# Detecting and Monitoring Desertification Indicators in Yobe State, Nigeria

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## ABSTRACT

*Owing to the environmental and socio economic impacts of desertification in Yobe State, this work sets out to detect the indicators of desertification in the study area and to monitor their spatio-temporal changes from 1975 to 2013. Five multi-temporal Landsat satellite imageries within the same season (October-November) of 1975 (from Landsat Multispectral Scanner (MSS), 1986 (from Thematic Mapper (TM)), 2000 and 2009 (from Enhanced Thematic Mapper (ETM+)) and 2013 was acquired from Earth Explorer by Google Earth Pro maps were used for this study. The acquired images were classified into four landcover types: surface water, trees, shrubs/grass and bare land/dunes. The result shows that the percentage of surface water recorded about 0.51% decrease between 1975 and 2013, the trees landcover class decreased from 582.76km$^2$ in 1975 to 284.73km$^2$ of the total land area in 2013, area covered by shrubs and grass also decreased from 1990.45km$^2$in 1975 to 669.06km$^2$ in 2013. Dryland areas covered by bare land and dunes increased from 5061.25km$^2$ to 6719.74km$^2$ in 1975 and 2013 respectively at a rate of 43.64km$^2$ annually. The results of the spatial distribution pattern of physical and biological indicators of desertification were used to establish the presence and spatial coverage of desertification in the study area. Assessment of area coverage of a selected dune at the northern part of the study area using Google Earth Pro map reveals that the dune increased from 0.19km$^2$in 2010 to 0.21km$^2$ in 2013. From these findings, constant monitoring and evaluation of areas affected by desertification and effective community-based tree planting programme is recommended among others.*

***Keywords**: Desertification, Desertification indicators, landuse and landcover, Yobe State*

## INTRODUCTION

Northern Nigeria is endowed with large expanse of arable land that has over the years proved a vital resource for agriculture, grazing, forestry, tourism or building purposes. One of the major challenges faced in this part of the country with regards to the potentiality of land as a resource is desertification. Desertification is a type of

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**ISSN: 2141-2731**

environmental change that occurs as a result of natural factors as well as long-term accumulation of poor management of farmlands and grasslands especially in the arid, semi-arid and sub-humid areas of the world. Some of the human factors that contribute towards desertification are poor agricultural practices, overgrazing and deforestation of marginal lands among others. Consequentially, various human populations are threatened with effects such as famine, disease, displacement and death of both man and livestock. Desertification affects the livelihoods of millions of people, including a large proportion of the poor in drylands (Millennium Ecosystem Assessment, MEA 2005).

According to an FAO/UNEP (1995) assessment of land degradation in Africa, an estimated 3.19 million hectares of land in Africa are vulnerable to desertification hazards due to sand movement. It was also reported that large area of countries north of the equator suffers from serious desertification problems, as the result of drought and increasing pressure on fragile arid and semi-arid land exerted by large number of people and livestock, thus accelerating land degradation throughout much of Africa. In Nigeria, the menace of desertification is mostly felt in the north, where the fragile arid, semi-arid and sub-humid nature of land exists. Yobe State is one of the eleven States facing this serious ecological challenge that exposes people to great danger (NAP, 2000) with nine out of seventeen LGAs affected (Musa, 2012), they include: Bade, Bursari, Geidam, Jakusko, Karasuwa, Machina, Nguru, Yusufari and Yunusari.as a result of dwindling rainfall. According to Idris and Matazu (2012), this manifests in perennial food shortage, occasioned by sand dunes manifestation among other environmental challenges which have remained a source of concern to affected communities. Desertification threatens the very source of livelihood of the rural community who are mostly small scale farmers and also affects food supply in the State (Ghahabo, 2011). Thus, this work sets out to determine the types, trend and magnitude of landcover changes as indicators of desertification in the study area from 1975 to 2013 and to create digital maps of the spatial distribution pattern of the changes as indicators of desertification in the study area using remotely sensed data and GIS technique.

## Desertification Indicators

An indicator is defined as "an observation or measurement that is assumed to be evidence of the attributes or properties of some phenomenon", which involves moving from the abstract conceptual level to the concrete and observable (Imeson, 2005). Indicators generally simplify reality to make complex processes quantifiable so that the information obtained can be communicated and is more meaningful to use indicators than try to interpret huge numbers of individual pieces of data (Kosmas *et al*, 2013). It was also added that indicators should be SMART, that is, specific, measurable, attainable, realistic, timely and affordable (CSFD, 2009). Various indication systems for measuring desertification were identified by researchers such


**ISSN: 2141-2731**

as Hongbo and Ma (2008), Imeson (2005) and Kosmas *et al* (2013). However, a common set of benchmarks and indicators agreed upon by the Task Group Meeting on Benchmarks and Indicators for Desertification Monitoring and Assessment under the TPN1 (Asian Region Thematic Programme Network on Desertification Monitoring and Assessment) held in Beijing (Hongbo and Ma, 2008) which was also used in Europe as enumerated by Imeson (2005) were identified and discussed. Four aspects of the indicator system identified were pressure, state, desertification impact and implementation indicators.

a. The driving forces of desertification are the pressure indicators which are both natural and man-made, they affect the status of natural resources and lead to desertification (Imeson, 2005). The main natural factors include climate, physiognomy and natural disasters, while the man-made factors include socioeconomic activities such as increased agricultural activities especially cultivation of crops on marginal lands and intensive overgrazing caused by accelerated human and animal population (Hongbo and Ma, 2008). In addition, pressure indicators are used to assess desertification trends and for early warning (Hongbo and Ma, 2008).

b. The degree of land degeneration of an area is indicated by the state indicators (physical, chemical and biological indicators) which are the characteristics of terrestrial ecosystem (Hongbo and Ma, 2008). The status of soil erosion, sand dune activity, bare area, surface water and ground water characterize the physical indicators, while the status of soil salinization and alkali land characterize the chemical indicators. Soil parameters like soil texture, soil depth, and soil moisture are regarded as one of the components of the indicator system. The types and community of vegetation, composition of plant species and animals, the vegetation biomass and the plant productivity make up the biological indicators (Hongbo and Ma, 2008). Imeson (2005) added that deforestation and vegetation degradation are also key factors that indicate land degradation and desertification. State indicators describe the extent to which an area will be affected by desertification.

c. Desertification impact indicators were used to evaluate the effects of desertification on humans and the environment. Such indicators include socioeconomic indicators such as deteriorating living conditions and loss in farm income, and environmental indicators such as the reduction in the capacity of soil and water resources to support life (Hongbo and Ma, 2008; Imeson, 2005).

d. Implementation indicators are used to assess the actions taken for combating desertification and its impact on natural resources and humans (Hongbo and Ma, 2008). Such indicators should include improvement of socioeconomic and natural conditions like sustainable farming systems, terracing, ground water recharge, storage of runoff water, controlled grazing and protection of forests from fires.


