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Reservoir operation under variable climate: Case of Rozva Dam, Zimbabwe

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ABSTRACT

The challenge of maintaining or improving the quality of rural livelihoods against the increasing threat of climate change (CC) and climate variability (CV) calls for the development of robust and tested systems, tools and procedures for the management of water resources. The research aimed at assessing reservoir operation under variable climate for Rozva Dam, a medium-sized reservoir in Zimbabwe. Rozva Dam is located in the Bikita District of Zimbabwe and has a full supply capacity of 2.8 Mm^3 at a maximum water level of 17.3 m. The research analysed 46 years of rainfall and temperature data to assess climate variability and or change. The CROPWAT model was used to estimate crop water requirements for the adjacent 80 hectare irrigation scheme. The WAFLEX model was applied to simulate the performance of the system under three scenarios: (1) existing demands and operational rules, (2) reduced water availability due to climate change, as predicted by the Ministry of Mines, but with increasing annual demands and (3) climate change situation coupled with change in irrigation technology. The results show a general decreasing linear trend for rainfall although the variance was not statistically significant at $p = 0.05$. A clearer cyclic pattern was observed for the decadal analysis. An increasing trend in both maximum and minimum temperature was observed although, again, these were not statistically significant with a Spearman's rank correlation coefficient (R_{sp}) of below 0.5. The research used rainfall and temperature data as the basis for confirmation climate change and variability in the study area. Analyses show that the area is experiencing more of CV than CC. Modelling results show that the reservoir can satisfy current demands but will fail to cope under the forecasted increase in demand. The conclusions from the research are that the available water resources in the studied system are sufficient to satisfy the current demands. The predicted level of climate change will result in shortages of up to 30% for the downstream users necessitating the need to review how the reservoir is operated. Water managers and policy makers should therefore promote awareness of anticipated consequences of climate change so that communities are better prepared to cope with CC and CV.

1. Introduction

There is a high probability of witnessing a temperature increase of 1 °C combined with high rainfall variability (±30%) in the Southern African region (Hulme et al., 1996). In the recent past, these indicators have been confirmed regionally by the droughts of 1992 and 1995, which further highlighted the sensitivity of the region's water resources to variations of climate. By the year 2025, physically water scarce countries in Southern Africa and regions like North Africa may not have adequate water resources to meet their projected water demands (Inocencio et al., 2003). The proportion of the Sub-Saharan Africa's population in water-stressed countries is also expected to rise from just above 30–85% by 2025 (U.N, 2006). Linear and generally decreasing trends were revealed in river flows in Southern Africa based on 40 year long flow time series (Alemaw and Chaoka, 2002). In Zimbabwe, for a doubling carbon emissions scenario, significant changes in climate were projected for Gwayi, Odzi and Sebakwe sub-catchments in the order of 50% reduction in inflow (Ministry of Mines, Environment and Tourism, 1998). Historically, challenges of water shortage have been solved through construction of dams, with communities served by the reservoirs being highly dependent on them for domestic and agricultural purposes. Climate change will imply an increased frequency of extreme events (Murwira et al., 2009), leading to increased frequency of low and high flows. Furthermore, an increase in temperature may also lead to increased water loss through evaporation. The combined effect of these two parameters is a reduction in dam yields which, in turn, leads to decreasing satisfaction levels of the demands served by such reservoirs. Reduced yields are particularly a problem in medium reservoirs as these water bodies are not normally designed as carryover structures.

The Zimbabwe National Water Authority (ZINWA) classifies small dams as those having a capacity of less than 1 Mm^3 and medium dams of between 1 and 3 Mm^3 (Zimbabwe Water Act, 1998). In Zimbabwe, small and medium sized dams have traditionally been

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operated as annual dams, with no strict operating rules to manage water scarcity between years. Until recently, the issue of climate change was not topical and, hence, coping mechanisms were not incorporated during reservoir design. Besides, discussions on climate change are generally taking place at larger spatial scales where data is readily available. There is very little evidence to show similar efforts to understand climate change and climate variability issues at local scales where their impacts would be mostly felt. The absence of higher security in managing these smaller dams results in serious failure to satisfy average demands under climate variability conditions. This then brings about the need for more robust management approaches for small to medium multi-purpose reservoirs through the application of scientifically developed and tested decision support tools (DST). The application of modelling techniques to simulate reservoir operation, incorporating uncertainties such as the projected effects of climate change would help to develop coping mechanisms against the impacts of climate change and variability. Models can also be used to optimise water allocation and assist in the operation of the reservoirs. Uncertainties related to how the climate will change and how water resource planning and management systems have to adapt to these changes are issues that water authorities are compelled to cope with (Ragab and Prudhomme, 2002). This study aimed to contribute, to the management of small to medium reservoirs under climate change and climate variability conditions. The objectives of the study were therefore (1) to investigate if there is evidence of climate change occurrence at a local scale with respect to rainfall and temperature, (2) apply modelling techniques to investigate the performance of Rozwa Dam and (3) predict the impacts of reduced inflows on reservoir operation, based on a climate change study done in Zimbabwe.

