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Variability of flow regimes in Namibian rivers: natural and human induced causes

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Abstract Namibia is the most arid sub-Saharan country in Africa In the short rainy season from December to April, runoff in the interior occurs as a direct response during the few heavy showers, due to the rainfall patterns and the physical features of the terrain and the river systems. There is no base flow and the inter-seasonal variability is extreme, with the coefficient of variation exceeding values of 1.5 to 10. The general concept found in literature of a positive serial correlation for seasonal flows, attributed to "bank storage", has been found to be not at all applicable in Namibia. Flow records on the contrary give evidence of a short-term negative serial correlation, which would be the result of an inter-seasonal vegetation persistence, irrespective of whether changes in vegetation are induced by natural or artificial causes, such as a different land use.

GENERAL HYDROLOGICAL CONDITIONS IN NAMIBIA

Climate

Namibia borders on to the Atlantic Ocean in the southwestern part of Africa. The climate is subtropical due to its geographical position and the influx of moisture is reduced by the high pressure systems associated with the cold Benguela Current along the coast. As a result, most of Namibia is semiarid to arid, with potential evaporation exceeding precipitation by a factor from 5 to more than 10 for most of the country.

As for many African countries, the climate is controlled by the dynamics of the Intertropical Convergence Zone (ITCZ) which moves north and south according to the apparent position of the sun. The weather therefore shows a definite bi-seasonal pattern. The rainy season can start in October and continue until the end of April, but most rain normally falls between the end of December and the middle of April, as is illustrated in Fig.1.

Runoff and river flow in the interior of the country

All rivers in the interior of Namibia are ephemeral and flow mainly or only as a direct surface runoff response during the few heavy and wide-spread thunder storms in the rainy season. There is little or no delayed surface or subsurface runoff and definitely no baseflow, the main reasons being the erratic rainfall pattern, the high river bed losses and the physical features of most drainage basins, characterized by impermeable surfaces with little or no topsoil, scarce vegetation and hilly or mountainous terrain. The resulting "flash floods" run over dry river beds, and can rise two or three metres in less than thirty minutes and then recede to zero within a few hours.

Namibia's border rivers

At its northern and southern borders, Namibia has access to perennial rivers, which are fed mainly by rainfall in the neighbouring countries and which show the typical pattern of one or two seasonal flood peaks with normally steady flow throughout the year. The physical features of the terrain to the north of Namibia, where the Kunene, Okavango and Zambezi rivers have their headwaters, are such that river flow is, to

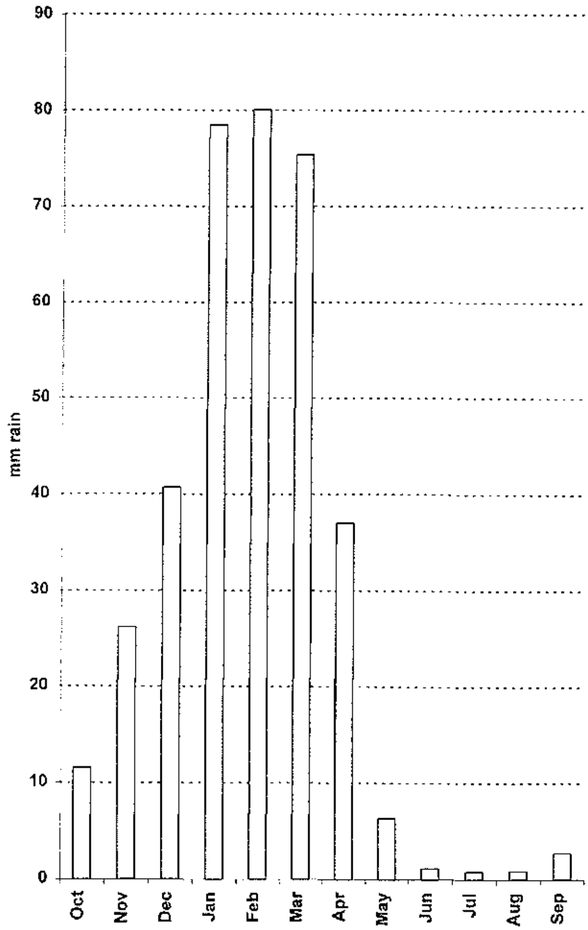

Fig. 1 Monthly means for Windhoek rainfall.

varying degrees, not only dependent on a direct surface runoff response. It also includes an important delayed flow component, due to major storage in the swamps and flood plains in the upper parts of the drainage basins. Figure 2 shows a typical hydrograph for the Okavango River, with the marked seasonal regime, in this case with a bimodal flood peak during the second half of the rainy season, and a relatively high minimum flow at the end of the dry season.