**ISSN: 2141-2731**

## Study Area

The study area is located in the north eastern part of Yobe State lying between latitudes 12Ú 182 N and 13Ú 212 N of the Equator and longitudes 11Ú 372 E and 12Ú 322 E. The area covers the entire Geidam LGA and eastern regions of Yunusari and Bursari LGAs (Fig 1). According to the 2006 National Housing and Population Census, the three LGAs Bursari, Geidam and Yunusari collectively had a total population of 376,171 persons representing 16.2% of the total population of Yobe State. Settlements in the area are found near oasis, along the rivers and roads. Agriculture is the main stay of the economy of the area and over 80 percent of the populations are farmers, with only few individuals engaged in non-farming activities in the urban centres. Food and cash crops in the area include groundnut, gum arabic, millet, rice, wheat, and sorghum (Oruonye, 2009).

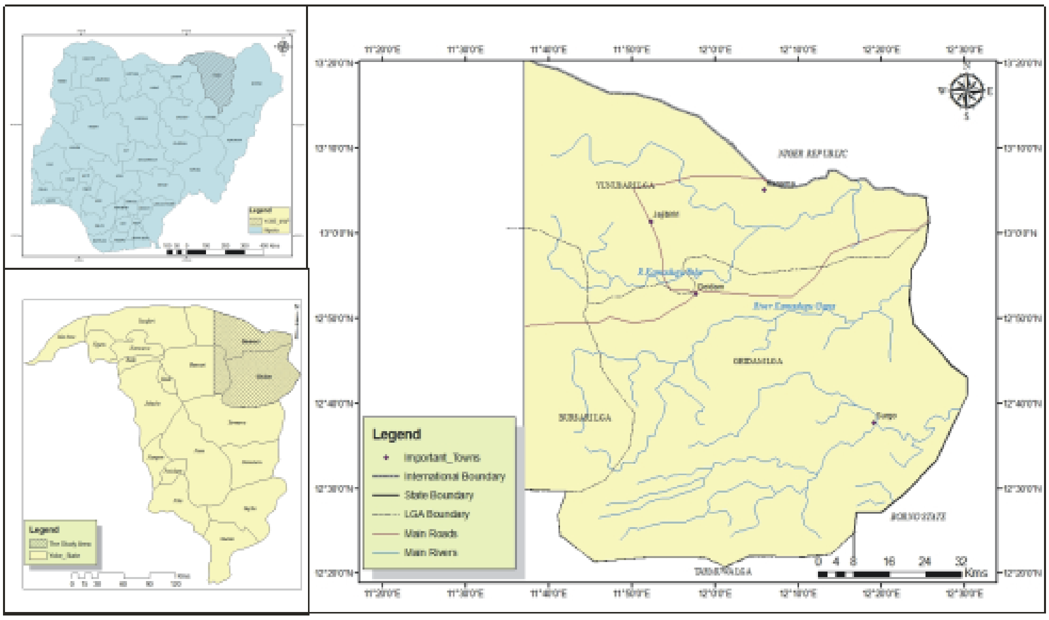


**Figure 1:** Location of Study Area. ***Source:*** Dada et al, 2006 and Earth explorer image of 2013

Geologically, the area largely consists of quaternary deposits of the Chad Formation overlying the Sedimentary Formations, comprising consolidated sands, clay, aeolian sands, beach sands and gravels, deltaic sands and clays, lagoonal clays, lacustrine sands and ancient alluvium which give rise to a complex landscape (Oruonye (2009). The relief of the Study area consists of a vast open plain, developed on young sedimentary rocks of the Chad Formation, according to Oruonye (2009). The area consists of extensive very gently undulating plains descending gradually from about 361m in the southern part to 304m in the north-eastern boundary of the study area. The main drainage system found in the study area is rivers (Komadugu) Yobe and (Komadugu) Gana, its major tributary. River (Komadugu) Gana flows north-eastward into the main River (Komadugu) Yobe (Fig 2) which also flows north-eastward into Lake Chad.



**ISSN: 2141-2731**

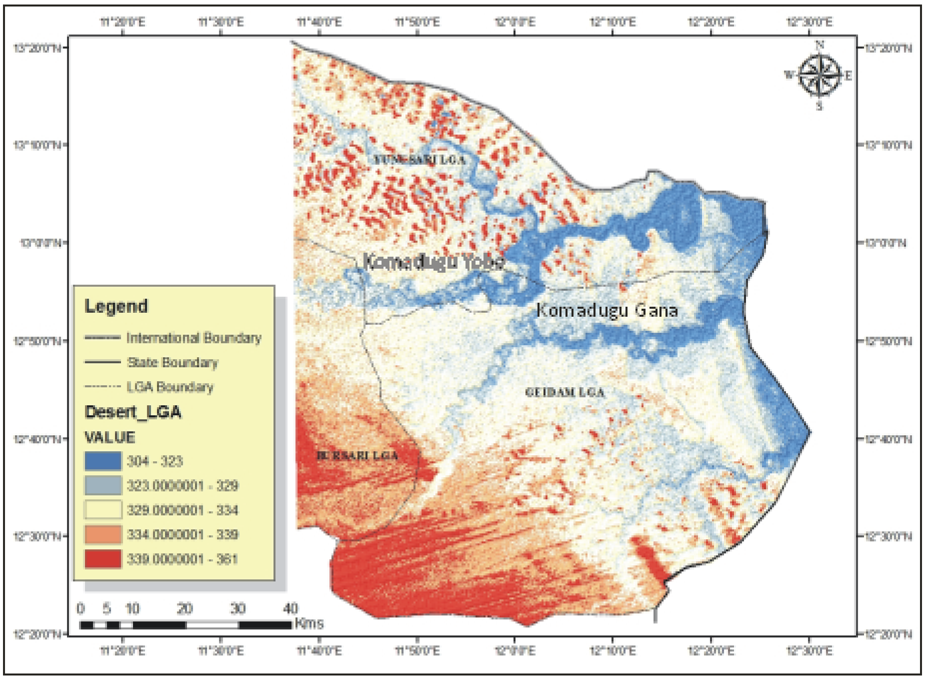


**Figure 2:** Relief and Drainage of the Study Area
***Source:*** Processed from SRTM Digital Elevation Model of Study Area

