnahmen mit längerem Zeithorizont ergreifen würden.

Die Verknüpfung der menschlichen Kognition, die dem menschlichen Verhalten bei der Wahrnehmung und Bewertung von Risiken zugrunde liegt, zeigt sich auch in autonomen Anpassungsmaßnahmen. Die Bewertung der Landnutzungsintensität aufgrund des jährlichen Mono- und Mischanbaus durch die Landwirte schafft somit kontextuelle Klarheit über die Klimaanpassung als potenzielle Belastung für Vegetationsüberdachungen. Da die Vegetationsdecke ständig den landwirtschaftlichen Aktivitäten der Landwirte ausgesetzt ist, ist das Potenzial für direkte Auswirkungen auf strukturelle und energieabsorbierende Organe in Pflanzen groß. So können die Anpassungsstrategien der Landwirte die spektrale Absorptionsfähigkeit der Pflanzen potenziell beeinträchtigen. Wie in der Studie beobachtet, bezieht sich das Muster der interannuellen Verteilung der vegetativen Grünfläche in Keffi eher auf landwirtschaftliche Aktivitäten (siehe Anhang II). Diess Muster deutet eher auf einen rotierenden Fußabdruck menschlicher Aktivitäten in Keffi hin als auf Niederschlagseffekte. Die beobachtete dynamische Verteilung der jährlichen Vegetationsdecke stimmt auch mit den Ansichten der befragten

Landwirte überein, die aufgrund der Herausforderungen instabiler und unsicherer Landrechte eine kurze jährliche Rotation des Pflanzenbaus bevorzugten.

Die Ergebnisse einer dekadischen Zeitscheibe reklassifizierter NDVI-Karten unterstrichen ebenfalls diese Beobachtung und Zuordnung. Bei der Untersuchung des Umfangs, in dem die Vegetationsdecke in Keffi sind beeinträchtigt durch Regenfälle im Vergleich zu nicht-nachhaltigen landwirtschaftlichen Methoden, eine bi-dekadischen NDVI Reklassifizierung durchgeführt wurde, um den Charakter der Vegetationsdecken ändern zu beobachten. Der räumliche Charakter der Dynamik der Vegetationsdecke und das Umfang der Pflanzenregeneration in Keffi wurden durch drei Klassen charakterisiert: "Vegetationszunahme", "Vegetationsverlust, "Signifikantverlust". Die Ergebnisse einer NDVI-Reklassifikationskarte über das Zeitfenster von 20 Jahren unterstützt auch die Attributierung von Fußabdrücken der zwischenjährlichen Rotationskultivierung und der reaktionären Anpassung der Bauern auf der Vegetationsdecke. Zwischen (1999-2018), die Fläche, die als " Zunahme" ca 4.218 km2 angemerkt ist , und einer Abnahme von -12 km2 entspricht. Innerhalb dieses Zeitraum gingen 6.692 km2 Landfläche in Keffi verloren, mit 2.892 km2 entsprachen der Legende "signifikanterverlust". Innerhalb dieses Zeitraums wurden 6.692 km2 Landfläche in Keffi verloren, mit 2.892 km2 entsprach der Legende "erheblicher Verlust". Zwischen 1999 und 2008 (1. dekadische Zeit), sind die Fläche, die dem "Vegetationsdeckungssteigerung" entspricht, 46.866 km2 und der Vegetationsdeckungsverlust 74.361 km2. Eine Fläche von insgesamt 32.136 km2 bezeichnet dem Anteil der Vegetationsdecke, der signifikant verloren war. Ein deutlicher Unterschied innerhalb der drei Klassen wurde in der zweiten dekadischen Phase bemerkt. Die Fläche, die dem Vegetationssteigerung entspricht, reduzierte sich von 46.866 km2 auf 35.087 km2 mit einer Prozentsatzänderung von -25%. Obwohl die Klassen, die dem "minimalen Verlust" an Vegetationsdecken zwischen 1999-2008 und 2009-2018 entsprechen, keine deutliche Dynamik zeigten, stiegen die Flächen, die in Keffi als "signifikanter Verlust" bezeichnet sind, von 32.136 km2 auf 45, 589 km2 entsprachen einer Zunahme der Veränderung um 42%. Die Veränderungen in den Flächen, die mit einer gesunden Vegetationsdecke bedeckt sind und als "Vegetationssteigerung" bezeichnet werden, waren negativ. Dies bedeutet eine Beeinträchtigung der quantitativen und qualitativen physiologischen Prozesse der Vegetationsdecken in Keffi. Eine plausible Zuschreibung ist entweder die eigenständige oder synergistische Wirkung von Klima und menschlichen Aktivitäten (anthropogener). Die in der Klasse "Verlust" beobachtete Prozentzahlsveränderung ist größer als die in der Klasse "Vegetationssteigerung" beobachtete Prozentzahl (-25%).

Fazit und Empfehlung

Die Ergebnisse dieser Forschung zeigen, dass autonome Anpassungspraktiken, insbesondere auf individueller oder landwirtschaftlicher Erzeugerebene, weitgehend durch eine Reihe von interagierenden kognitiven und sozioökonomischen Faktoren vermittelt werden. Sie zeigen auch, dass dieser reaktionäre Ansatz Störungen mit Trittschäden-Effekten auf die Vegetationsstrukturen darstellt. Intensive Bewirtschaftung ohne Zeitverzögerung hat das Potenzial, nicht nur Vegetationsstrukturen zu schädigen, sondern auch photosynthetische Raten und Mengen durch Schäden an energieabsorbierenden Pflanzenteilen zu beeinträchtigen. Für zukünftige Forschungsinteressen, die versuchen, diese Idee in andere geografische Regionen, Größenordnungen oder sozioökonomische Zusammenhänge zu übertragen, wird eine Empfehlung zur Beseitigung der mit dieser Studie verbundenen Einschränkungen vorgeschlagen. Einige dieser Einschränkungen sind die geringen NDVI- und Niederschlagsdatensätze, die die Analyse längerer Trends sowie mehrere Anpassungsoptionen und erklärende Variablen einschränkten, um eine robustere Modellierung zu gewährleisten. Andere sind begrenzte Möglichkeiten zur Klimaanpassung und erklärende Variablen, um eine robustere multinomiale Entscheidungsmodellierung zu unterstützen. Es wird daher empfohlen, diese Einschränkungen bei zukünftigen Studien zu berücksichtigen.

