

Forecasting water resources in South Africa

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Abstract The scarce water resources of Africa could be better managed if reliable forecasts of drought or flood risk are available. In this paper the potential for prediction of major dam inflows in South Africa is investigated. Naturalized dam inflow data are statistically analysed and climatic predictors are assembled. Multivariate linear regression models are formulated which account for 59% of the variance two seasons in advance. Relationships between predictors such as oceanic winds, pressure and sea surface temperature, and hydrological targets are modulated by the global El Niño. Predictability is greater for southern Africa than in many other areas of the world.

INTRODUCTION

South Africa's water resources are limited by low rainfall which is highly variable from year to year. Water storage systems periodically fail during El Niño-induced drought. Water resources are depleted by prolonged dry spells when average runoff is reduced to about 1% of catchment rainfall. Inflows to the Vaal Dam, near Johannesburg decline 6-fold on average (Lindesay, 1990). Limitations of water supply affects domestic and industrial activity in many areas, leading to enforced quotas and a downturn in production across diverse sectors of the economy. Dam levels across South Africa drop to ~30% of capacity if the El Niño drought is followed or preceded by a dry year (Vogel, 1994).

El Niño summers are characterized by an enhanced Indian Ocean monsoon, leading to deficient rainfall over the plateau of southern Africa. Heat waves are produced when westerlies flowing from the Kalahari desert subside in the Botswana high pressure cell, blocking the input of moisture from the tropics. For example in the 1992 El Niño event, temperatures in the Limpopo River Valley in northern South Africa reached 47°C for a brief spell. Jury & Lyons (1994) show that dewpoint temperatures can remain below zero for extended periods during El Niño-induced drought events.

Reliable forecasts of dam inflow two seasons in advance could improve management of water resources. Predictability in southern Africa may be exploitable because of links between global and regional El Niño conditions and regional weather systems.

PREDICTOR AND TARGET DEVELOPMENT

Statistical correlations between antecedent climatic conditions and inflows to major dams rainfall have been identified using monthly gridded sea surface temperature and air pressure patterns, surface and upper level winds, and global El Niño indices.

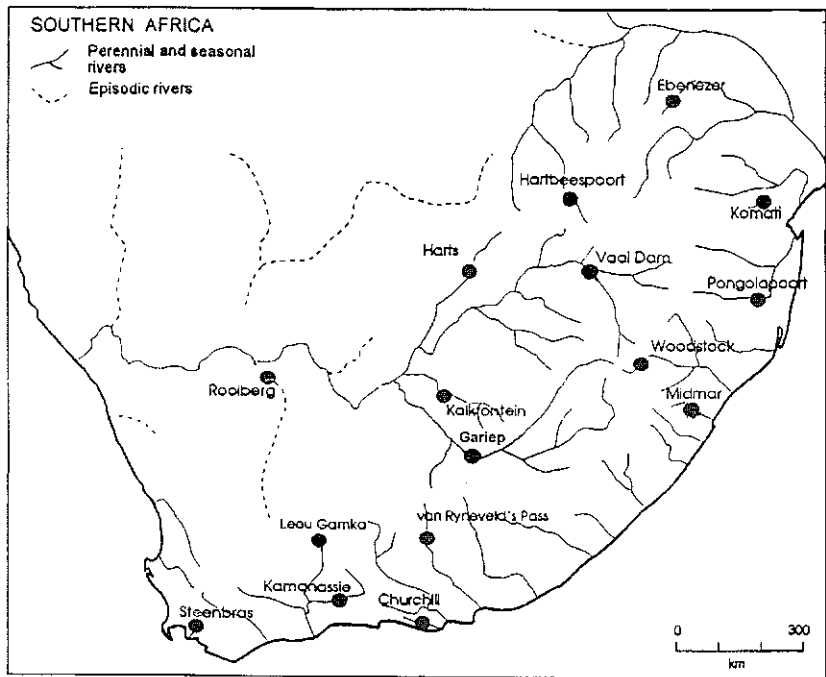


Fig. 1 Locations of the major dams within South Africa.

