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Table of Contents: Volume 9 Number 5 May 2017

ARTICLES

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Full Length Research Paper

Evaluation of water supply and demand: The case of Shambu town, Western Oromia, Ethiopia

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Shambu town has faced a problem of potable water supply, still large number of people did not have access to adequate amount of potable water and frequent water interruption is a common problem. The objective of this research was to evaluate the existing water pressure map and water demand. To achieve this goal, the following input data were collected, base population, growth rate, and pressure map of the area, water production data, and reservoir data. The pipe network and junction network system was simulated to understand its behavior for different inputs using EPANET 2.0. The results showed that the water pressure were not feasible enough to provide adequate water. Replacing the appropriate diameters to the distribution as well expanding the distribution network in necessary engagements, the total water demand was projected to be 567648 m^3/year or 18 L/s and the total water supply was estimated to be 252288 m^3/year or 8 L/s. Only 44% of the population was covered by water supply .Thus, use of ground water, or boreholes with an estimated yield of 8 L/s are to be drilled.

Key words: EPANET, water demand, water supply, distribution network.

INTRODUCTION

Water is a natural resource without which all living things cannot exist. This is so because 70% of our planet, earth, is covered by water; though the world population is facing water scarcity. Many countries in both the developed and developing world face significant problems in maintaining reliable water supplies, and this is expected to continue in future years.

Growing populations and lack of available cost effective supply augmentation options make reliable estimates of residential water demand important for policy making (Dharmaratna and Harris, 2010). Problems of providing safe water supply to the urban poor in developing cities are increasing with the increase in population. As a result, demand for additional water sources and infrastructure is growing. Very often, urban poor are not the users of the existing water supply facilities satisfactorily.

Ethiopia's population is now surpassing 100 million and is the second populous country in Africa next to Nigeria. As a result, reliable estimates of residential water demand, water source choice decisions and effects have become more important for policy making in the water

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supply sector.

Ethiopia is blessed with ample water resources. The country has 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6 to 6.5 billion m^3 of ground water potential, which makes an average of 1575 m^3 of physically available water per person per year, a relatively large volume.

However, distribution and availability of water is erratic both in space and time. Hence, despite the abundance, the country is highly water-scarce (Seleshi, 2006). Of the total water resources available to Ethiopia, only 9% remains in the country; the bulk flows downstream to neighboring countries, and is particularly important for Somalia, Kenya, Sudan and Egypt (World Bank, 2006; Seleshi, 2006).

Furthermore, the mountainous nature of the topography, the uneven spatial distribution of the surface water and increasing seasonal variability have limited the utilization of the fresh water resources and thus Ethiopia is projected to become a water-scarce country during the 21st century (USAID, 2003). Provision of safe and adequate water contributes to better health and increased individual productivity (Israel and Awdenegest, 2012).

In order to ensure the availability of sufficient quantities of good quality water to the increased population of the country, it becomes imperative, to evaluate the technical performance of existing schemes by using computer software such as EPANET that can be easily accessed to evaluate the performance of the water pressure and water quality simulation. Even though, the software can help to evaluate water pressure map and water quality simulation, this paper focused only on the water pressure map evaluation due to time and budget constraints. Therefore, the scope of this research was limited to water supply distribution and water demand prediction.

In addition, the present and future population projection should be done to design and build suitable water supply schemes which will provide potable water to the various sections of the community in accordance with their demands. The Ethiopian water supply system fails due to inappropriate design of the system and lack of population projection when designing water supply. Most of the projects were implemented by considering only the existed population. The pipe installations, did also not consider the population pressure.

As the authors' experience of the area for 10 years, acute water shortages were experienced in the study area. Residents adopted various coping strategies notably the use of ground water and drilling boreholes. Some residents had to walk for long distance and queue the whole day to get water from the surrounding source. Still no reseach was conducted in the area on evaluation of supply and demand. Therefore, this study was initiated to contribute a research idea by filling this gape.

The objectives of this research were (1) to evaluate existing water pressure map and (2) to forecast the water demand for the next ten years.

MATERIALS AND METHODS

Study area description

Location and relief

Shambu town is geographically located at latitude of 9° 38 N and longitude of 37° 4'E. It is found at a distance of about 325 km from Addis Ababa. Shambu is bounded by Kombolcha Chancho, Laku Higu, Haro Shote, and Tenno Peasant Associations. The area under study is having an average altitude of 2400 m above sea level. The mean annual temperature is 15.7°C; the mean monthly rainfall is 126.4 mm and the mean annual rainfall of 1543.4 mm (Figure 1).

Existing source of water supply

The source for the existing water supply system since its establishment is deep ground water. At present, there are two boreholes drilled by government organizations and spring and bore holes were also implemented. Because of the absence of electric power system in the town, so far generators are used as a source of electric power for the pumps at boreholes. The pumping station located in a place called FinchDebsa which produces 432 m^3/day and the spring and boreholes produces 259 m^3/day amount of water productions. At the existing condition, the town has a total water production of 691 m^3/day to be supplied to the Shambu town.

There are two reservoirs currently serving the town. The first reservoir serving Old Shambu is a steel reservoir having 25 m^3 capacity and is 6 m elevated. The second reservoir serving the New Shambu is a circular concrete ground reservoir having 50 m^3 capacities. As to the rising main, there are two main lines, one directed to a 25 m^3 steel elevated reservoirs and the other to a 50 m^3 ground reservoirs. From the two existing reservoirs, water is supplied to the distribution system by gravity. The distribution system is constructed with galvanized steel pipes the sizes of which vary between 3 and 1 inches.

Population

Based on the projection done by CSA (2007), the town has a total population number of 36,584 by the year 2015 from which 17,303 are men and 19,281 women with an average family size of 4 persons per house. The average population growth rate of the region was taken for the predication of Shambu town population for the year 2025.

Data collection and methodology

Data collection

Both primary and secondary data were collected, including, population data, water pressure map of the area, volume of water delivered, reservoir data, pipe size pipe length, pumping hour, elevations, and pipe diameter. The demand was obtained after considering the population of the study area as 36584, also the study area falls under the category of urban settlement. As a result of this development, the standard from the Federal Ministry of Water Resources manual on water demand was used. For this research, 180 L/capital/day was considered.

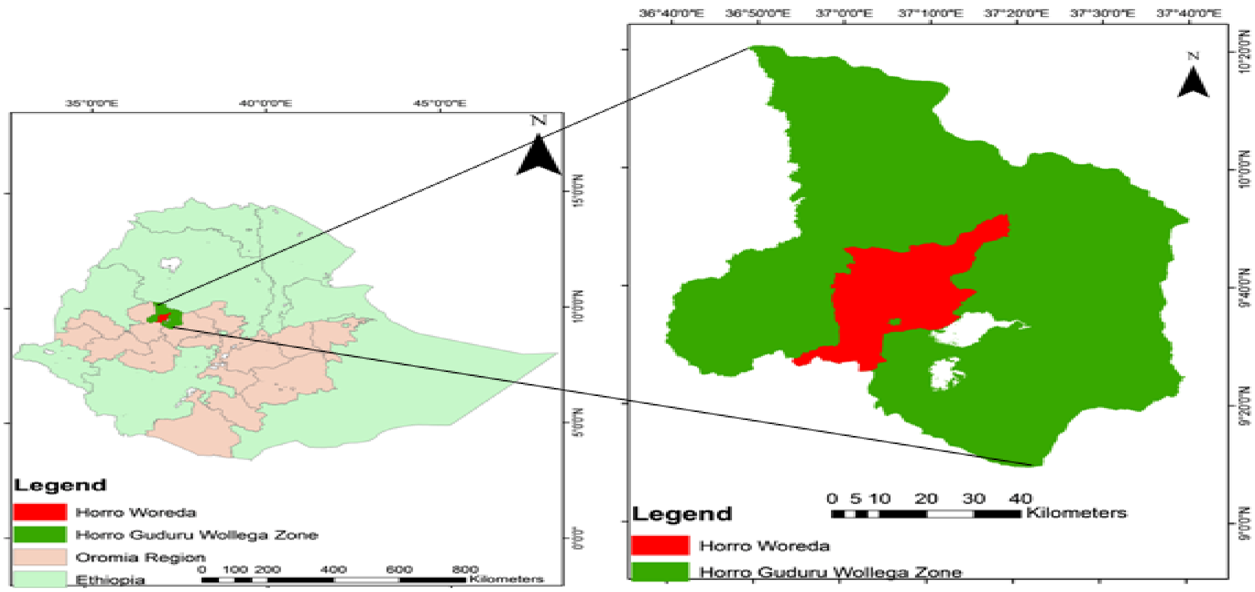

Figure 1. Map of the study area.

Methodology

Water pressure

The water demand at particular junction was obtained by dividing (the total population by the number of junctions and multiplying by 180 L/capital/day. After that, the following steps were carried out to analyze the water distribution network. Draw a network representation of the distribution system or import a basic description of the network. Edit the properties of the objects that make up the system. The (X, Y, Z) coordinates in each junction, the length of the pipes between each junction, and the node elevation, were all collected by using the existed pressure map of Shambu town and some missed values from the map were obtained by the help of geographical positioning system (GPS instrument) and analyzed by using Epanet-2 software (Figure 2).

Water demand and population projection

Water demand

The per capital water demand of urban areas varies depending on population size, economic, social and climatic factors as well as mode of service of the town (MoWR, 2006). Three mode of service were identified for domestic water consumers of Shambu town. These are yard connection (YC), house connection users (HCU) and public tap users (PTU). The rate established for Oromia region were used to forecast the population of Shambu town. Population and water demand projection were done making use of the geometric growth rate method with base population as recorded by CSA and depending on the existing demand of water. This method is mostly applicable for growing towns and cities having vast scopes of expansion (Bradley, 2004.). The geometric growth method is given by:

$$P = P_o\left(1 + \frac{r}{100}\right)^n \quad (1)$$

where P=projected population, P_0=base population, r=annual growth rate in percent, and n=number of years (annual rate of growth).

The water demand is projected for design period based on the following assumptions. There is no water shortage (water source is sufficient). The people have the ability to pay for the service. There is breakdown of population between the various standards of supply like house connection, yard connection, and public taps.

Other water demands

These water demands include non-domestic water demand, fire-fighting water demand, non-revenue water demand and industrial water demand. For all cases of percentage water demand in this research, the standard set by Ministry of Water Resource 2006 was considered to take the percentage of each demand category from the domestic demand.

Data analysis tools

Water supply distribution system was analyzed using EPANET-2 software. To generate pressure map, surfer-8 software was applied. The water demand was analyzed using Microsoft excel and presented using graphs.

