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Rainfall variability, drought and implications of its impacts on Zambia, 1886–1996

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Abstract The theory of runs was used in the investigation of frequency of occurrence, duration, magnitude and severity of drought in 46 districts of Zambia, 1886–1996. The 30-year "normal" rainfall was used as the threshold for drought occurrence with most analyses restricted to the 1921–1970 period. Analysis revealed that rainfall variability, indicated by increasing 11-year coefficients of variation (CVs) for selected stations and decreasing rainfall trends observed in southern Zambia after 1975, was not extraordinary as similar conditions were experienced before the turn of 19th century. What was new, however, is that the decreasing rainfall after 1975 seems to be related to the accelerated global warming associated with anthropogenic activities. Implications of impacts of drought were assessed from scenarios of drought occurrence under the threat of rising global warming. Various drought adaptation measures are discussed. It is concluded that, in Zambia drought is a chronic phenomenon which requires pre-planned measures for minimizing its impacts.

INTRODUCTION

In the last three decades, the African continent has experienced drought, one of the worst natural disasters in history. Millions of dollars and many man-hours have been spent on food relief, drought related services and research projects on drought and famine in Africa (Payne *et al.*, 1987). Yet, fundamental properties of drought such as the frequency of occurrence and duration are not known with sufficient accuracy to allow prediction (Oguntoyimbo, 1986; Kane & Trivedi, 1986). This implies that researchers have not been asking the right questions. Recent efforts of modelling some characteristics of drought offer hope for solutions to problems of drought (Sharma, 1997). In Zambia, the international donor community has provided food and non-food aid towards food relief. For the 1992 and 1995 droughts this was valued at over US$ 70 million (Sichingabula, 1994) and US$ 40 million (Banda *et al.*, 1997), respectively.

Statistical analysis of droughts requires that time series of rainfall data be considered as a success and failure process in which success is a positive outcome and failure a negative about a selected threshold value. This approach is amenable to the application of the statistical theory of runs (Yevjevich, 1967) which simplifies the analysis of time series of stochastic or deterministic variables such as hydrological and meteorological events which encompass drought.

The objectives of this paper which investigates the problem of drought in Zambia were to: (a) assess climatological and agricultural impacts of drought; and (b) assess implications of drought occurrence under the threat of global warming. Better knowledge of drought should help decision-makers in formulating mitigation strategies.

AREA OF STUDY AND DATA

This study includes 46 districts covering the whole of Zambia which has an area of 753 620 km^2 and is located in the southern tropics of Africa (Figs 1(a) and (b)).

