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Geo-Spatial Analysis of Rainfall Amounts and Rainy Days Using Satellites and Ground-Based Data in Nigeria

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Abstract: *Nigerian rainfall is critical for domestic use through the surface and sub-surface recharge and agricultural production, mostly rain-fed. Analysing three (3) long-term precipitation data (Rain Gauges, CHIRPSv2.0, and TAMSATv3) is vital to account for hydrological extremes in other design and operations of water systems and agricultural monitoring. This study analysed (i) the spatio-temporal variability of rainfall amounts focusing on inter-annual and seasonal variability, and (ii) average monthly rainy days for the period of 39 years (1981-2019).Temporal distribution was analysed using descriptive statistics. The kriging interpolation method in ArcGIS 10.4 was used to map the spatial distribution of rainfall amounts and wet-dry days. Findings revealed that the Southern part contributes 65.3 per cent to the total annual rainfall, and June - November rain contributes 76.6 per cent. 39 years climatological average of the total number of 14,244 days showed the least (57) and highest (235) monthly rainy days observed in the north and south. During June, July and August months, most parts of the country received rain with varying intensities, while the decline begins in September from the north-east and reaches the south in November. Rainfall amounts and rainy days increased from the north to the south and vice versa, except July, August, and September. Accurate and detailed rainfall observations are required and essential for many applications. Therefore, satellite precipitation estimates can be used as alternative sources of input data in many meteorological and hydrological applications, especially in Nigeria, characterised by a low density of rain gauge stations.*

***Keywords**: Geo-spatial analysis, Ground-based, Rainfall amounts, Satellite-based rainfall estimates, Wet-dry days.*

INTRODUCTION

Knowledge of current and historical hydro-climatological variables is pertinent to the future development and sustainable management of water resources of a given region, especially within the context of global warming, water and energy cycles and the increasing demand for water due to population and economic growth [1]. The climate of a location can be understood most easily in terms of annual or seasonal averages of temperature and precipitation. Therefore, precipitation, which is synonymous with rainfall in the tropics, is the present study's focus.

Precipitation is a very complicated parameter because of its high variability at small scales [2]. This variability is further significant when viewed within the climate system because of the potential for secular changes in its intensity and distribution characteristics. Global land precipitation has increased by about 2 percent in the twentieth century [3]. The tropical region, in particular, is highly sensitive to variations in rainfall amount owing to heavy dependence on rain-fed agriculture [4].

Precipitation, especially rain, dramatically affects agriculture because all plants need at least some water to survive. Therefore, high spatial and temporal rainfall variability is a major challenge in managing agricultural activities across Africa, as above or below average rainfall can lead to crop losses and failure [5]. Furthermore, the economy of most African countries is dependent on rain-fed agriculture and hence the African continent is vulnerable to prolonged periods of drought and floods that lead to food insecurity [6]. The knowledge of the amount, spatial, and temporal variation of precipitation is therefore important for improving water budgeting.

Rainfall is discontinuous in space and time and exhibits large natural variability, unlike many meteorological parameters. Its variation in intensity and duration can be in the form of a large storm to storm as well as from region to region. To help mitigate these climate-related risks, access to reliable rainfall information, both historical and near-real-time, is necessary. Historical data allows climate risks and long-term changes in the rainfall climate to be assessed, while near-real-time data is important to evaluate the present-day weather in a historical context. The latter is especially important in monitoring the evolution of hydrological hazards, allowing timely responses from governments and organisations before major crises occur. Although temporally coarse data can be useful for evaluating climatic trends and monitoring above or below-average rainfall.

Several studies have been carried out at different temporal scales and in different parts of the globe and have adduced extreme rainfall as the major cause of flood worldwide. Rain gauge data have been employed in several studies in Nigeria such as [7], [8]-[9], [10], [11], [12], [13], [14]-[15], [16], [17], to mention but a few. However, few studies conducted in Nigeria used remotely sensed data to provide a detailed study of rainfall characteristics and variations specific to extreme weather events, numerical weather prediction, local crop forecasting, and livelihoods. For this reason, accurate precipitation data with high temporal and spatial resolution and precipitation data are needed for the precipitation studies.

In this study, spatio-temporal variability of rainfall amounts focusing on inter-annual and seasonal variability and average monthly rainy days were analysed using three (3) different long-term precipitation datasets (ground-based and two satellite-based) for water resource management and agricultural production in Nigeria. This is especially apt at this time in Nigeria because of the country's low density of meteorological ground data collection.

RESEARCH METHODOLOGY

Study Area

The study area lies between latitudes 4° and 14° north of the equator and longitudes 2° 42' and 15° 00' east of the Greenwich Meridian (Fig. 1). It is bordered to the north through the North West by Niger Republic, to the north east by Chad, to the east by Republic of Cameroun, to the south by the Atlantic Ocean, and the west by the Benin Republic. The study area has a unique tropical climate with two precipitation regimes: low precipitation in the north leading to aridity and desertification and high precipitation in parts of the southwest and southeast leading to large scale flooding. The climate is dominated by the influence of three major atmospheric phenomena, namely: the maritime tropical (mT) air mass, the continental tropical (cT) air mass and the equatorial easterlies [14]. The Tropical Maritime (mT) air mass is dense and moist which originates from the Atlantic Ocean. Tropical Continental (cT) is dry and dusty which originates from the Sahara Desert. The equatorial easterlies are rather erratic, cool air masses that come from the East and flow in the upper atmosphere along the ITD. The least annual rainfall (<700 mm) occurs in the extreme north, while the highest amounts of annual rainfall (<2,000 mm) occurs in the coastal regions. Temperature and humidity remained relatively constant throughout the year in the south, while the seasons vary considerably in the north; during the northern dry season, the daily temperature range becomes great as well [18].

Materials and Methods

This study employed daily and monthly precipitation datasets from rain gauges, and two satellite-based precipitation estimates such as Climate Hazards Group InfraRed Precipitation with Station Data, Version 2.01, and Tropical Applications of Meteorology Using Satellite and Ground-Based Observations (TAMSAT) African Rainfall Climatology and Time series (TARCAT), version 3. Rainfall data for 48 weather stations that spread across the study area (Fig. 1) for 39 years (1981-2019) were used in this study. The main characteristics and sources of rain gauge and satellite-based precipitation products are summarised in Table 1, while the descriptions of the two satellite-based precipitation products are described hereafter. The use of rain gauge data from Nigerian Meteorological Agency (NiMet) and other two satellite-based rainfall estimates was to distinctively portray the evidence of spatio-temporal distribution of rainfall amounts and its average monthly rainy days for the studied period. Weather stations with missing monthly data were filled up with interpolation method of Inverse Distance Weighting (IDW) in ArcGIS version 10.4. Monthly precipitation data were aggregated to form seasonal (DJF, MAM, JJA, and SON), and annual (January - December) rainfall values. Descriptive statistics was employed for the analysis of annual and seasonal rainfall amounts, while the average monthly rainy days of CHIRPSv2.0 was assessed using Excel Logic Functions. Rainy day is described as when the rainfall amount is equal to or greater than 1mm (i.e. rain ≥ 1mm) [15], [19]. The kriging interpolation method in ArcGIS 10.4 was used to map the spatial distribution of rainfall amounts and average monthly rainy days for the study area.

