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Geography of Udi Cuesta Contribution to Hydro-Meteorological Pattern of the South Eastern Nigeria

Ngene Ben Uchechukwu, Jonah C. Agunwamba, Imokhai T. Tenebe and Gideon O. Bamigboye

Additional information is available at the end of the chapter

Abstract

The presence of cuesta with escarpment plays an important role in the distribution of rainfall. Its role was studied and was put together in this work. Various parameters were studied and they include: amount of rainfall, elevation, latitude and the distance from the sea. In this research, frequency analysis was performed on the parameters and the log-pearson type III was considered the most suitable distribution method. Also, principal component analysis was used to determine that two components best estimates the variables with close correlation to be rainfall, elevation, latitude and distance from the sea as component 1 and distance to nearest neighbour and longitude as component 2. With regional coefficient of variation of 22%, the area has low variability which is an indication of high rainfall values with good consistency. Annual average rainfall of South Eastern Nigeria is at 1744 mm with bi-modal double peaks in July and September as in most parts of Southern Nigeria. High rain bearing wind speed of the area with escarpment obviously affect the rainfall pattern. From the determination of the difference in mean of rainfall, it is again obvious that areas close to Udi escarpment of the cuesta have difference in mean below or slightly above mean, hence indicating the effect on rainfall.

Keywords: distance from the sea, distribution method, elevation, latitude, rainfall and escarpment

1. Introduction

The Udi escarpment of the South Eastern Nigeria is a long cliff or steep slope that separates an area of high elevation from an area of lower elevation as shown in **Figure 1** below. How this phenomenon affect rainfall pattern of the area and the water resources management is

Figure 1. Map of Nigeria showing zonal arrangement of areas of similar wind pattern.

the subject of this study. While the South Western Nigeria have a fair number of research on topography and water resources management, the South Eastern part have limited works in this regard, hence this work is needful.

Balogun [1] reported that areas of high rainfall also have low coefficient of variation and vice versa, this is the case for area around Udi. Areas around the range of Udi Plateau which runs perpendicular to the coastline of Nigeria have low coefficient of variation of rainfall. The importance of the variability study is seen in agriculture were there could be longer periods of rainfall absence thereby affecting plants and planting and also in hydrology, where drought is experienced and other human activities is affected.

Analysis of rainfall in general, enhances the management of water resources applications as well as the effective utilization of water resources [2]. Hydraulic Engineering designs such as dam height, embankment height, design discharge etc. are determined using results of frequency analysis. Specific areas such as the dimensioning of dams require the knowledge of frequency analysis and variability of annual rainfall to be efficiently carried out.

Even more compelling to the study of variability of rainfall data is the effect of climate change and global warming on water resources projects [3, 4]. This research has decided to look into the spatial and temporal variation of the area understudy. It also employed the use of frequency and principal component analysis to examine and interpret the collected data in the chosen areas [5].

1.1. Precipitation

Precipitation defines the term used to describe the moisture coming out of the cloud and falling on the ground [6]. Precipitation just before it falls to the ground is governed by physics of

meteorology, but on reaching the ground it is known to be element of hydrology. The region under study, south east Nigeria, is not known to have snow, hence the precipitation under discussion is limited to rainfall. Precipitation is the result of the cooling down of moisture containing air mass sufficiently to cause condensation to take place. The condensation is observed to take place in the presence of condensation nuclei that is present in the atmosphere.

1.1.1. Types of precipitation

Though adiabatic cooling of air mass is the cause of condensation and rainfall, it takes the vertical transport pf the air mass for the cooling to take place. The type of precipitation and the intensity will depend on the nature of the movement of the moisturized air mass in a given area and it is seen in the following forms: convection, orographic, cyclonic and thunderstorm.

i. Convective precipitation: This type of precipitation results from heating of the earth's surface. It is characterized by summer thunderstorm and the warm air is lifted up to be displaced by a cooler air above it with the release of latent heat of vapourization. At a higher altitude the vapourized water droplets become frozen and hail forms or are intermixed with rainfall [7]. Convection precipitations are known to cause high intensity short duration rainfall over a large area.

ii. Orographic precipitation: This type of rainfall takes place when an air mass rises over a mountain range. This occurs where the mechanical lifting of moist horizontal air mass occur over a natural barrier such as the Udi Cuesta. Since the area is close to the Niger Delta or the Nigeria coast, hot moist air mass moving horizontally will be lifted at the Cuesta. This will therefore cause rainfall in the windward slopes and lighter rainfall in the leeward slopes. A careful examination of **Figures 5–7** will confirm that the areas around the windward slope of the escarpment have a higher rainfall value than the leeward zone of Udi escarpment. This arises because the great source of air mass that causes rainfall is generated from the Niger Delta or coast of Nigeria moving northward as seen in **Figure 1**.

iii. Cyclonic precipitation: Cyclonic precipitation is associated with the movement of air masses from regions of high–pressure to low-pressure. The high and low–pressure regions are created by unequal heating of the earth's surface. Cyclonic precipitation may be classified as either frontal or non-frontal cyclones.

iv. Thunderstorms: Effect of thunderstorms which are usually very intense rainfall in nature is used when considering the sizing of urban drainage works. Thunderstorms often are localized in nature but are associated with surface heating orographic effect.

1.1.2. Measurement of precipitation

This is done with the aid of a rain gauge which may be recording or non-recording. The recording rain gauge is the automatic rain gauge which may be classified into three types (i) tipping bucket rain gauge (ii) weighing bucket rain gauge and (iii) syphon rain gauge. The non-recording rain gauge on the other hand is an ensemble and the rain to be measured is collected poured into a measuring cylinder which gives the value of the rainfall in millimeter of rain. Other methods used in obtaining rainfall measurement include weather radar, automatic weather stations, weather sensors and weather satellite [6].

1.1.3. Mean rainfall estimation for a watershed

Several methods are employed in calculating the mean rainfall value of a catchment which is useful for many hydrologic investigations. The methods include arithmetic mean, the Theissen polygon, the isohyetal method, application of mathematical surface fitting techniques, finite element method and two-axis technique [8]. The arithmetic mean, Thiessen polygon and isohyetal methods are explained in the following example. The annual rainfall in three locations of Nsukka (A), Enugu (B), Ezzamgbo (C) and Ishiagu (D) is shown in **Table 1** and **Figure 2** as 1517 mm, 1609 mm, 1468 mm and 1799 mm respectively.

The average mean rainfall for the area may be calculated as follows:

(a) Arithmetic mean method:

(1517 + 1609 + 1468 + 1799)/4 = 6393/4 = 1598 mm

(b) Thiessen polygon method:

STN	Depth (mm)	Area of polygon*	weighted depth (mm)
A	1517	0.23	348.9
B	1609	0.35	563.2
C	1468	0.29	425.7
D	1799	0.13	233.9

*As a fraction of total area sum = 1571.7 mm

(c) Isohyetal method:

Mean Depth	Area between Isohyetal*	weighted depth (mm)
1200	0.06	72
1300	0.13	169
1400	0.21	294
1500	0.26	390
1600	0.20	320
1700	0.11	187
1800	0.03	54

*As a fraction of total area Sum = 1486 mm

From the calculations using the three methods, the Isohyetal method has the lowest weighted average precipitation value and hence may be chosen depending on the overall objective of the hydrologic investigation.

