Spectral Analysis of Sandy Desertification in the Semi-Arid Zone of North Eastern Nigeria

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Abstract

The method of integrating remote sensing, Geographic Information System (GIS) and field survey was employed. Assessment of the rate and intensity of sand dune encroachment using multi-temporal Landsat images (Landsat.TM, 1986, Landsat.ETM, 2000 and Landsat.OLI, TIR, 2016) and GIS. The satellite images were processed by converting raw Digital Number (DNs) values to radiance images which were converted into reflectance images used for spectral analysis.The satellite images were processed accordingly for evaluating six (6) spectral indices; Crust Index (CI, Grain Size Index, Bare soil Index (BSI), Normalized Difference Sand Dune Index (NDSDI), Normalized Difference Sand Index (NDSI), Normalised Difference Soil Index (NDSLI). An aggregate index of each of the six (6) selected indices was evaluated and the long term geometric mean was determined and used for image differencing with the baseline date image. A combination of MEDALUS.ESA and Image Differencing was adopted for change detection technique. Sandy landscapes were mapped into four (4) natural classes using natural jenks classifier of the ArcGIS analytical tool based on pre-field field determination and post verification. The description of the four (4) sandy landscape classes is as follows: Active, Semi-active, Semi-fixed and Fixed sand dune/sheets. Results of overall sandy desertification based on Aggregate Sandification Index indicates that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.20 and 1.28 **km^2** and intensity for the of 0.13 and 0.23% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.24 and 1.39 **km^2** and intensity for the period of 0.17 and 0.47 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an an annual rate of 1.39 **km^2** and 0.47% intensity being the highest among other classes. The result of this study indicates that the natural ecology or vegetation, graze lands, irrigated lands, rainfed farmlands, settlements, infrastructure are at high risk of sandy desertification in the semi-arid zone of Nigeria. This study is also a pointer that the shelter belts have not been very effective in controlling wind erosion and thus sandy desertification.

Keywords: : desertification. sandification, eco-geomorphic landscape, semi-arid, encroachment

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1 INTRODUCTION

Sandy desertification an interesting topical issue in both bioscience and geoscience which has increasingly attracted the attention of the public, researchers, government officials, and international organizations. It is now one of the main eco-geomorphological hazard in the world today when viewed from the perspectives of the eco-geomorphological environment and food security (Wang, 2013). Rapid and continuous spread of sandy desertification during last 50 years has created major environmental and socio-economic problems in most parts of the world.

As was the case for the definition of desertification, the definition of sandy desertification has also evolved through several stages and definitions by different authors (Zhu et al., 1980; Zhu, 1994; Yang et al., 1986; Dong et al., 1988; Wu, 1991 and 2003). For the purpose of the approach in this study the definitions by Yang et al. (1986) and Wand et al., (2004) are adopted. Yang et al., (1986) defined sandy desertification as a series of geomorphological and climatic processes that occur in areas with sandy surface sediments in arid, semiarid, and sometimes sub-humid areas over a range of time scales, with wind and other factors acting as the major dynamic factors. While, Wand et al., (2004). Defined Sandy desertification as a form of land degradation characterized by wind erosion that mainly results from the excessive unsustainable human activities in arid, semiarid and part of sub-humid regions (Sandy desertification comprising sand dune and sand sheet encroachment has become a critical environmental and research issue in the last decades, especially in susceptible drylands areas of the world; in central and south Tunisia, China, Iraq, Iran, Egypt and other areas of the world (Ahmady-Birgani et al., 2017). Sand dunes and sheets advancement or encroachment is one of the most severe and desert like effect of desertification and a common and serious hazard in the semi-arid and arid regions. It threatens settlements, agricultural and grazing lands, infrastructure, forest and water resources (Zhu et al., 1980; Williams et al., 1998; Goudie, 2002; Brook et al., 2007 & Unkel et al., 2007). Sandy desertification determines degradation of land resources, slow recovery of vegetation and decrease of ecosystem productivity, services and livelihood (Ahmady-Birgani et al., 2017; Wang et al.,2014).

Sand dunes are found in all continents and in all world's climatic zones. They cover approximately 20% of the world's arid and hyper arid zones. They cover a total area of more than 5000 km2 including those of the humid regions and coastal areas. However, 99% of this is desert appearing in different shapes due to varying factors such as wind direction, grain size, vegetation etc. as a soil sand dunes and sheets are usually considered to be of poor benefits to production of both plants and animals because of their low fertility, low water retention capacity and poor structure as the lack cohesion of their particles. Aeolian erosion and resultant sand dune and sand sheet encroachment has become synonymous with desertification in dryland areas which include dry sub-humid, semi-arid, arid and hyper arid areas.

Desertification usually takes place when the rates of natural geomorphic processes in the drylands are accelerated by human action. As human use of the drylands is increasing, especially through modern technologies and for higher returns without much concern for sustainability of the land resources, there is now increasing impact of human pressures on the landscape manifested as different types of degradation. The scale of vulnerability of the landscape to accelerated degradation varies according to the landscape's inherent properties, including sediment characteristics, as well as plant cover, land use, etc., as well as on the climatic setting.

Arid and semi-arid when viewed as eco-climatic and eco-geomorphic landscapes are generally fragile and hence more sensitive or susceptible to sandy desertification especially due to intensive human activities in space and time (Koch, 2000). Sand encroachment is said to take place when grains of sand are carried by winds and deposited on cultivated or uncultivated land. Sand dunes encroachment is a combination of processes of sand transportation and accumulation. As the accumulations of sand (dunes) move, they bury villages, roads, oases, crops, market gardens, irrigation channels and dams, thus causing major material and socioeconomic damage. Desertification control programmes must then be implemented in order to counter this very serious situation.

Aeolian processes in arid and semi-arid areas need constant monitoring, as they often transcend into sandy desertification or sand encroachment. It is a common form of land degradation resulting from a combination of climate change and intensive or unsustainable human activities in ecologically fragile environments (Mihi, Tarai, & Chenchouni, 2017; Ren, Dong, Hu, Zhang, & Li, 2016). Sandification which is also refered to as sandy desertification is a very dynamic phenomenon.. It is experienced in many dryland areas of the world especially due adjoining desert fringes. Its evolution depends not only on the biophysical conditions of such arid environments but also on the management and exploitation methods of natural resources.

In arid regions, where desertification is most critical, monitoring the activation and movement of sand becomes of great importance. Most studies on desertification have focus mainly on vegetation monitoring to assess the extent of desertification. Desertification is not the advance of deserts, though it can include the encroachment of sand dunes on land. Sandy desertification is one of the most deleterious forms of desertification which diminutes land fertility and productivity. Although, being one of the most desert like landscapes, this has not really been focused as topical in the desertification literature. However, recently attention has shifted to this aspect especially in china and other Asian countries.

