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Citation: Tibebe, M., Zemadim, B., Haile, D. and Melesse, A. Runoff estimation and water management for the Holetta river in Ethiopia. In: Wolde Mekuria. (ed). 2013. *Rainwater management for resilient livelihoods in Ethiopia: Proceedings of the Nile Basin Development Challenge science meeting, Addis Ababa, 9–10 July 2013*. NBDC Technical Report 5. Nairobi, Kenya: International Livestock Research Institute.

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Runoff estimation and water management for the Holetta river in Ethiopia

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Abstract: The hydrology of Holetta River and its seasonal variability is not fully studied. In addition to this, due to scarcity of the available surface water and increase in water demand for irrigation, the major users of the river are facing a challenge to allocate the available water. Therefore, the aim of this research was to investigate the water availability of Holetta River and to study the water management in the catchment. Soil and Water Assessment Tool (SWAT) modelled the rainfall runoff process of the catchment. Statistical (coefficient of determination [R2], Nash-Sutcliffe Efficiency Coefficient [NSE] and Index of Volumetric Fit [IVF]) and graphical methods used to evaluate the performance of SWAT model. The result showed that R^2, NSE and IVF were 0.85, 0.84 and 102.8, respectively for monthly calibration and 0.73, 0.67 and 108.9, respectively, for monthly validation. These indicated that SWAT model performed well for simulation of the hydrology of the watershed. After modelling the rainfall runoff relation and studying the availability of water at the Holetta River, the water demand of the area assessed. CropWat model and the survey analysis performed to calculate the water demand in the area. The total water demand of all three major users was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM from January to May, respectively. The available river flow from January to May obtained from the result of SWAT simulation. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM from January to May respectively. From the five months, the demand and the supply showed a gap during February, March and April with 0.59 MCM. Therefore, in order to solve this problem alternative source of water supply should be studied and integrated water management system should be implemented.

Media grab: Identification of available water and demand is essential to implement water management system. SWAT model can estimate the available river water; and CropWat model and survey can be used to calculated water demand.

Introduction

Ethiopia is endowed with a huge surface and ground water resources. Many perennial and annual rivers exist in the country. Ethiopia has 12 river basins and Awash basin is one of the 12 basins in Ethiopia. Holetta River is one of the rivers found in the upper part of Awash basin and facing challenges of runoff variability and scarcity of water availability during the dry season. Holetta River is main source of surface water in the study area; it is a perennial river having three major users and these are Holetta Agricultural Research Center (HARC), Tsedey Farm and Village Farmers. In addition to increasing water demand in the area, there is no facility to store the water in the rainy season for future use in the dry season. Therefore, the competition for water is increasing due to scarcity of water and increasing pressure by expanding populations and increasing irrigation. In order to alleviate this challenge, integrated water resources management and effective water allocation system is essential. Therefore, the objective of this research was to study the hydrology of the Holetta River and to assess the water management in the catchment using GIS tool, statistical methods and hydrological model.

Methods

The study was conducted at Holetta catchment, which is located in the upper part of Awash River basin, Ethiopia. The study area lies at an altitude of 2069–3378 meters above sea level and located at a latitude range of 8°56'N to 9°13'N and longitude range of 38°24'E to 8°36' E. It is a catchment with drainage area of 403.47 km^2. The annual rainfall of the study area ranges between 818–1226 mm. The climate of the study area is described with the air temperature ranging from 6°C to 23°C with the mean of 14°C.

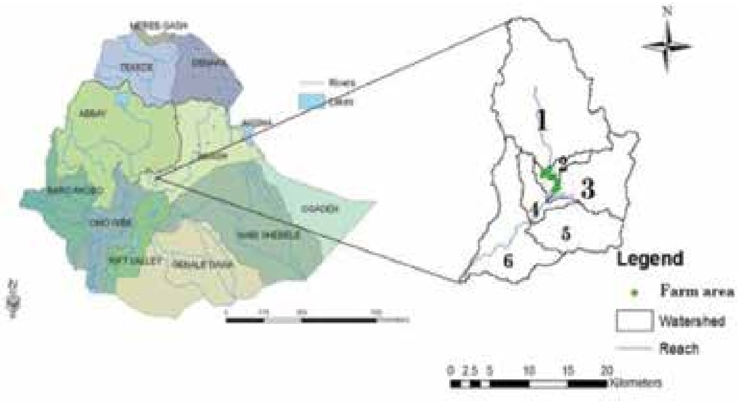

Figure 1. Location of Holetta catchment

All meteorological data (rainfall, temperature, relative humidity, wind speed and sunshine hour) collected from National Meteorology Agency and Holetta Research Center. Flow data and GIS data (topographic, land use/cover data and map, soil map) collected from Ministry of Water and Energy. Primary data of crop type and area coverage collected from major water users of Holetta River (Holetta Agricultural Research Center, Tsedey Farm and Farmers). The method of data collection was documents, field survey and questionnaire.

