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Monitoring Drought Occurrence over the Sahel and Sudan Savannah of Nigeria Using NDVI

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Abstract**: *Drought is a climatic phenomenon which can either be normal or abnormal. The probability of drought occurrence on the global environment suffers abrupt changes, thus developing strategies for mitigating drought effects becomes very imperative. This study monitors the magnitude of drought severity in the Sudan-Sahel region of Nigeria using NDVI (Normalized Difference Vegetation index) and rainfall data spanning through a period of 20 years (1981- 2001). Fourteen meteorological stations were covered. NDVI was used to depict periods of different drought scenario while drought risk maps were generated from classified NDVI anomaly for each station. In addition, vegetation cover of the study area was analyzed from the trend of NDVI anomaly from year to year and this shows the magnitude of dryness and wetness for the stations considered. The results revealed that from the beginning of 1983 through to 1986, the region suffered extreme to severe drought condition especially the northern part. Mild to moderate drought conditions were experienced in the early 1990s. A wet climatic condition was prevalent in the study area between 1994 and 1998 as no drought condition was experienced. Analysis and interpretation of the maps confirmed that remotely-sensed drought indices can accurately detect and map local and regional drought spatial occurrence. The study concluded that fine spatial resolution satellite data could be used to aid decision makers in monitoring and detecting drought to find how to mitigate the disaster.*****

Keywords— NDVI, Anomaly, drought, remote sensing, drought severity

I. INTRODUCTION

Drought is one of the most important natural disasters in Nigeria, a disastrous natural phenomenon that has several impacts on human and environment [21]. It is often aggravated by human actions. It also affects vast areas of land, leaving behind effects that lasts long time in its aftermath. It has serious influence on national food production; it reduces life expectancy and economic performance of large regions. Since the devastating Sahelian drought of the early 1970s, drought has reoccurred in many parts of Africa [18]. The ten major droughts waves in Africa within the period 1980-2003 were responsible for almost 42% of the weather-related monetary losses which was more than the losses from hurricanes and tropical storms (28%), [9]. In West Africa, decline in annual rainfall was observed since the end of the 1960s, with a decrease of 20–40% in the years between1968–1990 as compared with the 30 years between 1931 and 1960 [18], [1] and [2].

The economic and social impacts of drought are spread over a long period of time, thus making drought the worst of all natural hazards [26]. The International Disaster database of the Centre for Research on the Epidemiology of Disasters [4] reported that more than 0.5 million deaths and 253 million people were affected by drought events during the last 30 years (1981 and 2011). Political instability and economic isolation have further worsened the effects of drought especially in Nigeria where over 350,000ha of viable land were lost annually due to advancing desert [12] The visible sign of drought encroachment is the gradual shift in vegetation from grasses, bushes and occasional trees, to expansive areas of desert-like sand. Some villages and major access roads in the extreme northern parts of Katsina, Sokoto, Jigawa, Borno, and Yobe States have been buried under sand dunes. [27].The difficulty of studying drought occurrence comes from the fact that no one can recognize when drought started or even when it is ended. In most cases, its impact persists even after ending of the drought occurrence. Furthermore, the drought concept varies among regions of different climates [11].

As a result of the multiple effects occurrence of drought poses on human and the environment it is so much imperative to monitor previous occurrences of drought [5]. It is important that scientific studies are carried out in order to provide the society with accurate information on drought occurrence that will help concerned individuals and decision-makers make mitigation and adaptation plans [16]. In this dispensation, the world in general is experiencing diverse environmental problems which include global warming, ozone depletion, acid rain, killer hurricanes, destructive thunderstorms, and other impacts of climate change, efforts made to provide viable information on drought occurrence should be quite significant [21]. The study therefore examines the occurrence of drought in the Sahel and Sudan savanna of Nigeria using Normalized Difference Vegetation Index and drought risk maps were generated to

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reveal the classification of drought over time in this region.

II. STUDY AREA

The study area covered 11 states in the Northern Nigeria where 14 climatic stations exist. The region is covered with brush, grasses, and stunted trees. Rainfall is highly seasonal and variable in time and space, with two prevalent seasons, the wet and the dry. The dry season is from October to April or May, while the seasonal rainfall is concentrated in a short wet season that runs from May to September [3]. Annual rainfall in the region is marked by clear seasonal variation and by virtue of the geographical location; rainfall is the most critical element of climate [20]. The region experiences strong year-to-year variations in climate. The temperature of the region is sufficient throughout the year to allow plant growth but the insufficient rainfall and the single short rainy season imposes serious limitations on the growth of viable vegetal cover. The region is rich in agricultural production but the large inter annual variability of rainfall produces dry spells which lead to severe and widespread drought that imposes serious socio-economic constraints. [22], [13] and [24]. Agriculture through irrigation is widely practiced and crops cultivated include grains, cotton, groundnuts, tuber crops and sugar cane, which is produced between 9° and 11.5° N. Some economic minerals found in the area include, tin, columbite, gypsum, limestone and quartz. Figures 1 and 2 shows the map of Nigeria classified into different vegetation belts and the Sahel- Sudan Savannah of Nigeria respectively