Although sandy desertification is known in Nigeria. This is one of the major intends of shelter belts is to reduce wind erosion and sandy desertification. However, studies about sandy desertification in the semi-arid parts of Nigeria are limited and have largely focused on sand dunes encroachment with little or no emphasis on sand sheets expansion. Rather than focusing on sand dunes alone this study expand the scope to include sand sheets expansion or invasion which share similar risk. This approach has obvious implication on the actual status of extent and intensity of sandy desertification which is one of the most deleterious risk associated with desertification in Nigeria. Therefore, there a need for an approach that will re-position the outlook of desertification with regards to status of sandy landscapes in the semi-arid zone of Nigeria. The emphasis on both sand dune and sand sheet encroachment in this study will greatly improve the accuracy in the prediction criteria of risk-prone areas.

Remote sensing and GIS are powerful tools for monitoring sand encroachment dynamics, which, when integrated with ground observations, provide valid mapping techniques. Several authors have employed these techniques focusing on geomorphological, socio-economic or ecological aspects (Gasmi, Radebaugh, Barnes, & Ori, 2013; Ouerchefani, Dhaou, Delaitre, Callot, & Abdeljaoued, 2013)
Ndabula et al., (2017; 2018a; & 2018b). Studied and reported other features of desertification such as micro-climatic, pedo-geomorphic and hydro-geomorphic aspects of desertification. the sandification aspect of desertification which is one of the most devastating aspect has not been given premium in studies in Nigeria.

1.1 STUDY AREA

1.1.1 Location and Extent

The semi-arid zone or SSZ of northern Nigeria is approximately bounded by latitude 1 1°N and 13"N and by longitude 4" and 15"E (Kowal and Knabe, 1972). The land area covered is 26 160 km2 or 28% of Nigeria's total land area, including large portions of Borno, Katsina, Kano and Sokoto States. The low-rainfall ecologies of the northern fringes of Nigeria are prone to desertification and sand dune activities that are phenomenal and extensive

1.1.2 Physical Setting

1.1.2.1 Geology and Hydrogeology

Geology of the study area principally comprises crystalline and sedimentary rocks, underlain by basement complex rocks. Hydrogeology of the area is dominated by Chad formation and to less extent, is supplemented by basement complex and the Fika shales. Exploitable aquifers occur at depths of up to 650m and comprise the upper, middle and lower phreaticzones. The crystalline rocks are presented by older granites found in pockets of places, especially in the southern part. There are also crystalline rocks of younger granite especially in north western part of Yobe. Most of the older granites are Precambrian in origin and have undergone metamorphism to form gneiss, and amphibolites. Basalt rocks extruded during the tertiary/quaternary periods are found in some parts of Biu plateau. The extensive sedimentary deposits of cretaceous Bima sandstone; thickness 300-2000 and depth between 2200-4600 m. Pindiga, Fika and Gombe and karekare formations were overlaid by a large expanse of quaternary Chad formation stretching over Borno, Yobe and Jigawa states (Peters, 1981)..

1.1.2.2 Relief and Drainage

The relief is generally low lying between 300m-600m above sea level; except in the southern part where the ancient volcanic (basalt) form high relief plateau (Biu Plateau). Some other interesting relief features include sand dunes following series of longitudinal and transverse extensive sand dunes rising above 100m above their surroundings are found around Yunusari, Yusufari, Machina, Geidam, Tolutoluwa and Toshia villages. Some of the sand dunes are extensive, active and threatening these settlements. Although, remarkable efforts of the North Eastern Arid Zone Development Programme (NEAZDP) towards stabilizing the dunes by planting *Calotropis procera* and redirecting or diverting and minimizing expansion are well appreciated. Sand dunes threaten many oases, settlements and farmlands. The presence of oasis is another significant relief feature in this area; especially in Bade local government areas with swampy valleys that are very rich in potash deposits. The Chad trough (basin) is the lowest part; about 240-380m above sea level which is part of the structural depression that extends over a large areas of Niger, Chad, Cameroun and Nigeria; covering about 200,000 km^2 out of which Borno and Yobe part of Nigeria covers 58% (117,000km^2). Another important relief feature is the Yadzaram valley plain covered by river alluvium (Peters, 1981).

1.1.2.3 Climate

The climate is semi-arid with wide seasonal and diurnal temperatures. A long dry season is followed by a single short wet season. The hottest months are March to May. The cold and dry dust-laden north easterly Harmattan winds prevail from November to March, with significant diurnal temperature fluctuations and extremes of temperature (Rayar, 1987). Rainfall is seasonal with a wet season occurring from July to September; with mean annual rainfall varying between 1000-500 mm from south to north. Rainfall is highly variable in space and time with high intensities (Ati, 2006). Recent years have seen decreasing annual rainfall totals (Cater and Alhassan, 1998) and dry spell is becoming a frequent problem in the area (Oladipo, 1994). The mean annual temperature is around 25^oC (Alagbe, 2002). The vegetation is mainly savannah grasslands but the physical stress of overgrazing and deforestation due to demands for firewood has caused widespread grassland degradation and desertification.

Climate of Borno-Yobe is hot during the day for most period of the year. The mean temperature for most stations in the state is about 37°C and highest temperature (about 42°C) is normally experience in April, while minimum temperatures (about 30^{0c}) are usually recorded in December (Iloeje, 1977). The north part of Borno and Yobe are drained by River Yobe which is also highly seasonal. Lake Chad is one of the largest inbuilt drainage basins in Africa and among the largest in the world. The size of the Lake in 1962 was about 25,000km^2, reduced to 9000 km^2 during the Sahelian drought of 1972-74 and further reduced to around 3,000 km^2 in 1986 (Kolawole, 1988).

1.1.3 Socio-economic Setting

1.1.3.1 Agriculture

The major economic activity in this zone is agriculture which includes crop cultivation and livestock production. Rainfed and irrigation farming are the two major methods of crop cultivation in this zone with subsistence farming as constituting the greater proportion than commercial or mechanized farming. The major cash crops include cotton, groundnut, gum Arabic and food crops; such as rice and wheat. The major stable food crops are largely grains such as millet, guinea corn, maize and cowpea. Widespread irrigation is common along the natural lakes such as Lake Chad, man-made lakes/dams, rivers, and wetlands encouraged by rainfall seasonality characterized by a longer dry season and short rainy season.

Livestock population in Nigeria has been estimated to consist of about 16 million cattle, 13.5 million sheep, 25 million goats, 2.2 million pigs, and about 150 million poultry. The semi-arid zone supports about 90% of cattle population, 2/3 of goats and sheep and almost all the donkeys' camels and horses found in the country. Most of this livestock production is through extensive grazing. The nomadic herdsmen persistently graze their livestock throughout the area in search of pasture. They observe a steady seasonal pattern of southward migration during the dry season and northward during the rainy seasons (Blench, 1994).

Additional pressure is put on the pasture resources or range lands by livestock from other countries' Sahelian regions such as Chad, Niger, and Cameroon respectively. Livestock from the parts of these countries are attracted to these zones because of the rich supply of fodder around patches of wetlands of Lake Chad, Nguru and beyond (Bello, 2013).