VARIABILITY OF RIVER FLOW IN THE INTERIOR OF NAMIBIA

Rainfall variability

Figure 3 shows three typical long-term rainfall series for Namibia. The seasonal variability is very high, as is reflected in coefficients of variation ranging from 0.3 to 1.0. Many interpretations of these records are biased towards discovering periodic

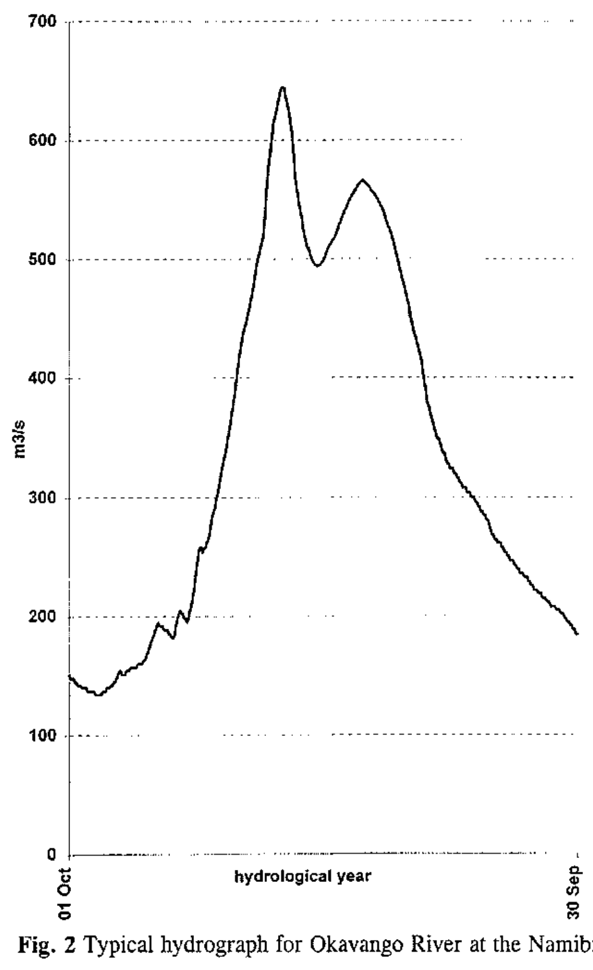

Fig. 2 Typical hydrograph for Okavango River at the Namibia/Botswana border.

