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SPATIO-TEMPORAL ANALYSIS OF SAND DUNES MIGRATION IN THE BULATURA OASES SECTOR OF CHAD BASIN NATIONAL PARK, NIGERIA

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Abstract

The Bulatura Oases Sector of Chad Basin National Park is the only portion of Nigeria's National Park showcasing sand-based ecotourism. Despite its 54 years functional existence, no information abounds on dune's location, distribution and migration hence the need for this study to provide the missing information to enhance effective ecotourism planning, infrastructural development, environmental management and desertification control in the last 2 decades. The study seeks to (i) assess sand dune's locations in 2003, 2013 and 2023 (ii) determine dune's distribution patterns over the above stated time periods and (iii) assess dune's migration pattern in the study area using geospatial analytical techniques to analyzed primary data obtained from google earth imageries. The result shows that in 2003, dunes were more in the northern, south-central and south-western parts of the study area compared to the extreme south-south. In 2013 and 2023 however, dunes were more concentrated in the northern and central parts with more dunes in the south-east of Kukatatawa in 2013 compared to 2023. Dune's distribution pattern observed were dispersed in 2003 and clustered in 2013 and 2023 with the number of dunes being 182 in 2003, 574 in 2013 and 440 in 2023. The average migration pattern from 2003-2023 was 35.95m^2/year in the N-S, E-W and W-E directions. The study concluded that although ecotourism infrastructures in the study area are not severely threatened however, they should not be centralized but strategically located

according to dune's migration direction to avoid redundancy. The study recommended the stabilization of sand dunes to mitigate its threats on ecotourism infrastructures in the study area.

Key words: Spatial, Temporal, Analysis, Sand Dunes, Migration, National Park.

1.1 Introduction

Wind erosion is a key process governing land degradation in drylands which makes their management very difficult [7]. In arid and semi-arid ecosystems, Sand and Dust Storms (SDS) are lower atmospheric events that result from wind erosion, liberating sediment from the earth's surfaces which eventually become dust and dunes [32]. Historical evidence has shown that since the documentary of Gore in [15] till 2024, arid land keeps expanding due to draught and desertification. As arid lands continue to increase, sand dunes being a strong indicator of draught and desertification also increases its spatial extent due to its migration [10]; [17]. In Nigeria, Olagunju, [27] used the desert encroachment experience of the 15 northernmost states which ranged from moderate to severe to illustrate the cause of about 580,841km^2 landmass that may have been lost to desertification leading to dunes formation. Although several desertification studies [22]; [2]; [10]; [1]; [17] have confirmed dunes presence in northern states like Sokoto, Jigawa and Yobe, particularly around Bulanguwa, Machina, Karasuwa, Yusufari, Yunusari, Geidam, Kanama Degeltura and Gashua in Yobe state however, their spatial locations, distribution and migration pattern in protected areas have not been researched upon. In these and many other locations, sand dunes competes with human for agricultural land, hindering land resources extraction, displacing human from their original and preferred settlements, bury infrastructure (roads and power plants), human assets and investment (buildings and farms), silting water bodies, shrinking desert oases, flora and fauna [20]; [28]; [21]; [9]; [1]. Due to the aforementioned, the situation had been worsened in recent time due to desertification, global warming and climate change hence the need for this study in the Bulatura Oases Sector of Chad Basin National Park where sand dune ecotourism is practiced.

The Bulatura Oases Sector of Chad Basin National Park is the only portion of Nigeria's National Park that has and showcased sand dunes for ecotourism [6]; [26]. Effective ecotourism planning in the study area required basic and essential dune's information like the locations, distribution and migration patterns to ensure proper installation and building of ecotourism infrastructure and equipment which would help to increase tourist satisfaction and sustained patronage. Since the above-mentioned geomorphological data are currently not available, ecotourism infrastructures like roads, buildings and power plants in addition to agricultural lands, human settlements, water bodies and biodiversity in the study area are therefore at the mercy of the prevailing wind direction which trigger an early destruction, deterioration and submergence [26]. Furthermore, a National Park is a pronounce ecotourism destination. Accurate determination of dune's locations, distribution and migration pattern in the Bulatura Oases Sector of Chad Basin National Park is necessary because dunes concentration in the core zone would imply maximum threat to desert oases and minimal utilization for ecotourism since the core zone is exclusively preserved for research and ecological restoration. Optimal dunes utilization for ecotourism would requires their strategic distribution in the buffer and transition zones where ecotourism activities is intensive. In spite of the role of research to provide answers on dune's locations, distribution and migration pattern in the study area however, non-have been done. The few available related researches in Nigeria, Yobe State and Yusufari LGA where the study area is located are mostly concentrated on draught [11], desertification [17]. socio-environmental destruction [1] or sand dune stabilization [33].

This study will therefore help to provide promising information needed for effective ecotourism planning, ecotourism management, infrastructural development planning, disaster mitigation and desertification control in the study area for the last 2 decades, in line with the Conservator General's 2024 ecotourism review policies for Nigeria's National Parks. The study will also scientifically provide valid findings based on historical satellite imageries of 2003, 2013 and 2023 acquired from google earth and analysed in Geographic Information System (GIS) using geospatial analytical techniques to enhance reliability and credibility of the findings.