RESULTS

Water pressure map

The result showed that the water pressure in some of the junctions and pipes were not functional and not working according to the standard set by MoWR (2006) which states that for adequate water supply, the water pressure should be between 15 and 70 m for Ethiopian condition. As a result, the residents accessed water only twice a

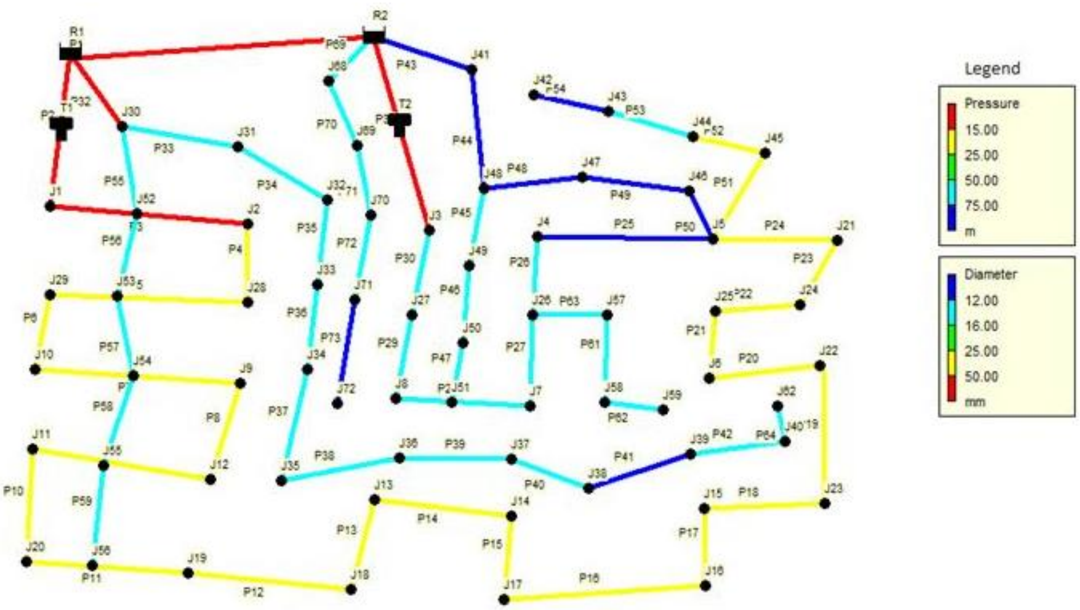

Figure 2. Water pressure map, EPANET result.

week or once a week only for a few hours. In places like Wollega Sefer, Jerba Sefer, Adebay, Mogn Sefer and around Medhanialem area (indicated by the red color), the pressure of the water could not be delivered to the community properly. There was negative pressure generated from the result (indicated by blue color). This indicated that during the design of water supply system, diameter of the pipe, length of pipe, topography of the area and population settlement were not considered. During field observation and interview with the community, it was also confirmed that people who lived at higher topography suffered from continuous water interruption than those who lived at lower topography.

Population and water demand projection

Population projection

According to CSA (2007), the base population of the town was 36,584 in the year 2015. The population estimation of the town for the year 2025 was projected by using (p=36, 584, n=10, and r=4%) (Equation 1) which resulted in 54,153 total population numbers.

Water demand projection

The water demand was calculated by taking into account the different categories and per capital demand standard set by WHO (2006). The result showed that by the year 2025, the average water demand was estimated to be 1625 $m^{3/}$day (Table 1).

Comparison of water demand and supply

Figure 3 revealed that there was a big difference in water demand and supply of water that is being delivered to the Shambu town community. Series of water supply problems will happen during the year 2025 unless some problem solving mechanisms are designed.

Determination of required number of bore holes

The result revealed that at the end of the design period, the water demand was estimated to be 18 L/s. The ground water source investigations previously studied at the site indicated that from existing well sites, there was a possibility of abstracting ground water at an average rate of 8 L/s. Therefore, there was deficiency of 10 L/s of water that must be designed to satisfy the water demand of the population by the year 2025 (Table 2).

DISCUSSION

The result of EPANET showed that at some parts of the study area, there was a serious water supply problem. The main reasons for the inadequate delivery of water to those areas where the topography is a bit higher, the water has no power to reach to the top (Lansey et al., 2014).

Moreover, the following situations were observed in the distribution pipe line network which could cause inadequate supply of water to the area. It was observed that the pipes connected to the tanks as distribution pipes

Table 1. Total average water demand.

Year	Unit	2015	2025
Adjusted average per capita domestic demand	L/Capital/Day	18	20
Population	Number	36584	54153
Domestic demand	L/day	658512	1083060
Public demand (10%)	L/day	65851.2	216612
Losses in the system (25%)	L/day	164628	270765
Fire fighting water demand (5%)	L/day	32925.6	54153
Total average demand	L/day	921916.8	1624590

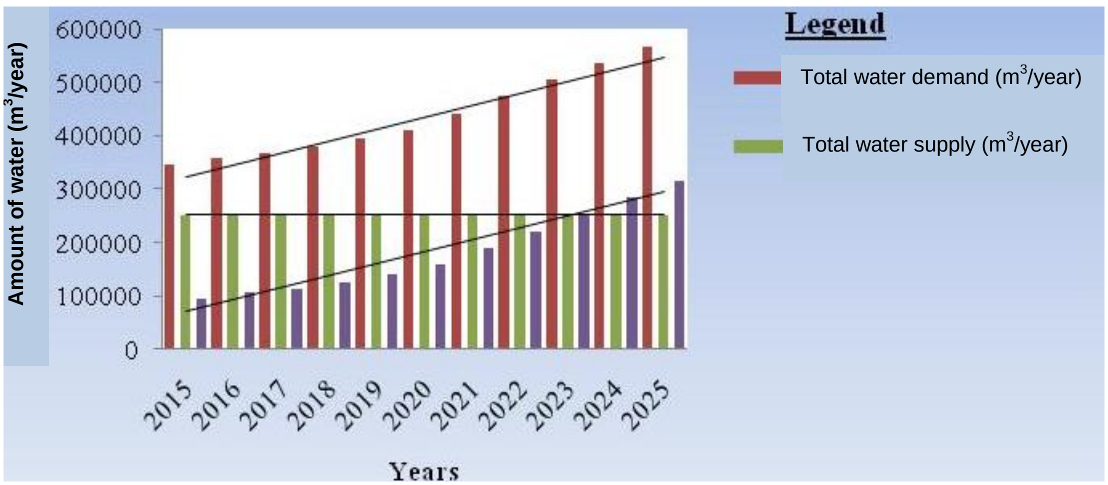

Figure 3. Gap between water demand and supply (2025).

Table 2. Gap between supply and demand of water.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Total water demand (L/s)	11	11.4	11.6	12	12.5	13	14	15	16	17	18
Total water supply (L/s)	8	8	8	8	8	8	8	8	8	8	8
Gap (L/s)	3	3.4	3.6	4	4.5	5	6	7	8	9	10

to the other pipes have smaller diameters. It was also observed that the network on the topographical map did not have a wider coverage of water distribution to some parts of the area; this as well, can cause water crisis as a result of rapid expansion of the area. Similar research was done by Vipinkumar et al. (2015). It was observed that the pipes connected to the tanks as distribution pipes to the other pipes have smaller diameters. Comparison of these results indicates that the simulated model seems to be reasonably close to the actual network.

To alleviate the problem of inadequate water pressure, Re analysis of the EPANET was under taken by the researcher. By changing the pipe diameter from 12 to 16 mm and making the tanker always at full level or improve the tanker elevation from 6 to 8 m showed that there was satisfactory pressure set by the Ethiopian standard of water at these low water pressure areas. The result was supported by Kassa (2015) who has found out that when the height of the tanker was increased by some height, satisfactory water pressure was generated. Replacing the appropriate diameters to the distribution main as well expanding the distribution network in order to obtain a proper coverage in the area, will save the consumers in having the water shortages. About 44% of the population in Shambu is covered by the town’s water supply from different types of sources. However, the service that the population is receiving is very poor. Thus, considering the use of ground water, 3 boreholes with an estimated yield of 8 L/second was recommended to be developed for water demand of 18 L/second despite the fact that the actual safe yield of each production borehole determines the ultimate number of boreholes to be drilled. Therefore, discharge should be increased to achieve the base demand. The quantity of fresh water available is sufficient to satisfy the need, but the real problems lie in the supply chain. Disruptions in this supply chain can result from strained and undeveloped infrastructure or deliberate interferences in water supply. This can pose difficulties in finding solutions to increasing population pressures.

Conclusion

This research work concluded that the water supply system of Shambu town has now serious problem to give satisfactory service to the community due to a number of reasons such as the system covers only very small area of the town despite the large size of the population, insufficient budget allocation to upgrade the system and cover organizational matters and lack of skilled manpower for the maintenance of generators, wells, and installed pumps. Re-analysis of pressure map of the water by changing the diameter of the pipe and relocating the tanker elevation improves the water supply to rich with adequate pressure to those low water pressure areas.

The water demands of Shambu town exceed supply by about 44% and its water supply distribution network reaches only about 35% of the capital. More than half of its population has less than 2 h of water service a day and has no service at all according to the standard set by WHO guideline. On account of the vital role of water to socio-economic life of humans, the author recommended an overall involvement of the private sector, the public sector, women, the local inhabitants, and the donor institutions to play their supportive roles in the improvement of the provision of water to the urban dwellers in the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Rainfall-runoff relation and runoff estimation for Holetta River, Awash subbasin, Ethiopia using SWAT model

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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 problem of allocating the available water. Therefore, the aim of this research was to investigate the water availability of Holetta River using Geographical Information Systems (GIS) tool and hydrological model. The rainfall runoff process of the catchment was modeled by using Soil and Water Assessment Tool (SWAT). According to SWAT classification, the watershed was divided in to 6 subbasins and 33 hydrological response units (HRUs). The only gauged subbasin in the catchment is subbasin one that is found in the upper part of the area. Therefore, sensitivity analysis, calibration and validation of the model were performed at subbasin one and then the calibrated model was used to estimate runoff at the ungauged part of the catchment. The performance of SWAT model was evaluated by using statistical (coefficient of determination [R^2], Nash-Sutcliffe Efficiency Coefficient [NSE] and Index of Volumetric Fit [IVF]) and graphical methods. 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.

Key words: Holetta River, SWAT, runoff, rainfall, variability.

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 also exist in various parts of Ethiopia. Holetta River is one of the rivers found in the upper part of Awash basin 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. These are Holetta Agricultural Research Center (HARC),

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Tesdey Farm and Village Farmers. The annual rainfall of the study area ranges between 818-1226 mm, with a bimodal pattern of main rainy season from June to September and short rainy season from 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 average annual river flow at Holetta River was 44 million cubic meters (Mcm). The flow was low from January to May and it started to increase at June. The peak flow was 17 Mcm, which occurred in August, and the minimum flow was 0.524 Mcm in February.

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 aim of this research was to investigate the seasonal variability of runoff and water availability in the catchment using GIS tool and hydrological model.

Theoretical background

Description of SWAT model

Soil and Water Assessment Tool (SWAT) is a river basin scale model developed by Dr. Jeff Arnold for the US Department of Agriculture (USDA) - Agricultural Research Service (ARS) (Neitsch et al., 2005). Soil and Water Assessment Tool is used to predict 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. Soil and Water Assessment Tool is physically based on distributed model requiring specific information on soil, topography, weather and land management practices within the watershed. The physical process associated with water movement, sediment movement, crop growth and nutrient cycling is directly modeled by SWAT using this input data (Arnold et al., 1998). For modeling purposes, the watershed is 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.

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrological cycle. The land phase of the hydrological cycle 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 hydrological cycle, which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet (Neitsch et al., 2005).

The application of SWAT in predicting stream flow and sediment as well as evaluation of the impact of land use and climate change on the hydrology of watersheds has been documented by various studies (Dessu and Melesse, 2012; Dessu et al., 2014; Wang and Melesse, 2006; Behulu et al., 2013, 2014; Setegn et al., 2014; Getachew and Melesse, 2012; Assefa et al., 2014; Grey et al., 2013; Mohammed et al., 2015).

MATERIALS AND METHODS

Description of the study area

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 m 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 38°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 to 23^{0}C with the mean of 14°C (Figure 1).

Data collection

All meteorological data (rainfall, temperature, relative humidity, wind speed and sunshine hour) were collected from National Meteorology Agency and Holetta Research Center. Flow data and data (topographic, land use/cover data and map, soil map) were collected from Ministry of Water and Energy.

