Occurrence, severity and magnitude of hydrological drought in Zambia: impacts and implications

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Abstract Persistent occurrence of drought under increasing water supply demands for municipalities and agriculture, and under increased threat of global warming, requires increased understanding of drought characteristics and sustainable use of water resources. Using the theory of runs, several hydrological drought parameters of frequency of occurrence, run length, magnitude and run intensity, were investigated for the Kafue and Zambezi rivers. Objectives were to (a) determine magnitude–frequency characteristics of hydrological droughts; (b) determine some drought run parameters and frequency of their occurrence; and (c) propose a new approach for increasing Zambia's utilization of its water resources without jeopardizing international relations with neighbouring countries. Better understanding of droughts and assessment of Zambia's present and future water requirements will enable planners and decision makers to bring increased economic benefits to citizens. Zambia's drought and water scarcity problems are outlined and linked to some proposed regional water projects designed to divert water from the Zambezi River system. One possible solution to problems of drought and dwindling water levels on Kafue River is proposed.

INTRODUCTION

In Zambia, planners and decision makers tend to favour large water projects for hydroelectric power (HEP) generation compared to those for flood control and irrigation, as exemplified by the Lake Kariba and Itezhi-Tezhi Dam on the Zambezi and Kafue rivers which are almost exclusively used for power generation. Elsewhere, projects of this nature are designed for multipurpose uses. Rivers should be utilized for their true value and worth of water for all citizens. Overutilization of rivers for one or two uses at the expense of other uses cannot sustain the economy in which all sectors are interdependent.

Large-scale water projects in Zambia are required if diversification of the economy is to be achieved, especially in view of the increasing threat of global warming and persistent occurrence of droughts. This situation demands increased conservation and sustainable use of water resources. Previous studies have assessed quantities of Zambia's water resources in catchments such as Kafue (FAO, 1968; DHV Consulting Engineers, 1980), Zambezi (Balek, 1971) and Chambeshi River in northern Zambia

(Sharma, 1980) and have shown that there is adequate water for present requirements. But the country continues to suffer from effects of droughts largely due to water management problems.

THEORETICAL BACKGROUND

In the theory of extreme values, droughts are defined as the smallest annual values with every year producing one lowest value or a drought. For droughts defined on the basis of water supply and demand, the lowest values are not necessarily deficit amounts because of the possibility that the threshold value for a particular drought may be smaller than the lowest value of a given event. This means that the methodology for determining the probabilities of droughts occurring below a threshold must be different from that of extreme values. Consequently, for the determination of drought run-parameters mean annual discharge series were utilized without detailed water balance analysis.

Methods for predicting recurrence intervals and probabilities of n-year droughts are not well established. Yevjevich (1967) has shown that for independent discrete time series of run length (n), one can obtain probabilities of values x greater than x_o as p and smaller values as $q = 1 - p$. The distribution of run length of size n, $n = 1, 2, ...,$ is given for an infinite population as $f(n) = qp^{n-1}$, where $f(n)$ is the probability of a run length of size n. Yevjevich further observed that values of p and q may be estimated by the frequencies $p_e = N1/N$ and $q_e = N2/N$, with $N1$ as the number of values x above x_o, and $N2 = N - N1$, the number of x-values below x_o. Salderriaga & Yevjevich (1970) have shown that the probabilities of run lengths are independent of the underlying distributions. The problem of determining recurrence intervals from probabilities of occurrence has previously been investigated by Srikanthan & McMahon (1986), who evaluated a long sequence of annual flows. Some recent studies on droughts have focused on modelling of some characteristics of drought and the development of formulae for analysis of extremal droughts analogous to the flood magnitude formula (e.g. Sen, 1977; Lee *et al* 1986; Sharma, 1997, 1998). Hopefully, it will soon be possible to predict droughts. This study sought to determine some run parameters of hydrological drought on two rivers in Zambia as a prelude to prediction of n-year droughts.