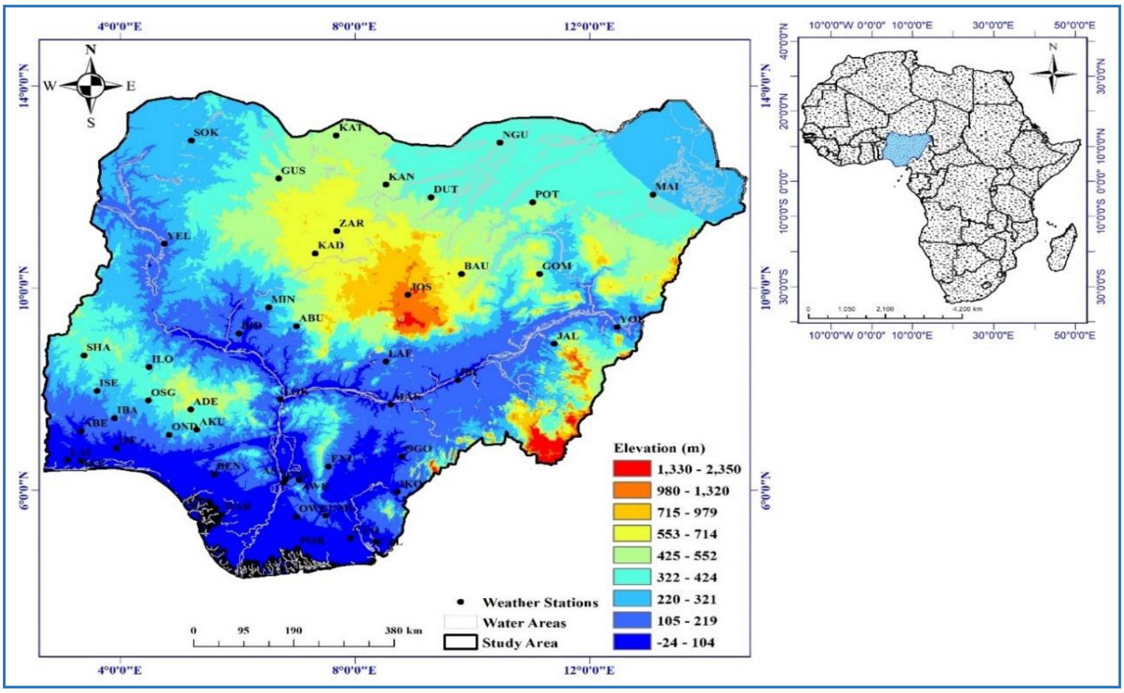

Fig. 1: The Meteorological Stations and Topography of the Study Area, Nigeria

Table 1: Precipitation Data used in this Study

Satellite-based Precipitation Products		Data input	Coverage		Resolution		Sources	
Full Name	Short Name		Temporal	Spatial	Temporal	Spatial	Principal Investigator	Citations
Nigerian Meteorological Agency	NiMet	Rain Gauge	1981-2019	Nigeria	Monthly	Scatter points	Nigerian Meteorological Agency	NiMet
Climate Hazards Group InfraRed Precipitation with Station Data, Version 2.01	CHIRPS V2.0	GEO-IR, gauges	1981 - 2019	Global -50°S to 50°N -180°W to 180⁰E	Daily Monthly	0.05°	Funk, Climate Hazards Group, University of California Santa Barbara, U.S. Geological Survey Data Series,	[20]
Tropical Applications of Meteorology Using Satellite and Ground-Based Observations (TAMSAT) African Rainfall Climatology and Time series (TARCAT), version 3	TAMSAT – TARCAT v3	GEO-IR, Climatological calibration with rain gauges	1983 - 2019	Africa, over land -35.98125°S to 38.04375°N - 19.03125°W to 51.99375°E	Monthly Seasonal	0.0375°	Maidment Ross, University of Reading	[21]

The CHIRPS dataset was developed and/or established by the United States Geological Survey (USGS) and the Climate Hazards Group of the University of California. CHIRPS are blended products that combine infrared from geostationary satellites and global climatological calibration with rain gauge observations from the Global Telecommunications System [20]. CHIRPS incorporate 0.05-degree spatial resolution satellite rainfall estimates with in situ station data to produce datasets of different time series from 1981 to the present. CHIRPS is a global rainfall estimate, available at different time scales such as sub-daily, daily, monthly, and annual. In this study, CHIRPS version 2.0 at daily and monthly time scales were used and accessed at http://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0.

TAMSAT was set up by the University of Reading in 1977. It is a rainfall estimation and quality assessment system providing high-resolution (~4 km), daily, pentadal, decadal, monthly and seasonal Pan-African rainfall estimates [21]. TAMSAT data input includes thermal infrared (TIR) from geostationary satellites and climatological calibration with rain gauges [21]-[22]. It covers the African continent (including Madagascar) at 0.0375-degree spatial resolution. The TAMSAT archive spans 1983 to the present available at daily, pentadal, dekadal, monthly, and seasonal time scales. The long-term TAMSAT data are suitable for risk assessment [21]. It can also be applied in famine early warning, drought insurance, and agricultural decision support. There are different versions of TAMSAT. This study made use of TAMSAT version 3.0 which was downloaded from http://dx.doi.org/10.17864/1947.112.

RESULTS AND DISCUSSION

Spatial Variability of Mean Annual Precipitation

Annual and seasonal precipitation distributions in many regions of Nigeria are shown in Fig. 2 and 6. Annual precipitation statistics such as Mean and percentage contributions of seasonal to annual rainfall were computed for 1981-2019 over the study area and the results are presented in Table 2. Nigeria, the study area, has significant diversity in topographical and climatological conditions and therefore the annual average precipitation varies significantly across Nigeria. Fig. 2 shows the spatial distribution of annual precipitation across Nigeria as per three precipitation datasets (NiMet, CHIRPS v2.0 and TAMSAT-TARCAT v3) for the study period.

