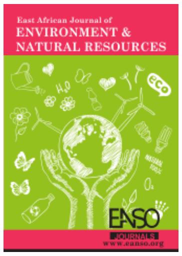


East African Journal of Environment and Natural Resources
eajenr.eanso.org
Volume 6, Issue 1, 2023
Print ISSN: 2707-4234 | Online ISSN: 2707-4242
Title DOI: https://doi.org/10.37284/2707-4242

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Application of SWAT and WEAP Models for Sustainable Management of Water Resources in the Two Rivers Dam Catchment, Uasin Gishu County, Kenya

Dennis Mailu Kiamba[1], Emmanuel Chessum Kipkorir[1], Job Rotich Kosgei[1], Simon Mburu Njoroge[1] & Gilbert Nyageikaro Nyandwaro[1]*

[1] Moi University, P. O. Box 3900-30100 Eldoret, Kenya
[*] Correspondence email: mailukiamba@gmail.com

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Date Published:

30 July 2023

Keywords:

GIS, Land Use Change, SWAT Model, WEAP Model, Calibration, Validation

ABSTRACT

Kaptagat Forest, the main source of the Ellegerini River, which feeds the Ellegerini Dam and Two Rivers Dam, is under threat of extinction due to human activity. The Two Rivers Dam catchment that has over the years been a source of water in Uasin Gishu County is slowly depleting and urgent measures are required to restore it. Activities including commercial logging, charcoal burning and firewood harvesting have exerted a lot of pressure on the catchment, posing a great threat to the livelihoods of the people of Eldoret town who depend on the reservoirs for water supply. The main objective of this study was to customise SWAT and WEAP models for the sustainable management of water resources in the Two Rivers Dam catchment. The specific objectives were to set up and apply the SWAT model to generate simulated river flows draining to the Two Rivers and Ellegerini Reservoirs as an input to the WEAP model to determine the impact of land use change on the hydrological function of the Two Rivers Dam catchment, to set up, calibrate and validate a WEAP model for the Two Rivers Dam catchment and to apply the WEAP model in analyses of various management and infrastructural development projects scenarios to enhance river flow and water storage in the Two Rivers and Ellegerini Reservoirs. The goodness of fit SWAT model statistical evaluation indices attained during the calibration period was R2 = 0.854, NSE = 0.822 and Bias = 0.392. Additionally, for the validation period, the R2 = 0.786, NSE = 0.815 and Bias = 0.381. The modelled results indicate that the land use change resulted in decreased baseflow and increased surface runoff hence the high fluctuations of water levels in the Two Rivers and Ellegerini reservoirs. The WEAP model results for actual and simulated water demand in the calibration period of 2019, the R2 = 0.88, while during the validation period in the year 2020, the R2 = 0.85. The results of the model simulation indicated that the management option that had the most impact on all the scenarios was the reduction of unaccounted-for water, while the one with the least impact was increased water use efficiency. It was concluded that

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

the models were able to simulate the observed conditions reasonably well and can therefore be used to effectively manage water resources and assist the relevant stakeholders in decision-making. The study recommended that forested areas need to be properly conserved in order to restore the hydrological function of the catchment.

APA CITATION

Kiamba, D. M, Kipkorir, E. C., Kosgei, J. R., Njoroge, S. M., & Nyandwaro, G. N. (2023). Application of SWAT and WEAP Models for Sustainable Management of Water Resources in the Two Rivers Dam Catchment, Uasin Gishu County, Kenya. *East African Journal of Environment and Natural Resources*, *6*(1), 262-276. https://doi.org/10.37284/eajenr.6.1.1336.

CHICAGO CITATION

Kiamba, Dennis Mailu, Emmanuel Chessum Kipkorir, Job Rotich Kosgei, Simon Mburu Njoroge and Gilbert Nyageikaro Nyandwaro. 2023. "Application of SWAT and WEAP Models for Sustainable Management of Water Resources in the Two Rivers Dam Catchment, Uasin Gishu County, Kenya". *East African Journal of Environment and Natural Resources* 6 (1), 262-276. https://doi.org/10.37284/eajenr.6.1.1336.

HARVARD CITATION

Kiamba, D. M, Kipkorir, E. C., Kosgei, J. R., Njoroge, S. M., & Nyandwaro, G. N. (2023) "Application of SWAT and WEAP Models for Sustainable Management of Water Resources in the Two Rivers Dam Catchment, Uasin Gishu County, Kenya", *East African Journal of Environment and Natural Resources*, 6 (1), pp. 262-276. doi: 10.37284/eajenr.6.1.1336.

IEEE CITATION

D. M., Kiamba, E. C., Kipkorir, J. R., Kosgei, S. M., Njoroge, & G. N., Nyandwaro. "Application of SWAT and WEAP Models for Sustainable Management of Water Resources in the Two Rivers Dam Catchment, Uasin Gishu County, Kenya", *EAJENR*, vol. 6, no. 1, pp. 262-276, Jul. 2023.

MLA CITATION

Kiamba, Dennis Mailu, Emmanuel Chessum Kipkorir, Job Rotich Kosgei, Simon Mburu Njoroge & Gilbert Nyageikaro Nyandwaro. "Application of SWAT and WEAP Models for Sustainable Management of Water Resources in the Two Rivers Dam Catchment, Uasin Gishu County, Kenya". *East African Journal of Environment and Natural Resources*, Vol. 6, no. 1, Jul 2023, pp. 262-276, doi:10.37284/eajenr.6.1.1336.

INTRODUCTION

In order to maximize the economic and social welfare that results, fairly and without sacrificing the sustainability of the environment, integrated water resources management (IWRM) is a strategy that can be used as it encourages the development of water, land, and related resources (Giordano & Shah, 2014). IWRM acknowledges that there are competing water uses, which are frequently linked and interdependent. The environment is always impacted by societal issues since they frequently have an impact on water supplies. The sustainable management of water resources is becoming increasingly important in light of rising water demand and climate change.

Kaptagat Forest, the source of the Ellegerini River, which feeds the Ellegerini and Two Rivers reservoirs, is under threat of extinction due to human activity. The ecosystem that has over the years, been a large water catchment and a source of water in Uasin Gishu County is slowly depleting and urgent measures are required to restore it. Activities including commercial logging, poor agricultural practices, charcoal burning and firewood harvesting have exerted a lot of pressure on the catchment, posing a great threat to the livelihoods of the people of Eldoret Town who depend on it as one of the water sources.

Water levels in the Two Rivers and Ellegerini Reservoirs that supply water to Eldoret town continue to recede due to the depletion of forest cover and rising demand for water. The situation has, on some occasions, become so dire that the Eldoret Water and Sanitation Company (ELDOWAS) announced on April 20 of 2019 that the water levels at the Two Rivers and Ellegerini reservoirs had reached critical levels. The company stated that the reservoirs would be closed down for a few days unless it rained. This necessitated the firm to begin drafting a water rationing plan for

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Eldoret Town. According to Cornelius Chepsoi, the Chairman of ELDOWAS, there is competition for water as the population of Eldoret Town continues to increase and there is a need to build more reservoirs to address the rising water requirement in the Town. The persisting water shortage in the Two Rivers Dam catchment has compelled ELDOWAS to propose the construction of more dams to alleviate the water crisis. This shows a need to do water management in the catchment.

The Kaptagat Forest is the catchment area for the Ellegerini River, which feeds the Ellegerini Reservoir and the Two Rivers Reservoir. The reservoirs have capacities of 3,450 m^3/day and 14,950 m^3/day, respectively (Sum, 2014). The Ellegerini Dam is located 12 km upstream of the Two Rivers Dam. The water is treated at the Sosiani Treatment Works, which has a capacity of 14,950 m^3/day, and Kapsoya Treatment Works with a capacity of 3,450 m^3/day. Kapsoya Treatment Works sources its water from the Ellegerini Reservoir, while Sosiani treatment works sources its water from the Two Rivers Reservoir. Eldoret gets additional water from the Chebara reservoir, which delivers 18,000 m^3/day to the town. The total water quantity distributed in Eldoret Town is 36,400 m^3/day. The water reticulation system in Eldoret is inadequate, with only 180,000 households connected to the system (Masakha, 2017). Residents of Eldoret town can also not rely on groundwater in Eldoret because it contains high levels of dissolved salts, thereby making use of groundwater not viable. Rivatex textile and Raiply wood processing companies, for instance, have boreholes with saline waters (Sum, 2014).