1.2. Wind

Winds are one of the main factors that affect the climate of a place. It is therefore important to have a good knowledge of the climatic factors that affect the movement of air mass or wind. A critical element in the process of generation of rainfall of any type is wind or movement of air which is also useful as a source of energy generation. Generally, air mass or wind can be harnessed for the supply electricity where they are in abundance such as the case in many locations in Nigeria as shown in **Table 1**. From the principal component analysis tables, it is shown that there exist a strong correlation between rainfall and distance from the sea which is the source of rain bearing moist air mass. Sea and land breeze is experience in the coastal area in Nigeria, which is close to the southeast. During the day, land area is heated more than the sea, thereby causing air over land to expand and rise, causing low-pressure areas on land. This causes cooler air from sea to move inland toward the low-pressure area on land resulting in light wind known as sea breeze. At night the reverse process is experienced where the land cool more rapidly than the sea resulting in land breeze.

1.2.1. Types of pressure and air mass (wind)

The air mass in Nigeria oscillates between North and South in harmony with the movement of the thermal equator and it is influenced by land mass and water bodies [9]. Nigeria has two types of wind movement in a year, also known as the North Western trade wind and a harbinger of harmattan season and the South Eastern trade wind, which bring the rainy season.

The South Western wind (June/July) is a result of the dominance of the tropical maritime air mass from the south atlantic which causes the rainy season. During the period (December/January),

STATION	TOPOGRAPHI-CAL SITUATION	ALTIT-UDE (m)	DATA PERIOD	ANNUAL AVE. SPEED	STANDARD DEV.	COEFF. OF VAR.	SHAPE FACTOR (K)	SCALE PARAMETER (C)	YRLY AVE. WIND POWER DENSITY (W/m²)	REMARKS
CALABAR	Coastal City	28	1995-2009	4.3	0.2	0.04	28	4	51	CLASS 1
IKEJA	Coastal City	36	1995-2009	5.7	0.5	0.09	14	5	150	CLASS 3
PORT-HARCOURT	Coastal City	19	1995-2009	3.1	0.2	0.07	20	3	24	CLASS 1
WARRI	Coastal City	5	1995-2009	3.1	0.2	0.06	20	3	21	CLASS 1
BENIN	Inland City	82	1995-2009	3.2	0.1	0.03	43	3	21	CLASS 1
ENUGU	Inland City	167	1995-2009	5.7	0.3	0.04	24	5	122	CLASS 2
IJEBU-ODE	Inland City	78	1995-2009	3.3	0.3	0.09	14	3	30	CLASS 1
IKOM	Inland City	101	1995-2009	5.2	0.3	0.05	22	5	107	CLASS 2
OWERRI	Inland City	72	1995-2009	3.7	0.3	0.08	15	3	35	CLASS 1
ONITSHA	Inland City	68	1995-2009	4.0	0.1	0.03	55	4	43	CLASS 1
BIDA	Middle Belt City	111	1995-2009	2.6	0.2	0.07	16	2	12	CLASS 1
MINNA	Middle Belt City	272	1995-2009	5.8	0.7	0.11	10	5	182	CLASS 3
ABUJA	Middle Belt City	475	1995-2009	3.7	0.3	0.07	15	3	40	CLASS 1
JOS	Middle Belt City	1172	1995-2009	10.4	0.5	0.05	27	10	759	CLASS 7
LOKOJA	Middle Belt City	36	1995-2009	2.8	0.2	0.07	18	3	19	CLASS 1
SOKOTO	Northern City	285	1995-2009	7.2	0.3	0.04	32	7	266	CLASS 5
GUSAU	Northern City	432	1995-2009	6.5	0.6	0.09	13	6	214	CLASS 4
KADUNA	Northern City	603	1995-2009	5.4	0.3	0.05	23	5	114	CLASS 2
KATSINA	Northern City	526	1995-2009	7.8	0.7	0.09	14	7	396	CLASS 6
ZARIA	Northern City	650	1995-2009	6.1	0.5	0.08	15	6	176	CLASS 3
KANO	Northern City	484	1995-2009	9.1	0.4	0.04	30	9	521	CLASS 7
BAUCHI	Northern City	628	1995-2009	3.6	0.7	0.20	6	3	59	CLASS 1
MAIDUGURI	Northern City	300	1995-2009	5.6	0.3	0.06	24	5	127	CLASS 2
YOLA	Northern City	180	1995-2009	2.1	0.2	0.10	13	2	10	CLASS 1

Table 1. Classification of wind power density according to location in Nigeria.

Figure 2. Map of Nigeria showing Udi escarpment and the two river basins [9].

the wind system shifts down from the tropic of Capricorn with the Sahara becoming the high pressure zone. This brings about the dry and cold wind – the tropical continental air mass with a northeasterly wind with low pressure belt in the south. At this time, the inter-tropical front will be in southern coastal fringes of Nigeria.

1.2.2. Characteristics and uses of Nigeria wind energy

Wind speed noted Back and Bretherton [10] explains a moderate amount of daily viability in pre-cipitation. According to their study, faster winds are related to high incidence of rainfall which also explains daily rainfall variability. As earlier noted there exist three main types of air mass lift-ing which include frontal lifting, orographic lifting and convective lifting and they are functions of the type of atmospheric circulation and local conditions, geography and wind included [11].

This work therefore looked at the influence of wind on the rainfall pattern of the south east Nigeria and the energy generating capacity of the wind available in the country. Wind is

described as air mass in motion and it is one of the climate parameters according to [12]. This motion is caused by pressure differences across the earth's surface due to the uneven heating of the earth by solar radiation [13] Energy for electricity and other uses in some part of Africa has been on the decline, and its demand has been on the increase irrespective of this fact. This fact aforementioned has prompted the supreme council of energy in Egypt to come up with a blue print geared towards improving/or improvising other potential and viable energy sources in the electricity sector thereby cutting down on dependents on fossil fuels [14] and to some scholars, wind is a viable option. Nigeria is growing rapidly with estimated population of over 140 million [15] and will shoot up undoubtedly in the coming years. This will adversely affect the need for more energy and this call for concern. In a quest to cushion the effects of human wants, lot of natural resources is required with most of these resources used for this purpose are not sustainable. Unfortunately, the daily activities of humans are hugely dependent on the natural resources available and their longevity somewhat proportionate to sustainable practice [16].

In Nigeria, as well as obtained elsewhere, it is necessary to determine the amount of air mass in motion to enable:

  i. Proper design of Civil Engineering Structures.

 ii. Planning for siting of wind turbines/generators

iii. Evaluation of productivity and cost effectiveness of a particular wind energy system based on available wind resources.

iv. Determine operational requirements such as resource information, load management, procedure and prediction of maintenance or system life.

Previous attempts aimed at determining the characteristics of wind energy in Nigeria have been insufficient as they are regional in nature. Such efforts in literature include the works of [17–21]. The work is aimed at determining the country wide character variation of Nigeria wind both in terms of location and time. It involves determining the shape and scale factors of various sites and hence the wind power densities will be ascertained to enable classification of sites in terms of their wind densities. Furthermore, the coefficient of variation of different sites is determined including the relationship it has with wind speed. Both the relationship between wind speed, altitude, the monthly and annual variation are computed for the various zones viz.: Coastal, Inland, Middle Belt and the Far-Northern region of Nigeria. The various characteristics of wind mentioned above gives an insight to the productivity of a turbine generator; hence, the need for proper location for their optimal and efficient utilization in electricity generation is required [19]. According to [22], sites with average wind speed of 7.5 m/s in Europe will generate wind power up to 250 KW. Using this criterion alone will limit the number of stations for possible wind turbine generators in Nigeria, hence further analysis to point out other areas of possible siting of such systems. This research also uses wind speed data from the Nigeria Meteorological Agency to determine available wind resources for each of the 24 stations in the Network. It further shows the zoning effects of the stations and how the area of same physical and climatic conditions affect wind speed and wind power density. The **Figure 1** below indicates the zonal arrangement of wind speed in Nigeria with South East falling under the Inland region.

