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Climate change, aridity trend and agricultural sustainability of the Sudano-Sahelian belt of Nigeria

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Abstract

Climate change aggravates degradation of the sub-humid and dry land ecosystem of the Sudano-Sahelian belt of Nigeria (Long. 3^0 - 15^0 East and Lat. 9^0 - 14^0 North). This has intensified aridity and aggravated plants moisture stress and subsequently decreasing the landscape ecology and bio-productivity of the physical environment in the belt. There is need to identify changes, trend and visualize the extent of aridity in the belt, lack of information on changes that have taken place is evident thus, the need to investigate and map changes that have taken place in the belt to identify sustainable issues for adaptation. This study used derived indicators of eco-climate parameters (1950-2006); rainfall related-onset dates, cessation dates, Moisture Quality Index, hydrologic growing season (HGS) and Aridity Index (AI). These were summarized; decadal mean determined and ranked using numerical identifiers for the interpretation of the decadal moisture effectiveness across the belt. The point data were transformed to spatial data, surfaces were interpolated, mapped and the area extent of each Moisture Effectiveness zone (MEZ) was used to determine spatio-temporal aridity trend. The result signals rapid advancement of desert condition such that areas of deficient moisture zones grew significantly. Consequently, the eco-climatic and agro-climatic zones we have always known might have been affected and need to be redefined using modern geospatial techniques.

Keywords: Climate change, Moisture effectiveness, Sudano-Sahelian Belt, Aridity and food security

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1. Introduction

Rainfall variability has numerous effects on human activities, thus intensifying the effect of climate change coupled with increase pressure on natural resources (water, land and vegetation), promote environmental degradation. Consequently, desertification has been on the increase and has aggravated erratic agricultural productivity and food insecurity that currently characterize the belt. The extreme rainfall variability in this belt, combined with fragile landscape, causes a high degree of environmental vulnerability thereby; complicating human activities in the zone since man's effort particularly, in developing countries generally is to always control the natural resource, which he relies on for survival/livelihood. The increased ecological imbalance and accelerated environmental problems may constitute disaster (El-Beltagy, 1997; Eswaran et al., 1998). In addition, Dregne and Chou (1992) estimated that 70% of the land in dry areas across the world was degraded in the 1990s. Climate change generally accelerates degradation of the sub-humid and dry land thus, intensifies drought condition and makes the natural environment more vulnerable.

Emphasis on spatial variation has led to increase interest in applying the basic knowledge needed to understand the ever changing-state of our environment as an aid towards the achievement of a sustainable development. In Nigeria, the devastating environmental conditions of Northern Nigeria particularly, the Sudano-Sahelian belt have been and is still an area of great concern. The greatest environmental problem faced in this belt is aridity, in response to climate change, rainfall variability and repeated drought, which is mainly an indication of intense environmental degradation due to anthropogenic and natural processes. Globally, researches have confirmed increase rate of desertification (Zhao et al*.,* 2005; Huang and Siegert, 2006; Susana and Kelley, 2006; Sonia et al., 2007; Sivakumar, 2007; Hanafi and Jauffret, 2008). In general, these are threat to agricultural productivity, food security and sustainability of rural livelihood in the belt where about 80% of the population depends on rainfed agriculture. Consequently, the agro-climatic zones, we have always known might have been affected and this may be responsible for the recurrent crops failure which slowly but surely induced a southward migration of Man and his livestock typical of the late nineteenth and early twentieth century's up to date. It is noteworthy that the effects of these migrations have created socio-cultural and political tensions across the country especially in the central geo-political zone.

The Sudano-Sahelian belt of Nigeria is historically prone to drought however, since 1960s the variability in the intra-and inter-annual distribution patterns of rainfall have been on increase. Moreover, the latitudinal location of the belt signified that climate can easily be modified due to the effect of climate change, consequently intensifying aridity. As a result, there is need to identify changes, trend and visualize the extent of aridity in the belt. The universal increasing effect of environmental degradation processes results in hydrologic and climatologic changes that could aggravate aridity in the belt and make the environment less productive. Generally, climate and its effects are dynamic thus; the entire northern Nigeria will be used in assessing and quantifying climate and aridity trend in the Sudano-Sahelian belt of Nigeria.

The assessment, visualization and quantification of eco-climatic factors trend in this belt over time and space using modern geospatial techniques, will give an insight into specific management actions that will minimize the progressive ecological degradation and enhance food security in the belt and the county at large. Since the earlier researches were based on investigating changes using traditional descriptive statistics and relationships. Decision-makers recognize food insecurity as a primary problem in Nigeria, but show little concern for the effect and impact of climate change and prolonged repeated drought in the belt. Therefore, the region tends towards greater aridity whereas no feasible effort is placed on identification and visualization of eco-climatic factor trend over the years. As a result, for improved quality of life and environmental sustainability, there is the need to visualize and quantify desertification rate for identification of agricultural sustainability measures and for the attainment of food security. By and large, sustainability of land productivity is highly a function of the environmental quality.

2. Literature

This study examined Spatio-temporal trend in aridity with a view of identifying adaptive strategies for sustainable agriculture. Existing literature indicates increasing trend toward aridity in recent times (Dregne and Chou, 1992; Nicholson, 2003; Hanafi and Jauffret, 2008; López et al., 2008; Gaughan and Waylen, 2012). Lázaro et al. (2001) mentioned that in order to understand the behaviour of ecosystems in semi-arid areas, rainfall must be analyzed over time. Intra- and inter- seasonal rainfall variability are imperative in studying moisture efficiency or moisture quality in the semi arid areas of the Sudano-Sahelian belt of Nigeria (Usman 2000). Srikantha and Uditha (2004) analyzed long-term rainfall trends in central mountainous region of Sri Lanka, using a 30-year, 60 rain gauge data set to investigate inter-annual as well as intra-annual rainfall trends to understand the adverse impacts on the environment.

Establishment of a land resource degradation index, the status and trend of degradation facilitate the design and planning of interventions for mitigation and establishment of sustainable land use and management practices (Zhang et al., 2006). Helmut and Eric (2004) used a meta-analytical research design to show that desertification is driven by a limited suite of recurrent core variables, of which the most prominent at the underlying level are climatic factors. Also Nicholson et al. (2000) conclude that long-term change in rainfall has occurred in the semiarid and sub-humid zones of West Africa as rainfall during the last 30 years (1968–97) has been on average some 15% to 40% lower than during the period 1931–60. The eco-climatic characteristics will be crucial in assessing aridity in the Sudano-Sahelian belt.

Tripathy et al. (1996) used temporal satellite information along with the surface and statistical data with the aid of a GIS in correlating indicators to establish the severity of desertification and factors helping the desertification process to continue. Yansui et al. (2003) used four desertification indicators (vegetative cover, proportion of drifting sand area, desertification rate, and population pressure) to assess the severity of desertification in a GIS. Nazzareno and Michele (2004) transformed values of individual variable, integrated them to form multiple variable indicator transform (MVIT) to evaluate the degree of soil degradation and delineate areas suited to soil degradation using geographical information system (GIS). Enrico et al. (2003) conclude that one advantage of Desertification Risk Index (DRI) is that, with the help of a GIS, DRI maps can be easily obtained in short time and at relatively low costs. GIS is essential tool for assessment and visualization of the spatio-temporal trend and vulnerability assessment of the Sudano-Sahelian belt for adaptive and proactive strategies for disaster Risk Reduction.

