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Quantitative Assessment of Land Cover Sensitivity to Desertification in Maigatari Local Government Area, Jigawa State, Nigeria

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ABSTRACT: Desertification alludes to land degradation in arid, semi-arid and sub-humid regions resulting from various variables, counting climatic variations and human activities. When land degradation transpire within the world's drylands. It regularly makes desert-like conditions. Land degradation occurs all over, but is characterized as desertification when it occurs within the drylands. The study employed adjusted MEDALUS methodology using eleven indicators rainfall, evapotranspiration, aridity, soil texture, soil depth, slope gradient, drainage density, plant cover, erosion protection, sensitivity desertification index and Normalized Difference Vegetation Index (NDVI). Remote Sensing and GIS were the main techniques used in the indices computations and mapping. Thus, Shuttle Rader Topographic Map (SRTM) and Landsat 8 satellite imagery for the year 2019 with 30 meter resolution, captured in the month of August (rainy season), covering the study area were acquired from Global Land cover Facility (GLCF) University of Maryland. The study finds that the duration and intensity of rainfall is declining especially at the edge of the desert, extreme north and western part of the area. Rain quickly drained through infiltration and surface runoff which carried the little nutrients attached to the soil. Rainfall and climate is of arid type recording about 300-400mm of rainfall and the soil is low in organic matter content making it weak and less fertile and support only the cultivation of cereals and legumes. The study recommends that there is need to strengthen the laws and policies in controlling desertification and land degradation, establishment of shelterbelts to control desertification and act also as wind breakers and encourage the use of modern techniques such as drip irrigation to check the rate of infiltration and runoff.

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The French forester Aubreville coined the word 'desertification' in 1949. He used it to define a general degradation cycle beginning with deforestation not necessarily in the drylands and ending in barren land (Aubreville, 1949). He was working in the sub-humid parts of West Africa. The most recent and commonly acknowledged definition is the globally accepted definition of desertification as "`land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities"' (UNCED, 1992). African drylands, like hyperarid deserts, constitute 1959 million ha or 66 per cent of the continent and about one third of the drylands of the planet (UNEP, 1992a). One-third of this region is an uninhabited hyper-arid desert (672 million ha), with the exception of small, and seasonal oasis, artificial lakes and some rivers, but the remaining part accounting for almost two-third covering an estimated area of 1287 million ha of land are arid, semiarid and dry sub-humid areas with an estimated 400 million people (two-thirds of all Africans). According to the UNEP assessment (1991), 1.9 million hectares of irrigated cropland (or 18% of the total area), 4,886 million hectares of rainfed cropland (or 61% of the total area), and 99,508 million hectares of rangelands (or 74% of the total area) in Africa are affected by desertification at moderate or higher levels. Desertification and land degradation are significant environmental problem facing the world today (Eliasson *et al,* 2003). It has extremely damaging effects on agricultural productivity and on ecosystem functioning which ultimately affect human livelihood and standard of living (Eliasson *et al*., 2003; Zehtabian and Jafari, 2002; Eliasson *et al.,* 2003; Masoudi, 2010, 2014; Boer, 1999; Barzani and Khairulmaini, 2013; Masoudi and Amiri, 2015). Almost 25% of the worldwide biomass has been degraded (Boer, 1999) due to the environmental

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factors on multiple scales of time and space, comprehending land degradation needs of multiple scale approach. The study utilized geographic information system and remote sensing to obtained, retrieved and analysed satellite images and field survey data. Several studies indicate that GIS and RS can examine worldly causes and variations in desertification and land degradation, analyze changes between land cover features, create baseline desertification maps, and able to monitor desertification as well. Nigeria is a vast nation with a considerable portion of its area extending into the Sudano-sahelian belt, with, which, together with neighbouring northern Guinea savanna, constitute the dryland of the country, with an estimate populace of 133 million, human pressure on the land especially within the minimal ranges has proceeded to take its toll on the environment, resulting in desertification. Desertification is more serious in the drylands of Nigeria by expanding human endeavors to abuse the assets of the biological zone even with tenacious dry spell. For decades, Nigeria has been handling the issue of desertification in the most ideal way it could, however with little achievement. It is presently clear that the threat ought to be tended to in an all-encompassing way so as to guarantee that the drylands of the nation keep on supporting human and natural resources. The natural causes of desertification include the poor states of the soils, vegetation, geography just as the inborn extraordinary climatic fluctuation as confirm in intermittent drought and anthropogenic causes such as fuel wood extraction, bush burning, marginal land cultivation, poor irrigation management practices and poverty, which have devastating impact on food security, livelihood, economic, social and cultural activities of the affected people. Climatic variations is perhaps the most significant cause of desertification and drought in the dry lands of Nigeria and. The degree of desertification in Nigeria has not been completely established neither the pace of encroachment appropriately recorded.