2. The study area

The study site is the South Eastern Zone of Nigeria. This region falls within the latitude 6' N and 8' N and longitude 4' 30'E and 7'30'E also described as the inland region of the country according to **Figure 1**. Udi escarpment divides the zone into two area viz. South Eastern scarplands under Anambra /Imo River Basin and Eastern borderlands under Cross River Basins and the apex of Udi plateau at 300 m above sea level. The whole region which is densely populated covers an area of about 40,000 sq. km and represent 4% of the country's land mass with the physical environment and climate described in the **Figure 2** below.

2.1. Physical environment

The site is of the lowland region of southern Nigeria, which drains to the Atlantic Ocean through the Anambra/Imo River Basin and the Cross River Basin. According to [9], the geology of the area is basically of the stratified sedimentary rock of secondary to tertiary geological era. The unroofing of the anticlines left the Udi escarpment and brought about the undulating Cross River Basin right of the scarpland.

2.2. Climate and hydrology of study area

The South Eastern Nigeria is of the wet tropical type climate with mean annual temperature in the range of between 27° C and 34° C. The temperature of the area as observed by [9] is highest around March–April when the overhead Sun passes through Nigeria latitude. The rainfall, however, of the area has an annual average of 1744 mm, which is decreasing inland from the Niger Delta area or the coast of Nigeria .This is quite clear in **Figure 3** below. The Annual rainfall regime of the area is of the double maxima with double peak in July and September and an August break period. The high rainfall between May–September has a lowering effect on temperature of the area.

The climate of Nigeria is classified into Rainy (April – October) and Dry (November – March) seasons, with each of the seasons lasting approximately six months. Annual rainfall ranges from 500 m in the extreme north to 3000 m along the coast. Nigeria is governed by high pressure southwest monsoon wind from the Atlantic in June–July pushing the inter-tropical front to the Sahara (northern) region of the country [1, 9]. At this point the sun is around the tropic of cancer or close to it, hence high temperature (25 °C south and 40 °C north) and low pressure. In December–January, on the other hand, the sun is at the tropic of Capricorn causing the wind system to shift to the south. At this time, the Sahara region becomes the high pressure belt forcing dry and cold wind to blow northeasterly to the low pressure area of the south. The wind system usually arrive the country about September and gradually spread throughout the country and last until March when the sun repeats the processes again. This process represents the wet and dry seasons of Nigeria of which the South East is a part. The **Table 1** represents the wind power available in various locations within the country. The area of the South East with the escarpment has maximum wind power of 122 w/m², altitude of 167 m and is classified as class 2 as shown in **Table 1** below. Classification indicates class 1 for the weakest location for siting of wind power generators to class 7 the strongest possible site for electric energy generator site.
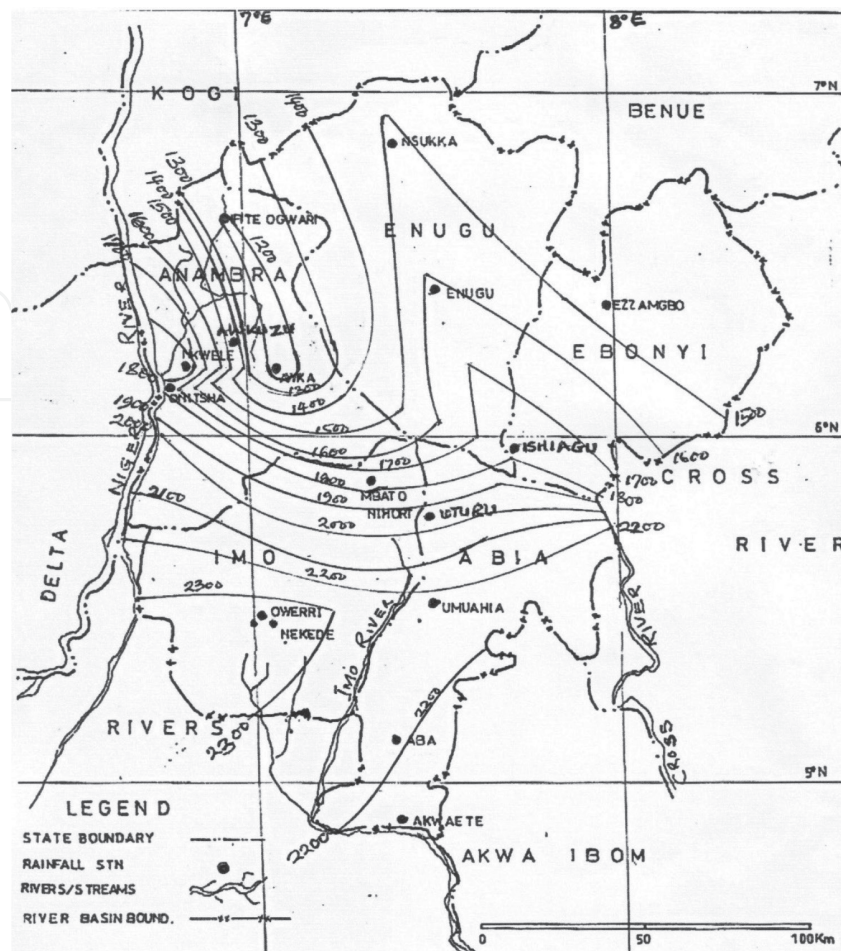
Figure 3. Contour map of South Eastern Nigeria rainfall.

3. Materials and methods

The data for this study area is the secondary data of 12 stations with monthly rainfall within the south eastern Nigeria obtained from the Nigeria Meteorological Agency, Lagos, Federal College of Agriculture, Ishiagu, Ebonyi State., Nigeria [23]. The data used is tabulated as shown in **Table 2** below. This table shows the location, annual rainfall amount, latitude, longitude elevation and period of data collection. For some areas however, it is necessary to observe that the data was for period less than 10 years owing to the absence of sufficient data. However, even with missing data as observed from the table below, the information obtained is tested for reliability and consistency before use.

3.1. Measure of reliability

(a) Mean

From the annual mean calculation of each station and the region, a departure from average is determined and plotted to indicate how mean rainfall for each stations differ from the mean. This helps us to determine the variability experienced in the rainfall distribution.

(b) Coefficient of variation

The coefficient of variation or relative dispersion is obtained using the formula

$$Cv = \frac{\sigma}{\bar{X}} \tag{1}$$

A coefficient of variation closer to one indicates greater consistency of data set. It is also an indication of the relationship amongst data set within the same area.

3.2. Frequency analysis

Frequency factors are used to fit theoretical distributions [6]. As proposed by [24], the general equation for hydrologic analysis is given as:

$$x_T = \bar{X} + K\sigma \tag{2}$$

Where k is the frequency factor, a function of return period and probability distribution, σ is the standard deviation of hydrologic data and $\bar{x}$ is the mean of hydrologic data. [25, 26] frequency factor is determined and used to determine the magnitude of x and the value of x correspond to return period T, denoted by x_T as defined in

$$P(X \geq X_T) = \frac{1}{T} \tag{3}$$

In hydrologic frequency analysis, the probability of occurrence of an event of known return period is evaluated. Several methods of frequency analysis are calculated and compared in this study viz.:

(i) Normal Distribution

The Gaussian distribution is used in the study of measurement errors and characteristics of normal distributions. This is the most important probability distribution.