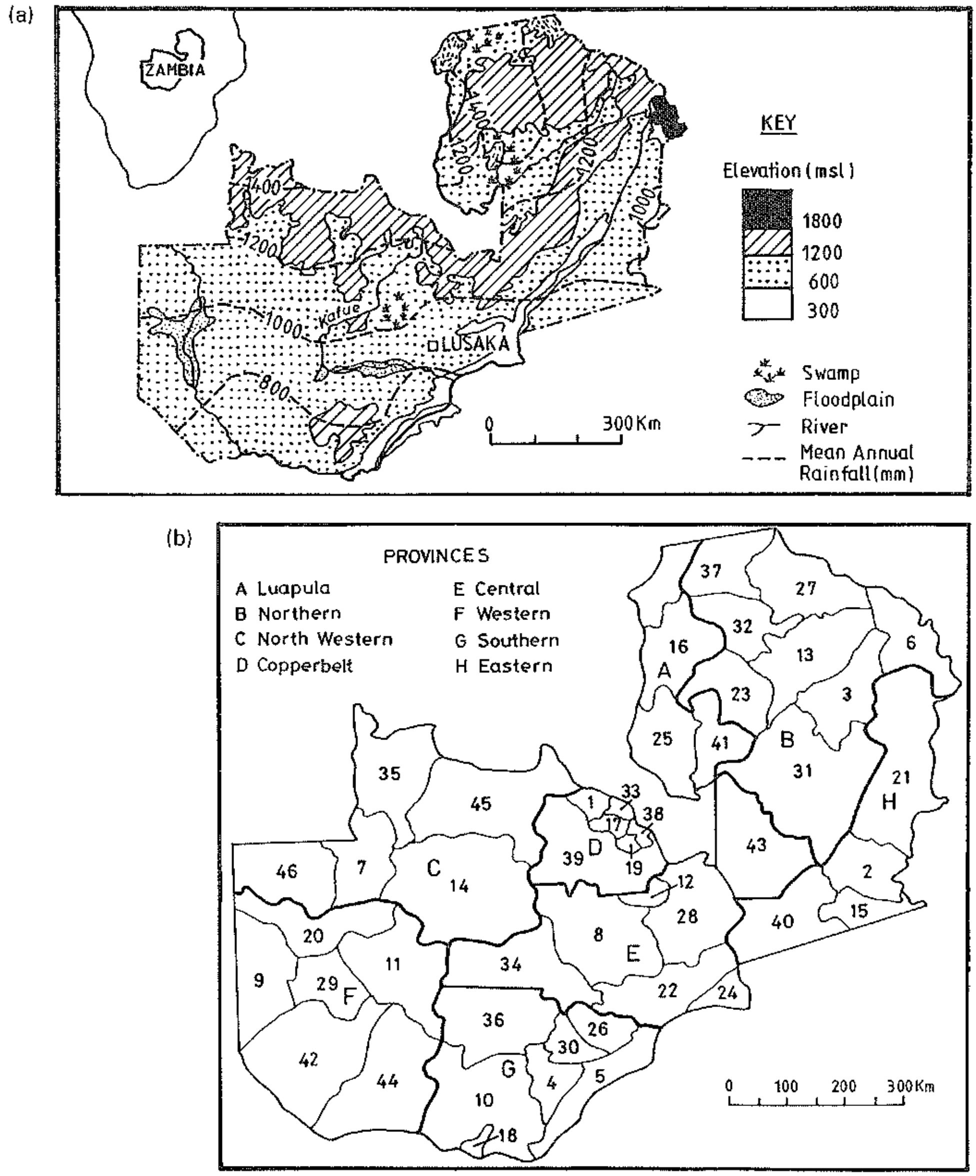

Fig. 1 Maps showing (a) location and physical features of Zambia, and (b) the study districts. Names of numbered districts are given in Table 1.

Zambia experiences a dry and wet type of climate with the rainy season occurring between November and April. The rainfall pattern increases northwards (Fig. 1(a)).

Analysed data include published (1886-1970) (Meteorological Department, 1972) and unpublished (1971–1996) rainfall data monitored by the Meteorological Department and maize production and consumption levels obtained from Department of Agriculture annual reports. Point rainfall at various rainfall stations were assumed to be representative of entire districts. In addition, due to the paucity of data, countrywide analysis of drought characteristics was restricted to the period 1921–1970.

ANALYSIS AND RESULTS

Rainfall variability was assessed from 11-year running coefficients of variation (CVs) for selected stations. Figure 2 shows that northern parts of Western Province (Mongu) (Fig. 2(a)) experienced less rainfall variability than southern areas (Sesheke) (Fig. 2(b)). Rainfall variability in Southern Province (Livingstone) before 1930 (Fig. 2(c)) was similar to that of Western Province. Sesheke and Livingstone were characterized by moderate and increasing variations in rainfall marked by large changes in CVs (17-46%), the effects of single unusually wet years. Conversely, Eastern Province (Chipata) experienced low to moderate rainfall variability (Fig. 2(d)). These rainfall variabilities are supported by rainfall trends about long-term means at Mongu, Livingstone and Chipata which show decreasing rainfall after 1975 (Figs 2(e), (f) and (g)). The contemporaneous occurrence of decreased rainfall and increased global warming whose trends could be modified by human actions on causative factors could not have been coincidental. Magnitude and frequency analysis was used in the determination of rainfall characteristics. The recurrence interval (T, in years) of rainfall events at each station was determined as:

$$T = N + 1 / m$$

where N is the period of record and m the rank of the event, the highest ranked one (Dalrymple, 1960). Probabilities of normal rainfall (p) per station were calculated from the constructed probability curves of annual series. Probabilities of drought occurrence determined as $(1 - p)$ (Table 1), were found to generally decrease northwards. Drought was said to have occurred below "normal" rainfall (1940–1970) without detailed analysis of conditions for the onset and termination of drought.