The climate regime of the study area is characterized by single eight to nine months long dry season, followed by a three to four months wet season. The area is characterized by scanty rainfall averaging 300mm with annual variation (Amadi, Maiguru, Zaku and Yakubu, 2013). Generally, in the area, rainfall lasts for about 120 days (Nigeria Physical Settings, 2012). The Nguru zonal weather station (1975-2014) observes that mean annual temperature in the area is about 37°C, with highest temperature of about 44°C normally experienced in April and a minimum of 19°C in December. Throughout the dry season, humidity is low and potential evapotranspiration exceeds rainfall except for the few wet months. Oruonye (2009) reports that the vegetation of the study area is mainly Sahel Savannah. The nature, appearance and characteristics of the vegetation are determined largely by rainfall and is said to be directly related to environmental factors such as climate, soil, and human interference. The vegetation is scanty and even during the wet season with a grass cover that never forms a continuous green carpet. The vegetation also consists of thorn bushes, shrubs and trees which grow under dry conditions, with Acacia and Commiphora species dominating and mostly interspersed by sand dunes (Musa, 2012). The textural characteristics of soils in the study area are mainly sandy soils and silt-clay. The soil is poorly developed and it has poor water retention capacity as stated by Price *et al* (2012). They concluded that inadequate vegetation cover which supplies organic matter has greatly impaired the productivity of soils in the study area. Another serious threat to the quality of soils in the study area is wind


**ISSN: 2141-2731**

erosion which blows off fine sand particles containing nutrients essential for plant growth. Another soil type found in Komadugu Yobe flood plain is the alluvial soil which is suitable for the cultivation of crops like rice and wheat.

## MATERIALS AND METHOD

For the purpose of this work, the data acquired include: Medium resolution satellite imageries of Landsat Multispectral Scanner (MSS) of 10th October, 1975; Thematic Mapper (TM) of 9th October, 1986; Enhanced Thematic Mapper (ETM+) of 8th November, 2000 and 16th October, 2009 and Earth Explorer image of 21st November, 2013 by USGS, a period of 38 years were used to detect and monitor the desertification indicators in the study area. Google Earth Pro maps of some areas in 2013 were acquired to compliment information obtained from Landsat imageries Maximum and minimum temperature data of 40 years in Geidam and Yunusari towns obtained from Nguru zonal weather station were used to analyze its role in desertification processes in the study area to know whether the area is getting hotter or cooler during the period of study. Annual amount of rainfall data of 40 years in Geidam and Yunusari towns were also obtained from Nguru zonal weather station and used to analyze rainfall patterns as indicator to desiccation or increasing wetness.

Various processes were used to analyze the Landsat images which were acquired as orthorectified images for this research which include: resampling and sub-mapping of the satellite images using ILWIS software, extraction of the study area from the scene acquired; selection of classes were based on features in the environment that served as pointers or indicators of desertification (Table 1), classification of the images and area coverage of each class for each year were calculated using ArcGIS 10 software. Variation in areas of a crescentic dune in the northern part of the study area was further used to verify sand dunes activities in the area using the Google Earth Pro images of 2010 and 2013.

## RESULTS AND DISCUSSION

### Image Classification

Supervised classification using maximum likelihood classification method was used to classify the satellite imageries into the landcover classes in Table 1. Representative training sites were chosen using high resolution image of the study area and NDVI images created for each selected year, where small portion of the area was closely studied to identify the position and nature of some trees, shrubs, grasses, water, bare land and sand dunes in other to identify the spectral signature of each of the landcover types on the acquired satellite imageries. However, during classification of the image, the spectral signature of harvested land areas was clashing with that of bare land areas and dune fields, thus the landuse and landcover types were classified as bare land and dunes.



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**Trend of landcover change from 1975 to 2013**

The trend of changes in land area covered by surface water, trees, shrubs, grass, bare land and dunes as well as their respective percentages is presented in Table 2. As shown in Table 2, between 1975 and 2013 the study area experienced decrease in the percentage of land area covered by surface water from 0.68% in 1975 to 0.17% in 2013, which also has a negative effect on the plant community present on the flood plain of Komadugu Yobe and Komadugu Gana and around ponds in the area. The table also shows the trend of change in the area covered by the tree class and the values indicates that there was decrease in the percentage of land area covered by trees between 1975 and 2013 from 7.58% to 3.70% at a rate of 7.84km$^2$ annually, this leads to increased wind movement and sand movement in the area since disruption by the trees has been reduced. Similar result was also reported by Musa (2012) who records decrease in woodland area from 5658.99km$^2$ to 551.76km$^2$ from 1986 to 2009 in Yobe State. The area was characterized by low number of trees per hectare which are mostly fire tolerant plant species added Amadi, Maiguru, Zaku and Yakubu (2013). This can also be attributed to increase in farming activities in the area, in which some of the tree communities were cleared for crop cultivation as observed on the Google Earth image (Appendix C, Plate III). The 1975 to 2000 result shows an increase in area coverage of trees due to re-growth of trees in some areas during the study period especially during years of high rainfall as the trend of rainfall pattern was seen to vary over the years from the charts on rainfall in Geidam and Yunusari LGAs presented in Figs 10 to 13 which also shows an overall decrease in the mean annual rainfall amount throughout the study period.

The shrub and grass class in Table 2 was also shown to drastically decrease from 1975 to 2013, with small increase recorded in 2009 which further decreased in 2013. The reduction in the area coverage of this class in the study period was related to the amount of rainfall recorded during that period, which was averagely below 450mm and the months that the images were captured (October and November) which affected especially the availability of grass in that period since most of the grassland areas have dried up with only few patches seen along the river valleys and floodplains of Komadugu Yobe and Komadugu Gana, and also in some wet areas distributed all over the study area. Amadi, Maiguru, Zaku and Yakubu (2013) also recorded that vegetation decreased in Gashua and Yusufari area between 1978 and 2002, but did not differentiate between the different vegetation types, Musa (2012) also records a considerable drop in shrub land in Yobe State from 12695.11km$^2$ to 6912.99km$^2$ between 1986 and 2009. In contrast to this finding, Musa and Shaib (2010) report that area of grasses and shrubs increased between 1986 and 2006 period in the same area.

Bare land and sand dunes are identified as physical indicators of desertification in this study. Between 1975 and 2013, from Table 2, it can be observed that the percentage of land area covered by this landcover class increased and covered more than half of the study area (65.84% in 1975 to 87.42% in 2013), at a rate of


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43.64km$^2$ annually, this can be associated with the decrease in the trees, shrubs and grassland communities which played major roles of intercepting or resisting the movement of sand blown by wind, the reduction of vegetation paved way for increased wind velocity in the area and consequentially movement of large amounts of sand particles as dust through increased soil erosion.

**Spatial Distribution of Landcover (1975 to 2013)**

The thematic maps produced from the classified imageries of 1975 to 2013 (Figures 3 to 7) shows the dynamics associated with the four landcover classes during the study period in relation to the trend in the changes of the landcover types as shown in Table 2.