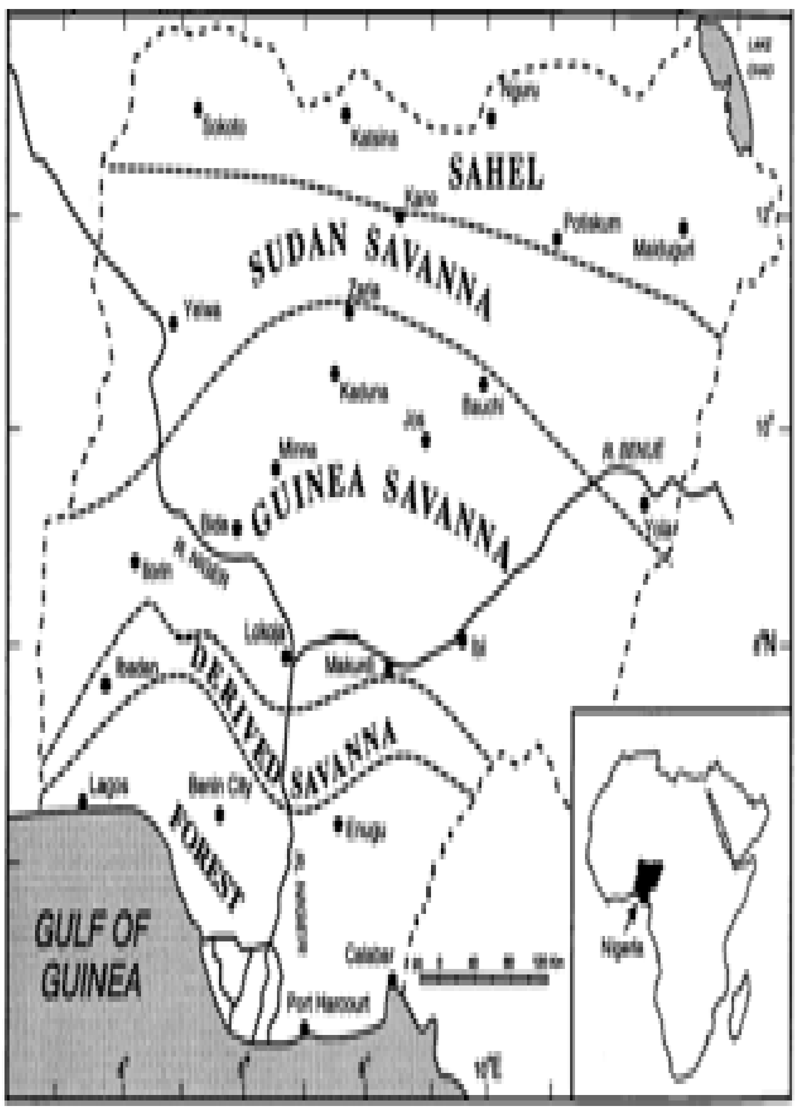

Fig. 1 Map of Nigeria divided into the different vegetation zones of Nigeria

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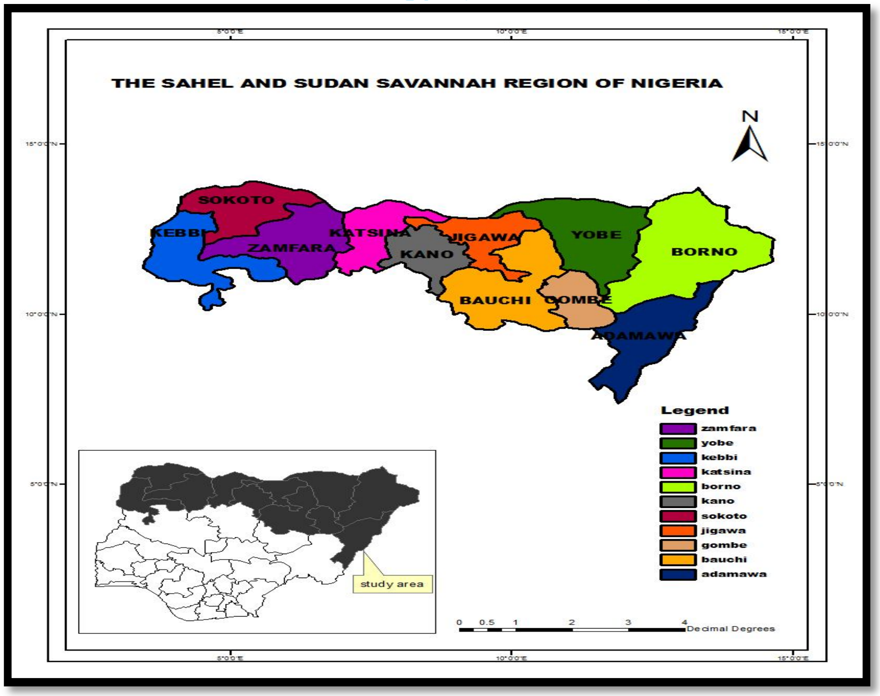

Fig. 2 Sahel and Sudan savannah of Nigeria

III. MATERIALS AND METHOD

The meteorological data used for this study was the rainfall data spanning through a period of 20 years (1981-2001). The data were sourced from the archives of Nigerian Meteorological Agency (NIMET), Oshodi, Lagos. The data were collected at different synoptic meteorological stations in the Sudano – Sahelian region of Nigeria.

TABLE I
METEOROLOGICAL STATIONS IN SAHEL- SUDAN SAVANNAH OF NIGERIA

S/N	STATIONS	LATITUDE	LONGITUDE	ALTITUDE
1	SOKOTO	13.01 ’N	05.15’ E	350.8
2	BAUCHI	10.17’ N	09.49’ E	609.7
3	NGURU	12.53’ N	10.28’ E	343.1
4	YELWA	10.53 ’N	04.45’ E	224.00
5	MAIDUGURI	11.51’ N	13.05’ E	353.8
6	KATSINA	13.01’ N	07.41’ E	517.6
7	POTISKUM	11.42’ N	11.02’ E	414.8
8	KANO	12.03’ N	08.12’ E	472.5
9	GUSAU	12.10’ N	06.42’ E	463.9
10	YOLA	09.14’ N	12.28’ E	186.1

The satellite data used in monitoring drought risk in the region is the NDVI (Normalized Difference Vegetation Index) obtained from AVHRR (Advanced Very High Resolution Radiometer). The NDVI was calculated from near-infrared (NIR) and visible (VIS) reflectance values. Given as

$$\mathrm{NDVI} = \frac{NIR - VIS}{NIR + VIS} \tag{1}$$

Severity of drought risk was estimated as the NDVI deviation from the long term NDVI mean.

$$\mathrm{DEVNDVI} = \mathrm{NDVI}\ i - \mathrm{NDVI}_{\text{mean m}} \tag{2}$$

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Anomaly of NDVI was calculated from the standardization of the NDVI $_{DEV.}$

$$\text{ANOMALY} = \frac{\text{NDVI dev}}{\sigma} \tag{3}$$

The classification scheme given in table 2 was used [10]

TABLE 2
DROUGHT CLASSIFICATION SCHEME

Percent of NDVI Anomalies	Anomalies Class
0% to -10%	Slight drought
-10% to -20%	Moderately drought
-20% to -30%	Severe drought
above -30%	Extreme drought

