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# RAINFALL ANALYSIS FOR ENVIRONMENTAL APPLICATIONS IN MAIDUGURI, NIGERIA

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ABSTRACT

Rainfall data for Maiduguri, the capital of Borno State in North-East, Nigeria, covering the period from 1927 to 1983 (57 years) was extracted from published literature and used in this study. The data was subjected to statistical tests for trends, inconsistency and stability. Six separate monthly series were created for the purpose of the analysis. All the series passed the trend test, which was based on the Spearman's rank correlation test. The F- and t-tests on the series showed consistency and stability of the variance and mean, respectively. It is therefore, concluded that the rainfall data can be used for further analysis and storm sewage facility design.


**KEY WORDS: rainfall, trend, stationary, homogeneous, consistent.**

## INTRODUCTION

Rainfall is important in many engineering and environmental applications. For example, in the design of a water supply system to increase the existing water supply to a community or metropolis (whenever supplies become inadequate especially during the dry seasons), precipitation is an important factor to be considered. Rainfall data for such application should be free of trends, and should be stationary. Such hydrologic data should also be consistent and homogeneous (Hassan, et al., 1998). Maiduguri, which is the capital of Borno State, Nigeria, is situated at about 11° 49' N and 13° 09' E and about 700km from the Atlantic coast. It is located within the semi-arid zone of northeastern Nigeria and has wide climatic variations . The statistical nature of rainfall data for an area experiencing sharp seasonal contrasts in climatic variables is of paramount importance. Jumps or trends bought about by inconsistency and non-homogeneity will make rainfall data unsuitable for use in the design of storm sewers. It is important to check whether any existing trend is independent of the gauging and due to meteorological conditions (Wilson, 1983). In this study, some statistical analyses were performed on rainfall data for Maiduguri, Nigeria, to test the suitability of the data for use in engineering applications.

## METHODOLOGY

### Statistical Characteristics of the Rainfall Data

Rainfall data was obtained from Akintola (1986). Available continuous rainfall data for the years 1927 to 1983 (57years) on monthly basis were used in this study. Annual series, partial duration series, independent series, full series and annual exceedance series are series used in hydrology. For this work, use is made of the annual maximum series. One month, 2month, 3 month-, 4 month-, 5 month-, and 6 month- series were constructed using the moving total method. This method ensures that wide variations of particular years are smoothed out. It also makes it easy to detect any existing trend when subjected to statistical analysis. Calculations of 1-, 2-, 3-, 4-, 5- and 6- month moving total were made for each year and the maximum was selected for each series per year. The statistical characteristics of these series are shown in Figure 1.

It can be seen from Figure 1 that the mean and standard deviation decrease with increase in time. The increase of the coefficient of variation with time indicates that rainfalls of long duration are more uniform. This can also be seen in the closeness of the coefficient of variation values for the 5- month and 6- month series.

### Preliminary Analysis of Rainfall Series

Changes in rainfall records can be caused by change in the gauging equipment, meteorology of the region, erection of a building or fence near the gauge, planting of trees or change of observer(Wilson, 1983). Using the double mass curve approach, any visible trend or inconsistency can easily be identified. This involves plotting cumulative total annual rainfall for a particular station against cumulative mean total annual rainfall of nearby stations in the same region. A sudden divergence from the straight-line correlation will mean that the change is due to the gauging and not meteorology since all the surrounding stations in the region would have been equally affected.

Figure 2 shows that there is no sudden divergence from the mean straight line. The cumulative rainfall data for Maiduguri was correlated with cumulative rainfall data for Potiskum, Bauchi and Nguru, which are in the same Northeast region as Maiduguri. The result shows that the rainfall data from Maiduguri is consistent with the rainfall data from surrounding stations in the same Northeast region. No obvious severe trend or discontinuity was observed when the time series of 6-month was plotted to assess the fluctuations about the mean as can be seen in Figure 3.

## STATISTICAL TESTS OF RAINFALL DATA

The statistical tests on the rainfall data followed after the initial inspection of the data as done above.

### Test for Absence of Trend

Freedom from trend for any statistical time series means that there should not be any correlation between the increase or decrease in magnitude of the data and the order in which the data have been collected (Hassan, et al., 1998). The Spearman rank-order correlation method was used. This is the earliest to be developed of all the statistics based on ranks. It measures the association between two variables, which requires that both variables be measured in at least an ordinal scale so that the objects or individuals under study may be ranked in two ordered series (Siegel and Castellan, 1988). The Spearman rank-correlation method is simple, distribution-free, and for both linear and non-linear trends, has nearly uniform power (Hassan et al. 1998).