***Spatial Distribution of Landcover Types in 1975:*** The Fig. 3 shows study area landscape in 1975 and the landcover types. It was observed from Fig.3 that the spatial coverage of surface water was small and mostly seen along the river valleys of Komadugu Yobe and Komadugu Gana. The southern part of the study area have higher densities of trees, shrubs and grassland and also on the flood plains of Rivers (Komadugu) Yobe, (Komadugu) Gana, while in the northern part of the area is mostly covered by few patches of shrubs and grass and scattered trees which have high resistance to drought like *Acacia tortilis* (Musa and Shaib, 2010). The class indicating bare land and dune field during this period (October) was mostly seen at the northern and central part of the study area especially on the highland and sloppy areas (Fig 2) which barely retains water due to high runoffs after rainfall. Some of the settlements located in the area during this period were Togua, Nganawa, Jajibiriri and Kassachia in Yunusari LGA. Others include Shame-kura, Damakarba and Geidam in Geidam LGA and Goniri, Kindilwa in Bursari LGA. This finding is similar to that of Musa and Shaib (2010) who carried their study in Yusufari, Bade, Nguru and Karasuwa LGAs where they noticed human impact on vegetation resulting in the creation of sandy area mostly in the northern part of their study area.

***Spatial Distribution of Landcover Types in 1986:*** The spatial distribution of the landcover types in the study area in 1986 is shown in Fig.4. During this period (October) which is a transitional period between rainy and dry season, water was found mainly along the river valleys of Komadugu Yobe and Komadugu Gana and in ponds scattered around the study area. The trees, shrubs and grassland landcover types were also mostly seen at the southern part of the study area and along the rivers flood plain due mainly to the presence of water in the area. It can also be observed that the density of trees, shrubs and grasses further decreased around the central and northern region of the study area, the vegetation cover was sparsely distributed around the area that it looks as if it was only covered by bare land as also observed in the work of Musa (2012). The trees, shrubs and grass landcover type was observed to be shifting southwards between 1975 and 1986 as has also been reported by Suleiman (2011) that desertification is the most pressing environmental



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problems in northern parts of Nigeria, which is obvious via the gradual shift in vegetation from occasional trees, shrubs, grasses, then to an expanse area of desert-like sand. The bare land area and dune fields which are indicators of desertification was observed to have increased and covered northern and major part of the central region compared to 1975. Musa (2012) has reported that bare surface area covered about 10811.82km$^2$ of northern Yobe in 1986. Some settlements that were surrounded by vegetation were found to have been surrounded by sand and dune fields, among which were: Dajina, Chirawa, Gajiga, Musari, and Moswa in Geidam Local Government Area. In addition, it was also observed that the presence of sandy area and dune fields was more pronounced in the north than the central part of the study area because of the presence of the two rivers. Musa and Shaib (2010) also reported similar findings that sand encroachment rapidly increased between 1973 and 1986 in Yusufari Local Government Area.

Human activities especially over-cultivation and over-grazing in the more communities of the north and the central part of the study area might have also contributed to increased bare land leading to accumulated dunes in the area coupled with the less rainfall amount recorded that year. The impact of human activities on desertification had been reported by Ayuba and Dami (2011) that over 90 percent of the population in the frontline states being farmers and animal rearers depend directly on a wide range of natural resource and the ecosystem services for their livelihood.

***Spatial Distribution of Landcover Types in 2000:*** The spatial distribution of the various landcover types in the area in 2000 is shown in Fig. 4. The period between 1986 and the year 2000 recorded another change in the landscape of the study area (Fig. 4). The nature of the landscape showed that water was also mostly found in river valleys and some patches around the south-south and south-eastern which can be hardly seen because of its quantity. The dense plant community of trees, shrubs and grassland found in the southern part of the study area is seen to have become sparser except those found along the river valleys and extreme south of the study area. Clusters of trees, shrubs and grasses are also scattered around Kindilwa, Gujiga, Zabadamu and Karamri in the southern part of the study area while the northern part further became sparser in vegetation cover consequentially the bare land and sand dunes were found to be more pronounced in 2000 than the previous periods. During this period, major part of the study area was covered by bare land, sand dunes and bare cultivated land.

***Spatial Distribution of Landcover Types in 2009:*** Figure 5 shows the spatial distribution of landcover in the area in 2009. Though the date of image capture in 2009 (16$^{th}$ October) differs from that taken in 2000 (8th November), the 2009 image still revealed the southward shift in the area coverage of bare land area and dune fields in the northern and central parts of the study area. The landscape also showed that some of the areas in the extreme south that used to have high densities of vegetation (trees, shrubs and grasses) in 2000 was covered with sparser vegetation


**ISSN: 2141-2731**

in 2009, however, some areas around Zabadamu, Karamri and Zuru-kuduk still maintained their vegetation cover mainly due to the soil type in the area which is clay-silt (Oruonye, 2005) and retains moisture for a long period. Re-growth of shrubs and grasses were also found around Amarti, Kirgai and Dilawa as also shown by the increase in land area of shrubs and grasses in Table 2. However, the thematic map of the area still reveals the large area coverage of bare land and dune fields in most parts of the study area as also complemented by the decrease in trend of mean annual rainfall amount during the study period (Fig 10 and 12).

***Spatial Distribution of Landcover Types in 2013:*** The spatial distribution of landcover in the area in 2013 is shown in Fig. 6. By 2013, the landscape of the study area indicates that accumulation of surface water was mostly seen at the north-eastern part of Komadugu Yobe and Komadugu Gana. There was disappearance of the communities of trees and shrubs that used to be at the extreme south of the study area and around Amarti, Dilawa, Karamri and Zuru-kuduk. Most of the trees, shrubs and grasses were found at the rivers valleys. Amadi, Maiguru, Zaku and Yakubu (2013) report that conducive climate can reduce the rate of desertification, however, in this study, despite the increase in rainfall (Fig 4.6 and 4.7) the bare land area still increased. This is also to verify the findings of Musa (2012) that desertification in Yobe State was not only the result of natural phenomenon of rainfall, temperature, and wind erosion but human activities such as over-cultivation, overgrazing and tree felling for fuel wood and charcoal.

**Assessment of Change in Dune area coverage from 2010 to 2013**

One of the indicators identified in the study area is the presence of sand dunes which were observed to increase in size or moved to another location during the study period. Figures 7, 8, and 9 showed the area coverage of a sampled cresentic dune in 2010 (Fig 7) and 2013 (Fig 8) and the overlaid image of the dune showing the change in size (Fig 9). The result of the overlaid images showed that the land area coverage of the dune in 2010 is 0.19km$^2$ (187547.51m$^2$), but increase to about 0.21km$^2$ (214919.45m$^2$) in 2013. This indicates that desertification is a serious environmental problem in the study area.