All things been equal, there is a general accord that desertification is by a wide margin the most squeezing ecological issue in the drylands part of the country (Nigeria). The obvious indication of this wonder is the progressive decline in vegetation from grasses, shrubs and incidental trees, to grass and bushes; and in the last stages, far reaching territories of desert-like sand. It has been assessed that between 50 % and 75 % of Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara States in Nigeria are being hit by desertification. These states, with a population of around 27 million individuals represent around 38% of the nation's absolute land zone. In these zones, population pressure resulting in over grazing and over exploitation of degraded land has triggered desertification and drought. Towns and villages access roads have been covered under sand dunes in the outrageous northern parts of Katsina, Sokoto, Jigawa, Borno, and Yobe States. The main purpose of this work is to quantitatively assess the sensitivity of land cover to desertification in Maigatari Local Government Area of Jigawa State, by using the modified version of the Mediterranean Desertification and Land Use (MEDALUS) method.

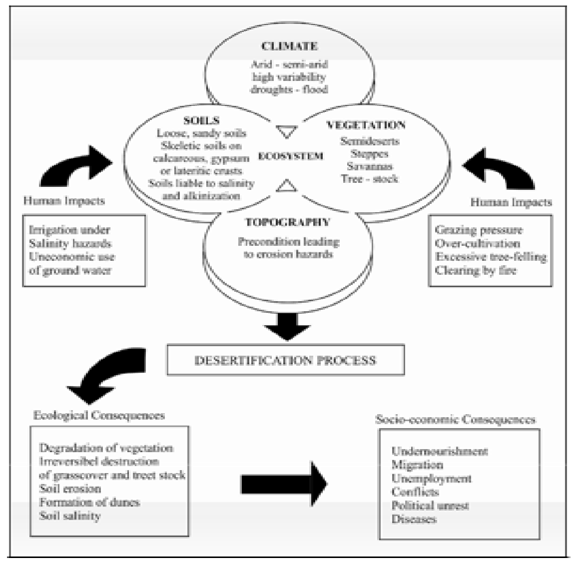

Fig.1. Model of desertification process (Adapted from Ibrahim, 1983).

MATERIAL AND METHODS

The Study Area: Maigatari LGA, is geographically located at latitude 12^0 48’ 26’’ and longitude 9^0 27’ 05’’ located in the northern part of Jigawa State, Nigeria. To the north, Jigawa shares an international border with Niger Republic which is a unique opportunity for cross-border trading activities. Government readily took advantage of this by initiating and establishing a Free-Trade Zone at the Border town of Maigatari (Ahmed *et al*., 2019a). Its headquarters are in the town of Maigatari, with an estimated area of about 870 km^2 and population of about 179,715 (NPC, 2006).

The area has AW Koppens climatic classification with distinctive dry and wet seasons and temperature ranges of 27^0C-35^0C and up to 45^0C in the month of May and as low as 15^0C during harmattan in the months of December and January. The vegetation is of Sahel type with scattered trees dominated by xerophytes, shrubs and grasses. The soil is typically sandy and supports the cultivation of cereals and legumes such as millet and cowpea. (Ahmed *et al*., 2019a; Ahmed *et al*., 2019b)

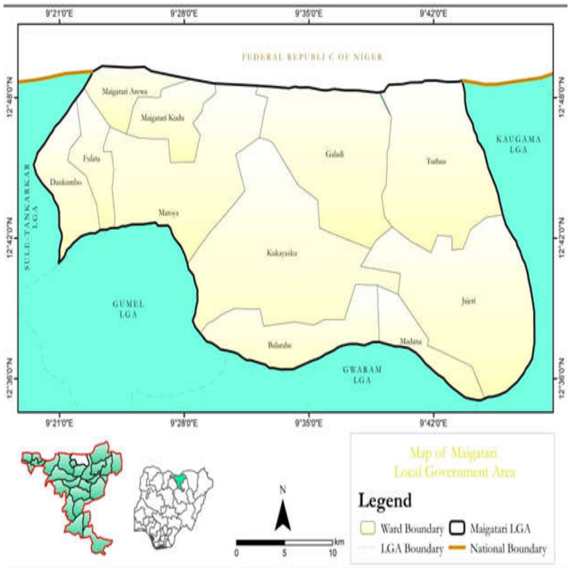

Fig.2. Map of the Study area. Source: Authors' GIS, 2020

Methods: The MEDALUS method was adjusted to be applied to Maigatari LGA using eleven (11) indicators that influence the most in the study area. These are: rainfall, evapotranspiration, aridity, soil texture, soil depth, slope gradient, drainage density, plant cover, erosion protection, sensitivity desertification index and Normalized Difference Vegetation Index (NDVI) (Lamqadem *et al.*, 2018). Remote Sensing and GIS were the main techniques used in indices computations and mapping (Lamqadem *et al*., 2018; Lee *et al*., 2019). Thus: Shuttle Rader Topographic Map (SRTM) and Landsat 8 satellite imagery for the year 2019 with 30meter resolution, captured in the month of August (rainy season), covering the study area were acquired from Global Land cover Facility (GLCF) University of Maryland. Using the "Erdas Imagine 9.2" Software, the landsat imagery was subjected to supervised classification correspondingly to first achieve categorization of the image to a LULC thematic feature to guide and depict the plant cover, erosion protection and drought resistance land used maps respectively. Furthermore, adopting "equation 1", the Landsat imagery was also analyzed for vegetation changes via normalized difference vegetation index (NDVI).