Although many variables are available from 1950 onwards, a few key predictors have historical records extending to 1971. Exploratory analyses have enabled about 50 area-averaged predictors to be assembled. Because forecasts are required in the austral spring for management purposes, predictors are considered for the July to November period.

The catchment inflow to major dams in South Africa was estimated from detailed daily rainfall records of the South African Weather Bureau. The major dams and their mean runoff, in descending order, are: Gariep $7.84 \times 10^9 \text{ m}^3$, Vaal $1.9 \times 10^9 \text{ m}^3$, Pongola $9.55 \times 10^8 \text{ m}^3$, Hartbeespoort $1.67 \times 10^8 \text{ m}^3$ and Midmar $1.75 \times 10^8 \text{ m}^3$ (positions shown in Fig. 1). In addition, streamflow data for the rivers feeding water resources in Namibia, Botswana, Zambia and Zimbabwe have been considered, but will not be discussed further here. The seasonality of dam inflow is illustrated in Fig. 2. Cumulative dam inflows for the summer rainy season from November to April are formulated into normalized departures. These become "targets" on which the antecedent climate teleconnections, as described by the candidate predictors, are trained.

MODEL FORMULATION AND VALIDATION

Multivariate linear regression statistical models are developed using standard software. The naturalized catchment inflow series are fitted by an optimum mix of area-averaged predictors for the preceding spring, using a forward stepwise

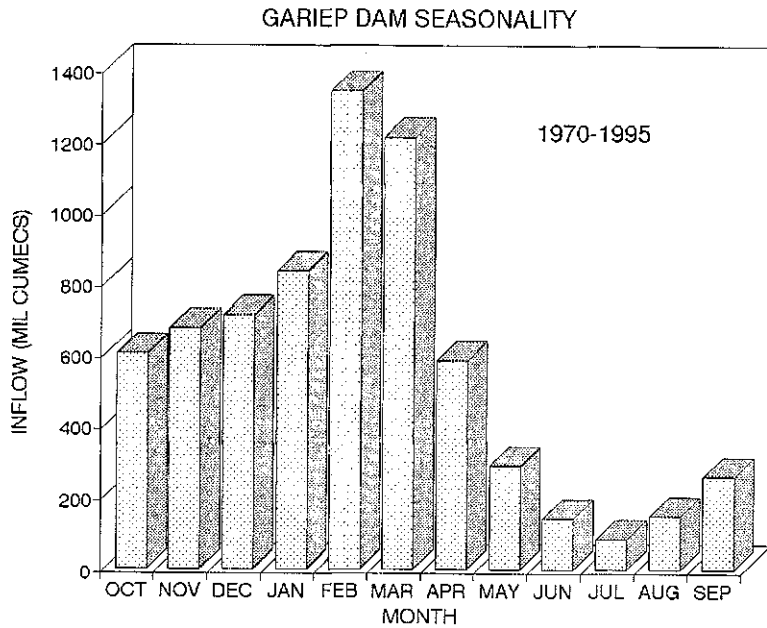


Fig. 2 Seasonality of inflow to the largest dam in South Africa (Gariep).

approach. Predictors with the highest partial correlation are successively drawn from the candidate pool. To prevent over-fitting and artificial skill for the training period 1971–1992, the multivariate algorithm is restricted to three predictors or less. The models are optimized for hindcast r^2 adjusted for degrees of freedom (~ 17). Example algorithms for each target are given in Table 1. Average hindcast fit for the hydrological targets is 59%. The various area-averaged predictors selected by the models are listed in Table 2.

A total of 11 predictors are utilized by five models. The most commonly selected predictors are winds mainly in the tropical Indian Ocean but also over the tropical Atlantic. Secondmost selected are pressure differences in the Indian Ocean. The traditionally used sea surface temperature predictors are only selected 15% of the time. The multivariate models are validated using a jackknife skill test, as illustrated in Fig. 3. The model forecasts “miss” the correct tercile category about once every four years. In the period 1993–1997, the models have produced tercile category “hits” of a similar percentage. The models are relatively simple so interpretations and conceptual models can be developed to identify the underlying climate dynamics, regional ocean–atmosphere coupling and influences of the global El Niño.

Table 1 Hydrological models.