IV. RESULTS

A. Correlation Coefficient for Mean Seasonal Rainfall

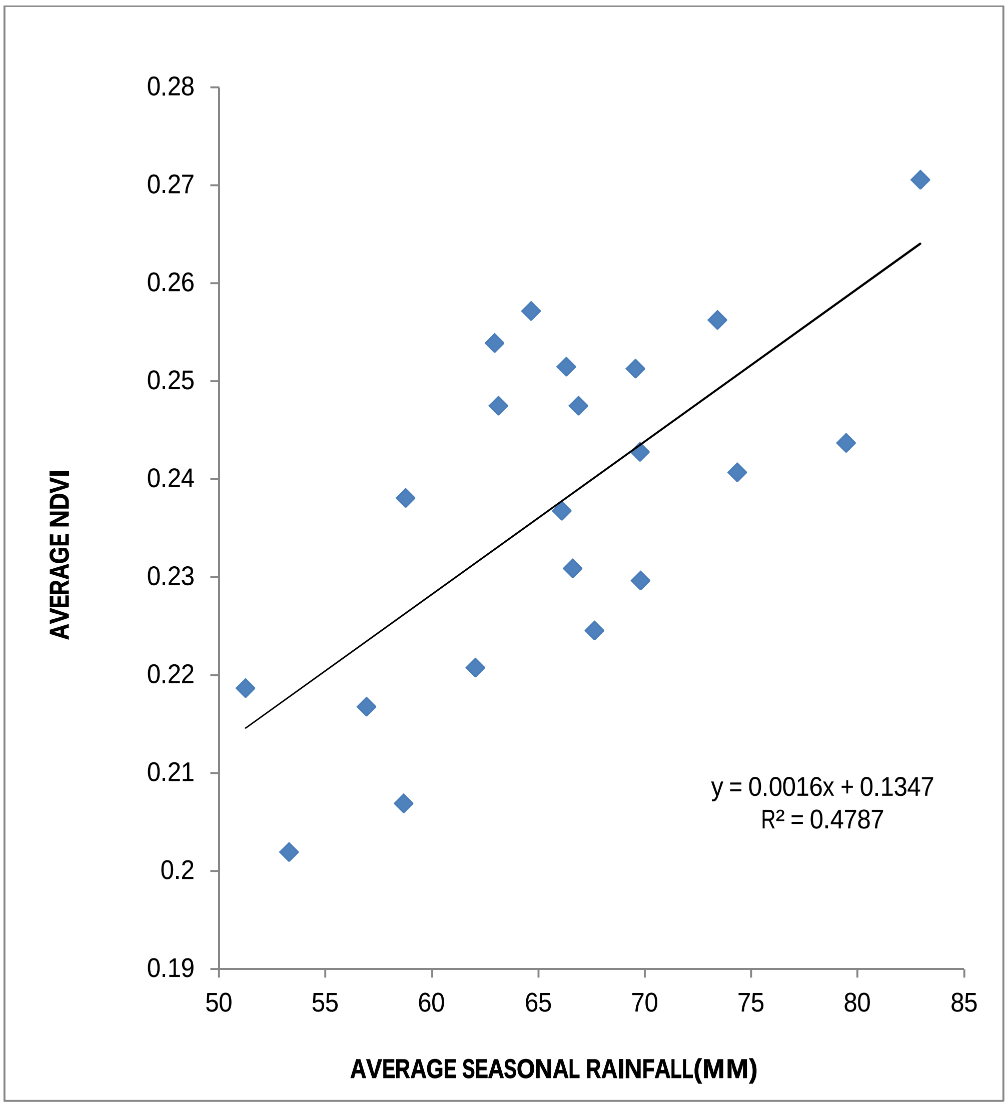

Fig. 3 Correlation Coefficient for mean seasonal rainfall

B. Drought Classification Map

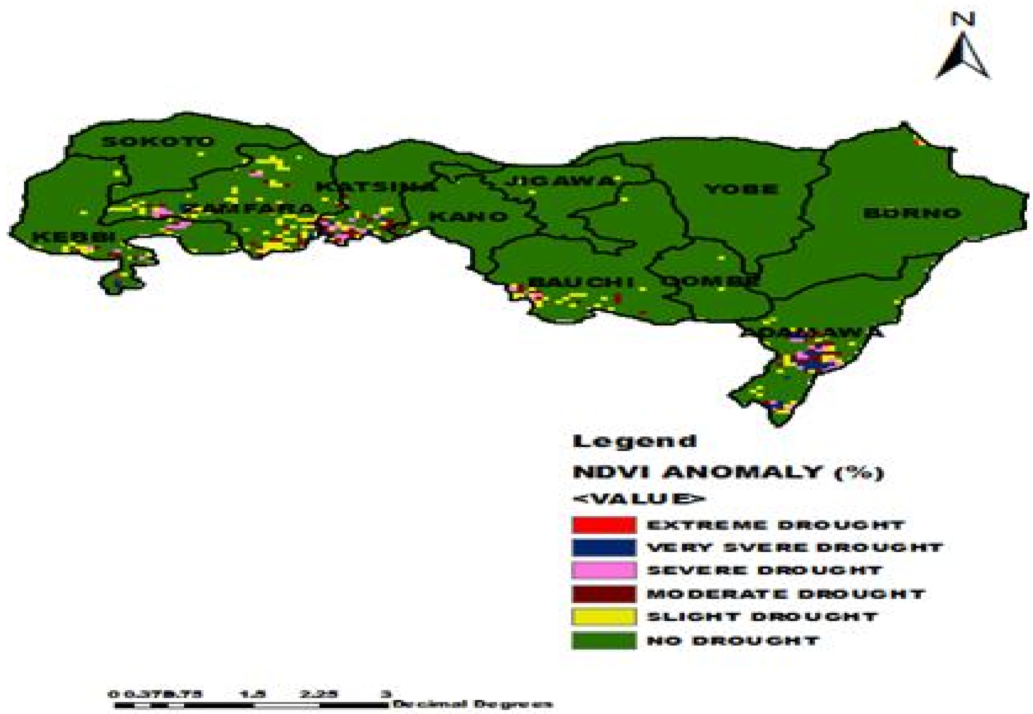

