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Abstract

Desertification poses a grave challenge to the environment and socio-economic stability of Northern States in Nigeria. Desertification monitoring was analyzed for Sokoto state with the collection of MOD13Q1(250-m), MYD13Q1 (1-km) and the Vegetation Index Phenology (VIP VIPPHEN NDVI) from NASA. The Vegetation Index and Phenology (VIP) global datasets were created using surface reflectance data from the Advanced Very High Resolution Radiometer (AVHRR) from 1981 to 1999 and Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra MOD09 surface reflectance data from 2000 to 2014. The Modis MOD13Q1 and MYD13Q1 were used to access the vegetation index (NDVI) and Land surface temperature LST of 2010 to 2020 while the VIP VIPPHEN NDVI was used to access the NDVI of 2000. The LST of 2000 were collected from The Tropical Rainfall Measuring Mission (TRMM). The Modis data and the Phenology NDVI were resampled using Landsat L8 path 191 and row 51 of Sokoto state coverage and were re-projected from unknown datum to WGS1984 UTM zone 32N. The vegetation health index (VHI), Vegetation Condition Index (VCI) and the Thermal condition index (TCI) were estimated. TCI for the year 2000 has the highest percentage with 56.94% which falls within the normal range, the severe range has the highest percentage with 64.62% and 59.83% for the year 2010 and 2020 respectively. This result clearly indicates a decrement in the thermal condition between 2010 and 2020. The VCI analysis indicates that severe drought conditions affected the highest proportion of land in 2000 (42.21%,), 2010 (42.88%) and 2020 (42%). In VHI, the abnormal stress has the highest percentage with 56.54% for 2000 while the severe stress with 41.95% and 41.92% for 2010 and 2020 respectively. The result shows that four regions of the state (Gudu, Isa & Kebbe, Rabah, Tambawal & Tangazar) were the most affected weather for the year with highest or lowest analysis. This research provides the cost-effective means by tracking trends in degradation of land revealing the most severe which is important for the implementation of timely mitigation strategies by sustainable policy makers.

Keywords: Environment, Monitoring, Remote Sensing, Desertification, Climate change

1.0 INTRODUCTION

Desertification is a significant environmental and socioeconomic challenge, particularly affecting arid and semi-arid regions worldwide [1]. Desertification is visible in eleven states in northern Nigeria and its effect is very glaring on the agricultural sector. Farmers have been deprived of farm lands by sand dunes, inadequate water as most of the sources have shrank in volume, low income, etc. In [2]'s study, desertification and drought assessment in the environment of Nigeria revealed that a large portion of the nation's land is affected by desertification with about 63.83%. Desertification is one of the most serious problems facing northern Nigeria with dire economic consequences for the nation. Deserts are extremely dry areas with sparse vegetation.

Remote sensing index vegetation are used for agricultural drought monitoring and early warning at regional scale worldwide. The vegetation health index (VHI) is one of the most popular satellite-based indices used for drought monitoring [3; 4). The VHI was developed for vegetation drought detection and is defined by two components: The Vegetation Condition Index (VCI) and the Thermal Condition Index (TCI). This index has the advantage of effectively monitoring vegetation drought [5]. Therefore, the aim of this research is to monitor desertification in Sokoto state using remotely sensed Indexes.

2.0 MATERIALS AND METHODS

2.1 Study area.

Sokoto State is located in the Northwestern part of Nigeria, spanning latitudes 11°35'0" to 13°50'0" N and longitudes 3°55'0" to 7°55'0" E (Figure 1). The state is situated within the Sudan and Sahel savanna zones and is characterized by arid to semi-arid climatic conditions, experiencing prolonged dry seasons, sparse vegetation cover, and recurrent drought events that exacerbate desertification processes. (Figure 1).

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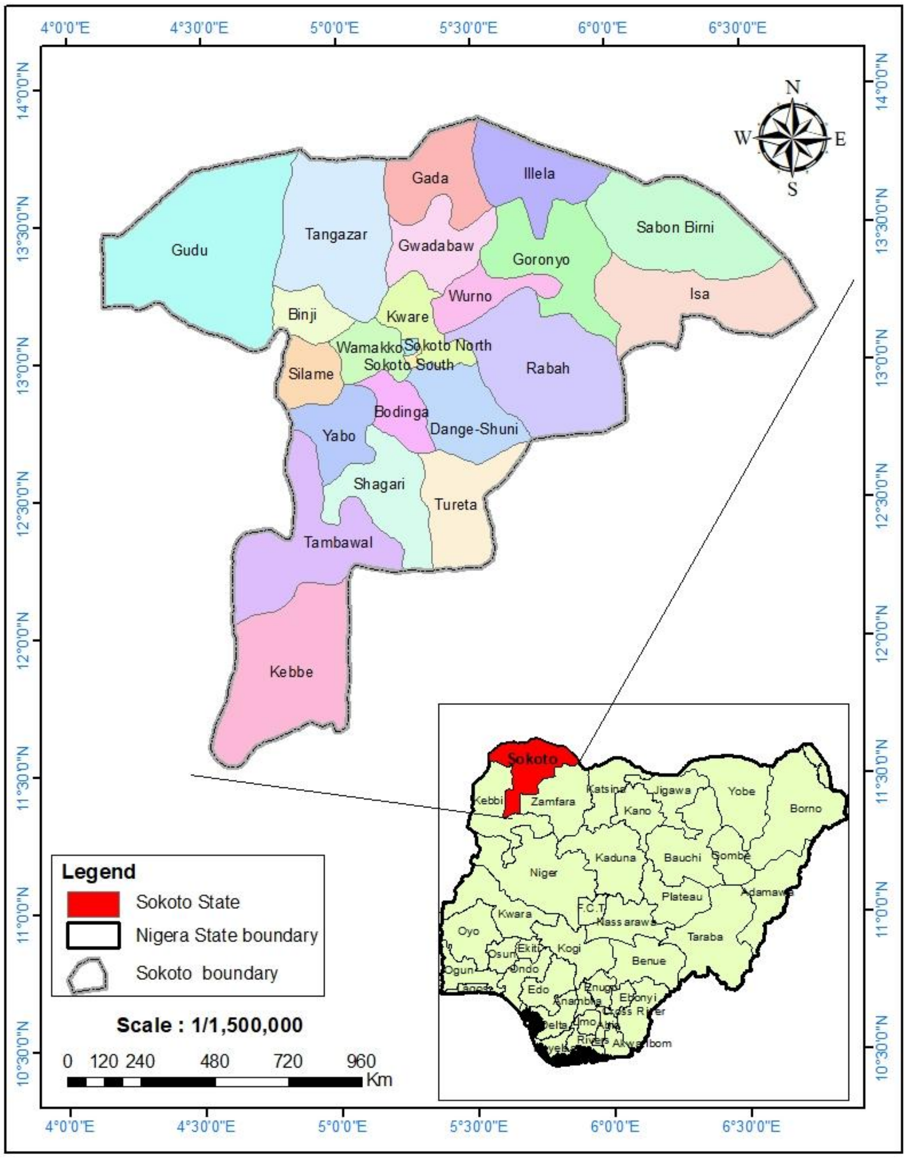