Based on the collected data (1994–2004), SWAT model, CropWat model and survey analysis are performed. The SWAT model used to estimate runoff for unguaged catchments, CropWat model used to estimate the irrigation water demand in the area and the survey analysis used to investigate the major crops grown in the area, area coverage and number of consumers.

Sensitivity analysis, model calibration and validation for SWAT model performed. The most sensitive parameters identified from sensitivity analysis and used for calibration of the model. For this study, the calibration carried out for six years (1994–1999) with one-year warm up period. Then, validation of SWAT model performed for the next five years (2000–2004). Statistical and graphical methods of comparing simulated with observed data used to evaluate the performance of SWAT model. The three statistical evaluation methods used were Coefficient of Determination (R^2), the Nash-Sutcliffe Efficiency Coefficient (NSE) and Index of Volumetric Fit (IVF).

Results and discussions

Hydrological analysis

Watershed delineation and determination of HRUs were the first step in SWAT model. Holetta River catchment delineated by SWAT model has six subbasins. Then, the subbasins divided into 33 HRUs. Out of the six subbabsins of Holetta catchment, only subbasin one is gauged. The calibration and validation of SWAT model was performed at subbasin one. Then, runoff for the ungauged subbasins of the catchment is estimated by regionalization approach.

About 270 iterations done by SWAT sensitivity analysis and 26 parameters reported as sensitive in different degree of sensitivity for flow. Among these 26 parameters, eight of them have more effect on the simulated result. After sensitivity analysis carried out, the calibration of SWAT model was done manually. The analysis of simulated result and observed flow data comparison considered daily and monthly. The calibration performed until the best-fit curve between simulated and observed flow obtained. The validation performed by simply executing the model for the different period using the previously calibrated input parameters. Statistical and graphical methods used to evaluate the performance of SWAT model. Figures 2 and 3 showed the graphical performance evaluation of SWAT model.

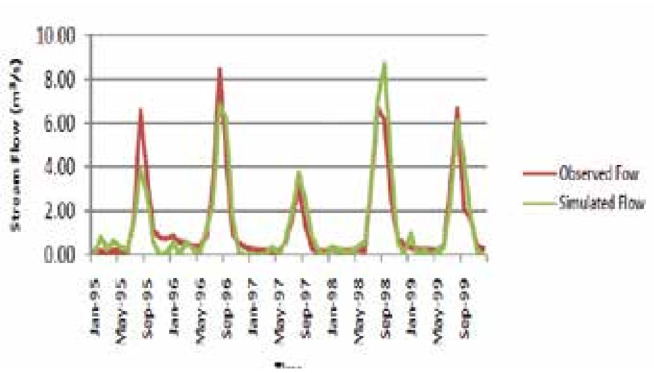

Figure 2. Observed and simulate hydrograph after monthly calibration

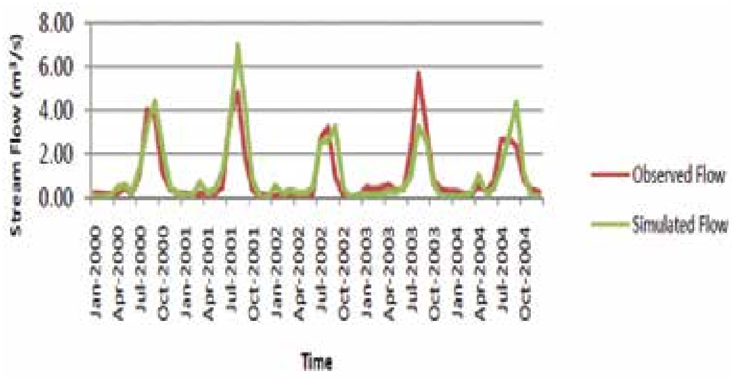

Figure 3. Observed and simulated hydrograph after monthly validation

Based on monthly calibration, the result showed that the regression coefficient (R^2) was 0.85; Nash-Sutcliffe Efficiency Coefficient was 0.84 and Index of Volumetric Fit was 102.8%. Based on the result of monthly validation, the regression coefficient was 0.73; Nash-Sutcliffe Efficiency Coefficient was 0.67 and Index of Volumetric fit was 108.9%. These indicated that the model performance was very good and highly acceptable during calibration and good in the acceptable limit during validation.