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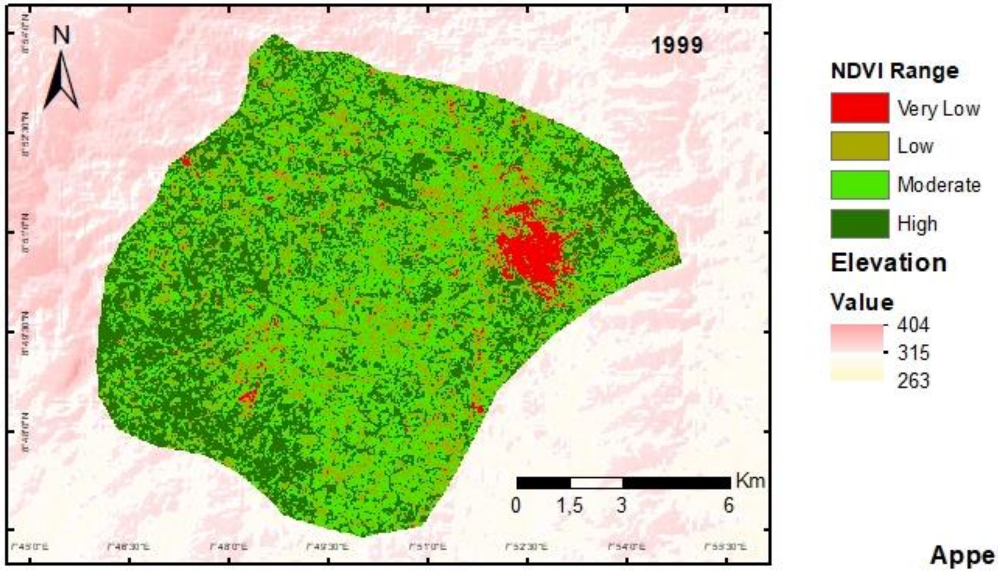
Appendix 1: Social Survey Questionnaire

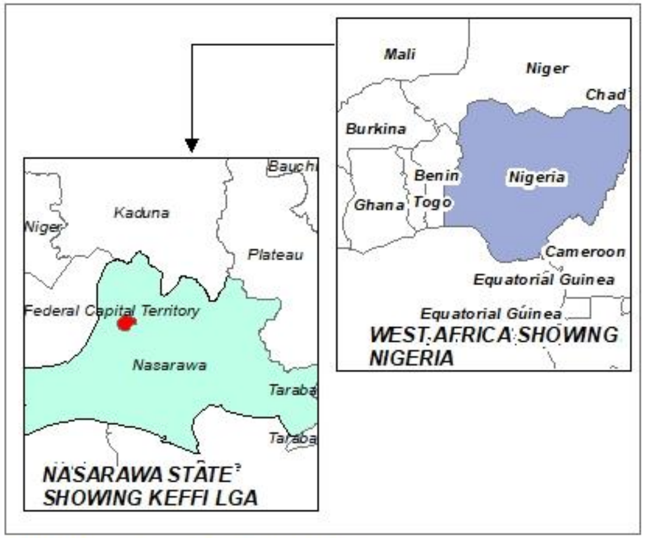
(Keffi Local Government Area, Nasarawa state, Nigeria; 2016 & 2017).

Name (Optional)	
Gender	☐ Male ☐ Female
Occupation/Livelihood Source	☐ Smallholder farmer ☐ Crop Vendor
Head of Household	☐ Yes ☐ No
Do you have an alternative source of income?	☐ Yes ☐ No
How large is your family?	☐ Less than 5 ☐ More than 5 but less than 10 ☐ More than 10
What is the size of your household needs financed from crop sales?	☐ Relatively small portion (10 -30%) ☐ Half of Household Needs (50%) ☐ All Household Needs (up to 100%)
What is the main purpose of farming / crop cultivation?	☐ Only to ensure food security at household level ☐ For both income generation and food security at household level ☐ Not Applicable
Commonly cultivated crops	☐ Yams ☐ Maize ☐ Cassava ☐ Millet
Comparing the last 6 - 10 years, how would you assess crop yields annually in Keffi?	☐ Decreasing ☐ Increasing ☐ Indifferent/cannot say
Tick the most appropriate reason (s) for your answer	☐ Impacts of Pests and Diseases ☐ Impact of Climate Change and weather ☐ Inadequate access to incentives like fertilizer ☐ Improved access to institutional incentives
Factors affecting cultivation decisions (including planting periods and types of crops)	☐ Weather and climate variability ☐ Land tenure title rights ☐ Availability or otherwise of seedlings
Preferred Planting periods or months	☐ Between November and January ☐ Between February and April

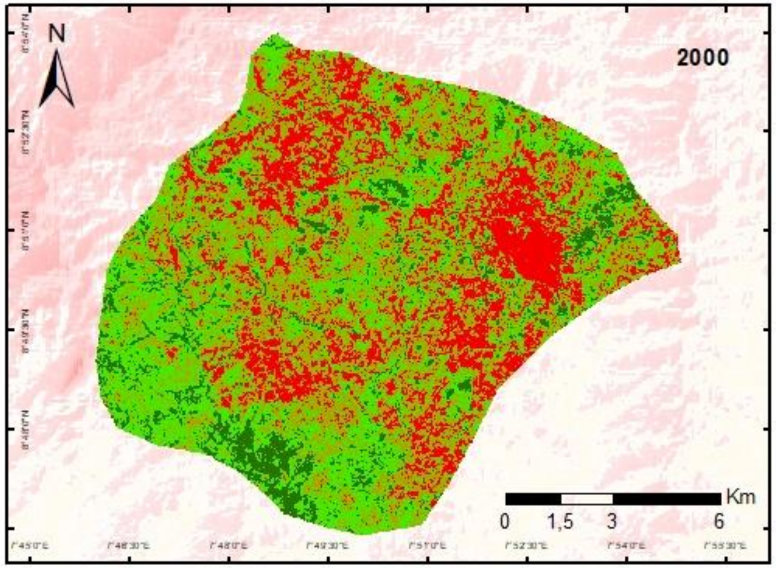
What informs your choice of farming or cultivation techniques and methods?	☐ Widespread local technologies ☐ Historical cultural farming practices tied to crop types ☐ Seasonal climate considerations and weather patterns ☐ Land tenureholdership and rights ☐ Not Applicable
Preferred Cultivation Practices (please tick as many as applies)	☐ Shifting cultivation with less fallow periods (6 months to 1 year) ☐ Shifting cultivation with more fallow periods (more than 1 year) ☐ Yearly mono and /mixed cropping on the same parcel of land ☐ Not Applicable
Perception about the abundance or otherwise of vegetation cover within your locality. Is vegetation spatial distribution decreasing or increasing?	☐ Increasing ☐ Decreasing ☐ Unable to say
Reasons for changes (if there has been changes) in crop cultivation practices	☐ Weather and Climate change ☐ Decreasing Soil conditions ☐ Not Applicable
What is your perception of local climate? Would you say there have been marked changes in temperature and rainfall events?	☐ Yes ☐ No ☐ Unable to say /Indifferent
Preferred adaptation measures or strategies to climate impacts in Keffi	☐ Diversification of livelihoods options (non-farm options) ☐ Changes in crop cultivation decisions and farming methods ☐ Changes in crop varieties ☐ Non-Applicable
What is your personal views and perception about the general living standard in Keffi?	☐ Moderate ☐ Low ☐ Very low