The least annual precipitation (<700 mm) was observed in the extreme north while the highest amounts (> 2,000 mm) occurred in the coastal regions. This simply means that other parts get less rain stretching from the Niger Delta regions. From NiMet, CHIRPS and TAMSAT-TARCAT (Fig. 2), Calabar receives the highest amount of annual rain while Nguru receives the least. Similarly, considering the average of the three precipitation datasets over the entire study area, it is indicated that minimum and maximum annual rainfall (415 mm and 2833 mm) occurred at Nguru and Calabar while the overall average is 1393 mm. The amount of rainfall decreased rapidly from the coast inland. These findings correspond with the study of [4], [23] on the rainfall conditions in Nigeria. The amount of rainfall received in an area is determined by the intensity and period of rainfall.

Regionally, the total annual rainfall amounts vary from region to region in the study area. The amount of precipitation decreased rapidly from the southern region towards the northern part of the country (Fig. 2). The findings of this study corroborates with the study of [24] which states that there is a general decrease in rainfall in Nigeria, the coastal area is experiencing slight increase. Similarly, the result of this study also justifies [14] study with two precipitation regimes that characterised Nigeria, with low precipitation in the north leading to aridity and desertification and high precipitation in parts of the southwest and southeast leading to large-scale flooding. The implications of rainfall patterns and distribution in Nigeria most importantly the increasing intensity of rainfall is the frequent causes of flooding in the coastal areas being currently experienced [25]. This study also revealed that the southern part of the country contributes 65.3 per cent to the total annual rainfall while the northern part contributes 34.7 per cent (Table 2). The annual precipitation amount also varies from zone to zone in the study area (Fig. 2). Table 2 presents six geo-political zones/regions of all weather stations in the study with their percentages of rainfall contribution.

Table 2: Annual and Seasonal Averages of Precipitation Estimates, and Percentages of contribution over Nigeria (1981-2019)

S/N	Stations	Coordinates		GE0-ZONE	Average of Precipitation					Percentage (%) of Precipitation Contribution				
		Lat.	Long.		Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON
							Northern Nigeria							
1	ABU	9.25	7	NC	1362.4	5.7	243.8	691.4	401.1	2.0	0	0.4	1.0	0.6
2	BID	9.1	6.02	NC	1133.0	5.5	220.9	601.0	307.0	1.7	0	0.3	0.9	0.5
3	ILO	8.44	4.49	NC	1199.9	28	301.8	488.3	390.1	1.8	0	0.4	0.7	0.6
4	JOS	9.87	8.9	NC	1226.9	4.2	269.9	732.1	220.8	1.8	0	0.4	1.1	0.3
5	LAF	8.55	8.53	NC	1308.4	7.4	239.2	684.0	355.5	1.9	0	0.4	1.0	0.5
6	LOK	7.8	6.73	NC	1227.5	23.7	307.5	565.8	401.1	1.9	0	0.5	0.8	0.6
7	MAK	7.7	8.61	NC	1218.9	11.3	251.3	595.3	368.4	1.8	0	0.4	0.9	0.6
8	MIN	9.62	6.53	NC	1164.9	2.7	201.4	623.5	336.2	1.7	0	0.3	0.9	0.5
9	BAU	10.28	9.82	NE	1030.4	0.9	117.1	690.1	205.7	1.5	0	0.2	1.0	0.3
10	GOM	10.28	11.15	NE	886.9	0.9	121.3	574.5	213.9	1.4	0	0.2	0.9	0.3
11	IBI	8.18	9.75	NE	1051.9	4.0	213.3	522.7	316.5	1.6	0	0.3	0.8	0.5
12	JAL	8.9	11.4	NE	1152.8	6.6	209.3	633.0	312.5	1.7	0	0.3	0.9	0.5
13	MAI	11.85	13.08	NE	549.9	0.1	35.1	412.5	108.2	0.8	0	0.1	0.6	0.2
14	NGU	12.88	10.47	NE	415.43	0.1	17.0	334.6	73.6	0.6	0	0.0	0.5	0.1
15	POT	11.7	11.03	NE	665.2	0.1	36.1	504.7	126.3	1.0	0	0.1	0.7	0.2
16	YOL	9.23	12.47	NE	891.3	0.7	151.6	523.0	222.7	1.3	0	0.2	0.8	0.3
17	DUT	11.8	9.3	NW	766.03	0.8	70.0	574.6	154.9	1.2	0	0.1	0.9	0.2
18	GUS	12.17	6.7	NW	877.8	1.3	98.5	572.2	211.7	1.3	0	0.1	0.8	0.3
19	KAD	10.69	7.32	NW	1178.1	1.1	166.8	691.8	311.1	1.7	0	0.2	1.0	0.5
20	KAN	12.05	8.53	NW	835.7	0.4	62.1	637.3	137.9	1.2	0	0.1	0.9	0.2
21	KAT	13.02	7.68	NW	564.4	0.2	32.9	428.3	96.0	0.8	0	0.0	0.6	0.1
22	SOK	12.92	5.21	NW	658.9	0.4	52.6	451.6	131.1	0.9	0	0.1	0.7	0.2
23	YEL	10.88	4.75	NW	952.7	1.5	138.8	594.6	225.5	1.4	0	0.2	0.9	0.3
24	ZAR	11.13	7.69	NW	973.1	0.9	149.2	615.1	211.2	1.5	0	0.2	0.9	0.3
							Southern Nigeria							
25	AWK	6.2	7.05	SE	1822.6	50.3	447.5	802.2	584.8	2.8	0.1	0.7	1.2	0.9
26	ENU	6.47	7.55	SE	1724.5	33.2	412.3	747.7	477.9	2.5	0	0.6	1.1	0.7
27	ONI	6.15	6.78	SE	1829.3	40.5	416.2	786.3	565.5	2.7	0.1	0.6	1.2	0.8
28	OWE	5.48	7	SE	2289.3	71.7	513.3	1104.3	699.1	3.5	0.1	0.8	1.6	1.0
29	UMU	5.5	7.5	SE	2248.8	92.2	579.7	1175.8	820.9	4.0	0.1	0.9	1.7	1.2
30	ASA	6.23	6.82	SS	1785.9	42.6	409.3	716.2	528.3	2.5	0.1	0.6	1.1	0.8
31	BEN	6.32	5.6	SS	2000.5	68.8	457.4	793.6	599.7	2.9	0.1	0.7	1.2	0.9
32	CAL	4.98	8.35	SS	2833.1	98.3	622.9	1201.0	814.0	4.1	0.1	0.9	1.8	1.2
33	IKO	5.97	8.72	SS	2549.6	61.8	520.2	1145.9	744.9	3.7	0.1	0.8	1.7	1.1
34	OGO	6.67	8.8	SS	1815.1	36.8	410.3	764.3	628.2	2.7	0.1	0.6	1.1	0.9
35	POR	4.85	7.02	SS	2333.7	101	544.0	957.5	716.4	3.4	0.2	0.8	1.4	1.1
36	UYO	5.05	7.92	SS	2424.2	81.0	581.8	999.3	755.2	3.6	0.1	0.9	1.5	1.1
37	WAR	5.52	5.73	SS	2692.4	97.9	566.8	1074.3	811.2	3.8	0.1	0.8	1.6	1.2
38	ABE	7.17	3.33	SW	1209.3	43.7	342.0	451.8	360.5	1.8	0.1	0.5	0.7	0.5
39	ADE	7.6	5.2	SW	1445.3	45.9	361.5	563.1	443.5	2.1	0.1	0.5	0.8	0.7
40	AKU	7.2	5.3	SW	1521.7	54.7	382.2	537.4	446.5	2.1	0.1	0.6	0.8	0.7
41	IBA	7.43	3.9	SW	1284.9	41.0	354.0	520.6	432.8	2.0	0.1	0.5	0.8	0.6
42	IJE	6.83	3.93	SW	1585.2	58.8	392.4	615.8	513.0	2.3	0.1	0.6	0.9	0.8
43	IKE	6.58	3.33	SW	1499.7	64.3	403.1	651.4	486.8	2.4	0.1	0.6	1.0	0.7
44	ISE	7.97	3.6	SW	1159.8	29.9	309.8	442.4	369.0	1.7	0	0.5	0.7	0.5
45	LAI	6.6	3.1	SW	1476.6	71.3	458.2	801.7	571.3	2.8	0.1	0.7	1.2	0.8
46	OND	7.1	4.83	SW	1538.3	56.1	397.4	584.6	456.9	2.2	0.1	0.6	0.9	0.7
47	OSG	7.78	4.48	SW	1392.7	37.0	341.9	545.1	419.7	2.0	0.1	0.5	0.8	0.6
48	SHA	8.67	3.38	SW	1100.1	20.8	281.5	478.0	323.4	1.6	0	0.4	0.7	0.5
	MIN.				***415.4***	***0.1***	***17.0***	***334.6***	***73.6***					
	MAX.				***2833.1***	***101***	***622.9***	***622.9***	***820.9***	***100***	***2.2***	***21.1***	***47.8***	***28.8***
	AVE.				***1392.8***	***31.4***	***296.1***	***670.9***	***404.3***					