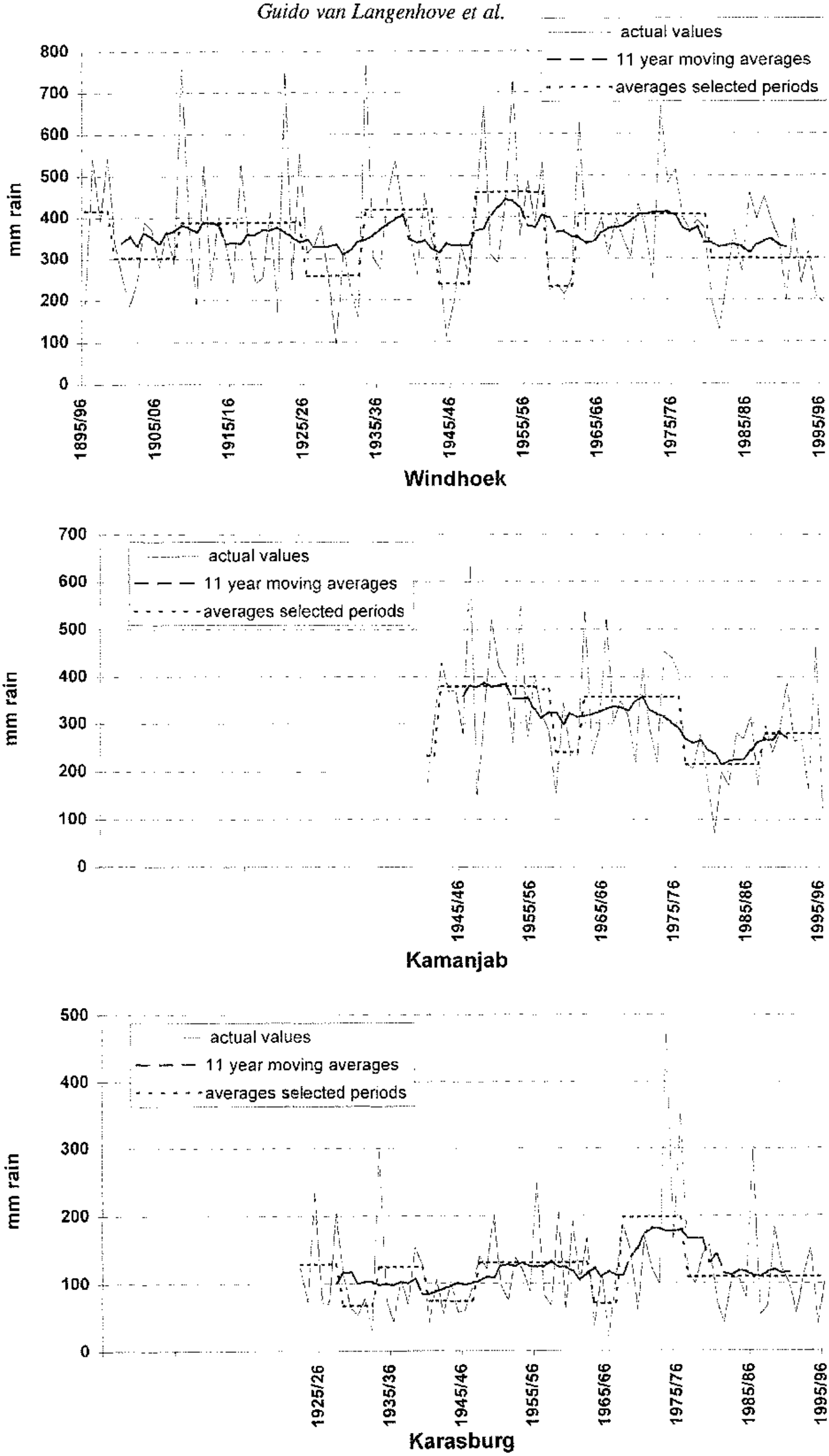

Fig. 3 Typical rainfall series for Namibia.

cycles, gradual trends or even sudden breaks. For instance, the average annual rainfall over the last 16 years from 1980/1981 to 1995/1996 in Windhoek has been 300.1 mm only, which is lower than the average rainfall over selected historic periods, such as the preceding 18 years from 1962/1963 to 1979/1980 with an average of 406.5 mm. This observation is often used as support for the theory that Namibia is getting drier as a result of global warming (WMO, 1966).

Against the inherent high variability, the statistical significance of such observations is not adequate, particularly since the physical explanation is also controversial. The fact that other historic periods with even lower averages can be found, for instance the 8 years from 1925/1926 to 1932/1933 with an average of 257.8 mm, clearly corroborates that drier periods may well be caused by statistical coincidence.

River flow variability

Because of the non-linear character of surface runoff response, with very high initial losses, the variability of river flows is expected to be much higher. Seasonal river flow series in Namibia, of which a typical example is given in Fig. 4, have coefficients of variation, which are never below 1.5 and which exceed 10 in extreme cases.

Unlike most other river systems throughout the world, where bank storage has a positive interseasonal carry-over effect, most river flow records for the interior of Namibia give evidence of a negative interseasonal correlation between successive years. First-order serial correlation coefficients range between -0.05 and -0.20, which would have little statistical significance for one site in isolation, but the trend is too systematic to be ignored. The only reason that has been identified is a vegetation persistence extending over 2 to 4 season cycles. Good rainy seasons result in a better vegetation cover, which increases the interception and thereby reduces the surface runoff potential during the next rainy season(s). Conversely, poor rainy seasons leave little vegetation, which has the opposite effect of a higher surface runoff potential.

Vegetation persistence can easily influence river flow by more than 50%, and this peculiarity has become an important feature for rainfall-runoff modelling. Generalized conceptual models, such as the Pitman Model, which is widely applied in the southern African region, need special adaptation before being applied in Namibia (De Bruine *et al.*, 1993; Mostert *et al.*, 1993).