Fig. 4 Drought classification for the region in 1982

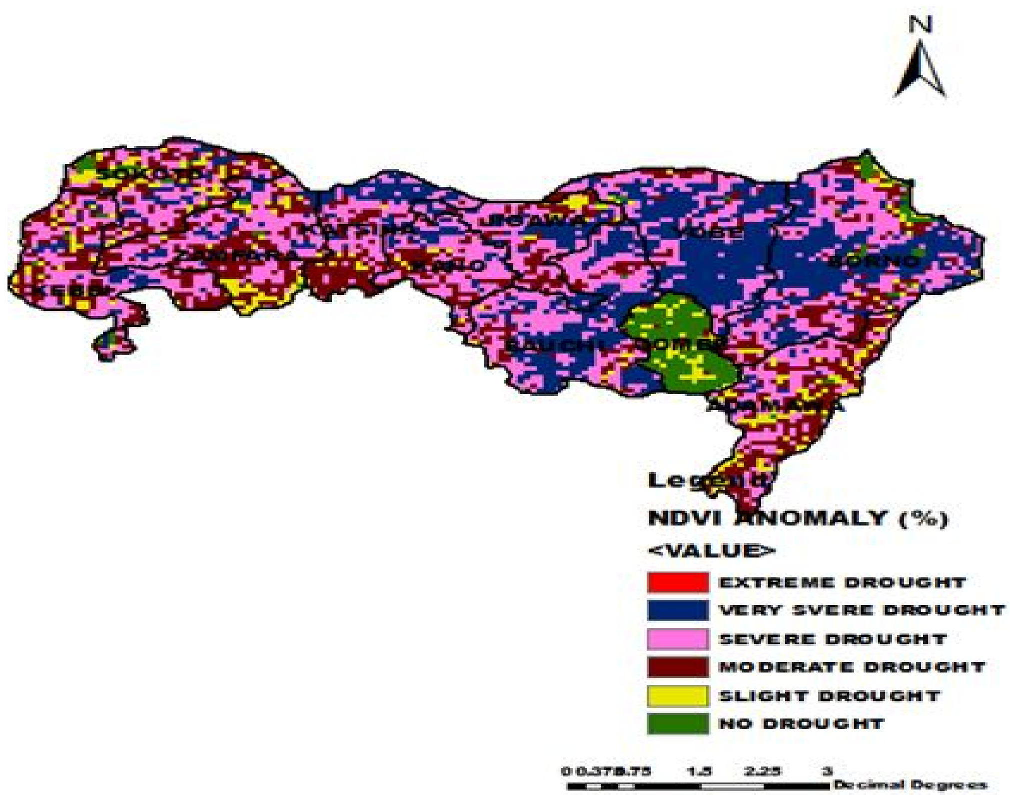

Fig. 5 Drought classification for the region in 1985

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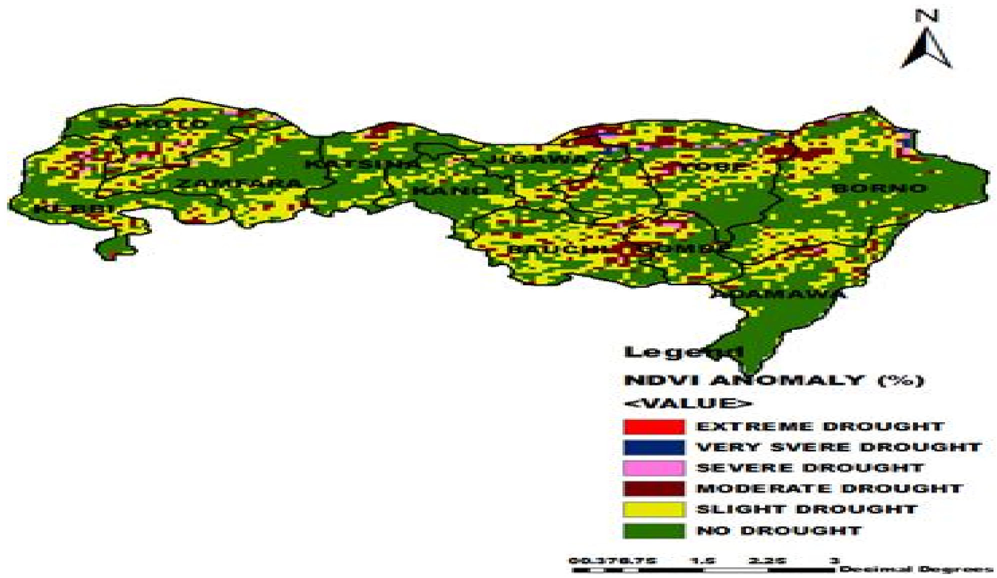