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2 Literature

2.1 Spatial Location of Sand Dune

Spatial location of sand dunes refers to the different locations on land or seascape where dunes can be seen and identified. It could also be viewed as the different portion of a study area where sand dunes are found. [14] studied the global distribution and morphology of Dome dunes using google earth imageries and literature. The result shows the locations of 32 different mega sand dunes in different parts of the globe. In the USA, the spatial extent of the Palen sand dune in Southern California desert changes location between 1984 - 2011 [28]. [19] assessed inland dunes of North America using remote sensing and land survey method. The result reveals dune's spatial locations in the North slope of Alaska, in the Sonoran Desert in northern Mexico, in the east of Delmarva Peninsula and in the west of Southern California. Around the Mediterranean, [12] determined the contribution of sand dune potential sources using radionuclides, trace and major elements in central Iran using meteorological data in combination with field survey and sand sample collection. The results show that dunes were spatially located in the south and the south-western part of Ashkzar erg in central Iran. In Nigeria, [1] assessed and studied the perception of the locals about sand deposits induced desertification in Sokoto State using ASTER image and primary data obtained from questionnaire and FGD. The result shows that sand dunes were spatially located in Illela, Gada and Tangaza LGAs of Sokoto State. Finally, [17] assessed desertification in the Sahel region: a product of climate change or human activities in Yusufari and Yunusari Local Government Areas of Yobe State from 1990-2015 using remote sensing techniques. The result shows that dunes were spatially located in the study area.

2.2 Sand Dune Distribution Pattern

Over different time periods, dunes in any given location tend to assume different distribution pattern in accordance with the prevailing wind. In Asia, [31] studied the geomorphology of sand dunes in the Taklamakan Desert of China based on ERA5 reanalysis data. It was observed that the spatial distribution of sand dune ranges from near irregular cluster to irregular disperse pattern.

[30] studied the spatial distribution of sand dunes and their relationship with fluvial systems on the southern margin of the Taklimakan Desert, China using google earth imageries. The result shows a linear regular clusters and irregular dispersed distributions. In south America, [13] studied parabolic dunes distribution, form, morphology and change using google earth and digital globe imageries. The result shows a regular clustered, irregular clustered to irregular dispersed spatial distributions of parabolic dunes in the west, central and eastern parts of the white sands in New Mexico, USA [13]. From the north of Rock Springs, Wyoming, USA, the distribution pattern was irregularly dispersed [13]. Around the Mediterranean, [29] monitored sand drift potential and sand dune mobility over the last three decades in the Khartouran Erg, Sabzevar in North-East Iran using meteorological and field data. A clustered and dispersed spatial distributions in the east, north-east and west of the study area were observed. [21] also showed the spatial distribution of sand dune in multi-temporal (2013 and 2016) google earth imageries in an attempt to illustrate their migration pattern in the Mesr erg of Iran. The result shows an irregular clustered to irregular dispersed distribution of sand dunes in different parts of the study area. Finally, in Africa, [8] assessed sand dunes mechanisms, impacts and control measures in Sudan using Remote sensing and GIS methodology. The result shows isolated irregular clustered and dispersed distributions of sand dunes.

2.3 Sand Dune Migration Pattern

Wherever sand dunes occur, they tend to migrate over time and this movement is responsible for most of the damages caused by sand dunes hence the need to monitor their migration patterns. Globally, [13] studied the form, morphology, global distribution and change of parabolic dunes using google earth and digital globe imageries. The result shows an average migration pattern of 4.2m/year in different directions with different level of threats for different regions of the world. In the United State of America, [28] analyzed desert sand dune migration patterns from Landsat image time series for the southern California desert between 1985 - 2014. The result shows a migration pattern of 50m/year between 1984 - 2011 in the SW-NE directions which presents a serious threat to existing Solar power plan in the region. [3] monitored and analyzed sand dune movement and growth on the Navajo Nation, Southwestern United State using surface mapping

and remote sensing. The result shows a migration pattern of 35m/year in the S-NE direction between 1953-2010. In the Sanlongsha dune field of the northern Kumtagh Sand Sea of China, [34] monitored the migration of barchan dunes and factors that influence migration using remote sensing and field data. An average annual migration pattern of 30.56m/year was recorded in the NSE-SSE directions with no significant threats on the adjourning settlements and infrastructures. In Central Europe, [18] examined sand sources and migration of the dune fields in the central European sand belt using pattern analytical approach. The result shows a migration pattern of 2m/year in the N-E, N-SE and E-ESE directions.

In Australia, [5] assessed the migration of limes-sand dunes in Western Australia and their impacts on geohazard along the Mid-West coast of Western Australia using remote sensing, GIS and maps from 1960 to 2010. The result shows an average annual migration pattern of 11.2m/year in the N-E direction with minimal impacts on geohazard along the Mid-West coast. Around the Mediterranean, [21] analyzed sand dunes migration patterns in Mesr Erg Region of Iran using multi-scale approach (Satellite imageries, google earth Imagery and weather data). Dune migration result from multi-temporal (2013 and 2016) google earth imageries shows an average pattern of 8m/year in the NW-SE, N-S and W-E directions which threatened infrastructure and human settlements in the region.