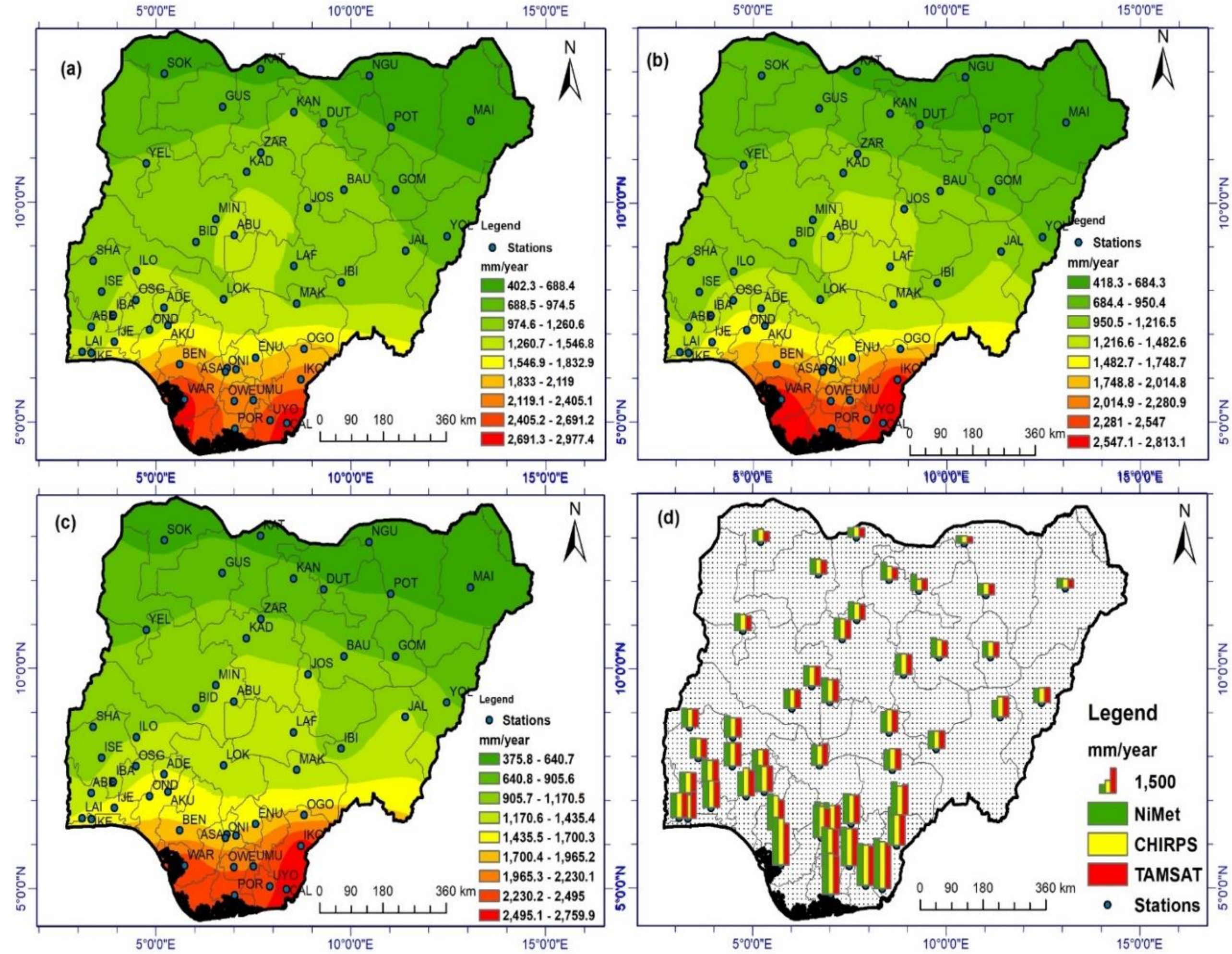

Fig. 2: Spatial distribution of average annual precipitation (1981-2019) in Nigeria for (a) NiMet, (b) CHIRPS v2.0, (c) TAMSAT-TARCAT V3, and (d) Bar Chart of the three datasets

Of all the zones in the study area, south-south receives the highest amount of annual rain (more than 2,200 mm) which is 26.7 per cent of the total amount of annual precipitation. In contrast, the least amount of annual rain (less than 820 mm) occurred in north-west (10 %) and north-east (9.9%), respectively (Table 2, Fig. 2). This is followed by South-west where a large amount of precipitation occurs in a year, with the highest amounts at Ijebu and Ikeja and the lowest amount of rain at Shaki, farther inland (Fig. 2). In the south-east, annual rainfall decreases from Owerri and Umuahia, on the coast, to the least amount of rain in Enugu. At the north-central, Abuja received the highest amount of rain while the Bida received the least. In the north-east, the highest and the least amount of rain in a year was received at Jalingo and Nguru. In contrast, Kaduna and Katsina received the highest and least rainfall amounts in the country's northwest.