Fig. 6 Drought classification for the region in 1988

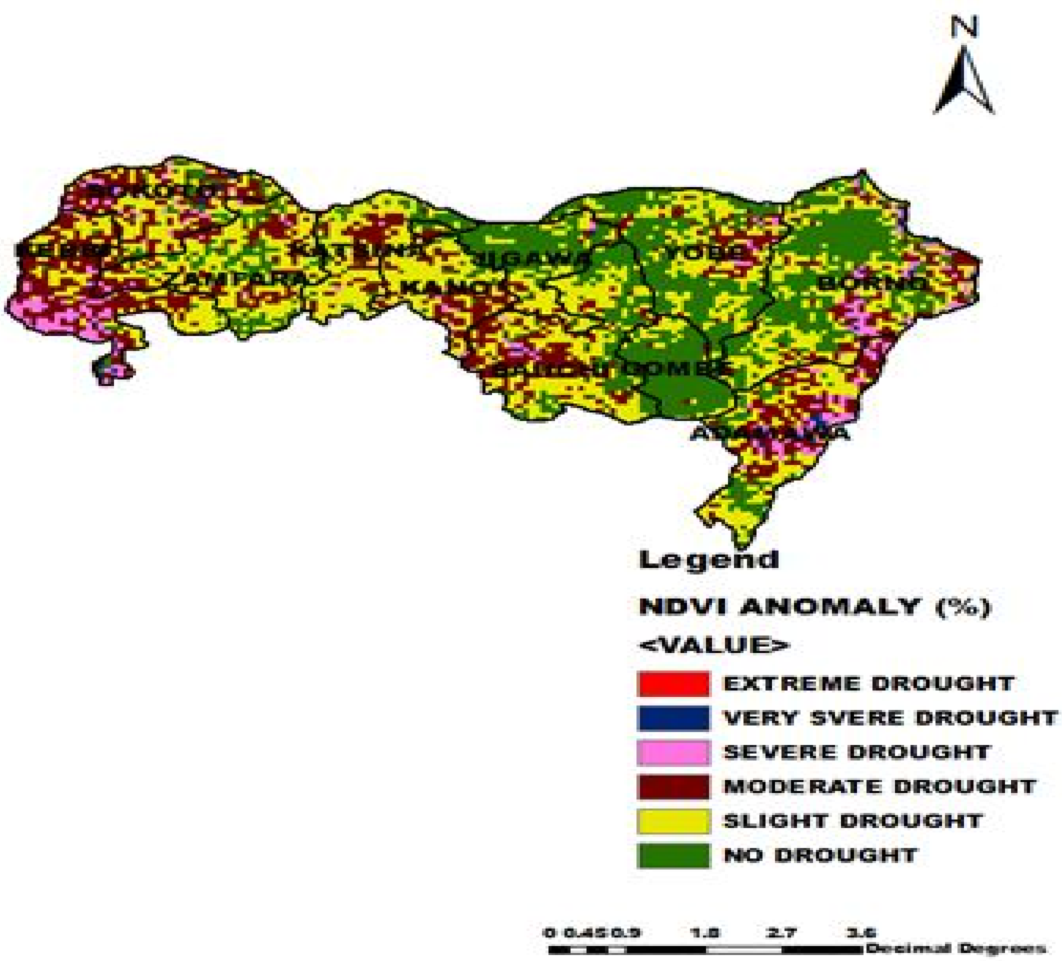

Fig. 7 Drought classification for the region in 1992

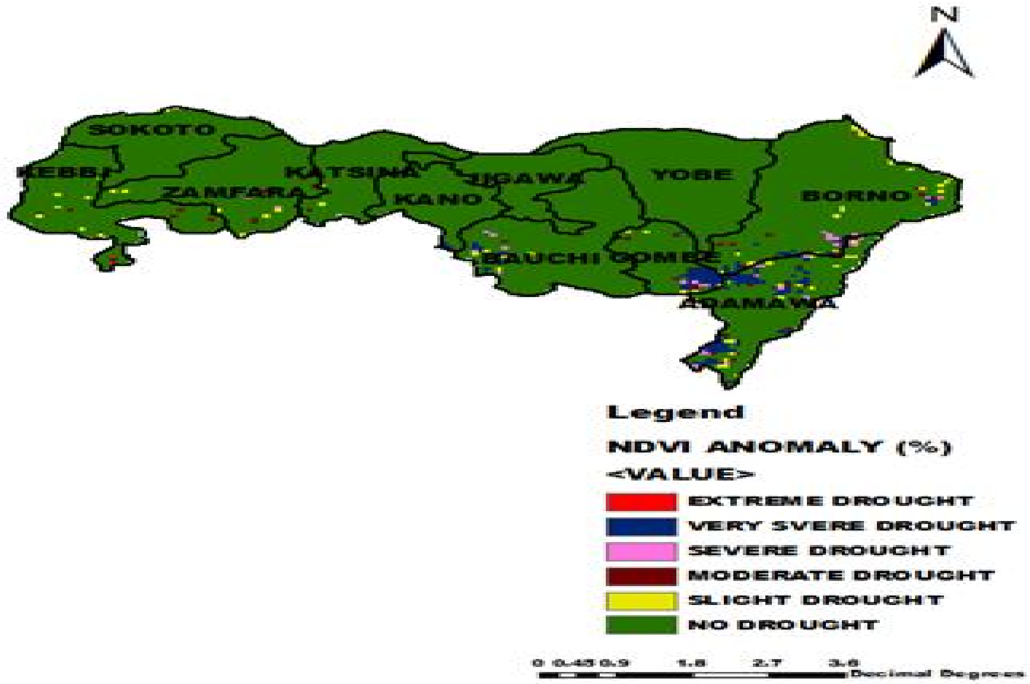

Fig. 8 Drought classification for the region in 1994

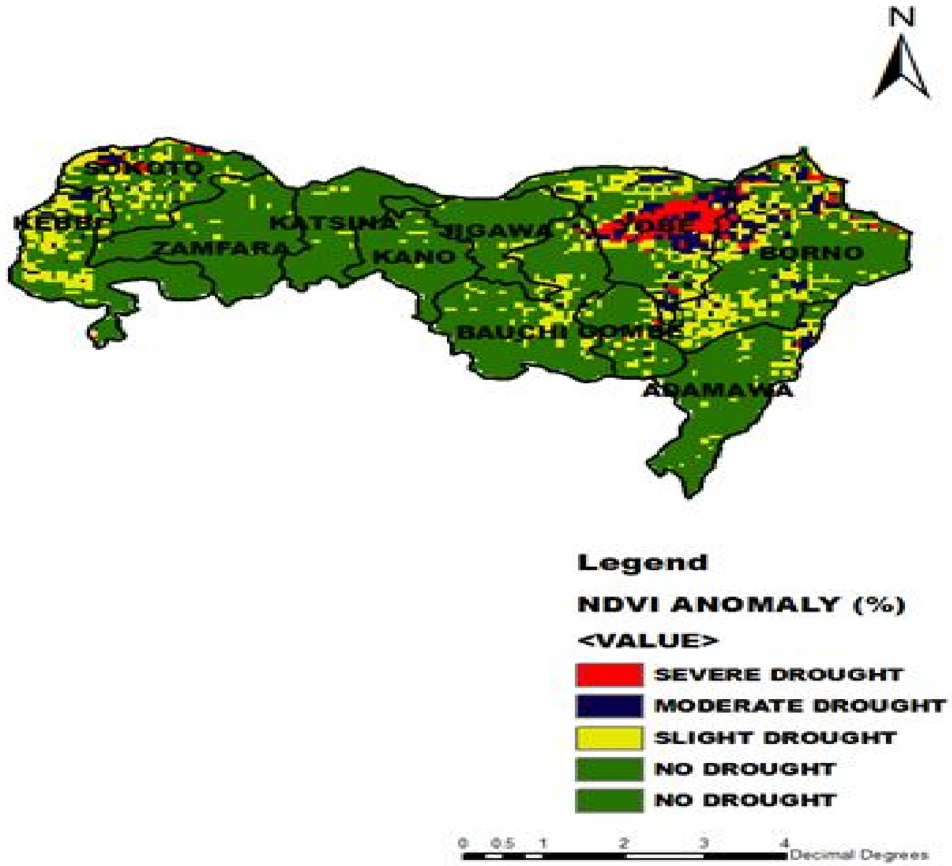

Fig. 9 Drought classification for the region in 1998

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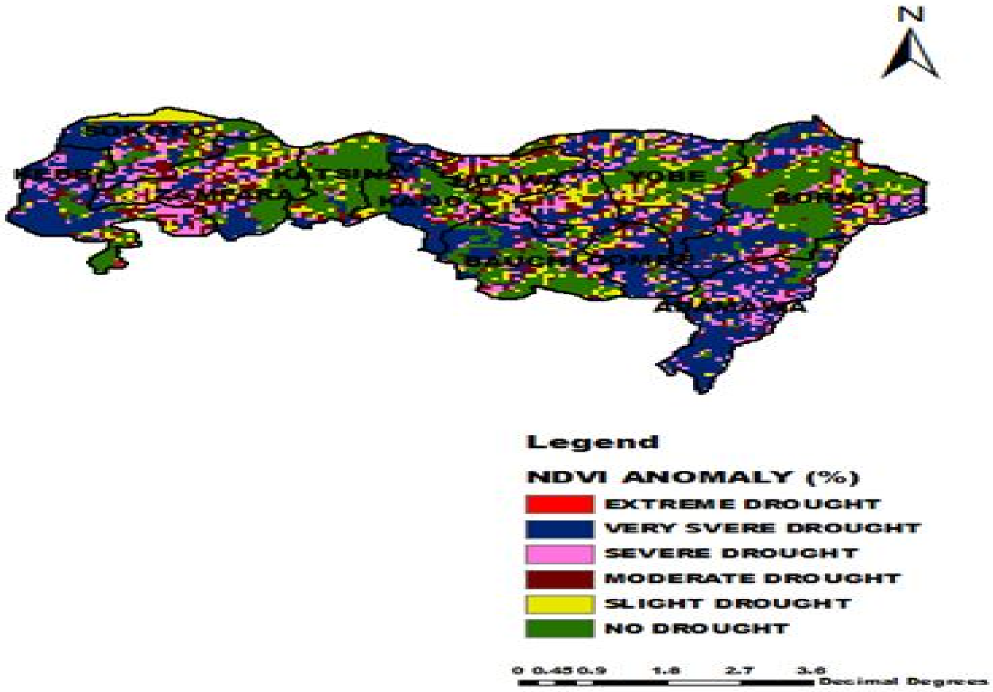