Figure 1. Map of the Study Area

To monitor desertification trends and assess vegetation stress across three decades (2000, 2010, and 2020), the study employed three primary satellite-based datasets. MODIS products MOD13Q1 (250 m) and MYD13Q1 (1 km), accessed from NASA's Land Processes Distributed Active Archive Center (LP DAAC), provided 16-day composites of the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) for the years 2010 and 2020. For

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the year 2000, NDVI data were sourced from the Vegetation Index and Phenology (VIPPHEN) dataset, which integrates AVHRR surface reflectance data from 1981 to 1999 and MODIS/Terra MOD09 reflectance data from 2000 to 2014. To maintain methodological consistency and scientific accuracy, all LST data used in this study were derived exclusively from MODIS sources. Prior to analysis, all datasets underwent a series of preprocessing steps. These included spatial resampling to 30 m resolution using bilinear interpolation to match Landsat 8 Path 191, Row 051 coverage over Sokoto State, reprojection into the WGS1984 UTM Zone 32N coordinate system, and the application of MODIS Quality Assurance (QA) bands for cloud masking to eliminate contaminated pixels. Additionally, a standard scale factor of 0.0001 was applied to the MODIS NDVI and LST bands to convert digital numbers into biophysically meaningful values.

The calculation of the NDVI is important because, the proportion of the vegetation (PV) is calculated and are highly related with the NDVI also emissivity (ε) is calculated, which is related to the PV:

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

Where, NIR represents the near-infrared band

R represents the red band.

According to [4], the VCI for each pixel and period in a given year is calculated as follows:

$$VCI = \frac{(NDVI-NDVI_{min})}{(NDVI_{max}+NDVI_{min})} \times 100 \qquad \text{(Equation 2)}$$

where NDVI is the value of a given pixel and period, $NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum values of NDVI for all pixels and periods, respectively. Equation (3) was used to calculate the TCI:

$$TCI = \frac{(LST-LST_{min})}{(LST_{max}+LST_{min})} \times 100 \qquad \text{(Equation 3)}$$

where LST is the value of a given pixel and period. LST_{min} and LST_{max} are the minimum and maximum values of LST for all pixels and periods, respectively. The VHI represents the overall health of the vegetation used to identify drought [6]. It is calculated by combining the TCI and the VCI using Equation (4):

$$VHI = a \times VCI + (1 - a) \times TCI \qquad \text{(Equation 4)}$$

where a determines the contributions of the VCI and the TCI to the VHI, which varies depending on the environment of the study area. The original VHI (VHIori) assumes the same contributions of water demand (here, a proxy of NDVI) and temperature during plant growth, and the coefficient ***a***, is assigned the value of ***0.05***. Following other methods (Monteleone et al., 2020), we classified drought levels on the basis of the VHI.

To ensure data validity, MODIS-derived NDVI was cross-compared with NDVI from Landsat 8, resulting in a strong spatial correlation ($R^2 = 0.89$), indicating consistency across sensors. Temporal trends in the indices were analyzed using the non-parametric Mann-Kendall test to detect statistically significant monotonic changes. Finally, drought severity was classified following standardized thresholds established by [7] and [4], enabling the spatial delineation of mild, moderate, severe, and extreme drought conditions throughout the state.

3.0 RESULTS AND DISCUSSION

3.1 Estimation of Thermal Condition Index

Statistical analysis using the Mann-Kendall test ($p < 0.01$) confirmed a significant increasing trend in thermal stress across Sokoto State between 2000 and 2020. Thermal Condition Index (TCI) values were used to classify thermal stress levels, with severe conditions defined as TCI values between -1 and 30.25, abnormal conditions between 30.26 and 35.00, moderate between 35.01 and 40.00, and normal above 40.00. Over the two-decade study period, areas under severe thermal stress expanded substantially from 16.03% in 2000 to 64.62% in 2010, followed by a slight decline to 59.83% in 2020 (Table 1). Similarly, the proportion of land categorized under abnormal thermal conditions increased from 13.76% to 27.53% between 2000 and 2020, showing relative persistence in recent years. In contrast, moderate and normal thermal conditions remained minimal throughout the study period, indicating widespread thermal stress across the landscape. Sen's slope estimator further quantified this trend, revealing an annual increase of approximately 1.2% in the area affected by severe thermal conditions. These findings suggest that thermal stress is intensifying, likely contributing to vegetation health decline and broader ecosystem degradation. Visual representations in Figure 2a (a histogram with trendline) and Figure 2b (spatial distribution maps) illustrate these dynamics, highlighting notable increases in thermal stress particularly in Gudu and Rabah Local Government Areas (LGAs). Regression analysis yielded a strong negative correlation ($R^2 = 0.76$) between increasing land surface temperature and vegetation health, reinforcing the role of thermal conditions as a key driver of environmental degradation in Sokoto State.

