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STATISTICAL EVALUATION OF HYDRO-METEOROLOGICAL DATA: A CASE STUDY OF ISHIAGU IN SOUTH-EAST ZONE NIGERIA

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ABSTRACT

For any Engineering project to be efficient, it must be based on consistent and reliable data with good analysis. Reliability, especially for hydro-meteorological data depends on the method of collection, analysis and storage. Ishiagu weather data has been collected since the inception of the school of agriculture in the town in 1997 to date. Statistical analysis of the randomly varying data to check for their consistency and reliability is necessary before use. In this regard, the monthly data set is analysed for annual mean, trends and seasonal distribution pattern. A significant finding of this analysis is that the monthly rainfall has bimodal distribution with peaks in July and September. For the temperature of the area, it showed a sinusoidal pattern due to the seasons and this also reflects on the relative humidity of the area. A regression analysis of the three data of rainfall, temperature and relative humidity indicates a coefficient of correlation of r = 0.3, t = -0.40 and rh = -0.67. Because of the low state of the coefficient of correlation of the three parameters it may be necessary to recheck with either power, exponential or polynomial functions. From the determination of frequency of extreme events using Gumbel distribution, the highest annual rainfall value is determined to have a return period of less than 20years and the 17years records also was adjudged adequate.

Keywords: hydrology, weather, hydro-meteorological, rainfall.

INTRODUCTION

Hydro-meteorological data are important to Engineers interested in water resources management. Hydrology is the study of the presence and distribution of waters on earth (Biswas, 1970), while Meteorology looks at the Physics of evaporation of the water and the transformation to rainfall (Shaw *et al*., 2011). Hydro-meteorological data study will help in understanding how variations in rainfall in different regions of the earth will affect water resources management. As observed by Sharon (1972), rainfall varies even within short distances which are particularly the case for tropical regions of the earth due to the nature of rain formation. Studies on South Eastern Nigeria Hydro-meteorological characteristics are very scarce in literature, hence the need for this analysis.

Water resources management projects includes: water supply for domestic and industrial use, drought and flood control, irrigation, hydro-electricity, watershed management, navigation, fisheries and wildlife habitat, recreation, drainage, groundwater recharge and abstraction, sediment and salinity control (Lee, 2005).

Global warming and climate change effect has made the study of weather data to enhance the knowledge of the variability of such data and how they affect water resources projects very necessary (Ngongodo *et al*., 2011; Odekunle, 2004). In this regard, trend analysis overtime, variability of extreme events and frequency of occurrence of extreme rainfall, will aid Engineering design and economic appraisal of structures required in water resources management.

The hydro-meteorological data of interest for the Ishiagu study include the rainfall, temperature and relative humidity. A correlation among the data set is established while the seasonal variability as it affects water resources management is determined.

Mean annual temperature affects rainfall since it is a critical factor affecting the process of evaporation and wind direction (Mutreja, 1990). Also it is noted that rainfall amount and frequency are greater in wind ward direction of air mass lift. Air mass lifting is the cause of most precipitation, hence, high elevation tend to have greater rainfall.

Flood is a meteorological hazard produced by persistent extreme rainfall event over an area (Obasi, 1991). The amount and consistency of available meteorological data contribute to the reliability of flood forecasting. Drought, on the other hand is a period of persistent below average availability of water either in form of precipitation, surface water runoff or ground water.

Agriculture consumes the largest amount of water at 80% of total water controlled by man (FAO, 1972; Orkuma, 2002). This notwithstanding efficiency of allocation and use is also important to humanity as scarcity of water possess economic danger. Heavy Engineering projects such as dams require information on extreme weather events to avoid failure risk and associated damages to downstream users. With the proposal for a dam at locations shown in figure-1 below, it is necessary to ensure constant availability and adequacy of the Ivo River to sustain such a dam. Since rain at Ishiagu and environment contributes to the recharge, it is important to understand the rainfall and other hydro-meteorological pattern of the area, hence this study.

