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ANALYSIS OF ANNUAL RAINFALL IN ZIMBABWE FOR TRENDS AND PERIODICITIES, 1891–1988.

by

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ABSTRACT

Recent droughts during the early 1980s have led to the belief that rainfall over Southern Africa has changed or follows some form of periodic behaviour. Annual rainfall at 20 stations in Zimbabwe covering the period 1891 to 1988 is analysed for the presence of trends, discontinuities, persistence and periodicities. The results show that droughts cannot be described by any of these processes.

INTRODUCTION

Zimbabwe, like most of the Southern African countries, experienced a severe drought during the 1982–1985 period. The occurrence of such droughts during this decade has been described as either a progressive dessication or as part of some oscillation in the rainfall series (Tyson, 1980). On the basis of a spectral analysis of 157 stations in South Africa covering the period 1910–1977, Tyson and Dyer (1978) concluded that a quasi-20 year oscillation existed in the annual rainfall of the summer rainfall region. A two wave model which used annual rainfall data smoothed using a binomial filter predicted that the 1970s will be generally wet till about 1982, while the present decade will be dry up to 1992. Vines (1980) reported similar findings using annual rainfall for South Africa, south-east Australia, and New Zealand. The possible influence of the sunspots was pointed out by Vines (1980). Tyson (1980) quoted several studies on Southern African rainfall which did show the existence of such an oscillation.

Statistically, the occurrence of droughts can be attributed to any of the following factors: a trend which results in decreasing amounts of rainfall being received, i.e. progressive dessication; a discontinuity (sudden decrease) in rainfall; autocorrelation in the annual rainfall can cause droughts to persist; periodic behaviour in the annual rainfall can cause droughts to occur on a regular cycle; and droughts can also be simply a result of the random variability of a stationary time series.

In this paper annual rainfall over Zimbabwe is analysed using statistical methods to determine which of the factors mentioned above best describes the occurrence of droughts in Zimbabwe.

METHODOLOGY

The determination of the statistical process which best describes the occurrence of droughts is a problem of statistical decision making. If it is assumed that droughts are a result of purely random variations (i.e. the null hypothesis), then the other possible processes become the alternative hypotheses. The different alternative hypotheses will determine the tests to use. Such tests should be able to distinguish the null hypothesis from the alternative hypotheses. The tests to be used for each of the alternative hypotheses are discussed below.

a) Trend

Kendall *et al.* (1983) recommended that any statistical test for the presence of trends in a time series should have the following properties; i) distribution free, ii) the number of calculations to be performed should be minimised, and iii) a high power to distinguish the null hypotheses from the alternatives. Several statistical tests satisfy the above criteria but they have different power. The turning point and difference sign tests have a low power of detecting trends in cyclical time series. The Kendall rank correlation test is one of the most powerful tests for detecting both linear and non-linear trends (Kendall, 1976; Kottegoda, 1980). This test will be used in the present analysis. The test is based on the number of pairs, p, for which $X_j > X_i$, where (i=1, j=2, 3, ..., N), (i=2, j=3, 4, ..., N), ..., (i=N–1, j=N). N is the sample size. For a random series,

$$\tau = \frac{4p}{N(N-1)} - 1 \qquad (1)$$

has E (τ) = 0 and

$$\mathrm{Var}\ (\tau) = \frac{2(2N+5)}{9N(N-1)} \qquad (2)$$

where E(τ) is the expectation of τ, and Var(τ) is the variance of τ. $\tau/[\mathrm{Var}(\tau)]^{1/2}$ tends to a standard normal distribution (Kendall *et al.*, 1983; Kottegoda, 1980).

b) Discontinuity

Droughts can also result from a sudden decrease in the rainfall. The problem becomes that of determining and locating any significant change-point in the series. If a change-point occurs in the time series, X_i, i=1, 2, ..., N, at a point t, then the distribution of X_i, for i=1, ..., t, is different from that of X_i, for i=t+1, ..., N. The null hypothesis to be tested is that there is no change in the rainfall, while the alternative hypothesis is that there has been a decrease (discontinuity) in the rainfall.

A non-parametric test suitable for this problem is a version of the Mann-Whitney test, developed by Pettitt (1979).