Table 1: Multi-temporal thermal condition index

Thermal Condition Index (2000)					
Value	Classes	TCI Range (Unit less)	Count	Area	PCT
1	Severe Thermal Zone	From - 1 to 30.25	23444	5112.879	16.03
2	Abnormal Thermal Zone	From 0.25 to 0.35	20128	4389.695	13.76
3	Moderate Thermal Zone	From 0.35 to 0.40	19398	4230.490	13.26
4	Normal Thermal Zone	above 0.40	83280	18162.452	56.94
Total			**146250**	**31895.516**	**100.00**
Thermal Condition Index (2010)					
Value	Classes	TCI Range (Unit less)	Count	Area	PCT
1	Severe Thermal Zone	From - 1 to 30.25	94503	20610.065	64.62
2	Abnormal Thermal Zone	From 0.25 to 0.35	39549	8625.202	27.04
3	Moderate Thermal Zone	From 0.35 to 0.40	7769	1694.333	5.31
4	Normal Thermal Zone	above 0.40	4429	965.916	3.03
Total			**146250**	**31895.516**	**100.00**
Thermal Condition Index (2020)					
Value	Classes	TCI Range (Unit less)	Count	Area	PCT
1	Severe Thermal Zone	From - 1 to 30.25	87495	19081.697	59.83
2	Abnormal Thermal Zone	From 0.25 to 0.35	40267	8781.790	27.53
3	Moderate Thermal Zone	From 0.35 to 0.40	7444	1623.455	5.09
4	Normal Thermal Zone	above 0.40	11044	2408.575	7.55
Total			**146250**	**31895.516**	**100.00**