Dam	Multivariate algorithm	r^2 fit
Gariep	+ 0.39(aVang) - 0.78(oSIp) - 0.45(oSocnS)	71
Vaal	- 0.71(oSIp) - 0.29(aElu) + 0.26(aWCI-AbP)	52
Pongo	- 0.76(aWip) + 0.25(aMaurV)	61
Hartebe	- 0.41(aElv) - 0.43(aCIst) + 0.44(aWCI-AbP)	46
Midmar	+ 0.44(aVang) + 0.37(oNiV) - 0.73(oAtlw)	64

Table 2 Predictor definition.

Predictor	Selected	Parameter	Area/borders	Lat., long.
aVang	2	sfc. Meridional wind	West of Angola	5°S, 5°E
aWci-ABp	2	air pressure	South-north dipole	2°N, 55°E
oSiP	2*	air pressure	South Indian Ocean	12°S, 55°-77°E
oAtlw	1*	upper zonal wind	Central Atlantic	2°S, 20°W
oNiV	1	sfc. meridional wind	Northern Indian Ocean	12°N, 65°E
oSocnS	1	sea surface temp.	Southern Ocean	45°S, 10°-40°E
aCist	1	sea surface temp.	Central Indian Ocean	2°S, 62°E
aEiU	1*	surface zonal wind	Eastern Indian Ocean	2°S, 77°E
aEiV	1	sfc. meridional wind	Eastern Indian Ocean	2°S, 77°E
aWiP	1	air pressure	Western Indian Ocean	2°S, 47°E
AMaurV	1	sfc. meridional wind	Mauritius area	17°S, 55°E

* Correlated with global El Niño; a = JAS, o = SON months; predictor areas > 10⁶ km².

PRODUCTS AND CONCLUSIONS

In operational use, climatic data mainly from NCEP are received via the Internet and monthly predictor anomalies are extracted for model input. Results of the multivariate algorithms are posted on the website of Organized Weather Links Africa during spring (September to November) at the URL address:

http://weather.iafrica.com/forecasts/cip_seasonal_outlook.html

Seasonal long-lead forecasts for southern Africa are disseminated to resource managers, government departments and national weather services, with a www hit rate > 10 000 per day. Hydrological impacts of climatic fluctuations can be mitigated using long-range forecasts, so improving the economic growth potential of southern Africa.

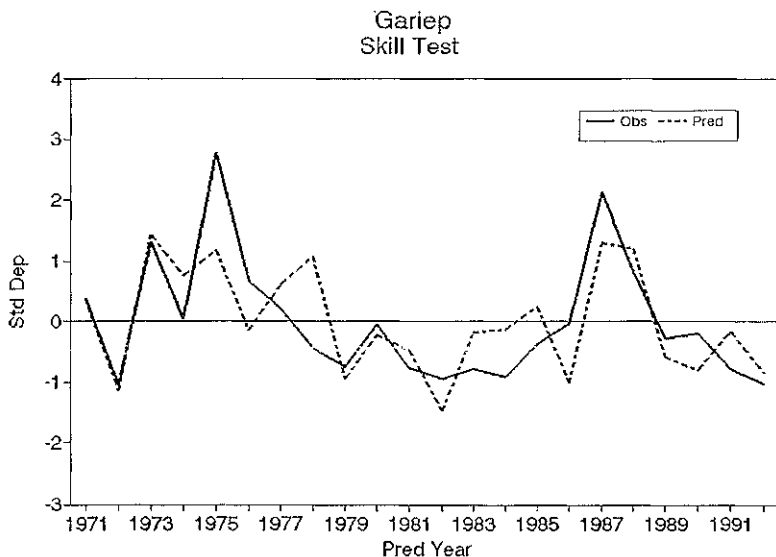


Fig. 3 Comparison of 4-month lead-time predicted and observed inflows for the Gariep dam.

Acknowledgements Prof. W. Alexander of Univ. Pretoria provided dam inflow estimates for South Africa. Model formulation and validation was assisted by Dr S. Mason, Scripps Institute of Oceanography and Dr A. Brandao, University of Cape Town. Predictors were assembled with the help of staff of the Climate Research Laboratory, University of Cape Town.

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