3. Materials and method

3.1. Study Area

Northern Nigeria is located between Longitudes 3^0 to 15^0 East of the Greenwich meridian and Latitudes 9^0 and 14^0 North of the Equator. The Sudano-Sahelian belt covers about 2/3 of the entire northern region of the country. This zone stretches from the Sokoto plains through the northern section of Hausa land to the Chad Basin. The extreme Northern part of the belt approaches the desert fringes, particularly sharing boundaries with the semi-arid and arid zone of the Niger Republic. The States located in this zone are Sokoto, Kebbi, Zamfara, Kastina, Kano, Jigawa, Yobe, Borno, Gombe, Bauchi, Adamawa, and Northern Kwara, Plateau, Taraba, and Niger state. The belt is bordered to the south by federal Capital Territory (FCT), Nassarawa, Kogi and Benue States.

The northern region, due to its latitudinal location is characterized by tropical continental dry climate. The climate is characterized by alternate wet and dry seasons in response to the changes in pressure patterns. Rainfall amount is low, erratic and characterized by spatial and temporal variability. The latitudinal location of the belt also implies high temperature throughout the year, at about 27^0C. Generally, the highest temperatures in the country are recorded in this belt, northern Nigeria is dominated by savanna vegetation types; Guinea to the south, Sudan and Sahel savanna to the north, the density of trees and grasses decrease northwards responding to climatic conditions. Agriculture is the most dominant economic activity in the belt; crops like groundnut, cotton, millet, beans, guinea corn, cassava, yam and maize are cultivated in the belt which also has the highest concentration of cattle in the country. Hence, the vegetation has suffered great degradation from the hands of man and his livestock.

3.2. Methodology

The derived eco-climatic parameter records (1950-2006) for tweleve selected meteorological stations in the study area were used; Minna, Zaria, Yola, Maiduguri, Bauchi, Sokoto, Yelwa, Kano, Jos, Gausau, Nguru, and Katsina (Abdulkadir and Usman, 2009). The derived rainfall characteristics; onset, cessation, hydrological growing season (HGS), Aridity Index (AI) and Moisture Quality index (MQI) are very crucial in assessing land degradation. The derived parameters were computed, summarized, analyzed and classified using decadal numerical identifiers for the interpretation of the various Moisture Effectiveness Classes (MECs); 5, 4, 3, 2 &1. The time series data summaries (1950-2006) for the entire factor were subjected to trend analysis using decadal mean for the various classes (1950-1959, 1960-1969……..2000-20006). Time series analysis is fundamental in investigating trend (Adefolalu, 1988; Marco et al., 2004). The derived decadal sub means were ranked, classified, imported to ArcGIS 9.2, and transformed to point data(X, Y, and Z). These were interpolated to surfaces using kriging module in 3D analyst and spatial analyst tools to derive decadal eco-climatic characteristics Moisture Effectiveness Zones (MEZs). Similarly, effective rainfall-related onset dates have been used to visualize fluctuations in rainfall (Wu and Wang, 2000). The decadal Eco-climatic zones attribute values / areas were extracted to determine decadal area extent for each MEZ and these were used in the assessment of spatio-temporal changes.

Trends in decadal extent of MEZs were used to determine the rate of desertification using rate of change as the ratio of the differences in area of the MEZs during the period of study. The relative change in its aridity is as follows;

$A_C = A_2/A_1$ Eqn. 1.1

A_C = Aridity change ratio

A_1= Aridity of initial date (Time)

A_2 = Aridity of later date (Time)

Then the year interval was identify as (Later date – initial date) Eqn. 1.2

And the growth rate of aridity is:

$A_2/A_1 = (1+ r)^n$ Eqn. 1.3

where r = annual growth

n = year interval

Converting this to logarithm format:

$\text{Log } (1+ r) = \log A_2/A_1 / n$ Eqn. 1.4

This is used to determine aridity rate in the belt.

The trend is confirmed using decadal image differencing (earlier minus later 1950-2000). Finally the decadal moisture effectiveness maps were subjected to standardized image differences (Z-scores) to confirm spatio-temporal changes using IDRISI Andes.

4. Result

Trend analysis of the factors provides fundamental evidence of aridity in the Sudano-Sahelian belt of Nigeria. The mean decadal time series analysis (1950-2006) of the entire factor signals rapid advancement of desert condition in response to both short, middle and long-term climatic fluctuations; short-term fluctuations were indicative of decadal variability, middle-term is typical of drought decades (1970s &1980s) and the long term changes were evident between 1950-2006. Inter decadal variability unveil the fact that eco-climatic factors moisture effectiveness is progressively declining; Late rainfall-related onset, early cessation, shorter HGS, decreasing AI values and deficient MQI signifying aridity in the belt as evidence in Figures 1- 6.

Rainfall-related onset has been generally stressful across the study area. In the 1950s, three moisture effectiveness zones were evident, early, late and very late onset. The extreme north west of Sokoto State, parts of Zamfara , Katsina, Jigawa, Borno and Yobe States experienced very late onset. The central portion was predominantly a zone of late onset while, early onset dominated the southern parts of Niger, Kaduna, Taraba, and Plateau State. In the 1960s, the extreme northeast became a zone of extremely late onset, very late onset moisture zone spread across most northern States; Areas of early onset declined southwards. The expected dry trend of drought years was evident in rainfall related-onset in the 1970s & 1980s when no zone experienced early onset of rain. All the zones were associated with one form of late rainfall onset or the other. This situation intensified in the 1980s with vast areas of the extreme north spreading from Sokoto across Katsina to Borno States being characterized by extremely late onset. In the 1990s, the rainfall-onset improved. Extremely late onset was limited to the northeast and early onset was apparent across the southern belt. In the 2000s, vast extents of the southern belt and central portions were characterized with late onset of rain, while northern areas became dominated by very late onset zone (Figure 1).

Rainfall cessation has been less stressful across the belt. In the 1950s, three MEZs were identified; latest, late and early cessation moisture zone to the extreme north. By 1960s similar MEZs were recognized but with increase in the extent of early cessation moisture zone to about Lat 12^0N in Northwest and Lat 10^0N in the northeast. The late cessation moisture zone decreased as the latest cessation moisture zone skewed to southwest and western portions of the belt. In the 1990s, moisture stress appreciated in the extreme north with extremely early cessation dominating and latest cessation moisture zone also appreciated across the south of the belt. By 2000s there was no extremely early cessation across the belt; however, the north eastern zone was dominated by early cessation while the late and latest cessation moisture zones were skewed to the southwest and western portion of the belt as portray in Figure 2.

The decadal maps (Figure 3) shows that there was no extremely short HGS moisture zone in 1950; however, very short HGS moisture zone is evident along areas above 12^0 of lat in extreme northeast and extreme north of Sokoto and Katsina state. Vast of the northern States have short HGS MEZ; Zamfara, Kano, parts of Sokoto, Katsina , Gombe States and southern Yobe and Borno state. Southern belt has longest HGS while the central portion has long HGS MEZ. Similar moisture condition prevailed in the 1960s, though in the northeast very short HGS moisture zone spread southwards to about lat 11^o 24^1 and short HGS moisture zone extended southwards more along the north east. The longest and long HGS moisture effectiveness zone skewed to southwest. In 1970s there was spread in areas of very short, short and long HGS MEZs while areas of longest HGS zone reduced. This moisture stress intensified in 1980s; the extreme northeast has extremely short HGS moisture, very short HGS zone stretch to northern parts of Sokoto, Katsina, Jigawa and the rest part of Yobe and Borno state. Specifically, this now extend to about lat 10^0 along the north east. There was no longest HGS zone whereas long HGS moisture zone dominates the southern states and parts of central States. The appreciation in moisture effectiveness was evident in 1990s as five MEZs were recognized; Long, short, very short and extremely short HGS moisture zone decreases whilst longest HGS zone was apparent along the southern belt. This trend persisted in 2000s as there was no extremely short HGS moisture zone, very short HGS zone dominates the extreme north and areas of longest HGS zone increases.