In north Africa, [16] studied morphological characterization and the movement of Barchan dunes in the Southeast of Egyptian western desert using multi-temporal google earth imageries. The result shows a dune migration rate of 6.5m/year in the SSW direction which signified serious danger to the adjourning infrastructures and agricultural lands. In the In-Salah region of the Central Algerian Sahara, [4] used climatic data and satellite imagery to assess aeolian sand deposit and barchan migration. The result shows an average annual migration pattern of 12.5m/ year in the N-NE and S-NE directions. In central Africa, [9] analyzed sand dunes accumulation in the Northern State of Sudan using remote sensing and GIS from 2000 -2018. The result shows a migration pattern of 3.75km/year between 2000-2018 in the N-NE directions which threatens infrastructure in the vicinity. In west Africa, [17] assessed desertification in the Sahel region of North-Eastern

Nigeria using multi-scale approach (Satellite and google earth imageries between 1990 – 2015). The result of dune migration from google earth shows mean annual pattern of 15.2 km/year in the N-SW direction signifying a serious threat to agricultural lands, infrastructure and human settlements. None of the above stated research was done in a protected area in general or a National Park in particular hence the need for this study to ensure the safety of ecotourism infrastructure and/or facilities in the study area.

3.0 Study Area and Methodology

3.1 Study Area

The Bulatura Oases Sector of Chad Basin National Park is a 92km^2 land mass. It is located in Yusufari Local Government Area (LGA) of Yobe State -Nigeria toward the extreme North-eastern corner. It is situated between Latitude 13°7'00"N-13°21'30"N of the equator and Longitude 11°11'20"E - 11°13'50"E of the Greenwich Meridian [6]. It is dominated by series of potash-rich oases separated by scenic sand dunes [6]; [25]. The climatic condition in the study area is characterized by eight to nine months of dry season (October-May) with three to four months of wet season, starting from June and September [10]. Scanty rainfall, averaging 300mm with a minimum of 19°C, mean of 37°C and highest temperature of 44°C have been recorded. These climatic conditions encourage soil lessening which increase their erodibility while the undulating relief of between 304m- 361m [11]; [10] encourages sand dune formation. The soils in the study area are predominantly loose and sandy with some elements of clay, Aeolian sands, beach sands and gravels, lacustrine sands and ancient alluvium which make them easily erodible. The scanty interspaced draught resistant shrubs, herbs and grasses in the study area serves as wind break. These vegetations helps to break the fine-sand-laden wind blowing across the study area leading to the formation of dunes.

Yusufari LGA where the study area is located shares borders to the north with the Republic of Niger, Yunusari LGA to the North-east, Machina LGA to the West, Karasuwa LGA to the south-west and Borsari LGA to the South-east as shown in Figure 1. In 2023, the National Bureau of

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Statistics (NBS) asserted that the population of Yusufari grew by 60.5% from 125,821 in 2006 to 201,948 in 2023 based on the National Population Commission (NPC) 2006 projections [23]. The people of this Local Government Area are largely members of the Hausa, Kanuries, Tangali, and Fulani ethnic division whose main economic activities are agriculture and commerce [11]; [26].

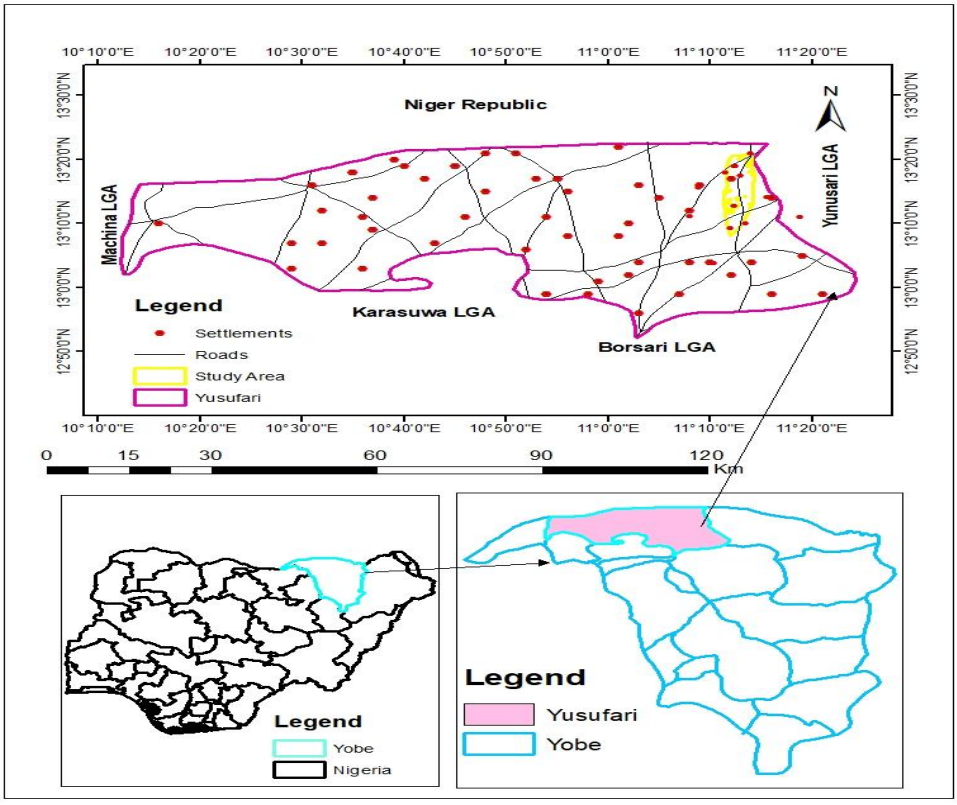

Figure 1: Study Area
Source: Field Survey.