The findings of this study correspond with the study of Acheampong (1990) which showed a general decrease in the annual rainfall from the southeast (Calabar) towards the west (Ikeja) and the north (Sokoto; Nguru, and Maiduguri). The areas of high annual rainfall overlap the hilly and mountainous regions and the southeast lowland areas. The driest parts are the extreme north and northeast. The mean annual rainfall in north-eastern Nigeria is not only dependent on distance but also other climatic factors such as relief, temperature, solar radiation, winds and nature of the soil [26].

The northern part of the country with ever decreasing rainfall has resulted to series of droughts, wind erosion and the encroachment of the desert. This corresponds to the findings of [27]. According to [7] three main features were observed in the annual rainfall of Nigeria. The first feature is that both the amount and area of the secondary rainfall maximum at 9^o – 10^o latitude in Nigeria has depreciated with time. Second, the belt of relative minimum rainfall coinciding with river Niger and Benue channels seems to be expanding with time. Third, places north of 8^o N latitude receive 90-100% of the annual rainfall between April and October.

Spatial Variability of Mean Seasonal Precipitation

Precipitation in the study area, Nigeria, has a high internal variability in all seasons. Every part of the country experiences both the wet and dry seasons but their durations partly vary from the south to the north. The wet (rainy) season is described as the year when most rain falls, while the dry season is when the least rainfalls. The wet season is associated with dry, sunny, cloudy, and rainy days, while there may be occasional rainy days during the dry season as all days are not without rain in some parts of the country, especially south. The spatial distribution of rainfall for all seasons is shown in Fig. 3-6.

During DJF, all parts of the country received the least rainfall, which is considered "dry season" (Fig. 3) due to the southwest winds' weakness. In DJF, no month is entire without rain in the coastal regions of the study area especially south-south region while the most northern parts experience no rain during this period. This corresponds to the study of [23], which stated that December- January has the most widespread dry conditions. In the extreme north, the dry period lasts from October to May. Based on the percentage of annual rainfall contribution, DJF rain contributes 2.2 per cent to the total annual precipitation, where the southern part contributes 2.1 per cent and the northern part with 0.1 per cent (Table 2). Similarly, during MAM, the highest rainfall was observed in the south-south of the study area, followed by south-west, south-east, north-central, north-west, and north-east, respectively (Fig. 4).

As a result, MAM rain contributes 21.1 per cent to the total annual rainfall, where south-south contributes the largest percentage of 15.6 per cent (Table 2). The spatial pattern of JJA is almost uniform across the study area, which has a unimodal precipitation regime (Fig. 5). Similarly, JJA and SON almost followed the same spatial distribution of rainfall with that of annual precipitation. Over the study area, the highest precipitation amounts were recorded in JJA (300 - 1,210 mm), and SON (57 – 882 mm) (Fig. 5). The findings of this study also revealed that the JJA and SON precipitation contribute 76.6 per cent (JJA= 47.8%, SON = 28.8%) to the total annual precipitation with the peak occurring in August with bimodal rainfall regime in the southern part of the country, while DJF and MAM periods contribute 23.3 per cent (DJF = 2.2%, MAM = 21.1%) to the total annual precipitation (Tables 2).

During JJA and SON, the southern part of the study area contributes 27.4 and 20.3 per cents of rainfall amount. The northern part contributes 20.4 and 8.7 per cents to the total annual precipitation (Table 2). In JJA, north-central received higher amounts of precipitation than other zones (excluding south-south and south-west zones) with a total of 7.3 per cent contribution to the total annual rain in Nigeria (Table 2). During all the seasons, south-south and south-west contribute a larger percentage of rainfall amount to the total annual precipitation while north-east contributes the least percentage of precipitation amount to the total annual rainfall.

The agricultural population of the study area is dependent on seasonal rainfall amounts for their crop and livestock production. Therefore, a slight change in the rainfall characteristics, such as the amount, intensity, onset and offset days, directly influences the agricultural activities. The southern part of the country received high rainfall in MAM, JJA, and SON periods which could be regarded as wet season (March to November), while the northern part mostly receives high rainfall in JJA and SON (Fig. 5 and 6). In other words, the climate regime of the northern part of the study area is characterised by a single long dry season followed by a short wet season.

This study showed that the coastal belt is the wettest part in the study area, where the south-west winds blow on-shore throughout the year while the northern part is the driest area in the study area. [14] justifies that varying length of precipitation regimes in Nigeria is dominated by three major atmospheric phenomena such as the tropical maritime (mT) air mass, the tropical continental (cT) air mass, and the equatorial easterlies. [4] observed that rainfall decreases from the coast (Warri, Calabar) to the Sahel (Ngurur, Katsina, Kano, Maiduguri) at all seasons. Rainfall is regarded as the main climatic parameter that determines water availability in the study area and is the main basis for the demarcation of the seasons into the rainy and dry seasons.

The influence of geographic features on the spatial distribution of mean annual precipitation has been long studied. Several studies have shown the impacts of topographic factors including physiographic features (topography), altitude, slope and proximity to a ridge or crest of mountains on the annual and seasonal rainfalls variability and distribution. For instance, Jos Plateau, where amount increases owing to the elevation. Previous studies in Nigeria have indicated that the rainfall of Nigeria is partly due to relief and is part of the convectional type. Studies found that the spatial variability of mean annual and mean topographic variables best capture monthly rainfall [28]. The study of [29] showed that altitude, longitude and continentally might explain most of the spatial changes in mean annual precipitation in South Africa. In general, altitude is an important predictor of rainfall distribution in the study area.