**Pattern of Rainfall Amount and Mean Annual Maximum Temperature in the Study Area**

The pattern of rainfall amount and mean maximum temperature in Geidam and Yunusari towns are presented in Fig 10, 11, 12 and 13. According to the figures, annual mean maximum temperature in Geidam and Yunusari from 1975 to 2014 was averagely about 36$^o$C since about 16 years recorded 36$^o$C as annual mean maximum temperature. 1981 was the coolest year in the study period with a mean annual maximum temperature of 32$^o$C, while 1984 and 2008 were the hottest years during the study period with about 37$^o$C mean annual maximum temperature. The



**ISSN: 2141-2731**

rainfall pattern shows that the wettest years of the study were 1983 and 2014 with approximately 717mm of rainfall, while the wettest period was between 1978 and 1983. Generally, the trend of the mean annual rainfall amount recorded for the study area indicates that there was a decrease in rainfall amount as shown by the trend line, with an average of 440mm of rainfall annually, which could have accounted for the decrease in the area covered by vegetation (trees, shrubs and grasses) within the study period (Table 2). Due to the rainfall amount, the area covered by bare land and dunes increased, this is to show that rainfall amount and temperature was also the cause of increased bare land in the area coupled with human activities.

## CONCLUSION AND RECOMMENDATIONS

The findings in this research identified decreased vegetation (trees, shrubs and grasses) and increased bare land and dunes area coverage as indicators of desertification in the study area, where 298.03km$^2$ of land areas covered by trees and 1321.39km$^2$ of land areas covered by shrubs and grasses where lost between 1975 and 2013, while Bare land areas and dune fields increased from 5061.25km$^2$ in 1975 to 6719.74km$^2$ in 2013. The spatial distribution of the land cover class also shows that the northern part of the study area was mostly affected by vegetation loss compared to the southern part, where they are mostly seen at the south-eastern portion and some areas in the south-south of Geidam LGA, and along the flood plains of Komadugu Yobe and Gana. Variation in annual amount of rainfall received in the area in relation to other anthropogenic factors such as farming influenced the rate of desertification in the study area. Therefore, it can be concluded that desertification is moderate in the study area through the desertification indicators detected and monitored. In other to address issues discussed through the findings of this study, the following recommendations are offered:

a) Remote sensing data and GIS techniques should be used for constant monitoring and evaluation of desertification in the affected areas and to ensure that desertification control measures put in place by communities and all stakeholders are making positive impacts on the environment and if not, more efforts should be exerted towards achieving such result.
b) Farmers should be encouraged to practice agroforestry on their farmlands as trees planted like Moringa, Acacia spp, and so on will help to minimize the impact of wind erosion and also serve as source of food and income for the family in the future.
c) Ecotourism should be encouraged where people can visit the sand dune area for site seeing and to create an awareness on desertification processes.
d) Effective community-based tree planting programme should be encouraged with incentives so as to boost their morale. Also they should take advantage of favourable climatic conditions to plant more trees.


**ISSN: 2141-2731**

**Table 1:** Classification Scheme for Landcover Mapping in N/E Nigeria

| **Categories** | **Subcategory** | **Description** |
|---|---|---|
| A. Surface water | River, lakes, ponds | A stream or standing body of water |
| B. Trees | Riparian tree | Trees along water channels |
| | Marsh woodland | Trees inundated by water |
| | Orchard | Collection of planted trees |
| | High tree Savannah (mixed) | Collection of trees, taller than 5m |
| | Short tree Savannah (mixed) | Collection of trees more than 70% mixed species , 3m – 5m tall |
| C. Shrub and Grass | High Shrub (Mixed) | Shrub more than 2m tall, mixed species |
| | Short Shrub (Mixed) | Shrub less than 2m tall, mixed species |
| | Dumb Palm Bush | Shrub like bush mainly dumb Palm |
| | Marsh Bush | Inundated shrubs and grass in water |
| | Grass shrub | Mixture of shrub and grass, more than 30% of each |
| | Grass | Grass, more than 70% |
| D. Bare land and Dunes | Bare ground | Bare ground, no gravel, not clay |
| | Dry mud surface | Bare ground, dry clay |
| | Dunes | All types of dunes |
| | Cultivated land | Harvested farmlands |

**Source:** Garba *et al*, 2010

**Table 2: Landcover Types and Trend from 1975 to 2013**

| **Landcover** | **1975** | **1986** | **2000** | **2009** | **2013** |
|---|---|---|---|---|---|
| | **Area (km$^2$)** | **Area (km$^2$)** | **Area (km$^2$)** | **Area (km$^2$)** | **Area (km$^2$)** |
| **Surface water** | 52.29(0.68) | 52.92(0.69) | 49.03(0.64) | 58.78(0.76) | 13.22(0.17) |
| **Trees** | 582.76(7.58) | 616.05(8.01) | 721.56(9.39) | 428.04(5.57) | 284.73(3.70) |
| **Shrubs and grass** | 1990.45(25.89) | 1235.75(16.08) | 826.84(10.76) | 843.37(10.97) | 669.06(8.70) |
| **Bare landand Dune** | 5061.25(65.84) | 5782.03(75.22) | 6081.32(79.22) | 6356.56(82.70) | 6719.74(87.42) |
| **Total** | **7686.75** | **7686.75** | **7686.75** | **7686.75** | **7686.75** |