(ii) Log-Normal Distribution

In situation where hydrologic variables are right skewed due to influence of natural phenomenon, their frequencies do not follow normal distribution but their logarithm does. This distribution as suggested by the [27] is valuable for the degree of accuracy in estimation.

(iii) Extreme Value Type I Distribution

This is also known as the Gumbel distribution for flood frequency analysis. In this case, which is specially used for weather study has largest and smallest values known as extreme values associated with floods and drought respectively. The distribution uses mean, standard deviation and skewness in the analysis of the probability of occurrence of an event.

(i) Gamma (Pearson Type III Distribution)

Pearson Type III distribution is a special case of Gamma distribution and it is a frequency analysis method. In this type of distribution, three parameters are used viz. mean, standard deviation and skewness.

STATION/ PARAMETER	ANNUAL RAINFALL (mm)	ELEVATION (m)	LATITUDE	LONGITUDE	No. OF YRS OF RECORD
NSUKKA	1517	447.1	6° 52' 12"	7° 24' 0"	1970-1990
ENUGU	1609	141.7	6° 25' 48"	7° 33' 0"	1971-1990
EZZAMGBO	1468	115.8	6° 22' 48"	7° 55' 12"	1981-1990
IFITE-OGWARI	1196	73.8	6° 37' 12"	7° 55' 48"	1975-1989
AWKA	1153	91.4	6° 9' 0"	7° 1' 12"	1975-1989
NKWELLE	1879	71.4	6° 13' 12"	6° 51' 0"	1931-1960
ONITSHA	1759	66.8	6° 10' 12"	6° 45' 0"	1974-1991
MBATO- NIHORT	1786	154.5	5° 33' 0"	7° 22' 48"	1979-1990
ISHIAGU	1799	150.0	5° 55' 48"	7° 31' 12"	1997-2013
UMUDIKE	2237	121.9	5° 28' 48"	7° 31' 12"	1971-1990
OWERRI	2349	91.4	5° 28' 48"	7° 1' 48"	1974-1990
AKWETE	2175	21.3	4° 52' 12"	7° 21' 0"	1972-1990

Table 2. Showing 12 station with site parameters.

(ii) Log-Pearson Type III Distribution

This is a form of Pearson Type III in which the hydrologic variables are log transformed before analysis using Pearson Type III distribution. The flood magnitude as a variable, for a desired recurrence interval is then estimated from

$$\log Q = \bar{Y} + K\sigma_y \tag{4}$$

Where k is a function of return period and skewness and mean $\bar{Y}$ is the mean of $\log Q$ and standard deviation σ_y.

3.3. Principal component analysis

Principal component analysis is used as a reduction procedure for variables that tend to empirical relationship. In this regard, large number of observed variables is reduced to smaller number of principal components which accounts for the variance of the observed variable [2]. The six component variable is reduced to two with linear combinations of data by this procedure.

3.4. General characteristics of Nigeria wind

Manwell, McGowan, & Roger [7] have observed that wind energy varies in both time (second and month) and space (Km^2). Space variations are function of elevation above sea level and

global and local geographical conditions. In Nigeria, regions of high altitude are observed to have higher wind speed, with Jos having the highest average wind speed in the country. For the 24 stations in Nigeria where records of wind speed are kept, measurement is made with cup anemometers at 10 m height. The nature of the wind in Nigeria is observed to follow the seasons, viz.: Rainy and Dry seasons. To determine the characteristics of Nigeria wind, the country is divided into four zones namely: Far-North, Middle Belt, Inland and Coastal areas. The monthly and annual characteristics of the wind speed for each zone are determined using the following parameters.

Long-term average wind speed,

$$\bar{V} = \frac{1}{N} \sum_{i=1}^{N} Vi \tag{5}$$

Standard Deviation,

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} \left(Vi - \bar{V}\right)^2} \tag{6}$$

Coefficient of variation,

$$Cv = \frac{\sigma}{\bar{V}} \tag{7}$$

Shape factor,

$$k = \left(\frac{\sigma}{\bar{V}}\right)^{-1.086} \tag{8}$$

and Scale factor,

$$c = \frac{\bar{V}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{9}$$

3.5. Analysis of wind speed

3.5.1. Time variation

A looked at Nigeria wind speed time variation in terms of Inter-annual and annual relationship.

(i) Inter-annual

This shows the difference in wind speed overtime scale of more than one year [13]. They have effect in the estimation of long-term wind for turbine production. Fourteen years record used for this work is adequate for long-term planning. Aspliden, Elliot, and Wendell [28] have suggested that one year mean wind speed have accuracy of 10% and is within 90% confidence level.

(ii) Annual

Significant variations exist within seasons (Wet and Dry) and monthly averaged wind speeds. The zonal average wind speed are calculated and plotted to show the seasonal variation.

3.5.2. Location variation

Local topographical and ground cover variations affect wind speed. Hiester & Pennell [29] have shown that difference of mean between two cities close to each other can be significant. Within each zone, a plot of the monthly and annual trend of wind against average wind speed is made. The plots are made for Coastal, Inland, Middle Belt and Far-Northern zones.

3.5.3. Estimation of available wind power resources

Available wind power density is calculated according to [20, 30] as:

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho\frac{1}{N}\sum_{i=1}^{N}Vi^3 \tag{10}$$

Where ρ is the air density (assumed 1.225 Kg/m^3), N the number of data, i the sample number and v is the wind speed. The computed wind power density is compared with the wind classification according to [13]. **Table 1** above shows the result of classification of wind power density for various stations.

4. Results and discussions

4.1. Spatial and temporal distribution of rainfall

The **Figure 3** above, it shows the rainfall concentration and distribution that exist in the South Eastern zone of Nigeria. From the coefficient of variation obtained, it is evident that the rainfall data of the area shows greater consistency with an average of 22% in these zones. Also in **Figure 4** below, the influence of Udi Plateau is also seen in the dispersion of the rain from the mean. On the location axis, it is seen that from Nkwelle–Akwette, there is a positive value in the rainfall difference which shows the escarpment in contact with the wind bearing rain while the other side of the escarpment is noticed by the negative result obtained from Nsukka–Awka. This has significantly resulted to a variance in rainfall pattern in areas around or within the escarpment.

Furthermore, it is clearly seen that Awka has the highest negative dispersion and this is attributed to its closeness to the plateau top with the effect of the distance of each of the stations under observation not neglected.

Generally, South Eastern Nigeria rainfall follow the same pattern as other parts of Southern Nigeria with bi-modal rainfall between May–October, that is, wet season and Nov-April dry season. The rainfall indicates a double peak in July and September.
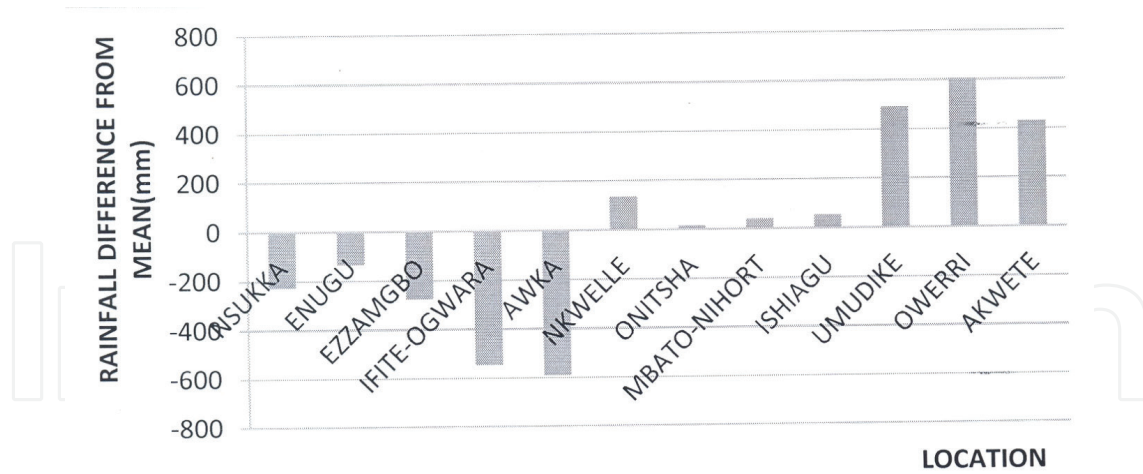
Figure 4. A graph showing the dispersion of rainfall from mean value.