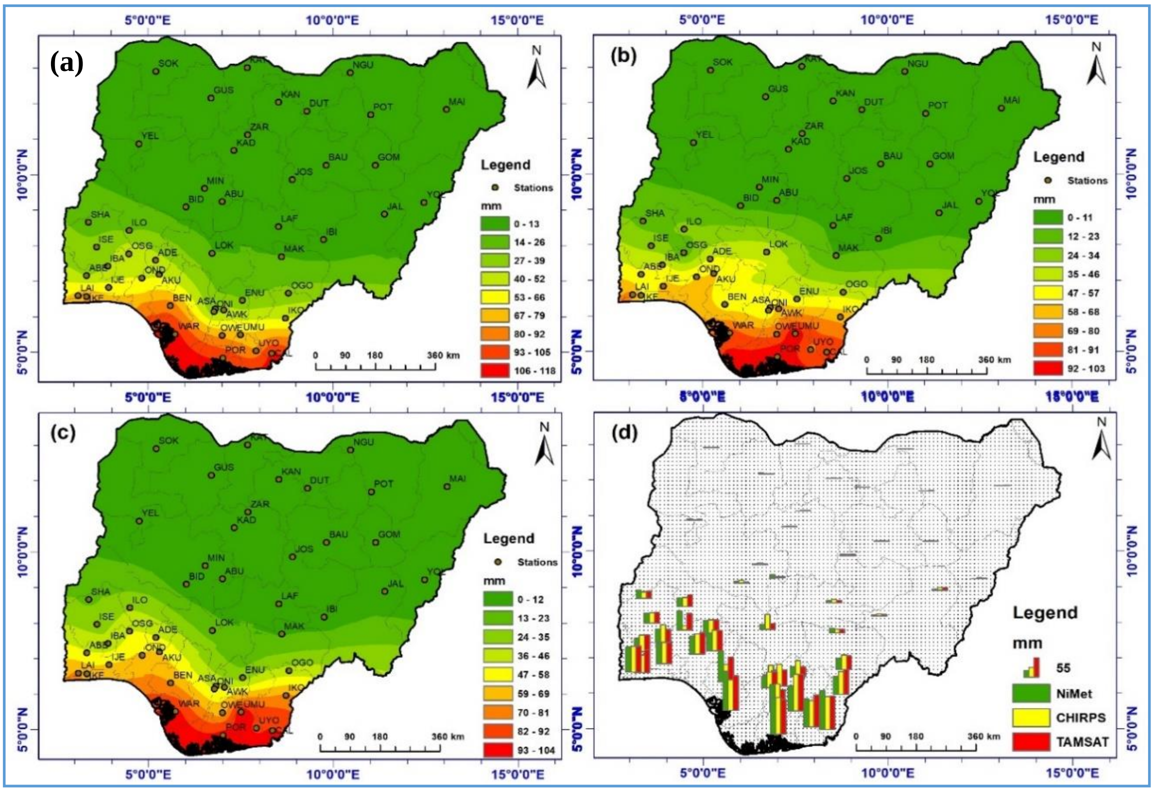

Fig. 3: Spatial distribution of average DJF precipitation in Nigeria over 1981-2019

(a) NiMet, (b) CHIRPS v2.0, (c) TAMSAT-TARCAT V3, and (d) Bar Chart of NiMet, CHIRPS v2.0, and TAMSAT-TARCAT v3

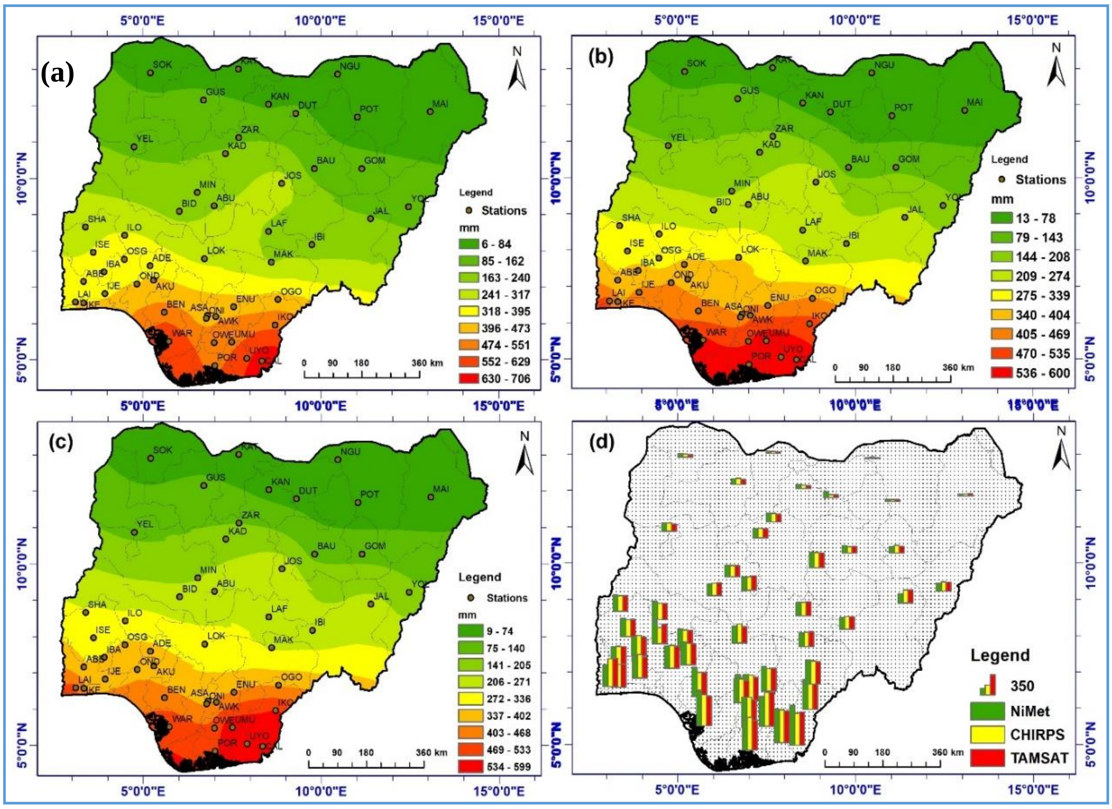

Fig. 4: Spatial distribution of average MAM precipitation in Nigeria over 1981-2019
(a) NiMet, (b) CHIRPS v2.0, (c) TAMSAT-TARCAT V3, and (d) Bar Chart of NiMet, CHIRPS v2.0, and TAMSAT-TARCAT v3