***Figures in bracket are percentages of areas calculated.** ***Source:*** Classified Satellite Images


**Figure 3:** Study Area Landscape in 1975 ***Source:*** Classified from 1975 Landsat Image



**ISSN: 2141-2731**

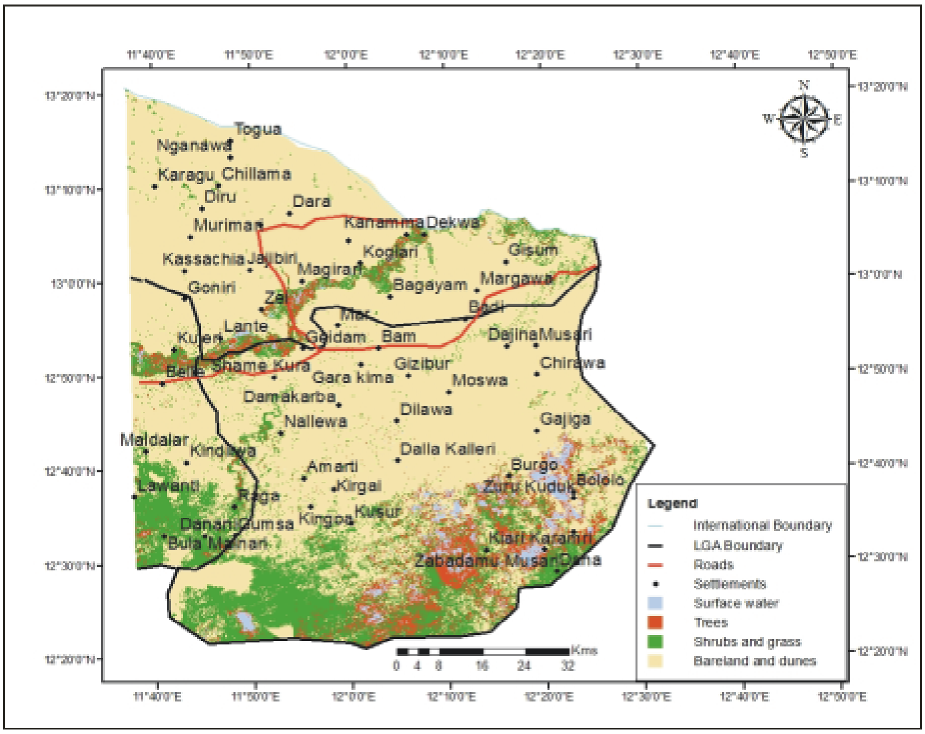


**Figure 4:** Study Area Landscape in 1986. ***Source:*** Classified from 1986 Landsat Image.

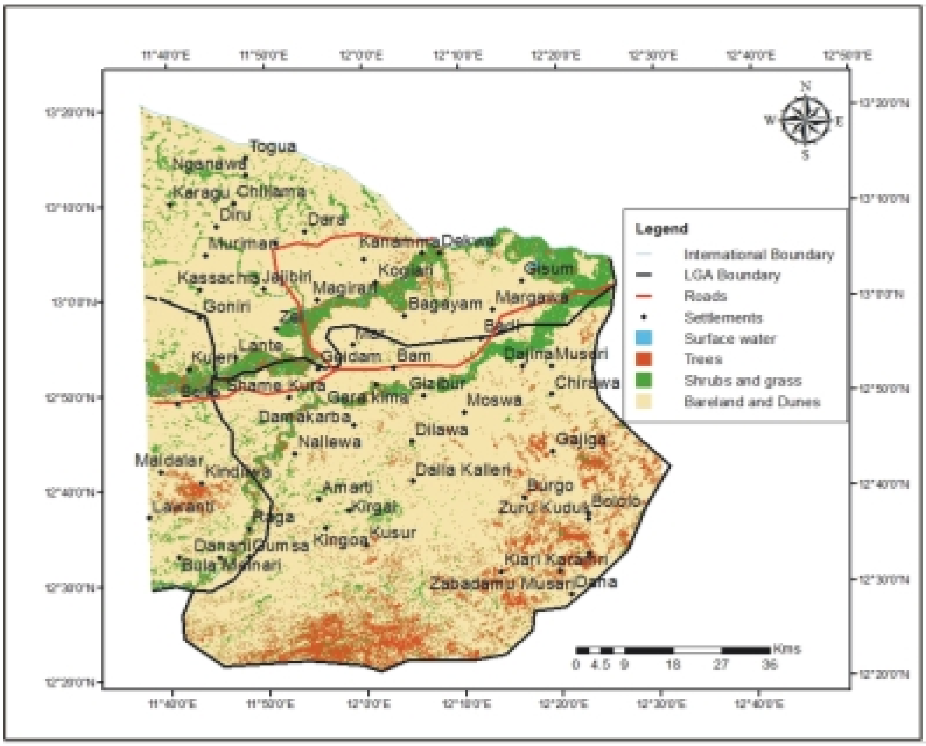


**Fig. 4:** Study Area Landscape in 2000. ***Source:*** Classified from 2000 Landsat Image.



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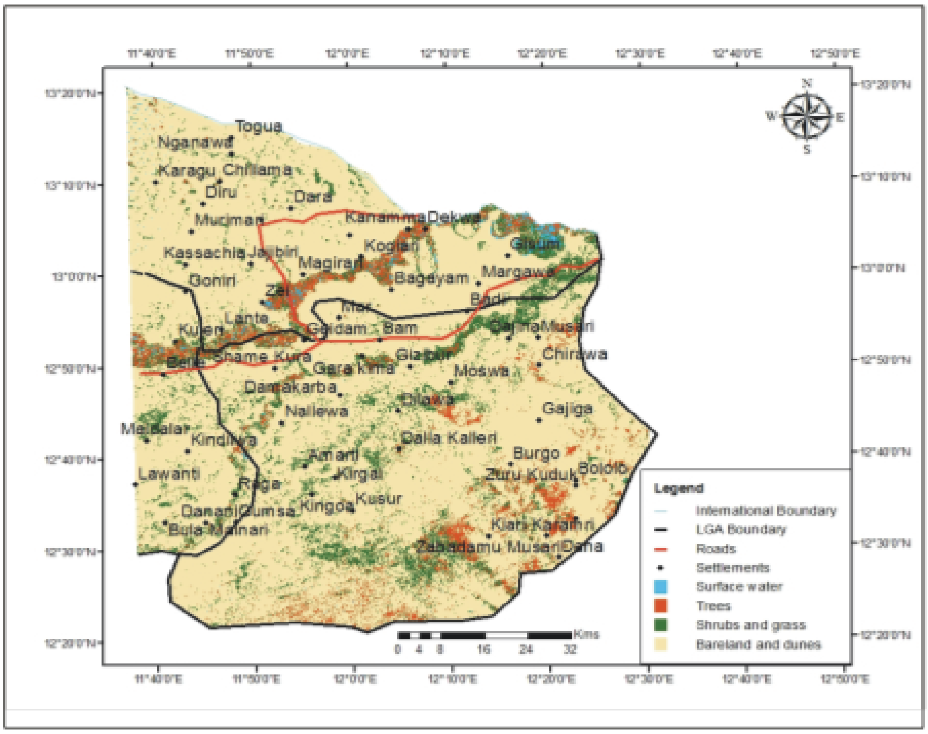


