The impacts of climate change on water resources in the Okavango basin

SONJA FOLWELL & FRANK FARQHUARSON

Centre for Ecology and Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK

ssf @ceh.ac.uk

Abstract The need for coherent river basin management plans has become a driving force behind the use of models in understanding how basin hydrology will be affected by change. Of particular interest is how water availability will be affected by climate change and by growing demands for a finite resource. The Okavango basin, located in sub-Saharan Africa is a large, endorheic basin with the river terminating in the vast expanse of the ecologically important Okavango delta. It is also a transboundary basin transecting Angola, Namibia and terminating in Botswana. The end of the Angolan civil war has brought stability and development to the region. With increasing abstractions, due to human development, and possible reductions in available water, due to changing rainfall and evaporation patterns, flows entering the delta will be altered. Considering these possibilities a grid-based model has been used to examine current and future water availability and flows entering the delta system.

Key words water resources; climate change impacts; Okavango basin

INTRODUCTION

The Okavango is a transboundary river basin located in central southern Africa (Fig.1). It has a hydrologically active area of 390 000 km^2 extending from the arid climate of northeast Namibia to the subtropical Angolan highlands which receive an annual rainfall in excess of 1200 mm. The river rises in the Angolan highlands draining south and then eastwards to form the border with Namibia before entering Botswana and terminating in the Okavango delta, a region of great natural and scientific importance. Nearly 95% of the total flow entering the delta system originates in the Angolan highlands. The annual floods peak at Mohembo, just inside Botswana, between February and April but this peak only reaches the end of the delta at Maun between June and August, five months later (McCarthy *et al.*, 2000).

Fig. 1 Map of the Okavango basin

The permanent and seasonal wetlands of the delta provide habitats for many rare and endangered species of flora and fauna now protected under the RAMSAR convention on wetlands. The delta is economically important generating 4.5% of the GDP in Botswana through tourism (Mbaiwa, 2004). The river is in itself an important resource for Namibia both locally and nationally, forming the main water supply for Rundu and for the commercial irrigation schemes along the river; it could potentially be exploited to augment scarce resources elsewhere in the country. In Angola 30 years of civil conflict have meant the upper basin is largely undeveloped.

The Permanent Okavango River Basin Commission (OKACOM), established in 1994 to increase co-operation between the three countries, recognises that future development is inevitable but must be coordinated to balance the conflicting demands of humans and the ecosystem. Compounding the effects of any development are the possible impacts on the basin water balance due to climate change. Indeed a recent study (Labat *et al*., 2004) of long term continental runoff has detected a link between increasing temperatures and reduced runoff in Africa.

Scenarios can be used in the formulation of river basin development plans and attempt to improve understanding among different users of the pressures within a basin. The use of hydrological models helps to translate the complex and differing pressures in the basin into hydrological outcomes e.g. on low or high flows. Using models it is hoped that scenarios can help to raise awareness of the impacts of various drivers among stakeholders, and strengthen understanding of the basin hydrology; in turn more realistic scenarios may be produced through regional cooperation.

THE GWAVA MODEL

The Global Water AVailability Assessment (GWAVA) model was developed to provide estimates of current and future water resources on a regional or global scale (Meigh *et al*., 1999). The method employs a gridded rainfall-runoff model operating at 0.5 degree resolution (approximately 50 × 50 km) to estimate water supply. Superimposed is the water resource network which estimate water abstractions, returns, transfers and influence of structures such as reservoirs. The approach enables a consistent methodology to be applied across countries at a resolution that can capture the spatial variation in water supply and demands. Key outputs of the model are comparisons of water supply and demands which are made at the grid cell basis, through a set of indices to take account of the annual and inter-annual variability in water supply. Using the GWAVA model both changes in climate and demands can be examined individually or in combination. In terms of water resources as a whole, ground water use is limited to the arid areas of the Namibian Omatako and local schemes across the delta. The results presented here therefore are restricted to the major component of hydrology in the basin: surface water. The main components of the GWAVA model are outlined below, for further details refer to Meigh *et al.* (1999).

