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Evaluating the Technical Performance of the Koga and Gomit Reservoirs in the Blue Nile under Existing Conditions and Possible Climate Change

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Introduction

Water storage is widely posited as a key adaptation strategy for climate change. However, climate change will also have impacts on water storage, affecting both the effectiveness and suitability of different storage options. To date, although there have been many studies on the effects of climate change on hydrological regimes, there has been very little systematic research into the potential impacts of climate change on different water storage options or how to plan and manage water storage under a changed climate (McCartney and Smakhtin, 2010). The aim of this study was to evaluate the possible impacts of climate change on the technical performance of two reservoirs in the Blue Nile basin of Ethiopia. The Koga dam is a new dam built to irrigate 7000 ha and provide water for electricity generation. The storage capacity of the reservoir is 83.1 Mm^3. It is located approximately 35km southwest of Bahir Dar, the capital of the west Gojam administrative region at an altitude of 1998 masl. The catchment is situated between 11^o10’ and 11^o32’N and 37^o04’ to 37^o17’E. The catchment area to the dam is 170.9 km^2 and extends to an altitude of 3,200 masl (Mott Macdonald, 2004). The Gomit dam is a community dam built to irrigate 90 ha with no hydropower capability. The storage capacity of the reservoir is 0.74 Mm^3. It is located about 10 km from the town of Mekaneyesus. Geographically the area lies on coordinates of 11^o33’43’’ N, 38^o01’20’’ E. The catchment area has an average altitude of 2,375 masl (Co-SAERAR, 2000).

Material and Methods

Daily rainfall runoff modeling and reservoir simulation were conducted for both dams using the HEC-HMS model (USACE, 2000). In each case, the model was calibrated and validated with model performance determined using the Nash and Sutcliffe efficiency, correlation of determination and percent volume difference (Krause, et al., 2005). The model simulations were used to determine the performance of the reservoirs, evaluated in terms of Reliability, Resilience and Vulnerability (RRV) criteria (Hashimoto et al., 1982):

- **Reliability** is a measure of the frequency of the reservoir to fail to supply water for all demands
- **Resilience** is a measure of the speed of recovery of the reservoir from failure
- **Vulnerability** is a measure of the cumulative maximum extent of failure (i.e. days)

In each case the RRV criteria were evaluated under both existing and hypothetical future climate conditions. The computational scheme for these indices was determined by defining the dead storage (C) as the minimum required storage. The simulated daily storage (X_t) at time t could then be classified as in either a satisfactory state (S) or in a state of failure (F), depending on whether there was storage in excess of C:

$$\begin{aligned} &If \quad X_t \geq C \quad then \quad X_t\, \varepsilon\, S \quad and \quad Z_t = 1 \\ &\qquad\qquad\qquad\; Else \quad X_t\, \varepsilon\, F \quad and \quad Z_t = 0 \end{aligned}$$

Where: Zt is a generic indicator of satisfaction or failure. Another indicator, Wt, which represents a transition from F to S, was defined as:

$$Wt = \begin{cases} 1, & Xt\ \varepsilon\ F\ and\ Xt+1\ \varepsilon\ S \\ 0, & Otherwise \end{cases}$$

If the periods of X_t in F are defined as U1, U2,…, UN where N is the number of F periods, then reliability, resilience, and vulnerability indices during the total time period (T) were defined as:

$$Reliability = \frac{\sum_{i=1}^{T} Zt}{T}$$

$$Resiliency = \frac{\sum_{i=1}^{T} Wt}{T - \sum_{i=1}^{T} Zt}$$

$$Vulnerability\ Time = max\{U1, U2, \dots, \quad UN\}$$

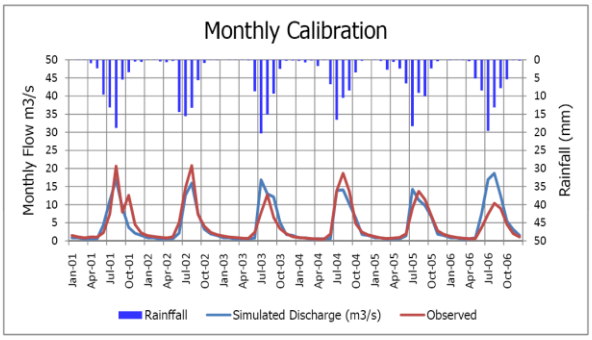
A Digital Elevation Model was used to extract the physical characteristics of the watersheds using Arc-Gis, Arc-Hydro and HEC-GeoHMS. Simulations of inflow time series to each reservoir were obtained from rainfall, evaporation and watershed characteristics. The model was used to simulate reservoir water levels and releases. After calibrating and validating the model, the Koga and Gomit reservoirs were simulated on a daily time-step for 20 and 10 years of historical data respectively. This was done, to determine the availability of water to meet irrigation, hydropower (only Koga) and environmental flow requirements. RRV characteristics were determined.