Let

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{N} \text{sgn}(X_i - X_j) \tag{3}$$

where sgn(x) = 1 if x > 0, sgn(x) = 0 if x = 0, and sgn(x) = −1 if x < 0. If there has been a shift downwards then

$$K_N = \max_{1 \leq t \geq N} U_t \tag{4}$$

is expected to be large. For a continuous variable such as annual rainfall, an approximate significance probability, p_s, of K_N is given by

$$p_s = \exp\left[\frac{-6(K_N)^2}{(N^3 + N^2)}\right] \tag{5}$$

If K_N is significant, then the location of the discontinuity is at that point at which $K_N = U_t$.

c) Autocorrelation

The presence of positive autocorrelation in annual rainfall would mean that wet (drought) years tend to be followed by wet (drought) years. With negative autocorrelation wet years tend to be followed by dry years. A study of the autocorrelation function of a time series often reveals the structure of the process generating the time series. The partial autocorrelation function can also be used to help with this identification (Box and Jenkins, 1976). Some common processes are the autoregressive, moving average, and a mixture of both processes. If a time series has a periodic component, the autocorrelation function may sometimes reveal this. The autocorrelation function is estimated by the serial correlation coefficients, r_l, given in (6).

$$r_l = \frac{\sum_{t=1}^{N-l} (X_t - \overline{X})(X_{t+l} - \overline{X})}{\sum_{t=1}^{N} (X_t - \overline{X})^2} \qquad (6)$$

The confidence limits of r_l, $CL(r_l)$, have been outlined by Yevjevich (1972) and are given in (7).

$$CL(r_l) = \frac{-1 \pm z_\alpha \sqrt{N-k-1}}{N-K} \qquad (7)$$

where z_a = standard normal deviate which corresponds to the α level of significance.

d) Periodicities

The autocorrelation is useful for detecting persistence as the source of non-randomness, but when non-randomness is due to quasi-periodicities, the autocorrelation cannot always detect such sources. For such cases techniques in the frequency domain such as spectral analysis are ideal (Jenkins and Watts, 1968). Spectral analysis aims at partitioning the variance of the stochastic process into the various frequencies generating the process.

The sample spectrum C_f of a sample x_t is given by

$$C_f = \frac{2}{N}\left[\left\{\sum_{t=1}^{N} x_t \cos\frac{2\pi ft}{N}\right\}^2 + \left\{\sum_{t=1}^{N} x_t \sin\frac{2\pi ft}{N}\right\}^2\right] \qquad (8)$$

where f=1, 2, ..., INT[(N/2) – 1], where INT[ ] is the integer part of (N/2) – 1. The standardised cumulative spectrum, I_k, defined in (9) is often used for testing the existence of any significant frequency.

$$I_k = \sum_{f=1}^{k} C_f/(N s^2) \qquad k = 1, 2, \ldots, \mathrm{INT}[(N/2) - 1] \qquad (9)$$

where s is the sample standard deviation of x_t. If x_t is a random process, then a plot of I_k against k/INT[(N/2) – 1] is scattered randomly around the line joining (0, 0) and (0.5, 1), which is the periodogram of a white noise. The significance of the deviations of the plotted points from the white noise straight line can be tested using the Kolmogorov-Smirnov test (Jenkins and Watts, 1968). If $(N - 1)/2 > 35$, the 95% confidence interval is defined by two parallel lines at a distance $1.36 / \sqrt{N}$ above and below the white noise line (Yevjevich, 1972).