SWAT model input

Soil and Water Assessment Tool required the following data to be defined for the physical watershed representation, topography data (Digital Elevation Model), climate (daily measured and monthly statistical weather data), flow data, soil and land use data (maps and physical parameters).

Digital elevation model data

The Digital Elevation Model (DEM) of Awash basin was taken from Ministry of Water and Energy GIS department. Then, a 90 m resolution DEM was used in SWAT model to delineate the Holetta catchment and to analyze the drainage patterns of the land surface terrain.

Land use map

The land use map of Awash basin was clipped and dissolved in Holetta River catchment. Then, the clipped land use map was used for SWAT land use reclassification. According to SWAT land use classification, the catchment 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% (Figure 2).

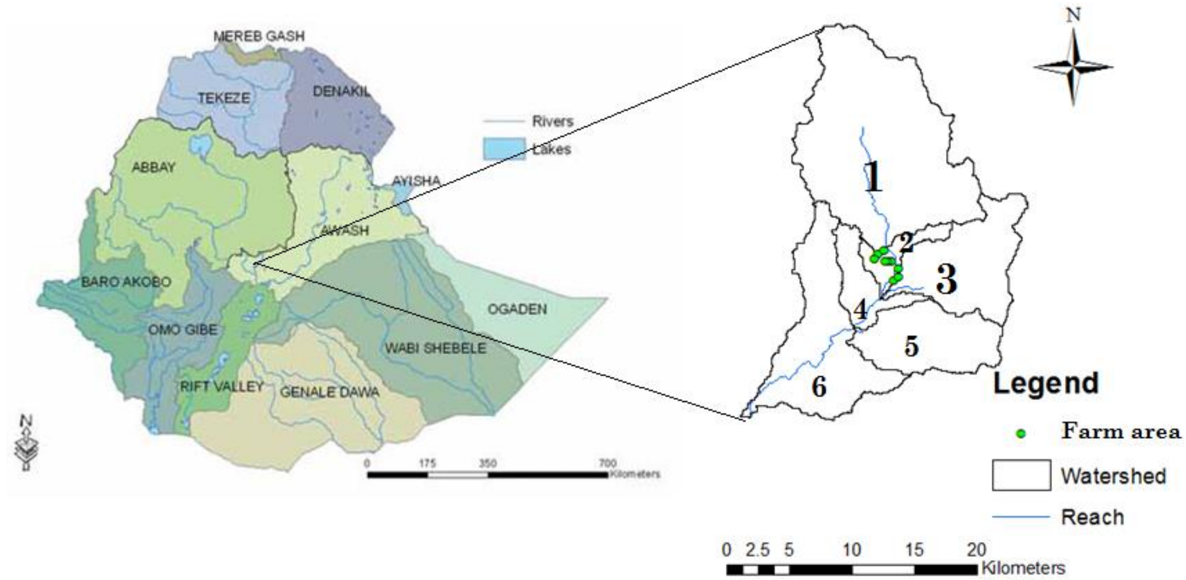

Figure 1. Location of Holetta catchment.

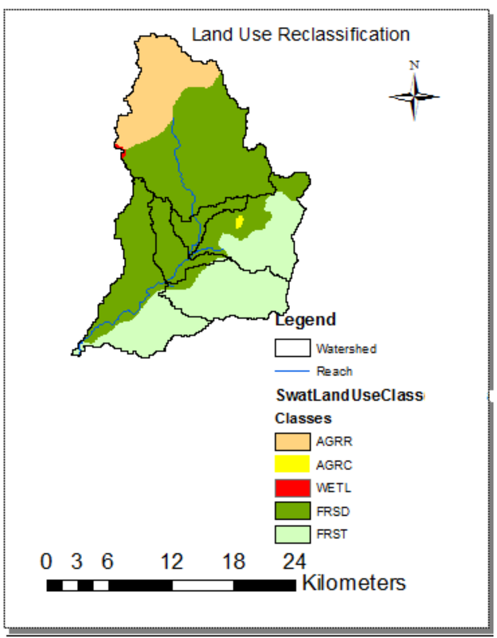

Figure 2. Land use classification of SWAT model for Holetta watershed.

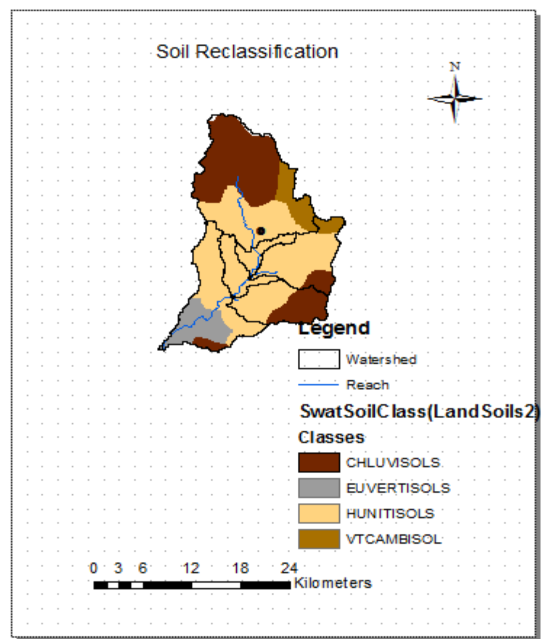

Figure 3. Soil classification of SWAT model for Holetta watershed.

Soil map

The soil map of Awash basin was clipped and dissolved in Holetta River catchment. Then, the clipped soil map was used for SWAT soil reclassification. Based on SWAT reclassification, the catchment has four soil categories. These are Chromic Luvisols (Chluvisols) with an area of 33.26%, Humic Nitisols (Huntisols) with an area of 56.57%, Vertic Cambisols (Vtcambisol) with an area of 1.71% and Eutric Vertisols (Euvertisols) with an area of 8.27% (Figure 3).

Meteorological data

One of the meteorological stations (Holetta) was found inside the catchment. The other meteorological stations, which were found outside the catchment, were Addis Alem, Kimoye and Welenkomi. The meteorological data measured from Holetta station were rainfall, maximum and minimum temperature, relative humidity, wind speed and sunshine hour. All the other meteorological stations were used for only rainfall data. The consistency, homogeneity and

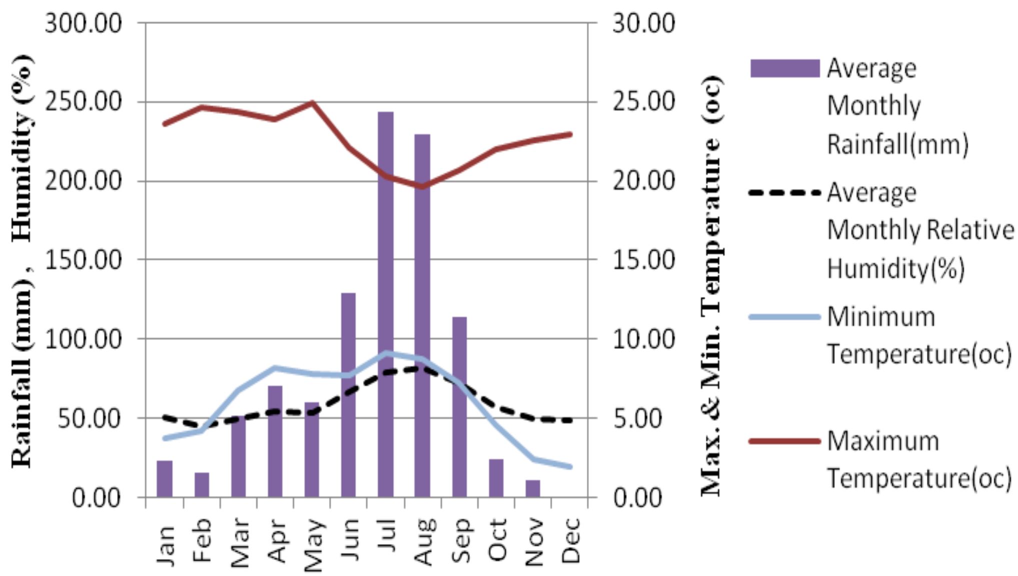

Figure 4. Average rainfall, temperature and relative humidity of Holetta watershed (1994 - 2004).

outlier test for the data was performed by using Excel software and XLSTAT software. The percentage of missing data for rainfall was 14% at Addis Alem station, 13% at Kimoye station, 1% at Holetta station and 18% at Welenkomi station. Therefore, missing data were filled from observations at the three nearby stations by using the normal ratio method. The normal ratio method is a better method than the arithmetic mean method and is usually applied when the normal annual precipitation at the site with the missing record differ by more than 10% of the normal annual precipitation at the other sites where the concurrent data are available (Chow et al., 1988).

The climate data obtained from Holetta station showed that the air temperature in the area ranges from 6 to 23°C. The mean maximum temperature was 25°C. Based on meteorological data from 1994 to 2004, the mean monthly relative humidity value varied from 45 to 85% (Figure 4).

Flow data

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

Figure 4 shows that there is relatively intensive rainfall during June to August with the highest mean monthly rainfall recorded in July - 243 mm. In all other months, there were only meager or almost zero rain fall.

The average annual river flow at Holetta River was 44 Mcm. The flow was low from January to May and it started to increase at June. The peak flow was 17 Mcm, which occurred in August, and the minimum flow was 0.524 Mcm in February (Figure 5). Both Figures 4 and 5 have the same pattern and the river flow rises in the same season when the rainfall increases. The rainfall runoff relation showed that there was a positive relation between rainfall and surface runoff in the watershed (Figure 6).

SWAT data preparation and model setting

First new SWAT project was set up and saved, and then watershed delineation was performed. In order to delineate the watershed, automatic watershed delineation was selected. Then, the DEM was added and stream network was defined. Finally, the watershed outlet was selected to delineate the basin. The next step in setting up a watershed simulation was to divide the watershed into subbasins. The subbasins possess a geographical position in watershed and they are spatially related to one another. In this study, the DEM of Awash basin was used to delineate the watershed. Once the subbasin delineation is completed, the user has the option of modeling a single soil, land use and management scheme for each subbasin or partitioning the subbasins into multiple hydrological response units (HRUs). 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 by lumping all similar soil and land use areas into a single response unit and it will increase the accuracy (Neitsch et al., 2004).

After that, land use/soil/slop definition and HRU definition was performed by using the land use and soil map in combination with look up tables. By using these data, SWAT classified the watershed. Then, writing of input tables was continued by defining weather data. The first step to proceed was to define the weather generator data. To define the weather generator data, the user weather station was created through edit SWAT database section. Then, the weather station parameters were fitted in the new station.