METHODOLOGY

Data and study area

Annual discharge series for two stations were analysed: one on the Zambezi River at Big Tree (1908–1997), located upstream of Victoria Falls near Livingstone town, and the other on Kafue River at Kasaka (1906–1969), before the construction of Itezhi-Tezhi Dam (Fig. 1). Below these stations are located HEP generation stations, Kariba North Bank shared by Zambia and Zimbabwe and the Kafue Gorge power station. These stations supply power to most towns and mining areas both in Zambia and

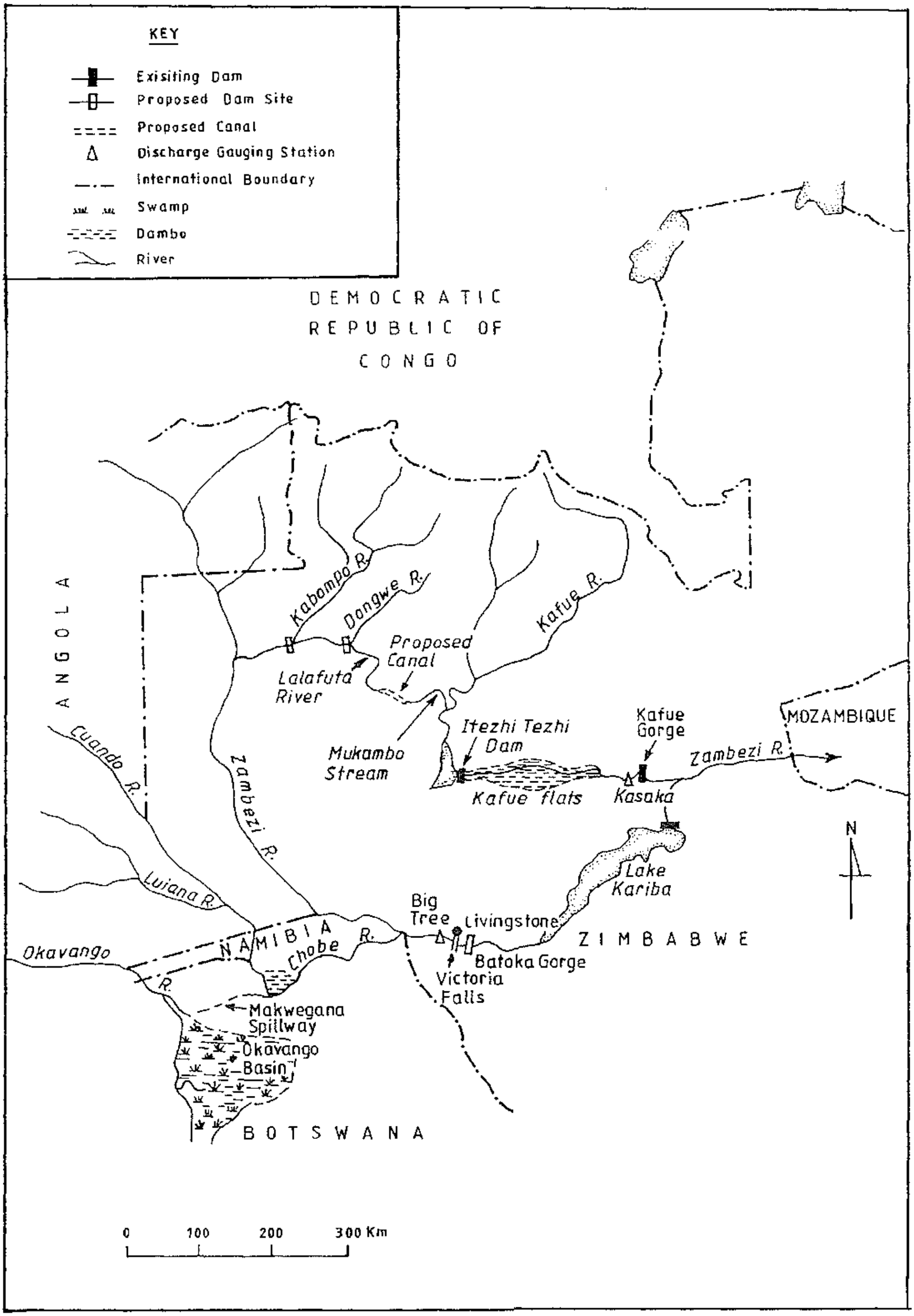

Fig. 1 Zambezi River system and some locations of dam sites.

