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EVALUATION OF PROPOSED MULTI-PURPOSE DAMS FOR FLOOD AND DROUGHT HAZARD REDUCTION IN THE UPPER EWASO NGIRO NORTH RIVER BASIN, KENYA

Це дослідження представляє результати оцінки посухи та ризику повені, з метою оцінки багатоцільових гребель Ісіоло та Нантенду в басейні Верхнього Північного Евасо Нгіро (ENNRB). Для оцінки минулих небезпек, було досліджуване довгостроковий облік опадів з використанням індексу стандартизованих опадів (SPI), а також індексу стандартизованих опадів евапотранспірації (SPEI).

***Ключові слова**: посуха та небезпека повені, багатоцільові греблі, стандартизований індекс опадів.*

Это исследование представляет результаты оценки засухи и риска наводнения, с целью оценки многоцелевых плотин Исиоло и Нантенду в бассейне Верхнего Северного Евасо Нгиро (ENNRB). Для оценки прошлых опасностей, было исследуемое долгосрочный учет осадков с использованием индекса стандартизированных осадков (SPI), а также индекса стандартизированных осадков эвапотранспирации (SPEI).

***Ключевые слова:** засуха и опасность наводнения, многоцелевые плотины, стандартизированный индекс осадков.*

This study presents results of the drought and flood hazard assessment adopted for the evaluation of proposed multi-purpose Isiolo and Nantundu Dams in the Upper Ewaso Ngiro North River Basin (ENNRB) For the evaluation of past hazards, the long-term precipitation record has been investigated with the use of Standardized Precipitation Index (SPI) as well as Standardized Precipitation Evapotranspiration Index (SPEI).

***Keywords**: drought and flood hazard, multi-purpose dam, Standardized Precipitation Index*

Introduction. Alternate incidents of floods and droughts have been causing fatalities and major economic losses in the Ewaso Ngiro North River Basin (ENNRB), which is the largest river basin in Kenya. In the high elevation reaches of the ENNRB, heavy rainfall contributes to flood inundation in the downstream low-lying areas that is the most densely populated area affecting day-to-day activities of agriculture, tourism and industries. For example, the 2010 flood killed 6 people inundating 120 houses and 10 tourist lodges and displacing more than 200 local people and 600 tourists [1]. The lower part of the basin is the semi-arid and drought prone area and has been experiencing water shortages that create conflicts between the upstream and downstream water users [2, 3]. When the drought extends beyond one dry season as the case was in 2008-2009 drought, these water supply sources dry up making water scarcity too devastating with major economic, social and environmental losses. Surface and groundwater sources of water supply such as river intake, shallow wells often carry limited amount of water that is only sufficient for one dry season. The 2008-2009 drought had a severe impact on Isiolo and Samburu counties, which are relying on livestock agriculture, causing over 50% of cattle and 60% of sheep death. Thousands of people had to rely on relief food as the fled from their drought stricken homes to seek food and water in the neighboring towns with only few of their cattle that survived.

This study aims to analyze the possibility of applying structural measures such as multi-purpose dam to mitigate flood and drought hazards by reducing flood peak flows and utilizing stored water for water supply during water scarce periods. For drought hazard reduction, the increase of available water storage and the adaptation of water allocation plans were selected as a viable option by Kenyan water management authorities in the previous ENNRB feasibility studies for the water resources management in the upper ENNRB catchment [4, 5]. Therefore, we evaluated two multi-purpose dams identified for construction in the headwaters of the ENNRB by national and local authorities with two main objectives: 1) to decrease flood peak discharges at the tourist lodges in Samburu and residential areas around Archers post town located in the downstream part of the river basin and 2) to maintain minimum river flows during droughts while providing municipal, livestock and minor irrigation water supply.