$$NDVI = \frac{(NIR-R)}{(NIR-R)} \qquad 1$$

Where: R and NIR are the red and near infrared bands

The SRTM data using the Spatial Analyst tool in ArcMap (extension of ArcGIS 10.3) was used to extract Digital Elevation Model (DEM) and generated from it the slope gradient map (%). The drainage of the study area was digitized in ArcMap from topographic map retrieved from Ministry of land, housing, urban development and regional planning of Jigawa State. Line Density was then employed to obtain the drainage density map. Rainfall amount and evapotranspiration data of the study area were collected from Nigerian Metrological Agency Abuja (NiMET) and mapped in ArcMap. The maps were subsequently interpolated in ArcMap and merged using raster calculator by employing "equation 2" to obtain the aridity map of the study area. A geo-database of Soil texture and depth was collected from Abuja Geographic Information System (AGIS) and imported in to ArcMap.

$$Aridity = \frac{AP}{APE} \qquad 2$$

Where: AP is the annual precipitation and APE is annual potential evapotranspiration

The 11 indicators were integrated into ArcGIS and each was weighted from 1 to 2 using weighted overlay in ArcMap; the higher the weighting the higher the sensitivity of the land to degradation according to the original MEDALUS method (European Commission-EC 1999), leading to the reclassification of the layers into different classes. The MEDALUS assumes that each index has only a limited capacity to influence the final value of ESAs index, and only when several parameters have a high score, an area can be assigned to high sensitivity class. Three indices of Soil quality index (SQI), Climate quality index (CQI) and Vegetation quality index (VQI) were computed respectively using the relevant indicators classified (equation 3,4 and 5) to yield the subsequent spatial distribution of land sensitivity desertification index (SDI) as a geometrical average of the three quality indices (equation 6). The procedure employed the weighted overlay (spatial analyst tool) in ArcMap environment.

$$SQI = (I_{St} \text{ x } I_{Sd})^{1/2} \qquad 3$$

Where: I_{St} is the index of soil texture, and I_{Sd} stands for the index of soil depth.

$$VQI = (I_{Ep} \text{ x } I_{Dr} \text{ x } I_{Pc})^{1/3} \qquad 4$$

Where: I_{Ep} is erosion protection index, I_{Dr} is drought resistance index and I_{Pc} is plant cover index

$$CQI = (I_{Rf} \text{ x } I_{Et} \text{ x } I_{Ar})^{1/3} \qquad 5$$

Where: I_{Rf} is the index of rainfall, I_{Et} the index of evapotranspiration and I_{Ar} the index of aridity

$$SDI = (SQI \times VQI \times CQI)^{1/3} \quad 6$$

RESULTS AND DISCUSSION

Environmental Indicators for Quality Indices: Most processes relevant to desertification assessment depend upon factors determining changes in climate and soil or vegetation properties which derive pathways to detect from those processes on relevant indicators for desertification sensitivity areas. The following 11 indicators are categorized into climatic, soil and vegetation indicators based on the available parameters quantified in relation to their influence on the desertification process in Maigatari LGA.

Climatic Quality Index (CQI) and Indicators: The spatial-distribution of precipitation and evapotranspiration, and their effects on surface environments, are the most pivotal factors in agriculture and nature (Zhu and Meng 2010). Precipitation is the most significant factor influencing land degradation and desertification, as it controls the seepage and water limit of the soil (EC-European Commission 1999). The average yearly precipitation of Maigatari, via land spread sort, is 350–400mm (Ahmed *et al.,* 2019a).

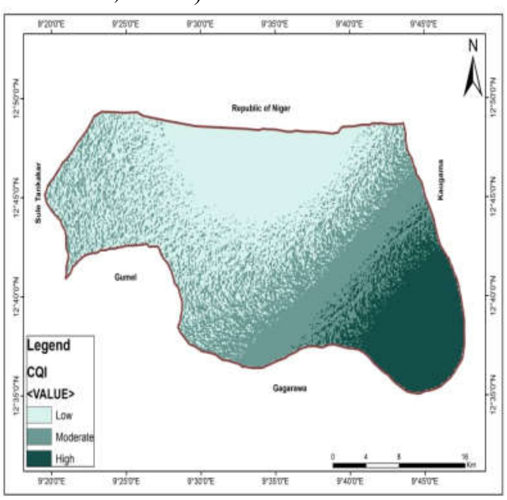

Fig. 3 Climate quality index (CQI): Source: Authors' GIS Analysis

The Aridity Index was determined by yearly precipitation divided by the yearly potential evapotranspiration. Maigatari is situated in the Sahel therefore, evapotranspiration is low throughout the year. When it rains the water quickly drained either through infiltration or surface runoff and the plants are xerophytes in nature require less moisture and are deciduous, shade their leaves in dry season to conserve moisture and there was no any temporary or permanent water body in area (Ahmed *et al,* 2019b)

Climatic Indicators: The rainfall pattern and intensity (Fig.4.) in the area indicates that the rainfall is decreasing from the north and northwestern part of the area and progressively increasing towards the south and southwestern part of the area. Overall the rainfall pattern and distribution is generally low throughout the area recording approximately 300-400mm annually.

