CHAPTER 7

Runoff Estimation and Water Demand Analysis for Holetta River, Awash subbasin, Ethiopia using SWAT and CropWat models

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Abstract

This chapter discusses the hydrology of Holetta River, Ethiopia, its seasonal variability and water management in the watershed. Soil and Water Assessment Tool (SWAT) modeled the rainfall runoff process of the watershed. Statistical (coefficient of determination [R^2], Nash- Sutcliffe Efficiency Coefficient [NSE] and Index of Volumetric Fit [IVF]) and graphical methods were used to evaluate the performance of the 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 modeling the rainfall runoff relation, the water demand of the area was assessed. CropWat model was applied and survey analyses were performed to calculate the water demand in the area. The total water demand for the three major users was 0.313, 0.583, 1.004, 0.873, and 0.341 million cubic meters (MCM) from January to May, respectively. The average flow obtained from SWAT simulation, 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. To solve the gap created by the demand alternative source of water supply should be studied and integrated water management systems should be implemented.

Key words: Holetta River; SWAT, water demand; CropWat, runoff

7.1 Introduction

Ethiopia is endowed with a huge surface and ground water resources. Many perennial and annual rivers exist in the country. A number of lakes, dams, and reservoirs exist in various parts of the country. Holetta River is one of the rivers found in the upper part of Awash River basin and facing challenges of runoff variability and scarcity of water availability during the dry season. The Holetta River is the main source of surface water in the study area and it is a perennial river having three major users; Holetta Agricultural Research Center (HARC), Tesdey 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 is essential. Therefore, this chapter discusses the water availability of Holetta River and the water management in the watershed using GIS, statistical methods and hydrological model.

7.2 Theoretical background

7.2.1 Global Water Management and Allocation Issues

Integrated Water Resources Management (IWRM) is a way of analyzing the change in demand and operation of water institutions that evaluates a variety of supply side and demand side management measures to determine the optimal way of providing water services. Demand side management includes any measure or initiative that will result in the reduction in the expected water usage or water demand. Supply side management includes any measure or initiative that will increase the capacity of a water resource or water supply system to supply water (Buyelwa 2004).

7.2.2 Hydrological Models

A hydrological model is a simplified representation of a real-world system, and consists of a set of simultaneous equations or a logical set of operations contained within a computer program. Models have parameters, which are numerical measures of a property or characteristics that are constant under specified conditions. Computer modeling offers a methodology to investigate hydrological processes and make predictions on what the flow might be in a river given a certain amount of rainfall. There are different types of models, with different amounts of complexity, but all are a simplification of reality and aim to either make a prediction or improve our understanding of biophysical processes (Davie 2008). Figure 7.1 shows different types of models (Chow et al. 1988).

Insert Figure 7.1 about here

For this study, SWAT model was selected because it has the following capabilities:

- It is physically based and distributed model
- Was capable of operating on a watershed scale with several subbasins
- Allowed topographical, land use and soil differences
- Was capable of simulating several management practices
- Could simulate long periods of time

7.2.3 Description of SWAT Model

Soil and Water Assessment Tool (SWAT) is a river basin, or watershed, scale model developed by Jeff Arnold for the US department of Agriculture (USDA) - Agricultural Research Service (ARS) (Neitsch et al. 2005). The model predicts the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods. The model is physically based and distributed requiring specific information about soil, topography, weather, and land management practices within the watershed. The physical processes associated with water movement, sediment movement, crop growth and nutrient cycling are directly modeled by SWAT using readily available input data (Arnold et al. 1998). For modeling purposes, the watershed can be divided into a number of sub watersheds or subbasins. Input information for each subbasin is organized into the following categories: climate, hydrological response units (HRUs); ponds/wetlands; groundwater; and the main channel or reach.

Hydrological response units are portion of a subbasin that possesses unique land use, management and soil attributes. A subbasin will contain at least one HRU, a tributary channel and a main channel or reach. Hydrological response units are used in most SWAT runs because they simplify a run lumping all similar soil and land use areas into a single response unit and it will increase the accuracy (Neitsch et al. 2004).

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle which controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each subbasin. The second division is the water or routing phase of the hydrologic cycle, which refers to the movement of water, sediments, etc. through the channel network of the watershed to the outlet (Neitsch et al. 2005).