In the 1950s the Moisture Quality Index (MOI) reveals that moisture quality effectiveness was adequate to support grain and root crops production across southern and central States, since it record the least MQI values an indication for adequate soil moisture. Deficient moisture zone was dominant in the extreme northern States, Sokoto, Jigawa,Yobe, Borno, and parts of Kebbi, Zamfara, Katsina, Gombe, and Adamawa

States. Similarly, in the 1960s, adequate moisture quality zone skewed towards the southeast. Vast north western and central States were characterized by deficient moisture quality, very deficient moisture quality zone was apparent in the Northeast. The 1970s MQI decadal map recognized moisture stress distinctive of drought decades. Deficient moisture zone spread across the extreme north and area of adequate moisture quality zone depreciated. The moisture quality stress intensified in the 1980s as extremely deficient moisture quality spread across the northeast. Northern Niger and Kebbi through Sokoto, Jigawa, Katsina to southern parts of the northeast were zones of very deficient moisture quality. Despite the moisture effectiveness appreciation in the 1990s, moisture quality was stressful across the extreme north. Adequate moisture zone declined southwards with the extreme northwest and northeast being dominantly areas of extreme deficient moisture quality. The 2000 decade unveils moisture quality appreciation; three moisture zones were evident; adequate, deficient and very deficient. The adequate moisture effectiveness zone skewed westwards across the belt, however the north east was dominated by very deficient moisture zone (Figure 4).

Similarly, 1950s, 1960s, 1990s & 2000s decadal aridity index maps (Figure 5) capture five MEZs with variability in the spatial extent of the MEZs. The 1950 decadal map identified extreme north east (areas above latitude 12^0) as areas of extremely high aridity since they are areas of least aridity values. Extreme north of Sokoto and Katsina states extending to vast areas south of this extreme aridity zone; Gombe, Southern Borno, Jigawa and Adamawa state were very high aridity zone. While the central and Southern States Kwara, Niger, Kaduna, F. C. T, Nassarawa and plateau States were zones of either low or lowest aridity in the region. The 1960 decades reveal similar moisture condition with gradual intensification of moisture stress across the MEZs, extremely high aridity condition now extend to about lat 11^0 24^1, very high aridity condition spread to entire Sokoto State, part of Zamfara, Katsina and Jigawa State. Areas of low and lowest aridity decline slightly; these are indications of short term changes. Generally, in 1970s &1980s aridity index map reveals severe moisture stress evident of drought decades, lowest aridity moisture zone disappeared and were recognized as low aridity moisture zone. The high, very high and extremely high aridity moisture zone increase in their area extents. By 1980s the lowest AI moisture effectiveness zone disappeared as the low aridity moisture zone decreases significantly and was only limited to the south. The high and very high aridity moisture zones extended southward, while the extremely high aridity moisture zone extends to southwest covering part of Sokoto, Katsina and Jigawa State. Thus middle-term changes were apparent. The AI moisture effectiveness appreciated generally in 1990s and 2000s, as five moisture classes were captured. As a result, the lowest and low aridity moisture zones were evident and skewed to the south west and the central portion. However, the extremely high aridity moisture zones extended to about lat 10^0 40^1 and 10^0 in 1990s and 2000s respectively, indicating southwards spread of aridity in the belt.

Furthermore, comparison of the entire percentage spatial area extent of the MEZs for the six decades confirms variability in decadal moisture effectiveness (Figure 6). Moisture degradation intensify gradually in the earlier decades in responds to short-term changes, severely in the middle decades (1970s and 1980s) and long term moisture stress is evident between 1950s and 2000s. Severe studies confirm amplified fluctuation in the time series precipitation analysis (Omar and Norma, 1999; Ayoub, 1999; Jiayu and Lau, 2001).

4.1. Aridity index decadal comparison and aridity growth rate

The derivative maps of decadal MEZs portray gradual moisture stress in 1950s and 1960s, severe moisture stress in 1970s and 1980s; these periods mark the most apparent dramatic ecological stress in the zone. The moisture effectiveness appreciated between 1990s and 2000s however, this doesn't imply that the ecological stress in the belt has recovered from the two decades moisture stress. Image differencing and aridity growth rate confirm deterioration of moisture effectiveness is in the belt. The positive growth rate of deficient moisture zones and the negative trend of the adequate MEZs of the entire eco-climatic parameters depict the southwards migration of the eco-climatic zones. This trend as illustrated in the Figures 1-6 depict the potential progressive moisture stress that could trigger negative socio-economic conditions which is a threat to political stability, environmental sustainability and the general quality of the biotic and abiotic life.

5. Discussion of result

Trend and aridity growth rate analysis of the entire factor unveils short, middle and long term moisture effectiveness dynamic that characterize the Sudano-Sahelian belt, high frequency climatic variability changes are driven by climate change (Kiunsi and Meadows, 2006). The short-term changes are distinctive of decadal variability in moisture quality, the middle term changes are indicative of severe changes noticeable of the drought decades (1970s and 1980s) that generally exaggerate moisture stresses in the zone. While, the long term changes are suggestive of significant changes that occur between 1950s and 2000s, where longest and long HGS zones decline and skulled to southwest and central portions. The deficient, very deficient and extremely deficient moistures typical of northeast spread southwards. This trend confirms the spread of desert condition that characterized the Sudano-Sahelian belt. The general appreciation of moisture effectiveness in 1990s and 2000s did not imply moisture effectiveness normalized or the ecological stress has recovered. Moreover, long-term changes are evident (Figures 1-5) in the general increase in areas of deficient, very deficient and extremely deficient MEZs across the belt and decline of longest, long HGS or very low and low AI MEZs to the south. In general, the spatial increase in the spread of areas of deficient MEZs within 1950s to 2000s signals the migratory trend of the eco-climatic characteristics resulting to apparent ecological stress in the zone.

These decadal derivative maps of MEZs portray the belt's vulnerability to increase aridity. Visualization of the eco-climatic characteristics illustrates severe deterioration of moisture effectiveness and migration of moisture effectiveness southwards. The areas of deficient MEZs grew significantly; AI appreciated from about .3 to 4.5%, MQI 2.3 to 6.1%, HGS .4 to 7%, onset 1.4 to 7.5% and cessation 1.8 to 6%. In addition, good moisture zone declined AI at about -1.4 to -4.2%, MQI -.7 to -6.2%, HGS -1.6 to -4.3%, onset -.1 to -1.5% and cessation -.7 to -6.3% as depicted in Figure 6. Of particular concern are potential increases in tree mortality associated with climate-induced physiological stress (Craig et al., 2009). These analyses confirm the anticipated eco-climatic shift in the zone, virtually; all the MEZs shifted southward but most significantly during the drought decade, Zeewdu and Peter (2004) stated that in (1982-1983) *karent* onset was later than normal. Furthermore, these unveil the creeping rate of desert condition in the belt southwards. These trends depict the potential decline in moisture effectiveness that could trigger the negative socio-economic conditions (Thomas and Julio, 1998).