1.1.3.2 Wood extraction for fuel and construction

Due to inadequate alternative sources of energy in the Sudano-Sahelian zone, demand for fuel wood has been on steady increase by the increasing population and rapid urbanization. Selling of fuel wood has become a very lucrative business and a major source of supplementary livelihood to many families. In addition wood is also exploited for building, arts, crafts, fencing in this area (Mohammed, 2015).

1.1.4 **Methodology**

The method integrating remote sensing, Geographic Information System (GIS) and field survey was employed. Assessment of the rate and intensity of sand dune encroachment using multi-temporal Landsat images (Landsat.TM, 1986, Landsat.ETM, 2000 and Landsat.OLI, TIR, 2016) and GIS. The satellite images were processed by converting raw Digital Number (DNs) values to radiance images which were converted into reflectance images used for spectral analysis.

A combination of MEDALUS.ESA and Image Differencing was adopted for change detection technique. Sandy landscapes were mapped into four (4) natural classes using natural jenks classifier of the ArcGIS analytical tool based on pre-field field determination and post verification. The description of the four (4) sandy landscape classes is as follows:

Active/Mobile: This corresponds to areas with thick azonal soil profile (usually > 50 cm) with >50% active dense moving sand dunes and thick sand sheets) widely distributed over most part of land surface with very sparse vegetation which is <5%.

Semi-mobile: Corresponds to a zone of about 30 – 50 cm azonal soil profile comprising sparsely disperse semi-active sand dunes and thick sandy sheets of about 25 – 50% and vegetation of 5 – 25% over the landscape.
Semi-fixed: This corresponds to a zone with semi-mature/zonal soil profile with about 5 – 25% large sheets of upper layer of moving sand and scattered sandy-bushy heaps with vegetation density of about 25 – 50%.
Fixed: zone of mature/zonal soils with thin upper layer of <5% moving sand sheets. May have stabilized sand dunes and sheets, sandy-bushy heaps and >50% vegetation cover.

Spectral Indices Analysis and Change Detection

The satellite images were processed accordingly for evaluating six (6) spectral indices using empirical algorithm in ArcGIS analyst tool. An aggregate index of each of the six (6) selected indices was evaluated and the long term geometric mean was determined and used for image differencing with the baseline date image (ie 1986). This approach was adopted to minimize over or under estimation that may arise from images due to short term variations that may exist between images captured on different dates even though of the same season as used in this study. The stretch values of the respective image differencing was classified into four (4) based on natural jenks. This was used to estimate the extents for the various sandy landscape classes and also to calculate the mean annual rate and intensity of sandification using the methods of Landis (3001) and Wang (2010) respectively. If the change is increasing then it is positive or if it is towards a decreasing trend, then changes are negative.

The six (6) indices of sandification were analysed as follows:

Crust Index (CI): Developed by Karnieli (1997) which when applied to the remote sensing imagery is used for detecting and differentiating between different lithologic/morphologic units, such as active crusted sand areas, which are expressed in the topography. It is based on the normalized difference between the red and the blue spectral values of the imagery when applied to the remote sensing imagery

CI = B3 – B1/B3 + B1 (for L5-L7 ie TM & ETM

OR

B4 – B2/B4 + B2 (for L8 ie OLI.TIR)

Grain Size Index: The GSI was developed by Xiao (2006) and was specifically designed for using Landsat TM/ETM and recently OLI.TIR data. The GSI is as follows

GSI = B3 – B1/B3 + B2 + B1 (for L5-L7 ie TM & ETM)

OR

B4 – B2/B4 + B3 + B2 (for L8 ie OLI.TIR)

GSI value is close to 0 or a smaller value in vegetated area, and for a body of water it is a negative value. Higher positive values of GSI represent the sand affected region.41 The difference between band R and B in the GSI equation illustrates the difference between vegetated or water surface and bare soil, while the accumulation of the reflectance in the R, G and B bands helps in differentiating the topsoil with different grain size composition.

Normalized Difference Sand Dune Index (NDSDI): This is a new index developed by to identify and assess the existence of the sand dune accumulations and sand spread. NDSDI mainly distinguishes vegetation and non-vegetation, water and arid surface, sandy or bare soil. The suggested index based on the normalized difference between the RED and the short wave infrared (SWIR) spectral values. This index is aimed at differentiating between sand dune accumulations, bare soils, and other types of soil.

NDSDI = B3 – B5/B3 + B5 (for L5-L7 ie TM & ETM)

OR

B4 - B6/B4 + B6 (for L8 ie OLI.TIR

Value of the NDSDI ranges between 21 and þ1, whereas the sand dune accumulations and drifting sands often give values below zero and vegetative cover produces values greater than zero

Normalized Difference Sand Index (NDSI)

The spectral characteristic of sand suggests that the reflectance signals can be obtained using the difference between Band 4 signal, which is high, and Band 1 signal, which is significantly low. This difference distinguishes rather well between sand and other ground features. Considering this strong discrimination possibility, Xin et al (2018) NDSI to detect sand. The NDSI can be written as

NDSI = (B3 – B1)/(B3+B1) (for L5-L7 ie TM & ETM)

OR

NDSI = (B4 – B1)/(B4 + B1) (for L8 ie OLI.TIR)

Obviously, the higher NDSI, the higher the content of sand dominates in a region.

The difference of the reflectance of Bands 1 and 4 for sand is evidently larger than that for soil, whereas the difference of the reflectance of Bands 7 and 4 for sand is similar to that for soil. Therefore, relative to other sand indices designed by other researchers, our index can distinguish the sand from soil better, and it is more suitable for the images of Landsat 8.

Bare soil Index (BSI)

Chen (2004) developed a spectral model for evaluating bare soil. Bare Soil Index (BSI) is a numerical indicator that combines blue, red, near infrared and short wave infrared spectral bands to capture soil variations. These spectral bands are used in a normalized manner. The short wave infrared and the red spectral bands are used to quantify the soil mineral composition, while the blue and the near infrared spectral bands are used to enhance the presence of vegetation.

BSI = (B5 + B3) – (B4 +B1)/(B5 + B3) – (B4 + B1) (for L5-L7 ie TM & ETM)

OR

BSI = (B6 + B4) – (B5 + B2)/(BB6 + B4) + (B5 + B2) (for L8 ie OLI.TIR)

Normalised Difference Soil Index (NDSLI)

This model was developed by Rogers (2004) for detecting a mixed of sand-soil background

NDSLI = (B5 – B2)/(B5 + B2) (for L5-L7 ie TM & ETM).

OR

NDSLI = (B6 – B3)/(B6 + B3) (for L8 ie OLI.TIR)

1.1.4 **Results and Discussions**

Four landscape classes, including active, semi-active, semi-fixed and fixed sand dunes were identified using six (6) different spectral indices. Results showed similar outcomes among the spectral indices in terms of extents, rate and intensity of sandification. Spatio-temporal pattrens on the other hand are very evident among the sandy landscape classes. The implication of this observed pattern is that the semi-arid landscape is very sensitive to both climatic and human factors of sandy desertification inter-annually but steadily over a long term period. The active and semi-active sandy landscapes have persistently increase over the period at expense of the semi-fixed and fixed landscapes. This trend spells serious sandification hazard and risk to graze lands, irrigated lands and rainfed farmlands in the semi-arid zone of Nigeria. The findings of the study is in agreement with the report of Shupel et al (2013) that the coverage of sand dunes has more than doubled from the start year.