4.2. Distribution characteristics of rainfall

The rainfalls of the South East Nigeria have high concentration from the coast reducing inland towards the Udi escarpment. From this research, as seen in **Table 2** above, the mean rainfall of the zone was found to be 1744 mm, and Awka having a mean of 1153 m. The heaviest rainfall of the area is around Owerri/Umudike axis at 2349 mm.

From the relation of elevation vs. annual rainfall **Figure 5** above, it is seen that rainfall decreases with increase in elevation. However elevation is not as significant as the effect of latitude and distance from the sea **Figures 6** and **7** below.

$$y = -101.9\ln(x) + 298.69$$
$$R^2 = 0.5126$$
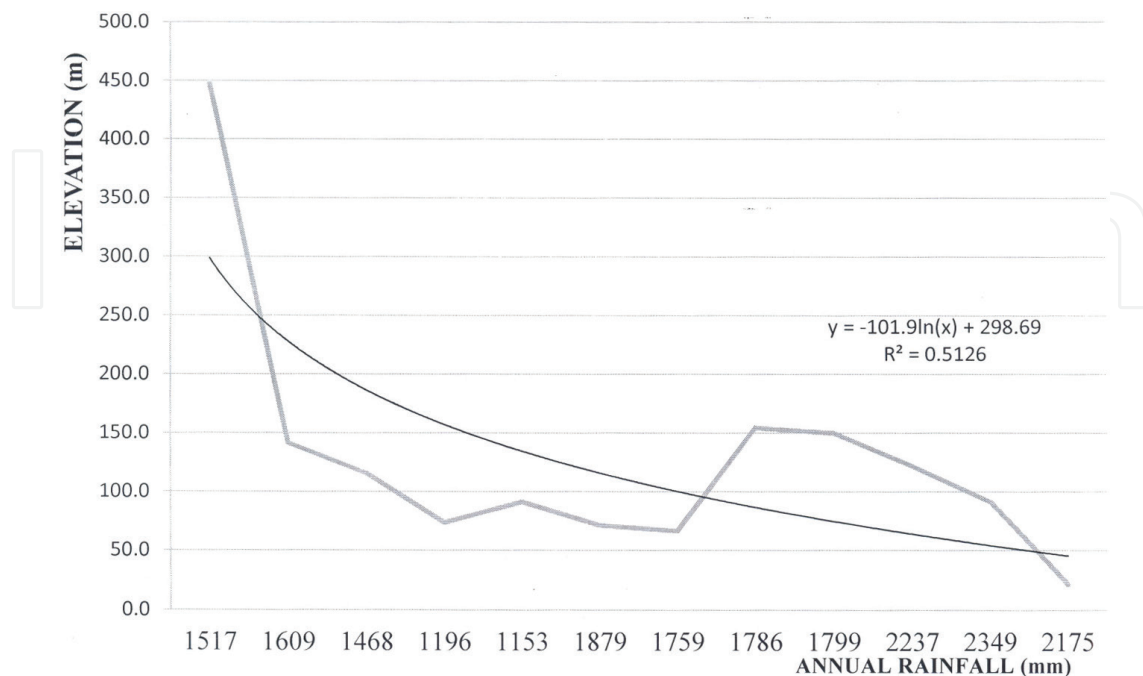
Figure 5. A graph showing elevation (m) against annual rainfall (mm).
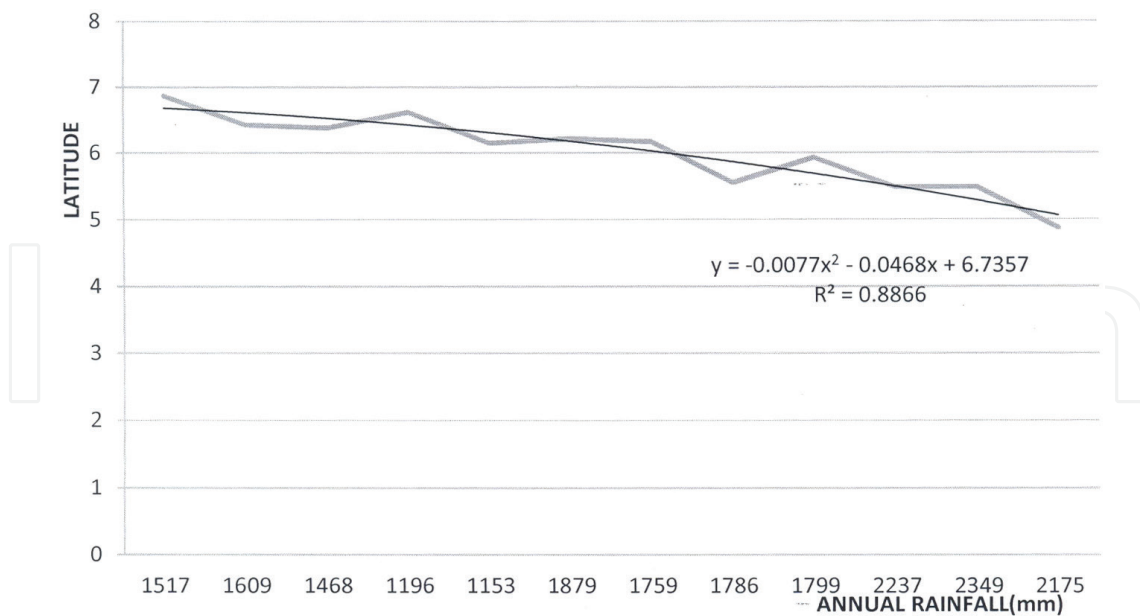
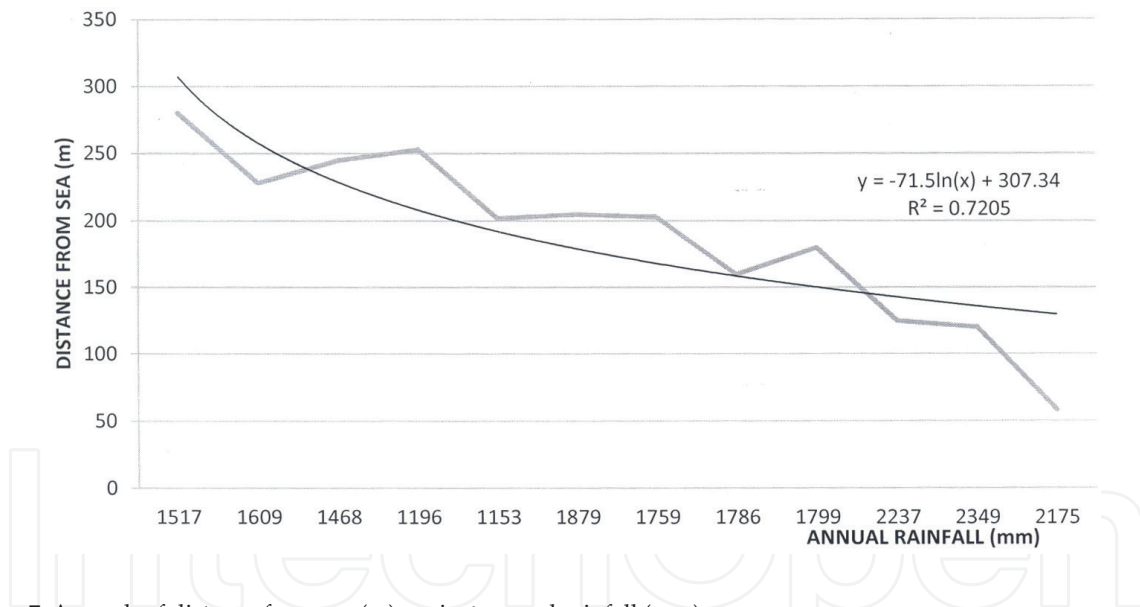**Figure 6.** A graph showing latitude against annual rainfall.