7.2.4 Description of CROPWAT Model

CropWat is a decision support system developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for planning and management of irrigation (Derek et al. 1998). CropWat is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes. For this study, CropWat 8.0 was used. CropWat 8.0 is a computer programme for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. In CropWat 8.0, the calculation of crop water requirements is carried out per decade.

7.3 Holetta River subbasin features

The following data were collected in order to characterize the features of Holetta River subbasin. All meteorological data (rainfall, temperature, relative humidity, wind speed, and sunshine hour) were collected from National Meteorology Agency (NMA) and Holetta Agricultural Research Center (HARC). Flow data and GIS data (topographic, land use/cover data and map, soil map) were collected from Ministry of Water and Energy (MoWE). Primary data of crop type and area coverage were collected from major water users of Holetta River (HARC, Tsedey Farm, and Farmers). These data were collected from literature, field survey, and questionnaire. One of the meteorological stations (Holetta) is found inside the watershed. The other meteorological stations, found outside the watershed are Addis Alem, Kimoye and Welenkomi. Table 7.1 shows the geographical location of these stations. The meteorological data measured from Holetta station are Rainfall, Maximum and Minimum temperature, Relative humidity, Wind speed, and Sunshine hour. All the other meteorological stations were used only for rainfall data. The consistency, homogeneity, and outlier test for the data was performed using Excel software and XLSTAT software. The percentage of missing data for rainfall is 14% at Addis Alem station, 13% at Kimoye station, 1% at Holetta station, and 18% at Welenkomi station. Missing data were filled from observations at the three nearby stations using the normal ratio method.

Table 7. 1. Geographical locations of meteorological stations

No	Station	Record Period	Coordinate		Elevation	Data collected
			XPR	YPR		
1	Addis Alem	1994 - 2004	475810.95	981592.52	2100	Rainfall
2	Holetta	1994 - 2004	447252.34	1003731.64	2395	Climate and Flow data
3	Kimoye	1994 - 2004	423058.00	998462.26	2260	Rainfall
4	Welenkomi	1994 - 2004	423058.00	996021.93	2160	Rainfall

7.3.1. Location and Topography of Holetta Watershed

The Holetta watershed is located in the upper part of Awash River basin, Ethiopia. It lies at an altitude of 2069 - 3378 meters (m) above sea level (a.s.l) and located at a latitude range of 8056'N to $9^0$13'N and longitude range of $38^0$24'E to $38^0$36' E. It is a watershed with drainage area of 403.47 km^2. Figure 7.2 shows the location of Holetta Watershed.

Insert Figure 7.2 about here

According to Food and Agricultural Organization (FAO/UNESCO 1974) slope classification, most slope in watershed (54.01%) are flat to gently undulating with a dominant slopes ranging between 0-8%, 41.9% of the area is rolling to hilly with a dominant slopes ranging between 8-30% and only 4.09% are steeply dissected to mountainous with dominant slopes over 30%. The slope classification of Holetta watershed is shown in figure 7.3.

Insert Figure 7.3 about here

7.3.2. Climate

The central and most of the eastern part of the country have two rainy periods and one dry period. These seasons are known locally as the main *Kiremt* rains from June to September, small *Belg* rains, from February to May, and dry *Bega* season from October to January. The annual rainfall of the Holetta watershed ranges between 818-1226 mm, with a bimodal pattern of main rainy season during June to September and short rainy season during January to May. There is relatively intensive rainfall during June to August with the highest mean monthly rainfall recorded in July (243 mm). The months with the lowest rainfall are November and December.

The climate data obtained from Holetta station showed that the air temperature in the area ranges from 6^0C to 23^0C. The mean maximum temperature was 25^0C. Based on meteorological data from 1994-2004, the mean monthly relative humidity value varies from 45 to 85%. Figure 7.4 shows the average rainfall, temperature and relative humidity of Holetta watershed.

Insert Figure 7.4 about here

7.3.3. Land Use/Land cover

The land use map of Awash basin clipped and dissolved into Holetta River watershed. Then, the clipped land use map was used for SWAT land use reclassification. According to SWAT land use classification (figure 7.5), the watershed has five categories. These are, Agricultural Land- Row Crops (AGRR) with an area of 13.54%, Agricultural Land -Close-Grown (AGRC) - 0.17%, Wetlands-Mixed (WETL) - 0.14%, Forest -Deciduous (FRSD) - 57.26% and Forest-Mixed (FRST) - 28.9%.