Run parameters determined include run-total (cumulative departure from normal rainfall) indicating severity; run-length (time in years between successive failures from normal) indicating duration; and run intensity (maximum departure from normal) indicating magnitude of drought for a given run-length (Yevjevich, 1967; Guerrero-Salazar, 1975). Drought frequency was determined as the number of drought occurrences in a 50-year period (1921–1970), expressed as a percentage of time while spatial distribution of droughts was assessed as area of districts affected by drought.

Between 1921 and 1970, droughts of up to 10 years duration occurred in Zambia's recorded history. One-year droughts occurred 53% of the time while those

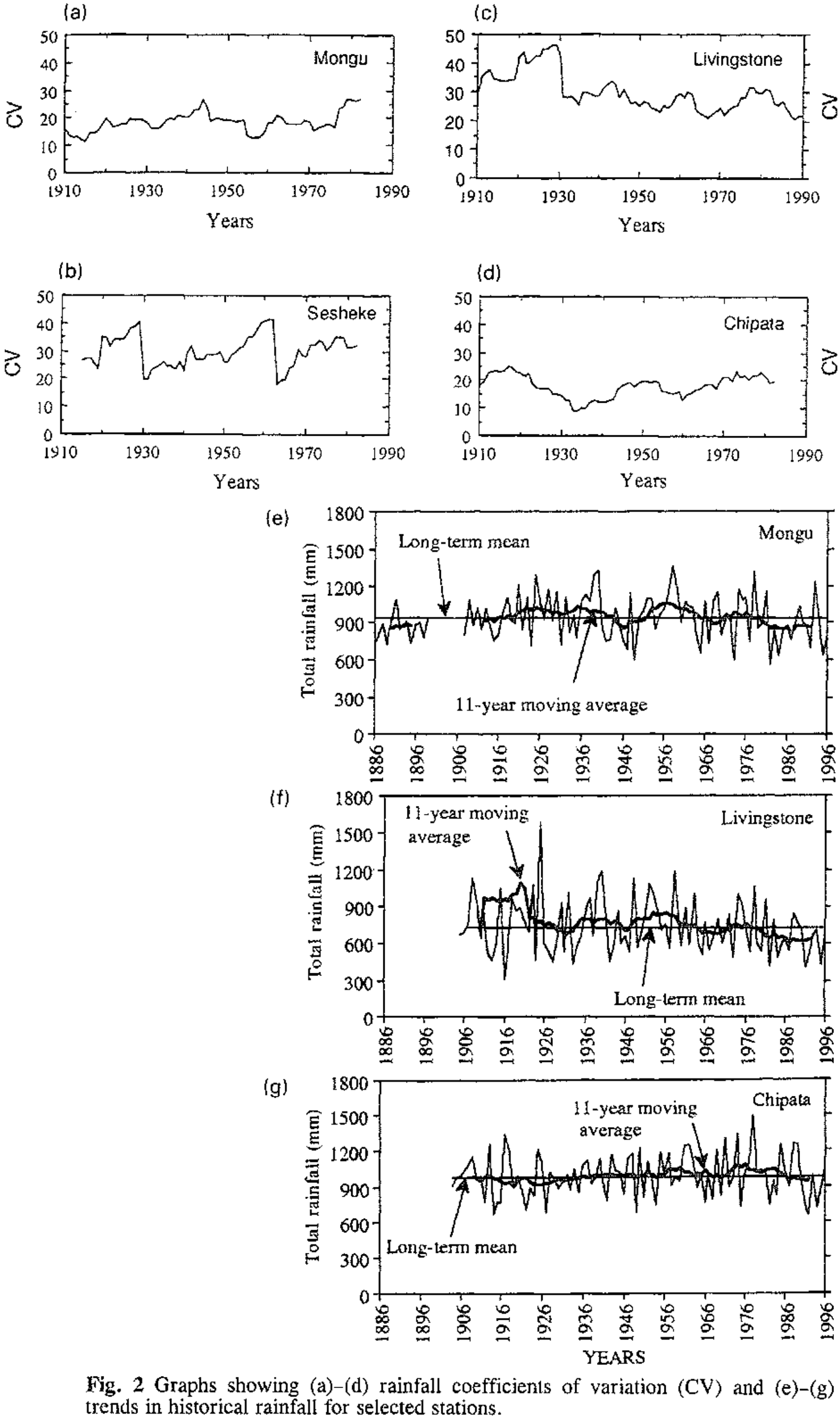

Fig. 2 Graphs showing (a)–(d) rainfall coefficients of variation (CV) and (e)–(g) trends in historical rainfall for selected stations.