MATERIALS AND METHODS

The study area is Ishiagu, Ivo Local Government Area, Ebonyi State; Nigeria. It is located on the plains of the south-eastern savannah belt in Nigeria. Ishiagu is located 5°56′55″N 7°34′00″E with a height above sea level

of 150m and approximately covering an area of 200sqkm (Wikipedia). Physical environment and climate of the study site is described below.

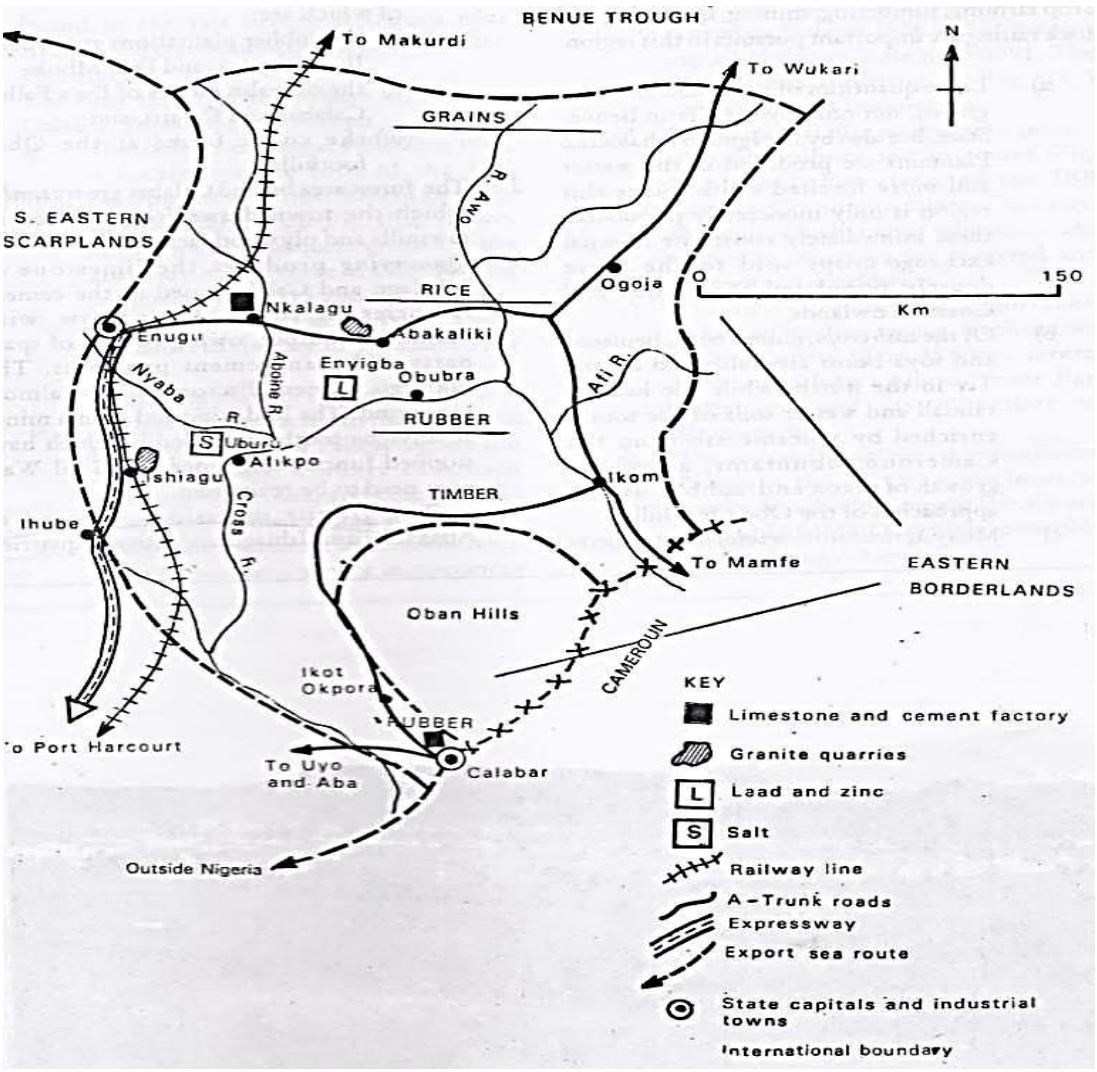


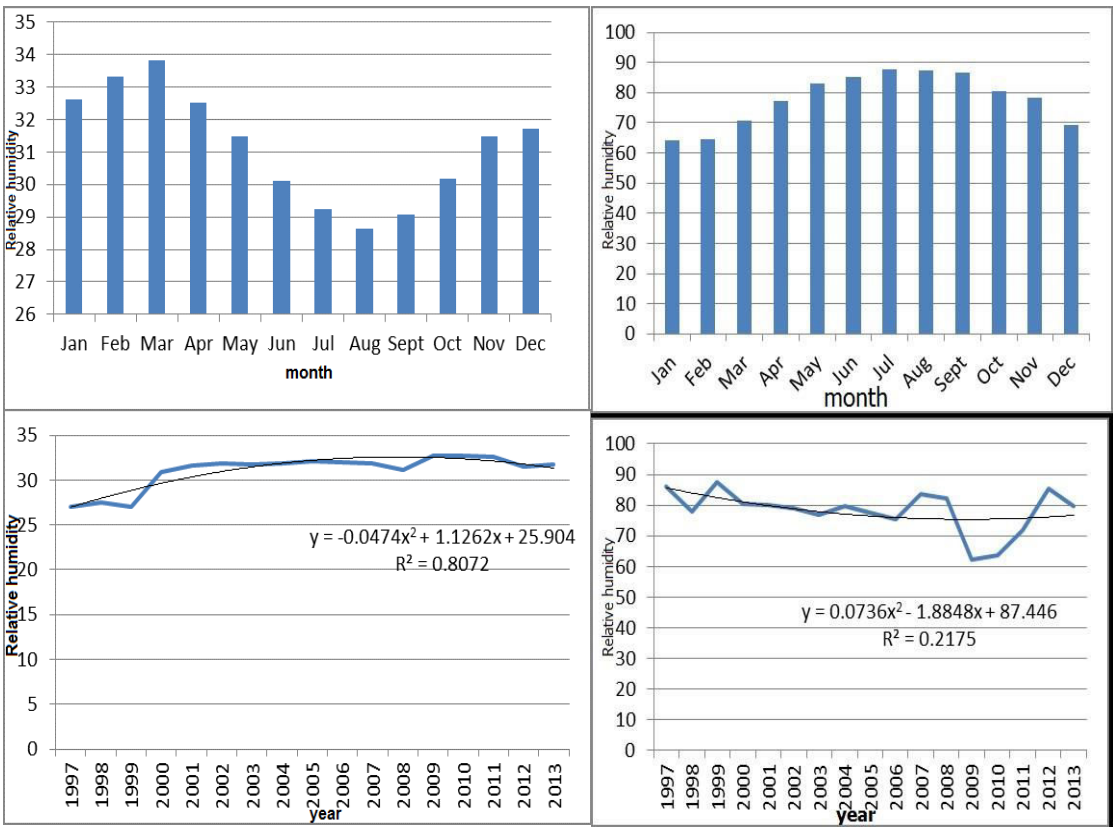
Figure-1. Map of study area, Ishiagu source: (Iloeje, 2009).