Fig. 10 Drought classification for the region in 2001

C. Temporal Trend of HDVI Anomaly

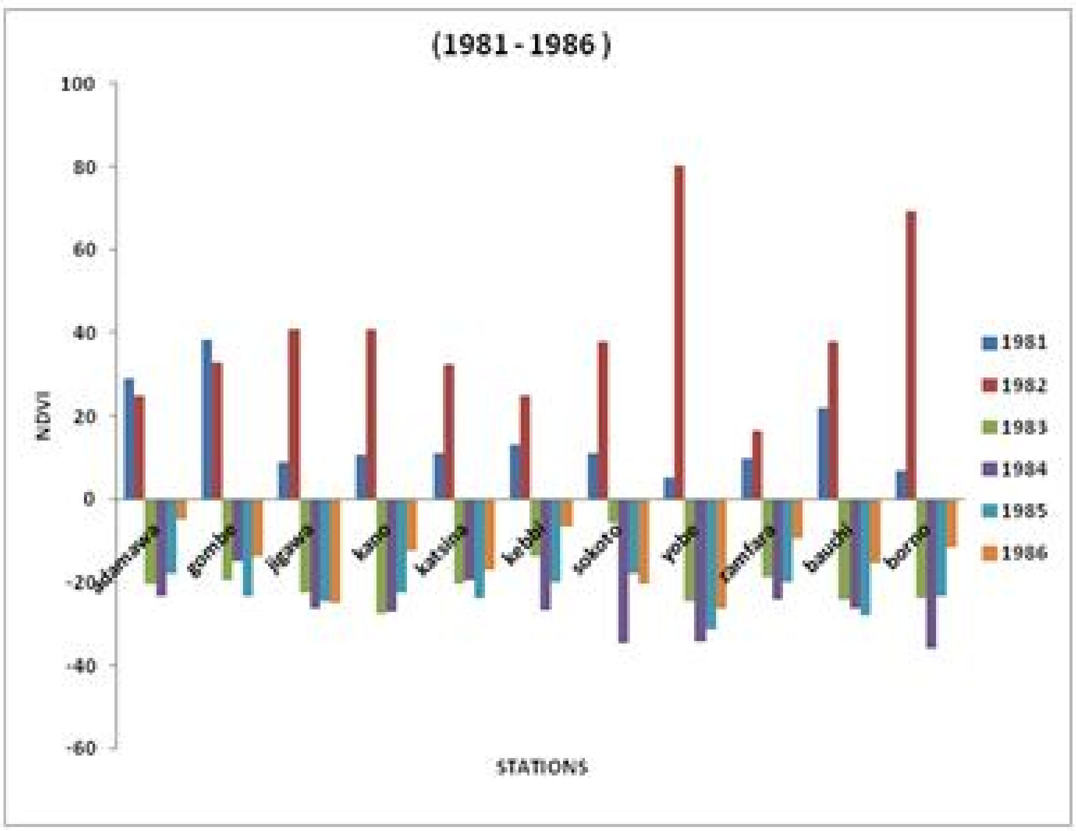

Fig. 11 Temporal tread of NDVI anomaly from the year 1981 to 1986

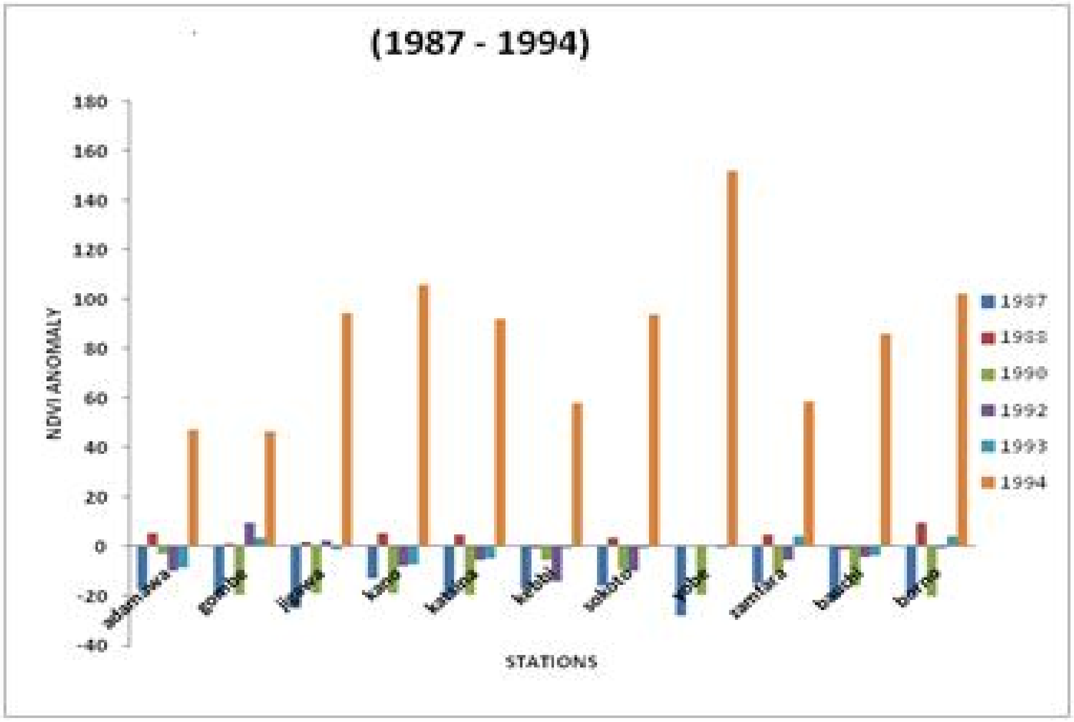

Fig. 12 Temporal tread of NDVI anomaly from the year 1987 to 1994

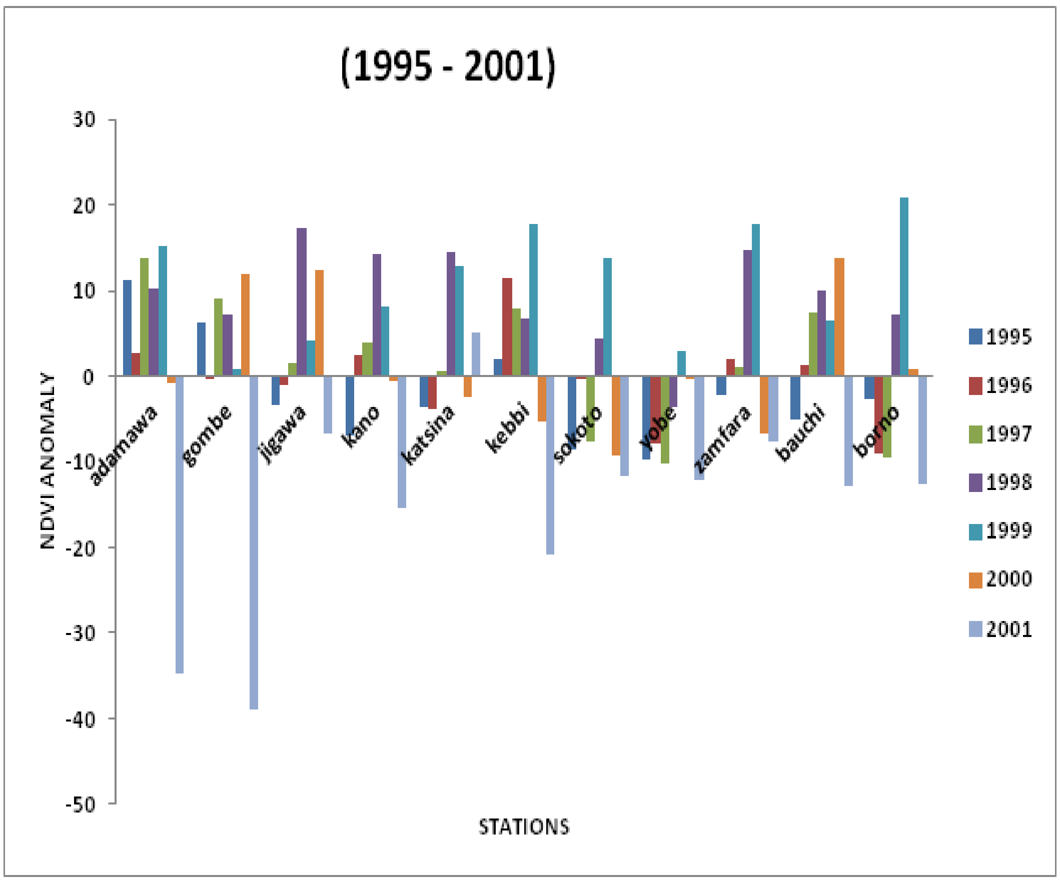

Fig. 13 Temporal tread of NDVI anomaly from the year 1995 to 2001

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V. DISCUSSION

The seasonal rainfall and NDVI pattern of the region was studied and the result revealed that there is a good correlation between rainfall and NDVI as shown in figure 3. The coefficient of correlation is $r = 0.68$. Timing and amount of rainfall was considered a factor besides rainfall distribution which have a remarkable effect on the response of vegetation to the existing vegetation apart from the rainfall distribution of the region [4].

The results of the classified spatial NDVI anomaly are shown in figure 4- 10 for each station in the study area. The degree of wetness and dryness in these years varies from year to year and also by location, this can also be explained from the movement of intertropical convergence zone in the area (ITCZ). In the year 1982, no drought condition was experienced in major parts of the study area. A detailed study of the map showed that some small areas of Zamfara which is located in the southern part of the study area experienced slight drought condition. However, the southern part of Katsina and Adamawa had more of severe drought than Zamfara while Bauchi was affected with slight drought during this period. In the year 1983 very extreme drought condition was prevalent in Borno,Yobe ,and Bauchi. These areas