Zimbabwe. Upstream of Kasaka station is located the Kafue Flats which is an important ecosystem not only for abundant wildlife but also for the provision of a huge amount of water for a large sugar plantation in the area. Flow regulation and the backflow effect caused by Itezhi-Tezhi Dam after 1973 precluded analysis of drought characteristics on Kafue River.

Methods of analysis

Drought was defined as a deficit in the mean discharge below the long-term mean. Standardized departures from the mean were obtained by dividing the deviations by the series long-term mean expressed as a ratio or percentage. Drought parameters determined included drought magnitude (mean sum run total of departures below the mean), severity (run total of departures), and run durations (*n* years of consecutive droughts). For determining the magnitude frequency characteristics of hydrological droughts, minimum discharge data were used. The aspect of predicting return periods and probabilities of occurrence of *n*-year droughts, not conducted in this study, was left for future research.

RESULTS AND FINDINGS

Analytical results revealed that on Kafue and Zambezi rivers droughts of different *n* years were experienced in Zambia's recorded history. Generally, on Kafue and Zambezi rivers, drought occurred in 60% and 58% of the time, respectively, showing that drought years were more frequent than wet years. On Kafue River in the 1906–1969 period, the most intense *n*-year event in terms of magnitude was the 8-year drought (1910–1917) with –233% departure from the mean followed by the 5-year event of 1927–1931 (–214%). The severest *n*-year droughts were those of 1924, 1949, 1927–1931 and 1942 with –66%, –58%, –43% and –38% departures from the mean, respectively. One-year droughts occurred 8% of the time while 2-, 3-, 4-, 5- and 8-year droughts occurred 2–3% of the time. This indicates that apart from 1-year droughts, other drought events have similar chances of occurrence. This makes planning for drought mitigation difficult.

On Zambezi River, in the period 1908–1997, the worst *n*-year drought in terms of magnitude was that of 1949 (–51%) followed by 1990–1997 (8 years) (–43%), 1972–1973 (2 years) (–29%), and 1982–1988 (7 years) and 1910–1925 (16 years), each with –28% departure from the mean. The severest drought was that of 1910–1925, followed by 1990–1997 with total departures from the mean of –448% and –341%, respectively. One-year droughts occurred 59% of the time with that of 1996 (–62%) being the severest followed by 1995 (–57%), 1915 (–56%), 1949 (–51%) and 1997 (–50%) droughts. In Table 1 eight *n*-year hydrological droughts experienced on the two rivers are ranked in order of decreasing severity.

Magnitude–frequency analysis of minimum flows revealed that the severest 1-year droughts based on mean flows did not in all cases follow the ranking of minimum flows. On the Zambezi River, some years with minimum flows which corresponded with the severest meteorological droughts were 1996 and 1997 with recurrence intervals of 91 and 46 years, respectively (Sichingabula, 1998). This is largely because the magnitude–frequency analysis technique does not distinguish between wet and dry years. The frequencies of hydrological drought were generally small ranging from 2 to 8% for 1- to 8-year droughts on Kafue River with the former being more frequent. On the Zambezi River, this ranged from 1 to 5% for 16-year and 1-year droughts, indicating that droughts were more frequent on Kafue than on the Zambezi River perhaps due to differences in flow records. Analysis has shown that, in a majority of cases, the worst meteorological droughts corresponded with the hydrological ones showing the very close relationship that exists between these two phenomena (Brendenkamp, 1974; Sichingabula, 1998). The annual series of discharges for Zambezi River at Big Tree and rainfall for Livingstone illustrate fairly well the close relationship that exists between rainfall amount and hydrological drought (Fig. 2(a), (b)).

Problems of water scarcity and drought occurrence has made Zambia and its neighbouring countries look for alternative ways of increasing water supply for various uses. Several large-scale projects have been proposed aimed at diverting flows and harnessing the waters of the Zambezi and Kafue rivers (Petitjean & Davies, 1988; The Herald, 1997). Some likely impacts and implications of such projects are discussed below.