Physical environment

The site is located on the lowland region of southern Nigeria, which drains to the Atlantic Ocean through the Cross River Basin. From geology, the area is part of the anticlinorium left over from the Udi plateau, over 300m height (Iloeje, 2009). The stratified sedimentary rock of the area is of the secondary to tertiary geological era. Specific to the study area as well as others in the River basin are the granite intrusions shown on Figure-1. Above, which outcropped as isolated hills and rocky whalebacks quarried at the site. The study area has good agricultural land with Ivo River which collects from other rivers with origin at the foot of Udi Escarpment draining into the Cross River (Ngene et. al., 2015)

Climate and hydrology of study area

The climate for Ishiagu and environment is of the wet tropical type with mean annual temperature in the range of between 27 ℃ and 34℃. The rainfall of the area is of the annual average 1799mm which decreases progressively from the 3000mm in the coastal areas. Annual rainfall regime of the area is of the double maxima with double peak in May and September and a break in August. The temperature of the study site is noted to be highest around March-April, when the overhead sun passes through Nigeria latitude while moving north to the tropic of cancer as suggested by Iloeje (2009). The high rain of May-September lowers the temperature while the sun is on the return journey in October.



2(a) 2(b)

Figure-2 (a) and **2 (b).** Seasonal temperature and relative humidity of study site.

The data used for this study are the monthly rainfall, temperature and relative humidity data collected from the Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria. The hydro-meteorological data was for a period 1997-2003, which started at the inception of the school and hence has not been affected by site relocation. Data consistency, homogeneity and adequacy will be tested to determine the reliability.

(a) Mean

The mean annual data values were used to obtain a regression equation of distribution pattern and trends, Yahaya and Abubakar (2002).

$$X = \frac{1}{n}\sum_{i=1}^{n} xi \quad (1)$$

where
xi = variable(rainfall etc) amount
n= number of years

Monthly mean rainfall etc. was however used to show the distribution of average rainfall over the period 1997-2013.

Also from the annual mean calculation, the departure from the average is determined and plotted to show year of possible drought and flooding.

(b) Standard deviation

Standard deviation defines the degree to which the data is dispersed or varied. The calculation is made to show how clustered around a mean the data are and also an indication of the data homogeneity, Akintola (1986).

$$\sigma = \sqrt{\sum_{i=1}^{n} \frac{(X-\bar{X})^2}{N}} \quad (2)$$

(c) Coefficient of variation

The coefficient of variation or relative dispersion is obtained by

$$Cv = \frac{\sigma}{\bar{X}} \quad (3)$$

A Coefficient of variation closer to one indicates greater consistency of data set.

(d) Standard error

This measure the difference between the sample and population mean as in

$$Sx = \frac{\sigma}{\sqrt{N}} \quad (4)$$

However the probability of occurrence of a certain event at a time in the future can be determined using the Bayesian approach according to Ang and Tang (1975) as follows.

$$fX(x) = N\left(\bar{X}, \left(\sqrt{\sigma^2 + \frac{\sigma^2}{N}}\right)\right) \quad (5)$$

In this situation the error in the estimation of mean is included in the computation of the probability.

(e) Range of variation

This determines the deviation of maximum or minimum values from mean in percentage terms. Range of variation is calculated as follows:

$$\text{Rv} = \frac{Max\ or\ Min - \bar{y}}{\bar{y}} x^{100\%} \quad (6)$$

(f) Cumulative relative frequency

To obtain the value of cumulative frequency, the percentage ogive is used

(g) Coefficient of skewness

Coefficient of skewness measures the asymmetry or departure from symmetry of a distribution. The 10%-90% percentile coefficient of skewness may be calculated as follows:

$$Skewness = \frac{P_{90} - 2P_{50} + P_{10}}{P_{90} - P_{10}} \quad (7)$$

The third moment is also measured by

$$Skewness = \sum_{i=1}^{N} \frac{(Xi - \bar{X})^3}{N\sigma^3} \quad (8)$$

(h) Coefficient of Kurtosis

Kurtosis measures how peaked the distribution is relative to normal distribution with k-value of zero. This is calculated using the following equation.

$$K = \frac{Q}{P_{90} - P_{10}} \quad (9)$$

Where $Q = \frac{(Q3 - Q1)}{2}$ obtained from the percentage ogive. The Kurtosis or fourth moment is also calculated using

$$K = \sum_{i=1}^{N} \frac{(Xi - \bar{X})^4}{N\sigma^4} \quad (10)$$

(i) Frequency distribution

A frequency distribution shows the arrangement of data by class. Note the bimodal nature of the rainfall data in the study area as in Figure-3 below. The rainfall data has double peaks in May and September.