Numerous watershed processes, such as soil erosion and rainfall-runoff processes, are impacted by changes in land cover. Maliehe and Mulungu (2017) claim that although numerous elements interact to affect rainfall-runoff connections within a watershed, the interaction of soils, land cover, and climate is the main driving force. The same authors advocated for the use of peak discharges and runoff depth as markers and forecasters of the effects brought on by alterations in land use and cover. In addition, Li et al. (2015) contend that the management of water resources revolves around water allocation. Water utilities can make a balanced and sustainable decision by using Decision Support Systems (DSSs) like WEAP, which are representative of scientific knowledge, to build acceptable water allocation techniques. A catchment is the smallest complete hydrological unit of analysis (Höllermann et al., 2010). Therefore, integrated catchment management is a useful and appropriate operational strategy for immediate and more detailed monitoring of a catchment (Höllermann et al., 2010). Furthermore, according to Hamlat et al. (2013), the use of hydrological models in decision-making applications facilitates the choice of the best course of action because these models are frequently built to permit reasoning about the processes of interest within an idealized logical framework.

The persisting water shortage in Eldoret is a result of the destruction of the Kaptagat forest, which is a key source of water for the reservoirs supplying water to the town. Catchment degradation of the water tower due to deforestation and conversion of forest area to agricultural land, coupled with the rising population in Eldoret town, has put a strain on the water resources in the catchment. The SWAT and WEAP models were therefore customised in this study for the development of sustainable water resources management strategies for the Two Rivers Dam Catchment. The SWAT model was developed to generate simulated river flows draining to the Two Rivers and Ellegerini Reservoirs as an input to the WEAP model. The SWAT model was calibrated and validated between the periods 1980–1984 and 1985–1989, respectively. Additionally, the WEAP Model was calibrated and validated in 2019 and 2020, respectively. The main objective of the study was to customise SWAT and WEAP models for the sustainable water resources management of the Two Rivers Dam Catchment.

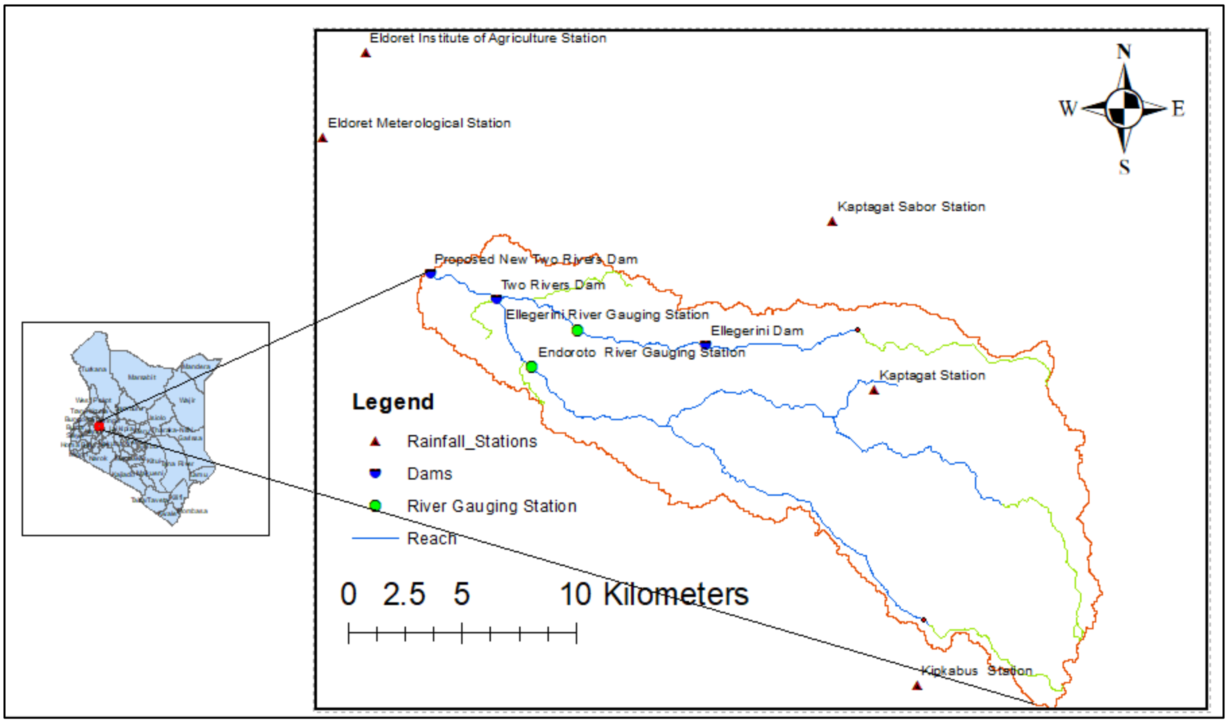
Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

MATERIALS AND METHODS

Study Area

Kaptagat Forest is one of the Kenya's five water towers in the greater Cherangany Forest Ecosystem. It is situated in the Chepkorio division of Elgeyo Marakwet County, Keiyo South Sub-County (Kenya Forest Service, 2014). The forest is located 350 kilometers northwest of Nairobi. It is situated in the South East peri-urban region of Eldoret town and is part of the North Rift Conservancy (Ontumbi et al., 2015). The map of the Two Rivers Dam Catchment is indicated in *Figure 1*. The watershed lies between latitude 00° 17′ N and 00° 30′ N and longitude 35° 20′ E and 35° 37′ E. Moreover, the catchment lies between an altitude of 2131 m and 2764 m above sea level.

Figure 1: Map of the two rivers' dam catchment



SWAT Model Description

The SWAT model was developed by the Agricultural Research Services of the United States Department of Agriculture. The model is physically based and semi-distributed (Pokhrel, 2018). A catchment's hydrology, water quality, climatic change, crop growth, sediment production, nutrient transfer, and the effects of land management methods are all simulated by this large-scale model (Marhaento et al., 2017). A watershed in the SWAT model is split up into sub-basins in SWAT, and the sub-basins are then split up into Hydrologic Response Units (HRUs). The HRUs are groups of areas with comparable soil types, slopes, and land uses (Krysanova & Srinivasan, 2014).

For each HRU, the model determines the water balance (Tasdighi et al., 2018). SWAT uses ArcSWAT, a GIS interface which makes the model user-friendly. The water balance equation (Eq. 1) is used in the model to simulate watershed hydrology in daily time steps:

The foundation for describing the hydrology in the model is the water balance equation (1):

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{deep} - Q_{gw}\right) \quad (1)$$

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Where; SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), $Qsurf$ is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{deep} is the amount of water percolating into the deep aquifer on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O). Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed (Pai & Saraswat, 2011).

WEAP Model Description

The Stockholm Environmental Institute's Boston Centre at the Tellus Institute created WEAP, a user-friendly software program that adopts an integrated strategy for planning water resources (Loucks, 2005).

WEAP simulates water supply, demand, flows, and storage as a forecasting tool. According to Amin et al. (2018), WEAP can be used in municipal and agricultural systems, one watershed, or a complex transboundary river basin system. It operates on the fundamental tenet of water balance. Additionally, WEAP is capable of simulating a wide variety of naturally occurring and artificially created elements of these systems, such as rainfall-runoff, base flow, and groundwater recharge from precipitation, demand analyses, water conservation, priorities for water rights and allocation, reservoir operations, pollution monitoring, and water quality (Agarwal et al., 2019).