Insert Figure 7.5 about here

7.3.4 Soil classification

The soil map of Awash basin clipped and dissolved in to Holetta River watershed. Then, the clipped soil map was used for SWAT soil reclassification. Based on SWAT soil reclassification (figure 7.6), the watershed has four soil categories. These are Chromic Luvisols (Chluvisols) with an area of 33.26%, Humic Nitisols (Huntisols) - 56.57%, Vertic Cambisols (Vtcambisol) -1.71% and Eutric Vertisols (Euvertisols) - 8.27%. Based on their texture, Vtcambisol and Euvertisol classified as clay whereas Chluvisols and Huntisols classified as loam (Belete et al. 2012).

Insert Figure 7.6 about here

7.3.5. Flow Data

The Holetta River is a tributary of the larger Awash River, which joins it after travelling about 25km downstream of the gauging station. The Holetta River is the main source of surface water in the study area. The River is gauged since 1975 and for this study, the 1994 - 2004 time series of the river discharge data was used. The daily flow data from gauging station was used for sensitivity analysis, model calibration (1994 – 1999) and validation (2000-2004).

The average annual river flow at Holetta River was 44 MCM. The flow was low from January to May and it started to increase in June. The peak flow volume was 17 MCM, which occurred in August, and the minimum was 0.524 MCM in February. Figure 7.7 and figure 7.8 shows the average monthly flows at Holetta River and the monthly rainfall runoff relations for Holetta subbasin respectively.

Insert Figure 7.7 about here

Insert Figure 7.8 about here

7.4. Hydrological Analysis

Watershed delineation and determination of HRUs were the first step in SWAT model analysis. Then, weather station and all the necessary data were fitted. After setting and running SWAT model, sensitivity analysis, calibration and validation was performed. In this study, the calibration and validation was performed at subbasin one, which is found in the upper part of the watershed (Figure 7.2). A long-term data was required for the analysis and the results are highly dependent on the accuracy of the data.

7.4.1. Watershed Delineation and Determination of HRUs

The Holetta River watershed was delineated by SWAT model and it has six sub-basins. Then, the sub-basins were divided into HRUs. The HRUs can be determined either by assigning only one HRU for each sub-basin considering the dominant soil/land use combinations, or by assigning multiple HRUs for each sub-basin considering the sensitivity of the hydrologic processes based on a certain threshold values of soil/land use combinations. In this study, a multiple HRU definition with a threshold value of 15% for land use, 20% for soil class, 5% for slope were given and as a result, 33 HRUs were identified.

7.4.2. Sensitivity Analysis

Sensitivity analysis was performed for the entire period (1994-2004). About 270 iteration have been done by SWAT sensitivity analysis for flow calibration with the output of 26 parameters were reported as sensitive in different degree of sensitivity for flow. Among these 26 parameters, eight of them have more effect on the simulated result when changed. Based on the result of sensitivity analysis, Table 7.2 shows the most sensitive parameters for the watershed. Then, these parameters were used for calibration.

Table 7.2. Result of sensitivity analysis of flow at Holetta subbasin

Rank	parameter	Description	Mean
1	Canmx	Maximum canopy storage [mm]	0.18
2	Alpha_Bf	Base flow alpha factor [days]	0.15
3	Revapmn	Threshold water depth in the shallow aquifer for "revap" [mm]	0.15
4	Gwqmn	Threshold water depth in the shallow aquifer for flow [mm]	0.06
5	Gw_Revap	Groundwater "revap" coefficient	0.06
6	Esco	Soil evaporation compensation factor	0.04
7	Cn2	Initial SCS CN II value	0.01
8	Sol_K	Saturated hydraulic conductivity [mm/hr]	0.00

7.4.3. Model Calibration

After sensitivity analysis has been carried out, the calibration of SWAT model was done manually. The calibration was carried out using the output of the sensitivity analysis of the model and by changing the more sensitive parameter at a time while keeping the rest of the parameters constant. The analysis of simulated result and observed flow data comparison was considered daily and monthly. The calibration was performed until the best-fit curve of simulated versus measured flow was obtained.