Table 1 District area, normal rainfall and probability of drought occurrence, by district in Zambia between 1921 and 1970.

District no.	District name	Rainfall station	Area of district (km^2)	Normal rainfall (mm)	% probability of drought occurrence
1	Chingola-Chililabombwe	Nchanga Mine	8 608	1322	60
2	Chipata	Chipata	12 194	1032	56
3	Chinsali	Lubwa Mission	15 395	1084	62
4	Choma	Choma	7 300	803	49
5	Gwembe	Gwembe	12 610	873	63
6	Isoka	Isoka	13 846	1031	34
7	Kabompo	Kabompo	14 530	1097	49
8	Kabwe	Kabwe	27 242	957	49
9	Kalabo	Kalabo	17 511	962	49
10	Kalomo	Kalomo	31 100	742	52
11	Kaoma	Kaoma	13 508	937	46
12	Kapiri-Mposhi	Kapiri-Mposhi	9 033	1075	56
13	Kasama	Kasama	20 550	1267	50
14	Kasempa	Kasempa	21 100	1161	63
15	Katete-Chadiza	Nyanje Mission	6 564	912	52
16	Kawambwa	Kawambwa	19 303	1348	60
17	Kitwe-Kalulushi	Nkana Rail	5 196	1253	52
18	Livingstone	Livingstone	1 430	747	55
19	Luanshya	Roan Antelope Mine	5 095	1204	51
20	Lukulu	Lukulu Mission	16 291	1058	48
21	Lundazi-Chama	Lundazi	30 339	878	55
22	Lusaka	Kasisi Mission	13 518	865	58
23	Luwingu	Luwingu	12 008	1349	44
24	Luangwa	Luangwa	3 002	721	61
25	Mansa	Mansa	12 698	1094	53
26	Mazabuka	Mazabuka	10 915	791	56
27	Mbala	Mbala	18 508	1190	57
28	Mkushi	Mkushi	22 608	931	47
29	Mongu	Mongu	12 155	950	42
30	Monze	Monze W.A.	4 854	802	57
31	Mpika	Mpika	40 935	1112	48
32	Mporokoso	Mporokoso	12 043	1324	57
33	Mufulira	Mufulira	5 176	1266	58
34	Mumbwa	Mumbwa	21 103	917	55
35	Mwinilunga	Mwinilunga	20 910	1381	48
36	Namwala	Namwala	21 750	806	55
37	Nchelenge-Kaputa	Nchelenge	34 847	1203	64
38	Ndola Urban	Ndola	1 924	1190	54
39	Ndola Rural	Mpongwe Mission	42 004	1098	49
40	Petauke	Petauke	13 007	948	47
41	Samfya-Chilubi	Samfya	15 764	1385	51
42	Senanga	Senanga	15 018	829	64
43	Serenje	Serenje	23 351	1136	46
44	Sesheke	Sesheke	15 007	717	66
45	Solwezi	Solwezi	29 690	1356	46
46	Zambezi	Zambezi	19 070	1049	47

of 3–5 years duration occurred up to 12% and much longer droughts were experienced in less than one percent of the time (Fig. 3(a)). This is partly because in Zambia rainfall distribution typically is skewed as most annual rainfall amounts are below the mean. In the 50-year period, Fig. 3(c) shows temporal distribution of droughts for each year while Fig. 3(d) shows that droughts in each year covered between 11–92% of the country's area.

Table 2 shows that centres of 2- to 10-year severest droughts (1905–1996) varied in time and space thereby indicating the difficulties of predicting drought. Regarding impacts of drought, the level of maize production versus consumption was used in the assessment of success or failure of rainfed agriculture under various meteorological conditions based on some apparent relationship between weather and maize yield (Fig. 3(b)). During years of drought consumption tended to exceed production levels thereby necessitating importation of food. Maize is grown by both commercial and subsistence farmers who rely exclusively on rain for its maturity.