In order to assess water demands, related priorities, and water availability for both the present and the future, WEAP employs a scenario method (answering "what if" questions) (Sieber, 2006).

The monthly time-step water balance accounting used by WEAP ensures that total inflows and total outflows are equal after accounting for any changes in storage (in reservoirs and aquifers). Subject to demand priority, supply preferences, mass balance, and other limitations, linear programming is utilized to maximize the fulfilment of demand site and user-specified instream flow needs (Purkey et al., 2008). Equation 2 illustrates the linear programming constraint for the mass balance.

$$\sum Inflow = \sum Outflow + Addition\ to\ Storage \quad (2)$$

SWAT Model Setup

The SWAT model requires many input data files (*Figure 2 -5*). In order to generate these files, the ArcSWAT interface was used to extract information from geographically referenced maps in the ArcGIS 10.3 environment. The process of setting up the SWAT model included defining a project folder, loading the DEM, rainfall, temperature, soil, and land use data through the ArcSWAT interface (Kimani, 2014). The interface is used to generate the stream network and delineate the catchment boundary from the DEM and further subdivide the catchment into sub-basins. The land cover and soil layers were used to generate HRUs. The climatic data were also integrated spatially to assign these data as the main drivers of the model to the various sub-basins (Shi et al., 2013).

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 2: Two rivers dam catchment sub-basins

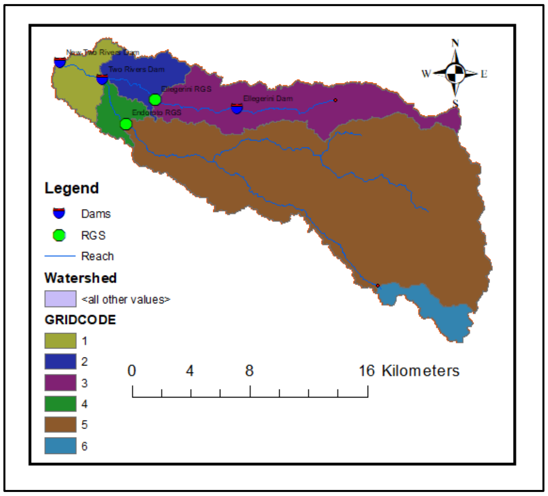


Figure 3: Two rivers dam catchment land use classes

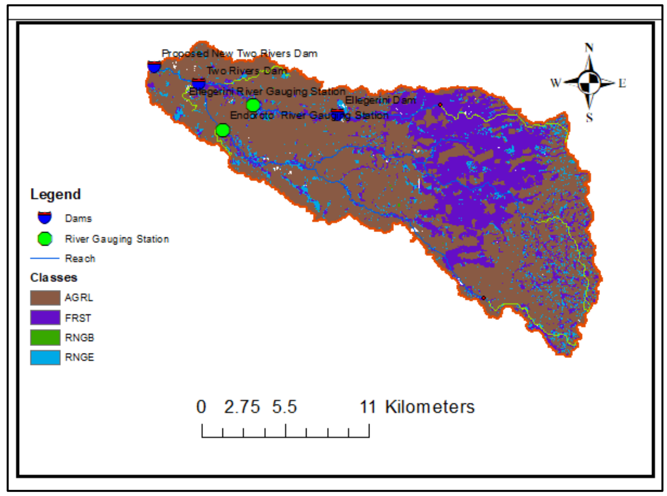


Figure 4: Soil class definition

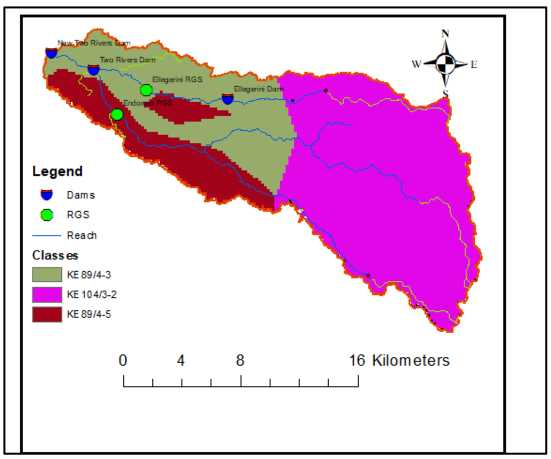
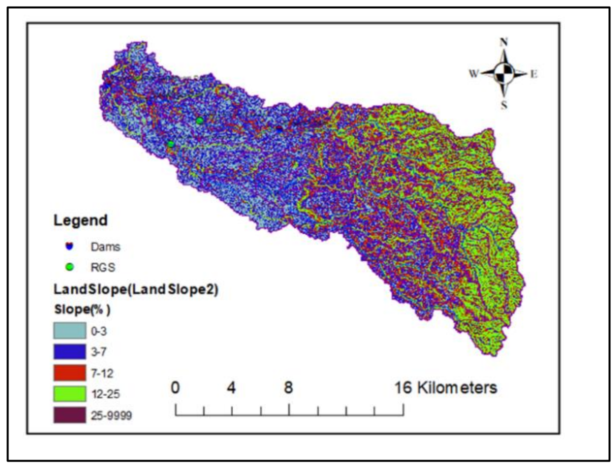


Figure 5: Slope class definition



The Two Rivers Dam Catchment Landsat land cover land use satellite images at ten-year intervals for the past 31 years were downloaded from the USGS website and were chosen in the period December – February, which was the months that presented the least cloud cover therefore enhancing the quality of the satellite images. The images indicated the land cover change in the catchment from 1989 to 2020.

The soil data for the catchment was obtained from the Kenya Soil and Terrain (KENSOTER) database at a scale of 1:1,000,000 that was compiled by the Kenya Soil Survey (KSS) with support from the International Soil Resource and Information Centre (ISRIC). The soil map was projected, clipped, and overlaid on the catchment. The main soils in the catchment were identified as KE 89/4-3 (FRh – Haplic Ferralsol), KE 89/4-5 (GLe – Eutric Gleysol) and KE 104/3-2 (NTu – Humic Nitisol).

The available rainfall data was sourced from Kenya Meteorological Department (KMD) and was analysed for use based on the periods with high percentages of complete data. This was done for a number of stations (*Table 1*) that fell within and around the Two Rivers Dam Catchment (*Figure 1*). Stations with little data were eliminated.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Table 1: Selected rainfall stations (KMD)

Station Name	Station Number	Latitude	Longitude	Year Opened	Year Closed
Eldoret Meteorological Station	8935181	0° 32.67'N	35° 17.18'E	1972	----
Kaptagat Forest Station	8935010	0° 26.34'N	35° 30.61'E	1928	----
Kaptagat, Sabor Forest Station	8935164	0° 30.16'N	35° 29.18'E	1965	----
Kipkabus Forest Station	8935117	0° 19.73'N	35° 31.14'E	1951	----
Eldoret Institute of Agriculture Station	8935133	0° 34.96'N	35° 18.73'E	1954	----

Key: --- = Still in Operation

Observed discharge data and stream gauge heights for the Endoroto and Ellegerini River Gauging Stations (RGS) were obtained from the Water Resources Authority (WRA). The discharge data from the Ellegerini (Station ID: 1CB09) and Endoroto (Station ID: 1CB08) River Gauging Stations (*Figure 1*) were used in the calibration of the SWAT Model. The gauging stations are located at coordinates (0.456944, 35.383333) and (0.445833, 35.366667), respectively.

SWAT Model Sensitivity Analysis

One-factor-at-a-time (OAT) analysis was used to conduct a sensitivity analysis on model parameters which is the procedure embedded in the SWAT model (Van Griensven et al., 2006). The list of sensitive parameters was then calibrated using the observed runoff data from the two river gauging stations (Ellegerini and Endototo RGS). The sensitivity ranking of the SWAT model parameters is indicated in *Table 2*.