In order to prepare the station parameters, different software were used. These are WGNmarker4.Xlsm, dew.exe and pcpSTAT.exe. WGNmaker4.Xlsm was used to calculate the weather station statistics needed to create user weather station files. The program dew.exe was used to calculate the average daily dewpoint temperature per month using daily temperature and humidity data. The program pcpSTAT.exe was used to calculate statistical parameters of daily precipitation data used by weather generator of SWAT model (Stefan, 2003). Then, SWAT weather generator to fill in missing information and to simulate weather data was used to

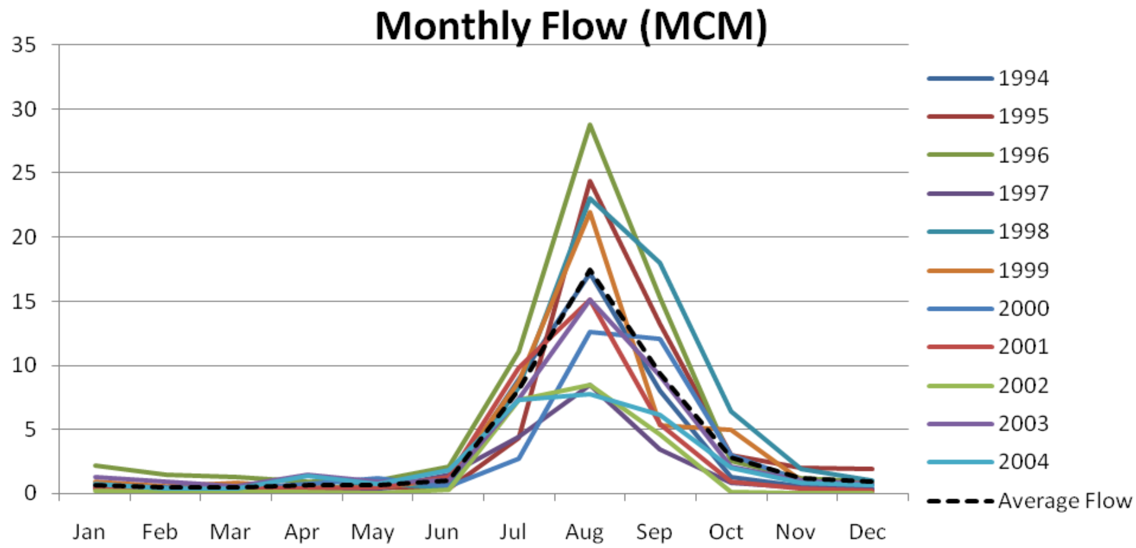

Figure 5. Average monthly flows in Mcm at Holetta River (1994 -2004).

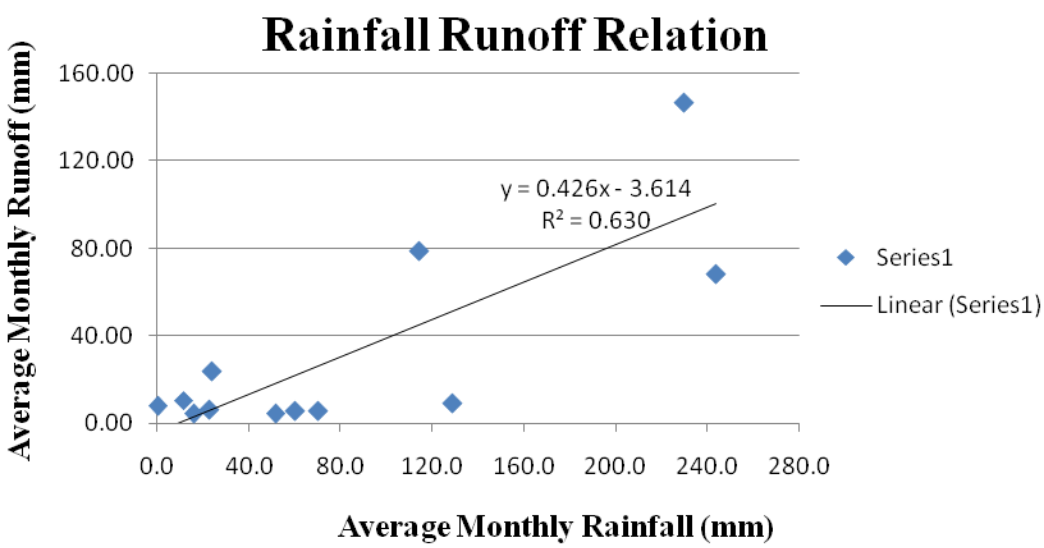

Figure 6. Monthly rainfall-runoff relations for Holetta subbasin (1994-2004).

arrange the data. To finalize the weather writing part, all sections written in the weather-writing window were selected and then all the watershed data was written and the model was made ready to be run. Once the model was run with default parameter setting, the sensitivity analysis and calibration was performed. The sensitivity analysis was performed by selecting the SWAT simulation, subbasin, sensitivity parameters and observed data. In this study, manual calibration was used. This was done by changing the sensitive parameters manually until the simulation was better fit with the observed data.

Sensitivity analysis

Sensitivity analysis explores how changes in parameter values affect the overall change in the output of the model. This can be done by using simple sensitivity analysis, where only one parameter is changed or more complex arrangements that explore the relationships between multiple parameters. Thus, a sensitivity analysis for SWAT model was performed for the entire data (1994 - 2004). Then, the most sensitive parameters was identified and used for calibration of the model.

Model calibration and validation

After sensitivity analysis was 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

Table 1. 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/h]	0.00

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.

In this process, model sensitive parameters varied until recorded flow patterns were accurately simulated. For this study, the calibration was carried out for six years (1994 - 1999) with one-year warm up period and it was done based on the result of sensitivity analysis. Then, validation of SWAT model was performed for the next five years (2000 -2004).

Model evaluation

The SWAT model performance was evaluated by using statistical measures and graphical methods of comparing simulated with observed data. The goodness-of-fit statistics was used in describing the model's performance relative to the observed data. These statistical measures used during the calibration and validation periods 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.

Runoff estimation

The Holetta catchment was divided into six subbasins. Only one of the subbasin which is found in the upper part of the catchment was gauged. The calibration and validation of SWAT model was performed at subbasin 1. Then, regionalization approach was used to estimate runoff for the ungauged subbasin's of the catchment.

RESULTS AND DISCUSSION

Watershed delineation and determination of HRUs

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.

Sensitivity analysis

Among these 26 parameters, eight had more effect on the simulated result when changed. Based on the result of sensitivity analysis, Table 1 shows the most sensitive parameters for the watershed. Then, these parameters were used for calibration.

Model calibration

In this study, the calibration of SWAT model was done manually and Table 2 shows the initial/default and finally adjusted parameter value.

Figures 7 and 8 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. During some years on daily bases, it was shown that the model did not exactly capture the peak values, which is because the catchment has only one gauging station and fail to represent the rainfall for the whole area.

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 9). These indicated that the model performance was very good and highly acceptable.

Model validation

Figures 10 and 11 showed 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.

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

Table 2. Initial and final adjusted value of calibrated flow parameters at Holetta subbasins.

S/N	Parameter	Default	Range (upper and 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

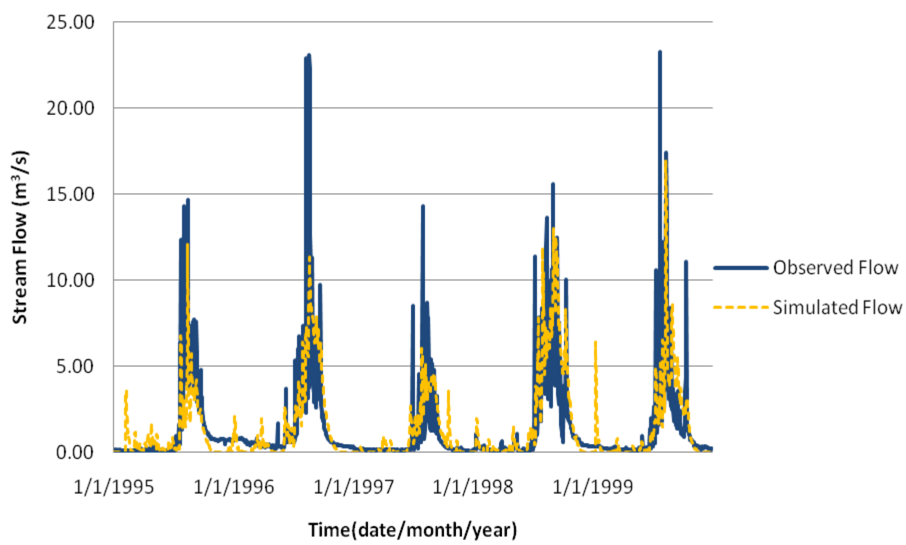

Figure 7. Observed and simulated hydrograph after daily calibration.

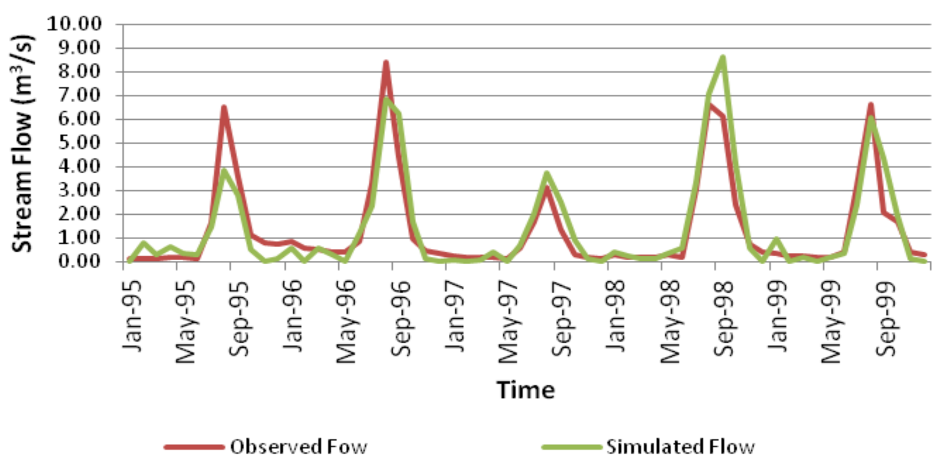

Figure 8. Observed and simulated hydrograph after monthly calibration.

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 12). These results indicated that the

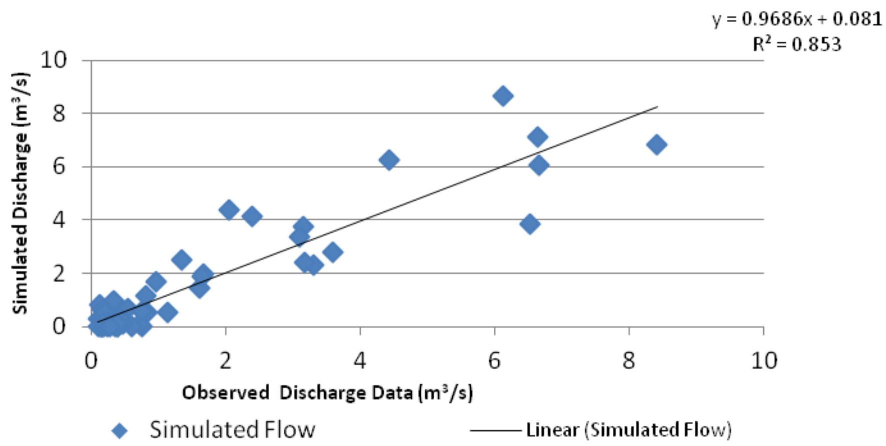

Figure 9. Scattered plot and correlation between simulated and observed monthly flow during calibration

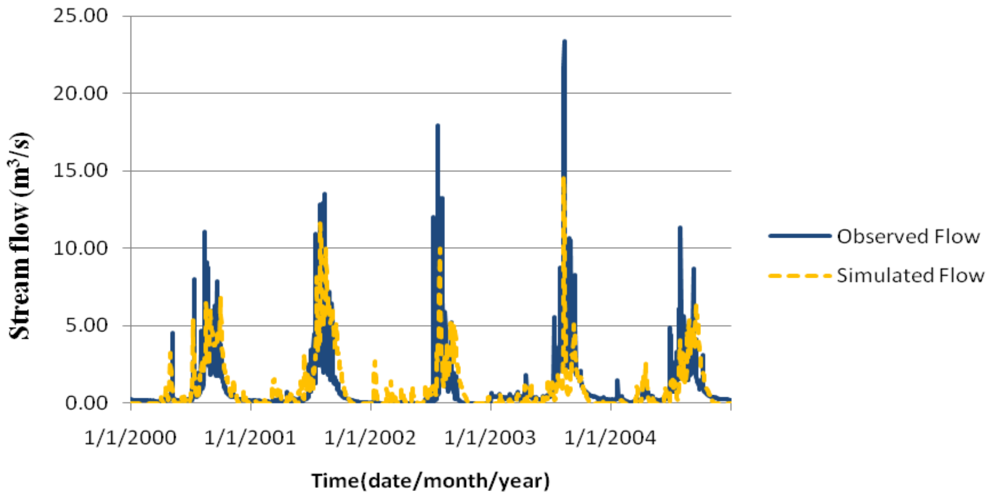

Figure 10. Observed and simulated hydrograph during daily model validation.