DISCUSSION

Rainfall variability in the African tropics has been linked to sea-surface temperatures (Nicholson, 1986). Since climatic changes are time-lagged, it should be possible to predict subsequent developments in weather patterns if original changes can be recognized. Thus, teleconnections or the linking of environmental events in time and space can help to predict occurrence of drought ahead of time once causes of drought are well understood and the forcing mechanisms known. The low rainfall regime experienced in southern and eastern Zambia after 1975 appears to be a repeat of climatic conditions which prevailed before the turn of last century (Fig. 2(e)). This is probably related to the accelerated global warming associated with anthropogenic human activities (Munn & Machta, 1978; Strong, 1989). It was after 1980 that the average world temperature effectively exceeded 0°C (Tyler, 1989) and hence the linkage between global warming and increased drought in Zambia.

Characteristics of droughts

Temporal, spatial and areal distribution In Zambia, droughts occur every year as there is always a part of the country experiencing below normal rainfall (Fig. 3(c)). Probability of drought occurrence is lowest in the wettest northeastern area (34%) and highest in the driest southwest area (66%). For most of the country this was found to be 50%. The droughts of 1924, 1933, 1946, 1949, 1965 impacted more than 80% of the 46 districts. The 1949 event was the most widespread and impacted the greatest area (92%). The 1987 and 1992 droughts each impacted 90% and 88% of the country's area. Thus, based on historical records (1921–1996) droughts covering more than three quarters of the country could be expected at least once in a decade.

Severity and magnitude Six of 10 non-overlapping droughts of at least 2-year duration with greatest climatological impacts were centred in Western and Southern provinces, drought prone areas (Table 2). In magnitude, among one-year droughts,