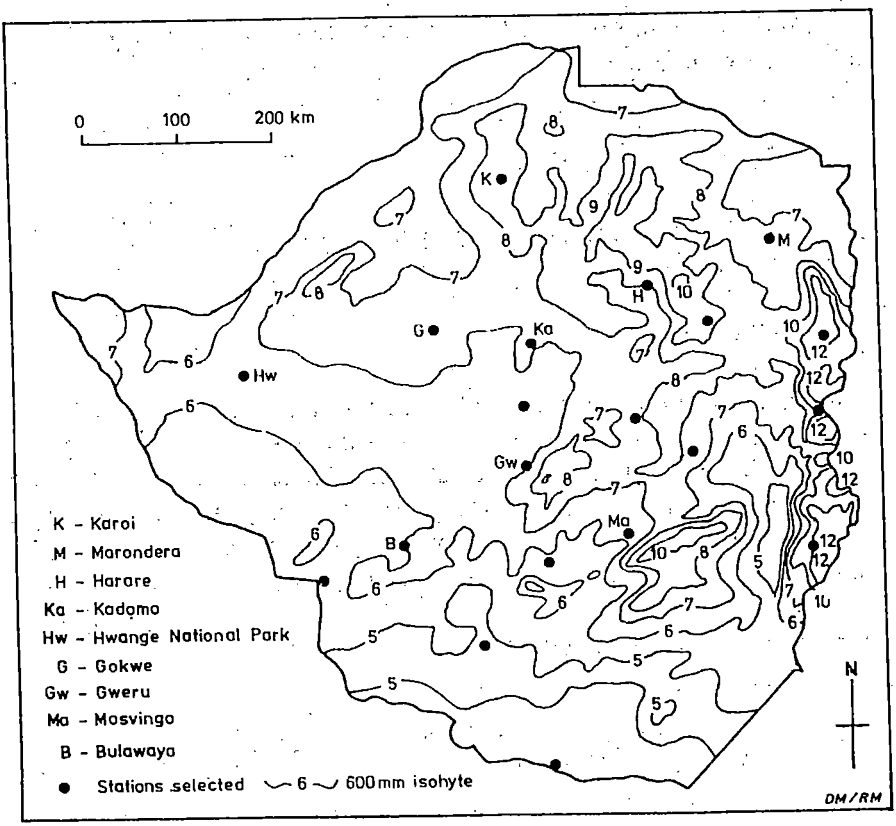

Figure 1: Mean Annual Rainfall: Zimbabwe

STUDY AREA

Zimbabwe lies within the tropics extending from 15° to 22°S, and from 25° to 33°E, with an area of about 400 000 sq. km. Rainfall in Zimbabwe is characterised by its occurrence in a distinct rainy season (typically mid-November to mid-March), while during other times no significant rainfall occurs. During the rainy season the moisture bearing winds are the northeast monsoons, south-east trades, and the Congo air mass. The Inter-Tropical Convergence Zone (ITCZ) is often overlying Zimbabwe (Department of Meteorological Services, 1981). While the average annual rainfall for the whole country is about 675mm, there is a great spatial variability (see Figure 1). The low lying areas, such as the Limpopo valley, receive about 300mm while parts of the Eastern Highlands receive annual rainfall greater than 1200mm. Interannual rainfall variability is high, and typical coefficients of variation for most parts of the country range between 20 and 40%. During the rainy season months, the rainfall distribution over the whole country tends to follow the annual distribution.

TABLE 1:
ANNUAL RAINFALL STATISTICS FOR THE 20 STATIONS SELECTED

STATION	LENGTH	MEAN	STD.D*	LAG–1
Beit Bridge	66	336	112	0.10
Buhera	63	827	292	–0.06
Bulawayo Goetz	91	597	203	–0.13
Chipinge	76	1121	330	–0.11
Chivhu	83	745	252	–0.10
Gokwe	75	786	225	–0.13
Gweru Thornhill	90	675	212	–0.20
Harare Belvedere	97	825	197	–0.10
Hwange	66	568	177	–0.12
Kadoma	80	765	224	–0.19
Karoi	62	831	175	–0.10
Kwekwe	80	696	236	–0.10
Marondera	48	904	263	–0.22
Masvingo	89	632	219	–0.13
Mutare	90	791	249	–0.11
Mutoko	80	717	204	–0.17
Nyanga	49	1179	283	–0.18
Plumtree	80	585	197	–0.20
West Nicholson	78	509	202	–0.08
Zvishavane	67	577	212	–0.15

* STD.D is the standard deviation of annual rainfall. LAG–1 is the lag 1 serial correlation coefficient.

Twenty rainfall stations with annual rainfall ranging from 336 to 1179 mm were selected for the present study (see Figure 1 and Table 1). These stations have record lengths varying from 48 to 97 years, and are complete to the end of the 1987/88 rainy season. All the stations selected are part of the main network of meteorological stations. The annual rainfall figures are based on the official meteorological year which is from July to June.

Table 1 gives some rainfall statistics of these stations. In Figure 2 annual rainfall for one of the stations, Harare Belvedere, has been plotted.

RESULTS

The null hypothesis H_0, tested by the various tests is that droughts are due to random fluctuations, i.e. annual rainfall is a white noise process. The interpretation of the rejection of H_0 will depend on the power of each of the tests to distinguish H_0 from alternative hypotheses (i.e. trends, discontinuity, autocorrelation, periodicities).

At the 5% significance level all cases of the null hypothesis are accepted. Figure 3 shows some correlograms obtained, and that of Harare Belvedere is typical of the other stations not shown, and similarly Figure 4 gives a typical periodogram obtained after spectral analysis.