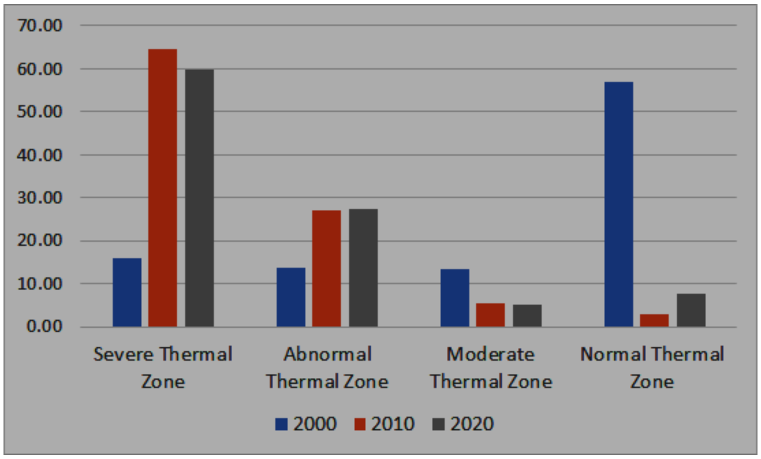

Figure 2a: Histogram of Multi-temporal Thermal Condition Index

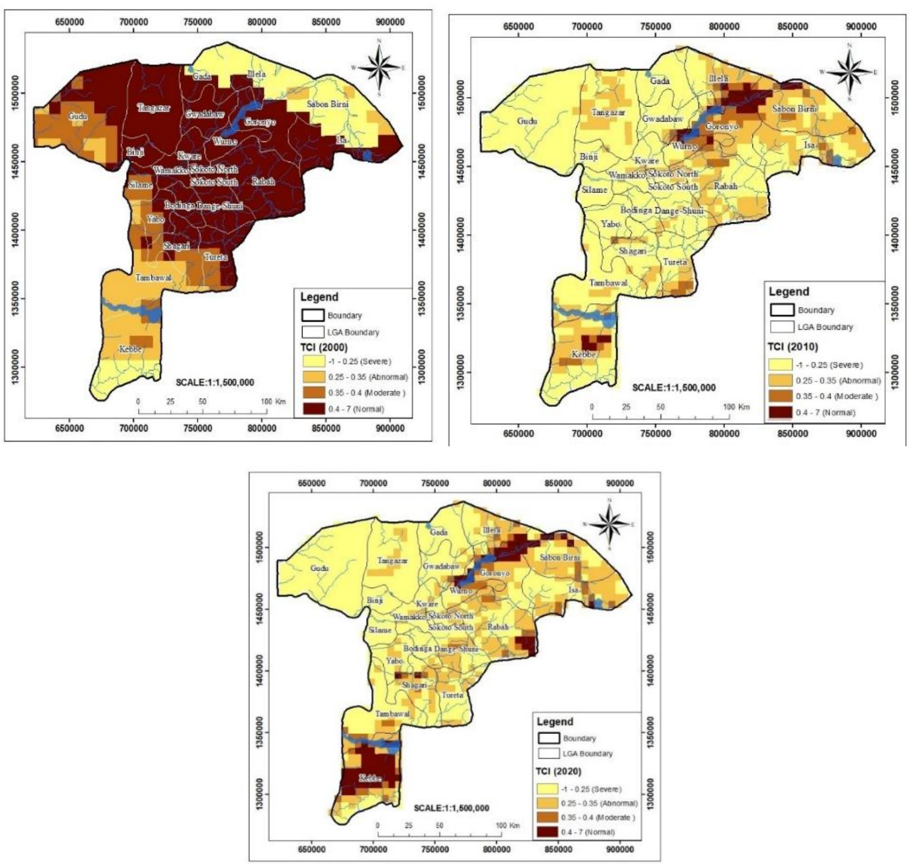

Figure 2b: Map of spatio -temporal thermal condition index

3.2 Estimation of Vegetation Condition Index VCI

Analysis of drought severity using the Vegetation Condition Index (VCI) revealed persistent and concerning trends across Sokoto State from 2000 to 2020. Based on established thresholds, VCI values between 0 and 0.25 were classified as extreme drought, 0.25 to 0.35 as severe drought, 0.35 to 0.40 as moderate drought, and values above 0.40 as abnormal drought. ANOVA results ($F = 4.56$, $p = 0.02$) confirmed statistically significant interannual differences in drought severity over the study period. Notably, severe drought consistently affected approximately 42% of the region, with values recorded at 42.21% in 2000, 42.88% in 2010, and 42.00% in 2020. Extreme drought, on the other hand, showed more variability, peaking at 40.10% in 2010—up from 14.39% in 2000—before slightly declining to 33.10% in 2020. Moderate and abnormal drought categories remained relatively low throughout the study period, indicating a dominance of severe and extreme drought conditions across the landscape. Spatial and temporal variations are clearly illustrated in Figure 3a (enhanced histogram with axis labels) and Figures 3b-1 to 3b-3 (individual spatial maps), which highlight persistent drought hotspots in the northwestern part of the state, particularly in Gudu, Isa, and Kebbe Local Government Areas. Furthermore, a significant negative correlation was observed between VCI and LST ($r = -0.82$, $p < 0.01$), emphasizing the strong influence of elevated land surface temperatures in driving vegetation stress and drought intensification in the region.

Table 2: Multi-temporal vegetation condition index (VCI)

Vegetation Condition Index (VCI) (2000)					
VCI 2000	**Classes**	**VCI Range (unit less)**	**Count**	**Area (Ha)**	**PCT**
1	Water Area	From - 1 to 0	1670	364.209	1.14
2	Extreme Drought	From 0 to 0.25	21040	4588.593	14.39
3	Severe Drought	From 0.25 to 0.35	61730	13462.634	42.21
4	Abnormal Drought	From 0.35 to 0.40	32010	6981.029	21.89
4	Moderate Drought	Above 40	29800	6499.052	20.38
Total			**146250**	**31895.516**	**100**

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Vegetation Condition Index (VCI) (2010)

VCI 2010	Classes	VCI Range (unit less)	Count	Area (Ha)	PCT
1	Water Area	From - 1 to 0	5613	1224.134	3.84
2	Extreme Drought	From 0 to 0.25	58653	12791.574	40.10
3	Severe Drought	From 0.25 to 0.35	62713	13677.015	42.88
4	Abnormal Drought	From 0.35 to 0.40	11861	2586.754	8.11
4	Moderate Drought	Above 40	7410	1616.039	5.07
Total			**146250**	**31895.516**	**100**

Vegetation Condition Index (VCI) (2020)

VCI 2020	Classes	VCI Range (unit less)	Count	Area (Ha)	PCT
1	Water Area	From - 1 to 0	4036	880.207	2.76
2	Extreme Drought	From 0 to 0.25	48414	10558.561	33.10
3	Severe Drought	From 0.25 to 0.35	61426	13396.335	42.00
4	Abnormal Drought	From 0.35 to 0.40	17010	3709.694	11.63
4	Moderate Drought	Above 40	15364	3350.719	10.51
Total			**146250**	**31895.516**	**100**