Table 2: Sensitivity ranking of swat model parameters

Parameter	Rank	Description
Cn2	1	SCS runoff curve number
Sol_Awc	2	Available water capacity of the soil layer.
Esco	3	Soil evaporation compensation factor.
Alpha_Bf	4	Base flow alpha factor (days).
Gwqmn	5	Threshold depth of water in the shallow aquifer required for return flow to occur.
Gw_Delay	6	Groundwater delay (days).
Gw_Revap	7	Groundwater revap coefficient.
Rchrg_Dp	8	Groundwater recharge to deep aquifer (fraction)
Surlag	9	Runoff lag time
Revapmn	10	Threshold storage in shallow aquifer for 'revap' (mm)

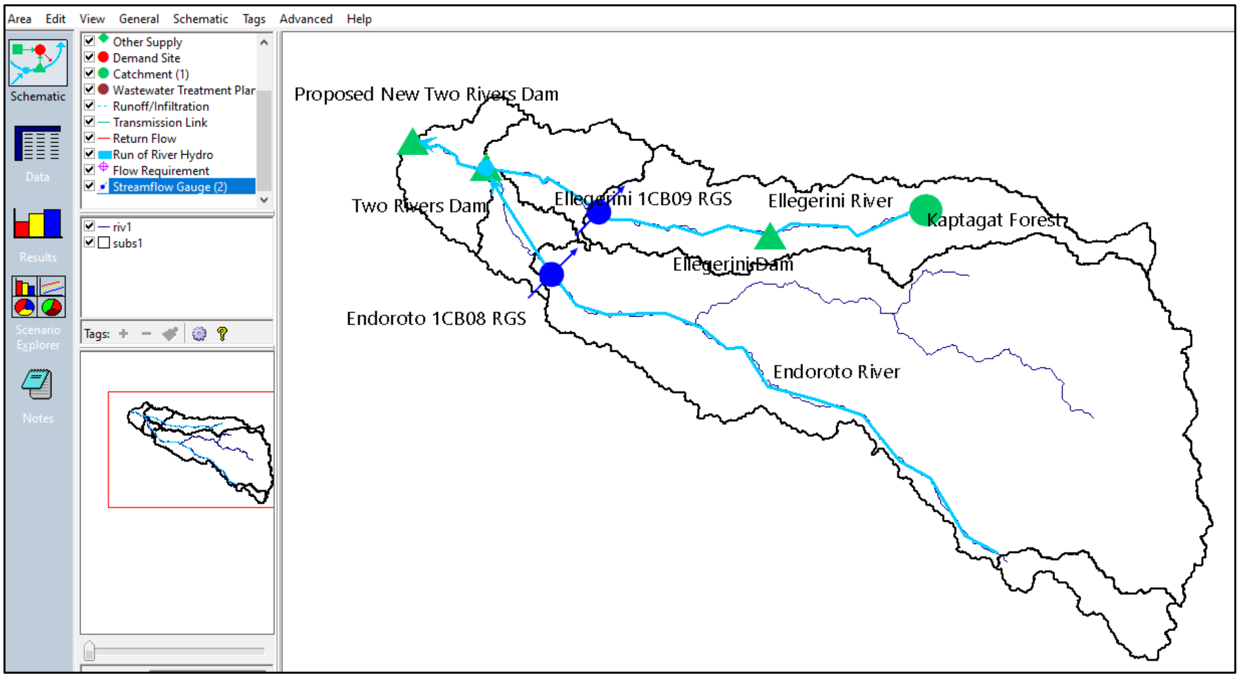
The goodness of fit statistics, which include the Coefficient of Determination (R^2), Percent Bias (PBIAS), Nash and Sutcliffe Model Efficiency (NSE), were used to evaluate the performance of the SWAT model. The model statistical evaluation indices attained during the calibration period are $R^2 = 0.854$, NSE = 0.822 and PBIAS = 39.18%. Additionally, for the validation period, the R^2 was 0.786, NSE = 0.815 and PBIAS = 38.14%.

WEAP Model Setup

For the WEAP model of the Two Rivers Dam Catchment, the water system was characterised by: water demand sites, reservoir (location, operation rules, water balance and dam capacity), flow gauging stations (streamflow including flows generated from the SWAT model) as indicated in *Figure 6*.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 6: Schematic presentation of the two rivers' dam catchment



The WEAP model that was created consisted of four demand sites, i.e., domestic demand, agricultural demand, industrial demand, and commercial demand (nodes). The main water use sectors that were simulated in the WEAP model were domestic water demand and institutions, e.g., schools, households and healthcare, agricultural water demand, and commercial demand. e.g., Business premises and hotels in Eldoret town and industrial demand, e.g., Rivatex, Raiply and Kenknit.

The water supply in the WEAP Model entailed the use of data on the quantity of water supplied from Kapsoya, Sosiani and Naiberi Treatment Works, i.e., water Supplied from Two Rivers and Ellegerini Reservoirs, which was collected from ELDOWAS. The proposed infrastructural development in Eldoret is the Proposed New Two Rivers Dam, with a capacity of 57,500 m^3/d, which is set to be completed by 2025. The New Two Rivers Dam will be located 700 meters downstream of the existing Two Rivers Dam. Initially, the treatment works capacity for The New Two Rivers Dam by 2025 will be 28,750 m^3/d. However, it will be extended to the full capacity of the Dam in 2035 (MIBP, 2018).

RESULTS AND DISCUSSION

SWAT Model Calibration and Validation Results

The ten sensitive parameters (Table 2) were identified, and each sensitive parameter was manually calibrated. The use of multiple gauging stations improved the effectiveness of model calibration and increased the model's representation of spatial variance (Cao et al., 2006). The years 1978-1979, 1980–1984 and 1985–1989 were treated as the warm-up, calibration, and validation periods, respectively. During calibration and validation, calculated annual, monthly, and daily runoff were evaluated against observed data from Ellegerini and Endoroto gauging stations using three indices: The model was calibrated using 1980 to 1984 data and validated using 1985 to 1989 data. The calibration and validation results are indicated in *Figures 7* & *8* and *Figures 9* & *10*, respectively.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 7: SWAT model calibration graphical results