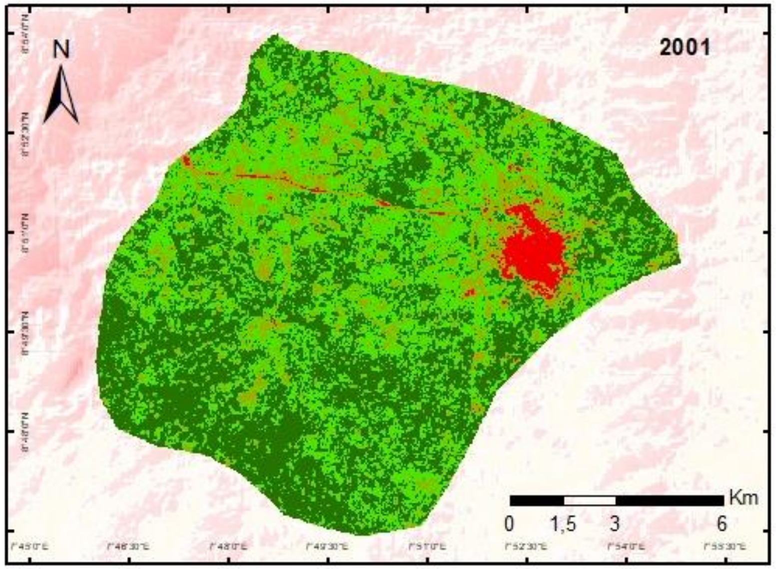
Appendix II NDVI maps showing the inter-annual conditions of vegetation cover dynamics, Keffi (1999-2018)

