

## Spatiotemporal Pattern of Vegetation Response to Rainfall Quality in the Sudano-Sahelian Ecological Zone, Nigeria

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### ABSTRACT

The study examined the spatiotemporal patterns of vegetation response to rainfall quality in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria. Rainfall data for 1981 to 2018 from the Climate Research Unit (CRU) and the United States Geological Survey (USGS) satellite imageries of the study area was used. The Monsoon Quality Index (MQI) and the Perpendicular Vegetation Index (PVI) methods were used for the analysis. The Monsoon Quality Index were used to determine the moisture quality (good or bad rainfall performance), while Perpendicular Vegetation Index was used to analyze the satellite images at the Infrared (IR) and Near Infrared (NIR) level. The result shows high variability in the amount of rainfall received across the ecological zone. The lowest average rainfall of 536mm was detected at Nguru while the highest was in Yelwa (1090.65mm). The analysis of rainfall quality shows that rainfall in the study area ranged from good at MQI value of <0.005 to extremely poor at MQI value of >0.02. Yelwa station shows an MQI value <0.005 which indicates a good rainfall performance and in return has NDVI values between 0.440-0.874 and signifies healthy vegetation. The same pattern was observed in the Sokoto, station where MQI value is >0.02, indicating extremely poor rainfall. This has implication for the vegetation vigour also because the NDVI falls between -2-0.09. The result shows that out of the eight (8) stations considered for this study, six (6) of the stations (Sokoto, Gusau, Katsina, Kano, Kaduna and Maiduguri) have NDVI values between -0.2-0.09 signifying poor vegetation vigour. However, Yelwa and Bauchi stations show NDVI values between 0.440-0.874 which signify healthy vegetation. The study shows a direct relationship between rainfall quality and vegetation vigour because the higher the rainfall quality, the healthier the vegetation and vice versa. The study recommends national green approach to restore the lost vegetation of the Sudano-Sahelian Ecological Zone to halt the loss of ecosystems and also mitigate the effect of climate change which has affected the quality of rainfall in the region.

**Keywords:** Rainfall, moisture quality Index, Normalised Difference in Vegetation Index.

### 1.0 INTRODUCTION

Rainfall and vegetation dynamics have been observed to be interconnected as the amount of rainfall received by vegetation is a major

factor determining its thickness or otherwise (Usman, 2000; Nayak *et al.*, 2005). For example, Studies reported that vegetation growth at high latitudes in some Northern

hemisphere regions had increased from 1981 to the 1990s due to an increase in the amount of rainfall received (Nayak *et al.*, 2005). Large scale changes in vegetation leaf area index are also known to have led to shifts in temperature and precipitation patterns, but these feedback mechanisms are complex, varying greatly from location to location and over time.

Remote sensing provides a vital tool in capturing the temporal dynamics of vegetation changes in response to weather (rainfall) or climate shifts, at spatial resolutions fine enough to capture the spatial heterogeneity (Bradley *et al.*, 2007; Guet *et al.*, 2009; Jacquin *et al.*, 2010 and Beck *et al.*, 2011). Frequent satellite data, for example, can provide the basis for studying time-series of ecological parameters related to vegetation dynamics (Bradley *et al.*, 2007; Gu *et al.*, 2009; Jacquin *et al.*, 2010; Beck *et al.*, 2011).

The Normalized-Difference Vegetation Index (NDVI) has been frequently used in vegetation dynamics studies, as this index is highly correlated with the leaf area index, photosynthetic capacity, biomass, dry matter accumulation and net primary productivity (Wang *et al.*, 2010). Therefore, NDVI data are frequently used to assess Spatio-temporal changes in regional vegetation dynamics (Kang *et al.*, 2011; Zhang *et al.*, 2011) in response to changes in regional climate. Normalised Difference Vegetation Index (NDVI) is one of the main characteristic descriptors of vegetation cover and is widely used to monitor the changing dynamics of vegetation cover, biomass and the ecosystem (Bradley *et al.*, 2007; Gu *et al.*, 2009; Jacquin *et al.*, 2010; Beck *et al.*, 2011). In addition, NDVI can be used to represent the proxy vegetation responses to climate change since it is well correlated with the fraction of active photosynthetic radiation absorbed by plant canopies and thus leaf area, leaf biomass and potential photosynthesis (Liu *et al.*, 2016).