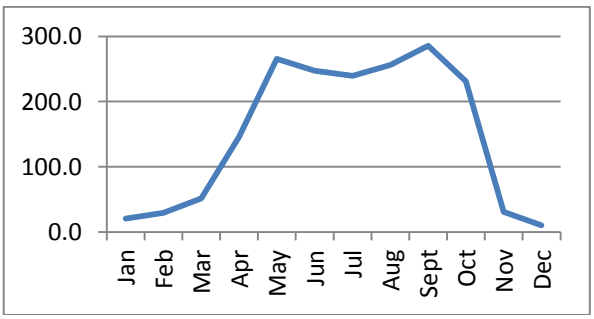


Figure-3. Bimodal nature of Ishiagu rainfall monthly distribution.

(j) Correlation analysis

Correlation analysis is used to determine the degree of relationship between variables using linear or other equations. To obtain a linear regression equation of the three variables (Rainfall, Relative Humidity and Temperature) the following equation is used.

$$Xr = b_r + b_{rh}X_{rh} + b_t X_t \quad (11)$$

Solving the three equations simultaneously will give the coefficients b_r, b_{rh} and b_t.

(k) Standard error of estimate

Estimate of the standard error is obtained using the following equation

$$Sx = \sqrt{\frac{\sum(X - Xest)^2}{N}} \quad (12)$$

(l) Drought and flood estimation

Drought period are seasons of lack of rainfall. This lack of rainfall as stated by Shaw et al (2011) is a function of climate regions of the world. It is observed that during this period, the usual rainfall will fall short of expected amount resulting in vegetation and agricultural crop failures. This rainfall deficiency in this instant looks at the departure from rainfall over a period. The reverse, however is the case for flooding.

According to Islam and Kumar (2003), the following can be used to determine month/year of drought/flooding or periods below or above normal rainfall.

a) Normal month - 50-200% of average monthly rainfall
b) Drought month - < 50%of average monthly rainfall
c) Abnormal month - > 200% of average monthly rainfall
d) Normal year - $(\bar{X} \mp SD)$
e) Drought year - $(\bar{X} - SD)$
f) Abnormal year - $(\bar{X} + SD)$

(m) Frequency analysis of extreme events

The theory of extreme value is used in the frequency analysis of floods and drought as per Kottegoda and Rosso (2008). Though several distribution methods are available for estimation, Gumbel distribution was used to calculate 2, 10, 20, 50, 100, 500 and 1000yrs return period of rainfall as follows

$$F(X) = \exp(-e^{-y}) \quad (13)$$

Where $y = \frac{1}{0.7797\sigma}(x - \bar{X} + 0.450\sigma)$ (14)

For the return period T, the formula is

$$T = \frac{1}{1 - P} \quad (15)$$

Where p, is the probability at return period.

(n) Adequacy of length of records

The adequacy of length of records is calculated using the following equation according to Islam and Kumar (2003).

$$Y = (4.3t \log_{10} R)^2 + 6 \quad (16)$$

where y represents the minimum acceptable year, t is the student's statistical value at 95% level of significance, with $(y - 6)$degree of freedom and R is the ratio, of 100yrs event to 2yrs event.

RESULTS AND DISCUSSIONS

Mean

Analysis of mean shown in Figure-4 below indicates average monthly rainfall to be bi-modal with double peaks in May and September and a reduction in July. A linear regression equation was established for yearly rainfall and year 2001 indicate a drought year at -486mm below 1799mm annual mean, while year 2003 has the highest rainfall of 2186mm since the record began.

Temperature of the area has a sinusoidal shape with downward concave and a polynomial equation having the best R^2.The relative humidity on the hand indicate a convex shape upwards and a polynomial regression equation for the monthly values having the best R^2 coefficient as seen in Figures 2a and 2b earlier.