Study area and approach. The study area is located in the upper ENNRB with a catchment area of 14,973km^2 and elevation between 430 and 4793 m above mean sea level (Figure 1A). The Nantundu Dam has a capacity of 0.363 km^3 at the crest level and is located 23 km downstream of the Isiolo Dam with the capacity of 0.311km^3. Nantundu and Isiolo Dams have similar submerged area of about 20 km2 and 0.260 and 0.214 km^3 of water supply storage, respectively. Figure 1 also demonstrates 8 rainfall and 3 river gauging stations with daily data available for this study. One river gauging station is located downstream of the proposed dam location at the Archers post and the Archers post river gauging station had data for period 1949 to 2013 with few data gaps in some years. During the year 2011 flood event, the station reported rise in water level from 2.8 m to 5.7 m to just below the bridge deck making it the most suitable reference flood event with properly observed flood peaks.

A combined drought and flood assessment is adopted for the multi-purpose dam operation to maintain full storage before the start of dry seasons and to keep flood capacity for the flood peak reduction during flood seasons. For the hazard severity assessment, meteorological drought has been investigated using long-term observed daily precipitation with the Standardized Precipitation Index (SPI) [6]. The Standardized Precipitation Evapotranspiration Index (SPEI) was obtained from available database of global coverage at about 55-km grid to indicate agricultural droughts by considering a difference between precipitation and potential evapotranspiration [7, 8]. Both indices have the same scale of dry and wet climate conditions due to standardization [9, 10]: extreme dry (SPI and SPEI≤-2), severe dry (-2.0<SPI and SPEI≤-1.5), moderately dry (-1.5< SPI and SPEI≤-1.0), near normal (-1.0<SPI and SPEI<1.0), moderately wet (1.0≤SPI and SPEI<1.5), severe wet (1.5≤SPI and SPEI<2.0) and extreme wet (2.0≤SPI and SPEI). The standardization is the main advantage of comparing these indices on the same scale and allows us to evaluate drought and flood hazards across various locations and climate conditions.

We evaluated water infrastructure effectiveness using multi-purpose dam operation [11] implemented in the Block-wise TOPMODEL [12], which has been applied in various river basins across the globe [11, 13-17]. For the BTOP project files, we applied existing 600-arcsec (about 18-km) grid BTOP model, which was developed for the entire ENNRB as a part of the global BTOP modelling system [17], for the catchment area located upstream of the Archers post (Figure 1A). The 600-arcsec grid BTOP model was run with short- and long-term local precipitation data and calibrated with river discharge data at the Archers post river gauging station to represent peak and low flows of the Ewaso Ngiro River. The BTOP model performance was evaluated using the Nash-Sutcliffe Efficiency (NSE), which has values close to 1 for the best performance [18]. From the calibrated BTOP model, the proposed dams were simulated to evaluate water supply and flood control using past flood and drought events. The application of dam reservoir operation in flood peak control was done under regulated scenario, which is prior to a major flood event like experienced in 2011 and the dam volume is maintained to the normal water level to create room for the flood storage volume.

For drought hazard reduction, the multi-purpose operation is simulated for a period between 2004 and 2014 to monitor the decline in reservoir water storage of multi-purpose dams during past severe to extreme droughts with three water supply options. These three options are arranged from smallest to largest dam outflow considering the worst, medium and best water supply cases, respectively. Option #1 with 2.9 m3/s dam daily outflow considered domestic water withdrawals of 0.9 m3/s and downstream environmental flow of 2 m3/s. Option #2 with 4.3 m3/s dam daily outflow included livestock water withdrawal of 1.4 m3/s in addition to domestic withdrawals and environmental flow. Option #3 is considered as the maximum daily dam water supply of 10.5 m3/s for small scale agriculture (6.2 m3/s), livestock (1.4 m3/s), and domestic (0.9 m3/s) users while maintaining environmental flow of 2 m3/s.