The sensitive parameters were adjusted based on the allowable range until the best fitting value was found. Table 7.3 showed the initial/default and finally adjusted parameter values.

Table 7. 3. Initial and final adjusted value of calibrated flow parameters at Holetta subbasin

No	parameter	Default	Range (Upper & Lower Limit)	Final Calibrated Value
1	Canmx	0	0-10	10
2	Alpha_Bf	0.048	0-1	0.4
3	Revapmn	1	0 -1	0.01
4	Gwqmn	0	0-5000	70
5	Gw_Revap	0.02	0.02 -0.2	0.2
6	Esco	0	0-1	0.01
7	Cn2	72	±50%	+12%
8	Soil_K	18	0-2000	120

The SWAT model performance was evaluated using statistical and graphical methods of comparing simulated with observed flow data. The goodness-of-fit statistics was used in describing the model's performance relative to the observed data. These statistical measures were the coefficient of determination (R^2), Nash-Sutcliffe Efficiency Coefficient (NSE), and Index of Volumetric Fit (IVF) between the observations and the final best simulations. Figures 7.9 and figure 7.10 shows the daily and monthly graphical performance evaluation of SWAT model during calibration period, respectively. Both the daily and monthly graphs implied that the model simulation is best fitted with the observed flow measurement.

Insert Figure 7.9 about here.

Insert Figure 7.10 about here.

The daily calibration result showed that the regression coefficient (R^2) was 0.57; Nash-Sutcliffe Efficiency Coefficient (NSE) was 0.55 and Index of Volumetric Fit (IVF) was 102.62 %. In addition, 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% (Figure 7.11). These indicated that the model performance was very good and highly acceptable.

Insert Figure 7.11 about here

7.4.4. Model Validation

The validation process was performed by simply executing the model for the different time period outside the calibration using the previously calibrated input parameters. Figures 7.12 and figure 7.13 shows the daily and monthly graphical performance evaluation of SWAT model during validation period respectively. Both the daily and monthly graphs implied that the model simulation is best fitted with the observed flow measurement.

Insert Figure 7.12 about here

Insert Figure 7.13 about here

The three goodness-of-fit measures were also calculated for the validation period. The daily calibration result showed that the regression coefficient (R^2) was 0.44; Nash-Sutcliffe Efficiency Coefficient (NSE) was 0.4 and Index of Volumetric Fit (IVF) was 108.9 %.

In addition, 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% (Figure 7.14). These results indicated that the model performance was good in the acceptable limit.

Insert Figure 7.14 about here

7.4.5. Runoff Estimation for Holetta Watershed

The Holetta watershed was divided into six subbasins. Only one of the subbasin, found in the upper part of the watershed was gauged. Calibration and validation of SWAT model was performed at subbasin one. Then, regionalization approach was used to estimate runoff for the ungauged subbasin's of the watershed.

In this study, Spatial Proximity method was used to estimate runoff at subbasins 2, 3, 4 and 5 where majority of the users located. Figures 7.15 and figure 7.16 show the monthly simulation result of SWAT model at the subbasins respectively. The mean flow (m^3/s) at the subbasin 2, 3, 4 and 5 was shown in Table 7.4.

Insert Figure 7.15 about here

Insert Figure 7.16 about here

Table 7. 4. Summary of mean flow (m^3/s) at the subbasins

Subbasin	Mean daily flow (m^3/s)	Mean monthly flow (m^3/s)	Mean annual flow (m^3/s)
2	1.358	1.351	1.358
3	0.564	0.561	0.564
4	2.109	2.099	2.109
5	0.525	0.522	0.525

7.5. Questionnaire Analysis

The survey form was used to identify information which includes the number of Holetta River consumers, major crops grown by irrigation, the total area coverage, conflict between users and water management system in the watershed. Over all 100 respondent were interviewed, 60 of them were from farmers, 10 from HARC , 10 from Tsedey farm , 10 from *Kebele* and 10 from Agricultural office. Then, the questionnaire was analyzed with Excel software and simple statistical description method was used. The majority of downstream users of Holetta River were from four *Kebele*s. These are *Medi Gudina*, *Dewana Lafto*, *Tulu Wato Dalecha* and *Hamus Gebeya*. For detail questionnaire survey only one *kebele* was selected which is *Medi Gudina*. *Tsedey* Farm is located at subbasin 2 and 3; HARC and *Medi Gudina kebele* located at subbasin 2 whereas *Dewana Lafto*, T*ulu Wato Dalecha* and *Hamus Gebeya* located at subbasin 3, 4 and 5(Figure 7.17).