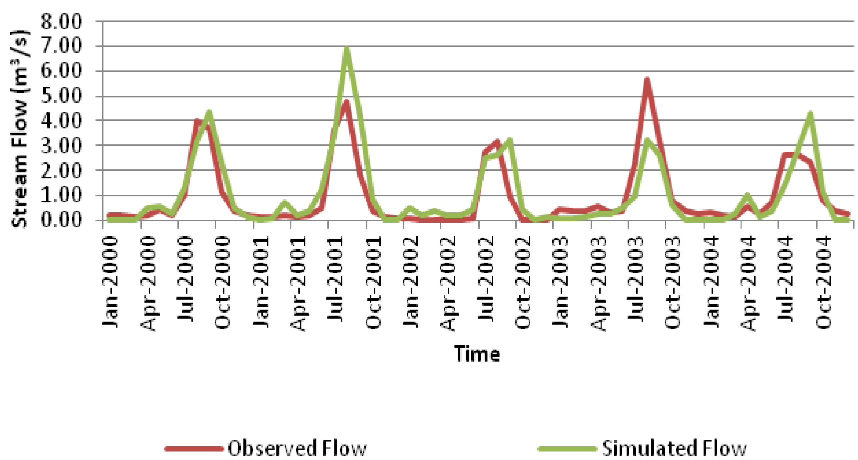

Figure 11. Observed and simulated hydrograph during monthly model validation.

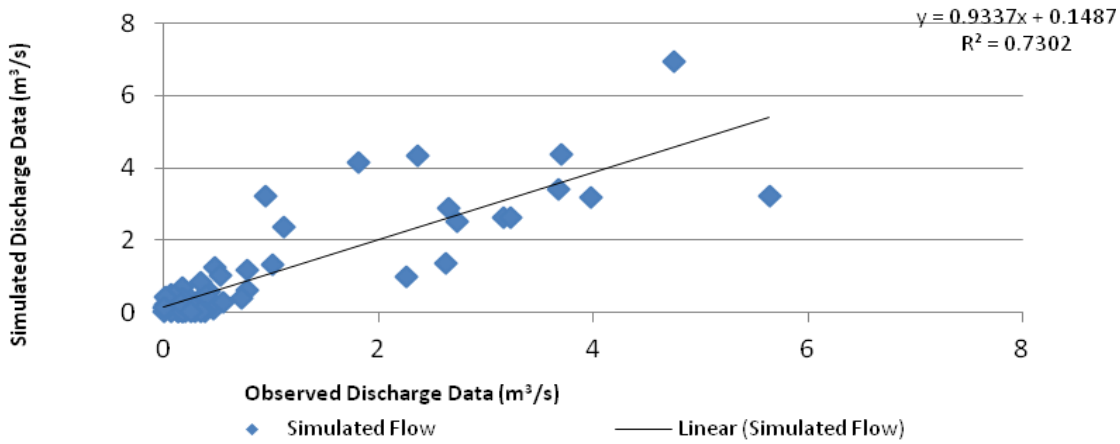

Figure 12. Scattered plot and correlation between simulated and observed monthly flow during validation.

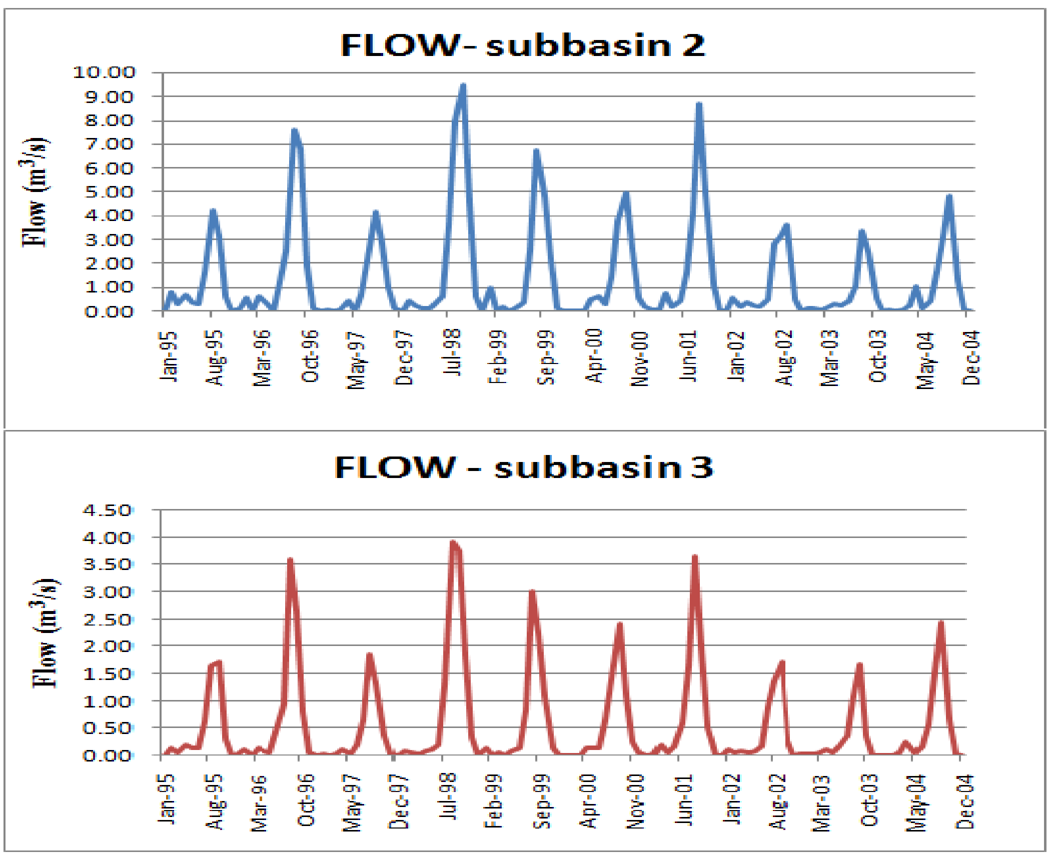

Figure 13. Monthly SWAT simulation result at subbasins 2 and 3.

model performance was good in the acceptable limit.

Runoff estimation for Holetta catchment

In this study, spatial proximity method was used to estimate runoff at subbasins 2, 3, 4 and 5 where majority of the users are located. Figures 13 and 14 showed the monthly simulation result of SWAT model at the subbasins.

The mean flow (m^3/s) that was simulated by SWAT model at the subbasin 2, 3, 4 and 5 is shown in Table 3.

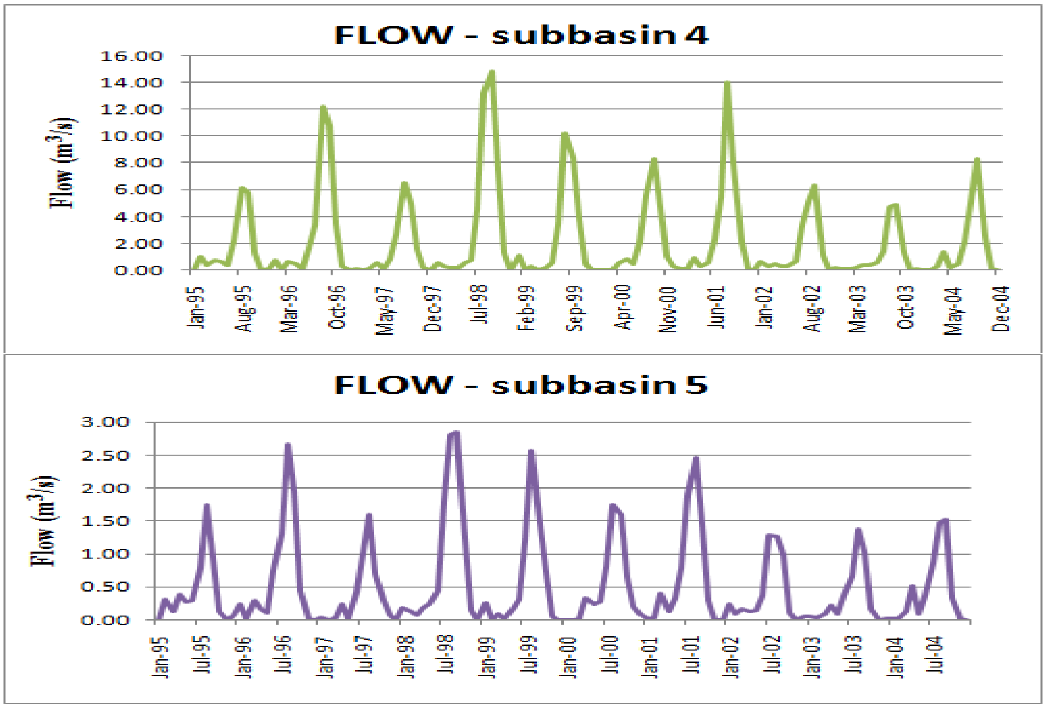

Figure 14. Monthly SWAT simulation result at subbasins 4 and 5

Table 3. 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)
1	1.358	1.351	1.358
2	0.564	0.561	0.564
3	2.109	2.099	2.109
4	0.525	0.522	0.525

Conclusion and recommendation

This study was conducted to estimate runoff at Holetta catchment and to model rainfall runoff relation in the area. The rainfall runoff process of the catchment was modeled by SWAT. According to SWAT classification, the watershed was divided into 6 subbasins and 33 hydrological response units (HRUs). Only subbasin one was gauged which is found in the upper part of the area. 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 catchment. The result of sensitive analysis showed that 26 parameters were sensitive; out of 26, eight were 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. Then, the calibrated model was used to estimate runoff for the ungauged part of the catchment, that is, subbasin 2, 3, 4 and 5.

SWAT model was used to estimate runoff at Holetta catchment and the performance was evaluated based on statistical and graphic methods. Even though the model performance was good, the accuracy was highly dependent on quality of data. The Holetta catchment has only one gauging point and the total area is 403.47 km^2. Therefore, in order to improve data quality, it is better to increase the gauging station in the catchment. In addition to this, in poorly gauged areas, use of satellite data is very advantageous.