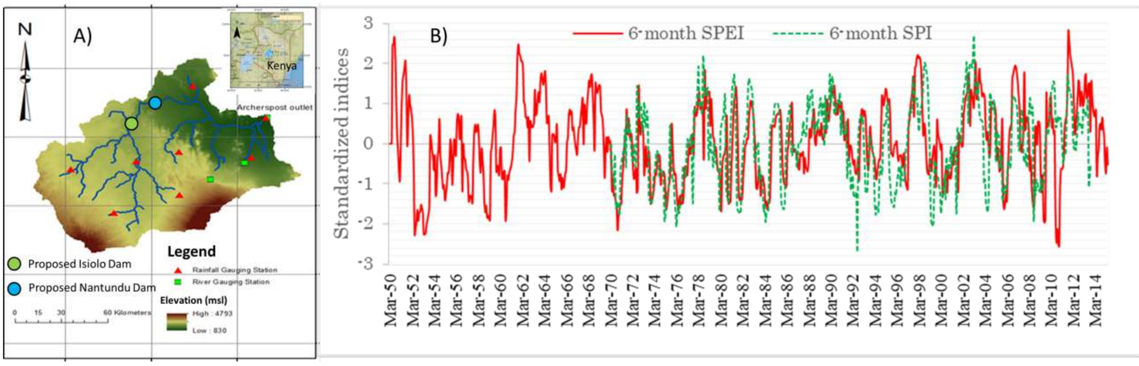

Figure 1. **Locations of rainfall and river gauging stations and the proposed Isiolo and Nantundu Dams in the Upper Ewaso Ngiro North River Basin, Kenya, A) and 6-month Standardized Precipitation Index (SPI) from Archers post precipitation and Standardized Precipitation Evapotranspiration Index (SPEI) obtained from [8] B).**

Results and discussion. We demonstrate 6-month SPI and SPEI values in Figure 1B. The 2004 and 2008/2009 droughts are represented as severe (-2<SPI & SPEI≤-1.5) and extreme (SPI & SPEI≤-2.0) droughts. The 2010 drought is considered extreme agricultural drought by the SPEI values while the meteorological drought is not detected by SPI. For drought incidents, the probability of recurrence of moderate droughts is once in 18 months and severe dryness at once in 5 years. For flood incidents, moderate wetness is experienced once in 7 months and severe wetness occur once in 18 months as demonstrated by the recent floods of March 2010, November 2011 and April 2013 and October 2014. The 3-month SPI/SPEI is used in analyzing short-term to mid-term soil moisture conditions and is effective in planning for farming activities while 12-month SPI/SPEI values indicated long-term trends in precipitation (not shown).

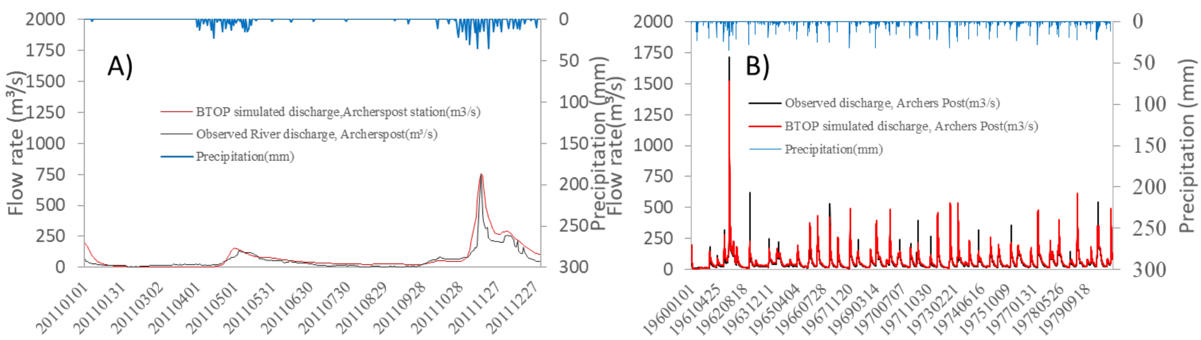

Figure 2. **Daily river discharge observed at Archers post gauge and simulated with the BTOP model for A) calibration period in 2011 and B) validation period from 1960 to 1980.**

Figure 2 demonstrates river discharge at the Archers post simulated by the 600-arcsec grid BTOP model using local precipitation. The BTOP model has a good performance of the 2011 calibration period with NSE of 0.72 (Figure 2A) and lesser performance with NSE of 0.49 for the long-term validation period from 1960 to 1980 (Figure 2B). The BTOP model performance is considered satisfactory in both calibration and validation and we use the calibrated BTOP model with multi-purpose operation of proposed Isiolo and Nantundu Dams.