Results of sandy desertification based on crusting index in Table1: and also Fig1: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.21 and 1.31 **km^2** and intensity for the of 0.14 and 0.28% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.22 and 1.38 **km^2** and intensity for the period of 0.15 and 0.44 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an an annual rate of 1.38 **km^2** and 0.44% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion.

Results of sandy desertification based on bare soil index in Table2: and also Fig2: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.22 and 1.31 **km^2** and intensity for the of 0.15 and 0.27% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.24 and 1.36 **km^2** and intensity for the period of 0.17 and 0.41 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is being lost at an annual rate of 1.36 **km^2** and 0.41% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion.

Results of sandy desertification based on Normalised Difference Sand Dune Index in Table3: and also Fig3: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.19 and 1.29 **km^2** and intensity for the of 0.13 and 0.25% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.24 and 1.38 **km^2** and intensity for the period of 0.18 and 0.44 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an an annual rate of 1.38 **km^2** and 0.44% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion.

Results of sandy desertification based on Grain Size Index in Table4: and also Fig4: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.22 and 1.31 **km^2** and intensity for the of 0.15 and 0.28% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.20 and 1.38 **km^2** and intensity for the period of 0.13 and 0.44 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an annual rate of 1.38 **km^2** and 0.44% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion.

Results of sandy desertification based on Normalised Difference Sand Index in Table5: and also Fig5: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.23 and 1.30 **km^2** and intensity for the period of 0.16 and 0.27% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.22 and 1.37 **km^2** and intensity for the period of 0.15 and 0.43 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an an annual rate of 1.37 **km^2** and 0.43% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion.

Results of sandy desertification based on Normalised Difference Soil Index in Table6: and also Fig6: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.23 and 1.31 **km^2** and intensity for the period of 0.16 and 0.27% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.21 and 1.37 **km^2** and intensity for the period of 0.14 and 0.42 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an an annual rate of 1.37 **km^2** and 0.42% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion.

Results of overall sandy desertification based on Aggregate Sandification Index in Table7: and also Fig7: indicate that active and semi-active sandy landscapes have progressed steadily at annual rate of expansion of 1.20 and 1.28 **km^2** and intensity for the period of 0.13 and 0.23% respectively. This has caused a corresponding decrease in the semi-fixed and fixed sandy landscapes of 1.24 and 1.39 **km^2** and intensity for the period of 0.17 and 0.47 % respectively. The highest risk of sandy desertification is in the fixed sandy landscape which is be lost an annual rate of 1.39 **km^2** and 0.47% intensity being the highest among other classes. Note that this landscape is characterized by vegetation cover of >50% which could be lost to sandy invasion. The result of this study is similar to that of Liu te al. (2008) that Sandy desertification occurred in the Otindag region of China in the past two decades from 1987 to 2006. The fixed sand dunes shrank, semi-fixed and active sand dunes increased remarkably. Similar observations made by CCICCD (2017) Who reported that from 1990-2000, the area of fixed and semi-fixed sandy land in Maowusu in China has been decreased, while the area of flowing sandy land has increased and desertification expanded; although in their case from 2000-2010, the area of fixed and semi-arid sandy land in Maowusu has increased, while that of flowing sandy land has decreased revealing reversal in the trend of sandy desertification. yan et al also observed expansion of sand dunes in the Ordos Plateau among the mobile, semi-mobile, semi-fixed and fixed sandy landscapes. Lam et al (2011) in California also tracked active sand extension. The study by Pandey et al. clearly depicts the severity of land degradation due to sand spread in the Jhunjhunu district in Rajasthan, representing a threat to the agricultural area and a potential decline in productivities. Increasing land use patterns were affected by the sand encroachment region of India. Several other studies that have reported similar trends in sandy desertification include Maowusu Desert, China (Shiu-Hung,1983), northern Alxa Plateau, Inner Mongolia, China (Yao et al., 2007), Dakhla Oases, western desert of Egypt (Ghadiry et al., 2012), some sites of Iraq (Fadhil, A.M., 2013), western part of

India (Pandey et al., 2013), Rigboland sand sea, central Iran (Ahmady-Birgani et al., 2017),

Coincidentally most of these studies were observed within the last 2 -3 decades and seem to suggest strong influence of climatic variation such as the global rising of sand storms Goudie, 1983).

The findings in this study suggest the need for concerted efforts to control sandy desertification in Nigeria. The present banded pattern, spacing and orientation of shelter belts need to be appraise with regards to their effectiveness in controlling wind erosion and sandy desertification and with a view towards improvement. Implementation of Nature Reserve Construction and the grassland with implementation of grassland ecological protection subsidy incentive mechanism policy.

Rational exploitation and utilization of the resources in this sandy area and developing characteristic sand industry to promote economic development and increase the income of farmers and herdsmen, and also an important way to reverse ecological construction in desert areas. Make full use of the opportunities and resources of the sandy area, to carry out the protective development and utilization, and construct the shrubbery forest, herbs and pasture bases in the sandy areas and develop tourism in sandy areas, develop new economic growth points, harnessing markets for restoration.

Comprehensive control by combining shrubs with grass, biotic measures with abiotic measures, as well as the implementation of artificial afforestation, selection of drought resistant and sand fixing plants, aerial cloud seeding, setting apart sand area for forests, shifting sand fixation, fencing, artificial grass, banned grazing and rotational grazing and protection tillage and other agricultural measures. Adoption and implementation of applicable recommendations, programmes and policies of dryland restoration such as restoring landscapes and livelihoods with economic trees, facilitating farmer managed natural regeneration of trees (FMNR). Mobilizing partnership at the international, national, regional, state and local levels through a vigorous action plan to remediate or mitigate sandy desertification. Nigeria should explore the opportunities offered by AFR100 initiative, the Great Green Wall for the Sahara and the Sahel initiative coordinated by the African Union to reverse sandy desertification in its semi-arid zone.

CONCLUSION

The predominant focus on vegetation as indicator of desertification by most researchers has almost relegated sandy desertification which is one of the most devastating and sensitive eco-geomorphic features of desertification in the semi-arid landscape. It is also one of the most aspects of desertification to remediate.
This is evident when shelter belts may suggest improvement in vegetation cover yet it has not effectively controlled sandy desertification and low land fertility and primary productivity. Spatial pattern of sandy desertification showed that both active and semi-active sandy landscapes have shown persistent expansion and encroachment over the semi-fixed and fixed sandy landscapes causing decreasing trend in their extents, rates and intensities that are higher than increasing trend in the active and semi-active classes in the 30year period (1986-2016) of this study. Several active sand belts have been formed, suggesting that sandy desertification control in the semi-arid zone of Nigeria may be a long-term task. The observation made in this study contradicts the report of Adesina and Gadiga (2014) that shelterbelts have proven to be necessary tool in fighting desertification in the area as they enhance the vegetation status thereby protecting the soil against wind erosion. The result of this study indicates that the natural ecology or vegetation, graze lands, irrigated lands, rainfed farmlands, settlements, infrastructure are at high risk of sandy desertification in the semi-arid zone of Nigeria. This study is also a pointer that the shelter belts have not been very effective in controlling wind erosion and thus sandy desertification. It should be noted that if this increasing trend of sandification is not checked in the study area, it may gradually reach proportions that it could be considered a major eco-geomorphological disaster and a threat to the nation’s economy, food security an issue that is already prominent in the news headlines for long (Olori, 2002) and livelihood of the indigenous inhabitants of this area.