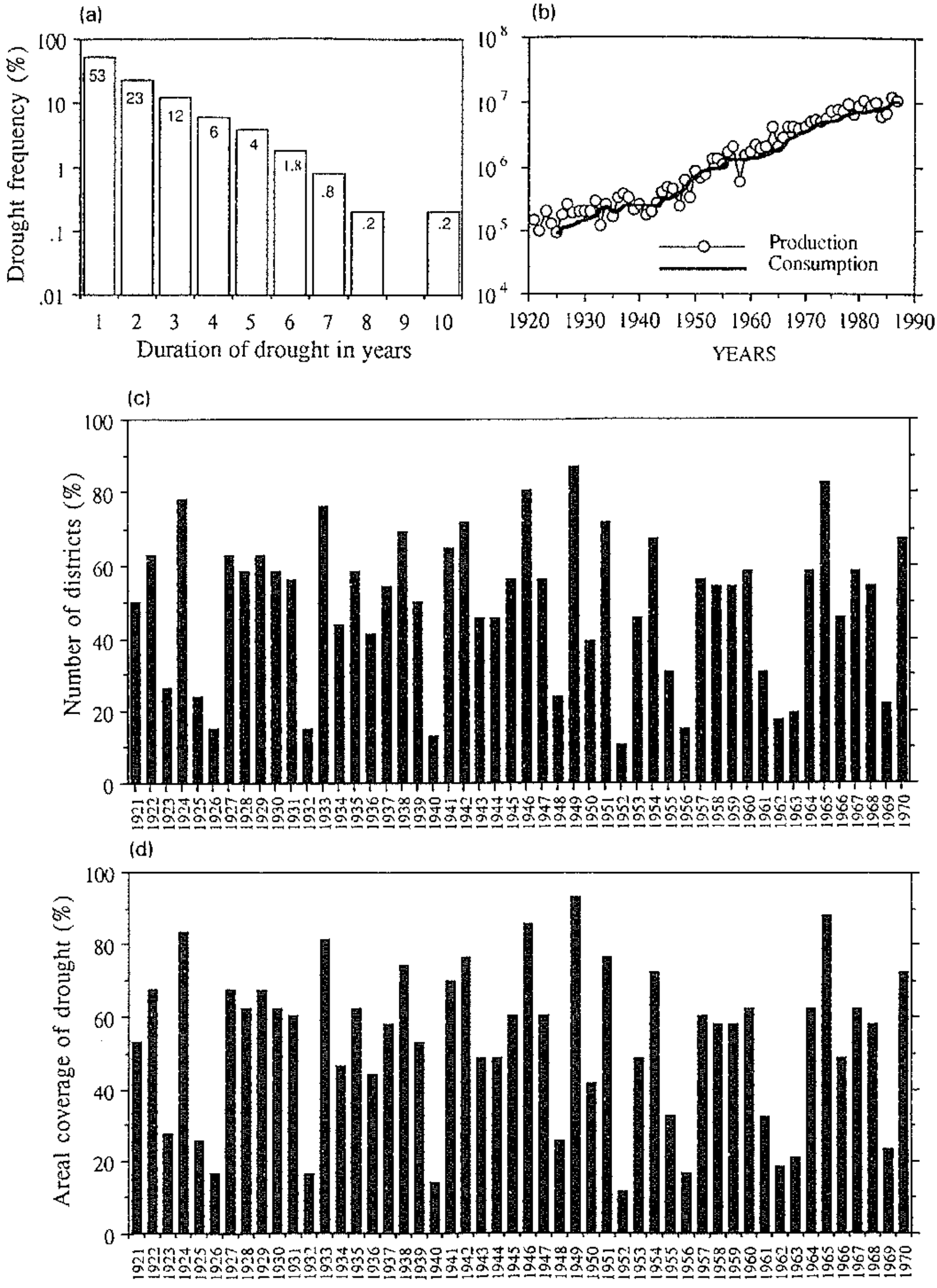

Fig. 3 Graphs showing (a) frequency of n-year droughts (1921–1970), (b) trends in production and consumption levels of maize (1921–1987), (c) coverage of drought by district per year, and (d) countrywide areal coverage of drought per year (1921–1970).

Table 2 Ranking of droughts with greatest climatological impacts in recorded history of Zambia for non-overlapping durations.

Rank	District no.	District name	Duration, in years	Drought years	Index of drought magnitude*
1	44	Sesheke	7	1990–1996	2.07
2	44	Sesheke	10	1926–1935	1.93
3	24	Luangwa	4	1921–1924	1.51
4	29	Mongu	6	1982–1987	1.34
5	26	Mazabuka	5	1964–1968	1.28
6	24	Luangwa	4	1970–1973	1.23
7	46	Zambezi	7	1941–1947	0.92
8	18	Livingstone	2	1916–1917	0.91
9	18	Livingstone	3	1912–1914	0.89
10	25	Mansa	8	1948–1955	0.79
11	34	Mumbwa	1	1955	0.60
12	18	Livingstone	1	1916	0.59
13	24	Luangwa	1	1925	0.58

* Index of drought magnitude is the standardized maximum cumulative departure of annual rainfall from normal.

the 1995 drought centred at Mumbwa was the greatest and caused severe suffering among the local people. It followed droughts of 1992 and 1994 which affected mostly southern Zambia (Tiffen & Mulele, 1994). The 1995 drought was followed by 1916 and 1925 droughts centred at Livingstone and Luangwa. Whenever centres of drought were located in high rainfall areas, droughts generally impacted more than 80% of the country's area (e.g. Mansa, Zambezi, Mazabuka) (Table 2).

Implications of drought occurrence Historical accounts reveal that, if droughts occurred in January, February and March (characterizing protracted droughts) (e.g. Colonial Office, 1930) worse crop yields would be expected because crops would have no chance to grow and mature than when droughts occurred in a different timing sequence. Four constructed scenarios of the implications of drought in Zambia under increased global warming were that there would be: (a) increased summer temperatures leading to lengthening of dry season and shortening of growing season; (b) a northward shift of the rainfed crop growing zone leading to reduced crop failures, but without necessarily a corresponding increase in food production (Sichingabula, 1995); (c) adverse impacts on water resources leading to increased water rationing in towns and a decline in hydroelectric power generation; and (d) reduced foreign exchange earnings from water based recreation activities and tourism. These implications suggest the need for mitigation measures against likely drought impacts.

Drought mitigation measures A variety of drought adaptive responses exist:
- Accepting the losses, thus, doing nothing or sharing the losses with farmers through crop insurance, introduction of subsidies and increased food imports. Since these responses do not reduce drought occurrence, drought should not be used as an alibi for failure to cushion the Zambian people from its adverse impacts.
- Suppressing evapotranspiration through cloud seeding though expensive and environmentally unfriendly. This has not been adopted in Zambia.