The SWAT model performed well for simulation of the hydrology of the watershed, therefore it can be used for further study to estimate sediment yield in the area and to evaluate the effect of different catchment changes on the river.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Characterization of Beles River Basin of Blue Nile sub-Basin in North-Western Ethiopia using Arc-Hydro tools in Arc-GIS

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Ethiopia is constantly affected by shortage of water for rain-fed agriculture, mainly because of lack of proper water resources utilization and management practices. For the efficient use of available surface water resources with balanced attention to maximize economic, social, and environmental benefits, it is necessary to have effective integrated water resources assessments and planning. Beles River Basin is one of the most potential river basins in Ethiopia, which is the main tributary for upper Blue Nile River Basin and accounting 14,200 km^2. In order to supplement planning and development of this area, a detailed characterization of the basin is important. The main objective of this study is to process and determine different terrain processing parameters and morphology by using Arc-Hydro tools in Arc-GIS for generating different data for the basin. Therefore, it has been observed from this study that the drainage density is higher in relatively elevated areas especially when the weathered section is thick or when the pattern of structures crossing the rocks is higher. Direction of flow of these rivers is controlled by the topography. The highlands (maximum 2729 m above sea level) from where the streams flow are general humid and rugged and the surrounding lowlands (minimum 458 m above sea level) in which the streams flow, are mostly arid and relatively flat. These topographic differences induce rapid run off, low retention in soil layers and soil erosion on the highlands. Considering a 30 × 30 m drainage area, 62 catchments, eight flow directions with 128 flow grids have been identified in the basin. The delineated watersheds were Gilgel Beles with 617.56 km^2, Upper Main Beles with 2866.05 km^2 and Lower Main Beles with 6613.84 km^2. Therefore, the watershed external boundary is determined to be 10,097.45 km^2. Important basin information, like slope and contour lines has been determined through spatial analysis and the result indicated that about 52.8 % of slope was found to be relatively suitable for agricultural soil and water management options in Beles River Basin. In the future, it would be advisable to consider emerging issues in water resource measures like GIS modeling with Remote Sensing data for effective and efficient water resource management when there is limited and lack of data.

Key words: River basin, Arc-Hydro, Arc-GIS, Degital Elevation Model (DEM).

INTRODUCTION

It is well known that water is life; now a day's different report shows that water is also a means livelihood. It is the route to come out of poverty for individuals and communities. Managing water is essential if the world is to achieve sustainable development (Cosgrove, 2006). This challenge is even more pressing as the world confronts the triple threats of climate change, rising food and energy costs, and the global economic crisis. All three are exacerbating poverty, inequality and underdevelopment (UNWWD, 2006; FAO, 2010). Hence, in many places of the world, there is competition for water resources because the population is increasing every day this means a major production of foods depends on the judicioisex3 and consumption of the available water resources (Abbadi and Nitin, 2011). Besides, the distribution of water is very irregular in space and time. This challenge needs the use of different tools that allow professionals and specialists to plan for improving the use of water resources effectively and efficiently in their respective regions (Tesfaye and Kemal, 1989). One of the most important tools that can be used to that end is Geographic Information Systems (GIS). It is a system with different features which enables to analyze and store as spatial information for being used later with other models of water resources. Besides there are many databases which are available on internet such as climate variability, soil, land use/land cover, gauging stations, and these can be processed in geographical information system GIS (Jasrotia et al., 2009). It is playing a great role by being used as an important tool for hydrological modeling, and it processes Digital Elevation Model (DEM) to delineate watersheds and stream network (Maidment, 2002). In that sense, hydrologists use several data sources to evaluate water quality, quantify water allocation, avoid flooding, plan and operate water resources systems, and interpret environmental problems. Likewise, experts or specialists and people involved in water resources who use GIS as a tool and as a database are increasing dramatically though out the world. Therefore, GIS today is being accepted as a powerful tool for storing spatial information around the globe (Walker and Zhang, 2001).

The overall objective of this study was to characterize and determine different terrain processing parameters and morphology, by using Arc-Hydro tools in Arc-GIS for generating different data for Beles River Basin. The specific objectives are: (1) determine and identify streams and drainage lines, (2) classify watershed and sub-watersheds and determine their respective areas, and (3) generate information of the basin for water resource and river basin management.

MATERIALS AND METHODS

Study area

This study focuses on the Beles River Basin, it is situated on the plateau of the north-western highlands and its adjacent lowlands of Ethiopia, in the southwestern direction of Lake Tana between 10° 56’ to 12° North latitude and 35°12’ to 37° East longitude. The total area of the basin is about 14,200 km^2. The topography of the area is mainly flat with altitudes variables from 458 to 2729 m above sea level. Beles is one of the most important basins in Ethiopia and one of the major sub-basins of Upper Blue Nile Basin (Figure 1).

Data sources and processing

The data source for this study, that is, ASTER Global DEM (GDEM) from the Ministry of Economy, Trade and Industry of Japan (METI) and the National Aeronautics and Space Administration (NASA) are collaborating on the project in order to develop ASTER Global Digital Elevation Model (ASTER GDEM), DEM data which are acquired by means of a satellite-borne sensor, so-called "ASTER", to cover all the surfaces of the earth (http://Earthexplorer.usgs.gov) carried out with a resolution of 1 arc second (30 × 30 m of position) digital elevation raster which covers almost the entire globe. These facilities allowed to download a DEM data for the study area in which four tiles having 170/52, 170/53, 171/52 and 171/53 path/row was first rectified, corrected and geo-referenced to the UTM (WSG-1984 UTM-37N) projection system. Before processing DEM, a buffer of the study area has been used to create a mask. Using DEM as input raster, all information of the area was extracted by masking and feature mask data was the Beles buffer (Figure 2).

Mosaic (Arc-GIS 9.3) standard DEM of four different tiles in one new raster by using Arc-Tool box and also processing seemless raster mosaic since it is necessary to fit the tiles together and for better visualization of mosaic image. The coordinate system was converted from geographic systems to a projected geographic system, by using Arc Tool box (Data Management Tools, projections and transformations, raster, project raster) in Arc-Map. Universe Transverse Mercator (UTM) was selected because it is a coordinate system that is more adaptable to the study area, and then extraction through spatial masking to clip processed DEM data to Beles River Basin (Figure 3).

RESULTS AND DISCUSSION

Terrain data processing

A terrain data processing has been started with the identification of drainage and catchment patterns through DEM which was mainly used to prepare the spatial information of the Beles River Basin for the subsequent use. The Digital Elevation Model was processed using Arc-Hydro Tools 9 in Arc-Map, because the application of this tool allowed generation of information of flow direction, flow accumulation, stream definition, stream segmentation, drainage lines, and watershed delineation for the Beles River Basin (USACE, 2010).

Once the area was specified, DEM reconditioning is necessary to consider unclear flow direction which occurred by any surface alteration. This technique allowed the adjustment of the surface of elevation of the DEM to be consistent with vector coverage. Therefore, it

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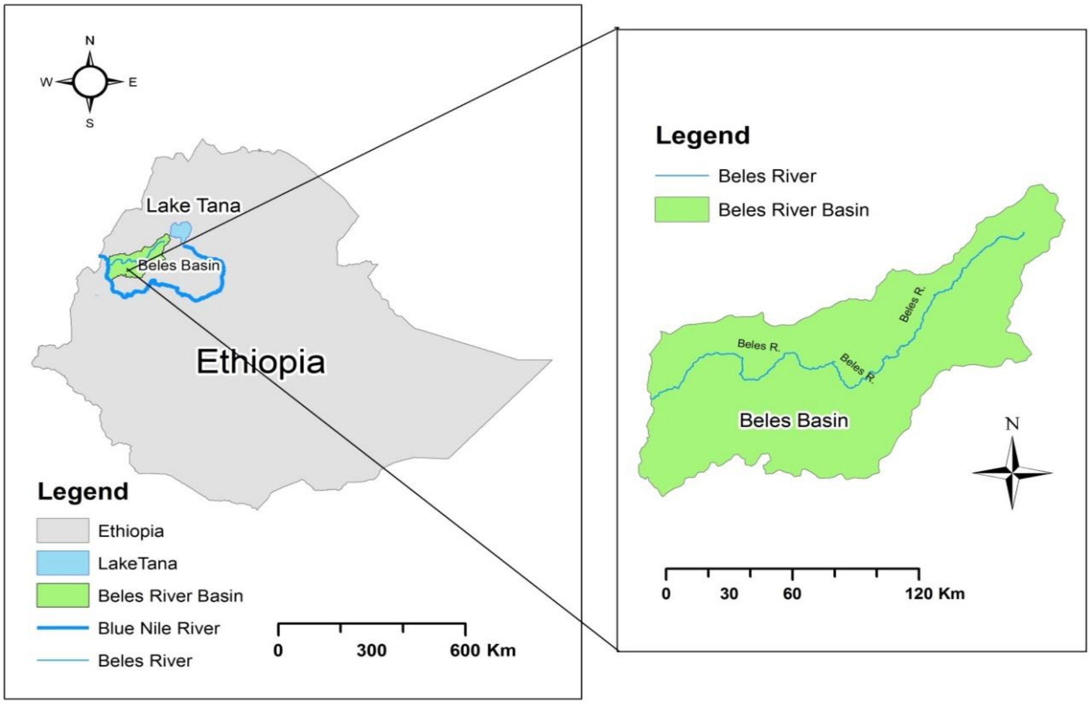

Figure 1. Location of Beles River Basin (a) in Ethiopia and (b) with enlargement.

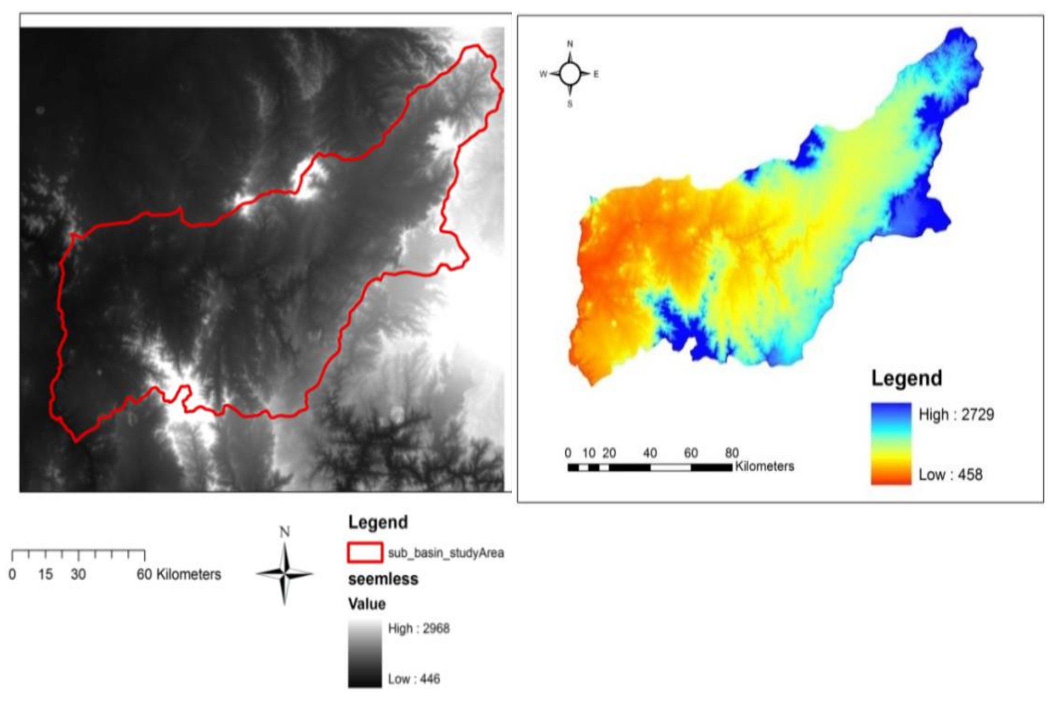

Figure 2. Delineation of River Basin from DEM by using (a) Buffer and (b) Elevation Model.

helped to find cells in a DEM with low elevation enclosed by other cells with high elevation. These low cells, so called "sinks", may be formed by the landscape features or errors during the DEM generation as well as by the limited resolution of the Digital Elevation Model. The sink is filled until it will drain the water to the next lowest point by using "fill sink" tool in Arc Hydro with Arc Map interface (Maidment, 2002).