**Figure 5:** Study Area Landscape in 2009. ***Source:*** Classified from 2009 Landsat Image.

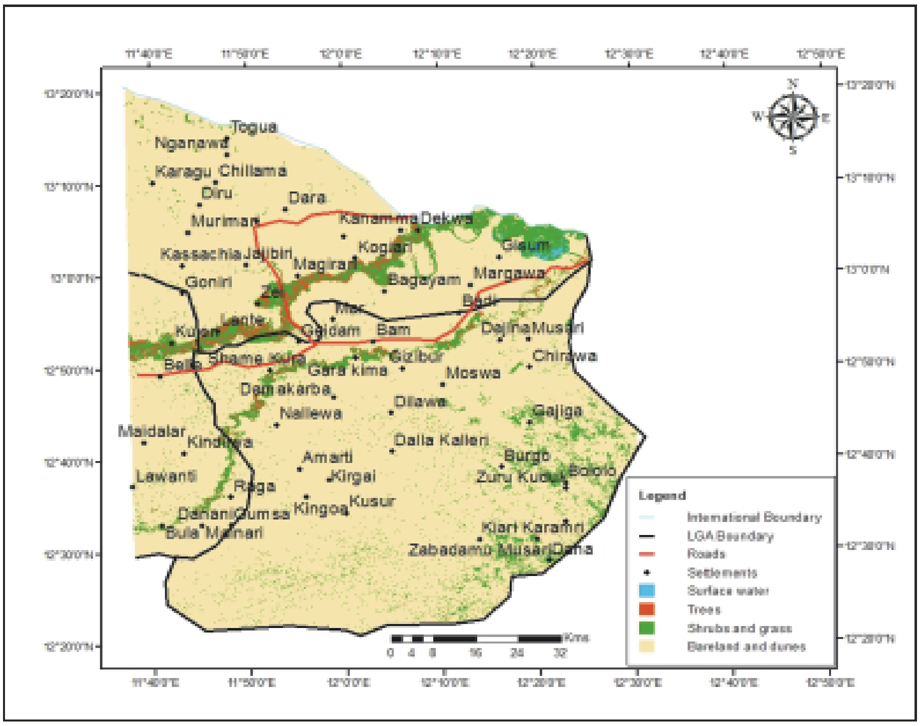


**Fig. 6:** Study Area Landscape in 2013. ***Source:*** Classified from 2013 Landsat Image.



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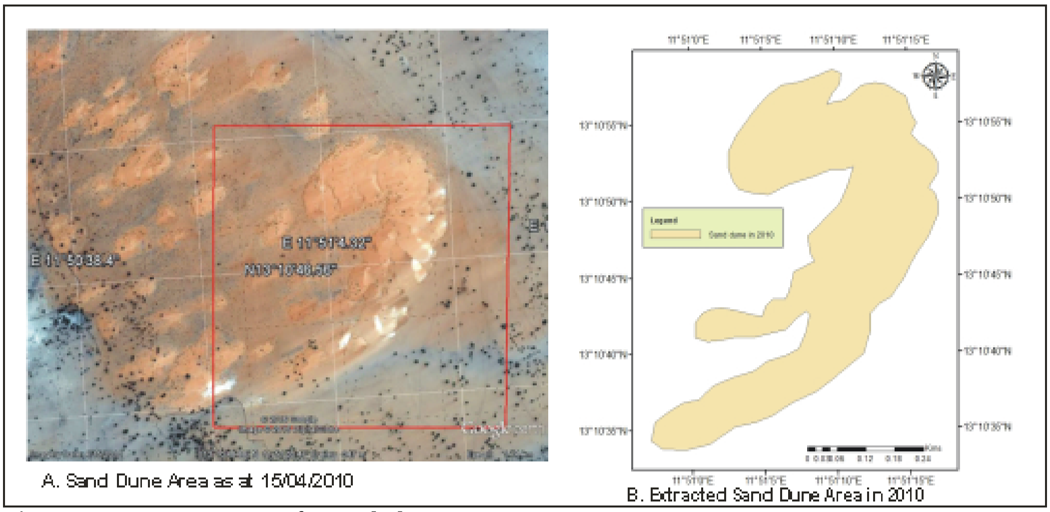