Insert Figure 7.17 about here

According to the collected data, majority of users have been using the river for more than ten years and 51.67% of the users use the river for 30- 50 years. All the farmers responded that they use the Holetta River for irrigation, livestock and human consumption but the main use of the river is for irrigation. HARC and *Tsedey* Farm use the river only for irrigation purpose.

In the survey, it was planned to determine the major crops grown in the study area. The major crops grown are potato, tomato, cabbage, carrot, onion, and lettuce. The farmers’ response showed that the three major crops are potato with 96.67%, cabbage with 91.67% and tomato with 56.67%. They use furrow irrigation to grow these crops during the off-season mainly from January to June. The area of irrigated land for each crops were about 0.25 hectares. The survey also indicated that the major crops for HARC are potato, cabbage, barely, and apple.

Potato, tomato, and cabbage are the major crops for *Tsedey* farm. Figure 7.18 explained the major crops for the three users of Holetta River.

Insert Figure 7.18 about here

All the farmers responded that the only source of water for irrigation is the river and there is no alternative means, but there are springs and wells for human consumption. About 63.33 % of the farmers agreed that there is conflict between the users. On contrary, 36.67 % of the farmers replied that there is no conflict. HARC and *Tsedey* Farm respondents believed that there is a conflict between users of Holetta River. They also mentioned that this conflict mostly occurs at the turning points and during allocation of the water. Even though it is not well established, there is an irrigation committee, which settles these conflicts.

During the survey, attempts were made to collect information about the number of households and livestock that use Holetta River at subbasin 2. According to the survey from Agricultural office and *kebele*, about 371 households use the river for irrigation purpose and 300 households use for human consumption (Figures 7.19 and figure 7.20).

Insert Figure 7.19 about here

Insert Figure 7.20 about here

The collected data indicated that some of the livestock exist in the subbasin 2 were ox, cow, sheep, goat, horse and donkey. According to the survey, the approximate number of livestock summarized in Table 7.5.

Table 7. 5. Summary of livestock which users Holetta River

Type of livestock	Number
Ox	154
Cow	250
Sheep	500
Goat	200
Horse	33
Donkey	34

7.6. CROPWAT Model Analysis

Reference evapotranspiration, effective rainfall, crop pattern data, and soil data were used for CropWat model analysis. The major crops identified from the survey analysis were used in the calculation of crop water requirement.

7.6.1. Reference Evapotranspiration

First, monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data (1994-2004) was fitted in CropWat model. Then, the model calculated crop evapotranspiration values based on the FAO Penman-Montieth equation. Figure 7.21 showed the calculated reference evapotranspiration.

Insert Figure 7.21 about here

7.6.2. Effective Rainfall

To account for the losses due to runoff or percolation, a choice was made from the four methods given in CropWat 8.0 (Fixed percentage, dependable rain empirical formula, USDA Soil Conservation Service). Rainfall data from 1994-2004 was taken to calculate effective rainfall and dependable rain empirical formula has been used (Figure 7.22).

Insert Figure 7.22 about here

7.6.3. Crop and Soil Data

Crop water requirement and irrigation requirements were calculated only for the major crops in the study area. The major crops are Potato, Cabbage, Apple and Barely for HARC; Potato, Cabbage and tomato for Tsedey farm and farmers. The development stages, Kc factor and root depth of each crop was taken from FAO-24 (Doorenbos and Pruitt 1992) and FAO-33 (Doorenbos and Kassam 1986).

The soil data required by the CropWat model includes, total available soil moisture, maximum rain infiltration rate, maximum root depth, initial soil moisture depletion and initial available soil moisture. The soil data used in the model was the same for all crops except the maximum root depth.

7.6.4. Crop Water Requirement and Irrigation Requirement

In order to estimate the water demand for agricultural use/ irrigation for each crop, evapotranspiration, effective rainfall, data of crop type, area coverage and soil data were fitted in CropWat model. The water demand of irrigation was assumed to occur during the growing season. All calculation procedures as used in CropWat 8.0 are based on the FAO-56 guidelines (Allen et al. 1998). The crop water requirement (CWR) and irrigation requirement (IR) of each crop for the entire growing period was summarized below. Table 7.6 describes the total crop water requirement and irrigation requirement for each crop and Table 7.7 shows the irrigation requirement for a month of January to May.