In the flood control operation, both Isiolo and Nantundu Dams reduced the 2011 flood peak discharge of 729 m³/s while their flood control volumes have different impacts on flood inundation at the Archers post. In the case of Isiolo Dam, the simulated November 2011 flood peak reduced to 352 m³/s, which is slightly above the estimated bank-full discharge of 340 m³/s and may result in flood inundation at the Archers post. The Nantundu Dam reduced the 2011 flood peak up to 220 m³/s preventing potential flood inundation at the Archers post. This evaluation indicates that Nantundu Dam as preferred option.

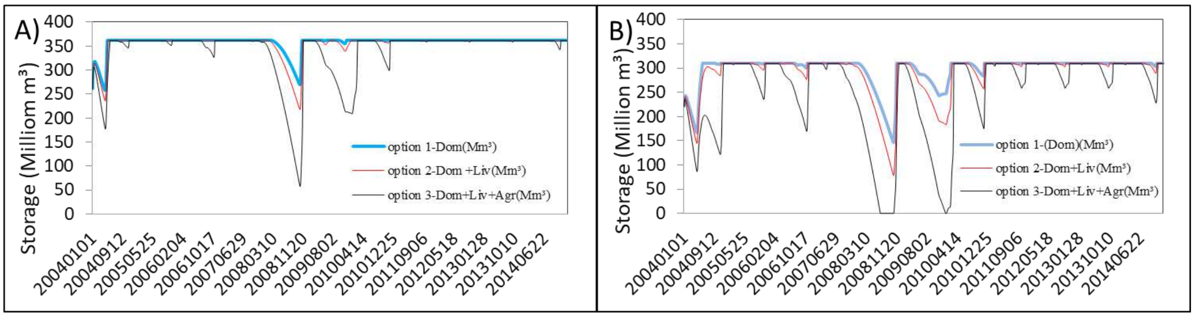

Figure 3. **Simulated multi-purpose operation of proposed A) Isiolo Dam and B) Nantundu Dam with BTOP model between 2004 and 2014 including the 2004, 2008/2009, and 2010 droughts.**

Figure 3 demonstrates water storage volumes of two proposed dams between 2004 and 2014 with three water supply options. Both Isiolo and Nantundu Dams demonstrate sufficient reservoir storage for domestic water supply and environmental flows (option #1) as well as domestic, livestock, and environmental flow water supply (option #2), especially during past droughts in 2004, 2008/2009 and 2010. However, the Nantundu Dam with 0.363 km³ capacity covers all water withdrawals in option #3 (Figure 3A) while the Isiolo Dam capacity of 0.311 km³ is insufficient (Figure 3B). In terms of location, the Isiolo Dam located about 23km upstream of the Nantundu dam is preferable since it can supply a bigger area within the study area by gravity, but it may not the best option in terms of dam water supply.

Conclusion. This study utilized a comprehensive approach for flood and drought hazard assessment. Severity and frequency analysis was conducted using Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) using local precipitation and global precipitation and evapotranspiration datasets, respectively. For river discharge simulations, the 600-arcsec (about 18-km) grid BTOP model with local precipitation was used for calibration and validation at the Archers post. Using the calibrated BTOP model, the multi-purpose operation of Isiolo and Nantundu Dams were simulated to confirm the optimum dam water storage for flood control and three options of water supply.

Simulation results of proposed Isiolo and Nantundu Dams demonstrated reduction of the 2011 flood peak discharge in relation to the estimated bank-full discharge at the Archers post while Nantundu dam with regulated flood control could have prevented 2011 flood inundation and Isiolo dam would not. For drought hazard reduction of water scarcity, both dams performed satisfactorily in providing water supply for domestic and livestock water users while maintaining environmental flows at the Archers post. The Nantundu Dam showed better performance in provision of water for agriculture water supply compared to Isiolo Dam. In terms of location, the Isiolo Dam located about 23km upstream of the Nantundu dam is preferable since it can supply a bigger area within the study area by gravity. Therefore, these preliminary results indicate the usefulness of combined drought and flood hazards assessment for selecting the multi-purpose dam and enables planning for a combined flood and drought risk reduction activities. This preliminary investigation should be further improved in future studies considering additional local data with the 0.5-km BTOP model to enable detailed simulation of river discharges.

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