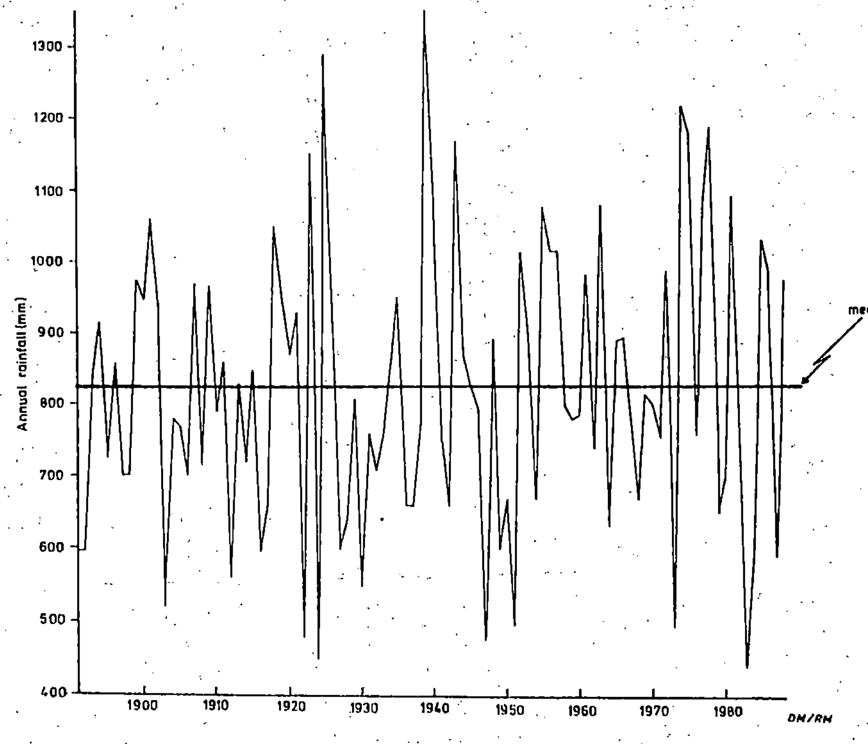

Figure 2: Harare Belvedere Annual Rainfall

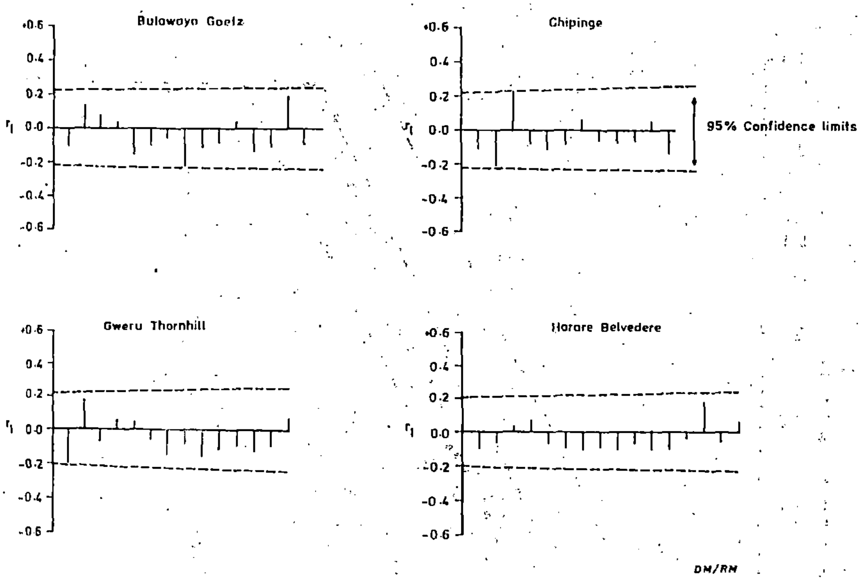

Figure 3: Annual Rainfall Correlograms

DISCUSSION

The acceptance of the white noise hypothesis by the Kendall rank correlation test indicates the absence of any linear or non-linear trend in the annual rainfall. Thus although droughts have been frequent and severe in the eighties there is no evidence to suggest that Zimbabwe is progressively drying. Similar observations concerning South Africa were made by Tyson (1986). According to the Pettitt test, the hypothesis that droughts are a result of a sudden decrease in rainfall is not acceptable. This shows that while the 1980s have been dry, the annual rainfall pattern has not changed significantly.