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Table 1. Spatio-temporal Pattern of Sandy Desertification based on Crusting Index (CI)

Status of sandune/sheet	**Extent in 1986 in km²**	**Extent in 2000 in km²**	**Extent in 2016 in km²**	**Change in extent for the period in km²**	**Annual Rate of sandification in km²**	**Intensity of sandification for the period in %**
Active	2575	5085	6289	4161	1.21	0.14
Semi-active	5548	11031	12837	8358	1.31	0.28
Semi-fixed	8155	9348	9644	4448	1.22	0.15
Fixed	14082	4899	1593	13406	1.38	0.44

Table 2: Spatio-temporal Patterns of Sandy Desertification based on Bare soil index (BSI)

Status of sandune/sheet	**Extent in 1986 in km²**	**Extent in 2000 in km²**	**Extent in 2016 in km²**	**Change in extent for the period in km²**	**Annual Rate of sandification in km²**	**Intensity of sandification for the period in %**
Active	2701	5248	7009	4615	1.22	0.15
Semi-active	5848	10787	12771	8279	1.31	0.27
Semi-fixed	7294	8136	7166	5132	1.24	0.17
Fixed	14520	6192-	3417	12347	1.36	0.41

Table 3: Spatio-temporal Patterns of Sandy Desertification based on Normalised Difference Sandune Index (NDSDI)

Status of sandune/sheet	**Extent in 1986 in km²**	**Extent in 2000 in km²**	**Extent in 2016 in km²**	**Change in extent for the period in km²**	**Annual Rate of sandification in km²**	**Intensity of sandification for the period in %**
Active	1866	4173	7560	3834	1.19	0.13
Semi-active	3427	9984	12170	7614	1.29	0.25
Semi-fixed	6041	9930	7040	5432	1.24	0.18
Fixed	19029	6276	3593	13493	1.38	0.44

Table 4 : Spatio-temporal Patterns of Sandy Desertification based on Grain Size Index (GSI)

Status of sandune/sheet	**Extent in 1986 in km²**	**Extent in 2000 in km²**	**Extent in 2016 in km²**	**Change in extent for the period in km²**	**Annual Rate of sandification in km²**	**Intensity of sandification for the period in %**
Active	2623	4984	6268	4463	1.22	0.15
Semi-active	5693	11021	12876	8415	1.31	0.28
Semi-fixed	7882	9146	9546	4080	1.20	0.13
Fixed	14165	5212	1673	13415	1.38	0.44

Table 5: Spatio-temporal Patterns of Sandy Desertification based on Normalised Difference Sand Index (NDSI)

Status of sandune/sheet	Extent in 1986 in km^2	Extent in 2000 in km^2	Extent in 2016 in km^2	Change in extent for the period in km^2	Annual Rate of sandification in km^2	Intensity of sandification for the period in %
Active	2763	6121	7560	4794	1.23	0.16
Semi-active	5919	12043	12170	8065	1.30	0.27
Semi-fixed	7920	7983	7040	4482	1.22	0.15
Fixed	13761	4216	3593	13032	1.37	0.43

Table 6: Spatio-temporal Patterns of Sandy Desertification based on Normalised Difference Soil Index (NDSLI)

Status of sandune/sheet	Extent in 1986 in km^2	Extent in 2000 in km^2	Extent in 2016 in km^2	Change in extent for the period in km^2	Annual Rate of sandification in km^2	Intensity of sandification for the period in %
Active	3053	5584	7688	4887	1.23	0.16
Semi-active	7044	12184	12895	8344	1.31	0.27
Semi-fixed	6921	8202	8202	4289	1.21	0.14
Fixed	13345	4393	4393	12853	1.37	0.42

Table7: spatio-temporal patterns of sandy desertification based on Aggregate Sandification Index (ASI)

Status of sandune/sheet	Extent in 1986 in km^2	Extent in 2000 in km^2	Extent in 2016 in km^2	Change in extent for the period in km^2	Annual Rate of sandification in km^2	Intensity of sandification for the period in %
Active	2623	5037	6282	3875	1.20	0.13
Semi-active	5548	11038	12168	7012	1.28	0.23
Semi-fixed	7391	8215	8249	5123	1.24	0.17
Fixed	14801	6073	3664	14363	1.39	0.47