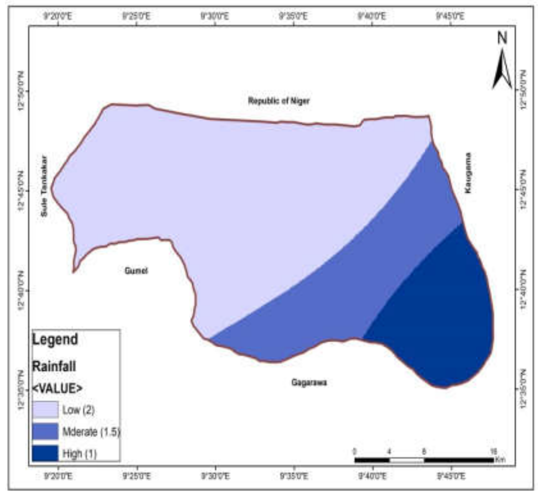

Fig. 4. Re-Classified Rainfall. Authors' GIS Analysis

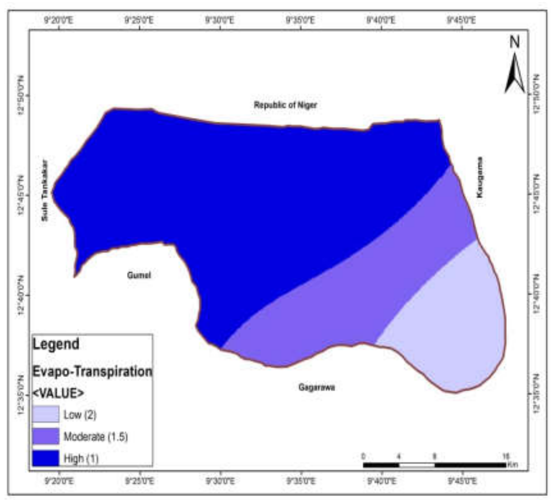

Fig. 5. Re-Classified Evapotranspiration. Authors' GIS Analysis

Owing to its location the area recorded high level of evapotranspiration (Fig.5) with little variation within the area from north to northwest and southwestern part of the area. However, the study area has no permanent water body only temporary ponds during the rainy season which last to about four months. The soil is entirely sandy combined with poor agricultural practices such as tillage which aid evapotranspiration and isolated Sahel vegetation. The aridity index also varies within the study area, although the variation is negligible. The southwestern part of the area is classified as semi-arid (Fig. 6) with improved vegetation compared to the north and northwestern parts of the area where the aridity index is high; this was based on the variation of rainfall received within the area, where the southern part recorded high amount of rainfall compared to the northern part of the area.

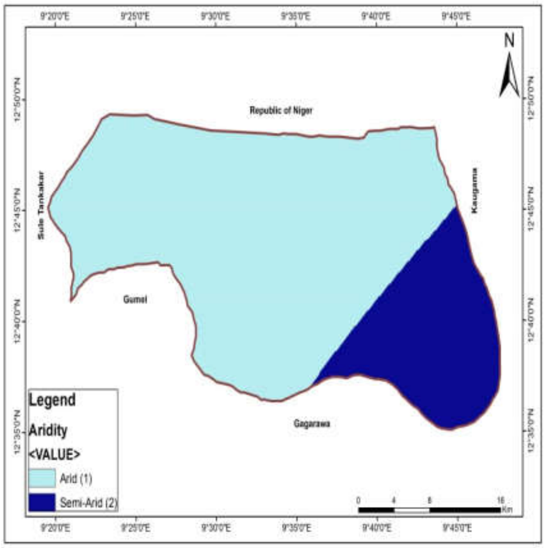

Fig. 6. Re-Classified Aridity Authors' GIS Analysis

organic matter content, with excessive aeolian erosion and surface runoff which wash away the minute organic matter content. The remaining portion at the southern part of the area, the soil contains fractions of sand and clay; due the climatic variations from northern to southern parts of the study area.