A point worthwhile is that, this study signals the fact that moisture effectiveness variability and its impacts have been on the increase in the last four decades indicating moisture effectiveness as a primary factor in desertification of the sub-region. Consequently, these require identifying ways of coping with the current moisture zones using significant approaches in relation to the carrying capacity of natural environment. Specifically, 1970s and 1980s generally reflect the period of agrarian economic stagnation in the country as signals by the disappearance of much of the countries agricultural crop export and even the decline agricultural production obvious in the country to date. During these periods the extreme north stretching from Maiduguri through Katsina to Sokoto was under extremely deficient moisture effectiveness condition. The increase in spatial and temporal spread of drought also intensifies aridity in the Sudano-Sahelian belt and the country in general; these have being impacting negatively on relevant socio-economic sector. Consequence, signals the capability of drought to intensify desert condition since the damaged layer of ecosystem between these periods may be irreversible particularly in the fragile environment of the Sudano-Sahelian.

It is a known fact that later onset of rain and earlier cessation imply shorter HGS, this aggravated plant moisture stress that usually result to the recurring drought, massive crop failure and ecological stress that characterize the belt. In addition, during these extended dry conditions, temperatures are high, subsequently; evapo-transpiration is high, thereby leading to high potential evapotranspiration. As a result, aridity and climate change are threat to the majority of the population who derive their livelihood from subsistence agriculture. The challenges of environmental sustainability in this belt lie on adequate information on the state of the environment. The sustainable management of environmental resources is not possible until their worth is appreciated and an appropriate price is paid for the benefits received (Soussan, 1992). Therefore, understanding and identifying these changes is requisite for redefining the classic eco-climatic zone in the Sudano-Sahelian belt and a pathway for the achievement of sustainable development and food security.

5.1. Agricultural sustainability of the Sudano-Sahelian Belt

The early effective onset of rain, late cessation, longest HGS, lowest aridity index values and adequate effective moisture zone to the south, indicate the southern belt may support cultivation of most root and grain crop species in the zone. The gradual moisture stress northwards could be used to identify crops suitability for each eco-climatic zones based on moisture effectiveness across the region. Similarly, John and Barry (1997) recognized the characteristics of climatic events, the ecological properties of systems which mediate effects, and the distinctions which are possible among different types of adaptation. Thus, the decline trend of moisture effectiveness (intensification of moisture stress) in the region, necessitate the need for the development and adoption of drought resistant root and grain crop species across northern Nigeria, as this will minimize the recurring crop failure that characterized the region.

By inference, trend analysis of the eco-climatic map, indicates that drought severity in the region is a function of negative trend in rainfall effectiveness. The negative trend of eco-climatic factors explains the impact of climate change on the natural environment that adversely intensifies drought and recurring crops failure widespread in northern Nigeria. Peter (1998) states that a wide range of ecological and human crises result from inadequate access to, and the inappropriate management of the resources. The eco-climatic parameters trend is fundamental for the identification of adaptive measure that may boost the efficiency of food production. Particularly, the varying levels of late effective onset, earlier cessation, shorter HGS, higher aridity index and deficient moisture quality trend of rain can be use to develop cropping calendar to enhance agricultural productivity. The decline in the hydrologic growing days may be use to select appropriate root and grain crop species that will grow to maturity within the HGS across the region, drought resistant and short time maturing species should be adapted in the extreme north of the belt. In addition, the identified eco-climatic condition suggests that effort should be channelled towards recovery of the natural environment. Adaptation to climate variability and change are important both for impact assessment and for policy development (Kenny et al., 2000). Thus, for agricultural and natural resources sustainability these declining trends and climate change adaptation should be incorporating in the regional policy.

6. Conclusion

The paper visualized the spatio-temporal moisture effectiveness trend in the sudano sahelian belt that has posed challenges to food security and sustainability of the physical environment. This study, identified decline trend in moisture effectiveness that intensified moisture stress across the belt in the last six decades signifying the fact that decrease moisture effectiveness is a prime aridity factor in the sub-region. By this result, the Sudan-sahelian belt is increasingly vulnerable to crops failure due to increased aridity (AI), late onset, and early retreat of rainfall resulting to shorter hydrologic growing season already obvious across the belt. The trend confirm the effect of climate change and is disastrous to agriculture, as delayed onset often leads to late planting of crops, while premature cessation leads to wilting and dryness of the crops before maturity, there by endangering food security in the belt. The short, middle-term and long term moisture effectiveness stress identified necessitate a drastic reappraisal of the classic climatic, eco-climatic and ago-climatic zones as pathway towards the achievement of food security. Finally, the eco-climatic parameters trend is fundamental for the identification of adaptive measures that may boost the efficiency of food production and enhance sustainability of the physical environment for attainment of food security in the region.

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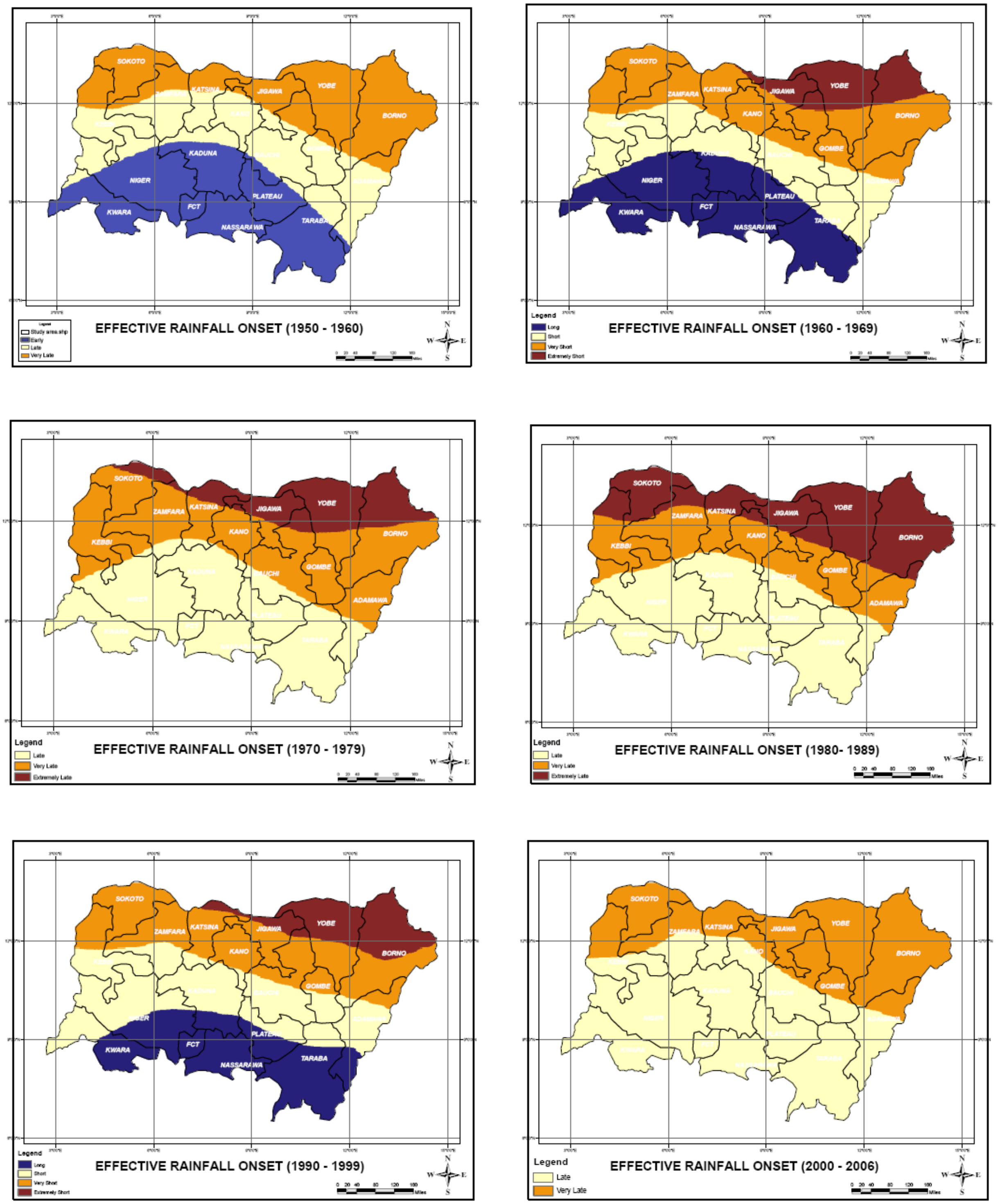