Vegetation dynamics is affected by many factors, including rainfall. This study utilized spatial interpolation techniques in understanding the influence of rainfall quality on vegetation dynamics. Therefore, this study examined the Spatio-temporal pattern of vegetation response to the quality of rainfall received in the study area during the study period. Specifically, the objectives include assessing mean annual rainfall distribution, Moisture Quality Index (MQI) and vegetation response to rainfall quality in the study area with a view of establishing a relationship between rainfall quality and vegetation vigour in the Sudano-Sahelian Ecological Zone.

## 2.0 MATERIALS AND METHODS

### 2.1 The Study Area

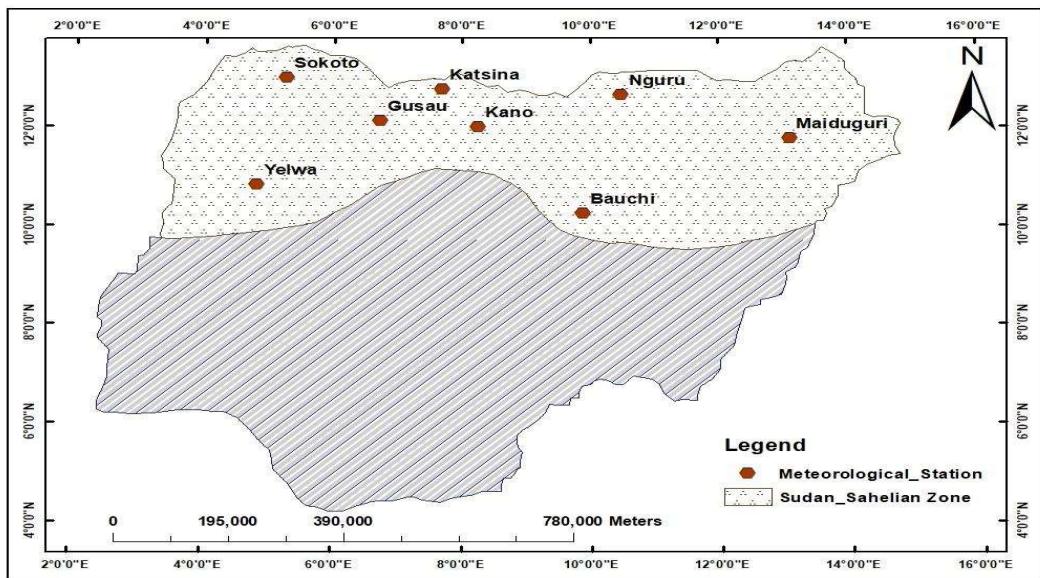
The Sudano-Sahelian Ecological Zone (SSEZ) is located in northern Nigeria between latitude  $10^0\text{N}$  and  $14^0\text{N}$  and longitude  $4^0\text{E}$  and  $14^0\text{E}$  (see Figure 1).

This is the largest ecological zone in the country and stretches from the Sokoto plains through the northern section of the high plains down to the Chad Basins (Odekunle *et al.*, 2008). The average annual rainfall in this zone varies from less than 500mm in the extreme northeastern part to 1000mm in the southern sub-region (Abaje *et al.*, 2012).

### 2.2 Methods of Data Collection and Analysis

The data used for the study are summarized in Table 1.