The river flow sequence shown in Fig. 5 also displays a marked decline in flows since the end of the 1970s. For instance, the ratio of the average flows after and before the 1977/1978 rainy season is less than 0.25. No corresponding changes in rainfall patterns have been observed, but two other artificial changes related to human interference have been identified:

(a) The proliferation of small and medium size reservoirs in the drainage basins, which are being built by farmers to augment their water supplies. These, however are thought to have only a marginal influence, because their storage is relatively less significant and because there is also an on-going loss of storage due to sedimentation of existing reservoirs.

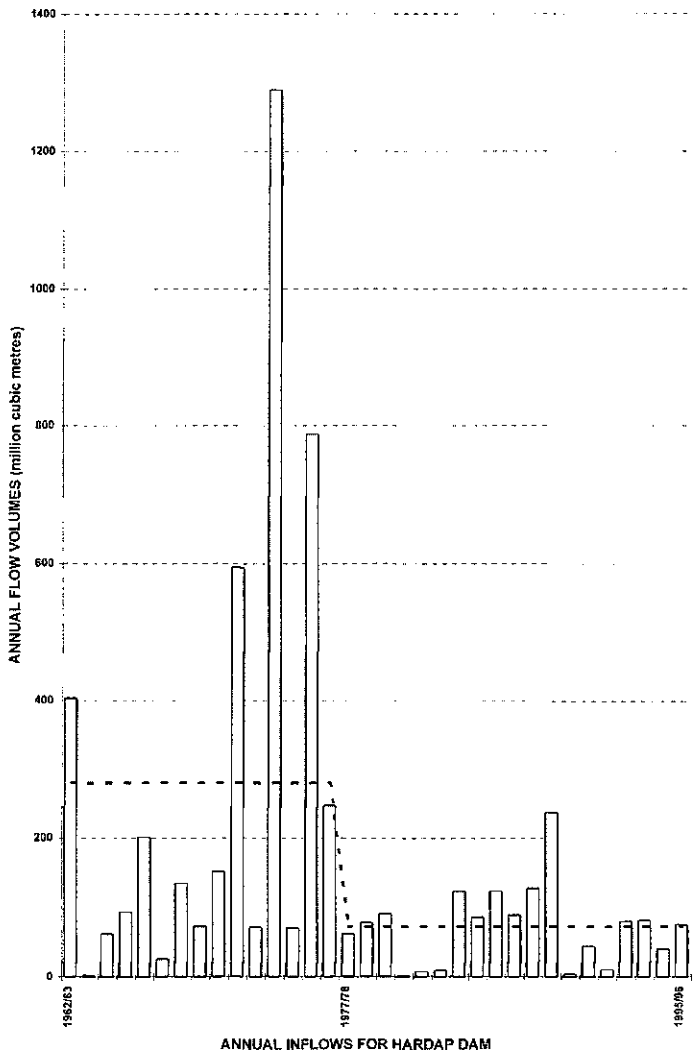

Fig. 4 Typical river flow series for ephemeral river in the interior of Namibia.

(b) Better land use due to stock rotation which keeps grazed fields in better condition reducing the possibility for overgrazing relative to earlier years. Whether vegetation is affected by natural causes or by human intervention, the effect on rainfall interception is the same (ICSU, 1990).

VARIABILITY OF RIVER FLOWS ON THE NORTHERN BORDERS OF NAMIBIA

Figure 5 shows the long-term record of the Zambezi River at Victoria Falls, near to the Namibian border. Four periods with significantly different average seasonal flow volumes can be distinguished:

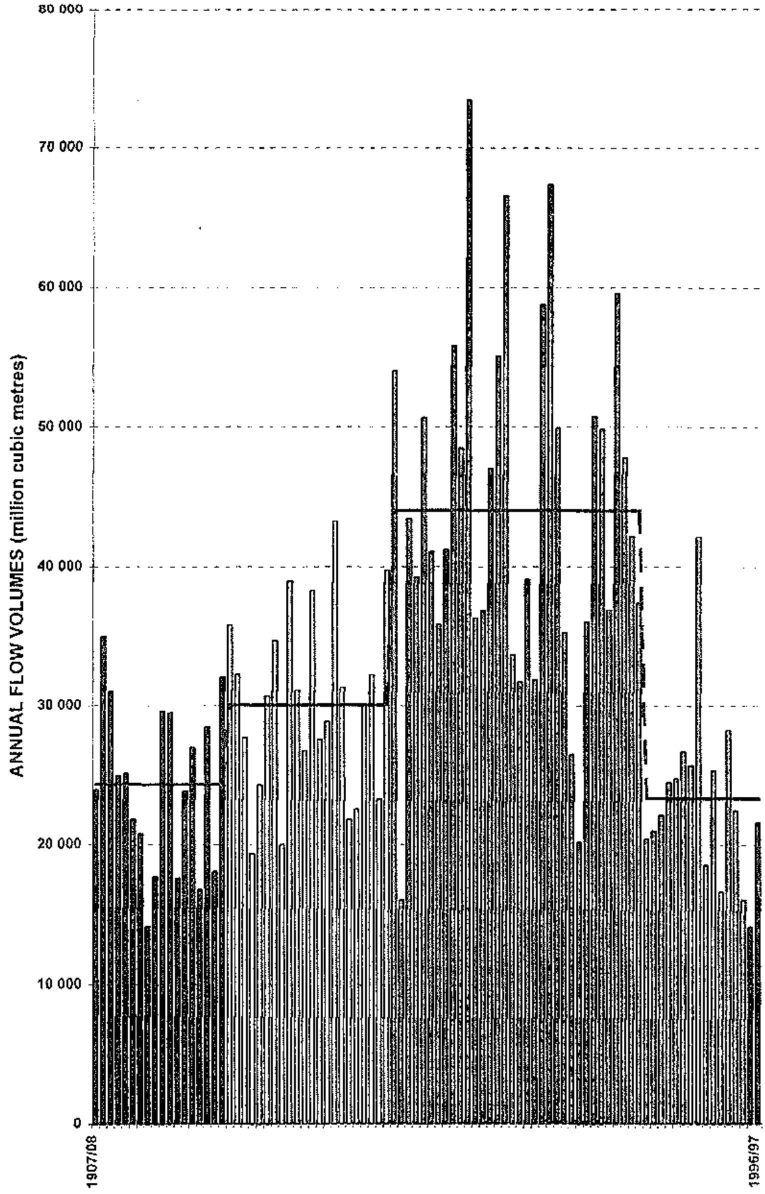

Fig. 5 Annual riverflow series for the Zambezi at Victoria Falls.

- 1907/1908 to 1923/1924: 24 300 Mm^3 $year^{-1}$,
- 1924/1945 to 1945/1946: 30 000 Mm^3 $year^{-1}$,
- 1946/1947 to 1980/1981: 44 000 Mm^3 $year^{-1}$,
- 1981/1982 to 1996/1997: 23 300 Mm^3 $year^{-1}$.

The records for the Kunene and Okavango rivers are shorter, but they also consistently show the marked decline at the beginning of the 1980s. The reasons for this sudden change are difficult to ascertain. Rainfall patterns in the Sahel zone have shown a similar sudden decline, but starting much earlier, in 1968, according to

Demarée (1990), and factual information on rainfall in the drainage basins of Namibia's northern border rivers is very limited. There has definitely been no significant infrastructural development, which would have included large reservoirs and resulted in major abstractions. The only other explanation left is based on the idea that changes in land use may induce a modified river flow regime. The speculation is that there was agricultural development during the 30 or 40 years before the start of independence and civil wars and foreign armed intervention in the catchment in Angola, which interrupted development and from which less dense vegetation and surface runoff interception would have resulted. Indigenous forest and bush growth would have returned subsequently leading to reduced surface runoff.

RECENT TRENDS IN HYDROLOGICAL METHODOLOGY

Conventional hydrological monitoring and investigations put the emphasis on establishing long-term rainfall and river flow records and the statistical interpretation thereof. In semiarid to arid conditions, the natural variability of hydrological series is very high and records are relatively short.

In Namibia, the observation has been that direct surface runoff is much affected by vegetation conditions which may markedly change due to natural conditions, mainly rainfall patterns, or by human intervention, which results in different land use conditions. These factors could be more important than reservoirs or abstractions. The Namibian Hydrological Services are therefore embarking on areal remote sensing of land use and vegetation as an integral part of hydrological monitoring of drainage basins. The better understanding of river flow regime changes is considered to be required to arrive at optimal basin management.

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