Figure 1. Effective Rainfall-related onset Zones 1950-2006

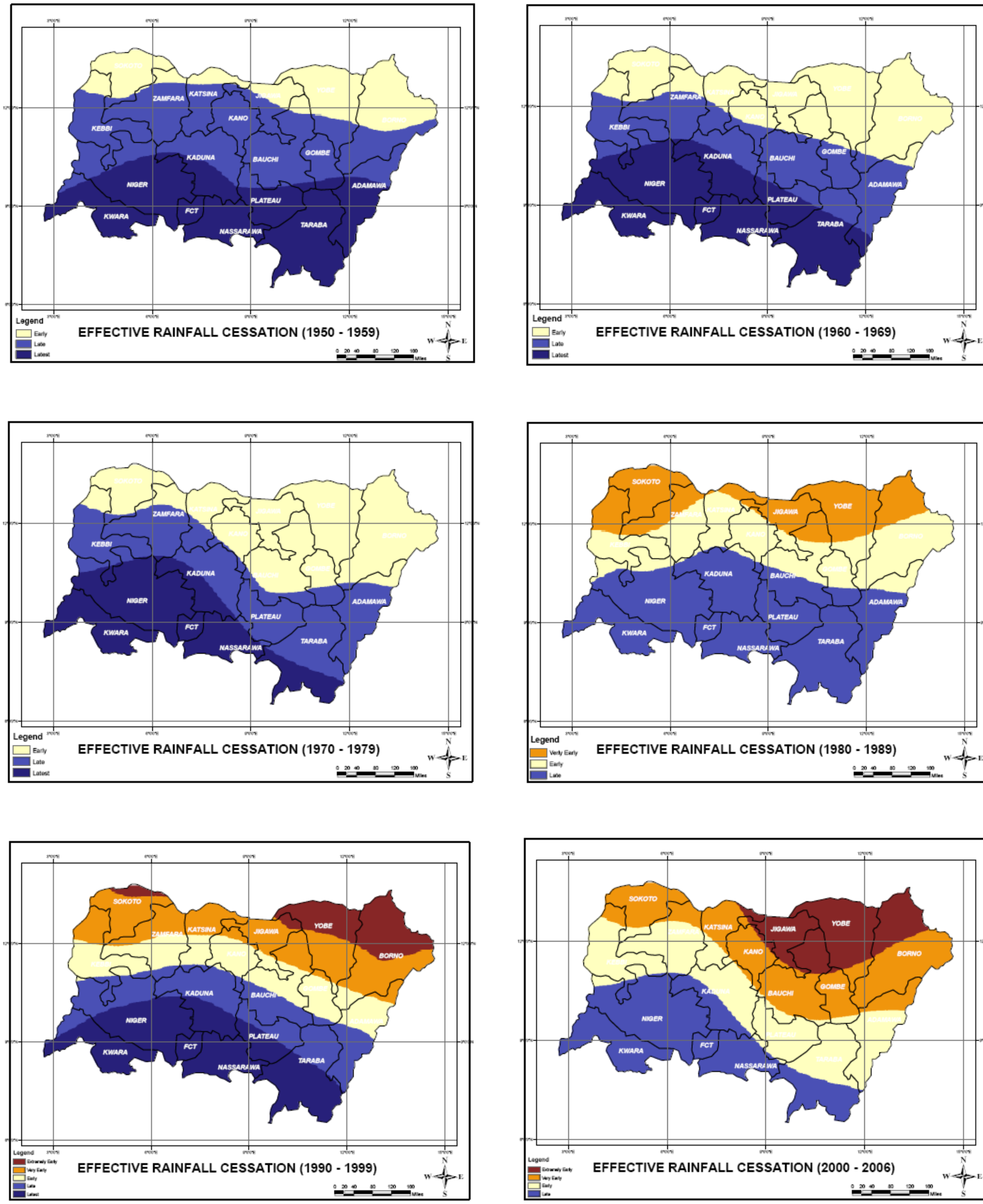

Figure 2. Effective Rainfall Cessation Zones 1950-2006

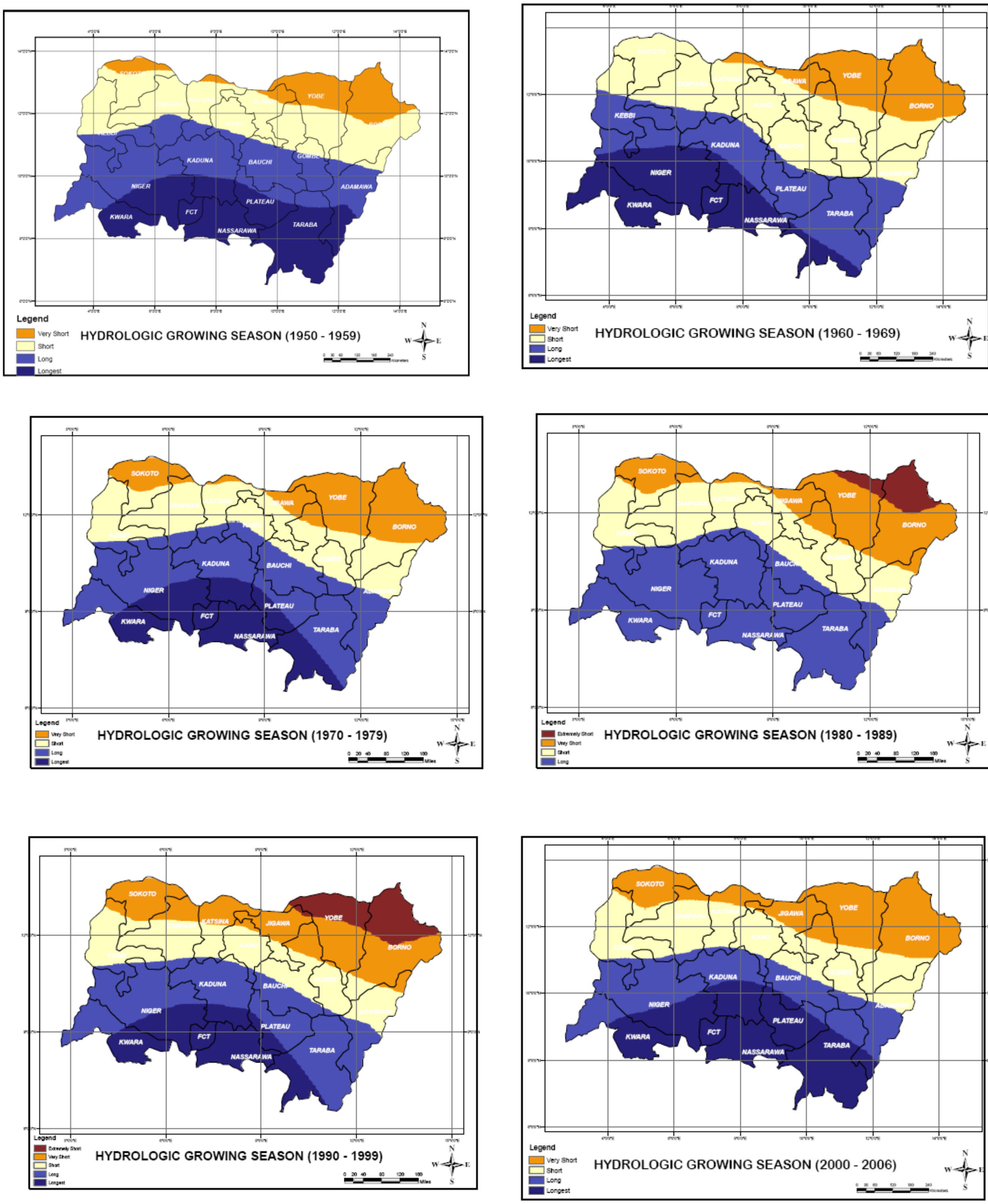