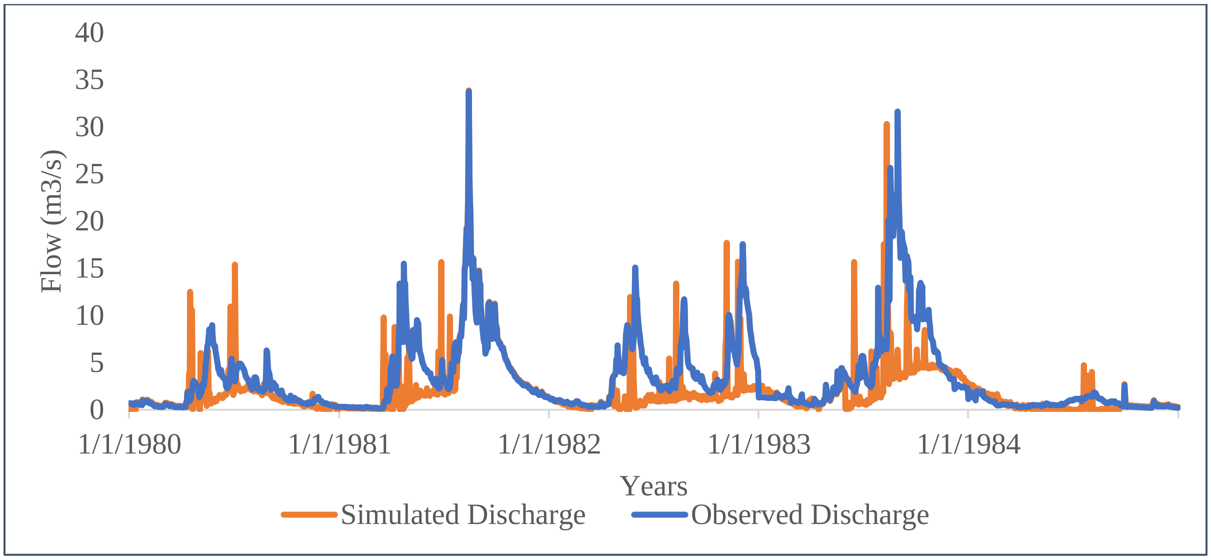


Figure 8: Scatter plot for calibrated SWAT model results

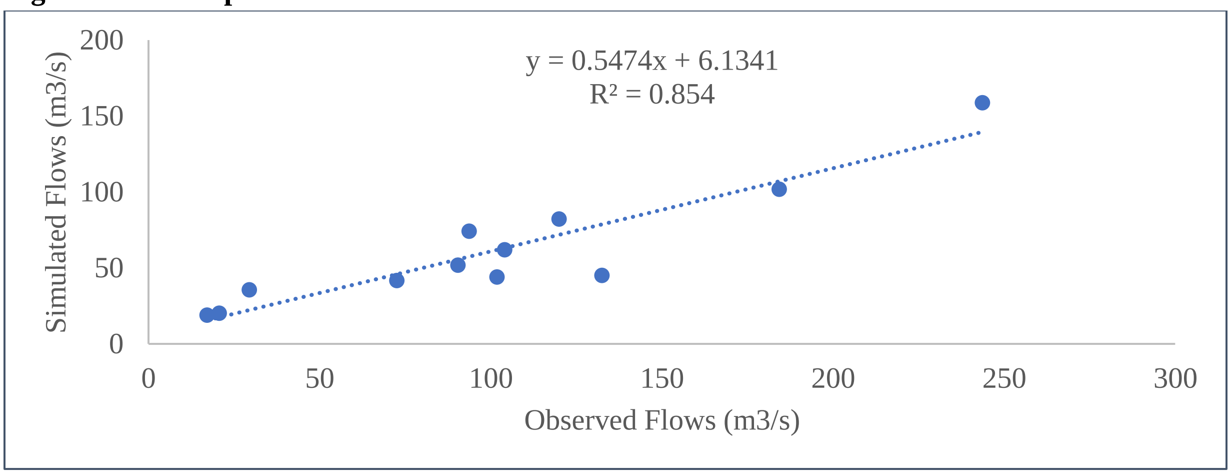
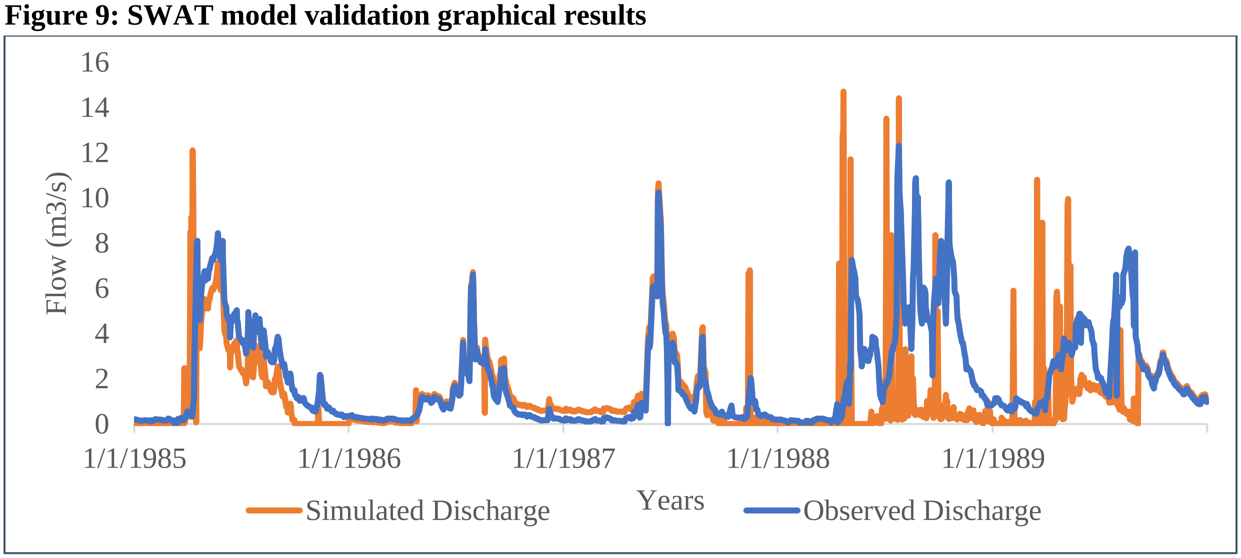
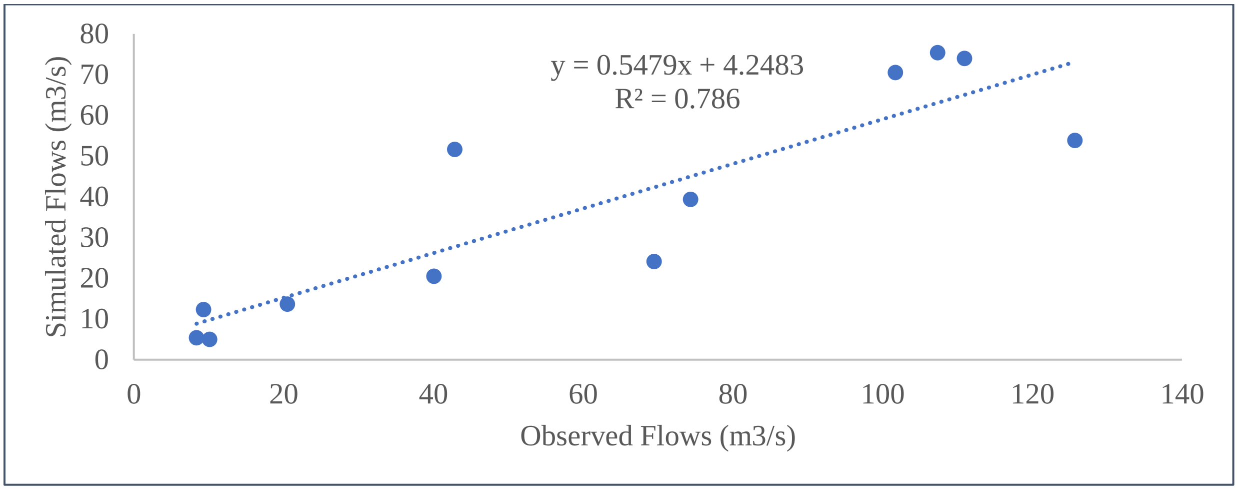


Figure 9: SWAT model validation graphical results



Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 10: Scatter plot for validated SWAT model results



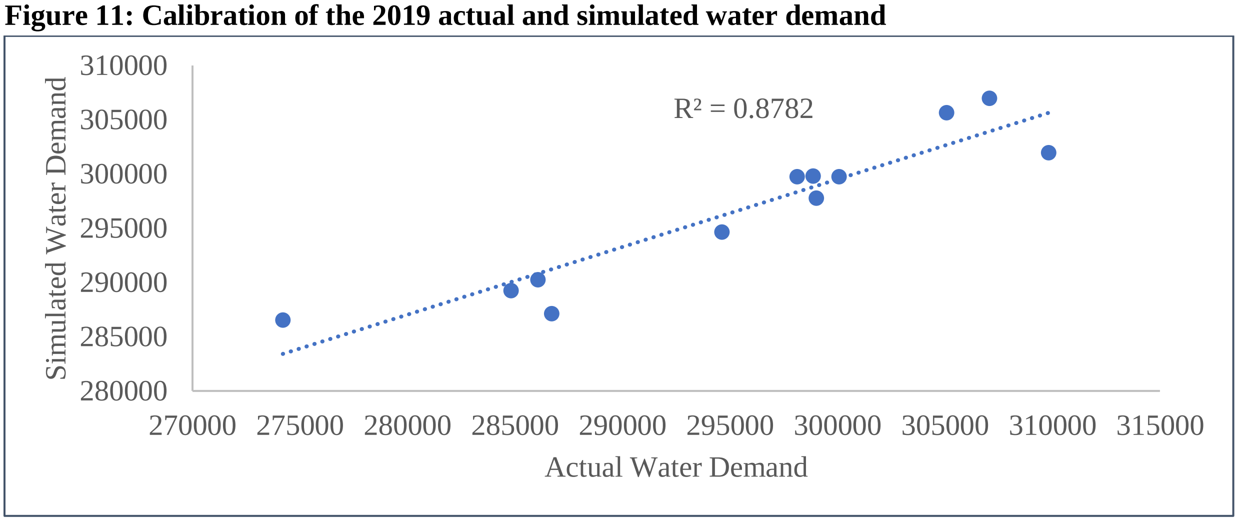
The model statistical evaluation indices attained during the calibration period are R^2 = 0.854, NSE= 0.822 and PBIAS= 39.18%. Additionally, for the validation period, the R^2 was 0.786, NSE = 0.815 and PBIAS= 38.14%.