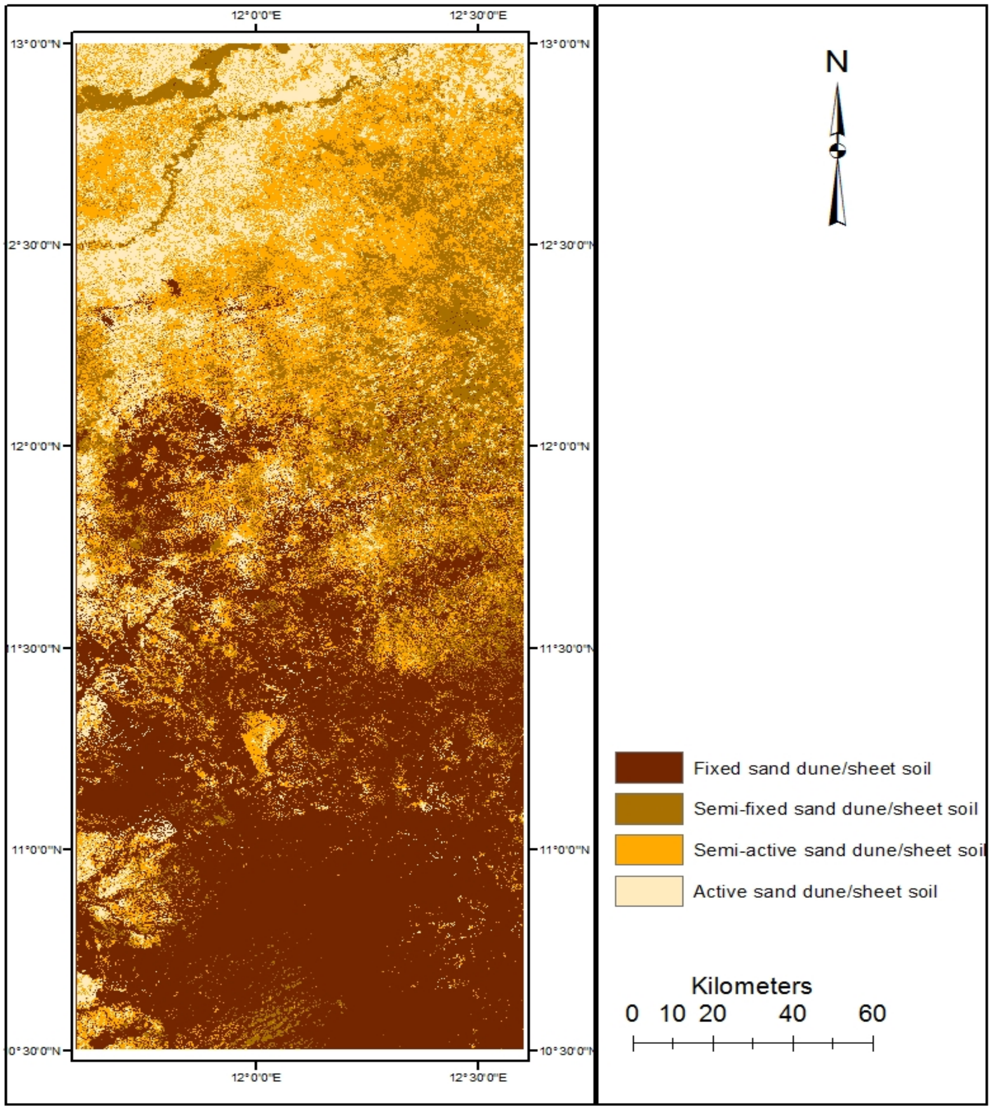

Fig 1: . Spatio-temporal Pattern of Sandy Desertification based on Crusting Index (CI)

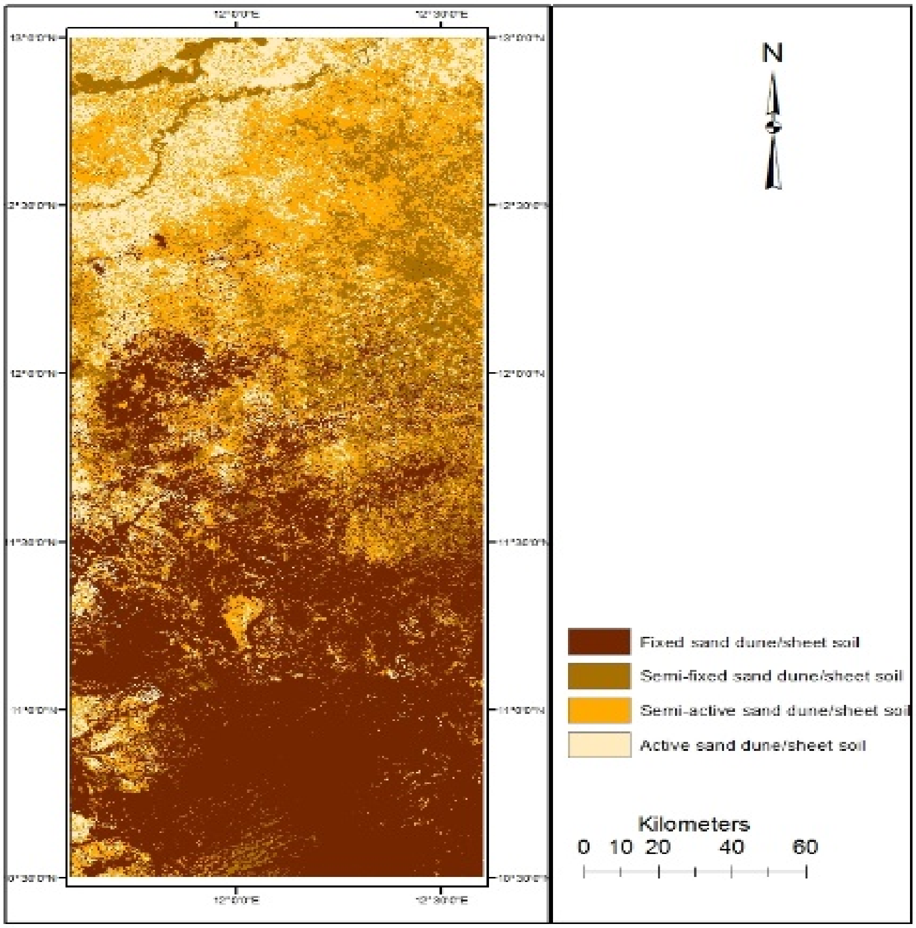

Figure 2: Spatio-temporal Patterns of Sandy Desertification based on Bare soil index (BSI)

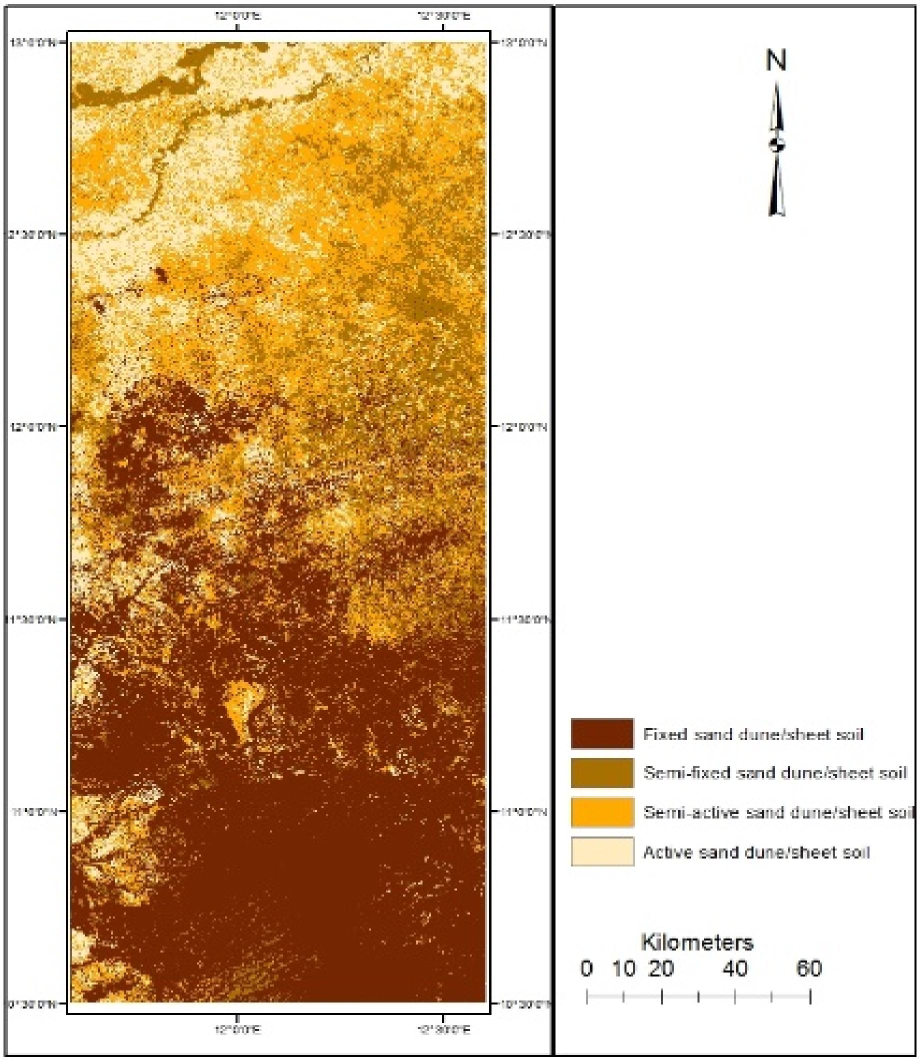

Fig3: Spatio-temporal Patterns of Sandy Desertification based on Normalised Difference Sandune Index (NDSDI)