Questionnaire analysis

Survey was used to identify the number of Holetta River consumers, major crops grown by irrigation, the total area coverage and conflict between users. Major crops identified from the survey was potato with 96.67%, cabbage with 91.67% and tomato with 56.67% for farmers; potato, cabbage, barely and apple for HARC; and Potato, tomato and cabbage for Tsedey farm. Based on the analysis, 371 households use the river for irrigation purpose, 300 households use for human consumption.

CropWat model analyses

The major crops identified from the survey analysis used in the calculation of crop water requirement. In order to estimate the irrigation water demand for each crop, evapotranspiration, effective rainfall, crop type data, area coverage and soil data fitted in CropWat model. Then, CropWat model calculated the irrigation water requirement (mm/month) for each crop. Based on the result, the total irrigation water demand of all three users was 0.305, 0.575, 0.995, 0.865 and 0.332 MCM for January, February, March, April and May, respectively.

Water demand analysis

The result of CropWat model and survey analysis was used as an input for the calculation of water demand. The period taken was only for the dry seasons, from January to May. Based on the analysis, the total irrigation water demand of all three users was 0.305, 0.575, 0.995, 0.865 and 0.332 MCM for January, February, March, April and May, respectively. The farmers also use the river for human consumption and livestock. Therefore, the water demand for human consumption and livestock is calculated for the farmers. The total human consumptive requirement was 0.00279, 0.0025, 0.00279, 0.0027 and 0.0279 MCM for January, February, March, April and May, respectively. According to the result, total livestock consumptive requirement was 0.0059, 0.0053, 0.0059, 0.0057 and 0.0059 MCM for January, February, March, April and May, respectively. The overall water demand of all three major users was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM for January, February, March, April and May, respectively. The available river flow from January to May obtained from the result of SWAT simulation at subbasins 2, 3, 4 and 5. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM for January, February, March, April and May, respectively. From the five months, the demand and the supply showed a gap during February, March and April. This indicated that there is shortage of supply during these months with 0.59 MCM.

Conclusions

The study was conducted to estimate runoff at Holetta catchment and to model rainfall runoff in the area. The study also analysed the water demand in the area and the gap between the water supply and demand. The catchment has 6 subbasins and 33 hydrological response units (HRUs). Only subbasin one is gauged; therefore, sensitivity analysis, calibration and validation of the model performed at subbasin one and then the calibrated model was used to estimate runoff for the ungauged part of the catchment. Statistical and graphical methods were used to evaluate the performance of the model. The statistical methods used were R^2, NSE and IVF. The result showed, R^2, NSE and IVF were 0.85, 0.84 and 102.8, respectively for monthly calibration and 0.73, 0.67 and 108.9, respectively, for monthly validation. Therefore, this indicated that SWAT model performed well for simulation of the hydrology of the catchment.

CropWat model was used to calculate the irrigation water requirement for major crops and the area coverage determined from questionnaire. The overall water demand in the area was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM for January, February, March, April and May, respectively. The available flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM for January, February, March, April and May, respectively. Comparing the available flow and water demand in each month, it showed a gap during February, March and April. Therefore, there is shortage of supply during these months with 0.59 MCM.

Recommendations

Even though the SWAT model performs well in the study area, the accuracy was highly dependent on quality of data. The Holetta catchment has only one gauging station. In order to improve data quality, it is better to have at least two gauging stations in the catchment. In addition to this, in poorly gauged areas, use of satellite data is very advantageous. For future studies, SWAT model can apply to estimate sediment yield in the area and to evaluate the effect of different catchment changes on the river.

The water demand analysis showed that there was shortage of river water supply during February, March and April. The analysis also showed that there is conflict between users. In order to solve water shortage, alternative source of water supply should be studied and integrated water management system should be implemented. In order to minimize the conflict, well-established irrigation committees including all the users with a clear guide and management rules is required and establishing water allocation system is essential.

Acknowledgements

At first, I would like to express my deepest thanks for Holetta Research Center, Ministry of Water and Energy and United States Agency for International Development (USAID) /HED for all their support. Next, my heartfelt thanks goes to all my family and friends for their encouragement and wonderful support.

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