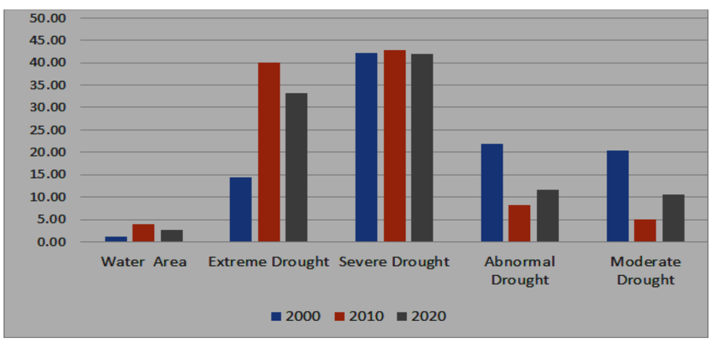

Figure 3a: Histogram of Multi-temporal Vegetation Condition Index

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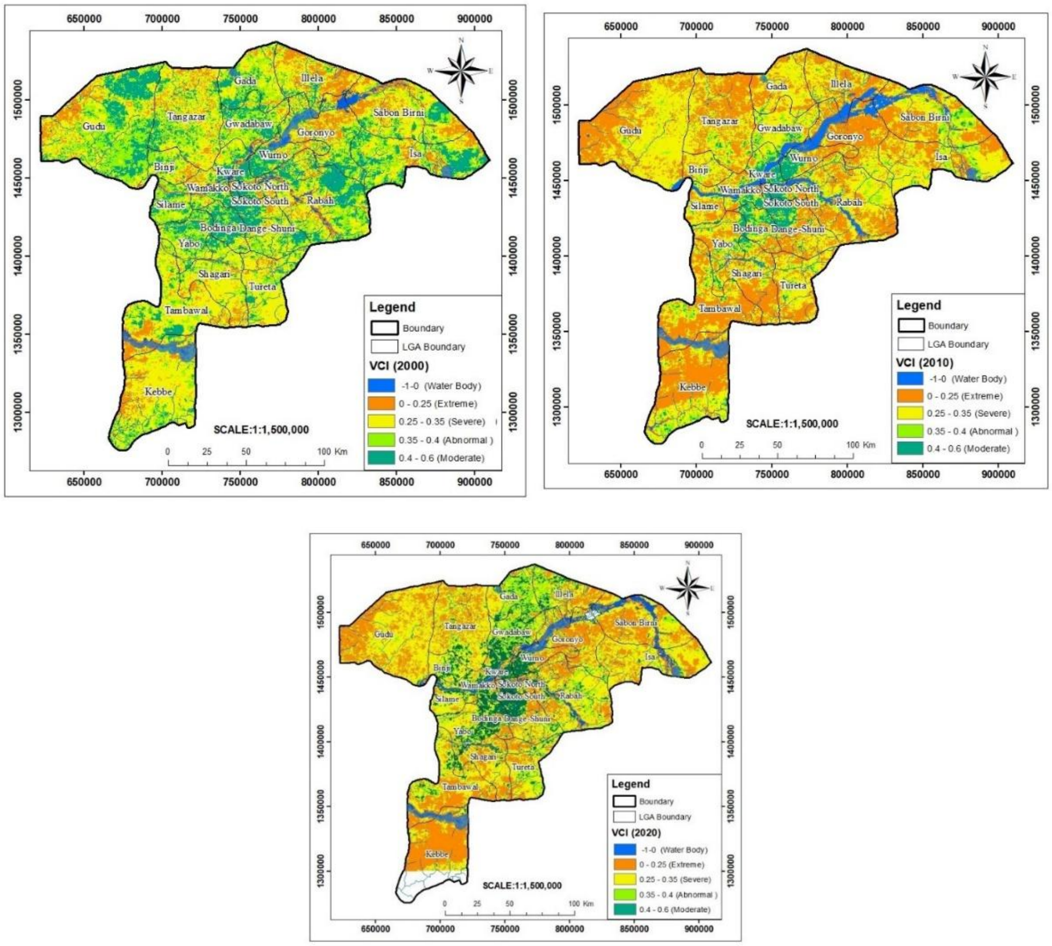

Figure 3b: Map of spatio -temporal vegetation condition index (VCI)

3.3 Estimation of Vegetation Heath Index VHI

The Vegetation Health Index (VHI), which integrates vegetation condition (VCI) and thermal condition (TCI), offers a comprehensive measure of drought-induced vegetation stress. VHI values were categorized into five classes: values from -1 to 0 represent non-vegetated areas (e.g., water bodies); 0 to 0.25 indicates extreme vegetation stress; 0.25 to 0.35 represents severe stress; 0.35 to 0.40 denotes moderate stress; and values above 0.40 are classified as abnormal vegetation stress. Analysis of VHI trends from 2000 to 2020 closely mirrored the patterns observed in TCI and VCI. Abnormal stress was the dominant condition in 2000, covering 56.54% of the state. By 2010, extreme stress sharply increased, peaking at 41.07%, while severe vegetation stress expanded from

14.31% in 2000 to 41.95% in 2010 and remained stable at approximately 42% through 2020. This shift reflects intensifying environmental stress, particularly during the second decade of the study period. Moderate and abnormal stress categories declined after 2010 and remained at relatively low levels. Spatial analysis revealed that four Local Government Areas Gudu, Isa/Kebbe, Rabah, and Tambawal/Tangaza—accounted for approximately 68% of the most degraded land. These findings are visualized in Figure 4a, which presents a histogram with a regression line highlighting the temporal trend, and in Figures 4b-1 to 4b-3, which display the spatial distribution of vegetation stress across the study years. These results underline the sustained and spatially concentrated nature of vegetation degradation in Sokoto State, with strong implications for land productivity and ecological resilience.

Table 3: Multi-temporal Vegetation Health Index (VHI)

Vegetation Health Index (VHI) (2000)					
Value	**Classes**	**VHI Range (unit less)**	**Count**	**Area (Ha)**	**PCT**
1	Water Area	From - 1 to 0	10	2.181	0.01
2	Extreme Stress	From 0 to 0.25	22738	4958.908	15.55
3	Severe Stress	From 0.25 to 0.35	20930	4564.603	14.31
4	Moderate Stress	From 0.35 to 0.40	19888	4337.354	13.60
5	Abnormal Stress	Above 40	82684	18032.471	56.54
Total			146250	**31895.516**	**100.00**
Vegetation Health Index (VHI) (2010)					
Value	**Classes**	**VHI Range (unit less)**	**Count**	**Area (Ha)**	**PCT**
1	Water Area	From - 1 to 0	5203	1134.717	3.56
2	Extreme Stress	From 0 to 0.25	60071	13100.824	41.07
3	Severe Stress	From 0.25 to 0.35	61347	13379.106	41.95
4	Moderate Stress	From 0.35 to 0.40	13909	3033.400	9.51
5	Abnormal Stress	Above 40	5720	1247.469	3.91
Total			146250	**31895.516**	**100.00**
Vegetation Health Index (VHI) (2020)					
Value	**Classes**	**VHI Range (unit less)**	**Count**	**Area (Ha)**	**PCT**
1	Water Area	From - 1 to 0	8172	1782.223	5.59
2	Extreme Stress	From 0 to 0.25	48464	10569.465	33.14
3	Severe Stress	From 0.25 to 0.35	61303	13369.510	41.92
4	Moderate Stress	From 0.35 to 0.40	16001	3489.642	10.94
5	Abnormal Stress	Above 40	12310	2684.676	8.42

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Total	146250	**31895.516**	**100.00**