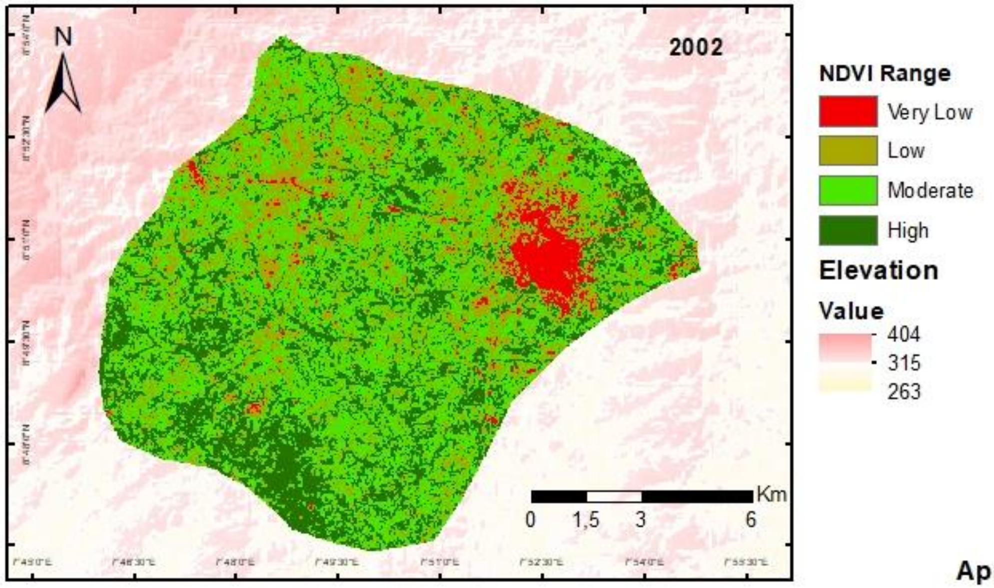


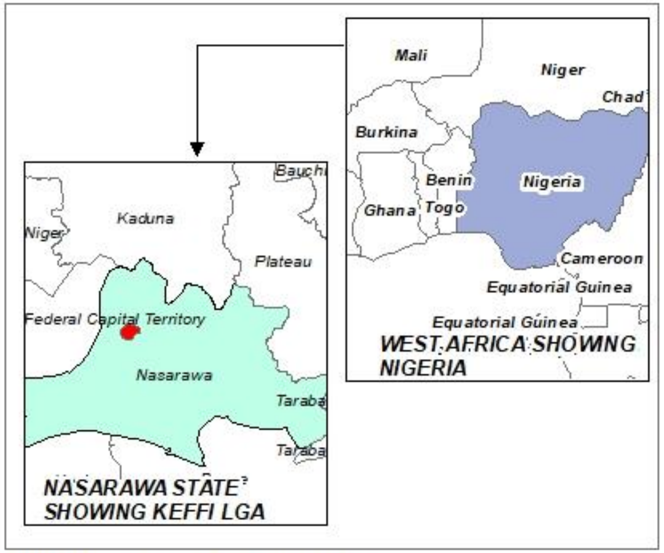


Appendix II - Inter-annual NDVI Maps









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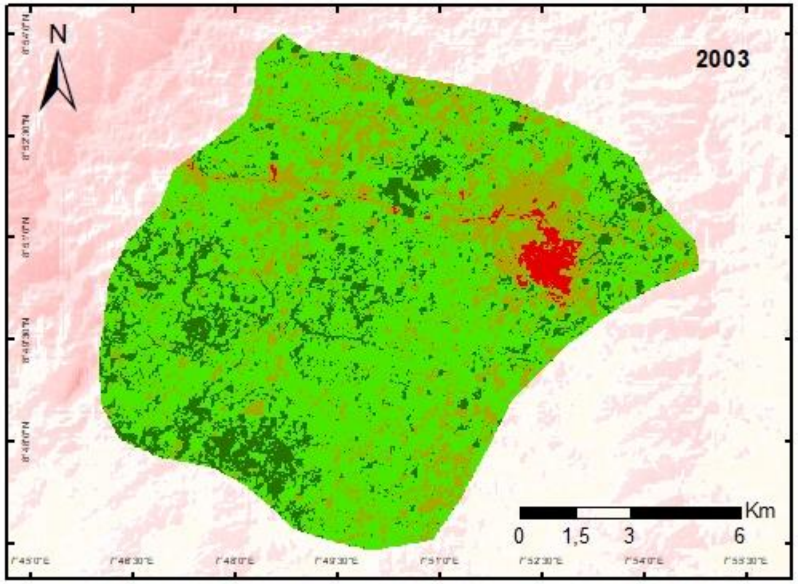

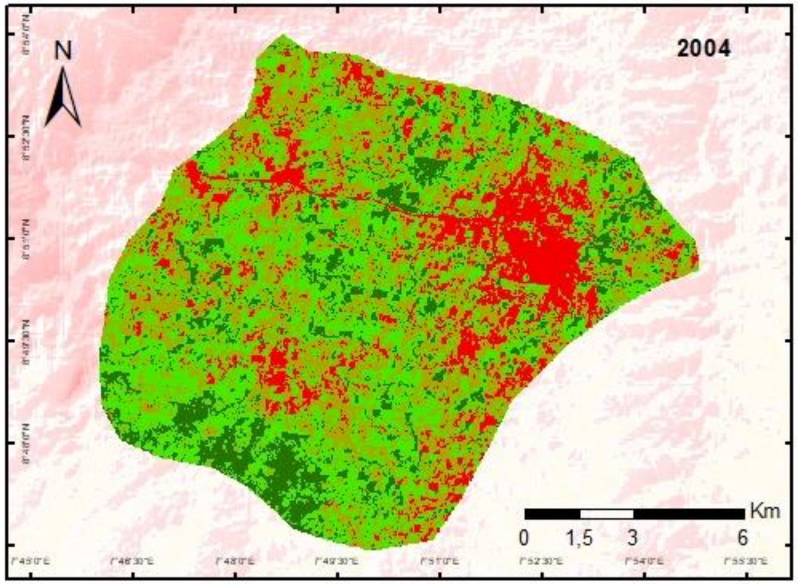

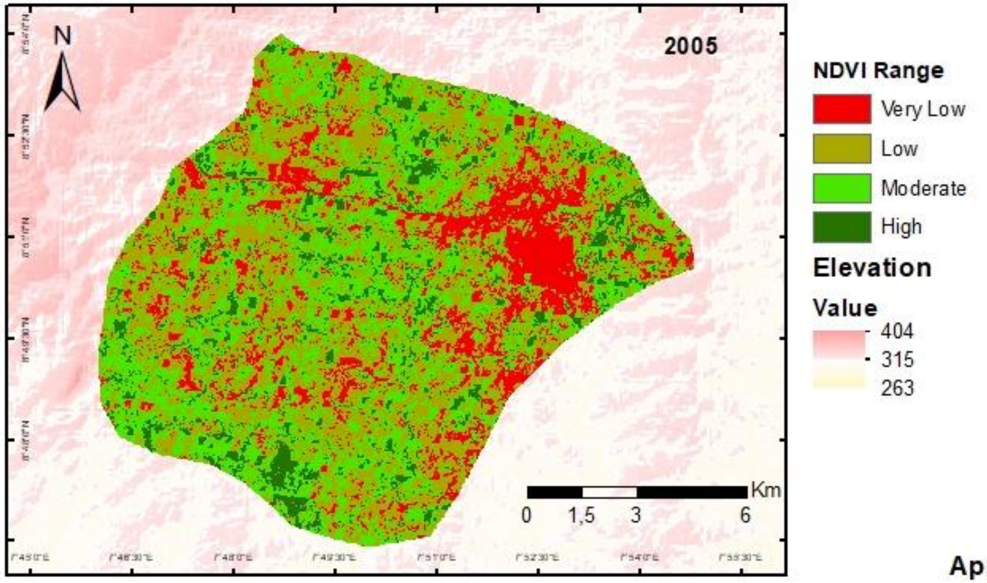

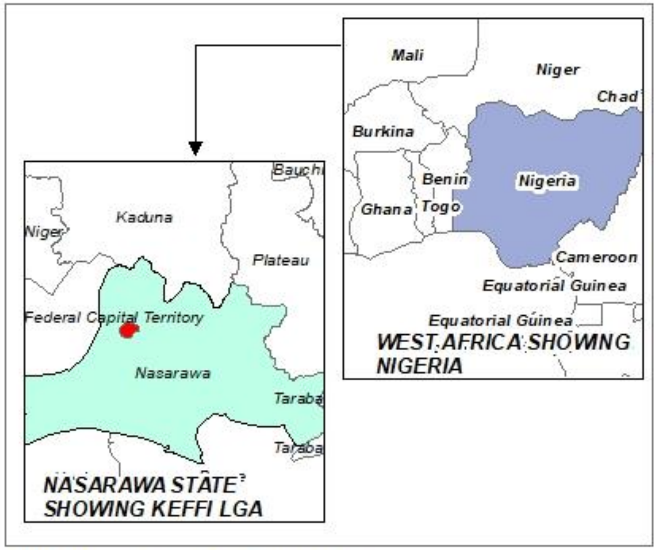

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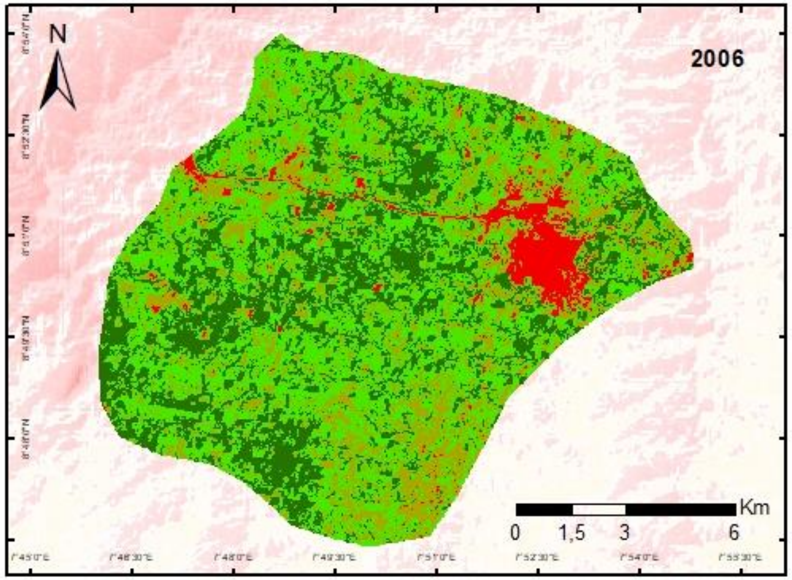