3.2 Methodology

The coordinates of the study area were obtained from boundary demarcation exercise of the Bulatura Oases sector of Chad Basin National Park. These coordinates were compiled in Microsoft excel CSV comma delimited file format, imported into ArcGIS 10.8, converted to shapefile and used to create the study area shapefile. The study area shapefile was overlaid on a scanned and georeferenced Topographic map of Yobe State to verify the accuracy of the study area shapefile

created. This shapefile was thereafter exported from ArcGIS 10.8 to personal computer (PC) and imported into google earth pro (satellite) to accurately identify the study area in google earth image. Chad Basin National Park needs historical data on sand dune distributions in the last 2 decades to improve and enhance ecotourism planning and infrastructural development in the study area hence the choice of 2003, 2013 and 2023. Historical time adjuster of google earth satellite was used to adjust the satellite coverage and imageries of 2003, 2013 and 2023 were captured. Accuracy assessment was done by visiting the study area and collecting the coordinates of 12 random dunes. These dunes were used as Ground Control Points (GCP) and their coordinates were collected with the help of a Global Positioning System (GPS). These GCP located about 100m away from each and were used for the purpose of ground truthing.

Dune's locations in 2003, 2013 and 2023 google earth imageries were identified using a point place marker and the coordinate of each dune was collected and saved in Microsoft excel as CSV comma delimited file with each year having a different file. These CSV files in decimal degrees were imported into ArcGIS 10.8, converted to shapefile and used to create a comprehensive map of sand dune's locations for each period as shown in Figure **2** (**a**, **b & c**). Sand dune's distribution pattern over different time periods were obtained in ArcGIS 10.8 from the dunes location maps using Average Nearest Neighbourhood analysis (ANN) for each time period as shown in Figure **3** (**a, b & c**) while their migrations pattern was obtained by measuring dune's leading edges between 2003 - 2013 and 2013 – 2023.

The outline of each dune identified in google earth using a point place marker was digitized as polygon and saved in google earth in a kml file and folder with each year having its own files and folders as shown in Figure **4** (**a, b, c & d**). These kml folders containing files created for 2003, 2013 and 2023 were exported from google earth to personal computer (PC) and imported from PC to ArcGIS 10.8. The kml folder for each year was converted separately in ArcGIS to shapefiles using Arc tool box converter to enhance map overlay analysis as shown in Figure **4** (**e, f & g**). Dunes in 2013 were overlaid on dunes in 2003 while dunes in 2023 were also overlaid on dunes in 2013 as shown in Figure **4 e, f & g**. Twelve (12) dunes in 2013 that migrated farther than their nearest neighbours in 2003 were selected from different directions (3 each from the north, south,

east and west) and the differences in the distances between these 12 selected dunes and their nearest neighbours were calculated using a distance calculator in ArcGIS. The difference between the edges of the 12 selected dunes in 2013 and their nearest neighbours in 2003 constitute the leading edges of dune for 2003-2013. The differences in the values of these 12 leading dunes and their nearest neighbours were summed and divided by the number of dunes selected to obtain the mean values of the leading edges. This value represents the average distance for which the 2013 dunes lead their counterparts in 2003. The same process was repeated for 2013-2023 and the mean value for which the 12 selected dunes in 2023 leads their nearest neighbours in 2013 was obtained and tabulated. The result from the average leading edges of the 12 reference dunes in each time periods (2003 - 2013 and between 2013 – 2023) were used to compute the migration pattern over the two reference time periods. From the results obtained, the average annual migration distances, speed and directions over different time periods were determined as shown in Table 1.

4.0 Results and Discussion

4.1 Spatial Locations of Dunes Over Different Time Periods

Figure 2 shows the spatial distributions of dunes in (**a**) 2003 (**b**) 2013 and (**c**) 2023 in the study area using ArcGIS.