**Figure 7:** Area Coverage of Sampled Crecentic Dune in 2010

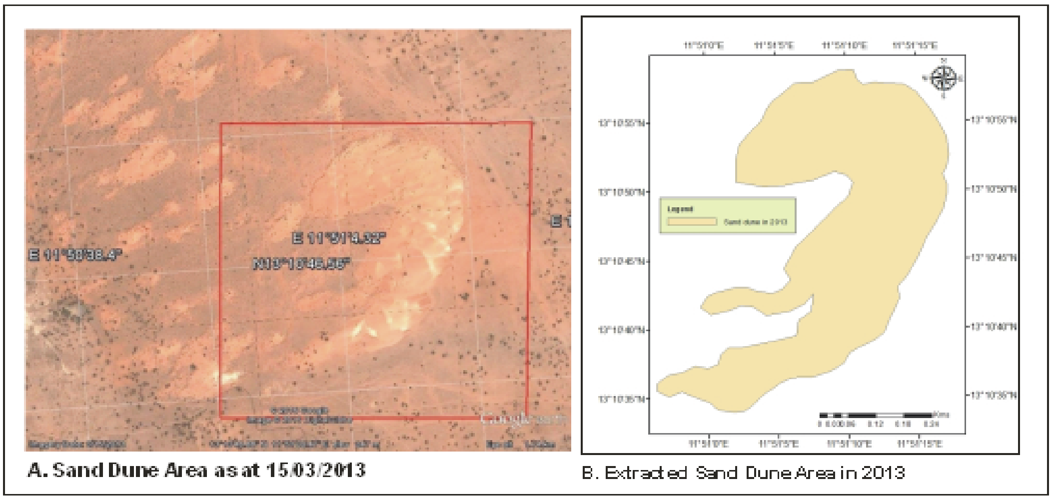


**Figure 8:** Area Coverage of Sampled Crecentic Dune in 2013

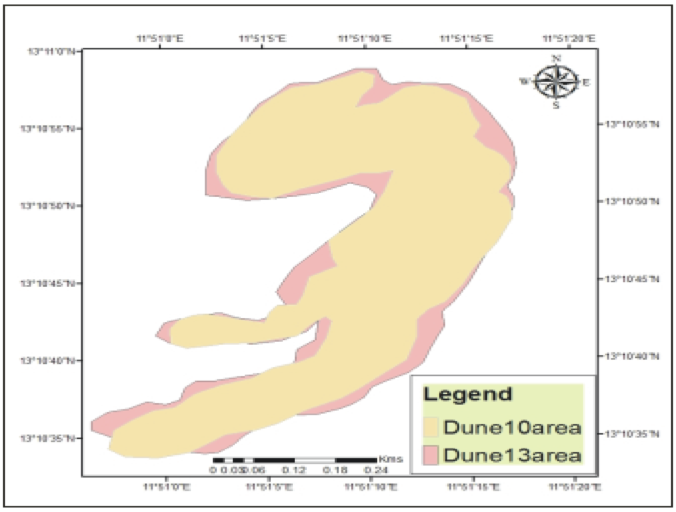


**Figure 9:** Overlaid Sand dune area in 2010 and 2013



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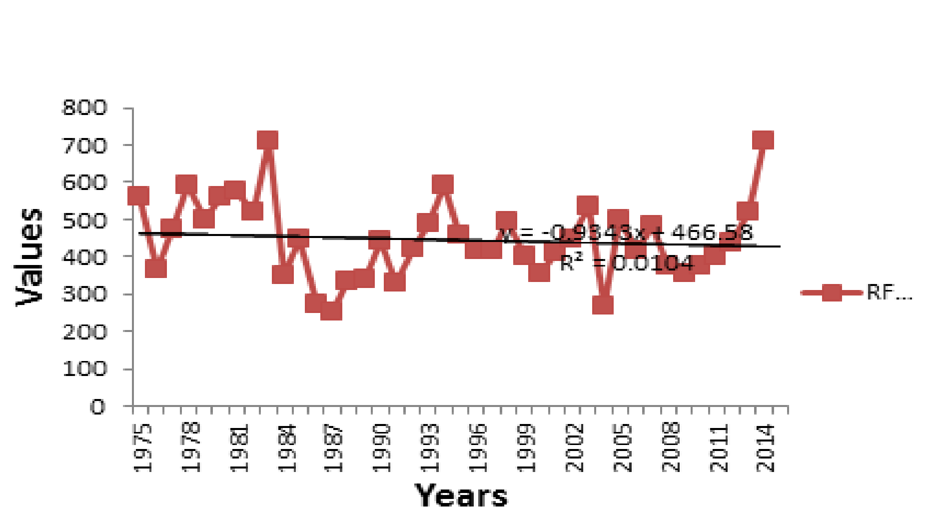


**Figure 10:** Annual Rainfall Amount in Geidam (1975-2014). ***Source:*** Nguru Zonal Weather Station, Yobe State.

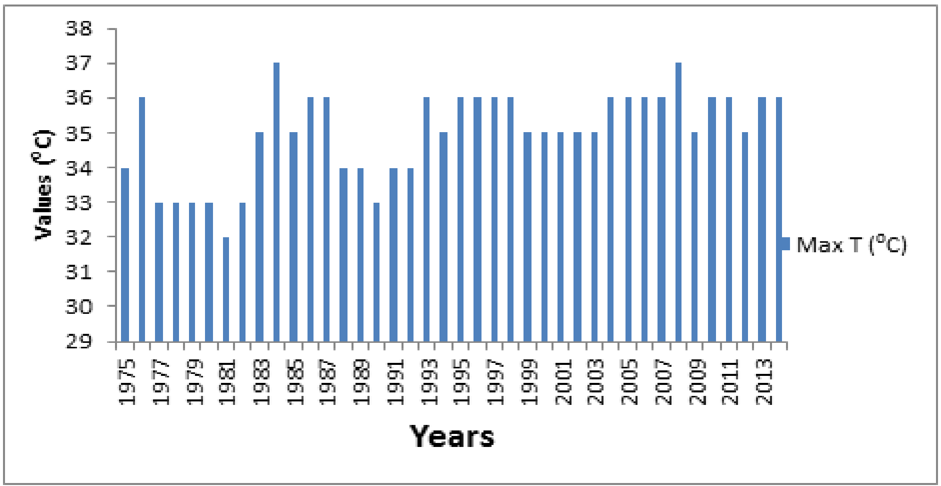


**Figure 11:** Annual Mean Maximum Temperature in Geidam (1975-2014).
***Source:*** Nguru Zonal Weather Station, Yobe State.

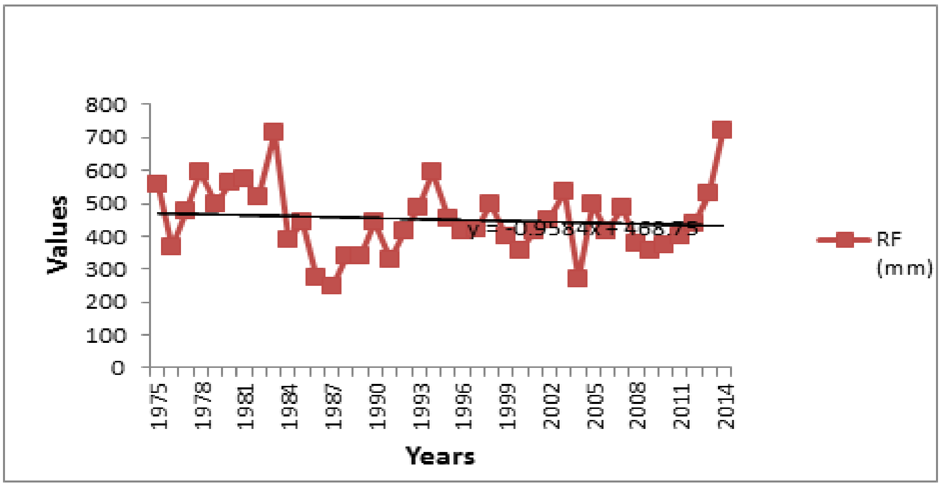


**Figure 12:** Annual Rainfall Amount in Yunusari (1975-2014). ***Source:*** Nguru Zonal Weather Station, Yobe State.



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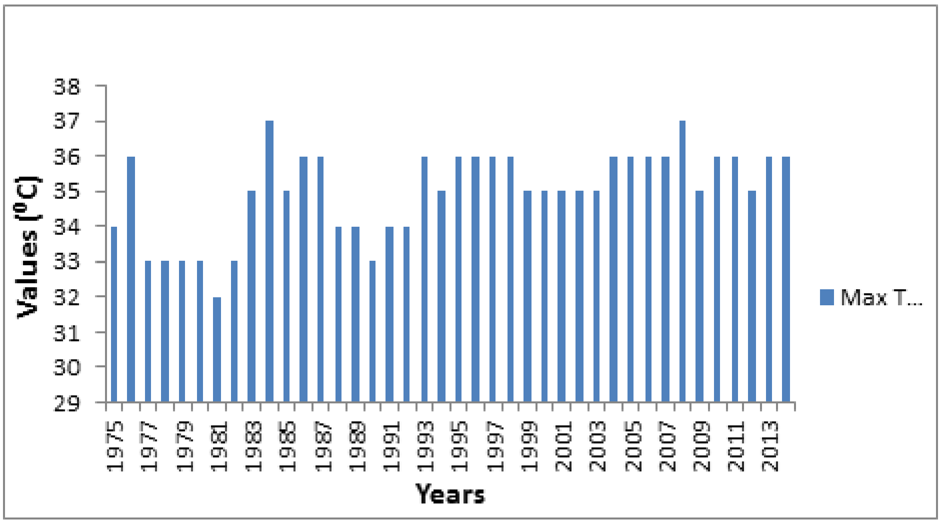


Figure 13: Annual Mean Maximum Temperature in Yunusari (1975-2014)
Source: Nguru Zonal Weather Station, Yobe State.

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**ISSN: 2141-2731**