are towards the eastern part of the region, the western part of the study area experienced severe drought condition. During 1988, most area in the region experienced no drought at all although a slight drought condition was spotted but no so significant. Yobe, Borno and Katsina were affected with severe drought condition. According to the drought montoring and early warning sysytems in Nigeria,these states have been identified as area with severe and frequent drought condition. [2]. The agricultural drought map revelealed that 1994 and 1998 were wet years. In 1994, most stations in the region exprienced no drought condition except for Adamawa ,Gombe and Kebbi which had insignificant areas with very severe drought condition. Other areas like Borno, Sokoto and Kebbi experienced slight drought. Yobe experienced severe drought and a little of moderate drought during this year. This may be due to absence of vegetative surface in the area. However 1994 and 1998 year was regarded as a wet year. [19]. It was further observed that from late 1990s towards the year 2000, there is significant and gradual reduction in the occurrence of drought in the region as compared to the early 1980s. In the year 2001, severe drought was prevalent in the entire region although areas like Katsina, Kano,Yobe, Borno and Bauchi had small portions where there was no drought. This conditon could be suggested to result from the presence irrigation projects to compensate for inadequacy of water on those areas. The reslts on the magnitude and timing of drought occurence from this study agrees with observations by earlier researchers about the susceptibility of the Sudan- Sahel region of Nigeria to drought and desertification [22], [13], and [8].