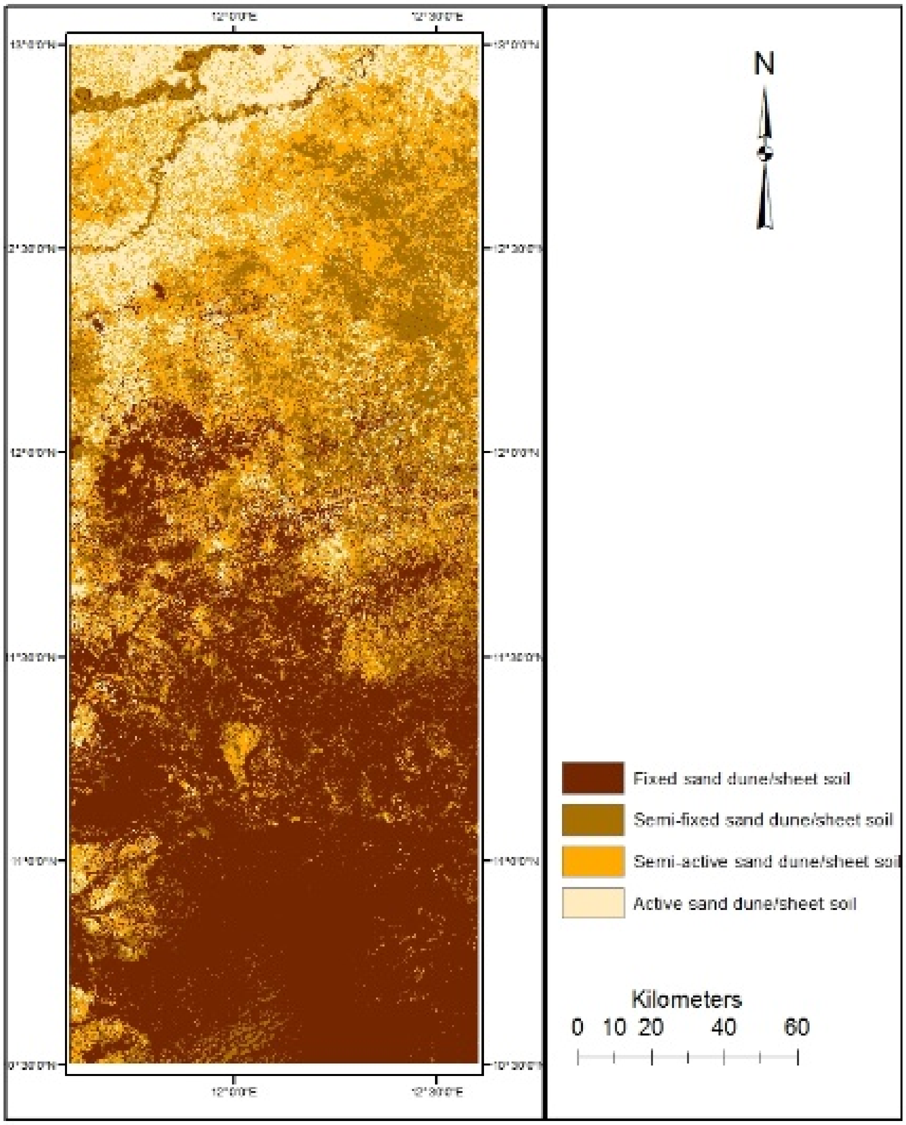

Fig 4: Spatio-temporal Patterns of Sandy Desertification based on Grain Size Index

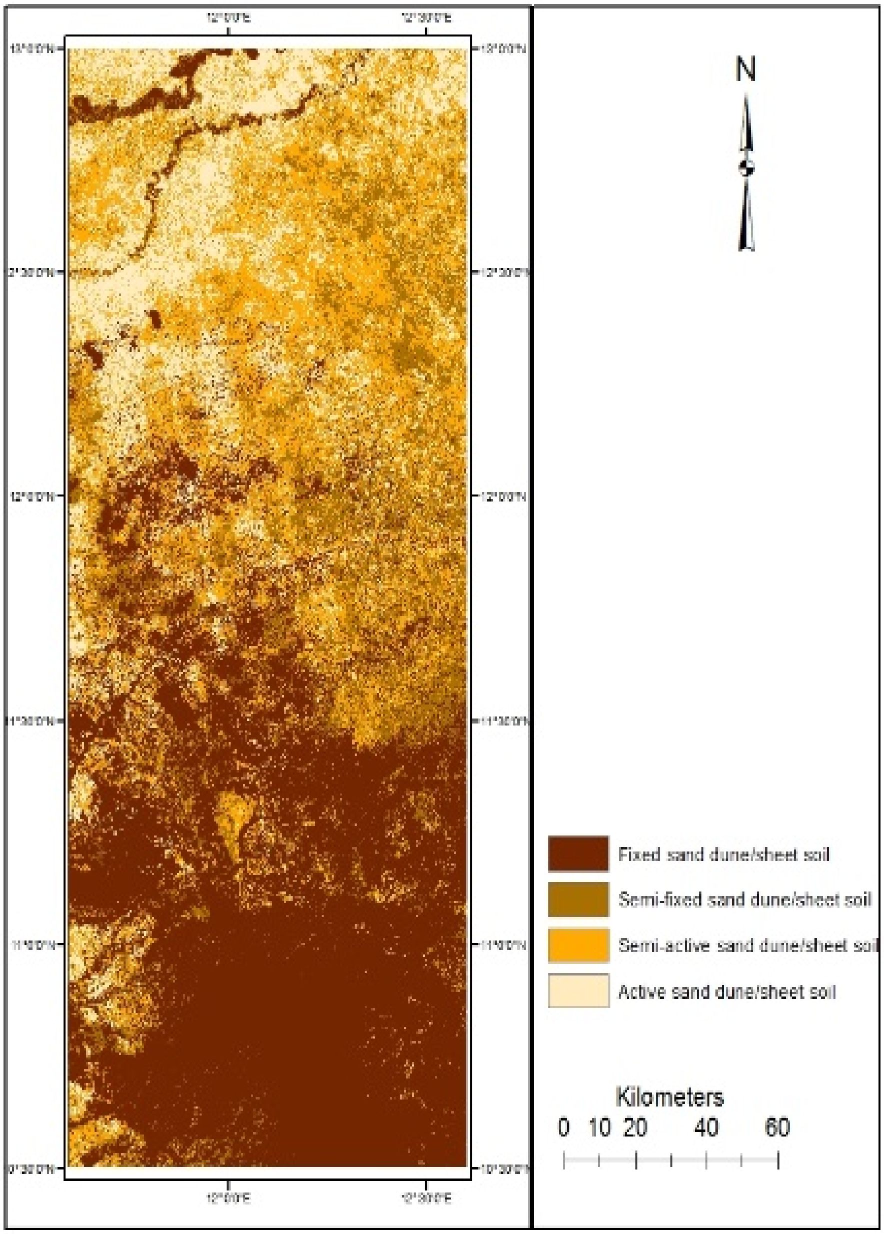

Fig5: Spatio-temporal Patterns of Sandy Desertification based on Normalised Difference Sand Index (NDSI)