Figure 7. A graph of distance from sea (m) against annual rainfall (mm).

From **Table 1** above, it shows that the coefficient of variation of wind is lowest around the coast progressing up to the far-North where it is highest. This pattern has reversed analogous to the rainfall system of the country, which has high value in the coast and low rainfall in the North. Camberlin and Wairoto [31] have shown that there exist a relationship between the Westerlies anomalous wind pattern of Western Kenya and the rainfall of the area. More work need to be done on Nigeria wind speed and rainfall pattern.

Another important observation to make is that most cities with high altitude especially in the far north have good/higher wind speed and hence wind power density. This is illustrated in **Figure 8** below where elevation values are plotted against average wind speed.
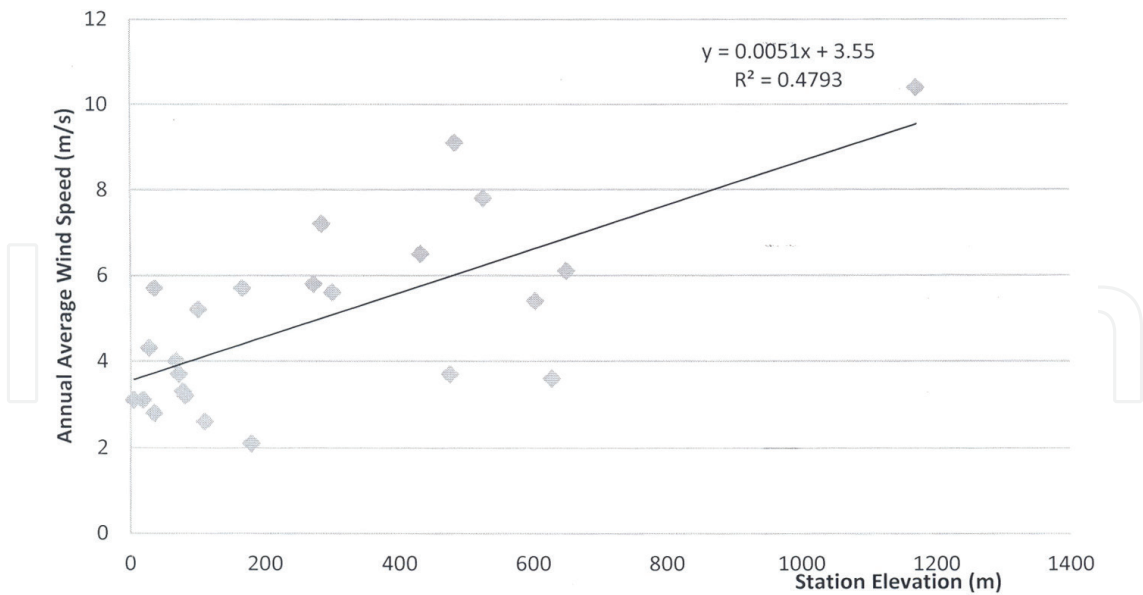
Figure 8. Annual average wind speed (m/s) against station elevation (m).

However, Bauchi which is at the base of Jos plateau with an altitude of 628 m is of class 1, the same can be said of Yola, which is on the foot of Alantika mountains. Both Weibull scale and shape factors c and k, are related by a second degree polynomial as shown in **Figure 9** below:

In Nigeria, average yearly wind speed varies from region to region. Analysis of this average indicates that Coastal area has 4.1 m/s, Inland cities has 4.2 m/s, Middle Belt area 5.0 m/s, and Far-Northern cities 5.9 m/s. This is illustrated in **Figure 10a** and **b** below for coastal and inland cities.
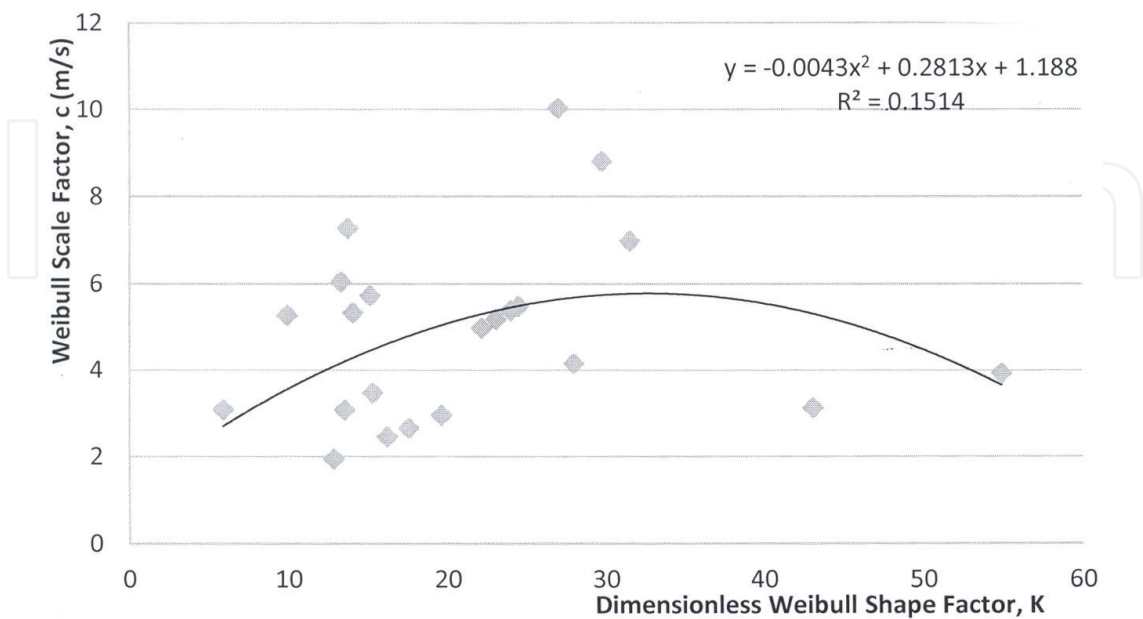