The Monsoon Quality Index (MQI) developed by Usman (2000) was used to examine moisture quality for the study area. The MQI measures the quality of rainfall



**Figure 1:** Geographical Location of the Study Area

**Table 1:** Types and Sources of Data Used

S/N	Type of Data	Source	Amount/Scale/Resolution
1	MODIS	Earth Data	30 meter resolution
2	Satellite-derived Rainfall Data	Climate Research Unit (CRU)	Gridded data at 15meter resolution, 1981-2018 Converted into Pentads
3	Landsat 8	USGS Earth Explorer	30 meter resolution

received in terms of both the annual amount and seasonal spread. It is expressed as:

$$MQI = \frac{(r_{mmi} \times Nb_i)}{(R_i)^2} \quad (\text{Equation 1})$$

Where:  $i$  = Year identifier

$r_{mm}$  = Highest monthly rainfall total

$R$  = Annual monthly rainfall total

$N_b$  = Number of „breaks“ in rainfall.

A break is taken as any pentad period with less than 5mm of rain.

The estimated MQI values were interpreted according to the MQI classification table (Table 2).

The Perpendicular Vegetation Index (PVI) method was used to investigate the spatio-temporal pattern of vegetation response to

**Table 2:** Monsoon Quality Index Classification Values

MQI Value	Category
$\geq 0.015$	Very poor
$\geq 0.01 < 0.015$	Poor
$\geq 0.005 < 0.01$	Fair
$\geq 0.001 < 0.005$	Good
$< 0.001$	Very good

*Source: Usman (2000)*

quality of rainfall in the study area (Richardson and Wiegand, 1977). The equation is expressed as:

$$PVI = \frac{\rho_r - \rho_{ir,s}}{\sqrt{(\rho G_{ir,s} - \rho P_{ir}) - (\rho G_{r,s} - \rho P_r)^2}} \quad (\text{Equation 2})$$

Where:  $\rho_{r,s}$  and  $\rho_{ir,s}$  = reflectance of soil background in R and NIR bands, respectively

$\rho_r$  and  $\rho_{ir}$  = reflectance of vegetation in R and NIR bands

### 3.0 RESULTS AND DISCUSSIONS

#### 3.1 Annual Rainfall Distribution in the Study Area

Annual rainfall distribution across the study area is presented in Table 3.

**Table 3:** Annual Average Rainfall Distributions in the Study Area

S.N	Stations	Annual Average Rainfall
1	Nguru	536.91
2	Sokoto	567.15
3	Maiduguri	631.04
4	Katsina	652.48
5	Kano	663.18
6	Gusau	797.52
7	Bauchi	856.71
8	Yelwa	1090.65

The result shows that the lowest annual rainfall amount was received in Nguru station at 536.91mm while the highest was in Yelwa station with 1090.65mm rainfall. In comparison, the North-eastern axis of the study area received lower annual rainfall amounts than the North-western axis except in Bauchi where average annual rainfall of 856.71mm was recorded.