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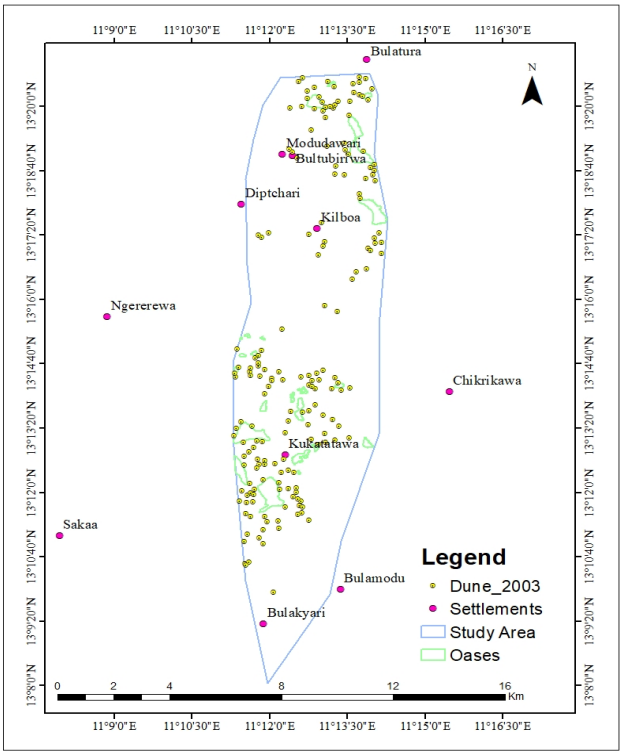
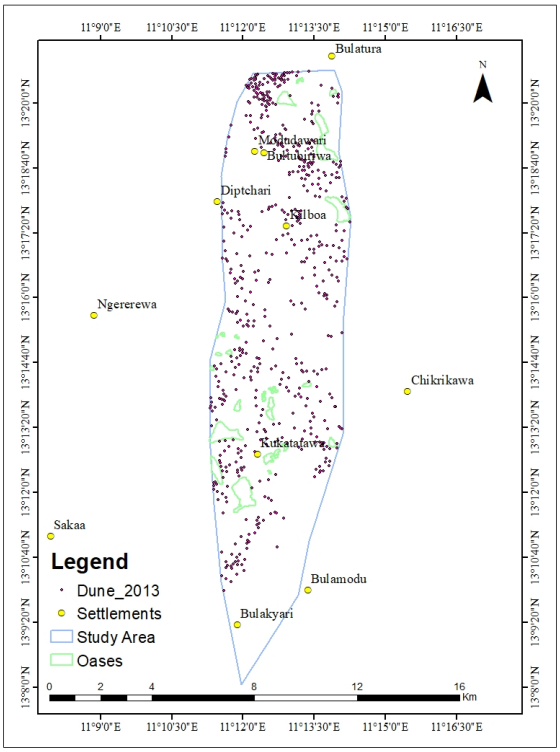


(**2a**) Spatial distribution in 2003



(**2b**) Spatial distribution in 2013

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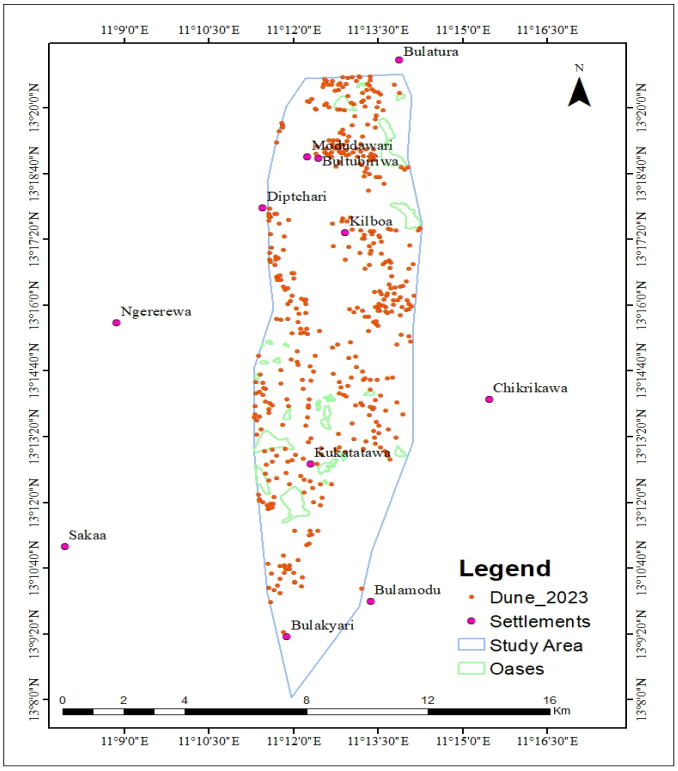

(**2c**) Spatial distribution in 2023.
Source: Geospatial Analysis.

It was observed from Figure **2a** that in 2003, dunes were more spatially concentrated in the north of Modudawari and around Kukatatawa compared to the south of Kilboa and Diptchari. In 2013 however, the spatial concentration of dunes in the southern part of Kilboa and Diptchari increased compared to 2003 as shown in Figure **2b** with the Bulakyari region having no dune. In 2023 however (Figure **2c**), dune's locations were similar to what was observed in 2013 with the central part of Kilboa and Diptchari being less spatially populated compared to 2013. These results agree with [30] and [34]. The distribution of dunes in the study area implies that for maximum utilization, ecotourism infrastructures should be located in densely populated dune areas. Dune's locational studies is essential for ecotourism planning and infrastructural development planning which helps to increase tourists' patronage, revenue generation and sustainable ecotourism in the study area.