WEAP Model Calibration and Validation Results

Results for water supply and water demand modelling using the WEAP model and its subsequent calibration and validation of observed data are also presented. Calibration of the WEAP model was done based on water demand and water supply. The calibration period of the model was taken to be the year 2019, and the validation period was the year 2020. Four possible scenarios were defined, and water balance simulations were run.

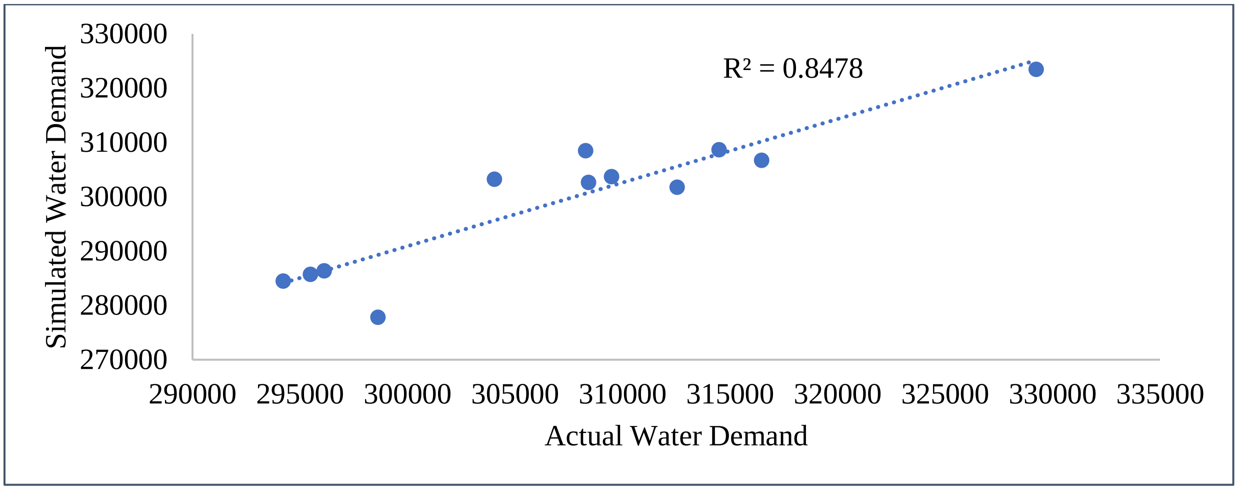
A comparison between the water demand in Eldoret town simulated with the WEAP model and the measured water demand goodness of fit is shown in *Figures 11* and *12*. The model performance is evaluated using standard statistics; mean error (ME), mean square error (MSE) and model coefficient of efficiency (EF).

Figure 11: Calibration of the 2019 actual and simulated water demand



Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 12: Validation of the 2020 actual and simulated water demand



A scatter plot diagram of observed and simulated results was drawn, and the regression line was indicated, as shown in *Figures 11* and *12*. During the calibration period in the year 2019, R^2 for the measured and simulated water demand was found to be 0.88, while during the validation period in 2020, the R^2 was found to be 0.85. The results indicate that the model simulates the observed conditions reasonably well.

WEAP Model Scenario Analysis Results

WEAP was applied to assess all the proposed scenarios and recommended management options. The scenarios analysed include; The Reference Scenario, The Infrastructural Development Scenario and the Population Growth Scenario. A summary of sample results is provided in *Figures 13 to 17*. WEAP provides the results in charts, which include all demand sites (including all users: residential, health care centres, schools, and institutions). The management options applied to the Kaptagat WEAP Model include; Increased Groundwater Use, Reduction of Unaccounted Water from 41% to 15%, Increased Rainwater Harvesting and Increased Water Use Efficiency.

The reference scenario WEAP results indicate that the projected total water demand will increase from 13.14 M m^3 in 2015 to 26.71 M m^3 by the end of 2050. Additionally, the projected unmet demand will increase from 3.68 M m^3 to 10.07 M m^3 over the same period. The management option that had the most impact was the reduction of unaccounted-for water losses, while the least impact was through increased rainwater harvesting. The infrastructural development scenario's results indicate that the water supply capacity of Eldoret will increase from 36,400 m^3/d in 2015 to 93,900 m^3/d in 2050. The management option that had the most impact was the reduction of unaccounted-for water, while the least impact was through increased rainwater harvesting. The population growth scenario from the normal average intercensal population growth rate of 3.92% to 6%. The projected population growth indicates that the population will rise from approximately 350,000 people in 2017 to about 1.1 million people in 2050. The WEAP results indicate that the management option that had the most impact on all the scenarios was the reduction of unaccounted-for water, while the one with the least impact was increased water use efficiency.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 13: The impact of the management options on the reference scenario

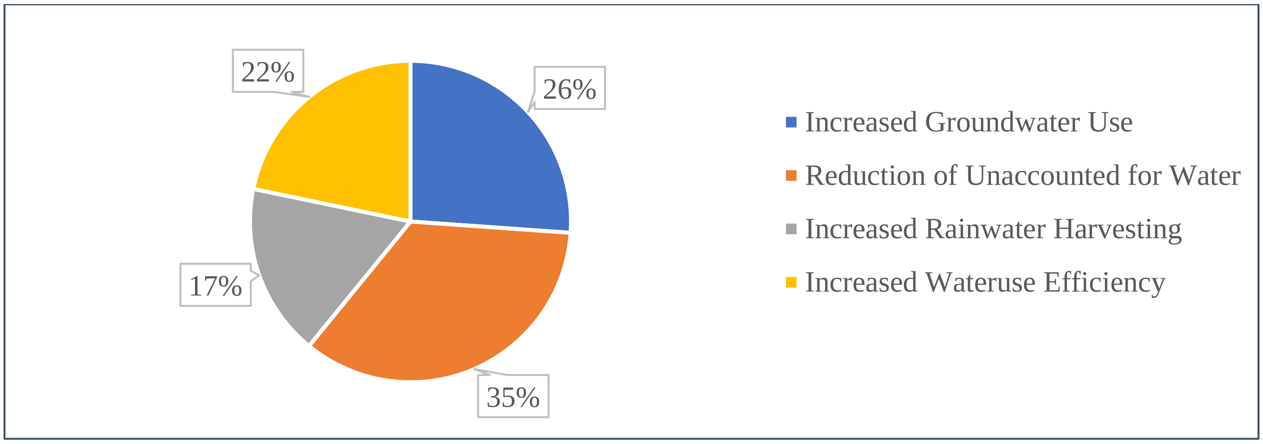


Figure 14: The impact of the management options on the infrastructural development scenario