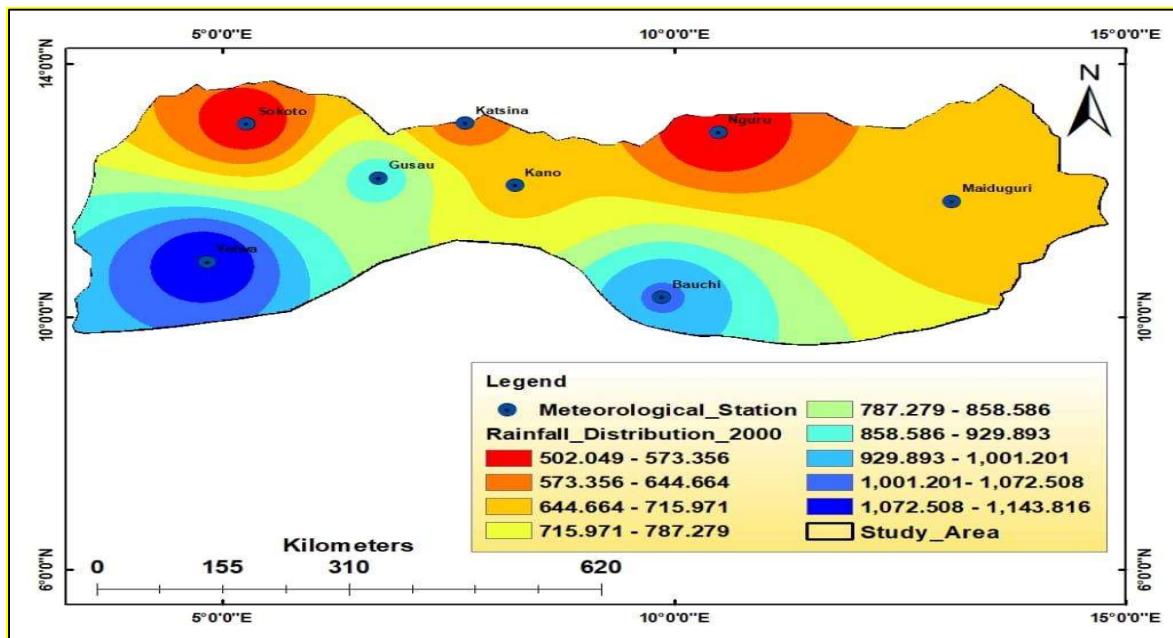
Figure 2 shows the annual average rainfall distribution which was used to compute the MQI in the study area, the result ranges from Poor, Moderate and Good rainfall distribution across stations. The region with poor rainfall distribution (shown in red) has an annual average rainfall range between 400.305 - 556.896mm (between Maiduguri,

Nguru and part of Sokoto). Similarly, the region with moderate rainfall distribution (in yellow) has an annual average rainfall range of 635.192 - 870.079mm and is made up of Kano, Kaduna and part of Gusau. Finally, regions with good rainfall distribution (Yelwa and Bauchi) shown in blue are areas which receive annual average rainfall of 870.079 mm - 1104.966mm.

#### 3.2 Analysis of Moisture Quality Index (MQI) over the Study Area

The analysis of the Moisture Quality Index for the study area is shown in Figure 3. The Bauchi station recorded the highest MQI value of 0.0593 in 2006 which indicates an extremely poor rainfall performance, while the lowest MQI value of 0.006 was found in 1994, indicating good rainfall.

The result for Gusau station shows that the highest MQI value of 0.0345 was in 2013 and indicated an extremely poor rainfall performance, while the lowest MQI value of 0.0088 was in 1994 and indicates good rainfall performance. Similarly, the Kano station recorded the highest MQI value of 0.0632 in 2006 indicating an extremely poor rainfall performance, while the lowest at 0.0116 in 1996 is an indicator for good rainfall performance. For the Katsina station, the result shows that the highest MQI value of 0.0418 was in 2013 and indicates an extremely poor rainfall performance, while the lowest MQI value of 0.0153 in 2012 showed good rainfall performance. The Maiduguri station recorded the highest MQI value of 0.0566 in 2004 which indicates an extremely poor rainfall performance and the lowest at 0.016 in 1986, indicating a good rainfall performance. The result for Nguru station shows that the highest MQI value of 0.0559 was in 2015, indicating an extremely