The Spearman rank-correlation coefficient $r_s$ can be calculated using the equation (1);

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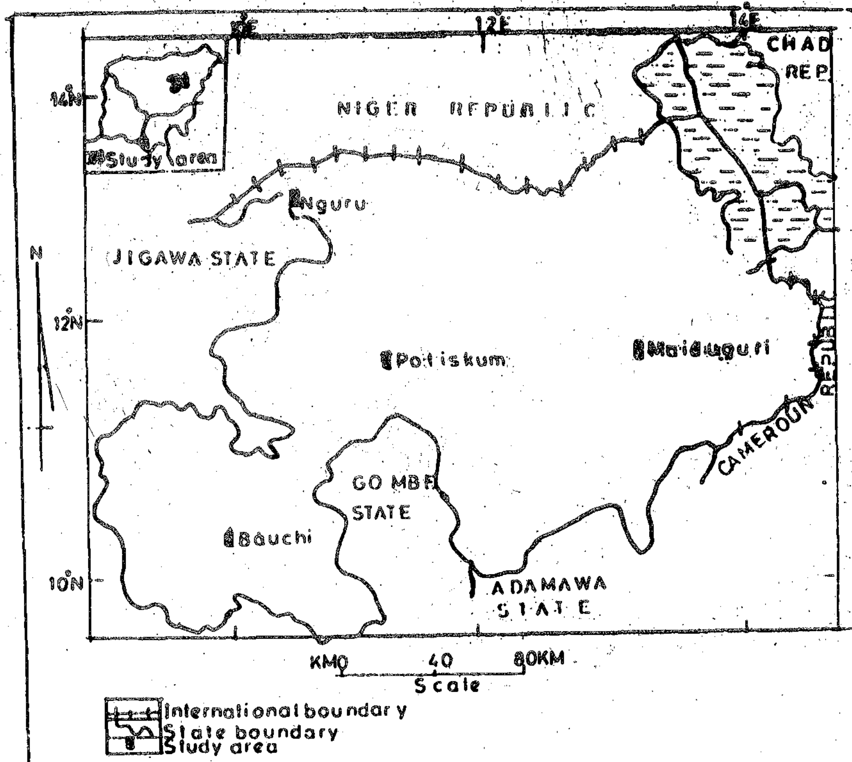


Fig. 1a: Part of North-Eastern Nigeria showing the study area

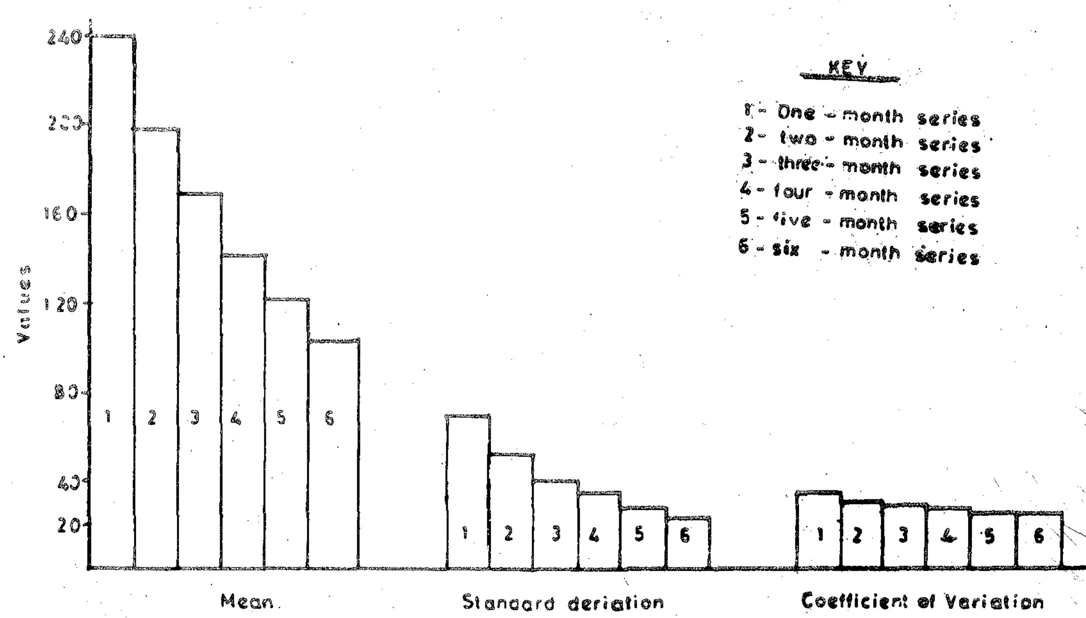


Fig 1b PRELIMINARY STATISTICAL ANALYSIS OF RAINFALL

$$r_s = 1 - \left\{ \left( \frac{6 \sum_{i=1}^{n} d_i^2}{n^3 - n} \right) \right\} \quad (1)$$

where,
$d_i$= difference in ranks = $x_i$-$y_i$
$x_i$ = chronological order number of the original observation
$y_i$ = rank of observation when the series is arranged in ascending order.
$n$ = number of samples.