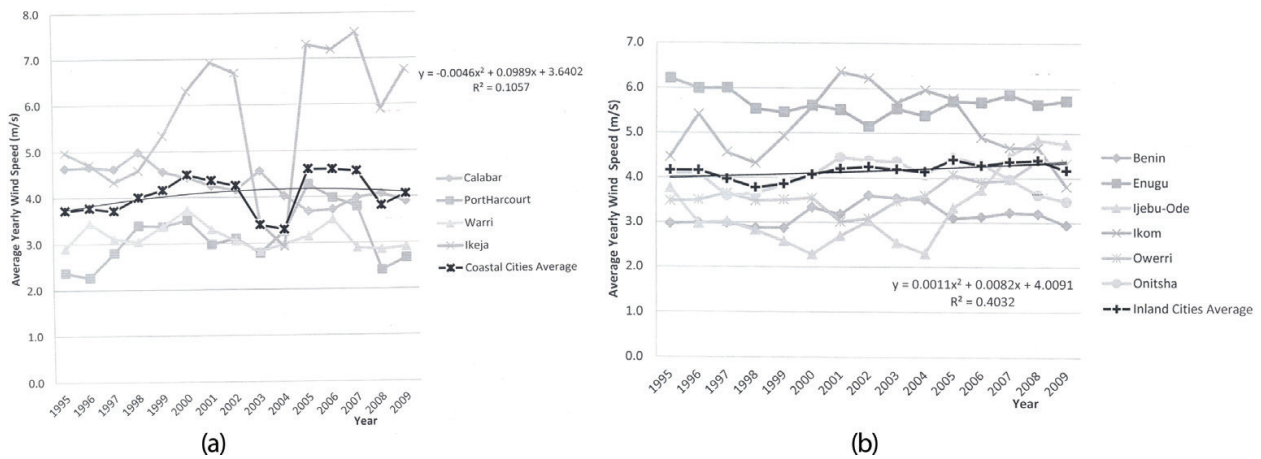**Figure 9.** Scale factor c (m/s) against shape factor.

Figure 10. (a) Trend showing annual average wind speed (m/s) for Coastal cities against year. (b) Trend showing annual average wind speed (m/s) for Inland cities against year.

Inland and Middle Belt areas have strong correlation coefficient above 0.8 while Coastal and Far-Northern zone show weak correlation below 0.25. This study has also show that Nigeria wind system exhibit bimodal peak pattern especially in the Coastal and the Inland cities corresponding with the rainfall seasons of the country while the middle belt and far-north has unimodal peak mode. From **Figures 11a** and **b** below, the Coast and Inland cities have their minimum wind speed in November at an average of 3.3 and 3.2 m/s respectively. The maximum wind speed for the zones are however highest in April and August with values of 4.6 m/s for both months in the Coast and 4.9 and 4.3 m/s for Inland cities. The middle belt and far north have minimum wind speed of 4.1 and 4.4 m/s respectively in October and maximum of 6.0 and 6.8 m/s respectively in April.

For all the regions, as shown from the graphs above, the maximum wind speed occurs in April–May which is the onset of Rainy season and minimum in October–November the start of Dry season in Nigeria.
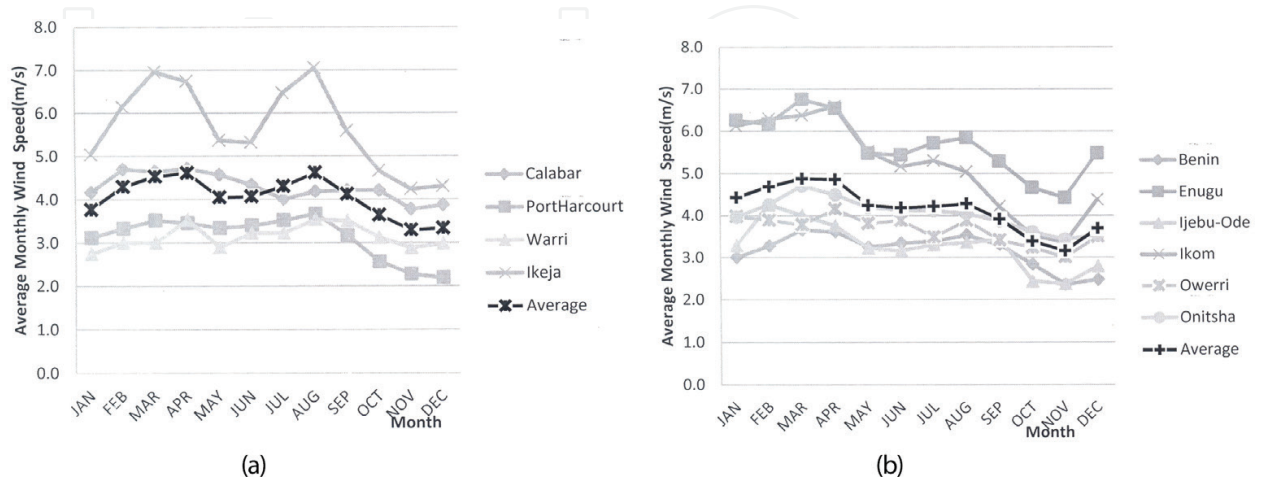

Figure 11. (a) Seasonal variation of average monthly wind speed (m/s) for Coastal cities against months of the year. (b) Seasonal variation of average monthly wind speed (m/s) for Inland cities against months of the year.

4.3. Frequency analysis results

Frequency analysis of rainfall data for South Eastern Nigeria is computed comparatively using normal, log-normal, extreme value type I, pearson type III and log-pearson type III distributions with rainfall data average 8 years and above. For the 12 stations in the zone, log-pearson type III has the best probability distribution at 50% of stations in the zone followed by pearson type III and with Log-normal and extreme value type I having no significance in the zones.as shown in **Figure 12** below.
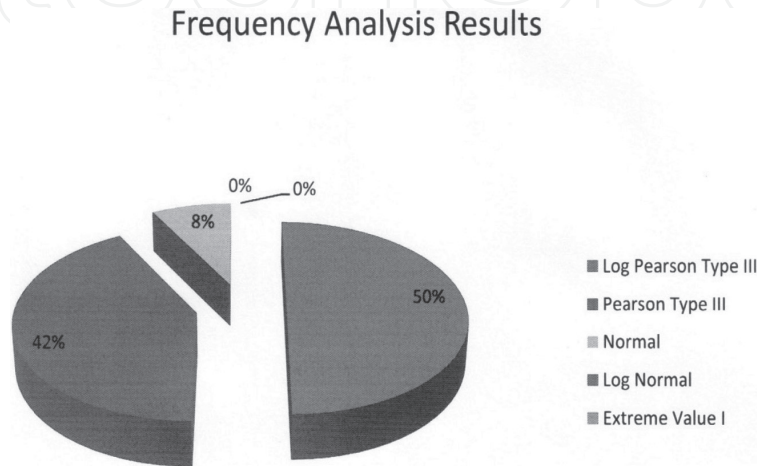

Figure 12. Frequency analysis results.

4.4. Results from principal component analysis

Variables used in this analysis consist of annual rainfall, elevation, latitude, longitude, distance from the sea and distance from the nearest neighbour data. Principal component analysis is carried out to transform the original data with the correlation and eigenvalues determined. The two components are capable of interpreting 71.85% of the entire information as shown in **Table 3** below.

	Total Variance Explained					
Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.036	50.598	50.598	2.972	49.535	49.535
2	1.275	21.248	71.846	1.339	22.311	71.846
3	0.888	14.796	86.642			
4	0.639	10.656	97.298			
5	0.112	1.869	99.167			
6	0.05	0.833	100			

Table 3. Extraction method: Principal component analysis.