**Figure 2:** Rainfall Distribution in the Sudano-Sahelian Ecological Zone of Nigeria

**Source:** Authors' work.

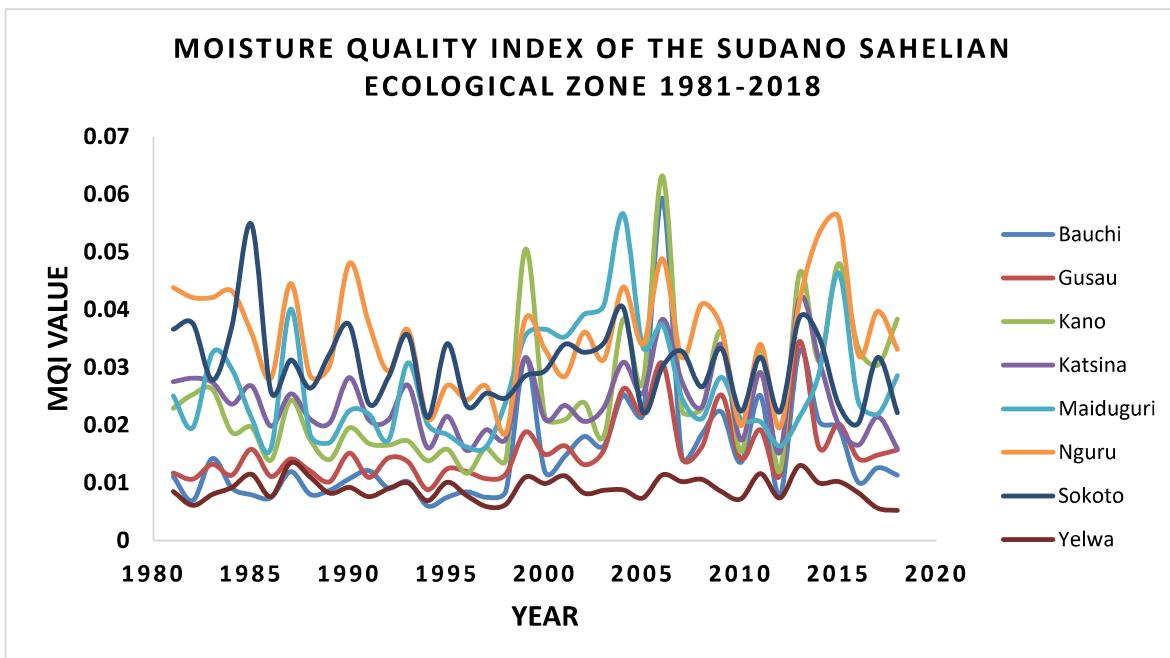
poor rainfall performance. However, the lowest MQI value at 0.0186 in 1998 indicates good rainfall performance that year. The Sokoto station showed the highest MQI value of 0.0548 in 1985 which indicates an extremely poor rainfall performance while the lowest MQI value at 0.0221 in 2018 indicates good rainfall performance. Finally, the highest MQI value for Yelwa at 0.0135 in 1987 indicates an extremely poor rainfall performance while the lowest value of 0.0052 in 2018 indicates a good rainfall performance. According to Usman (2000), when the MQI value is small, it indicates that the season receives quality moisture, affecting vegetation response to rainfall variability and vice versa. Generally, the MQI values for the study area show a decreasing trend and imply that rainfall received in the study area has been declining in terms of quantity and spread.