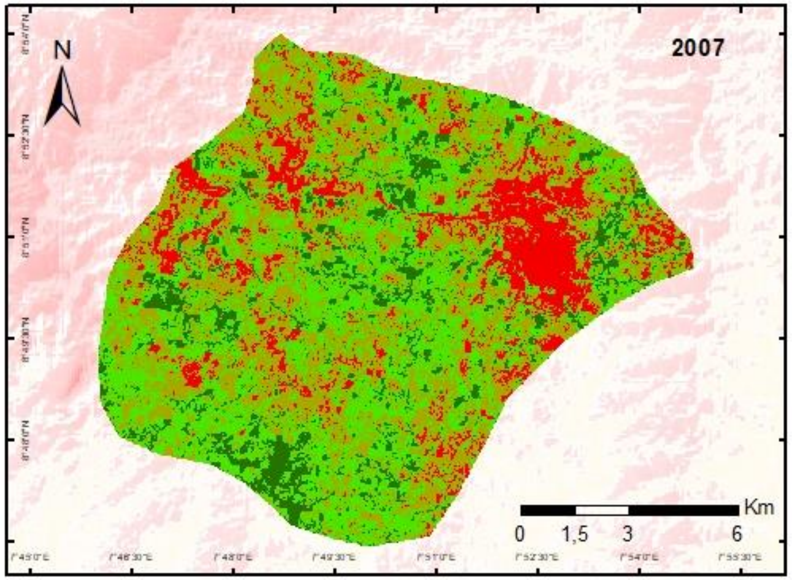

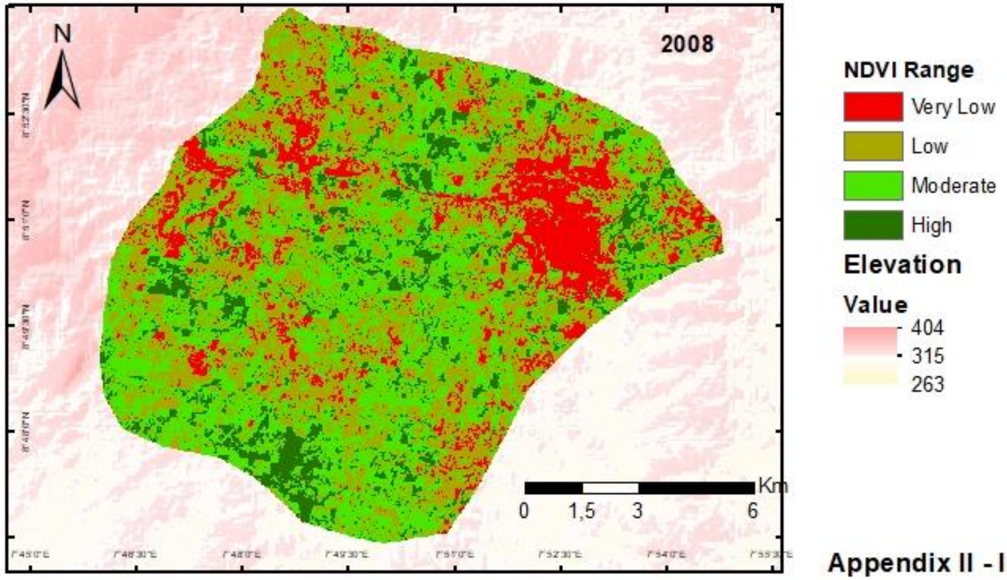

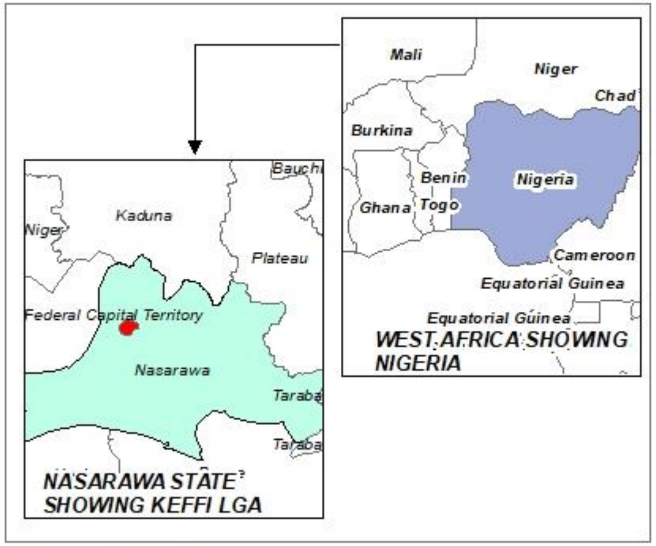

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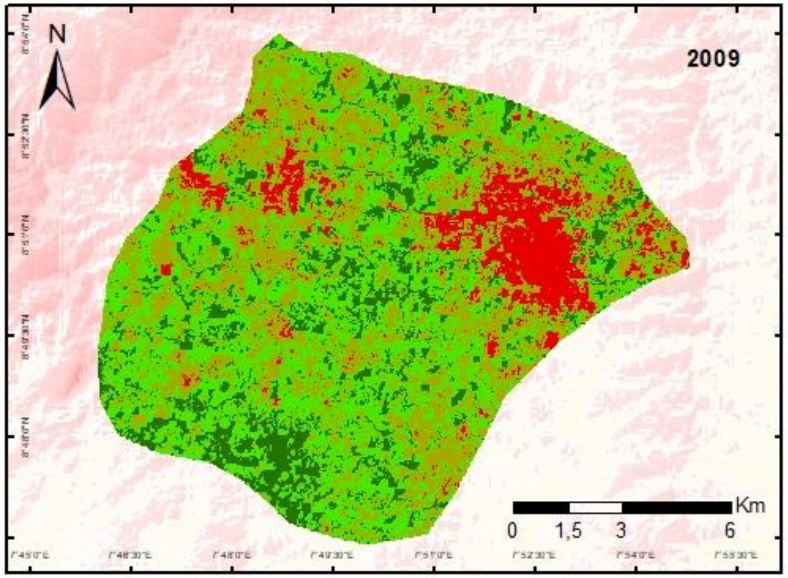