- Improving irrigation and drainage by building dams and canals.
- Change to drought-resistant crops and adopt agricultural practices which conserve soil moisture.
- Voluntary relocation as where some people from Southern Province are moving into Central and Northern provinces which are less prone to drought.

But, success in national drought mitigation measures requires that the government takes the lead in the selection of appropriate adaptive responses. Long-term on-going and short-term mitigation programmes are required to develop and conserve land and water resources and to provide a safeguard against the normal vagaries of weather and climate. Pre-planned policies and guidelines are also required in order to ensure that potential changes are well understood. Zambia requires a new attitude to drought and a realization that this menace is a drain on its resources. The country could be more prosperous than it is if impacts of droughts were minimized. But once droughts pass they are easily forgotten and wastage of maize yields is not uncommon due to either being left uncollected in rural depots or getting soaked by rains (e.g. Good, 1986), causing unnecessary importation of food.

CONCLUSION

Drought is a chronic phenomenon in Zambia which requires pre-planned measures for minimizing its impacts. The country should seriously embark on some possible adaptive responses to climatic variation because drought costs the country lots of money meant for various developmental projects. The state of preparedness for future droughts should be seen as one mitigation measure against drought.

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REFERENCES

Banda, G. P. A., Mutoti, N., Mwiinga, B., Sichingabula, H. M. & Phiri, J. K., (1997) *An Assessment of the 1995/96 Programme Against Malnutrition (PAM) Drought Relief Food Programme.* The Study Fund, Lusaka., Zambia.

Colonial Office (1930) *Report on Northern Rhodesia.* Government Printer, Lusaka, Zambia.

Dalrymple, T. (1960) Flood Frequency Analysis. *US Geol. Survey, 1543-A.*

Good, K. (1986) Systematic agricultural mismanagement: the 1985 bumper harvest in Zambia. *J. Modern Afr. Studies* **24**(2), 257–284.

Guerrero-Salazar, P. (1975) Analysis of drought characteristics by the theory of runs. *Hydrol. Pap. no. 80, Colorado State University, Fort Collins, Colorado, USA.*

Kane, R. P. & Trivedi, N. B. (1986) Are droughts predictable? *Climatic Change* **8**, 209–223.

Munn, R. E. & Machta, L. (1978) Human activities that affect climate. In: *Proc. World Climate Conference: a Conference of Experts on Climate and Mankind.* WMO no. 537, Geneva, Switzerland.

Nicholson, S. E. (1986) The spatial coherence of African rainfall anomalies: interhemispheric teleconnections. *J. Clim. Appl. Met.* **25**, 1364–1381.

Oguntoyimbo, J. S. (1986) Drought prediction. *Climatic Change* **9**, 79–90.

Payne, R., Rummel, L. & Glantz, M. (1987) Denying famine a future: concluding remarks. In: *Drought and Hunger in Africa* (ed. by M. H. Glantz), 435-433. Cambridge University Press, London, UK.

Sharma, T. C. (1997) A drought frequency formula. *Hydrol. Sci. J.* **42**(6), 803–814.

Sichingabula, H. M. (1994) Some historical perspectives on drought in Zambia. Paper presented at the International Conference on Climate and Survival in Southern Africa, Victoria Falls, Zimbabwe, 21–25 February 1994.

Sichingabula, H. M. (1995) The climate system and climatic change: global warming, drought and desertification in Zambia. Paper presented at Zambia's National Awareness Workshop on the Convention to Combat Desertification, 22–23 June 1995, Lusaka, Zambia.

Strong, A. E. (1989) Greater global warming revealed by satellite-derived sea-surface temperature trends. *Nature* **338**, 642–645.

Tiffen, M. & Mulele, M. R. (1994) *The Environmental Impact of the 1991–92 Drought on Zambia*. IUCN, Gland, Switzerland.

Tyler, C. (1989) Towards a warmer world. *Geogr. Mag.* **61**(3), 40–43.

Yevjevich, V. (1967) An objective approach to the definition and investigation of continental hydrological droughts. *Hydrol. Pap. no. 23, Colorado State University, Fort Collins, Colorado, USA*.