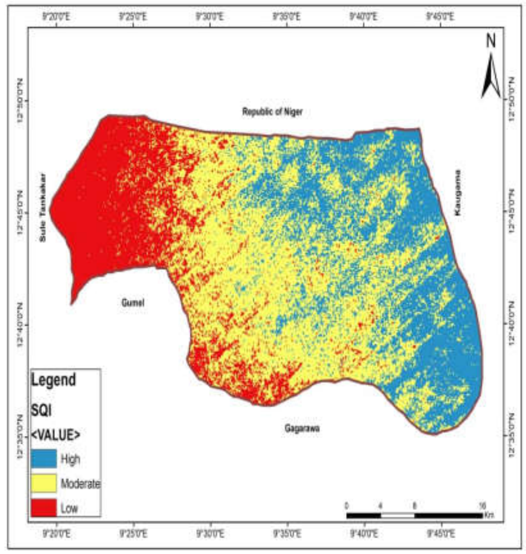

Fig. 7. Soil quality Index (SQI) Source: Authors' GIS

Soil Quality Index (SQI) and Indicators: Soil quality is one of the predominant factors in earthbound agricultural systems, particularly in degraded environments, for example, dry and semi-dry areas (Albaladejo *et al.* 1998; European Commission 1999). The nature of the soil assumes the most essential job in deciding the farming sustainability, ecological quality, and the capability of the land to debase (Doran and Parkin 1996). In this study, the soil quality involved the accompanying four markers; soil texture, soil depth, slope, and drainage. Since the soil quality shifts by area and land type (Seybold *et al*. 1997), every one of the distinctive soil types ought to be evaluated. Soil depth is one of the key components which decide dampness stockpiling and protection limit (Boer *et al.* 1996). Drainage can be one of the significant imperatives that control the soil yield (Abid and Lal 2008). Slope is one of the significant determinants of soil disintegration, which connects straightforwardly to land degradation and desertification.

*Soil indicators***:** Soil texture (Fig.8) refers to the coarseness or finesse of soil particles. Two third of the soil in the area is dominated by sandy soil. The soil particle sizes are about 2mm in diameter especially in the north and northeastern parts of the area. The soil is entirely coarse in nature with high infiltration and evapotranspiration capacity. The soil is poor in

The soil particle size is the immediate determinant of the physical and chemical characteristics in the soils. The texture of the soil influences the properties of soil, for example, pliancy, penetrability, hardness, drought and productivity (Atalay 2006). The sandy soils have poor water retention capacity, yet clayed soils have high. Therefore, the southern parts recording about 400mm of rainfall throughout the year with spatio-temporal differences in vegetation cover within the area. Soil depth (Fig. 9), is the depth of soil profile from the top to parent material or bedrock or to the layer of obstacles for roots. It differs significantly for different soil types. It is one of basic criterions used in soil classification. Soils can be very shallow (less than 25 cm), shallow (25 cm-50 cm), moderately deep (50 cm-90 cm), deep (90cm-150 cm) and very deep (more than 150 cm). Soil depth varies within the study area. The extreme northern part of the area has deep soil (Fig.9) and the trend continues to decline towards the southern part of the area with low organic matter content. Natural additives such as organic matter accumulation in soil give a decent textural development (Mater, 1998). Soil yield as far as soil ripeness, microbial action and water holding capacity of the soil is much significant as organic matter content. At the end of the day, organic matter is one of the significant parameters that bind the soil particles together and reduce the impacts of desertification and land degradation.