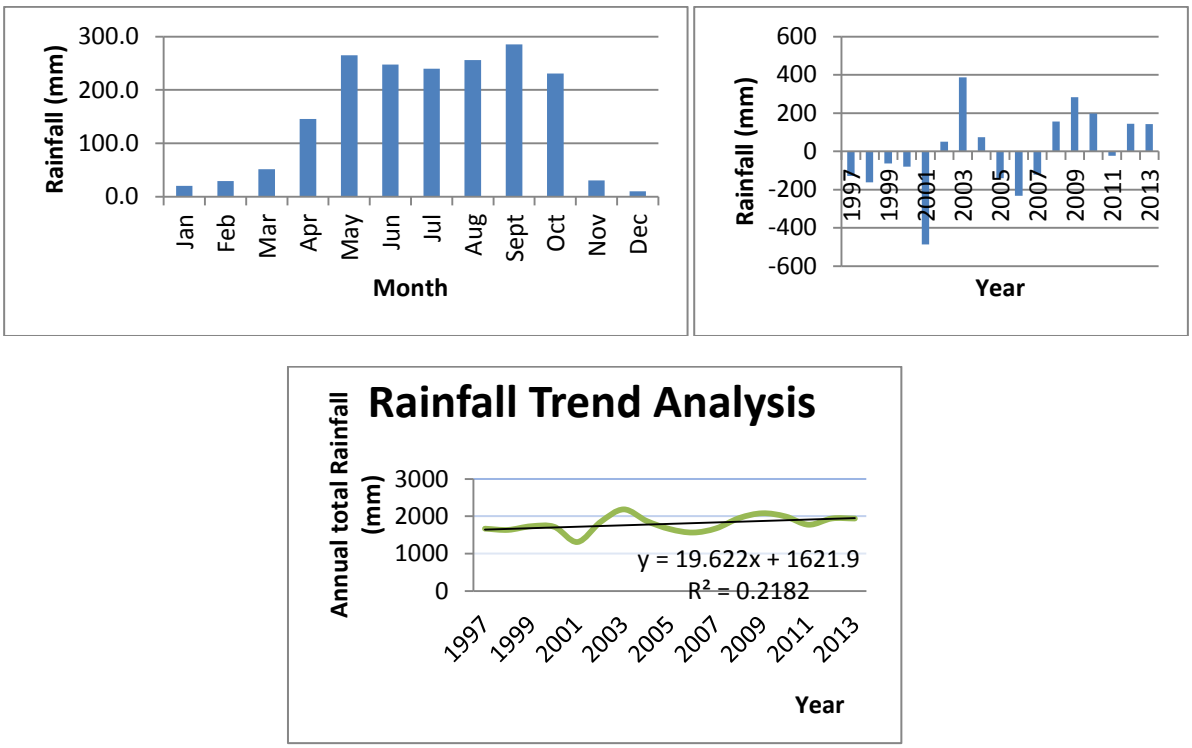


Figure-4. Mean rainfall trend analysis and difference in mean.

Standard deviation

The yearly rainfall data showed a standard deviation of 212.14 while the monthly mean temperature and relative humidity has standard deviation of 1.92 and 6.99 respectively. These values were more useful in the calculation of standard error and frequency analysis of extreme value.

Coefficient of variation

The Table-1 below showed a coefficient of variation of the weather parameters. From the table it is obvious that Rainfall values have a cluster around one an indication of consistency. However, temperature and relative humidity does not represent a consistent data.

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Table-1. Rainfall, temperature and relative humidity coefficient of variation.