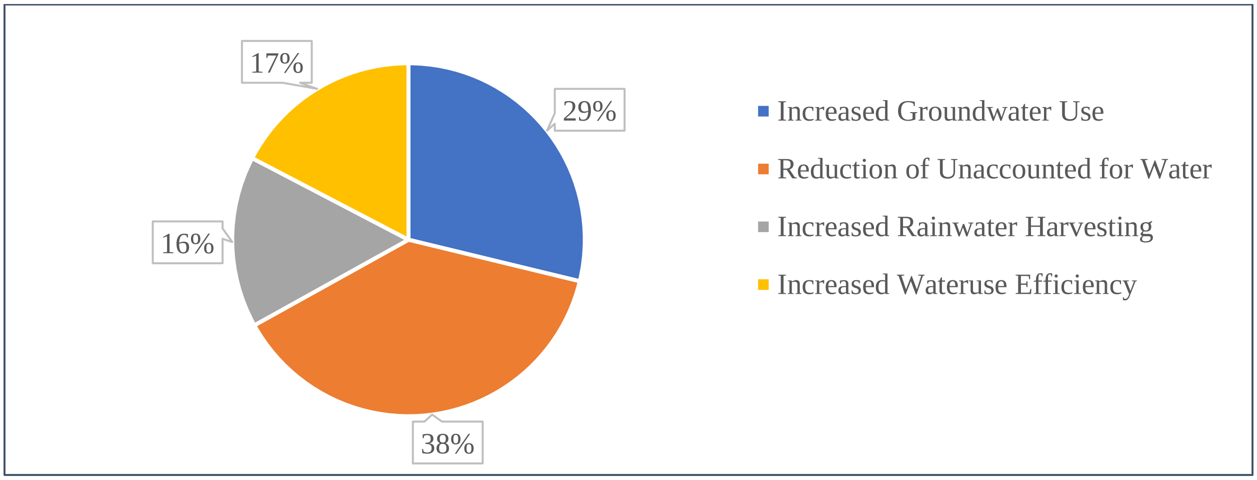
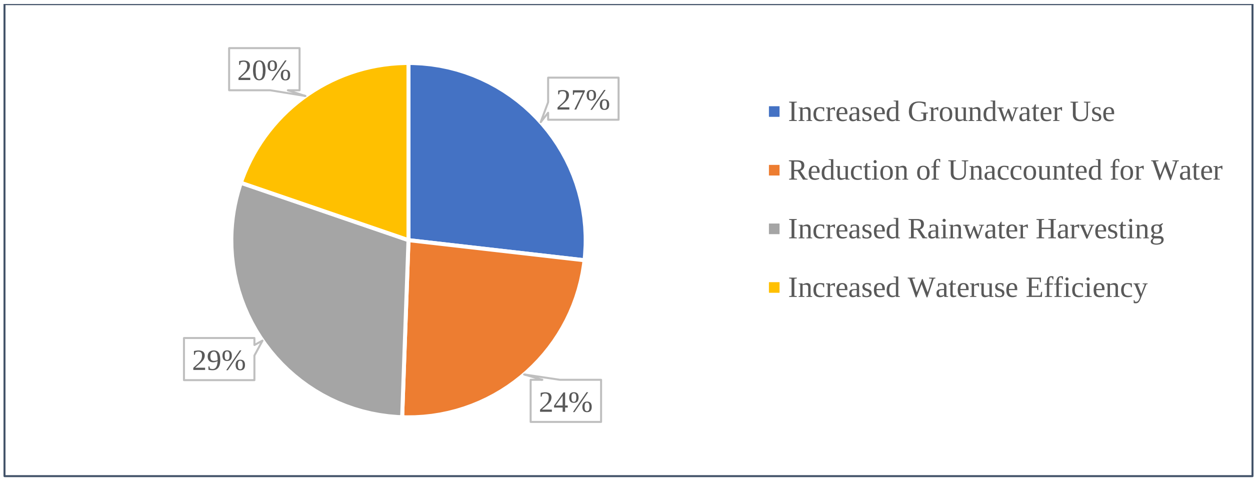


Figure 15: The impact of the management options on the population growth scenario



Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

Figure 16: Projected water demand when using the reference scenario

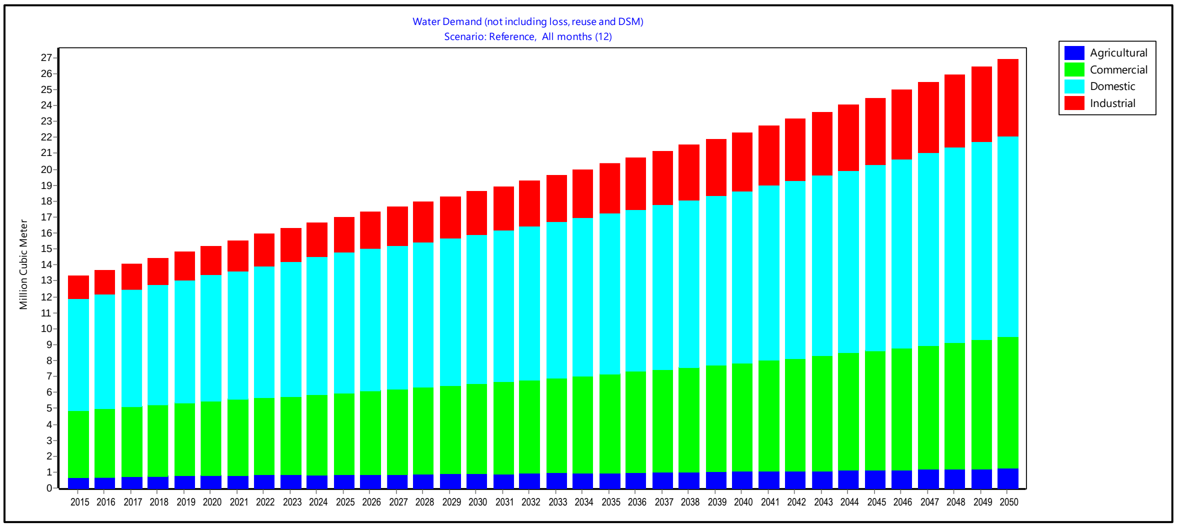
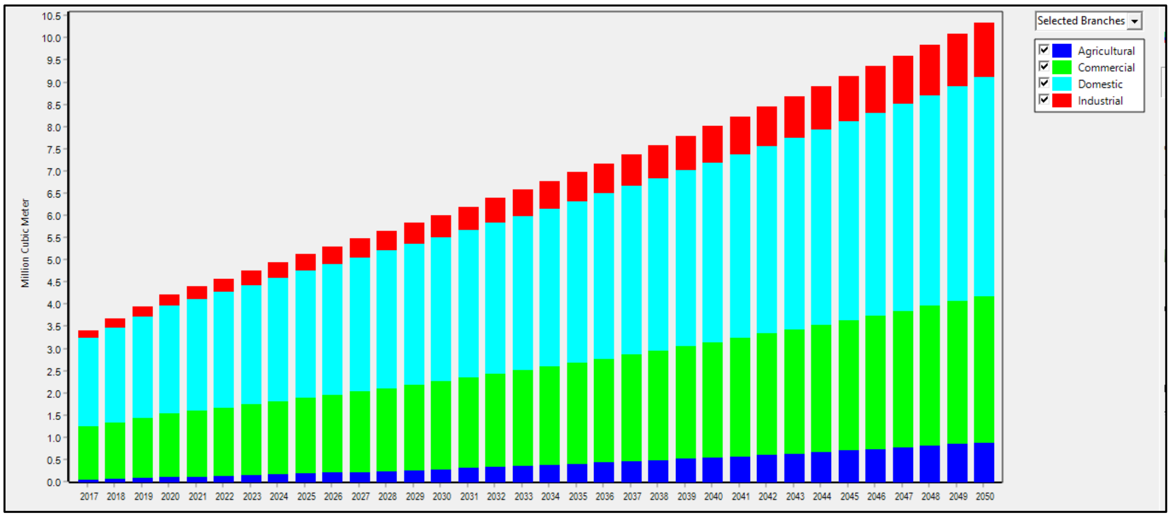