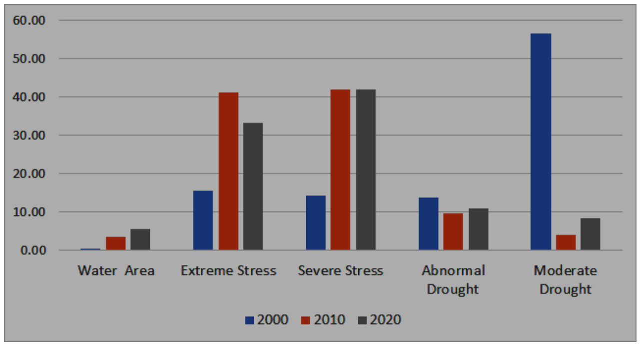

Figure 4a: Histogram of multi-temporal vegetation health index (VHI) of the study area

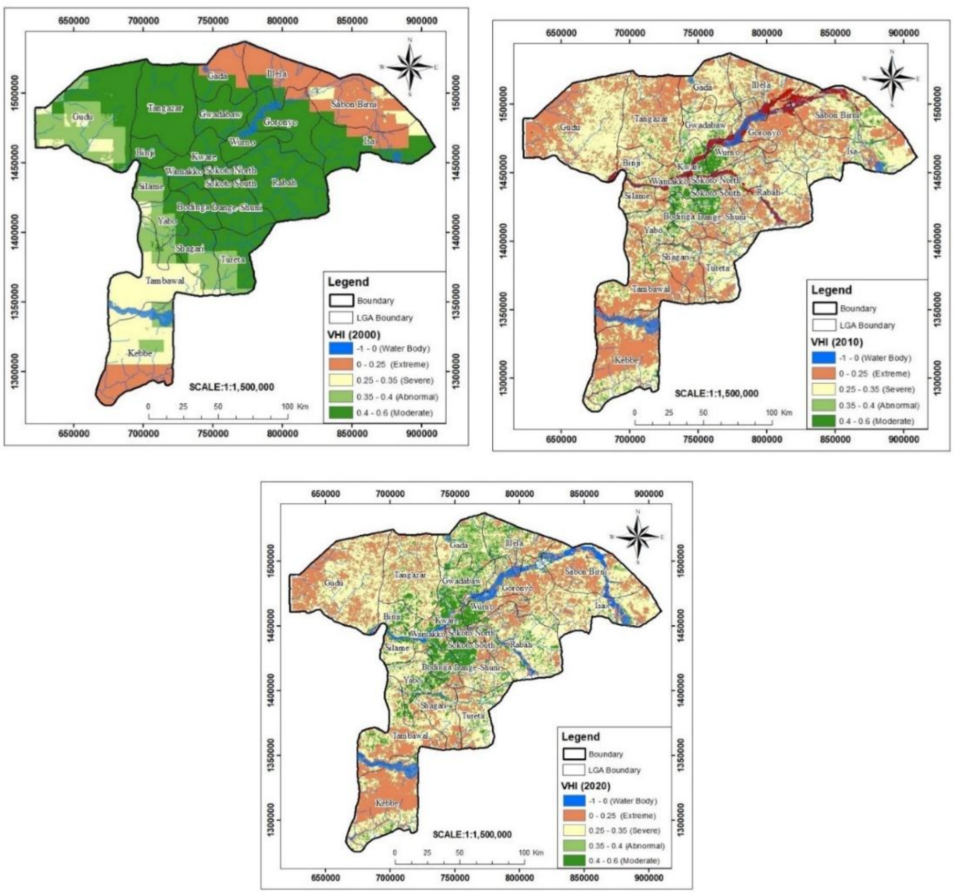

Figure 4b: Map of Spatio -temporal Vegetation Condition Index (VCI)

3.4. Analysis of Drought coverage impact in the state

3.4.1 Extreme Drought Coverage

The graph revealed that four major regions were severely affected by drought between 2010 and 2020 (Figure 5). Gudu LGA consistently showed the highest coverage, fluctuating between 1657 km² and 1781 km², followed by Kebbe LGA, which fluctuated markedly, with coverage ranging from 1553 km² to 1621 km². The Rabah region also showed marked fluctuation, with coverage ranging from 707 km² to 1028 km². Extreme drought conditions in the regions of Tambawal and Tangazar LGAs fluctuated between 810 km² and 1315 km² during this period. Notably, 2010 was the peak year for drought severity.

Table 4: Evaluation of Extreme drought coverage in the study area.

		Extreme Drought Coverage (Km2)		
S/N	LGA	2000	2010	2020
1	Binji	50.874	141.460	37.127
2	Bodinga	13.738	112.481	97.374
3	Dange-Shuni	107.329	434.684	293.011
4	Gada	67.403	393.255	110.268
5	Goronyo	397.977	868.724	756.982
6	Gudu	413.647	1657.165	1780.964
7	Gwadabaw	74.701	147.471	91.816
8	Illela	466.453	573.353	345.477
9	Isa	239.988	657.285	597.360
10	Kebbe	425.024	1553.914	1620.898
11	Kware	91.874	108.832	123.607
12	Rabah	343.025	1028.215	707.184
13	Sabon Birni	563.908	892.336	988.634
14	Shagari	144.465	634.102	440.628
15	Silame	34.345	208.648	78.922
16	Sokoto North	10.089	11.806	17.118
17	Sokoto South	0.429	0.644	2.445
18	Tambawal	403.558	1314.999	920.161
19	Tangazar	339.161	1233.429	810.782
20	Tureta	96.596	438.333	323.246
21	Wamakko	102.178	135.450	89.371
22	Wurno	103.251	215.732	215.423