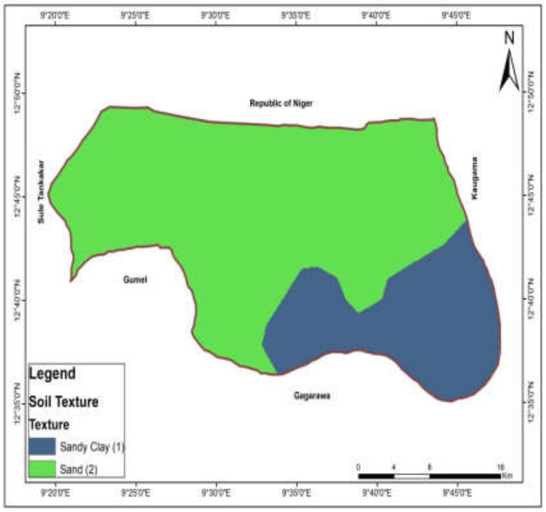

Fig. 8. Soil Texture. Authors' GIS Analysis

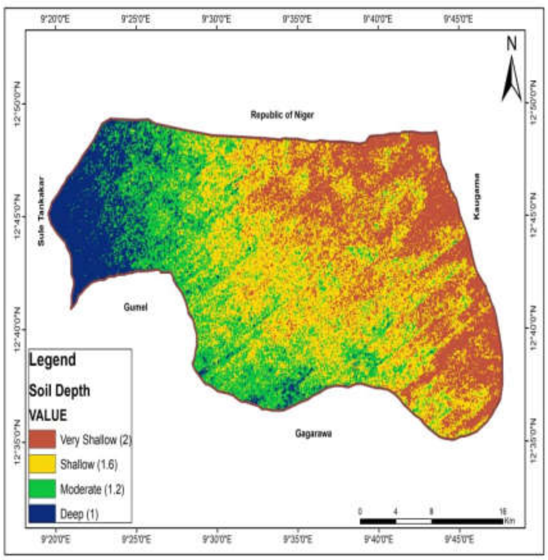

Fig. 9. Re-Classified Soil Depth. Authors' GIS Analysis

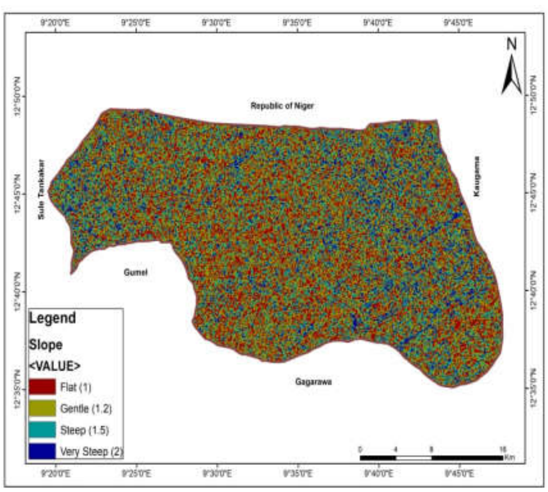

Fig. 10. Re-Classified Slope Gradient. Authors' GIS Analysis

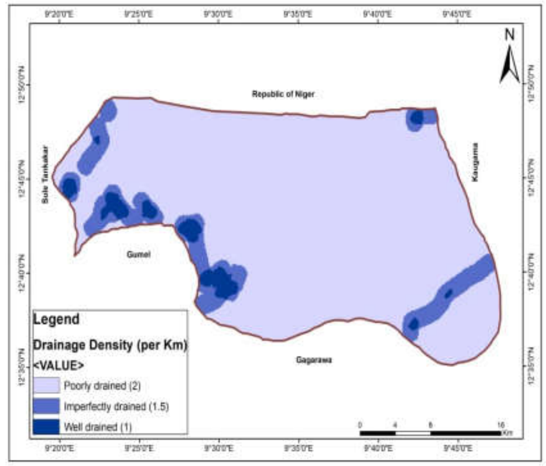

Fig. 11. Re-Classified Drainage Density Authors' GIS Analysis

It has been demonstrated by contemplates that high organic matter sum is a significant quality pointer for erosion and soil degradation (Hacısalihoğlu *et al*., 2017). It is a significant parameter normally utilized particularly in dry and semi-arid climatic regions in soil quality investigations (Vasu *et al*., 2016; Raiesi 2017). There are low sloping lands throughout the study area. Eventhough the land is entirely sandy and flat. Looking at the slope gradient value (Fig. 10) the whole study area is sensitive to desertification. In contrast, the slope values in the western and northeastern of the site are quite high (Fig. 10). Slope values are low in the central part of the site which is seen in the approximately north–south direction. The area is poorly drained looking at the drainage density value and the extent of the coverage (Fig. 11). The area featuring drainage systems that only exists during the wet season around June-August and disappears after September when the rainfall ceases.

Vegetation quality index (VQI) and indicators: Vegetation quality is the prevailing biotic land part (Bryan and Campbell 1986) in evaluating land sensitivity to desertification. In this investigation, vegetation quality is surveyed by erosion prevention and control and plant cover. Land cover is one of the significant elements in assessing land erosion. As per the MEDALUS methodology is concerned, all forest land cover has a higher erosion control rate than bush, shrubs and grassland, and cropland. Plant cover is one of the primary agents of vegetation quality and it tends to be examined utilizing a vegetation index. The Normalized Differentiated Vegetation Index (NDVI) was first proposed by Rouse *et al.* (1974) and it comprises of the proportion between the total and distinction of the Near Infrared (NIR) and red wavelength. In this study, the NDVI is utilized in determining the state of plant cover and the degree to desertification.

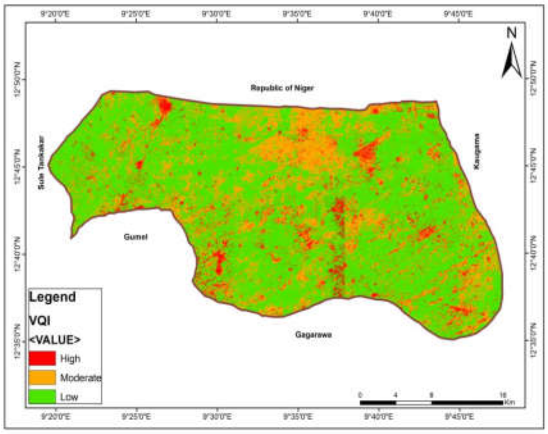

Fig. 12. Vegetation quality index (VQI). Source: Authors' GIS Analysis

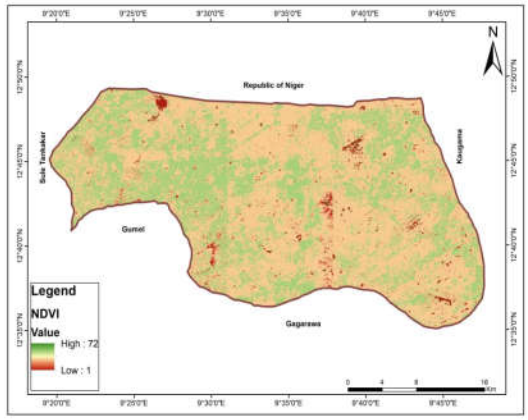

Fig. 14. Normalized Difference Vegetation Index (NDVI). Source: Authors' Remote Sensing Analysis