Figures 10- 13 show the temporal trend of NDVI anomaly from 1981 to 2001.For the years between 1981 to 1986 the change in vegetation cover is sinusoidial and the magnitude of dryness in the region increased gradually from Adamawa to Kano, it however reduced from Kano to Katsina. Between 1987-1994, all the values of NDVI anaomaly were positive and the degree of wetness was high . this scenerio confirmed that 1994 is a predominantly a wet year for all the stations in the region. From 1995 to 2001, Adamawa and Gombe had a low vegetation cover indicating that there exist a very severe drought condition while other areas experienced dryness but not as extreme as Adamawa and Gombe. 1995 to 1999 are wet years, the vegetation cover did not exceed 20%.

VI. CONCLUSION

Agricultural drought condition experienced in the sahel and sudan region of Nigeria was succesfully classified and mapped out using the Remote Sensing and GIS technology. Drought risk areas were delineated by the integration of satellite images and meteorological information. The relationship between annual Rainfall amount and vegetation cover was established and a strong relationship between NDVI and rainfall amount existed in most of the stations. The Sudan Sahel region of Nigeria is generally replete with severe and prolonged drought scenarios. As from the 1980s, drought in the study area started gradually from the northern part and retreated southwards until 2001 when the whole study area was not affected by drought. These findings agree with results obtained from previous studies. Drought was more prevalent in the region between 1983 and 1989, during this period more of extreme drought condition was experienced. The late 1990s through to year 2000 witnessed a gradual decrease in drought occurrences. These results are very useful for making decisions on developing strategies for mitigating drought effects in the Sahel-Sudan region of Nigeria

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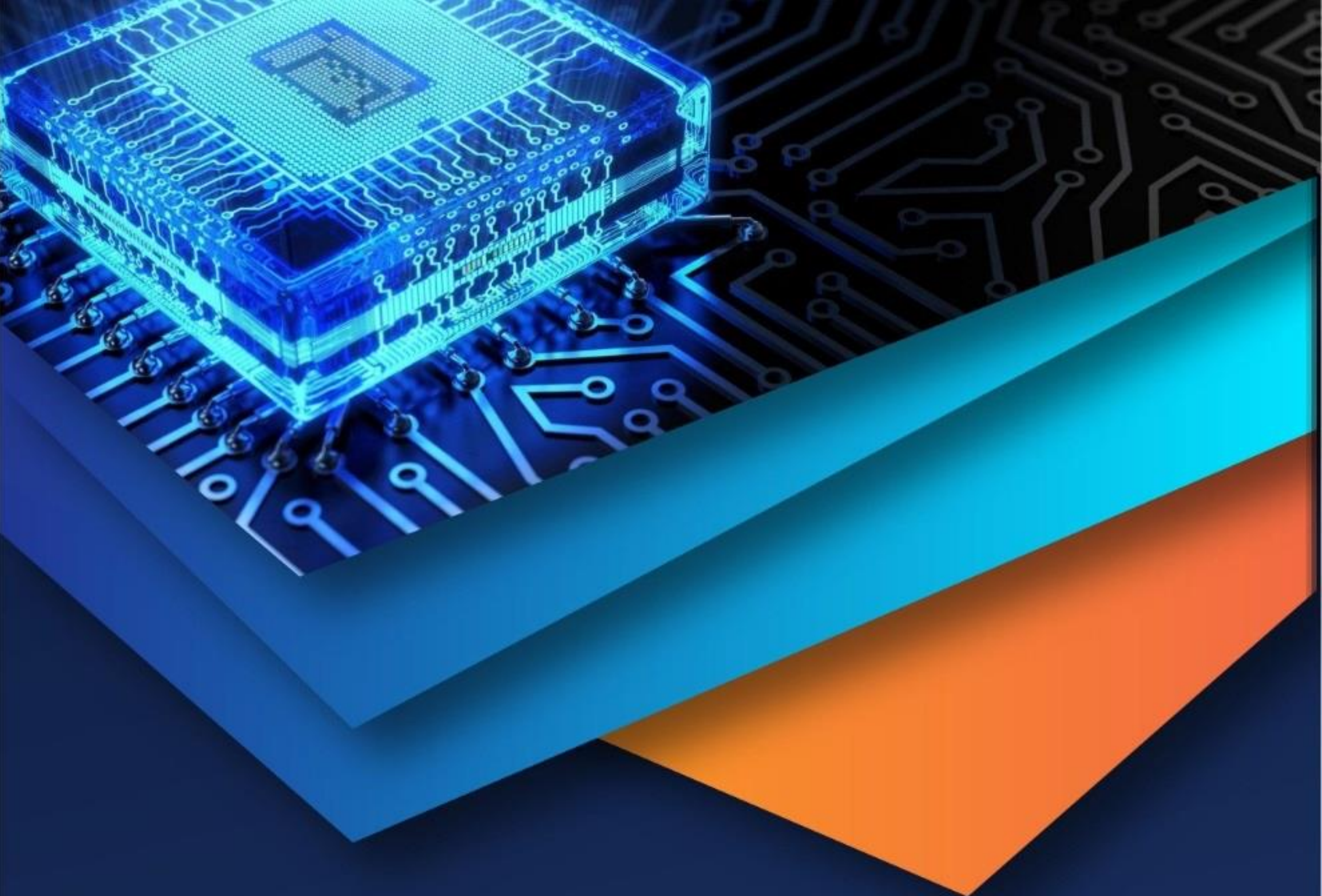

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