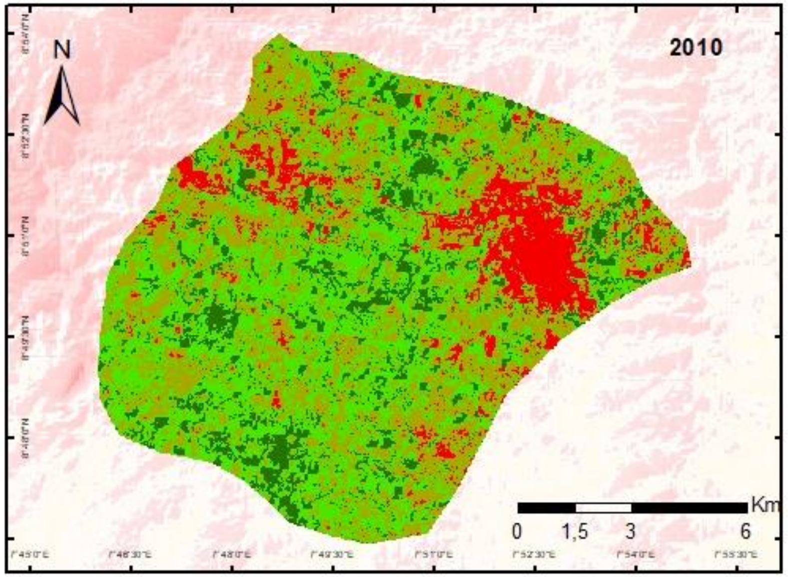

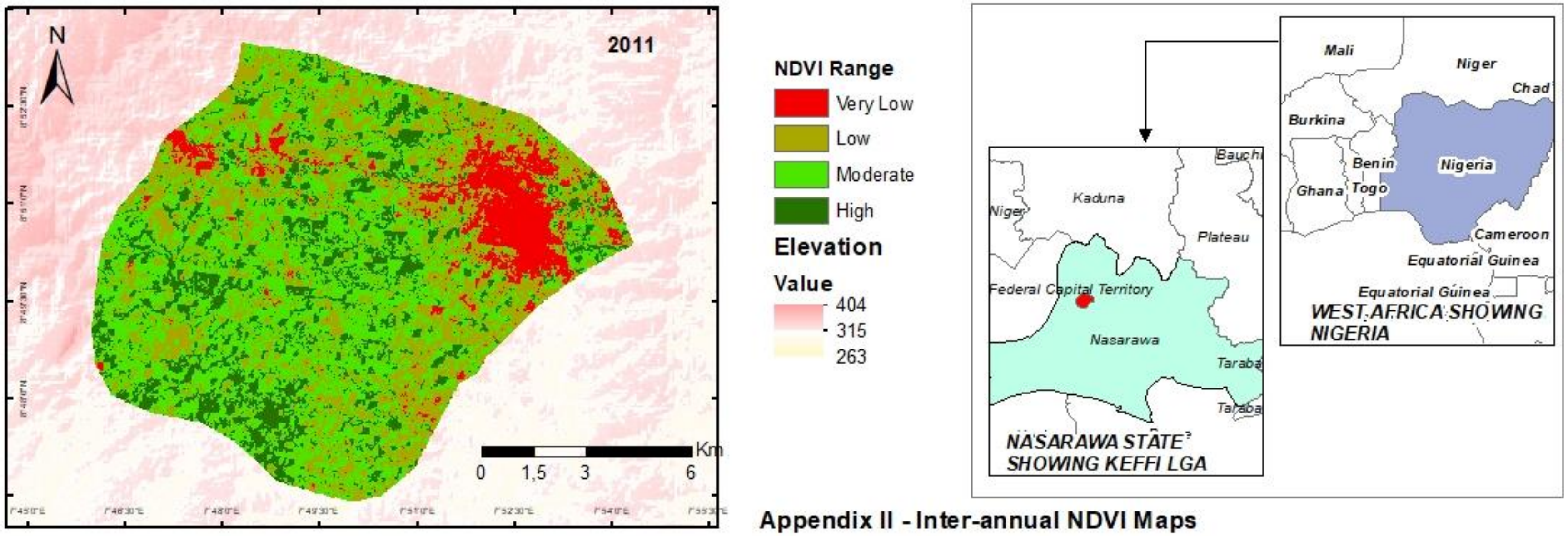

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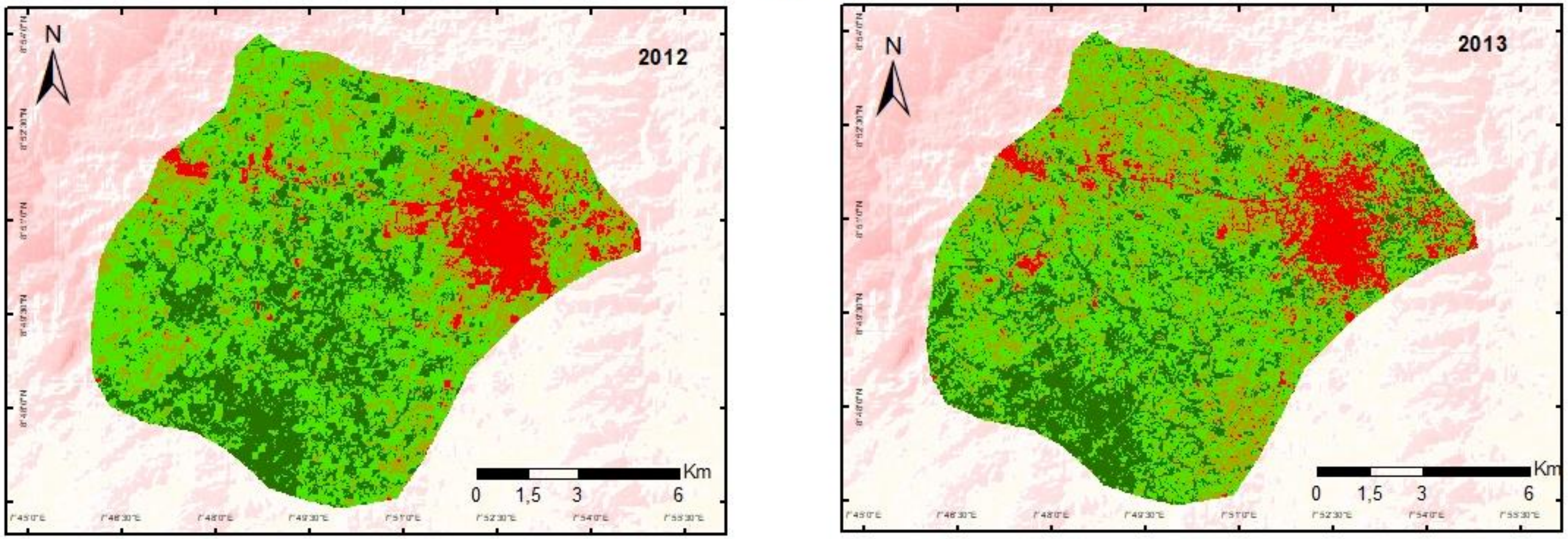