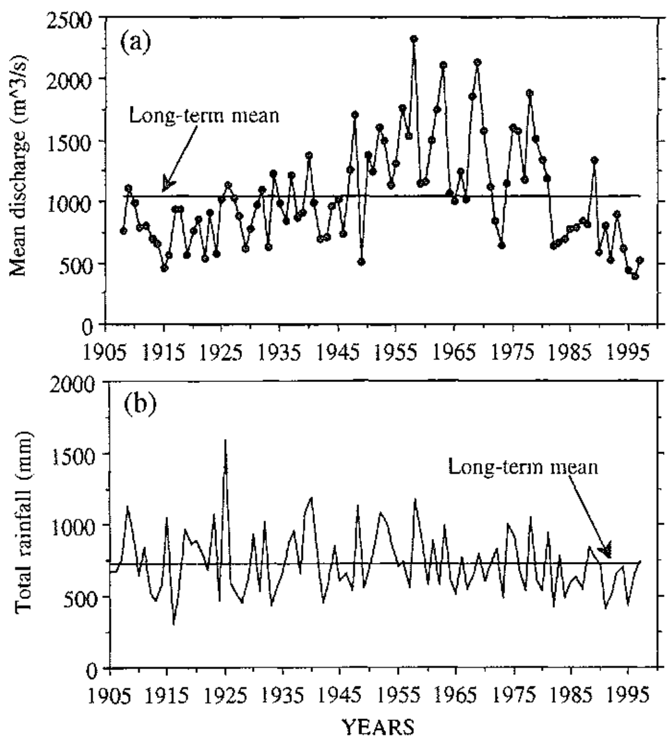

Fig. 2 Variations in historical records of (a) mean discharge for Zambezi River at Big Tree (1908–1997), and (b) total rainfall for Livingstone (1905–1997).

DISCUSSION

Impacts and implications

In the period of study, river flows in central and southern Zambia were generally below average from 1910 to 1950 and the period after 1980. The wet period was that between 1951 and 1979 with the early 1970s having been dry years (Fig. 2(a)). Hydrological drought occurrence on Kafue and Zambezi rivers were observed to occur contemporaneously although those on the Zambezi tended to be of longer duration for the same period. This is exemplified by the durations and indices of drought severity determined for eight *n*-year droughts. Table 1 shows that the longest and severest 16-year drought on Zambezi River overlapped the first and third ranked droughts on Kafue River and also that drought severity increased with duration. In spite of differences in periods of records, the frequencies of drought on both Zambezi and Kafue rivers were similar. Hydrological and meteorological droughts in southern Zambia generally increased after 1980 partly due to decreased rainfall experienced in the region (Sichingabula, 1998). By implication this placed a higher premium on Zambia's water resources utilization and especially on those countries to the south which generally receive far less rainfall than Zambia.

Protracted droughts on rivers imply decreased annual rates of storage capacity in reservoirs such as Lake Kariba, located on the Zambezi River, which has previously been estimated to be between 7 and 70 10^6 m^3 (Bolton, 1984). Impacts of recent droughts in the region, especially that of 1991–1997, have been disastrous. These included reduced power generation at Kariba, widespread failures of crops, loss of livestock and disruption of urban lifestyles due to water rationing, such that measures are required to cushion countries from the whims of nature. Countries to the south of Zambia have looked at the waters of the Zambezi with envy and have not hidden their intentions to divert some of this water at Zambia's expense. For instance, the implementation of the proposed Zambezi River Water project by South Africa would transfer a cumulative volume of at least 2.5–4.0 10^9 m^3 of water (Petitjean & Davies,

Table 1 Ranking of droughts with greatest hydrological impacts in recorded history of two Zambian rivers for non-overlapping durations.

Kafue River		(1906–1969)		Zambezi River		(1908–1997)	
Rank	Drought period	Duration (years)	Index of drought severity*	Rank	Drought period	Duration (years)	Index of drought severity*
1	1914–1917	8	–2.32	1	1910–1925	16	–4.48
2	1927–1931	5	–2.14	2	1990–1997	8	–3.41
3	1919–1922	4	–1.43	3	1982–1987	7	–1.60
4	1906–1908	3	–1.04	4	1941–1946	6	–1.38
5	1933–1937	5	–1.01	5	1927–1931	5	–0.91
6	1959–1960, 1924	2, 1	–0.66	6	1965–1966	2	–0.58
7	1964–1966	3	–0.62	7	1949	1	–0.51
8	1949	1	–0.58	8	1933	1	–0.39

* Index of drought severity is the standardized maximum cumulative departure of annual runoff from long-term mean.