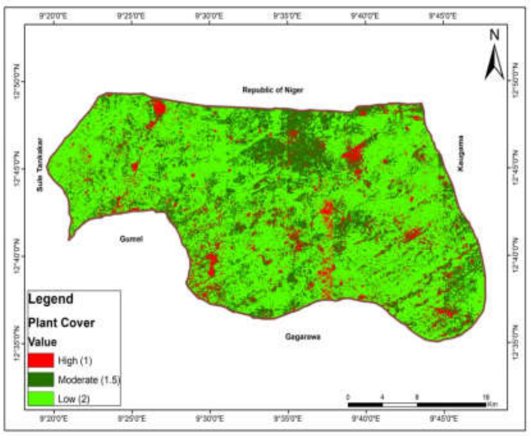

Fig.13. Plant Cover. Authors' Remote Sensing Analysis

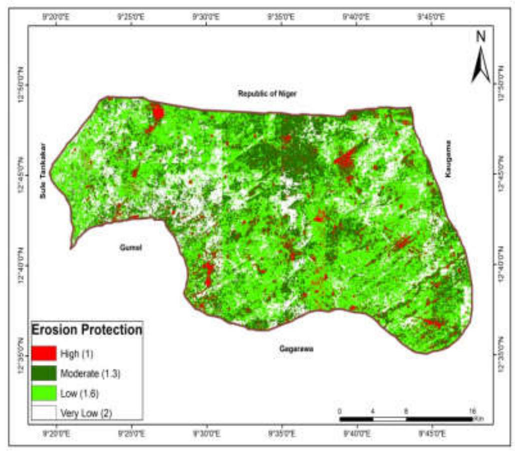

Fig. 15 Erosion Protection. Authors' Remote Sensing Analysis

The vegetation cover is generally scanty and very sensitive to desertification looking at the plant cover value index (Fig.13). However, there is vegetation around settlements and the afforestation that has taken place through various successive governments notably the establishment of shelterbelts to serve as wind breaker and to control erosion and desertification. There were also individual planting of trees in form of agroforestry in various farms and incentives were given to farmers that allow natural regeneration through World Bank assisted project, Jigawa State Afforestation Program Second forestry "JIGAP II" which elapses in 1996. Despite these the vegetation density is very low and sensitive to desertification. Clearing of common vegetation for agriculture, grazing, logging, urbanization, infrastructural and development. Soils and vegetation under the combine effect of drought and over exploitation of marginal ecosystem having been the major anthropogenic handle changing the land cover. The human activities that affect the vegetation cover emerge as a result of population growth and the development of economic activities.

Comparing the erosion protection index (Fig. 15) in the study area signifies that the whole area is prone to erosion with variation in magnitude. The rate of erosion is low around settlements because of the houses, infrastructure and individual tree stands mostly at the houses gate and within the premises which serve as wind breaker and reduce the magnitude of wind erosion especially during the dry season and runoff during wet season. Minor afforestation especially around shelterbelts helps in reducing the rate of wind erosion and runoff. Despite that the whole area is absolutely prone to erosion and desertification due to the absence of vegetation and plant cover. In arid and Semi-arid zones, soils with small or no vegetation cover are uncovered to torrential rainfall occasion, which are characterized by brief lengths and high intensities, and are provoke to the event of physical and chemical forms that change the surface layer conditions, such as surface fixing and crusting. When the surface is dry, a hard pan layer is formed (crust). Crusting soils are ordinary of these regions, where soil degrading is initiated by decreasing infiltration rates and expanding runoff and erosion rates (Ries and Hirt, 2008). The overwhelming land use cover types within the region (study area) are grasslands and croplands. The NDVI (Fig. 14) indicates increment in the disregard of croplands and increase degradation significantly. The nature of agricultural practices combined with climate change and variability results in degraded soil and abandonment of cropland. As a result of that xerophytes such *as Cassia singueana, Guiera senegalensis, Diospyros mespiliformis, Piliostigma reticulatum, Parkia biglobosa, Tapinanthus spp etc take* over in this area which signifies the ongoing process of the desertification. However, this region shows a low NDVI value indicating sparse vegetation cover. About five spectral classes of land use land cover types are identified (Fig. 16). The built-up area indicates that the settlements are dispersed within the area, with two major settlements, the local government headquarters and Bosuwa town, the rest were identified as villages, with little vegetation cover around the settlement and few surviving shelterbelts.