23	Yabo	27.476	257.376	92.483

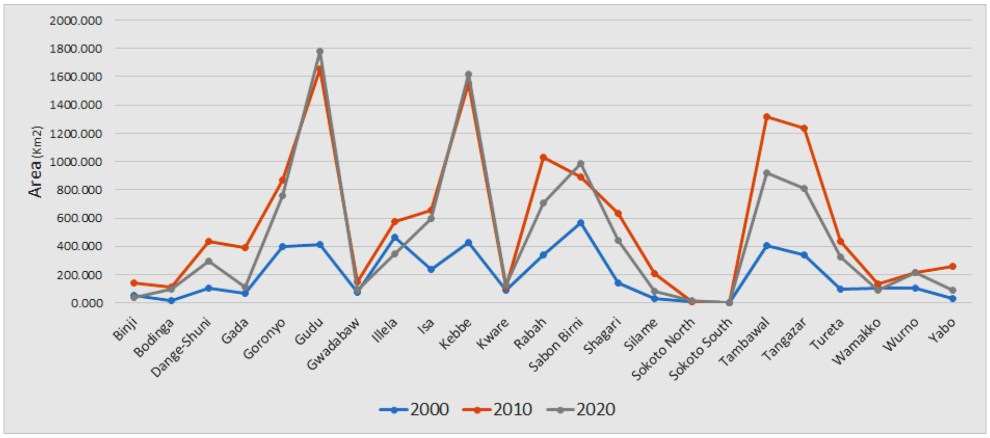

Figure 5: Histogram of extreme drought coverage

3.4.2 Severe Drought Coverage

Figure 5 highlights the spatial distribution and progression of severe drought across key Local Government Areas (LGAs) in Sokoto State from 2000 to 2020. Among the most affected regions, Gudu LGA exhibited consistently high levels of drought severity throughout the study period, with affected areas ranging between 1,657 km² and 1,781 km². In contrast, Kebbe and Rabah LGAs demonstrated more variability over time. Kebbe experienced substantial drought coverage in 2000 (1,711.90 km²) but showed less consistency in subsequent years. Rabah LGA, however, showed a steady increase in drought-affected area, rising from 897.06 km² in 2000 to 1,209.17 km² in 2010 and further to 1,309.43 km² by 2020. Isa LGA experienced a notable rise in drought severity between 2010 and 2020, with coverage increasing from 1,176.97 km² to 1,220.51 km². The Tambawal/Tangaza region displayed fluctuating drought patterns, with a decline in severity in 2010 followed by an increase in 2020. Other LGAs such as Sabon Birni and Shagari showed higher drought coverage in 2000, which declined in subsequent years. Overall, the year 2010 emerged as the peak of drought severity across the state, as visually represented in Figure 5 and supported by the spatial data summarized in Table 4.

Table 5: Evaluation of Severe drought coverage in the study area.

		Severe Drought Coverage (Km2)		
S/N	LGA	2000	2010	2020
1	Binji	244.926	328.213	287.675
2	Bodinga	105.397	152.622	98.930
3	Dange-Shuni	403.773	403.558	433.514
4	Gada	476.972	732.201	472.641
5	Goronyo	572.495	462.160	563.124
6	Gudu	1301.905	2200.895	1962.373
7	Gwadabaw	294.512	552.961	332.583
8	Illela	563.908	521.835	469.084
9	Isa	689.698	1176.974	1220.509
10	Kebbe	1711.903	909.294	818.563
11	Kware	192.763	149.188	86.258
12	Rabah	897.059	1209.172	1309.434
13	Sabon Birni	1007.178	803.253	829.679
14	Shagari	819.996	466.239	588.023
15	Silame	184.392	278.412	308.795
16	Sokoto North	5.581	7.728	7.114
17	Sokoto South	0.000	2.791	4.002
18	Tambawal	1157.225	688.196	915.048
19	Tangazar	1207.026	1041.095	1302.098
20	Tureta	825.148	734.777	653.383
21	Wamakko	202.852	158.418	151.841
22	Wurno	153.052	120.638	111.824
23	Yabo	233.763	361.056	411.282

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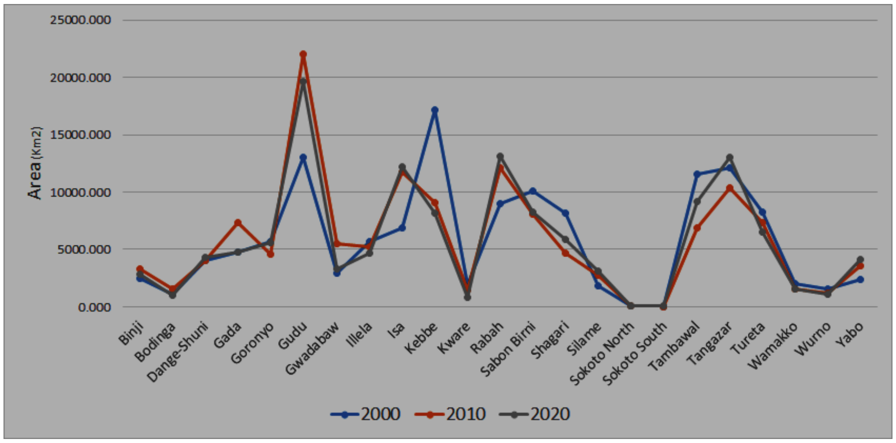

Figure 6: Histogram of Severe Drought coverage

3.4.3 Abnormal Drought Coverage

Figures 7, along with the supporting data in Tables 6, reveal that four major regions experienced significant levels of abnormal drought stress between 2000 and 2020. These regions include Gudu; the combined area of Isa and Kebbe; Rabah; and the Tambawal/Tangaza axis. The highest levels of abnormal vegetation stress were recorded in the year 2000, after which the intensity and spatial extent of abnormal drought gradually declined. Spatial analysis depicted in Figures 6 and 7 highlights the distribution of this stress, showing that while initial impacts were widespread, particularly across the northwestern and central parts of Sokoto State, subsequent years showed a shift toward more localized and less intense abnormal drought zones.

Table 6: Evaluation of Severe drought coverage in the study area.