1988) and would create an acute shortage of water needed for power generation at Kariba Dam. This situation would be worsened by yet another project planned to transfer water from the Zambezi to the dry region of Zimbabwe in Bulawayo area (*The Herald*, 1997). These projects have the potential of heightening drought as a source of international conflict (Gleick, 1987).

Already there are indications that the interests of the governments of Zambia and Zimbabwe over the planned Batoka Gorge hydroelectric power project are at variance such that Zambia seems not to be keen on having the project implemented (Fig. 1). This is despite the fact the Batoka Gorge project would partly solve the problem of low flows on Lake Kariba experienced in recent years. But Zambia's major interest of wanting to expand the capacity of its power stations on Kafue River at Kafue Gorge also suffers from low water levels in the Itezhi-Tezhi Dam. Consequently, the construction of another dam below Kafue Gorge has been proposed. Solutions to problems of drought and water scarcity of providing short-term quick-fix water supplies by projects such as those referred to above, may in the long term lead to adverse impacts on the environment and society.

Some adverse impacts could however be natural. For instance, if the current climatological and hydrological trends continue, especially under the influence of extreme events caused by El Niño, the Zambezi River above the Victoria Falls could again start flowing to the south. This would happen if the current lead of Chobe River to flood earlier than the Zambezi caused by the storage in the Barotse Plains, which allows water to flow from the Chobe to the Zambezi River, was delayed. This could most likely happen during large-scale flood events in northwestern Zambia and during exceptionally dry years in northern Botswana and eastern Namibia which would make the backflow of the Zambezi start flowing into the Okavango-Chobe River system. The low elevations and subdued topography of southwestern Zambia, and northeastern Botswana and Caprivi Strip would make such an occurrence not inconceivable, especially if the Makwegana spillway is reactivated by the backflows from the Zambezi (Debenham, 1948a,b) (Fig. 1). The hydrological regime of the Zambezi would be changed towards drier conditions making life worse for downstream water users. The periodic reactivation of the Makwegana spillway by backflows from the Zambezi in recent years has been confirmed by Mr. Guido van Langenhoven (Hydrological Division, Department of Water Affairs, Namibia; personal communication).

Possible solutions

In view of increased frequency of droughts in the last two decades, Zambia ought to maximize its utilization of available water resources but without causing international conflicts with its neighbours. Therefore, it is proposed that waters of the Kafue River be augmented by increasing the storage capacity of Itezhi-Tezhi Dam by diverting part of the Kabompo River into the Kafue (Fig. 1). This could be done at either Kabompo-Dongwe River confluence or at the Dongwe-Lalafuta River confluence, and constructing a canal sloping towards Kafue River between the headwaters of Lalafuta and Mukambo rivers. The subdued topography and low elevations along a system of "dambos" (marshes) would not present problems to river diversion. However, this proposal is not meant to offer a panacea to problems of droughts experienced in the country. Rather, other planned measures are required to mitigate against adverse impacts of droughts on the Zambian people and the economy.

CONCLUSION

Hydrological droughts on Kafue and Zambezi rivers occurred in 60% and 58% of the time, respectively. Durations of droughts ranged from one to eight years on Kafue and up to 16 years on the Zambezi. The most intense droughts in terms of magnitude occurred from 1910 to 1917 and from 1910 to 1925 on the Kafue and Zambezi rivers, respectively. The severest one-year droughts were those of 1924 (–66%) on the Kafue and 1995 (–62%) on the Zambezi River. Drought frequency generally increased after 1980 in concert with decreased rainfall experienced in southern Africa. Water projects designed to divert water from the Zambezi in order to solve water scarcity problems have the potential of heightening drought as a source of international conflict. An approach aimed at maximizing Zambia's utilization of available water resources without jeopardizing international relations with neighbouring countries is proposed. It is concluded that hydrological droughts are not uncommon in Zambia such that more research is required for their prediction so as to afford decision makers some measure of preparedness before they occur.

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