Runoff generation

The spatial extent of the model includes the fossil river system of the Omatako and the delta system as far as the delta outlet, at Maun. The basin is modelled on a 0.5 degree grid with 161 cells linked to represent the river network (Fig. 2). Runoff generation is estimated using the probability distributed model (PDM) (Moore, 1985). The PDM parameters *Cmax* and *fc* are derived from soil textures and land surface cover based on the approach by Vorosmarty *et al*. (1989), whilst parameters relating to the shape of the soil moisture distribution and reservoir lag times are derived through calibration. Land cover data are derived from the Global Land Characterization dataset using the IGBP DIS classification. These are reclassified into four classes denoted as bare soil, grass, shrub and tree. At each cell linkage any abstractions from within the cell are removed and return flows added.

Climate data

The model is driven by input of monthly rainfall, temperature and potential evaporation with rainfall disaggregated into daily values using the monthly average rain days and randomly

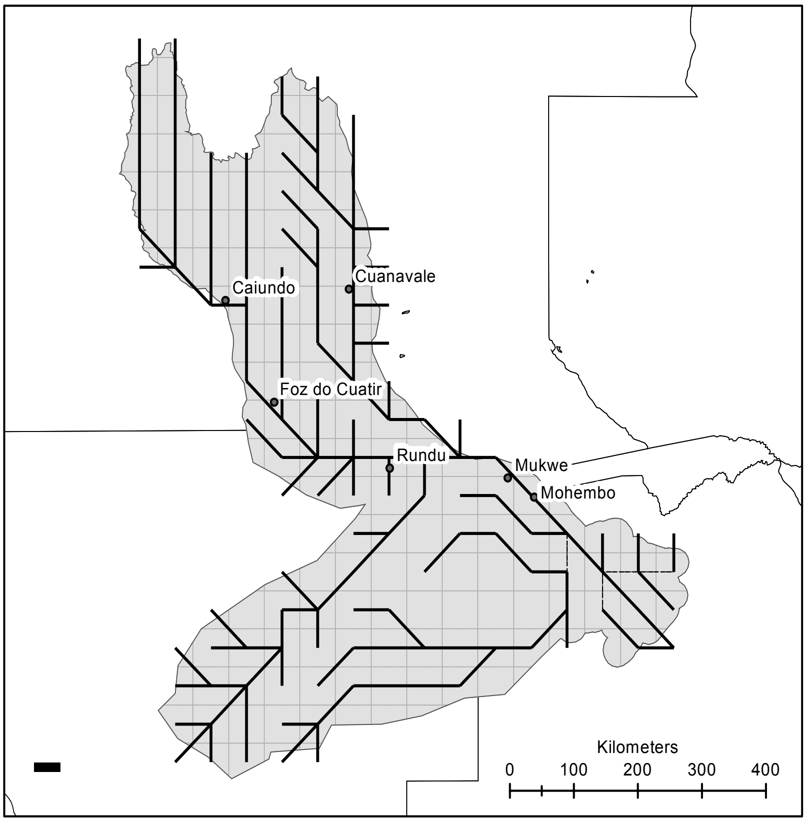

Fig. 2 Gridded river network and stations used for sub-catchment calibration.

assigning rainfall in the each day of the month. Good quality rainfall data are rather scarce within the basin particularly in the upper reaches of the basin where runoff generation is highest. This is partly due to the abandonment of the climate and hydrological monitoring networks within Angola during the civil war. There is a reasonable rainfall network in neighbouring Botswana and Namibia; and the gridded datasets held by Climate Research Unit (CRU) at the University of East Anglia, UK, were used to drive the model (New *et al.*, 2000).