Table 1a Shows Coefficient of Variation of Annual Rainfall of Ishiagu

Month/Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Annual Total Rainfall	1670	1638	1735	1718	1313	1849	2186	1873	1658	1566	1678	1954	2082	1997	1775	1943	1941
Coeff. Of Variation	0.52	0.87	0.82	0.91	0.83	0.82	0.92	0.92	0.74	0.96	0.93	0.96	0.81	0.87	0.89	0.79	0.68

Table 1b Shows Coefficient of Variation of Annual Temperature Average of Ishiagu

Month/Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Annual Ave. Temp.	27	28	27	31	32	32	32	32	32	32	32	31	33	33	33	32	32
Coeff. Of Variation	0.03	0.07	0.04	0.07	0.07	0.06	0.06	0.06	0.05	0.04	0.06	0.05	0.05	0.07	0.05	0.06	0.06

Table 1c Shows Coefficient of Variation of Annual Relative Humidity Average of Ishiagu

Month/Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Annual Ave.	86	78	88	80	80	79	77	80	78	76	84	82	62	64	72	85	80
Coeff. Of Variation	0.06	0.16	0.08	0.16	0.17	0.14	0.15	0.18	0.10	0.13	0.10	0.17	0.23	0.24	0.14	0.09	0.11

Standard error

An example of the calculation of standard error and probability of future event will explain this better. With annual rainfall value and standard deviation of N (1799mm, 212.14mm), the probability that the annual rainfall will fall between lowest and highest recorded values is (1313mm and 2186mm) and also that the rainfall will exceed 2186mm is determined as below.

$$P(1313 < X \leq 2186) = \varphi\frac{(2186-1799)}{212.14} - \varphi\frac{(1313-1799)}{212.14}$$
$$= \varphi(1.82) - \varphi(-2.29)$$
$$= 0.9656 - (1-0.9881)$$
$$= 0.9537$$

This Probability indicates a 95% chance of rainfall value falling between current lowest and highest annual reading.

By use of Gaussian variate X, mean of 1799 and standard deviation 212.14 in a density function, as in equation 5 above, the probability that rainfall will exceed 2186mm in the future will be.

$$P(X > 2186) = \varphi(\infty) - \varphi\left(\frac{2186-1799}{\sqrt{212.14^2} + \frac{(212.14)^2}{\sqrt{17}}}\right)$$
$$= 1 - \varphi(1.77) = 1 - 0.9616$$
$$= 0.0384$$

In other words, there is approximately 4% chance of annual rainfall total being higher than the current highest value in the future. Also note that the standard error value of $\frac{\sigma}{\sqrt{N}}$ is used in the probability estimation.

Range of variation

Equation 6 is used to calculate the range of variation as percentage of mean. For rainfall the range is between a minimum of -27% and maximum of 22%. Temperature is in the range of -13 and 5%, while relative humidity is in the range of -21% and 12%. The results indicate that there is a wide range of variation in the annual rainfall reflected even in the lowest and highest rainfall years. The same result is seen in the relative humidity reading while the temperature values have low variation. The Temperature figures reflect the tropical nature of the nation Nigeria, in general, with low range of variation.

Cumulative relative frequency

A plot of the cumulative frequency against annual total rainfall is made as shown in Figure-5 below. From this plot is determined the 25, 50 and 75 percentile which correspond to the 1st, 2nd, and 3rd Quartile of values 1675mm, 1775mm and 1940mm respectively.