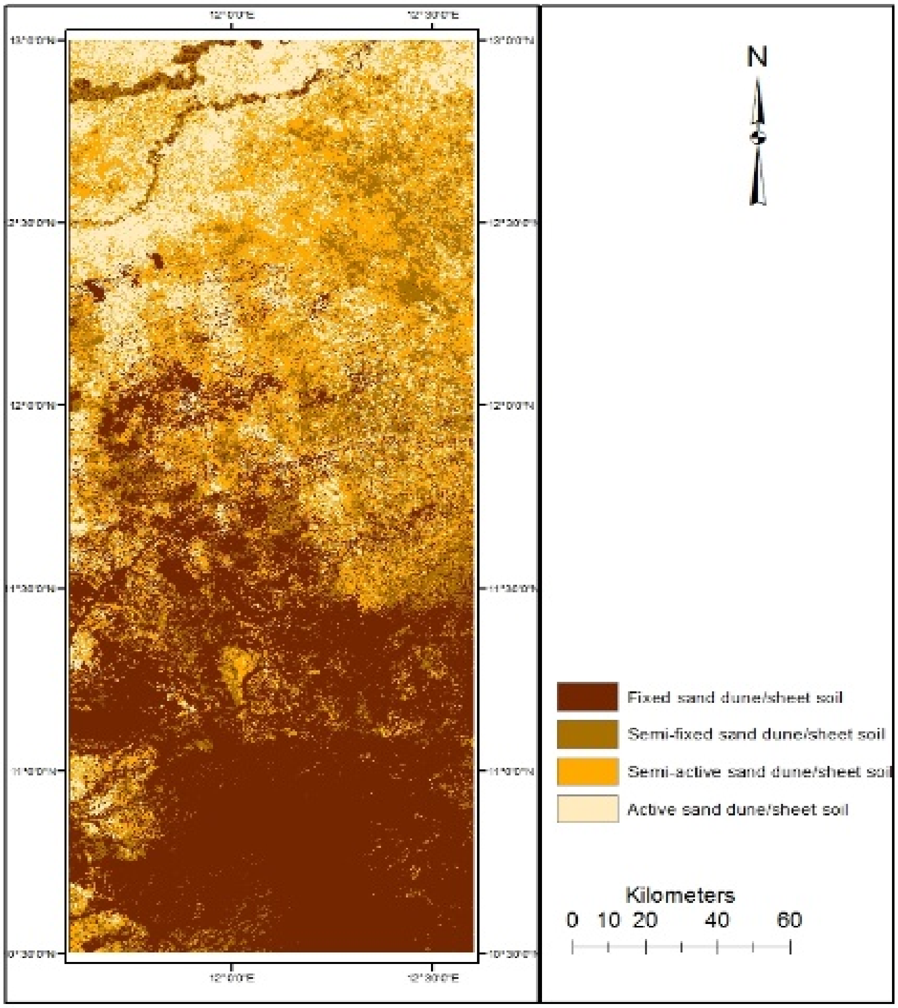

Fig6: Spatio-temporal Patterns of Sandy Desertification based on Normalised Difference Soil Index (NDSLI)

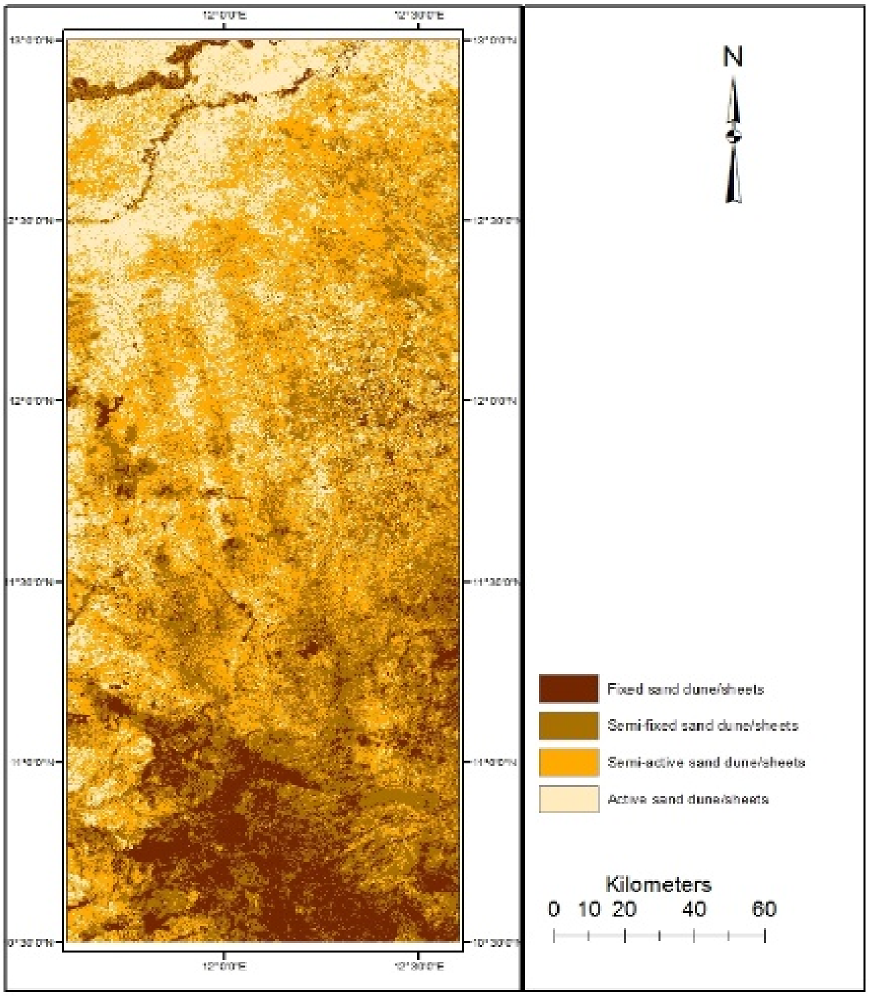

Fig7: Spatio-temporal patterns of sandy desertification based on Aggregate Sandification Index (ASI)