Figure 3. Effective Hydrologic Growing Season Zones 1950-2006

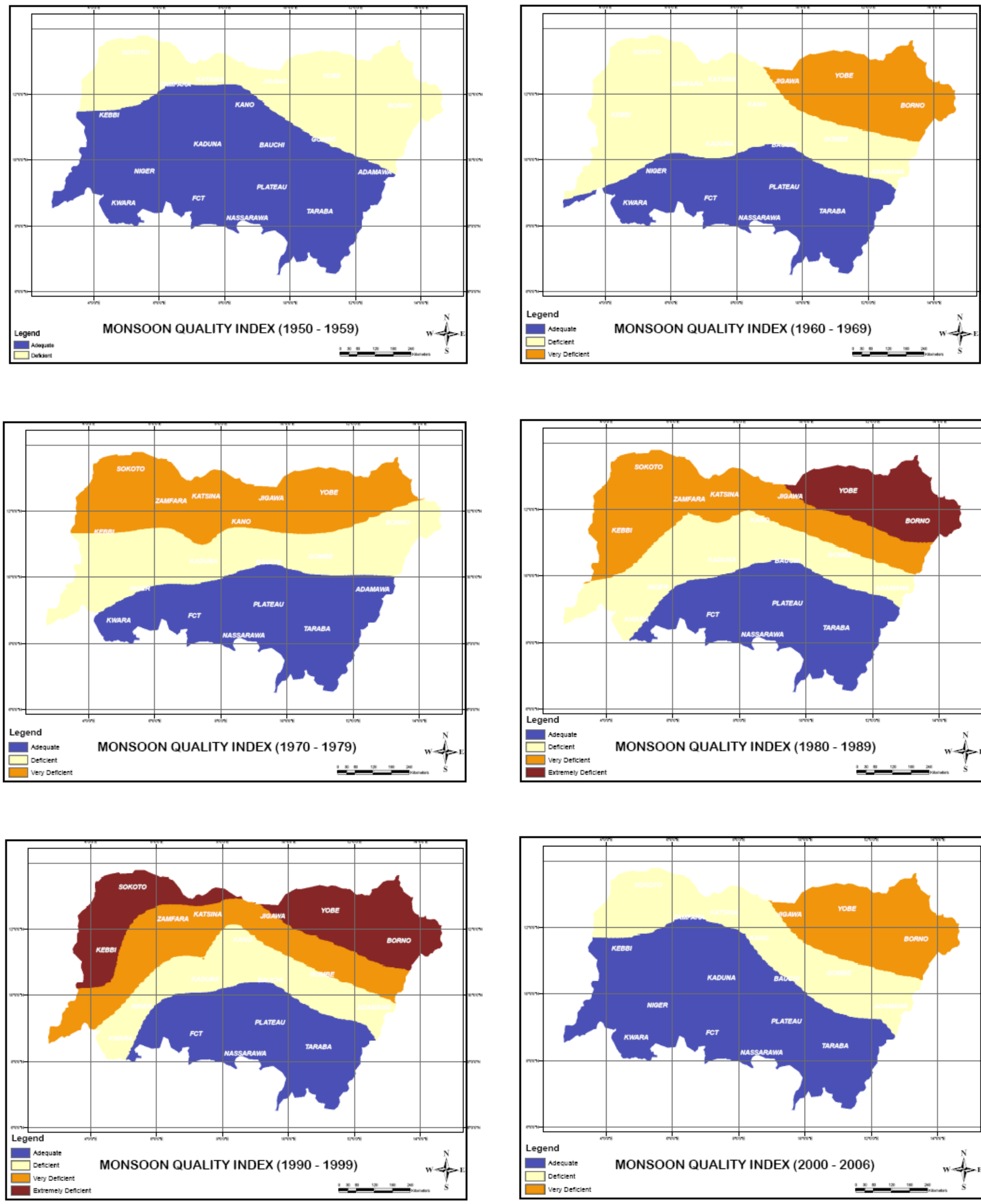

Figure 4. Effective Monsoon Quality Zones 1950-2006

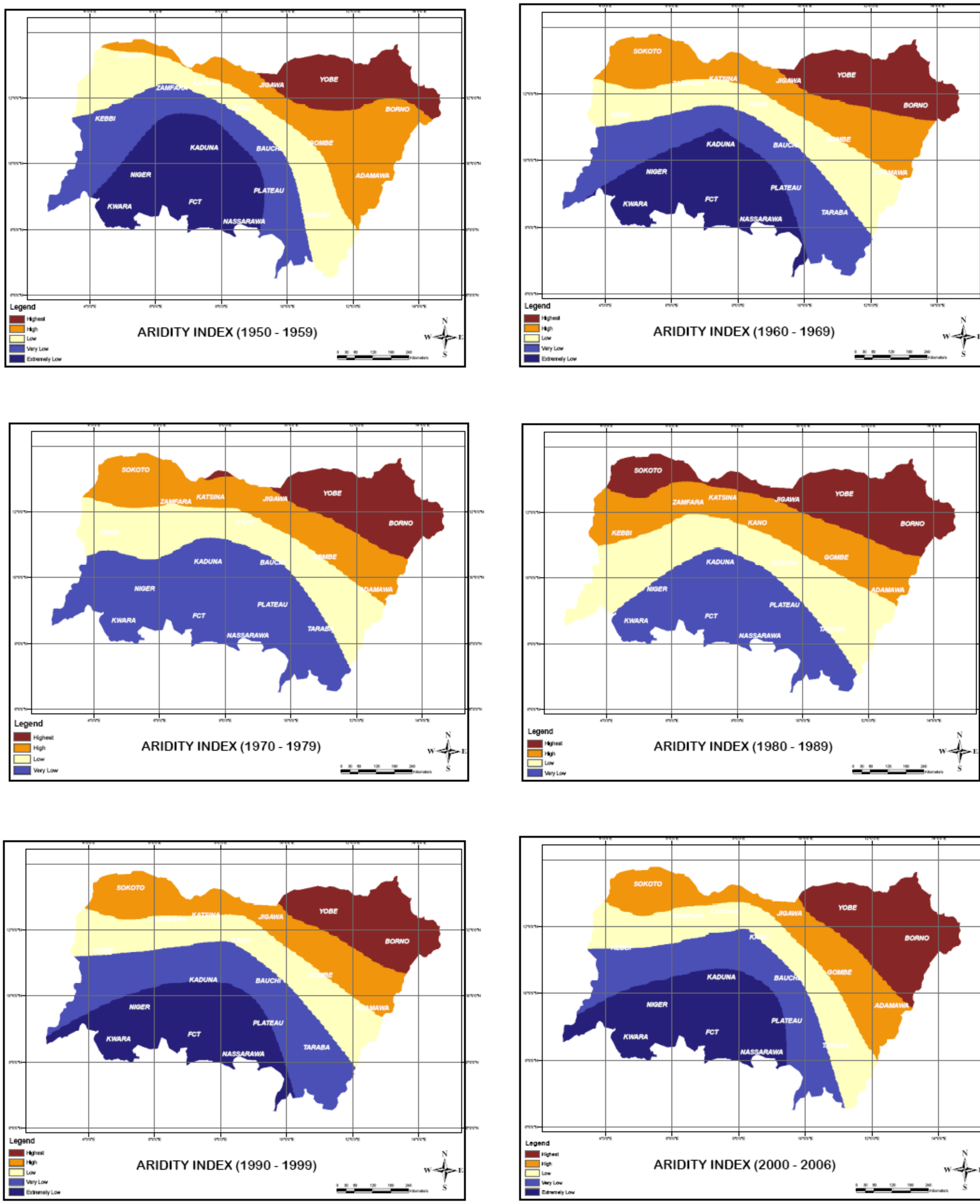

Figure 5. Aridity Index Zones 1950-2006