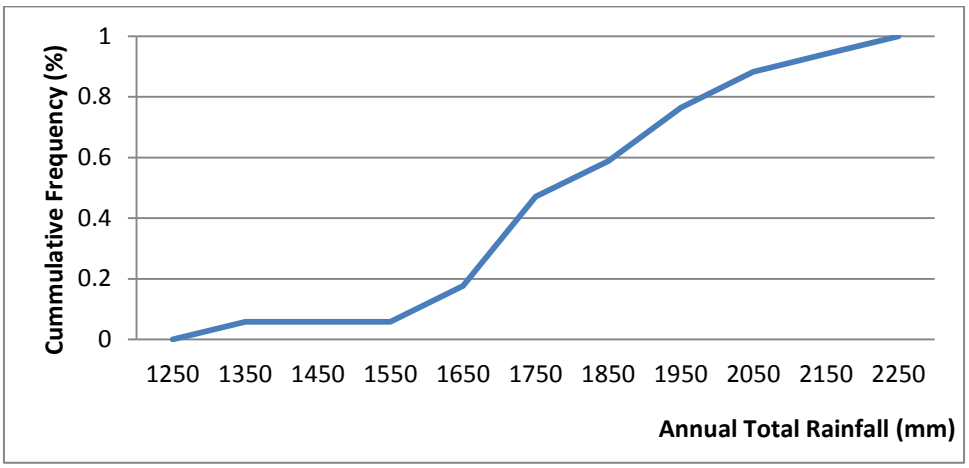

Figure-5. Cumulative frequency distribution of Ishiagu rainfall.

Coefficient of skewness

The 10%-90% percentile coefficient of skewness was calculated for annual rainfall to be 0.23, which is skewness to the right, while the Quartile skewness is 0.25. The skewness used for this work is however based on Windows Excel programme.

Coefficient of Kurtosis

This coefficient was determined using the Quartile and 10-90percentile to be 0.27. The positive value indicates how peaked from zero the data set is. Again the Kurtosis used for the work is however based on Windows Excel programme.

Correlation analysis

The correlation amongst the three parameters of Rainfall, Temperature and Relative Humidity is governed by the following equation:

$$Rain = 2571.68 + 5.26Temp. - 11.97R.Hum \quad (17)$$

The regression equation has partial correlation coefficients of r= 0.3, t = -0.40 and rh = -0.67.

Standard error of estimate

The standard error of estimate is determined based on linear equation 17 to be193. The Value is better appreciated when coefficient of correlation is calculated and in this situation as r = 0.3, t = -0.40 and rh = -0.67. A check on power function, exponential or polynomial equations can be compared since the coefficients have values close to zero.

Drought and flood estimation

The rainfall that corresponds to the period of drought and flood was determined as follows:

a) Normal month - 76mm-302mm
b) Drought month < 76mm
c) Abnormal month > 302mm
d) Normal year - 1799mm
e) Drought year - 1587mm
f) Abnormal year - 2011mm

From these values, the study area has January-March, November-December as dry seasons. The rainfall for this period is mostly below drought values. Again the years 2001 and 2006 defines the drought year or years with below average rainfall. In contrast, from site records, year 2003 and 2009 define flood years.

Frequency analysis of extreme events

By Gumbel method in equations 13 to 15 with 17years record, mean rainfall of 1799mm and standard deviation of 212.14mm, the rainfall of return periods are shown in Table-2 below. From this table also, the highest rainfall event of 2186mm for year 2003 has a return period of less than 20years.

Table-2. Return period against rainfall amount.

Return period (yrs)	**Rainfall amount** (mm)
2	1764
10	2076
20	2195
50	2349
100	2464
500	2731
1000	2846

Adequacy of length of records

The length of record is adequate at 7years from equation 16 and at 95% level of significance.

CONCLUSIONS

The rainfall for the study area showed an increasing annual trend with average monthly values in bimodal mode and a double peak in May and September. Because of the popular August break which occurs mostly in the southern part of the country, there is a depression or low rainfall during the period. Temperature follows the

same pattern as rain with a sinusoidal movement from January to December, while the relative humidity is highest between June-September.

From the coefficient of variation, it is evident that the data is consistent. The calculation of the standard error and probability of rainfall exceeding the maximum and minimum showed that the data is reliable at 95% level of significance

November to March is the dry season for the area while April-October is the rainy season. A study of the extreme event frequency indicates that abnormal year rainfall has a return period less than 10years. Though the available hydro-meteorological data is for 17years, it is adequate for the calculation made with mean rainfall of 1799mm and standard deviation of 212.14mm. From the return period against rainfall calculations a water resources planner or designer for a bridge, water supply, dam or any water retaining structure for the area will be better informed in choosing appropriate design life and service efficiency of his structure.

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