2. Research methods

2.1. Description of the study area

Rozva Dam lies about 100 km east of Masvingo town in southern Zimbabwe in the Lower Save sub-catchment, at grid reference 1957S and 3211E. It is a medium sized dam with a full supply capacity 2.8 Mm^3 and is located on the Rozva River adjacent to Nyika Growth point, in Bikita District (Fig. 1). The main purpose of the dam is to supply Nyika and Bikita Growth points with water, irrigate 80 hectares at the Rozva Irrigation Scheme and to cater for environmental needs and users downstream of the dam. The dam was commissioned in October 1994. Other key characteristics of the dam are given in Table 1. The dam is located in agro-ecological region III and hydrological sub-zone ES3 which are characterised by relatively high average rainfall of about 700 mm/yr and mean annual evaporation of 2000 mm/yr. The study area has a warm tropical climate typified by one rainfall season of 5 months, starting from November to April, and dry weather in the remaining months of the year. Rainfall is mainly due to the passage of the Inter-Tropical Convergence Zone (ITCZ), experienced between December and June.

The irrigation scheme comprises a drag-hose surface irrigation system with the water being pumped from Rozva Dam onto furrows in the field through polythene pipes connected to hydrants. Since the irrigation system is partially piped, the irrigation efficiency is assumed to be 60% compared to the usual 40–50% employed for surface irrigation systems (FAO, 1989). The scheme is divided into three blocks (A–C). From the dam, water is pumped into a night storage reservoir of capacity 4000 m^3 which was originally constructed to serve Blocks A and B. The crops grown at the scheme include maize, wheat, beans, and tomatoes. The cropping period for rain-fed agriculture is between October/November and March, but irrigated agriculture is practiced throughout the year. The average yield for maize, which is the staple food in the area, varies between 1.1 and 3 ton/ha under rain-fed agriculture (Makadho, 1996). Irrigated agriculture has the potential to improve the yield to around 6 ton/ha (FAO, 1997) provided there is adequate balance between water and nutrients.

Water supplied to Nyika and Bikita Growth points is mainly for domestic use to serve a population of around 18,099 (CSO, 2002). The volume of water supplied to the growth points from 2002 to 2009 ranged from 14.3×10^3 m^3/a to 21×10^3 m^3/a. Downstream

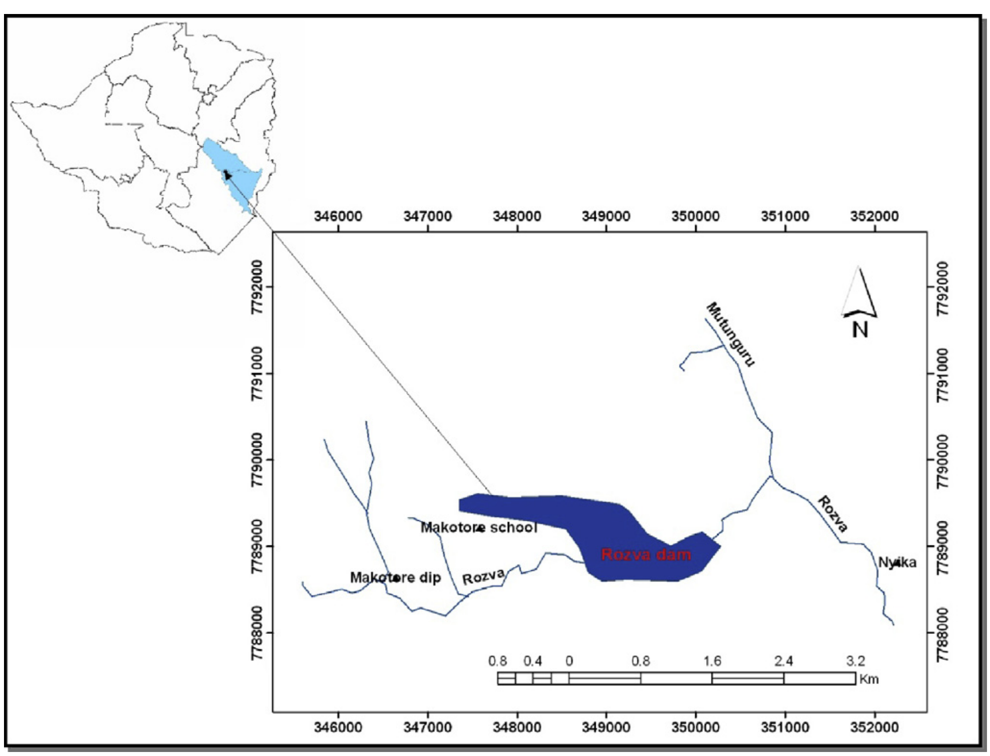

Fig. 1. Map showing location of the Rozva Dam.