Water demands

Water demands must be defined for each cell. Three broad categories of water demands are considered: Domestic, industrial and agricultural. Domestic demands are estimated for rural and urban water use using the gridded population data (UNEP-GRID) and a per capita water use (25 l h^{-1} day^{-1} for rural and 60 l h^{-1} day^{-1} for urban areas). There were no industrial water users identified with the basin. Agricultural water demand includes livestock water and irrigation. Livestock populations are estimated from the FAO Global Livestock Distributions dataset. Irrigation demands are derived from calculations of crop water demands requiring information on cropping areas, types and cropping calendars.

Calibration

An effect of the civil war in Angola has meant hydrometric stations installed in the early 1960s in the basin were abandoned with records extending for just a few years. This is a particular problem in the Cuito tributary for which there are just 30 months of continuous flow records. The model is calibrated against observed monthly flows at 5 locations for the baseline period 1961 to 1990 against which future scenarios (described below) are compared. Simulated and observed streamflows at two most downstream gauges are shown in Fig. 3. Overall the model captures the flow variability however the model tends to over predict extreme low flows, particularly during the middle period 1967 to 1979.

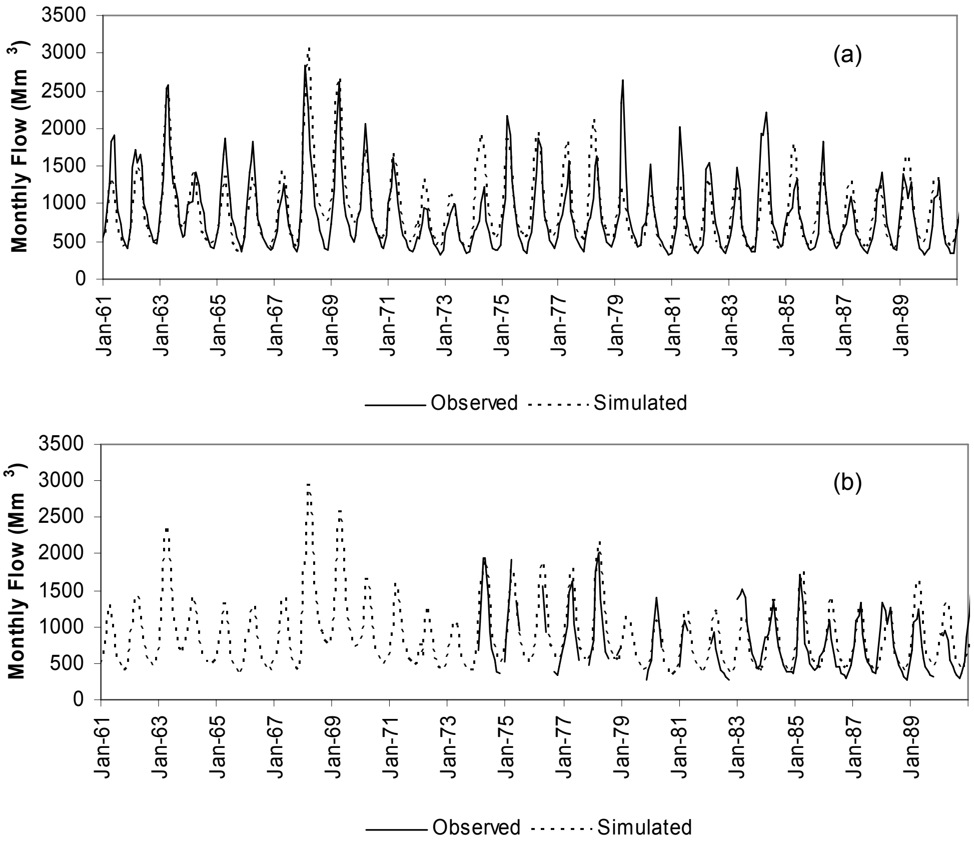

Fig. 3 Calibrated and observed streamflows for: (a) the Okavango at Mukwe; and (b) the Okavango at Mohembo.