Rotated Component Matrix^a

	Component	
	1	2
DIST. FROM SEA	0.958	
LATITUDE	0.946	-0.171
ANNUAL RAINFALL	-0.835	0.214
ATTITUDE	0.648	0.378
DIST. FROM NEAREST NEIGB.	-0.205	0.775
LONGITUDE		0.715

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Table 4. The principal components determined.

From **Table 4**, component 1, shows the strongest correlation exist between rainfall and distance from the sea, rainfall with latitude and rainfall with elevation. In all the cases there is a decrease in rainfall for increase in those parameters, that is, places with high elevation correspond with high latitude and shortest distance from sea and high rainfall value. As for the second component there is an increase in longitude and distance from nearest neighbour with increase in this component. This suggests that places with long distance between stations are also along increase in longitude.

5. Conclusions

The result of this study indicates that out of the five frequency distributions, log-pearson type III best describes the frequency distribution of 50% of stations. It is necessary to observe that the rainfall data used is on average 8 years and above with some missing data. A better result could be achieved with increase in number of data available to a higher accuracy. From the principal component analysis, the variation can be explained with two components and in these, the elevation, latitude, distance from sea and rainfall are the main factors, while others such as temperature, humidity, air pressure, presence of acid rain can be checked for. Since elevation has influence, as one of the main factors, it is evident that the presence of Udi escarpment is affecting the value of rainfall of the South Eastern Nigeria.

From the computed wind parameters of the 24 stations in Nigeria, it is obvious that:

Most of the Coastal regions are of class 1, that is, poor wind power density. Ikeja in the south-western part of the country is however an exception with good wind power density, hence good location for siting wind power generators. In the Inland region most cities show poor wind power density of class 1. Enugu and Ikom are however in class 2. The center of

Udi escarpment Enugu has high rain bearing wind speed but not very good for siting wind generators.

It is suggested that another study should be conducted to include the South–South zone in order to have a better picture of the influence of the main variables on the rainfall pattern of the Southern part of Nigeria.

Conflict of interest

We declare that there are no conflicts of interest in this research work.

Author details

Ngene Ben Uchechukwu[1]*, Jonah C. Agunwamba[2], Imokhai T. Tenebe[1] and Gideon O. Bamigboye[1]

*Address all correspondence to: ben.ngene@cu.edu.ng

1 Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria

2 Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

References

[1] Balogun C. The variability of rainfall in Nigeria. Nigeria Journal of Science. 1972;**6**:87-91

[2] Lee C. Application of rainfall frequency analysis on studying rainfall distribution characteristics of Chia-Nam plain area in Southern Taiwan. Crop, Environment and Bioinformatics. 2005;**2**:31-38

[3] Ngongondo C, Xu C, Gottschalk L, Akmaw B. Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scarce region. Theor. Appli. Climatol. 2011;**106**:79-93

[4] Odekunle TO. Rainfall and the length of growing season in Nigeria. Int. J. Climatol. 2004;**24**:467-479

[5] Ngene BU, Agunwamba JC, Tenebe TI, Emenike PC. Influence of escarpment on rainfall pattern: A case study of Udi-South Eastern Nigeria. Int. Journal of Applied Engineering Research. 2015;**10**:35045-35049

[6] Mutreja KN. Applied Hydrology. New Delhi, India: Tata McGraw-Hill Publication; 1990

[7] Brooks NK, Ffolliott FP, Magner AJ. Hydrology and the Management of Watershed. 4th ed. USA: John Wiley and Sons Inc.; 2013

[8] Ngene BU, Agunwamba JC, Nwachukwu BC, Okoro BC. Comparing network design approaches in areal rainfall estimate of Nigeria river basins. ARPN Journal of Engineering and applied science. 2015;**10**:1-16

[9] Iloeje NP. A New Geography of Nigeria. 5th ed. Nigeria: Longman; 2009

[10] Back EL, Bretherton SC. The relationship between wind speed and precipitation in the pacific ITCZ. Journal of Climate. 2003;**18**:4317-4328

[11] Mays WL. Water Resources Engineering. 2nd ed. United Kingdom: John Wiley and Sons; 2011

[12] Ayoade JO. Introduction to Climatology for the Tropics. 2nd ed. Nigeria: Spectrum Books; 2004

[13] Manwell JF, McGowan JG, Roger AL. Wind Energy Explained: Theory, Design and Application. West Sussex, United Kingdom: John Wiley and Sons; 2002

[14] Abdel Halim AS, Metwally E, El-desoukky MM. Environmental pollution study around a large industrial area near Cairo-Egypt. J Radioanal. Nucl. Chem. 2003;**257**:123-124

[15] Anthony T, Eniayejuni, Mary AA. Biometrics Approach to Population census and national identification in Nigeria: A Prerequisite for Planning and Development. Asian Transactions on Basic & Applied Sciences. 2011;**1**:60-67

[16] Omole DO, Ndambuki JM. Sustainable living in Africa: Case of water, sanitation, air pollution & energy. Sustainability. 2014;**6**:5187-5202

[17] Ajayi OO. The potential for wind energy in Nigeria. Wind Engineering, Multi-Science Pub. 2010;**34**:303-312

[18] Aidan J, Ododo JC. Wind speed distribution and power densities of some cities in Northern Nigeria. Journal of Energy and Applied Sciences. 2010;**5**:420-426

[19] Odo FC, Akubue, GU. Comparative assessment of three models for estimating weibull parameters for wind energy applications in a Nigerian location. International Journal of energy science (IJES). 2012;**2**:22-25

[20] Oyedepo SO, Adaramola MS, Paul SS. Analysis of Wind Speed data and Wind Energy Potential in Three Selected Locations in South-east Nigeria. Int. Journal of Energy and Environmental Engineering. 2012;**3**:1-7

[21] Dikko I, Yahaya DB. Evaluation of wind power density in Gombe, Yola and Maiduguri, North eastern Nigeria. Journal of Research in Peace, Gender and Development. 2012;**2**:115-122

[22] Houghton J. Global Warming: The Complete Briefing. 3rd ed. United Kingdom: Cambridge University Press; 2004

[23] Akintola JO. Rainfall Distribution in Nigeria. 1892-1983. Nigeria: Impact publishers; 1986

[24] Chow VT. A general formula for hydrologic frequency analysis. Transactions American Geophysical Union. 1951;**32**:231-237

[25] Kite GW. Frequency and risk analysis in hydrology, Water resources publications. 1988

[26] Cheng KS, Chiang JL, Hsu CW. Simulation of Probability Distributions Commonly Used in Hydrological Frequency Analysis. John Wiley & Sons; 2006. www.interscience.wiley.com. Accessed: 28/10/2014

[27] US Army corps of Engineer. "Engineering and design hydrologic frequency analysis", CECN-EH-Y Engineers Manual 1110-2-1415. 1993. www.irpi.to.cnr.it accessed 28/10/2014

[28] Aspliden CI, Elliot DL, Wendell LL. Resource Assessment Methods, Siting, and Performance Evaluation. In Guzzi R. & Justus CG. (Eds.), Physical Climatology for Solar and Wind Energy. New Jersey: World Scientific. 1986

[29] Hiester TR, Pennell, WT. The Meteorological Aspects of siting large Wind Turbines". U.S.DoE Report No. PNL-2522; 1981

[30] Ko K, Kim K, Huh J. Characteristics of Wind variations on Jeju Island, Korea. Int. Journal of Energy Research. 2010;**34**:36-45

[31] Camberlin P, Wairoto JG. IntraSeasonal Wind Anomalies Related to Wet and Dry Spells during the "Long" and "Short" Rainy Seasons in Kenya. Theor. Appli. Climatol. 1997;**58**:57-69