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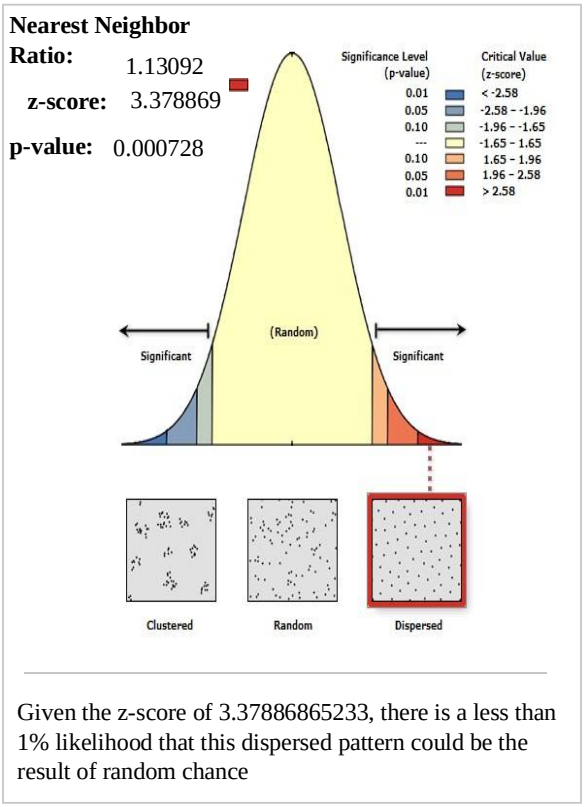
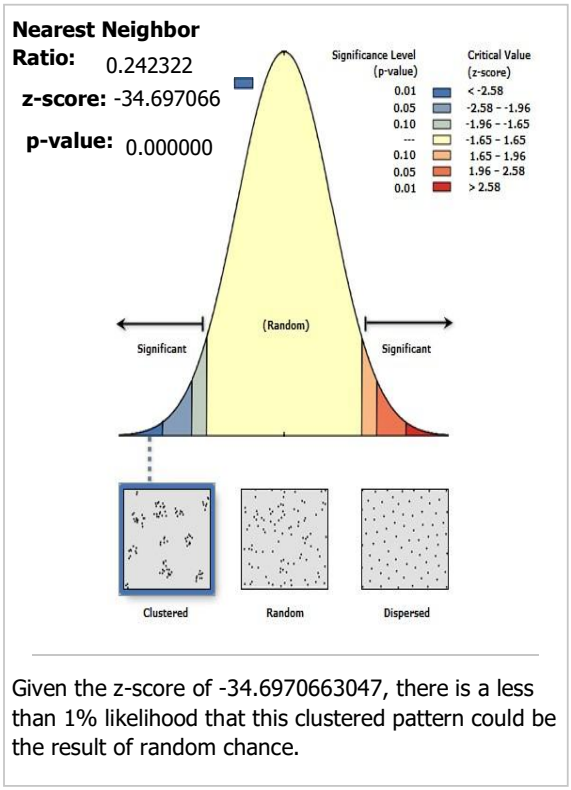
4.2 Spatial Distributions Pattern of Dunes Over Different Time Periods

The spatial distribution patterns of dunes over different time periods are shown in Figure **3a**, **b** and **c** using Average Nearest Neighbourhood (ANN) techniques in ArcGIS.



(**3a**) Spatial pattern in 2003 using ANN.



(**3b**) Spatial pattern in 2013 using ANN.

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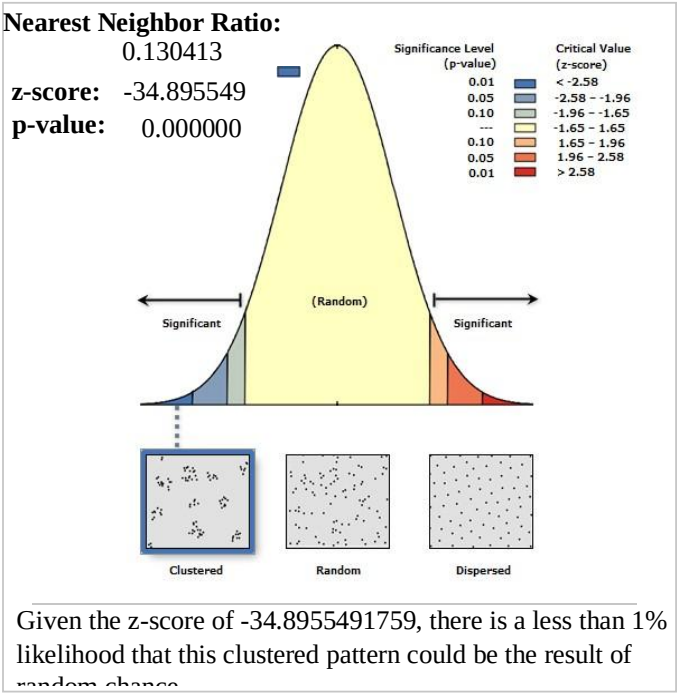

(**3c**) Spatial pattern in 2023 using ANN.

Source: Geospatial Analysis.