Water availability

The amount of water that is 'realistically' available to meet demand is taken as the 90th percentile of monthly flows. This water availability is compared to the total demand in each cell using a suite of indices ranging in complexity from a simple annual ratio of total water demands to supply, to a more complex approach to take account of the varying supply and demand throughout the year. This index (denoted WAI4) expresses the deficit in relation to the demand such that a value of 1 means water supply is in excess of demands, through 0 water supply equals demands, to -1, water supply is insufficient to meet the demand. Indices are calculated and mapped showing the spatial variation of water availability in absolute terms and scaled according to the size of the demand.

CHANGE SCENARIOS

Climate change

Climate change scenarios for the basin are derived from the outputs of General Circulation Models (GCMs) which are available from the IPCC data distribution centre. The scenarios presented here use the UK Hadley centre's HadCM3 GCM under two SRES emissions scenarios, A2 and B2, for which global temperatures rise by between 3.53ºC and 3.69ºC, and 2.60ºC and 2.64ºC by 2080, respectively (Arnell, 2003). The HadCM3 model operates at a coarse spatial scale such that the basin is covered by just six 2.5 × 3.75 degree grids cells, with data downscaled using bilinear interpolation. Results from a Regional Climate Model, PRECIS, whose finer resolution, at 50 km, is commensurate with the hydrological model were also available for the A2 emissions scenario and time horizon 2080 (Tadross *et al.*, 2005). For each scenario, changes in precipitation, temperature and potential evaporation (Table 1), are calculated from the baseline, these changes are then applied to the CRU baseline.

Table 1 Percentage change in rainfall and potential evaporation in the Okavango Basin for time horizons 2050 and 2080 and emissions scenarios A2 and B2.

Year/scenario	Percentage change Precipitation	Potential Evaporation
2050		
HadCMA2	–13.6	18.3
HadCMB2	–15.5	16.3
2080		
HadCM A2	–20.6	30.8
HadCM B2	–27.15	28.4
PRECIS A2	–2.4	15.6

Demand change

Population growth and the corresponding increase in domestic water supply, and increased irrigation are the main drivers for growing water demand. The UNPD World Population Prospects (WWP) Database provides estimates of total and urban national populations up to the year 2050. Whilst the populations in Botswana and Namibia are predicted to plateau by 2050 the Angolan population will continue to rise resulting in a basin population of 5.1 million, assuming a medium variant growth. Increases in population are assumed to be greatest where population centres exist, such that the greatest increase in population would take place in the upper reaches of the Cubango basin. In a study of irrigation potential (Marques, 1998), up to 54 000 ha of land could be utilised in the lower reaches of the Okavango in Angola. A further 8000 ha may be utilised in Namibia.

RESULTS

The results in Table 2 summarize key model output for each scenario in terms of changes to the seasonal flows entering the delta where the dry season extends from February to July. In the final column the total number of cells which have a WAI4 of less than 0, i.e. the water supply does not meet the water demand or experiencing "water stress" is given. Comparing the baseline situation with the scenarios of demand change and climate change demonstrates that the human abstractions will have a moderately small impact on flows both in the dry and wet season.

The predicted changes in precipitation and potential evaporation are summarised in Table 1, and examination of the GCM results shows decreases in precipitation and increases in potential evaporation across the basin for every month. The impacts on both the wet and dry season flows are necessarily dramatic with dry season flows dropping by between 49–54% by 2050, and 68–73% by 2080. In contrast the results from the PRECIS RCM indicate a more modest drop in basin precipitation by 2080 of 2% annually with increasing precipitation in the Angolan highland

Table 2 Relative impacts of change on wet and dry season flows at Rundu and Mohembo.