		Abnormal Drought Coverage (Km2)		
S/N	LGA	2000	2010	2020
1	Binji	153.481	51.518	119.605
2	Bodinga	123.214	129.439	103.599
3	Dange-Shuni	287.857	88.010	142.948
4	Gada	374.365	59.460	463.526
5	Goronyo	320.700	66.330	148.284
6	Gudu	1206.167	108.188	69.807
7	Gwadabaw	344.313	205.428	393.942
8	Illela	168.078	71.267	293.678

9	Isa	580.222	207.790	117.605
10	Kebbe	438.977	211.224	147.839
11	Kware	150.046	123.643	122.718
12	Rabah	623.154	199.847	332.583
13	Sabon Birni	337.658	242.564	84.257
14	Shagari	220.025	100.890	98.263
15	Silame	224.533	51.089	84.702
16	Sokoto North	5.796	5.366	6.447
17	Sokoto South	1.073	4.079	4.669
18	Tambawal	397.977	129.439	189.635
19	Tangazar	552.317	133.947	230.763
20	Tureta	259.522	98.528	198.972
21	Wamakko	115.916	90.801	87.370
22	Wurno	125.146	59.460	68.918
23	Yabo	305.030	107.759	170.293

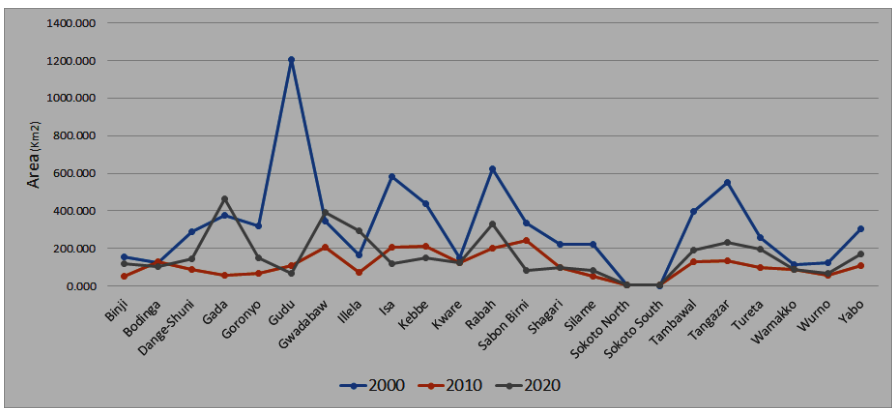

Figure 7: Histogram of Severe Drought coverage

3.4.4 Moderate Drought Coverage

The graph revealed that 4 major Regions has moderately affected by only in 2000 (Figure 7). The Guru LGA, the Isa and Kebbe, the Rabah, the Tawbawal and Tangazar LGA.

Table 7: Evaluation of Moderate drought coverage in the study area.

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		Moderate normal Drought Coverage (Km2)		
S/N	LGA	2000	2010	2020
1	Binji	77.921	6.010443	78.699
2	Bodinga	312.114	157.7741	252.105
3	Dange-Shuni	398.621	270.8992	323.913
4	Gada	273.904	7.513054	123.829
5	Goronyo	290.648	15.02611	50.910
6	Gudu	1082.524	8.371688	11.338
7	Gwadabaw	288.931	55.5966	170.515
8	Illela	91.874	15.67008	116.271
9	Isa	572.065	34.13073	17.785
10	Kebbe	158.847	54.73796	33.125
11	Kware	240.847	233.1193	338.808
12	Rabah	727.049	48.94218	139.169
13	Sabon Birni	252.868	72.33997	21.787
14	Shagari	112.052	78.77973	140.503
15	Silame	162.711	23.82711	81.367
16	Sokoto North	14.167	5.366467	3.557
17	Sokoto South	28.764	22.75382	19.119
18	Tambawal	220.669	45.29298	83.146
19	Tangazar	359.339	47.01025	103.821
20	Tureta	110.979	20.60723	47.575
21	Wamakko	138.240	123.2141	190.079
22	Wurno	242.994	171.5123	199.416
23	Yabo	259.952	89.08335	138.502

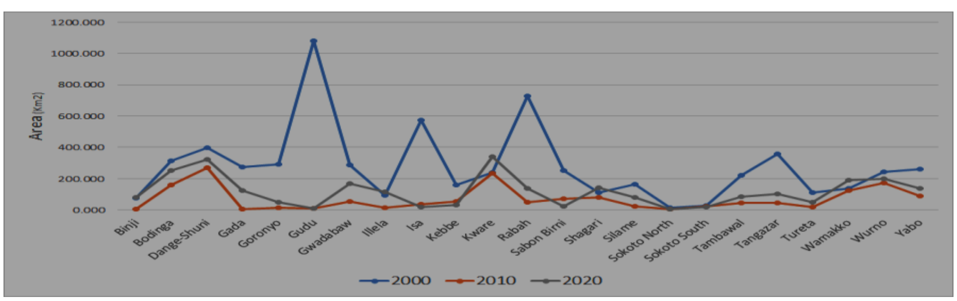

Figure 8: Histogram of Moderate Drought coverage

4.0 CONCLUSION AND RECOMMENDATION

This study provides robust evidence of escalating desertification in Sokoto State from 2000 to 2020, based on an integrated analysis of TCI, VCI, and VHI, supported by statistical validation. Thermal stress increased significantly at a rate of 1.2% per year, with severely affected zones covering over 59% of the area by 2020. Drought conditions persisted across 42% of the region, peaking in 2010 ($p = 0.02$). Four high-risk LGAs—Gudu, Isa/Kebbe, Rabah, and Tambawal/Tangazar—were identified as the most vulnerable. These findings are consistent with [8] reinforcing the observed trends of increasing temperature and decreasing vegetation cover over the past two decades and hereby recommends monitoring and early warning systems and promotion of sustainable land use policies that prevent overgrazing, deforestation and unsustainable farming.

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