It was observed from Figure **3a** that sand dunes were more irregularly dispersed with a z-score value of 3.37886865233. The z-score value of 3.37886865233 for the 2003 distribution indicate that there is a less than 1% likelihood that this dispersed pattern was the result of random chance. This result agrees with [21]; [8]; [29] who observed similar pattern in Iran and Sudan. In 2013, dunes were more irregularly clustered as shown in Figure **3b**. The z-score value of -34.6970663047 for the 2013 distribution suggest that there is a less than 1% likelihood that this clustered pattern was as a result of random chance. This result agrees with [13]; [30]; [8] who recorded similar pattern in Sudan and China. In 2023 however, dunes were less clustered as shown in Figure **3c** with a z-score of -34.8955491759. The z-score of -34.8955491759 for the 2023 distribution imply that there is a less than 1% likelihood that the clustered pattern observed was as a result of random chance. This result agrees with [21]; [30] who observed very similar pattern in central Iran and China. The dispersed distribution pattern observed in 2003 infer that ecotourism infrastructure and/or facilities in the study area should be spatially dispersed across all parts of the study area

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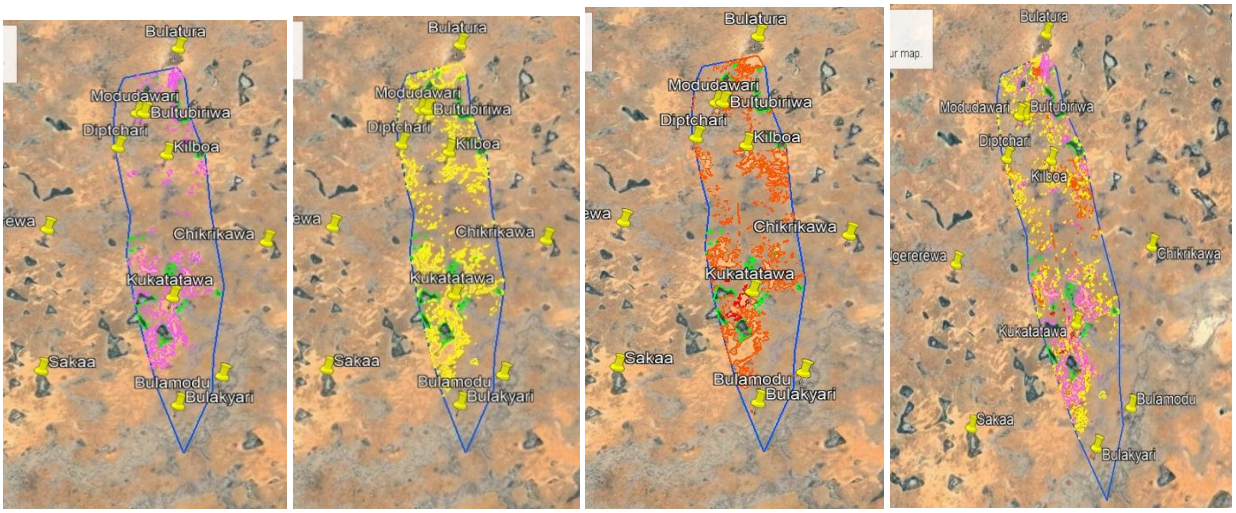
while the clustered pattern recorded in 2013 and 2023 connote that these infrastructure and/or facilities should be clustered in and around dune complexes only to ensure maximum utilization. The inconsistent pattern of dunes distribution in the study area implies that ecotourism infrastructure and/or facilities should be carefully and strategically located not only in in dunes complexes but across all the parts of the study area to ensure optimal utilization.

4.3 Spatial Migration Pattern of Dunes Over Different Time Periods in the Study Area

Figure 4 shows the overlay analysis of sand dunes over different time periods (2003-2023) in google earth (**4a, b, c & d**) and ArcGIS (**e, f & g**) to obtain their average leading edges between 2003-2013 and 2013-2023 in ArcGIS using distant calculator.



(4a) Dune in 2003 **(4b)** dune in 2013 **(4c)** dune in 2023 **(4d)** from 2003-2023

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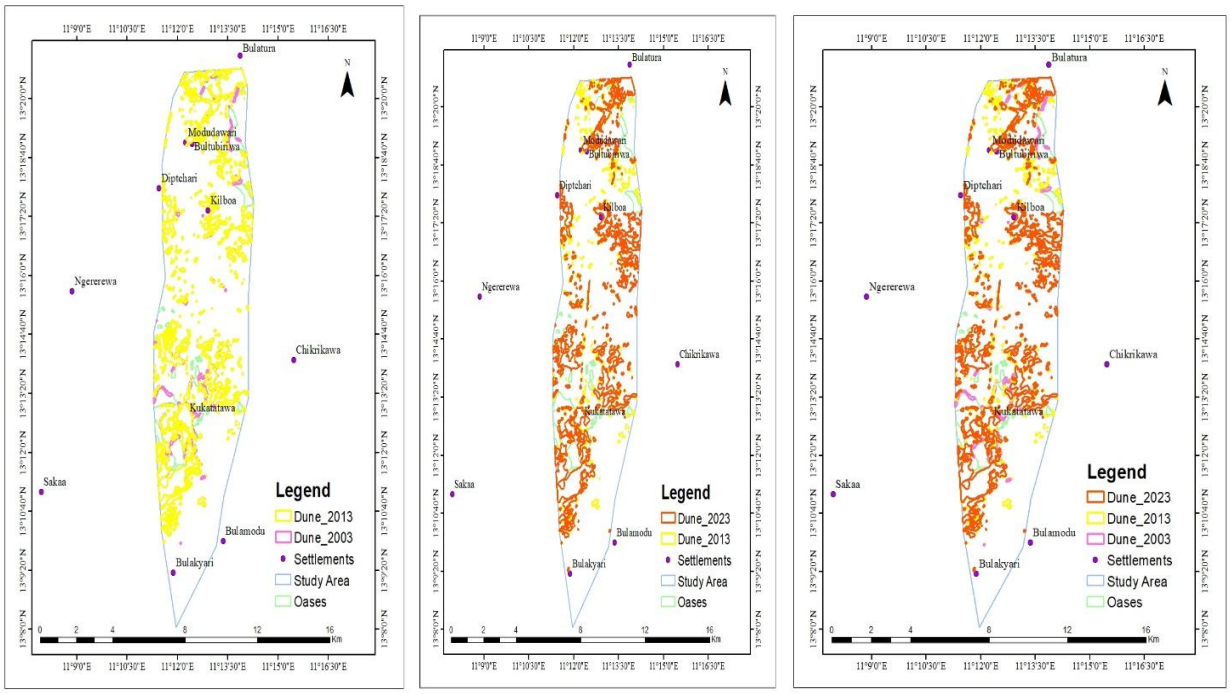