Table 7.6. Estimation of total crop water requirement and irrigation requirement

crop	CWR (mm)	Effective rain(mm)	Net IR (mm)
potato	440.1	78.3	360.9
cabbage	425.4	73.5	350.6
tomato	600.8	116.8	480.8
apple	668.7	103.6	565.0
barely	466.2	86.7	378.7

Table 7.7. Estimation of irrigation water requirement (mm/month) for each crop

Month	Potato	cabbage	tomato	barely	apple
January	32	45.3	38.7	19.1	125
February	69.7	82.50	68	95	114.5
March	138.1	122.70	122.5	144.3	121.7
April	110.8	100.30	122.7	104.9	102.5
May	10.2		118.3	15.4	101.3

7.7. Water Demand Analysis

The result of CropWat model and survey analysis was used as an input for the calculation of water demand. The CropWat calculated the irrigation water requirement of the major crops in the area. The survey analysis indicated the area coverage and number of users of Holetta River.

Based on the result of CropWat model and survey analysis, the irrigation water demand for the three major users of Holetta River was calculated. The period was taken only for the dry seasons, from January to May. Table 7.8 to table 7.10 shows the monthly irrigation requirement of major crops in million cubic meters (MCM) for HARC, Tsedey Farm, and farmers, respectively.

Table 7.8. Monthly irrigation requirement (MCM) for each major crop of HARC

Crop Type	Area (ha)	Total IR(MCM)				
		January	**February**	**March**	**April**	**May**
potato	6	0.00192	0.004182	0.008286	0.006648	0.000612
cabbage	3	0.001359	0.002475	0.003681	0.003009	
apple	6	0.0075	0.00687	0.007302	0.00615	0.006078
barely	5	0.000955	0.00475	0.007215	0.005245	0.00077
total	**20**	**0.01173**	**0.01828**	**0.02648**	**0.02105**	**0.00746**

Table 7.9. Monthly irrigation requirement (MCM) for each major crop of Tsedey Farm

Crop type	Area (ha)	Total IR (MCM)				
		January	**February**	**March**	**April**	**May**
potato	7	0.00224	0.004879	0.009667	0.007756	0.000714
cabbage	5	0.002265	0.004125	0.006135	0.005015	
tomato	6	0.002322	0.00408	0.00735	0.007362	0.007098
total	**18**	**0.006827**	**0.013084**	**0.023152**	**0.020133**	**0.007812**

Table 7. 10. Monthly irrigation requirement (MCM) for each major crop of farmers

Crop type	Area (ha)	Total IR(MCM)				
		January	**February**	**March**	**April**	**May**
potato	92.75	0.02968	0.064647	0.128088	0.102767	0.009461
cabbage	92.75	0.042016	0.076519	0.113804	0.093028	
tomato	92.75	0.035894	0.06307	0.113619	0.113804	0.109723
total	278.25	**0.10759**	**0.20424**	**0.35551**	**0.3096**	**0.11918**

The three other *kebele* farmers only differ based on the area of irrigated land. *Dewana Lafto Kebele* has 94 ha of irrigated land, *Tulu Wato Dalecha* has 150 ha and *Hamus Gebeya* has 218 ha. Therefore, the irrigation requirement for these kebele's was summarized in table 7.11.

Table 7. 11. Total monthly irrigation requirement (MCM) for the four kebele farmers

Kebele	Total IR (MCM)				
	January	**February**	**March**	**April**	**May**
Medi Gudina	0.10759	0.204236	0.355511	0.3096	0.119184
Dewana Lafto	0.03633	0.068987	0.120127	0.10459	0.040182
Tulu wato Dalecha	0.058	0.1101	0.19165	0.1669	0.06425
Hamus Gebeya	0.084293	0.160026	0.278545	0.242533	0.093188
Total	**0.286213**	**0.543348**	**0.945832**	**0.823622**	**0.316804**

Then, the total monthly irrigation requirement (IR) for all the three major users was added and summarized (Table 7.12). 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.