The significance of $r_s$ needs to be tested. This will involve testing the null hypothesis that there is no trend ($H_0$: there is no trend; alternative hypothesis $H_1$: there is a trend) and that the observed value of $r_s$ differs from zero by chance.

The t-test

$$t_t = r_s \sqrt{\frac{(n-2)}{(1-r_s^2)}} \quad (2)$$

where $n$ = number of observations and $n$-2 = degree of freedom

**Table 1 Trend analysis using Spearman's rank correlation coefficient for different series of rainfall in Maiduguri from 1927to1983**

| Rainfall series | r | Z(1%) | Z | Z(99%) | H |
|---|---|---|---|---|---|
| 1 month | -0.095 | -2.576 | -0.71 | 2.576 | Accepted |
| 2 month | -0.276 | -2.576 | -2.069 | 2.576 | Accepted |
| 3 month | -0.244 | -2.576 | -1.829 | 2.576 | Accepted |
| 4 month | -0.207 | -2.576 | -1.545 | 2.576 | Accepted |
| 5 month | -0.225 | -2.576 | -1.682 | 2.576 | Accepted |
| 6 month | -0.224 | -2.576 | -1.676 | 2.576 | Accepted |
| Remark: | There is no trend in the rainfall series. | | | | |

and the Z test

$$z = \sqrt{(n-1)} \quad (3)$$

can be used to test the null hypothesis. Due to the large number of observations (N is greater than 50) the Z-test was adopted since in actual practice and with large N, the advantage of t-test over the Z-test is very small (Hassan et al 1998). The acceptance region at a significance level of 2% (two tailed) is:

**Lower limit = Z (v,1%); Upper limit = Z (v, 99%)** **(4)**

The Z value was calculated for annual maximum rainfall of 1, 2, 3, 4, 5, and 6 months, respectively. The alternative hypothesis $H_1$ is rejected if $r_s$ lies in the acceptance region of a two-tailed test. As can be seen in Table 1, all the $r_s$ values lie within the acceptance region of −2.328 to +2.326. This means that the null hypothesis $H_0$ that there is no trend is accepted.