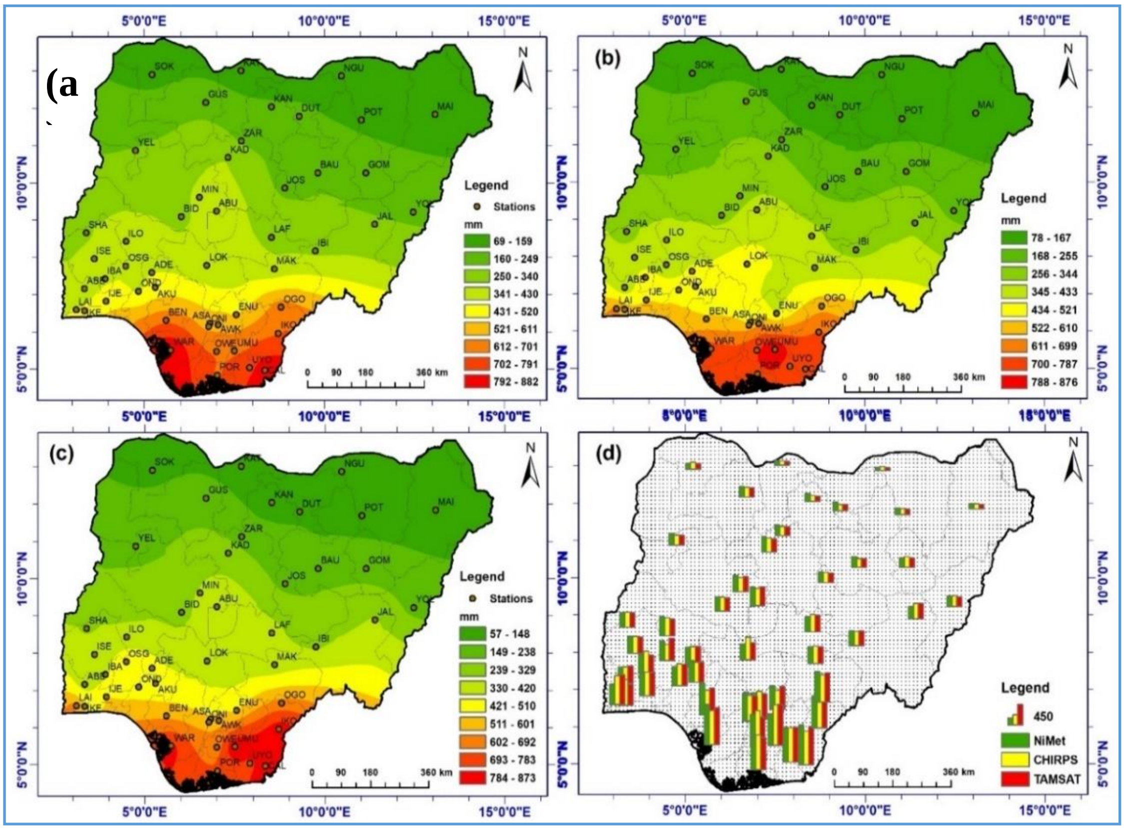

Fig. 6: Spatial distribution of average SON precipitation in Nigeria over 1981-2019
(a) NiMet, (b) CHIRPS v2.0, (c) TAMSAT-TARCAT V3, and (d) Bar Chart of NiMet, CHIRPS v2.0, and TAMSAT-TARCAT v3

Monthly and Annual Rainy and Dry Days in Nigeria for 39 Years Average

The 39–year average precipitation climatology of wet (rainy) and dry days at monthly and annual scales for all the meteorological stations in Nigeria is presented in Table 3 and Fig. 7 and 8. In other words, the climatological number of wet (rainy) days of each duration is estimated at each weather station. For instance, for 39 years (1981-2019) climatology, there were a total of 14244 days. The wet (rainy) day is considered when precipitation amount is equal or greater than 1.00 mm (R >=1.00mm).

The number of rainy days decreased from the south towards the north in the study area and vice versa (Fig. 7 and 8). For the whole year (January – December), no month is without rain, especially in the southern part of the study area. Even during the driest season (December-January-February), the rainy days ranged from 0-9 days, while the northern part has the least or no rainy day. The rainy days increased in the March-April-May period/season between 0 and 27. Every part of the study area received rain in May, but its intensity varies in a different geographical area. The extreme north (east and west) received the least days with rain between 4-8 days in May (Fig. 7).

In June, South-south and North-central highland received a higher number of rainy days than other places in the study area, while only the extreme north-east received the least number of rainy days. During July and August, every part of the study area experienced rain, while the extreme south-west received the least number of rainy days between 12 and 15 (Fig. 7). The rainy days increased in north-central highland, especially Jos, Kaduna, and Abuja where it reached its peak in August. This might be due to the influence of topography.

The rainy days declined from the extreme north-east in September. During September and October months, rainy days decreased, especially in the north. In November, the entire north received little or no rain, while a few places in the south received rain (Fig. 7). The entire north is completely dry in November, December, January, February and March, while the extreme north is completely dry in April, May, and October. In the south, rainy days decreased in November while the driest period is December-January-February. This is the period where the entire study area received the least rainy days (Fig. 7). On the basis of the annual scale, the analysis of wet (rainy) and dry days is presented in Fig. 8. Dry days decreased from the north to the south and vice versa. The total average number of annual raining days in the entire study ranged from 57 – 235 days, representing 15.6 – 64.2%. The highest percentage of rainy days in a year is recorded in the extreme north, ranged from 79.2 – 84.5% in the study area (Fig. 8).