Table 7. 12. Total monthly irrigation requirement (MCM) for all major users of Holetta River

Total IR for the three (MCM)				
January	**February**	**March**	**April**	**May**
0.304774	0.5747088	0.99546775	0.8648068	0.33207550

Tsedey Farm and HARC use the river only for irrigation purpose but the farmers' further use the river for human consumption and livestock. Therefore, the water demand for human consumption and livestock was calculated for the farmers.

Water demand for livestock and human consumption was estimated by multiplying the number of user/consumer by standard consumption

$$CR = \frac{N * q * t}{1000} \quad .... \quad (7.1)$$

Where, CR is human and livestock consumptive requirement (m^3);
N is the consumer size (number);
q is the consumptive rate (lt/day) and, t is the number of days

Based on the above formula, the monthly human consumption at *Medi Gudina Kebele* was calculated and showed in tables 7.13 to table 7.15. The monthly livestock consumption at the same *Kebele* was calculated and showed in table 7.16 to table 7.18. 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.

Table 7. 13. Human consumptive requirement for January, March and May

Description	Quantity	t (days)	N (number)	q (lt/day)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
# of HH	300	31	1500	15	**697.5**	**0.0006975**
# of members	5					
lts/day	15					

Table 7. 14. Human consumptive requirement for February

Description	Quantity	t (days)	N (number)	q (lt/day)	consumptive requirement CR(m^3) = N*q*t/1000	consumptive requirement CR (MCM)
# of HH	300	28	1500	15	**630.0**	**0.00063**
# of members	5					
lts/day	15					

Table 7. 15. Human consumptive requirement for April

Description	Quantity	t (days)	N (number)	q (lt/day)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
# of HH	300	30	1500	15	**675.0**	**0.000675**
# of members	5					
lts/day	15					

Table 7. 16. Livestock consumptive requirement for January, March and May

Type of livestock	N (number)	q (lts/head/day)	t (days)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
Ox	154	45	31	214.83	
Cow	250	130	31	1007.5	
Sheep	500	7.5	31	116.25	
Goat	200	7.5	31	46.5	
Horse	33	45	31	46.035	
Donkey	34	45	31	47.43	
total				**1478.545**	**0.001478545**

Table 7. 17. Livestock consumptive requirement for February

Type of livestock	N (number)	q (lts/head/day)	t (days)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
Ox	154	45	28	194.04	
Cow	250	130	28	910	
Sheep	500	7.5	28	105	
Goat	200	7.5	28	42	
Horse	33	45	28	41.58	
Donkey	34	45	28	42.84	
total				**1335.46**	**0.001335460**

Table 7. 18. Livestock consumptive requirement for April

Type of livestock	N (number)	q (lts/head/day)	t (days)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
Ox	154	45	30	207.9	
Cow	250	130	30	975	
Sheep	500	7.5	30	112.5	
Goat	200	7.5	30	45	
Horse	33	45	30	44.55	
Donkey	34	45	30	45.9	
total				**1430.85**	**0.001430850**

Monthly value of irrigation requirement, human consumptive requirement and livestock consumptive requirement was added in order to get the overall water demand of the three major users of Holetta River. Finally, table 7.19 summarizes the total water demand requirement of each month for all the three users

Table 7. 19. Overall summary of total water demand and supply at Holetta watershed

	January	February	March	April	May
Total IR for the three(MCM)	0.30477425	0.5747088	0.99546775	0.86480675	0.3320755
Human consumptive requirement CR(MCM)	0.0027900	0.002520	0.0027900	0.0027	0.0027900
Livestock consumptive requirement CR(MCM)	0.00591418	0.00534184	0.00591418	0.0057234	0.00591418
Total (MCM)	**0.313**	**0.583**	**1.004**	**0.873**	**0.341**

The total 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 was taken from the result of SWAT simulation at subbasins 2, 3, 4 and 5. The flow taken is the inflow (m^3/s) at each subbasins. 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 (Table 7.20).

Table 7. 20. The summary of available flow and water demand in the study area

	January	**February**	**March**	**April**	**May**
Flow (MCM)	0.749	0.419	0.829	0.623	0.471
Total Water demand (MCM)	0.313	0.583	1.004	0.873	0.341
Difference	0.436	-0.164	-0.175	-0.25	0.13

7.9 Summary

The study was conducted to estimate runoff at Holetta watershed and to model rainfall runoff relation in the area. The study also analyzed the water demand and the gap between the river water supply and demand.