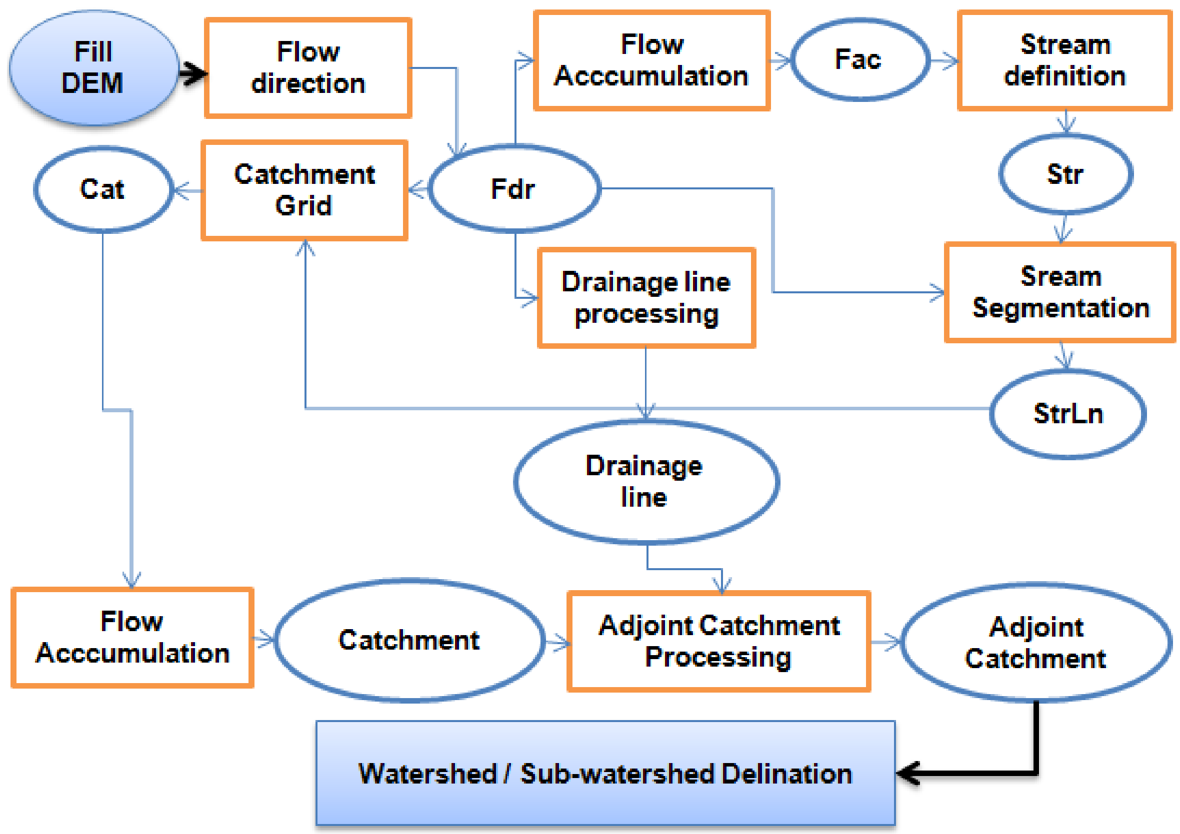

Figure 3. Flow chart of conceptual framework working in GIS.

Flow direction and accumulation

The flow direction for the Beles River Basin was determined for the filled DEM, which is one of the most important for generating the hydrologic characteristics of the river basin. In Arc Map, the flow direction function calculates the direction of the flow out finding the direction of the steepest descent from each cell in the grid. There are eight output directions in which the flow of a cell can move in the basin (Figure 4).

The flow accumulation for the Beles River Basin was calculated taking as base the flow direction (Figure 5). Its procedure consisted of calculating the accumulated flow for each cell as the weight of each of them which flows through down slope. Therefore, the output of the flow accumulation represents the amount of water which would flow through each cell and it is also used as a base to create the drainage lines.

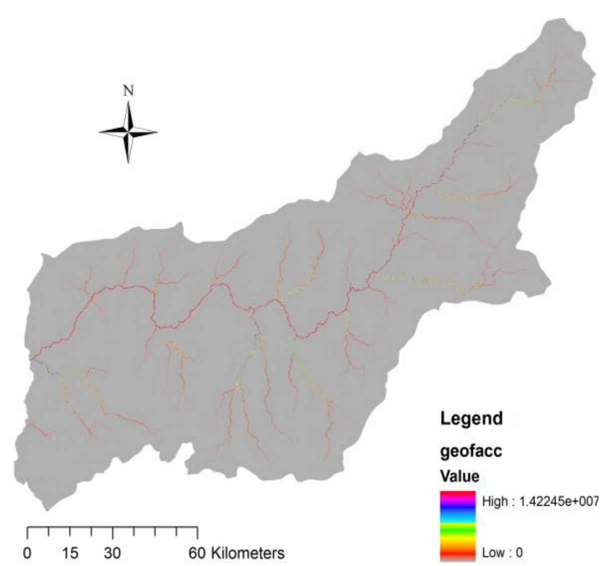

Figure 4. Flow direction grid for Beles River Basin.

Stream definition and segmentation

The streams definition for the Beles River Basin was made considering the default threshold for cells of 30 × 30 m. It was to identify the threshold drainage area used to generate a stream in the study basin. After the definition of streams, a grid of stream segments was created by using the “stream segmentation” function in Arc Hydro Tool. In Figure 6, the detailed stream definition for the basin of study is shown.

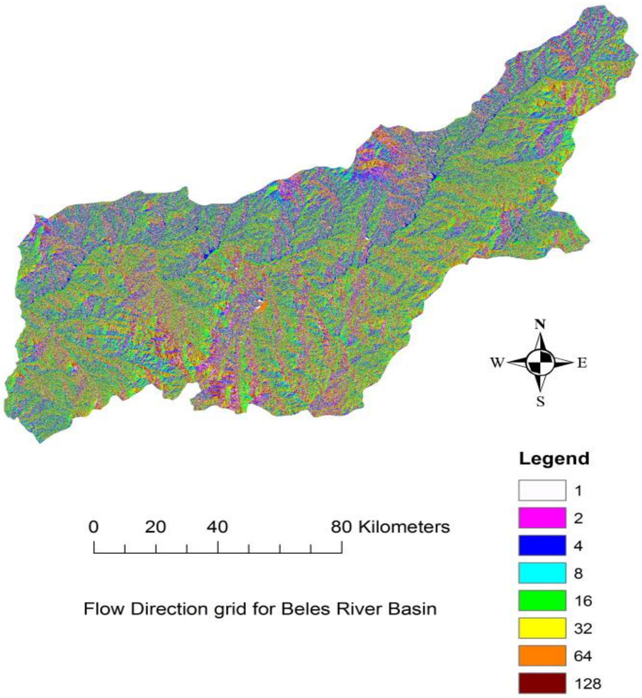

Figure 5. Beles basin flow accumulation.

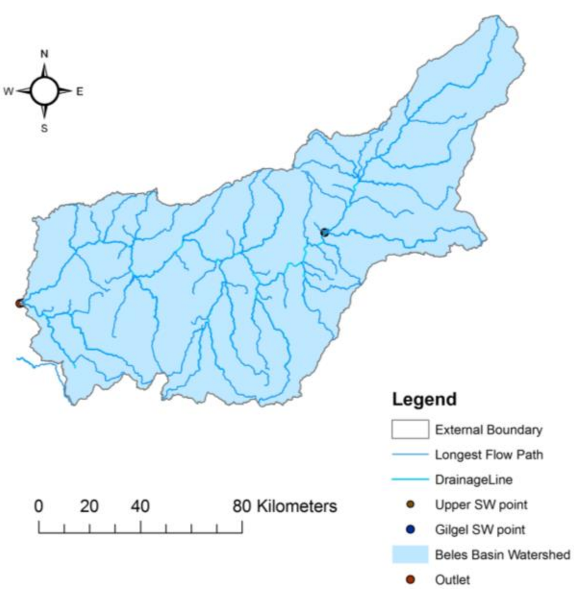

Figure 6. Stream definition (top left).

Catchment grid delineation and polygon

Catchment grid delineation in Arc Map allowed creating a grid for segment in the stream link grid (stream segmentation). These functions allowed converting the raster data into a vector format. Catchment polygons were created from the catchment grids, and by converting

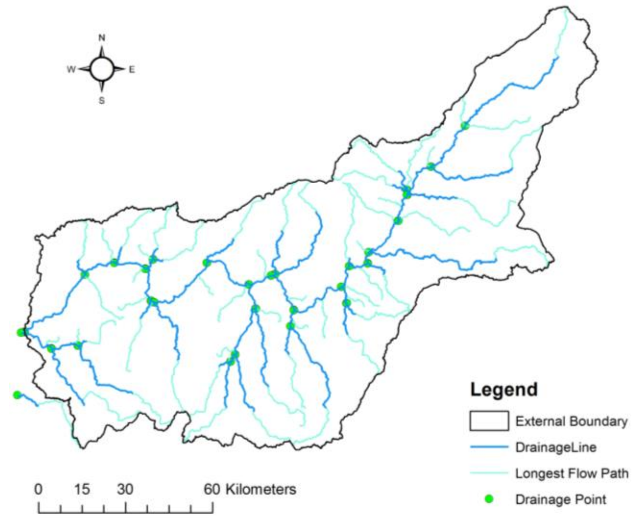

Figure 7. Catchment grid delineated for Beles Basin (top right).

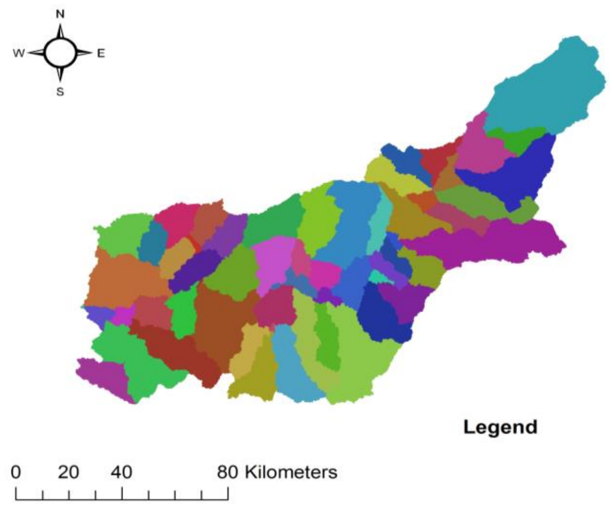

Figure 8. Catchment polygon of Beles Basin (bottom left).

the stream link grid into a drainage line feature created by drainage lines. For Beles River Basin, 62 catchments were created and also a drainage line belongs for each of them. Moreover, this method could allow us to identify the drainage areas into each stream link as shown Figures 7 and 8.