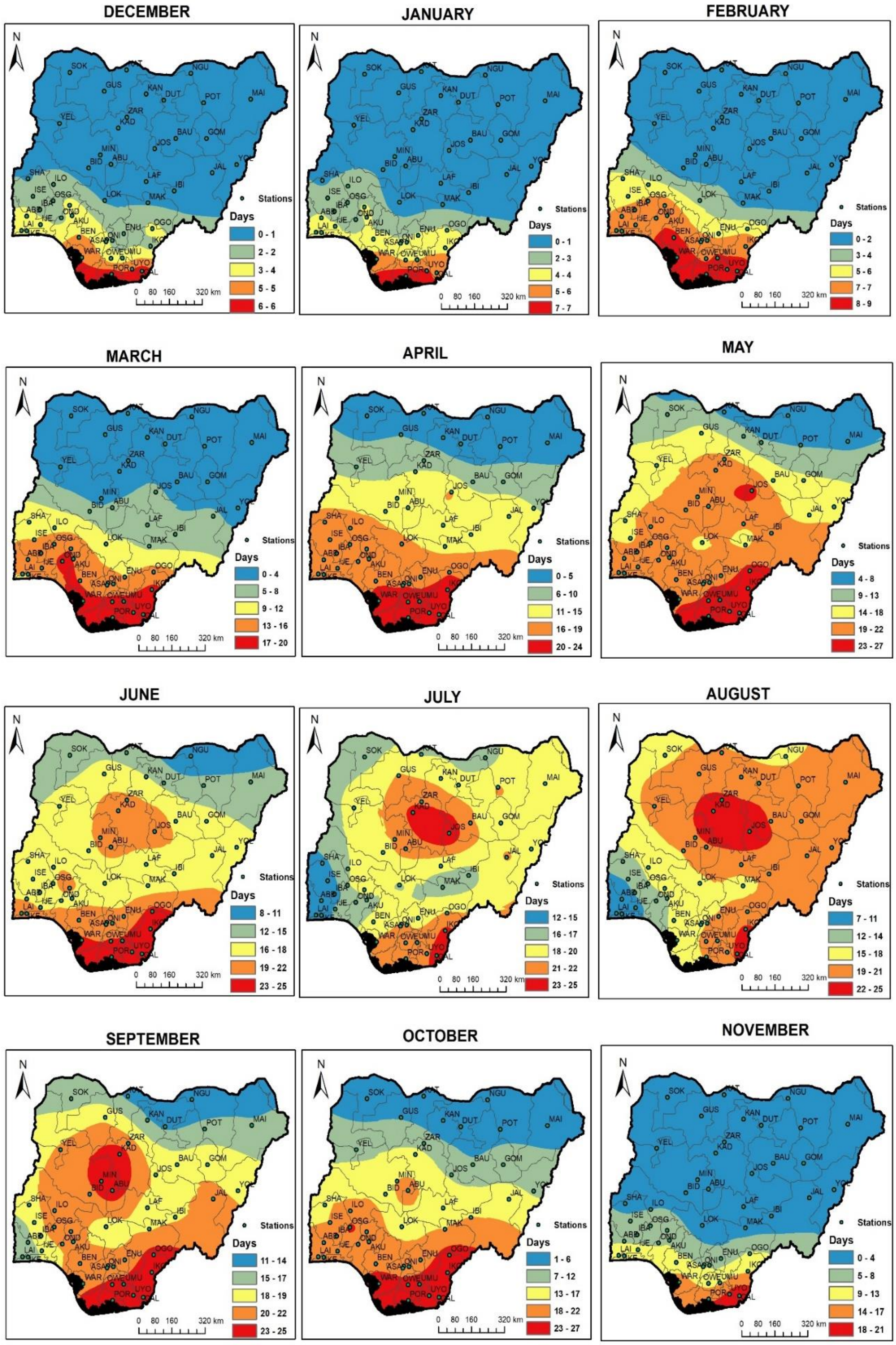

Fig. 7: Average Monthly Precipitation Climatology of Wet (Rainy) and Dry Days for 39 Years (1981-2019)

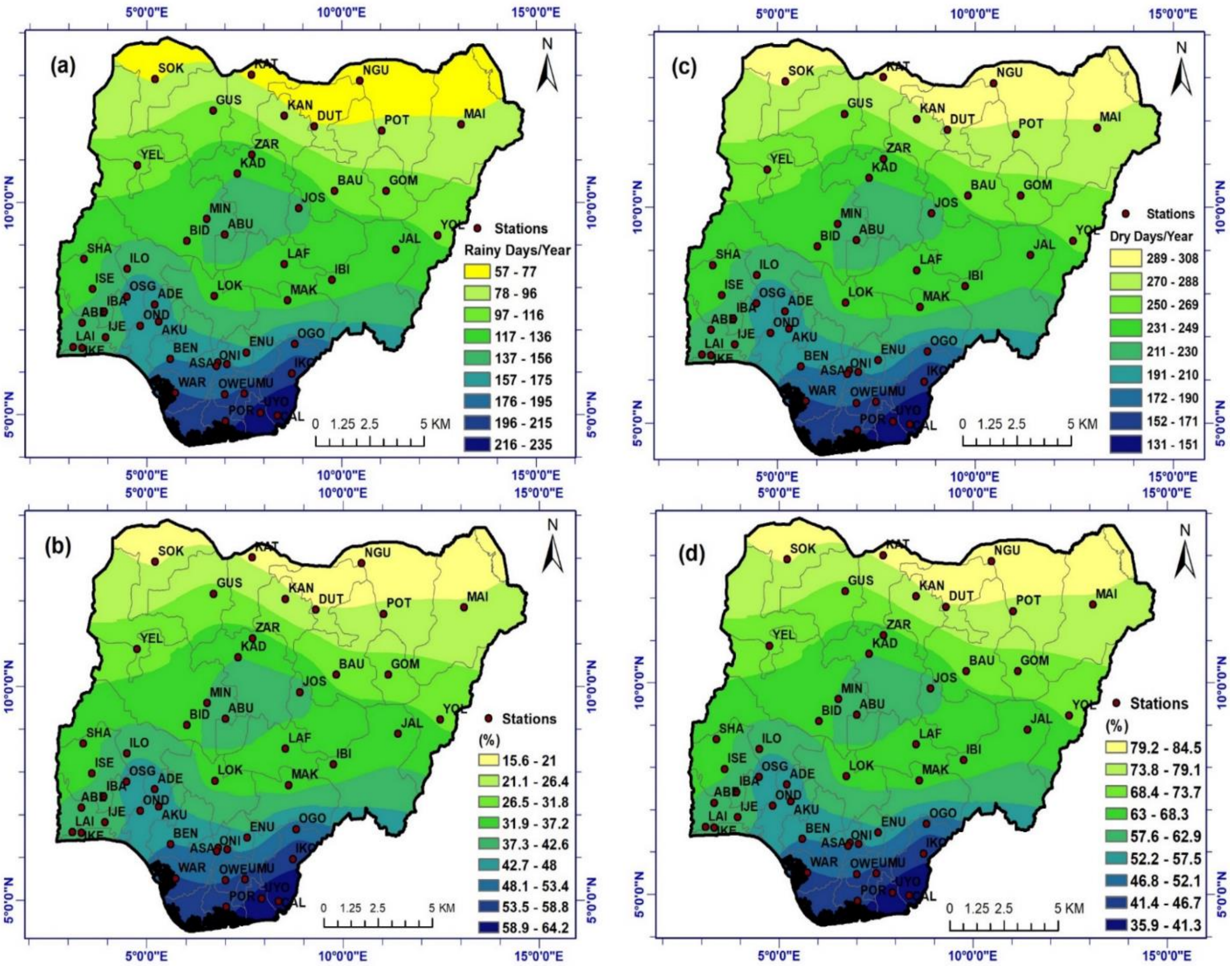

Fig. 8: Average Annual Precipitation Climatology of Wet (Rainy) and Dry Days for 39 Years (1981-

CONCLUSIONS AND RECOMMENDATION

Seasonal and inter-annual spatial variability characterise Nigerian rainfall. Thus, understanding rainfall characteristics is a key factor in establishing a future rainfall prediction model and future managing the country's water resources. For this reason, this study was directed toward analysing rainfall time series on both annual and seasonal scales and monthly rainy days over Nigeria using ground-based and satellite-based precipitation products for the study period (1981-2019). Satellites precipitation estimates were extracted into time series and then aggregated into seasonal (DJF, MAM, JJA, and SON) and annual (January-December) time steps. The kriging interpolation method in ArcGIS version 10.4 environment was used to display the spatial variability of precipitation amounts and monthly rainy days. This study has shown that precipitation amounts and rainy days vary at different geographical areas and at different time scales in the study area. In this study, the concerned precipitation characteristics decreased from the coastal inland and reached their peak in July/August. The northern part experienced a long dry period than the south, leading to droughts and flooding. Therefore, it is recommended to use satellite precipitation estimates for a vast region like Nigeria as effective input data for forecasting Nigerian rainfall forecasting at different time scales for decision-making processes.

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