The rainfall runoff process of the watershed was modeled by SWAT. According to SWAT classification, the watershed was divided in to 6 subbasins and 33 hydrological response units (HRUs). Only one subbasin at the upstream side was gauged. Therefore, sensitivity analysis, calibration, and validation of the model were performed at this subbasin and then the calibrated model was used to estimate runoff for the ungauged part of the watershed. The result of sensitive analysis showed that 26 parameters were sensitive; out of 26, eight of them are the most sensitive ones. These parameters were used for model calibration.

The performance of the model was evaluated by statistical and graphical method. The statistical methods used were coefficient of determination (R^2), Nash-Sutcliffe Efficiency Coefficient (NSE) and Index of Volumetric Fit (IVF). 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. Therefore, this indicated that SWAT model performed well for simulation of the hydrology of the watershed.

After modeling the rainfall runoff relation and studying availability of water at the Holetta River, the water demand in the area was assessed. CropWat model was used to calculate the irrigation water requirement for major crops and the area coverage was determined from questionnaire. The study identified the three major users of Holetta River that is Holetta Agriculture Research Center, Tsedey Farm and village farmers. 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. In addition to irrigation, the farmers use the river for livestock and human consumption. Therefore, the study also included the water demand for livestock and human's use. According to the result, 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 human consumptive requirement was 0.00279, 0.0025, 0.00279, 0.0027, and 0.00279 MCM for January, February, March, April, and May respectively. Overall, the water demand in the area was 0.313, 0.583, 1.004, 0.873, and 0.341 for January, February, March, April, and May respectively. The available river flow from January to May was taken 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. Therefore, it is possible to conclude that there is shortage of river water supply during February, March, and April comparing the water demand with the available river flow at the same months. The total shortage of supply during these months was 0.59MCM.

In addition to shortage of water supply, the analysis of the questionnaire indicated that there is a conflict between users at diversion points and during water allocation. There is an irrigation committee to settle this conflict but the conflict become more and more concerning issue in the area.

The water demand analysis showed that there was shortage of river water supply for February, March, and April. During these months, there was also conflict between users at diversion and water allocation. Therefore, in order to solve water shortage, alternative source of water supply like ground water and water harvesting technologies should be studied and integrated water management system should be implemented. In addition to this, to improve the efficiency of irrigation water, different irrigation methods like drip irrigation should be improved in the area.

In order to minimize the conflict, well established irrigation committee including all the users with a clear guide and management rules is required and water allocation system should be developed. In addition to this, water management and irrigation training should be improved in the area in order to establish river management system and to properly use the scarce water resource.

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Figure Legends

Figure 7.1 Hydrological model classifications (Chow et al., 1988)

Figure 7.2 Location of Holetta Watershed

Figure 7.3 Graphical distributions of Holetta watershed slopes.

Figure 7.4 Average Rainfall, Temperature and Relative humidity of Holetta watershed (1994 - 2004)

Figure 7.5 Land use classification of SWAT model for Holetta watershed

Figure 7.6 Soil classification of SWAT model for Holetta watershed

Figure 7.7 Average monthly flows at Holetta River (1994 -2004)

Figure 7.8 Monthly rainfall runoff relations for Holetta subbasin (1994-2004)

Figure 7.9 Observed and simulated hydrograph after daily calibration

Figure 7.10 Observed and simulated hydrograph after monthly calibration

Figure 7.11 Scattered plot & correlation between simulated & observed monthly flow during calibration

Figure 7.12 Observed and simulated hydrograph during daily model validation

Figure 7.13 Observed and simulated hydrograph during monthly model validation

Figure 7.14 Scattered plot & correlation between simulated & observed monthly flow during validation

Figure 7.15 Monthly SWAT simulation result at subbasins 2 and 3

Figure 7.16 Monthly SWAT simulation result at subbasins 4 and 5

Figure 7.17 Location of users of Holetta River

Figure 7.18 Summary of major crops for the three users of Holetta River

Figure 7.19 Summary of irrigation users of Holetta River

Figure 7.20 Summary of human consumption users of Holetta River

Figure 7.21 Reference Evapotranspiration (ETo) used by CropWat8.0

Figure 7.22 Rainfall