There is considerable uncertainty about the possible impacts of climate change, particularly with respect to rainfall. Previous studies indicate that future rainfall changes in the area are likely to lie within range of -20% to +20 %. Hence, the effects of hypothetical rainfall changes over this range were determined. RRV values were recalculated with the reservoir inflow generated with these changes in rainfall.

Results and Discussion

Daily and monthly discharge data at the Koga dam site from 1996 to 2006 were used for model calibration (2001 to 2006) and validation (1996 to 1999) (Figure 1). For the Gomit reservoir only two years of water level data were available (May 2006 to July 2008) and so it was only possible to do a model calibration (Figure 2).

a)



b)

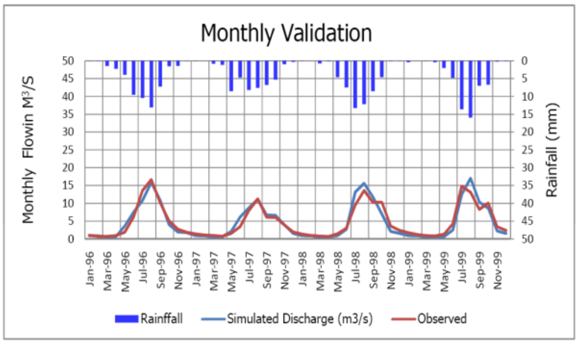


Figure 1: For the Koga reservoir a) calibration and b) validation

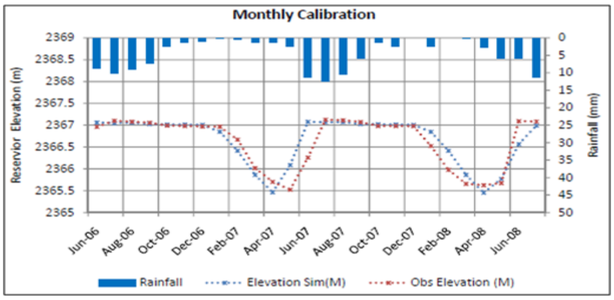


Figure 2: For the Gomit reservoir a) calibration

Tables 1 and 2 show the RRV results for Koga and Gomit reservoirs under the historic conditions and with the hypothetical changes in rainfall that may arise from climate change. Although there are sometimes trade-offs in RRV terms (e.g. a reservoir that is highly resilient maybe less reliable), the results indicate that:

- Under all conditions, the larger Koga reservoir is more resilient and reliable and less vulnerable than the smaller Gomit reservoir
- Higher rainfall in the future will increase resilience and reliability and decrease the vulnerability of both reservoirs
- Reduced rainfall in the future will decrease resilience and reliability and increase vulnerability of both reservoirs
- The magnitude of the impact of possible changes in rainfall on the RRV terms is greater for the smaller reservoir than the larger

Table 1: *RRV results for the Koga Reservoir*

	Resilience	Reliability	Vulnerability
Irrigation			
Historic	0.037	0.992	37
-20%	0.020	0.968	64
+20%	1.000	1.000	0
Hydropower			
Historic	0.023	0.948	66
-20%	0.020	0.927	76
+20%	0.033	0.975	60

Table 2: *RRV results for the Gomit Reservoir*

	Resilience	Reliability	Vulnerability
Irrigation			
Historic	0.032	0.950	71
-20%	0.016	0.874	88
+20%	0.055	0.979	44

Concluding Remarks

Making appropriate choices from the range of storage options available is the key to planning and management of future water storage. In any given situation this requires an understanding of the possible implications of climate change on the technical performance of different storage options. The RRV criteria are a useful tool for determining how the technical performance of reservoirs may alter as a consequence of climate change. They provide a starting point for building climate change into dam planning and management and as well as single reservoirs they can be used to assess the technical performance of reservoirs linked in systems.

Research is needed to determine how RRV terms can be extended to other storage types (e.g. groundwater and small ponds and tanks) as well as storage systems comprising more than one storage type. Such combined systems are more flexible and more likely to be effective under changed climate conditions. Furthermore, beyond assessments of technical performance it is also necessary to consider suitability of different storage options. This requires consideration of a wide range of socio-economic factors.

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