### 3.3 Analysis of Vegetation Response to Rainfall Quality in the SSEZ

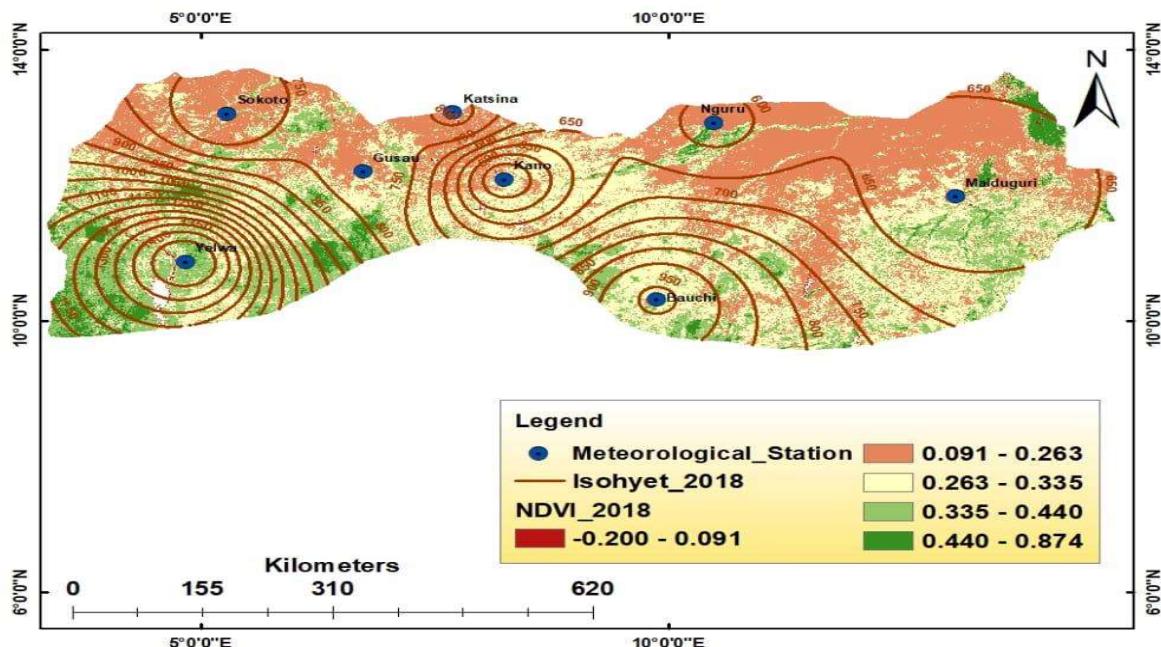
The results of the analysis of vegetation response to rainfall quality in the Sudano-

Sahelian Ecological Zone are shown in Figure 4. The results show that stations with good rainfall performance (MQI value  $<0.005$ ) had good vegetation vigour, while vegetation vigour was poor in stations where rainfall quality is poor (MQI value  $>0.02$ ). For example, the Yelwa station had an MQI value  $<0.005$  throughout the year and NDVI value of 0.440-0.874. These indicate good rainfall performance and healthy vegetation. The pattern however, is different in the Sokoto station where the MQI value of  $>0.02$  and NDVI range of -2 - 0.09 indicate extremely poor rainfall and poor vegetation vigour.

The results also show that the Sokoto, Gusau, Katsina, Kano, Kaduna and Maiduguri stations have NDVI values which range between -0.2 - 0.09 thereby indicating poor vegetation vigour, while the Yelwa and Bauchi stations have NDVI values between 0.440 - 0.874 indicating healthy vegetation. The findings of this study show that when the



**Figure 3:** Moisture Quality Index of the Sudano-Sahelian Ecological Zone 1981-2018



**Figure 4:** Vegetation Response to Rainfall Quality in the Study Area.

*Source:* Authors work.

MQI value is  $>0.02$  (indicating poor rainfall quality), the NDVI value decreases and implies poor vegetation vigour. Similarly, when the MQI value is  $<0.005$  (indicating

good rainfall performance), the NDVI value increases and consequently indicates healthy vegetation.

#### 4.0 CONCLUSION

The study investigated the spatio-temporal pattern of vegetation response to rainfall quality in the Sudano-Sahelian Ecological Zone, Nigeria. The study shows inter-annual variability in rainfall distribution across the study area. The study established that 6 stations (Sokoto, Gusau, Katsina, Kano, Kaduna and Maiduguri) with NDVI values between -0.2 - 0.09 showed poor vegetation vigour due to poor rainfall quality, while Yelwa and Bauchi stations had healthy vegetation vigour attributable to good rainfall quality. The study concluded that there is a direct relationship between rainfall quality and vegetation vigour as the findings of this study show that when the MQI value is  $>0.02$ , the NDVI value decreases with implication for poor vegetation vigour. The study recommends a green approach to restore the lost vegetation of the Sudano-Sahelian Ecological Zone, mitigate the loss of the ecosystem and also help check the effect of climate change in the region.

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