None of the correlograms showed any persistence in annual rainfall. Thus the occurrence of droughts in Zimbabwe cannot be described in terms of persistence in the annual rainfall pattern. The autocorrelation may also show regular periodic behaviour in time series. The results do not show the presence of such behaviour in the annual rainfall.

None of the periodograms indicated the presence of any significant pure or quasi-periodicities. This contradicts the results of Tyson and Dyer (1975, 1978) who concluded that an 18 to 20 year oscillation, with about 9 wet years followed by 9 dry years existed in the summer South African rainfall. The contradiction may be due to the low power of the Kolmogorov-

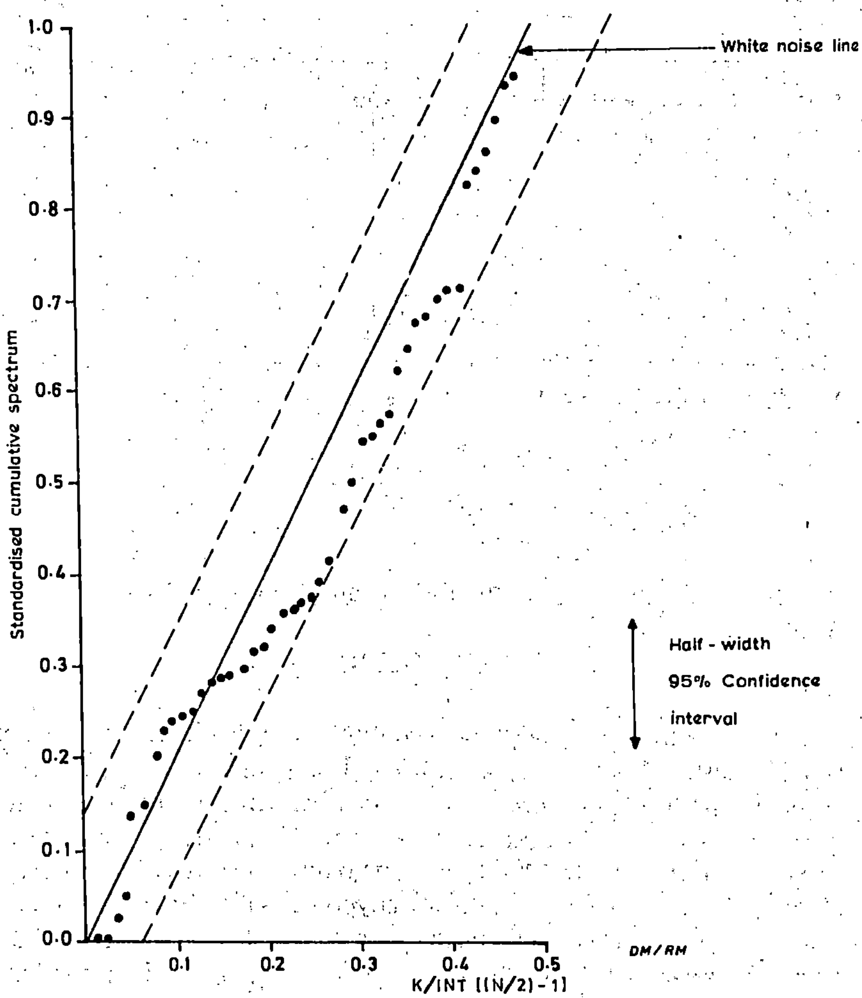

Figure 4: Bulawayo Goetz Periodogram

Smirnov test. However, this does not seem to be the case because the same results were obtained when the Fisher test of significant harmonics (Fisher, 1929; Andel and Balek, 1971), and the Chi-square test (Jenkins and Watts, 1968) were used. The differences in the results may be due to the use of point annual rainfall in this study, whereas Tyson and Dyer (1975, 1978) used areal rainfall.

The results of the present analysis agree with those obtained when the same techniques were applied to the annual number of rainy days at Bulawayo Goetz, Gweru Thornhill, and Harare Belvedere. In a separate study of the annual runoff in Zimbabwe, Mazvimavi and Vandewiele (1987) found no significant autocorrelation or quasi-periodicities.

CONCLUSION

The analysis of 20 annual rainfall series of varying length between 48 to 97 years, has shown that droughts in Zimbabwe cannot be described as a progressive dessication or by some sudden change in the annual rainfall. Neither can droughts be described in terms of autocorrelation or some quasi-periodicities. It is suggested therefore that droughts in Zimbabwe are due to random fluctuations in annual rainfall.

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