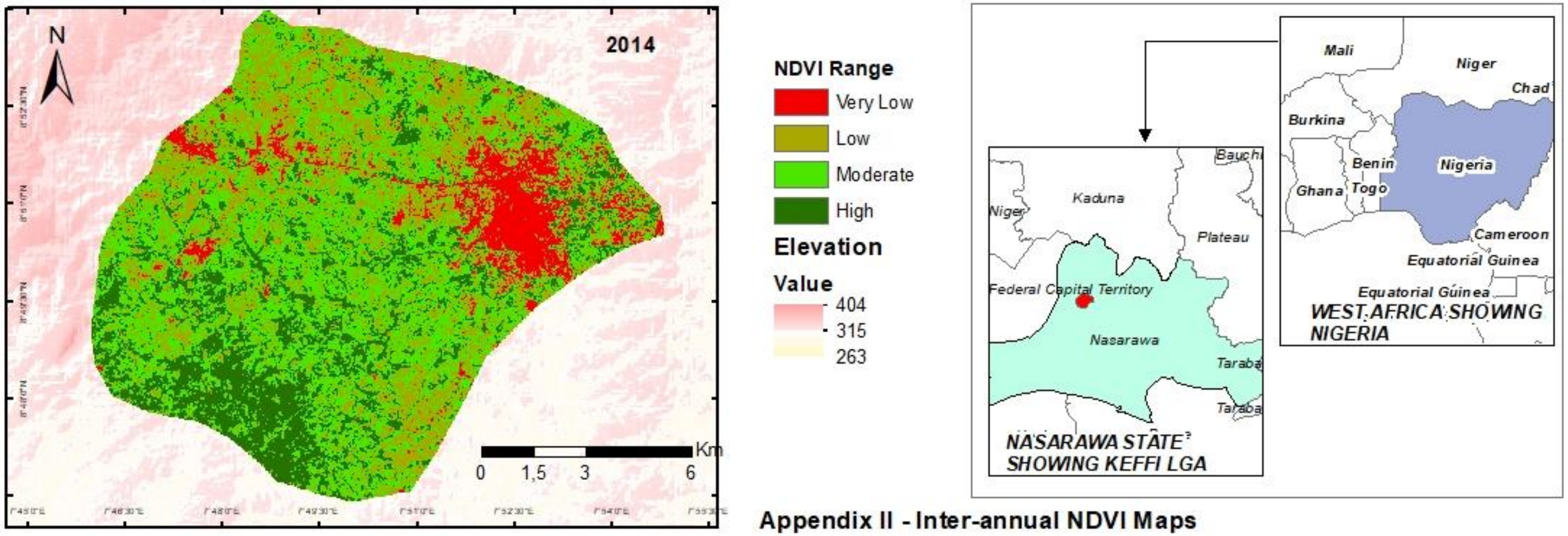

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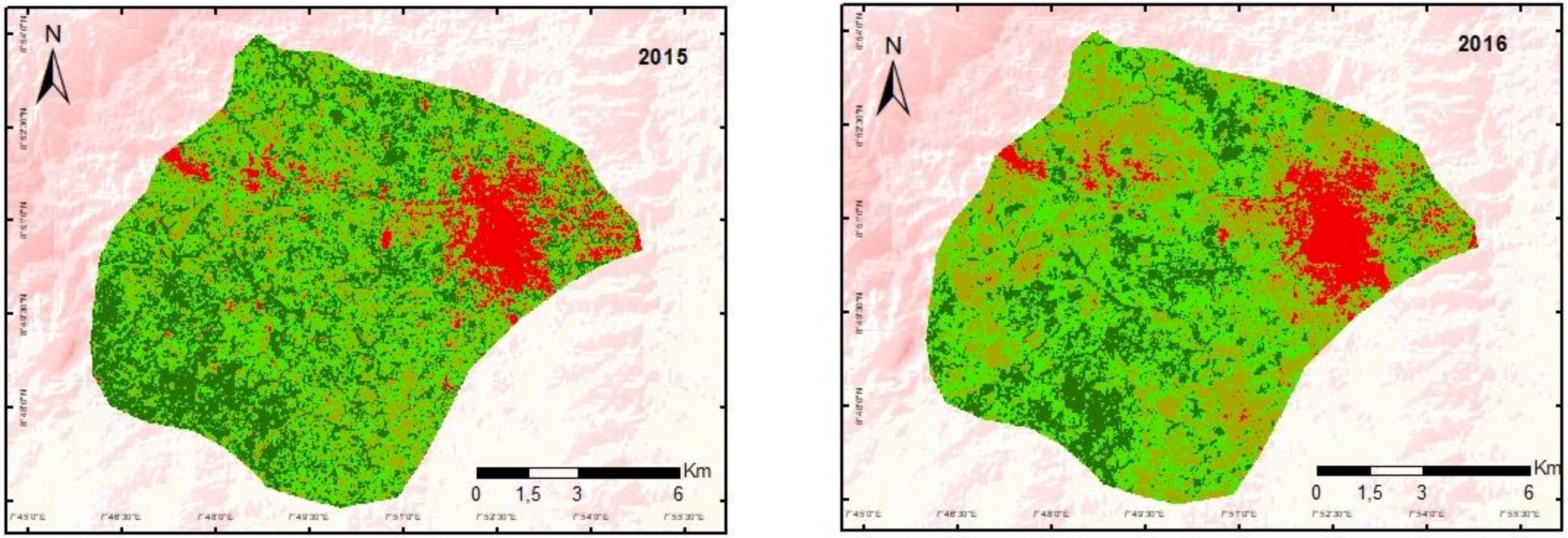
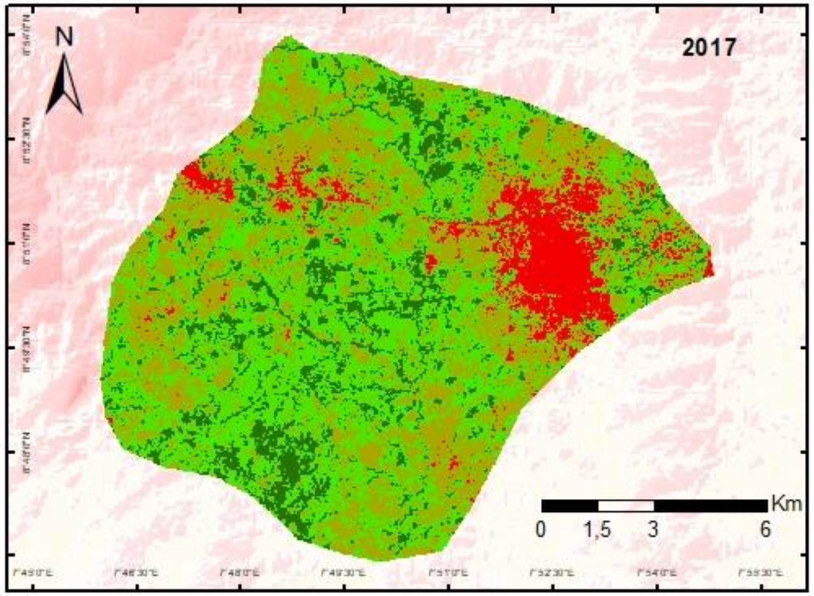




NDVI Range Values

🟥 Ver Low

▨ Low

🟩 Moderate

▨ High

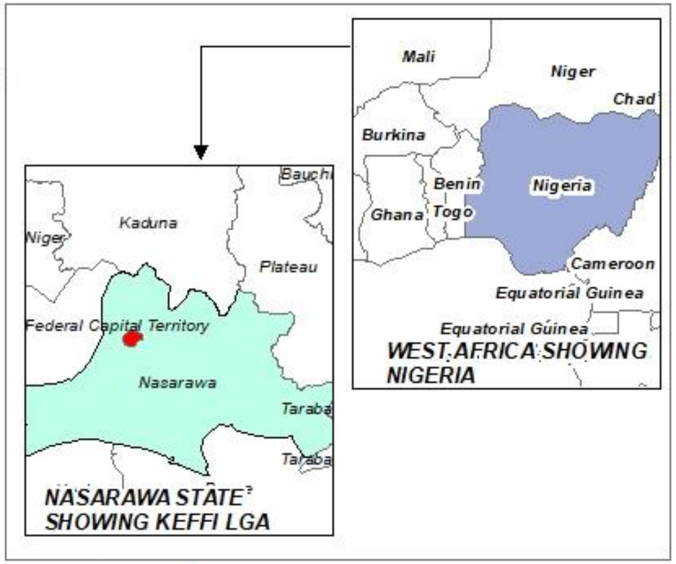
Elevation

Value

404

315

263



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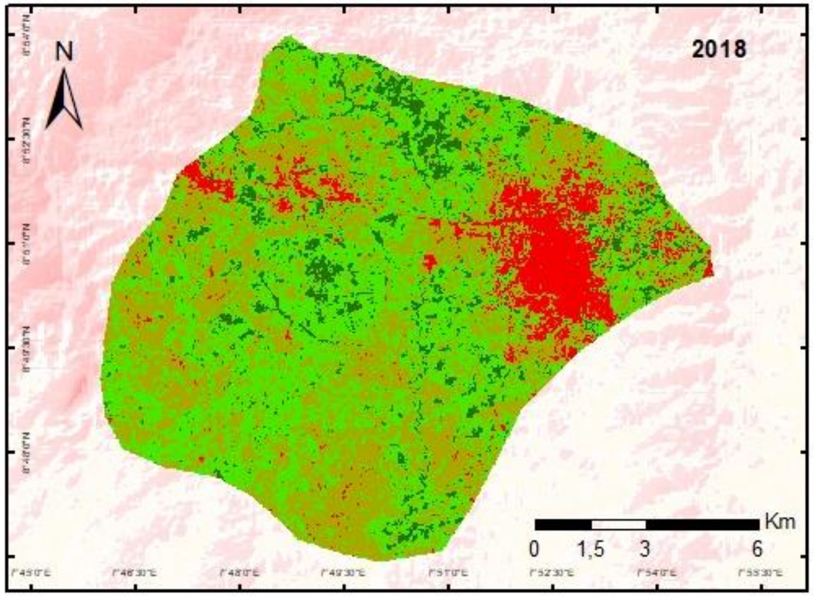

Eidesstattliche Versicherung

Ich erkläre hiermit an Eides statt, dass ich die vorgelegte Dissertation über das

„ Investigating Potential Feedbacks of Smallholder Farmers’ Reactionary Climate Adaptation on Vegetation Cover Dynamics in Keffi, Nigeria (1999-2018) “

selbständig angefertigt und mich anderer Hilfsmittel als der in ihr angegebenen nicht

bedient habe, insbesondere, dass alle Entlehnungen aus anderen Schriften mit

Angabe der betreffenden Schrift gekennzeichnet sind.

Ich versichere, nicht die Hilfe einer kommerziellen Promotionsvermittlung in Anspruch genommen zu haben.

Frankfurt am Main, den 16.12.2020

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(Nsikan-George Emana)