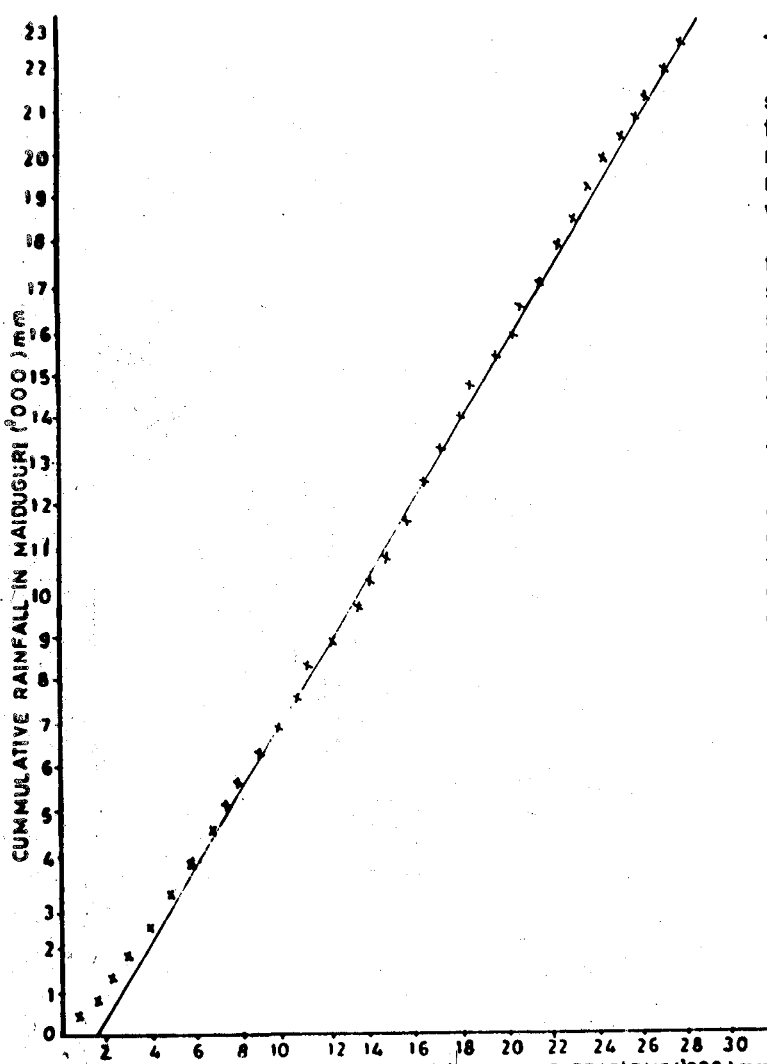


Fig. 2. Double mass diagram of maiduguri with stations in the same region.

**Test for Stationarity, Consistency and Homogeneity**

Any choice of time of origin is not supposed to affect the statistical properties of a time series. These include mean, (the first moment about the origin) and the variance (the second moment about the origin) (Miller and Freund, 1977). This means that the estimated properties of these parameters lie within an expected range.

The F-test and the t-test can normally be used to test for the stability of mean and variance. The results are used to show whether or not any given hydrological series is stationary, consistent and homogeneous. The procedure is to split the data into non-overlapping subsets, calculate the mean and variance for each subset and then subject them to F- and t-tests.

**The F-test**

This test is utilized to ascertain the stability of the hydrological series. The F distribution is related to the beta distribution and it has two parameters $v_1$, the degrees of freedom for the sample variance in the numerator and $v_2$ the degrees of freedom for the sample variance in the denominator. The theorem for the F-distribution means that if independent random samples of $n_1$ and $n_2$ are taken from normal populations having the same variance, then

$$F_t = \frac{S_1^2}{S_2^2} \quad (5)$$

where $s_1$ and $s_2$ are standard deviations of the independent random samples $n_1$ and $n_2$. Equation (5) is a value of a random variable having the F distribution with

$$v_1 = n_1 \quad (6)$$

$$v_2 = n_2 - 2 \quad (7)$$

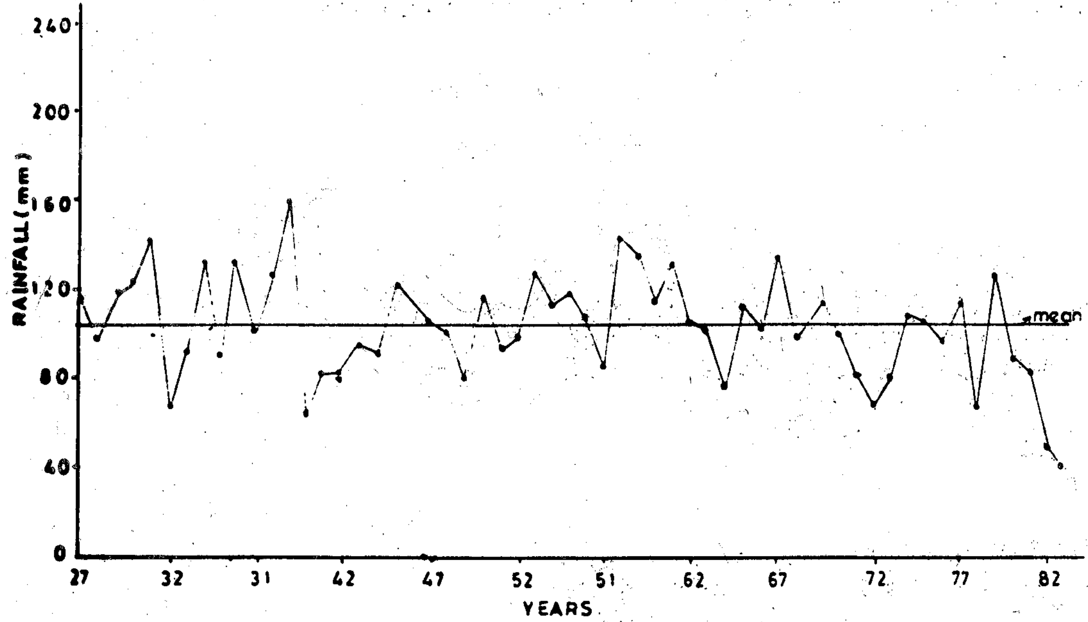


FIG 3 PLOT RAINFALL DATA FOR 6-MONTH SERIES AROUND MEAN.