Year/scenario	Seasonal flow (Mm^3) Rundu Dry	Wet	Mohembo Dry	Wet	Number of cells WAI4 < 0
Baseline (1961 to 1990)	1552	4108	3010	5677	14
Abstractions					
Increased irrigation	1534	4073	2968	5577	28
Increased population (2050 med. variant)	1529	4087	2989	5657	14
Climate change					
HADCM3_A2 2050	713	1934	1307	2567	26
HADCM3_B2 2050	788	2050	1487	2839	28
HADCM3_A2 2080	495	1470	874	1865	42
HADCM3_B2 2080	418	1243	706	1570	44
PRECIS_A2 2080	1362	4264	2358	5187	14

observed in the winter months contributing to larger wet season flows observed at Rundu. Across the whole basin, annual evaporation increases substantially, however, this is biased by the high increases in the southwest arid regions as such increases in the rest of the basin are more moderate. The impact of increasing evaporation on the water balance in this region is manifest in Fig. 4, comparing the WAI4 for the baseline and 2080, and shows that the majority of cells moving to a more water scarce situation are located within the Omatako sub-basin. These results also indicate the sensitivity of water resources in the basin to the spatial distribution of water supply and patterns of future climate change.

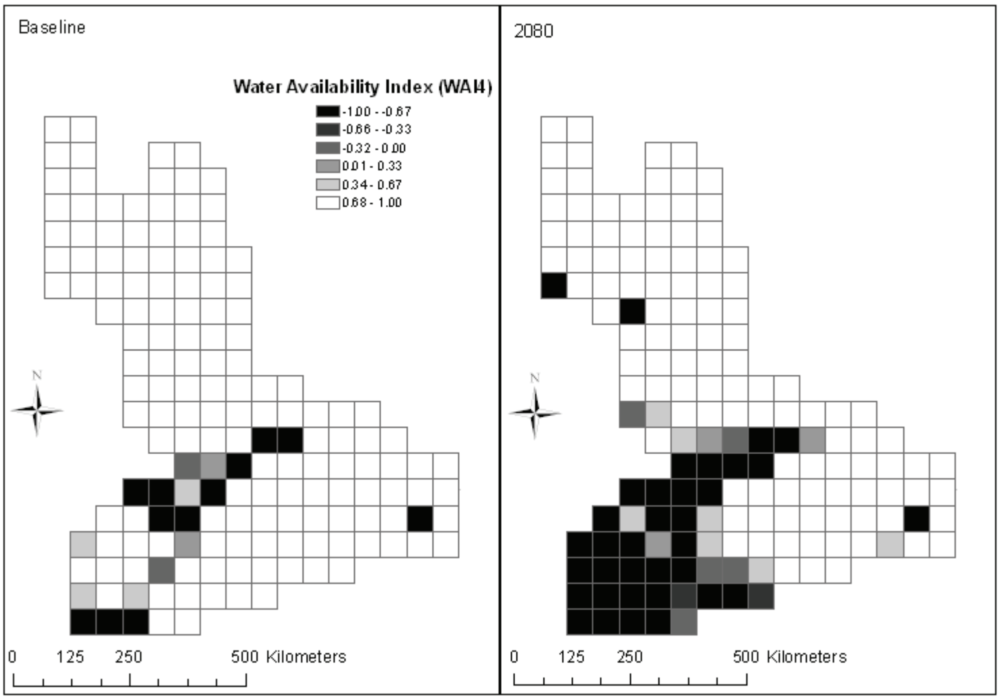

Fig. 4 Water availability indices for the baseline and 2080 (A2 scenarios).

The impacts of increased abstractions whether for irrigation or water supply appear relatively small because the largest population increases will take place in the wettest parts of the catchment, and, although WAI4 falls it remains above zero, indicating water supply is still sufficient to meet increased demand.

CONCLUDING REMARKS

A large-scale gridded model such as GWAVA provides a useful and consistent methodology to model water resources and water availability across large regions. Through the mapping of indices which compare water demand and supply vulnerable areas can be identified. The difference in predicted changes of precipitation and evaporation between the HADCM3-A2 scenarios and the PRECIS model suggest there is considerable uncertainty in the GCMs at present even for the scale of the Okavango basin.

Whilst the basin response to changing aspects of the water budget is useful, 'realistic' scenarios using both human development and climate change may be as informative.

Acknowledgements This work has been supported by the EU and NERC through funding of the TWINBAS project. The authors wish to acknowledge the contribution of our former colleague Dr Jeremy Meigh (1954–2006).

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