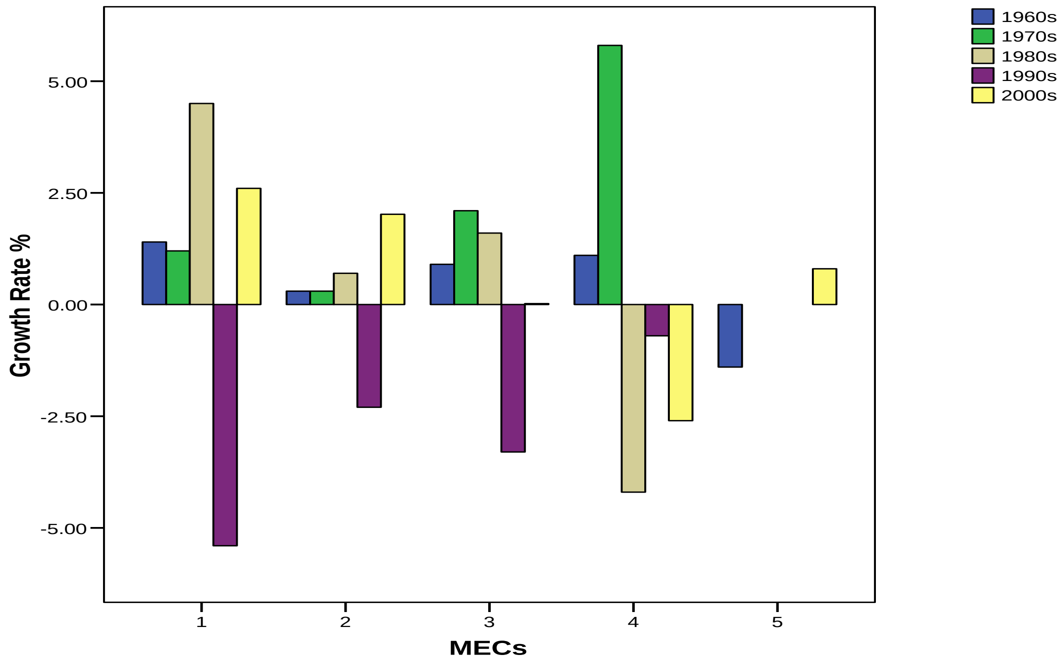

Figure 6 (a). Aridity Index Aridity Growth

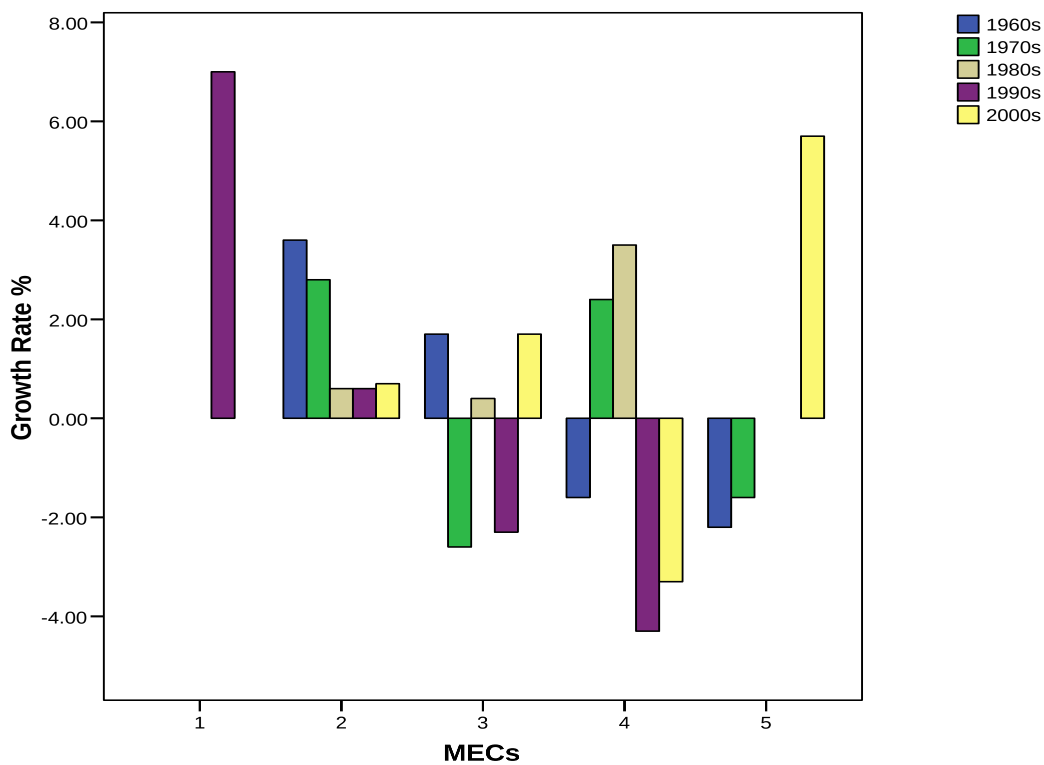

Figure 6 (b). HGS Aridity Growth Rate

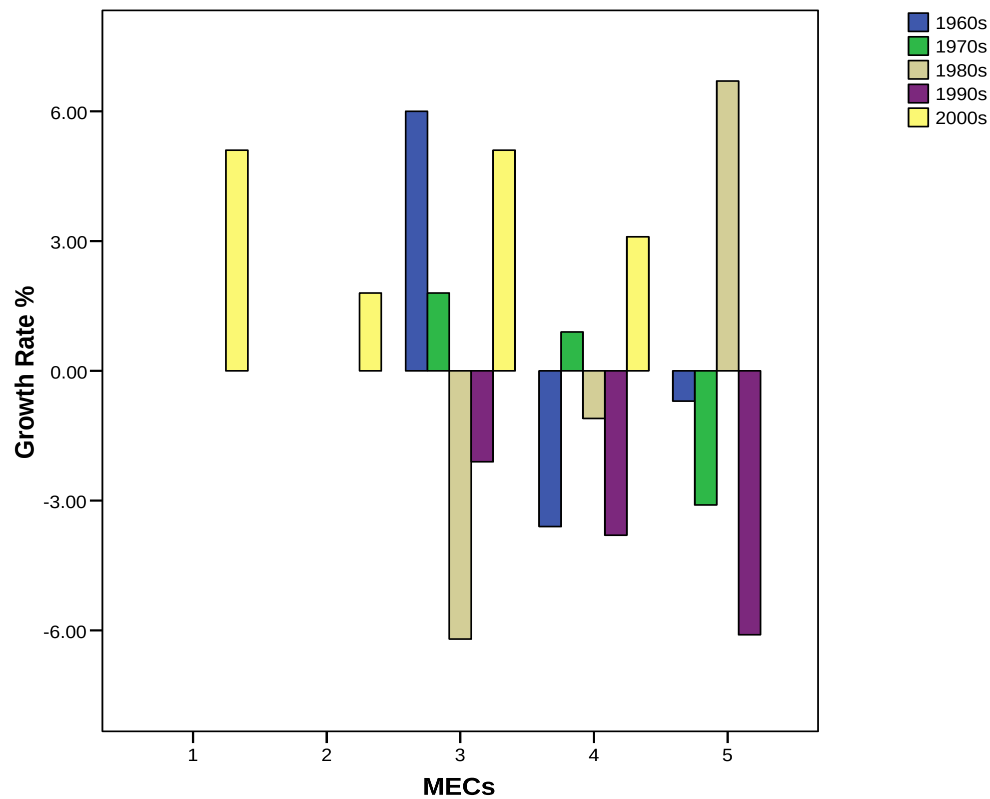