**Table 2 F-test for stability of variance (2 sets)**

| | Series | | | | | |
|---|---|---|---|---|---|---|
| | 1 month | 2month | 3 month | 4 month | 5 month | 6 month |
| Standard deviation 1 | 59.26 | 43.79 | 33.2 | 31.05 | 25.7 | 22.11 |
| Standard deviation 2 | 81.99 | 59.36 | 47.43 | 38.02 | 29.9 | 25.24 |
| F (1%) | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 |
| F | 0.521 | 5.45 | 0.489 | 0.667 | 0.739 | 0.767 |
| F (99%) | 2.39 | 2.39 | 2.39 | 2.39 | 2.39 | 2.39 |
| $H_0$ | Accepted | Accepted | Accepted | Accepted | Accepted | Accepted |
| Remark: | Variances are stable for all the series. | | | | | |

**Table 3 t-test for stability of mean**

| | Series | | | | | |
|---|---|---|---|---|---|---|
| | 1 month | 2 month | 3 month | 4 month | 5 month | 6 month |
| Mean 1 | 240.4 | 204.25 | 173.66 | 146.53 | 125.12 | 106.91 |
| Mean 2 | 240.47 | 192.72 | 164.19 | 139.3 | 117.66 | 100.56 |
| t (!%) | -2.67 | -2.67 | -2.67 | -2.67 | -2.67 | -2.67 |
| t | -0.03 | 0.84 | 0.88 | 0.79 | 1.01 | 1.01 |
| t (99%) | 2.67 | 2.67 | 2.67 | 2.67 | 2.67 | 2.67 |
| $H_0$ | Accepted | Accepted | Accepted | Accepted | Accepted | Accepted |
| Remark: | The means of the series are stable. | | | | | |

The null hypothesis $H_0 : \sigma_1^2 = \sigma_2^2$ (8)

is being tested against an alternative hypothesis of

$$H_1 : \sigma_1^2 \neq \sigma_2^2 \quad (9)$$

Considering a two-tailed test, $H_0$ is rejected if

$$F_{\alpha/2}(v_2, v_1) \rangle F \rangle + F_{1-\alpha/2}(v_2, v_1) \quad (10)$$

where,

$$F_{1-\alpha/2} = 1 \big/ F_{\alpha/2}(v_2, v_1) \quad (11)$$

From Table 2, $H_0$ is within the range of

$$F_{0.01}(v_2, v_1) \langle F \langle F_{0.99}(v_2, v_1) \quad (12)$$

That is F is within the range of –0.417 to +2.40 for all series for a significance level of $\alpha = 0.02$.

**The t-test for stability of mean**

The variance as well as the mean of a time series should not be affected by selection of time of origin if the series is stationary, consistent and homogeneous. Two non-overlapping subsets were used to test the stability of the two subsets.

$$t_t = \frac{x_1 - x_2}{\sqrt{\left[\left\{\frac{(n_2-n)s_1^2+(n_2-1)s_2^2}{n+n_2-2}\right\}\left\{\frac{1}{n}+\frac{1}{n_2}\right\}\right]}} \quad (13)$$

The two hypothesis tested were:

The null hypothesis $H_0 : x_1 = x_2$ and (14)

The alternative hypothesis $H_0 : x_1 \neq x_2$ (15)

Prior to the testing of a time series for stability of mean, the stability of the variance is normally tested for first. Using a 2% level of significance, $H_0$ should be accepted if

$$t_{(v,1\%)} \langle t_t \langle t_{(v,99\%)} \quad (16)$$

where $v = n_1 + n_2 - 2$ (17)

$n_1$ and $n_2$ are the numbers of observations of the two subsets, respectively.

From Table 3, the null hypothesis is accepted for all series since all the $t_t$ values lie between-2.671 and +2.671. These tests indicate that the rainfall series derived for Maiduguri rainfall data are stationary, consistent, and homogeneous.

## DISCUSSION

There are no trends or inconsistencies in the rainfall data from preliminary screening. The double mass diagram shows that the rainfall data for Maiduguri is consistent with other rainfall data for Nguru, Bauchi and Potiskum, which are in the same Northeast region of Nigeria.

Statistical analysis of the data also shows the absence of trends in the rainfall series. At 2% level of significance, the means and standard deviations were stable. This implies that the data can be used for the analysis or design without any objection. A 2% level of significance was used in this study showing that there is 98% confidence level in the results obtained.

## CONCLUSIONS

From the above study, the following can be concluded:

1) Preliminary investigation shows that all the series are without trends
2) The mass curve diagram shows that the data are consistent
3) From the statistical analysis the data are also seen to be without trends.
4) Tests on the variances and means show that the series are consistent, homogeneous and stable.
5) The data can be used for further analysis.

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