Figure 17: Projected unmet water demand when using the reference scenario



CONCLUSIONS

The poor availability of observed accurate streamflow data was a hindrance to the development of the WEAP model, and therefore the SWAT model was used to generate simulated river flows draining to the Two Rivers and Ellegerini Reservoirs as an input to the WEAP model. However, the availability of adequate and accurate land use, climate, and flow data enabled the proper development of the SWAT model for the study area and comprehension of the hydrology of the Two Rivers Dam Catchment. The SWAT model results indicate that the land use change resulted in increased surface runoff in the catchment with a change in land use. Additionally, the WEAP model results indicate that the model was able to effectively simulate the water supply and demand of the Two Rivers Dam Catchment. The calibration and validation results indicated that the modelled results were good; thus, the model was well adapted to the study. Therefore, the WEAP model can be used efficiently to manage water resources as regards water balance and can assist in decision-making. Furthermore, the model showed that the infrastructure development in the catchment improves the demand coverage in the catchment, and the unmet water demand will continue to increase over the coming years.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

This is mainly due to the increase in population with limited water resources if the available water remains the same and no new water resources are developed. Moreover, the WEAP model was able to show that the catchment cannot be able to perform well with additional demands. It predicted that the proposed New Two Rivers Reservoir would not be sufficient to fully satisfy the rising water demand in the catchment. The study recommends that the forested areas need to be properly conserved and, in certain areas, reforested to restore the hydrological function. Also, additional work should follow in this regard by other researchers in order to address all the outstanding issues, including carrying out an economic analysis of the developed scenarios.

ACKNOWLEDGMENTS

The research study reported herein, was conducted as part of the Building Capacity in Water Engineering for Addressing Sustainable Development Goals in East Africa (*CAWESDEA*), which is a component of the initiative on Strengthening Engineering Ecosystems in Sub-Saharan Africa, which is financed by IDRC. The Global Water Partnership Tanzania in partnership with Moi University (Kenya), the University of Dar es Salaam (Tanzania) and Makerere University (Uganda) led the CAWESDEA project. We would like to express our sincere gratitude to Moi University for graciously hosting the research study reported in this article.

Funding

Data collection for this study was financially supported by the CAWESDEA internship program.

REFERENCES

Agarwal, S., Patil, J. P., Goyal, V. C., & Singh, A. (2019). Assessment of water supply–demand using water evaluation and planning (WEAP) model for Ur River watershed, Madhya Pradesh, India. *Journal of The Institution of Engineers (India): Series A*, *100*(1), 21–32.

Amin, A., Iqbal, J., Asghar, A., & Ribbe, L. (2018). Analysis of current and future water demands in the Upper Indus Basin under IPCC climate and socio-economic scenarios using a hydro-economic WEAP model. *Water*, *10*(5), 537.

Cao, W., Bowden, W. B., Davie, T., & Fenemor, A. (2006). Multi‐variable and multi‐site calibration and validation of SWAT in a large mountainous catchment with high spatial variability. *Hydrological Processes: An International Journal*, 20(5), 1057-1073.

Giordano, M., & Shah, T. (2014). From IWRM back to integrated water resources management. *International Journal of Water Resources Development*, *30*(3), 364–376.

Hamlat, A., Errih, M., & Guidoum, A. (2013). Simulation of water resources management scenarios in western Algeria watersheds using the WEAP model. *Arabian Journal of Geosciences*, *6*(7), 2225–2236.

Höllermann, B., Giertz, S., & Diekkrüger, B. (2010). Benin 2025 Balancing Future Water Availability and Demand Using the WEAP ' Water Evaluation and Planning ' System. 3591–3613.https://doi.org/10.1007/s11269- 010- 962 2-z

Kenya Forest Service. (2014). Kaptagat forest. Retrieved February 7, 2020, from http://www.kenyaforestservice.org/?option=com_content&view=article&id=700%3Akaptagat-forest&catid=185

Kimani, P. (2014). Hydrological modelling of the Sergoit Basin for the estimation of catchment yield: A comparative study of the "Lumped Conceptual MIKE 11 NAM" and the "Semi Distributed Physically Based SWAT" models. [Master's thesis, Moi University]. http://ir.mu.ac.ke:8080/xmlui/handle/123456789/883

Krysanova, V., & Srinivasan, R. (2014). Assessment of climate and land use change

Article DOI: https://doi.org/10.37284/eajenr.6.1.1336

impacts with SWAT. *Regional Environmental Change*, *15*(3), 431– 434. https://doi.org/10.1007/s10113-014-0742-5

Li, X., Zhao, Y., Shi, C., Sha, J., Wang, Z. L., & Wang, Y. (2015). Application of Water Evaluation and Planning (WEAP) model for water resources management strategy estimation in coastal Binhai New Area, China. *Ocean and Coastal Management*, *106*, 97–109. https://doi.org/10.1016/j.ocecoaman.2015.01.016

Loucks, D. P. (2005). Examples Decision Support Systems for River Basin Simulation. *ECommons Cornell's Digital Repository*, 1– 5. https://ecommons.cornell.edu/handle/1813/2830

Maliehe, M., & Mulungu, D. M. M. (2017). Assessment of water availability for competing uses using SWAT and WEAP in South Phuthiatsana catchment, Lesotho. *Physics and Chemistry of the Earth*, *100*(May 2012), 305–316. https://doi.org/10.1016/j.pce.2017.02.014

Marhaento, H., Booij, M. J., Rientjes, T. H. M., & Hoekstra, A. Y. (2017). Attribution of changes in the water balance of a tropical catchment to land use change using the SWAT model. *Hydrological Processes*, *31*(11), 2029–2040. https://doi.org/10.1002/hyp.11167

Masakha, E. J. (2017). Seasonal and Longitudinal Variations of Water Quality in an Urban Stream : Case Study of Sosiani River Uasin Gishu County. 33

MIBP (2018). Water Supply Masterplan for Eldoret and Surrounding Satellite Towns. Mangat IB Patel Consulting Engineers.

N. Pai, & D. Saraswat. (2011). SWAT2009_LUC: A Tool to Activate the Land Use Change Module in SWAT 2009. *Transactions of the ASABE*, *54*(5), 1649–1658. https://doi.org/10.13031/2013.39854

Ontumbi, G., Obando, J., & Ondieki, C. (2015). The Influence of Agricultural Activities on the Water Quality of the River Sosiani in Uasin Gishu County, Kenya. 2(1), 34–40.

Pokhrel, B. K. (2018). Impact of land use change on flow and sediment yields in the Khokana outlet of the Bagmati River, Kathmandu, Nepal. *Hydrology*, *5*(2). https://doi.org/10.3390/hydrology5020022

Purkey, D. R., Joyce, B., Vicuna, S., Hanemann, M. W., Dale, L. L., Yates, D., & Dracup, J. A. (2008). Robust analysis of future climate change impacts on water for agriculture and other sectors: a case study in the Sacramento Valley. *Climatic Change*, *87*(1), 109–122.

Shi, P., Hou, Y., Xie, Y., Chen, C., Chen, X., Li, Q., Qu, S., Fang, X., & Srinivasan, R. (2013). Application of a swat model for hydrological modeling in the Xixian watershed, China. *Journal of Hydrologic Engineering*, *18*(11), 1522– 1529. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000578

Sieber, J. (2006). WEAP water evaluation and planning system.

Sum, L. K. (2014). Modelling of water demand and supply of Chebara reservoir using WEAP model. [Master's thesis, Moi University]. Retrieved from http://ir.mu.ac.ke:8080/xmlui/handle/123456789/1651

Tasdighi, A., Arabi, M., & Harmel, D. (2018). A probabilistic appraisal of rainfall-runoff modelling approaches within SWAT in mixed land use watersheds. *Journal of Hydrology*, *564*, 476– 489. https://doi.org/10.1016/j.jhydrol.2018.07.035

Van Griensven, A., & Meixner, T. (2006). Methods to quantify and identify the sources of uncertainty for river basin water quality models. *Water Science and Technology*, 53(1), 51-59.