The vast area of land is covered by barelands and farmlands. Barelands are either left for shifting cultivation or the land is unsuitable for agricultural production due to desertification. Water body only exists during wet season in form of temporary pond and drained few months after wet season. In short there is no temporary or permanent pond in the area. Farmlands around settlements are resistant to drought (Fig. 17). Animal dungs, manure and home left over are easily dumped at farms around settlements. Other villages and hamlets keep animals at their farms in herds especially goat, sheep and cattle which directly enrich the soil with nutrients and strengthen the fertility of the soil. Proportionally, the area is generally low in terms of crop resistivity to drought. The study area is exposed and sensitive to desertification (Fig. 18).

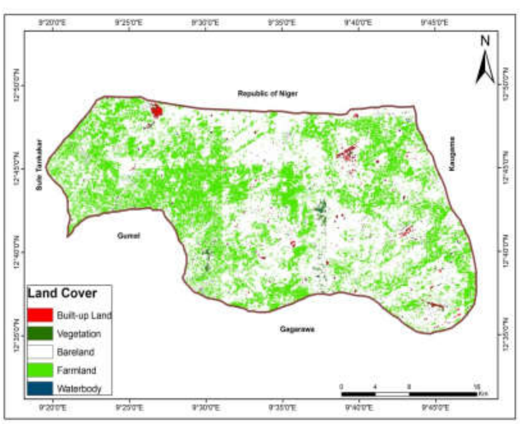

Fig. 16. Land Use Land Cover (2019). Source: Authors' Remote Sensing Analysis

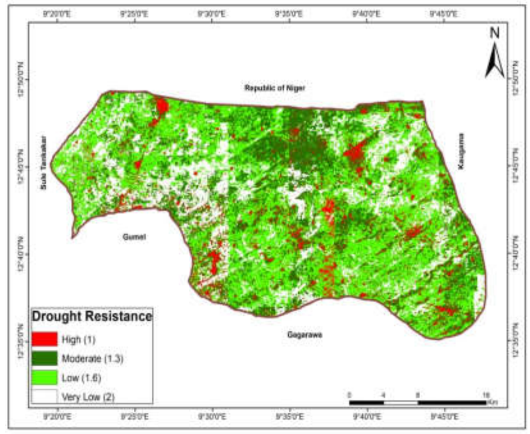

Fig. 17. Drought Resistance. Authors' Remote Sensing Analysis

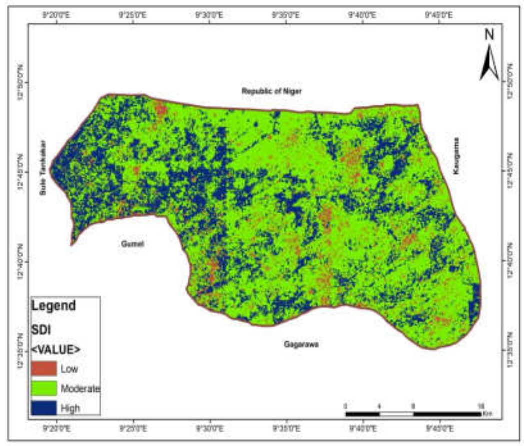

Fig. 18. Sensitivity Desertification index (SDI). Source: Authors' GIS Analysis

The exposure and sensitivity varies within the area. The northern and northwestern parts of the area are more sensitive to desertification and also part of the area that have been degraded most. The central, southern and eastern part of the area shows moderate sensitivity to desertification. The variation is in form of rainfall received and minor difference in vegetation cover compared to north and western parts of the area. Areas that show low sensitivity to desertification are settlements and farms around settlements. Around settlements trees are planted for shade and to protect the direct impacts of sunlight and also serve as a resting place, especially when the sun is overhead. In and around farms trees are planted (Agro-forestry) especially economic trees such Tamarin and xerophytes *acacia spp* along farms demarcations, while manure, animal dungs and home left over can easily be transported to the farm in short period of time.

Conclusion: Desertification is of both natural and anthropogenic in origin, any measure must bargain with the issues of economic development, particularly the development of agriculture. Desertification, negatively destroy the fertility of the soil and making it only support the cultivation of cereal crops and legumes that require micro-nutrients and less moisture. Strengthen of institutional capacity and policies can help in reducing the menace of desertification in the area. Based on the findings the study recommends the following (1) Establishment of shelterbelts across the north and western part of the study area. This can help in checking desertification and also improve the soil fertility and quality. However, the shelterbelts can act as wind breakers to check wind erosion and dangerous wind from the Sahara desert that destroy crops. (2) Government should strength the institutions and policies toward desertification and environmental degradation to campaign and punish fuel wood extraction activities which trigger and exacerbate the combine impacts of desertification and climate change. (3) Farmers should adopt improved agricultural technologies. Such as drip irrigation to minimize moisture loss and infiltration. And also include adoption of new technologies, planting improve and early maturing varieties especially millet, sorghum and cowpea. (4) Delayed farm clearance until the middle of rainy season in order to reduce erosion of the exposed soils by the often heavy showers of the first rains, this should be encouraged.

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