(**4e**) Dune migration between 2003-2013, (**4f**) 2013-2023 and (**4g**) 2003-2023

It was observed from Figure **4a, b** and **e** that sand dunes migrated in the E-W and W-E directions between 2003-2013. Between 2013-2023, the migration was in the N-S and W-E directions as shown in Figure **4b, c** and **f** while Figure **4d, 4g** and Table 1 summarized the migration parameters of sand dunes over different (2003-2023) time periods. It was observed from Table 1 and Figure **4a, b** and **e** that between 2003-2013, sand dunes migrated in the E-W and W-E directions with an average speed of 81.6m/year covering a distance of 816m while between 2013-2023 (**4c** and **f)**, the migration directions were N-S and W-E with an average speed of 62.2m/year covering a distance of 622m. The total migration direction, speed and distance from 2003-2023 was W-E, E-W and N-S, 143.8m/year and 1438m respectively while the total average migration pattern was 35.95m/year covering a distance of 719m in the W-E, E-W and N-S directions. These results partly agree with [10] and [17] who observed a higher pattern in northeastern Nigeria. [10] observed a pattern of 43.64km/year between 1975-2013 while [17] recorded a pattern of 15.2km/year in similar directions in Yobe state-Nigeria between 1990-2015.

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These results completely disagree with [18]; [5] who recorded lower patterns in Europe and Australia. Whereas [18] recorded a pattern of 2m/year in Central Europe, [5] documented a pattern of 11.2m/year in Australia. The cold climatic condition and dense vegetation cover in Central Europe and Australia could be responsible for the lower migration pattern observed compared to Africa where higher rates of about 43.64km/year and 15.2km/year have been recorded in northern Nigeria experiencing severe desertification. Finally, these results aligned with global and regional documentaries where an average migration pattern of 50m/year was recorded in America [28], 2m/year in Europe [18], 11.2m/year in Australia [5], 30.56m/ year in China [34], 8m/year in Iran [21], 12.5m/year in North Africa-Algeria [4], 3.75km/year in Central Africa -Sudan [9] and 15.2km/year in West Africa-Nigeria [17].

Table 1 Sand Dunes Migration Distance, Speed and Direction Over Different Time Periods

Period	Migration Distance (m)	Migration Speed (m/yr)	Migration Direction
2003-2013	816	81.6	E-W, W-E
2013-2023	622	62.2	N-S, W-E
2003-2023	1438	143.8	W-E, E-W, N-S
Total Average	719	35.95	W-E, E-W, N-S

Source: Data Survey

Sand dunes migration was more pronounced in the northern part of Modudawari, Bultubiriwa, Kilboa and Kukatatawa compared to the extreme south-south and southeast around Bulakyari and Bulamodu. These migration patterns present a moderate danger to ecotourism infrastructure and/or facilities in the study area. It also signifies a modest threat to the surrounding communities, oases, fauna and agricultural land in and around the study area. Proper and adequate planning is therefore

required before developing and installing ecotourism infrastructures and/or facilities in the study area.

Conclusion

Sand dunes in the Bulatura Oases Sector of Chad Basin National Park are not evenly distributed and their pattern changes over time. The distribution pattern recorded imply that permanent or long-term ecotourism infrastructure and/or facilities in any given location in the study area should be discouraged because dunes migration pattern changes over time. More so, the spatial migration pattern observed present a moderate threat on fixed ecotourism infrastructure and/or facilities in the study area thereby discouraging subsequent development and installation of these infrastructures and/or facilities. The use of remote sensing and GIS methodologies has fast tracked the process of data collection and analysis in addition to making the findings valuable for scholarly application, policy formulation and decision making in protected areas.

Recommendations

Below are the recommendations that emanated from this study

i. The inconsistent spatial distribution of dunes over different time periods imply that frequent and continuous research using remote sensing and GIS should be done to monitor dune's locations to enhance ecotourism planning, forecasting and reporting.
ii. Frequent and continuous research using remote sensing and GIS should be done in the study area to determine safer sites for building and/or installation of fixed ecotourism infrastructures and/or facilities to optimize utilization over different time periods based on the changing patterns of sand dunes distributions.

iii. Sand dune's stabilization activities using biological and/or chemical stabilizers should be intensified around the oases and other parts of the study area where dunes are encroaching into ecotourism facilities, settlements, farms and agricultural lands to reduce their migration pattern in the northern and central portion of the study area.

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