Figure 6 (c). Cessation Aridity Growth Rate

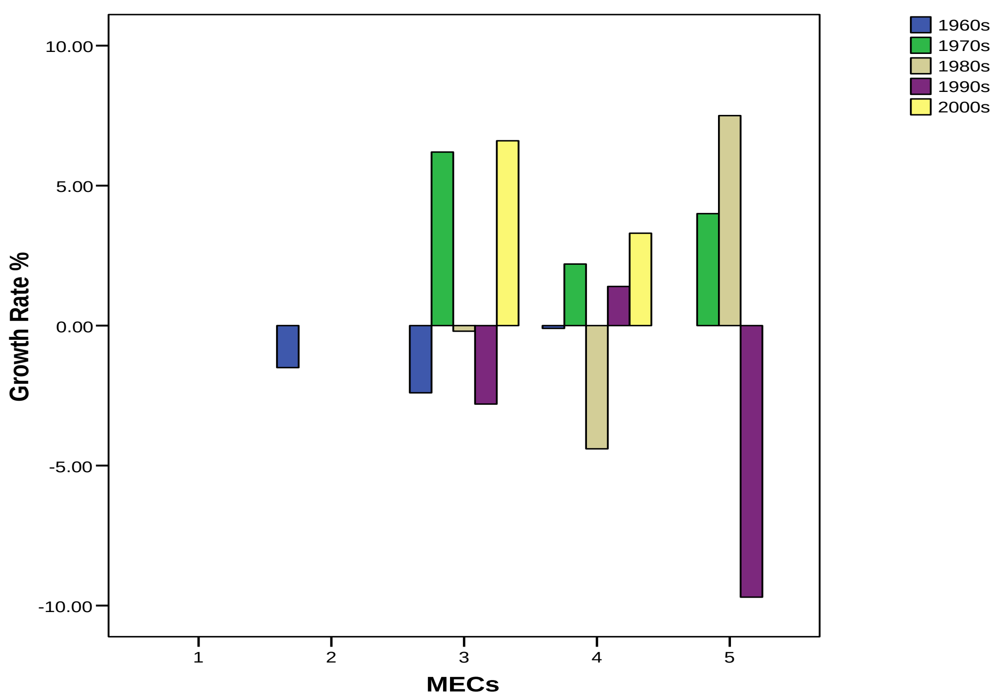

Figure 6 (d). Onset Aridity Growth Rate

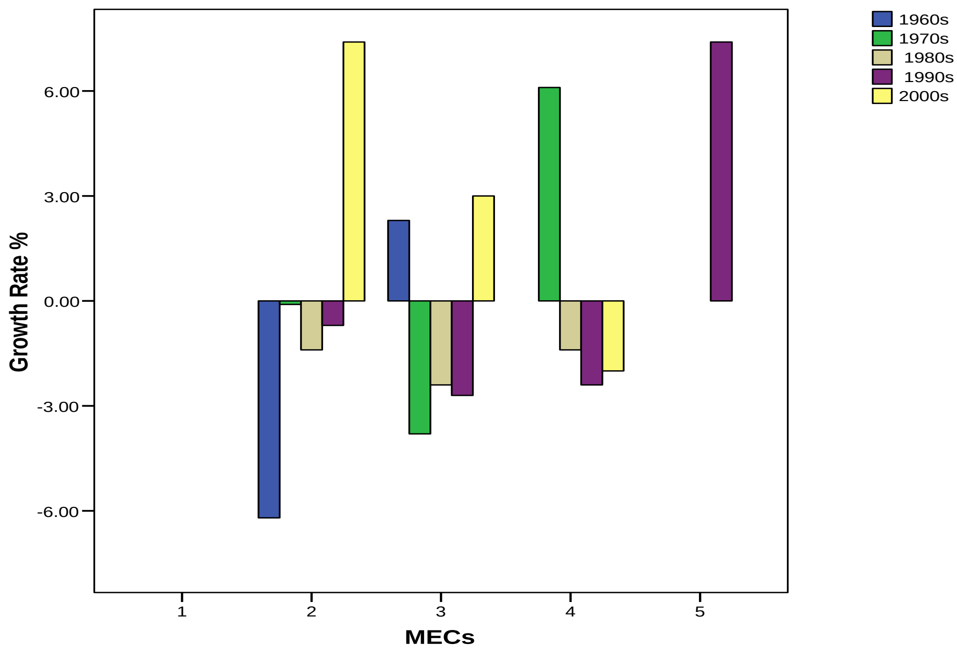

Figure 6 (d). Moisture Quality Index Aridity Growth Rate