Drainage line, and drainage point processing

These functions are allowed to convert the raster data into a vector format. Catchment polygons were created from the catchment grids, and by converting the stream link grid into a drainage line feature created by drainage

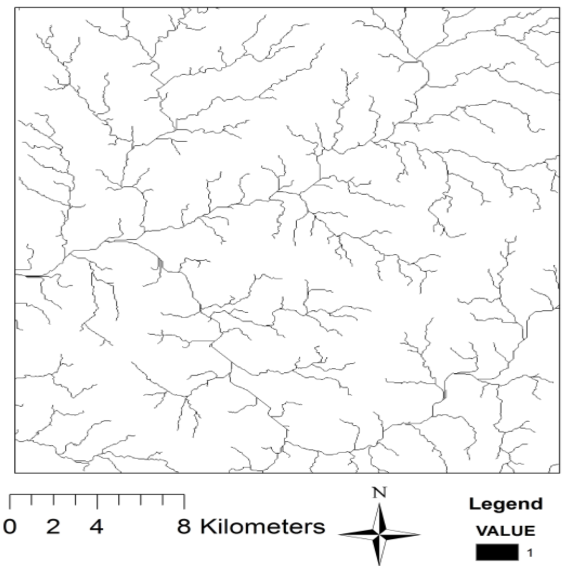

Figure 9. Drainage line and point of the basin.

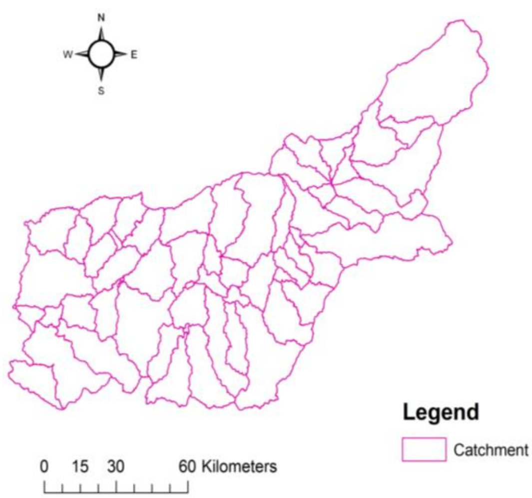

Figure 10. Delineated watershed for Beles River.

lines. For Beles River Basin, 62 catchments were created and also a drainage line belongs to each of them. The catchment polygon, drainage line processing and drainage points generated are as shown in Figures 9 and 10.

Watershed processing

In watershed processing delineation of the watershed and sub-watersheds as well as determination of the flow path in the river basin have been done. Arc Hydro in Arc Map was used to carry out this process. In this part, a bath point was created in the outlet of the basin in order to delineate it. After that, the sub-watersheds are delineated by using the sub-menu batch sub-watershed delineation.

Batch watershed delineation

The drainage lines, accumulated flow, flow lines and the preliminary delimitation of the river basin fundamentally have delineated the watershed. Firstly, outlet point was created on the flow accumulation path where the flow leaves the Beles River Basin which in this case, the point is where exactly Beles River meets the Blue Nile at the extreme bottom of the catchment of the basin since it is one of the tributary of Blue Nile. For this end, the “Batch Point Generation” button in Arc Hydro was used. This point can be used as an input for using the “batch watershed” and “sub watershed delineation” functions. The drainage area of the delineated watershed is 10,097.45 km^2.

Batch sub-watershed delineation

The sub-watersheds are divisions based upon the drainage area, divided by a watershed. In this part, sub watershed was created for every point in the bath point feature class; and the result was stored in a sub-watershed feature class. Therefore, sub watersheds were delineated by considering three very important points in the river basin. Two of them are located on higher ground of the basin through which the major amount water resources drain from those sub watersheds. Another point is located in the outlet of the Beles River Basin, and it defines the sub watershed in the lowest altitude. Once the watersheds have been defined, they were used as measurement areas to calculate different parameters. The drainage areas cover surfaces of 6613.84, 2866.05, and 617.56 km^2 for the sub watershed Lower Main Beles-Outlet, Upper Main Beles, and Gilgel Beles, respectively. The results of the delineation of the sub-watershed are as shown in Figure 11.

Spatial analysis

Slope and contour lines

The slopes and contour lines were calculated with “Spatial Analyst” tool in Arc GIS by using Beles-DEM as input, then slopes and contour lines were calculated as output. The mean slope calculated for Beles watershed was 3%. With regard to the sub watersheds, the values of mean slope were 3.8, 1.9, and 3.3% for upper main Beles, Lower Main Beles and Gilgel Beles, respectively. The result showed that 41.3% of the basin was less than

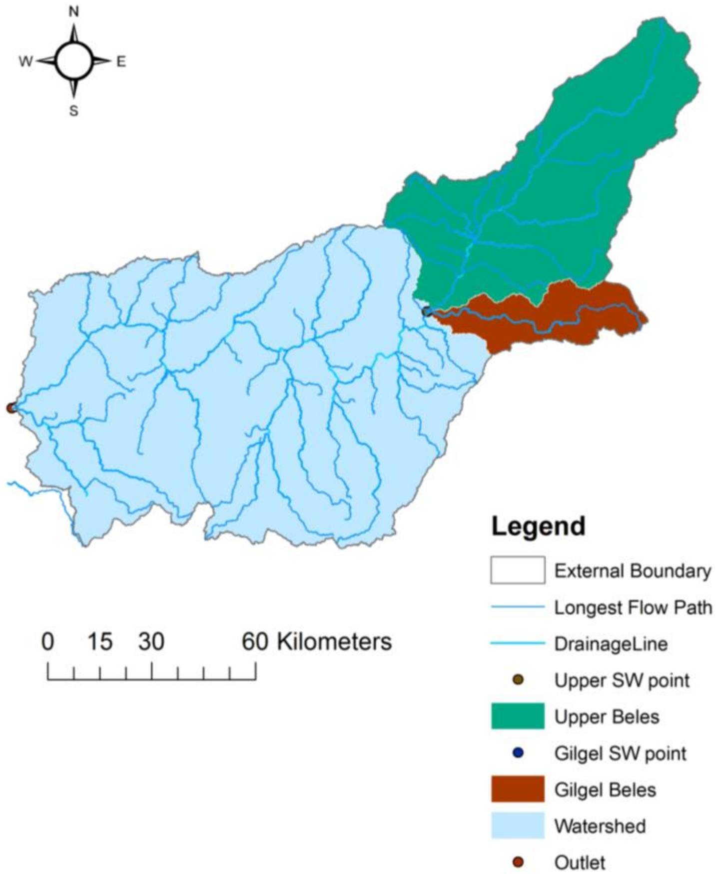

Figure 11. Delineated sub-watershed for Beles River.

3% of slope, 11.5% of the basin was from 3 to 5% of slope, 19.4% from 5 to 9% of slope and 27.8% of the basin slope was greater than 9%. Therefore, with regard to the mean slope calculated for the watershed and sub-watersheds, the values were higher for the Upper Main Beles, indicating that this area where the stream lines start to drain down the watershed is at higher elevation. The input surface was the Beles DEM with a contour line distance of 50 m interval (Figures 12 and 13).

Conclusions

The conclusions of this work are summarized in the following paragraphs.

Delineating and organizing data for river basins, like Beles River Basin for which where information and databases are not available, by using an "Arc-Hydro" in Arc-Map which is powerful as well as a decision supporting tool. So, this project shows the possibility of using information available on the internet and processing it with "Arc-Hydro" tool, in order to generate and store data which will contribute finally to improve the operation and planning of the water resources systems in the Beles River Basin.

The drainage density was higher relatively in elevated areas especially when the weathered section is thick or when the pattern of structures crossing the rocks was higher. Direction of flow of the river was controlled by the topography. The highlands, from where the streams flow, are in general humid and rugged and the surrounding lowlands, into which the streams flow, was mostly arid and relatively flat. These topographic differences induced a rapid run off, low retention in soil layers and soil erosion on the highlands.

The delineated watersheds were Gilgel Beles with 617.56 km^2, Upper Main Beles with 2866.05 km^2, and Lower Main Beles with 6613.84 km^2. Therefore, the watershed external boundary is determined to be 10,097.45 km^2. The sub-watersheds of Upper and Lower Beles River are the main source of water resources in the basin which may be related to their area and the mean annual rainfall recorded in the respective sub-basin.

From the spatial analysis, important basin information, like slopes and contour lines, has been determined and the result indicated that about 52.8% of slope was found to be relatively suitable in agricultural soil and water management options in Beles River Basin.

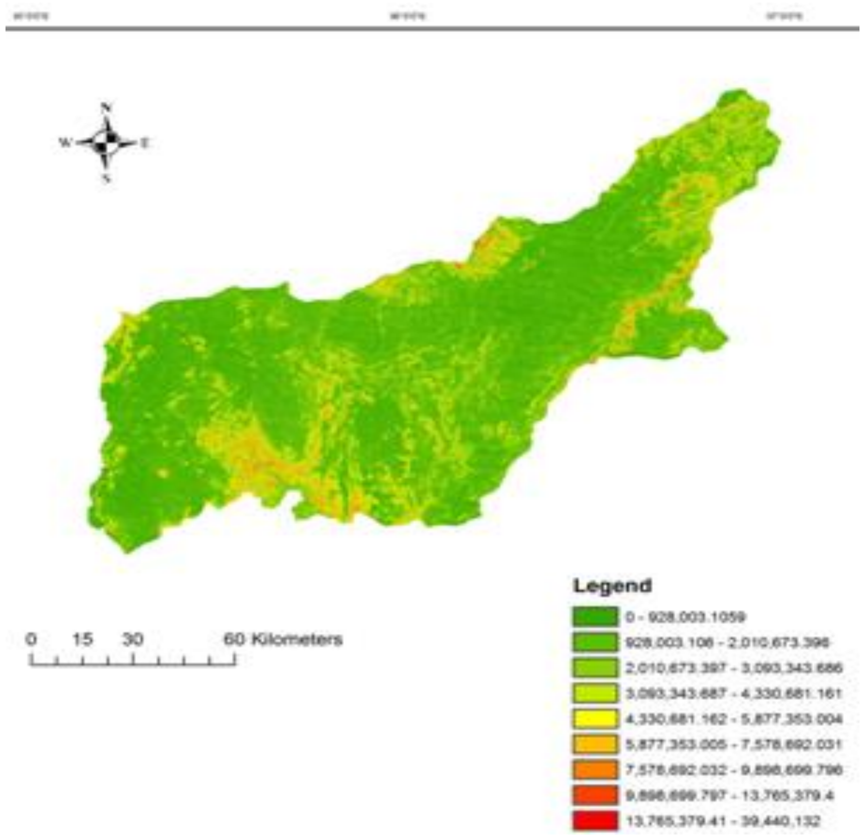

Figure 12. Slope percentage for Beles.

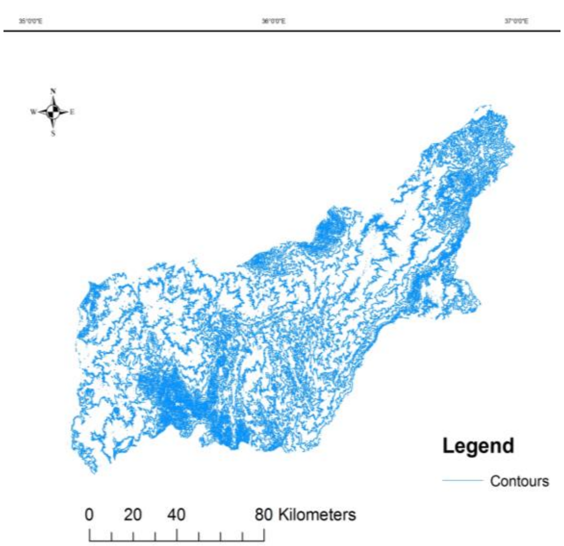

Figure 13. Contour lines of Beles River Basin.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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