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Water Resource Assessment and Management Options in Beles River Basin using HEC-HMS Model

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Abstract
Ethiopia is commonly referred to as "the water tower of east Africa", because of the huge amount of surface runoff from the Ethiopian highlands that make up over 86% of the flow of the Nile River but 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 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 Blue Nile River Basin and accounting 14,200 km2. The objectives of this study was to assess the available surface water resources in the Beles River basin, using a HEC-HMS hydrological modeling system by estimating surface runoff and simulating hydrological processes due to distributed land use, soil, climatological and hydro- metrological condition in the entire river basin. The GIS layers that were used as input data for the flow simulation were prepared using Arc GIS 9.3 and used in the HEC-HMS 3.5 calibration of the Beles River sub basin using daily precipitation and flow data from 2003 and 2004 and validated by 2005 and tested statistically by relative error and the residual method. Then the validated surface runoff is used for water balance assessment. From the delineation of the entire basin and sub- basin; it has been obtained that drainage areas of 9078.20 km2, 3461.80 km2, and 747.11 km2 for the sub watershed Lower, Upper, and Gilgel Beles respectively. Result of mean monthly simulated runoff show that 76mm for Gilgel Beles, 55.7 mm for Upper Beles and 42.4 mm for Lower Beles. According to the result of water balance assessment; the highest water deficit was observed in 2004 (-463 mm/yr) & 2003 (-180 mm/yr) of Lower Beles but 2004 for Gilgel Beles (129 mm/yr) and Upper Beles (61.24 mm/yr) was observed to be a water surplus year were as 2003 showed the deficit year in the entire basin. However, there is no significant change in soil moisture storage in Beles River Basin in 2005. In the future, it would be advisable to consider immerging issues in water resource assessment like GIS modeling with Remote Sensing data for effective and efficient water resource management and planning when there is limited and lack of data.
Keywords: River Basin, HEC-HMS, Beles and DEM.

1. INTRODUCTION

Ethiopia has about 3.8 million ha of the cultivable land area is potentially irrigable but, so far, only about 289,000 ha has been irrigated (FAO, 2014). According to (MoWR, 2013), the total renewable freshwater (mean annual flow) of the country is estimated at 122 billion m^3, and 54.4 billion m^3 of surface water and 2.6 billion m^3 of groundwater could be developed for utilization. Currently less than 5% of the surface water potential is used for consumptive purposes while groundwater is virtually untouched.

The river Nile is one of the longest rivers in the world and the basin area covers approximately 10% of the African continent. According to the World Bank (2015), the Nile River Basin is home to an estimated 229 million people in the year 1995 while the basin can be characterized by dramatic increasing of population load, variability and natural resource losses leading to poverty (Conway, 1997). Also by climate and land use changes, recurrent droughts may further effect agricultural production and food supply in Ethiopia (Diriba *et.al,* 2013). For efficient use of available water resources with balanced attention to maximize economic, social, and environmental benefits, it is necessary to have effective integrated water resources assessments and planning (Jyrkama and Sykes, 2007). The most potential concern of this study is hydrological components which are subsequently changes Beles river basin water balance. Among the water balance components surface water inflow from gauged and un-gauged catchments, precipitation and evaporation pattern and their impact on Beles river basin water balance is not yet studied well. On the other hand, water resource planning and management requires information of inflows from each catchment and total out flow from the entire river basin. There are only few researches available, which well discussed on Beles river water resource management (Ashebir, 2017), Collick et.al (2008) and Conway (1997). However none of them performed sub-basin stream flow simulation for gauged and ungraded catchment and indicate the available water sources in the river basin with aid of integrating remote sensing and GIS application tools using HEC-HMS. Therefore; surface water balance simulation using HEC-HMS model with the help of using remote sensing & GIS for integrated water resources management may be a better option to fill this gap in the river basin (Jasrotia et.al, 2009).

Hence, the overall objective of this study is to assess surface hydrological dynamics and evaluate distribution and the available water resource using water balance model which can support planning and decision making process to improve water productivity for sustainable agricultural production in the entire river basin. The specific objectives are: (1) to assess the available water resources in the entire river basin, (2) to estimate surface runoff and evapo-transpiration distribution for sustainable water resource utilization in the basin, (3) to simulate hydrological processes using land use, soil, climatological and hydro metrological input parameters and generate data in the entire Beles river basin.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The Beles basin is situated on the Plateau of the north-western highlands and its one of the major tributary of Blue Nile. Its geographic location between from 10°56'00" to 12° 00'00" N latitude and 35°15'00" to 37°00'00" E longitude (Figure 1) and total area of the basin is about 14,200 Km2. The topography of the area is mostly flat with altitudes between 458 m and 2729 m above sea level. The Beles basin is one of the most important basins in Ethiopia. It is one of the major sub-basins of upper Blue Nile basin. The recorded mean annual rainfall ranges from 700 mm to 1800 mm, annual average daily minimum and maximum temperature ranges between 16^{o}c and 33^{o}c and Annual potential evapo-transpiration is about 1500 mm.

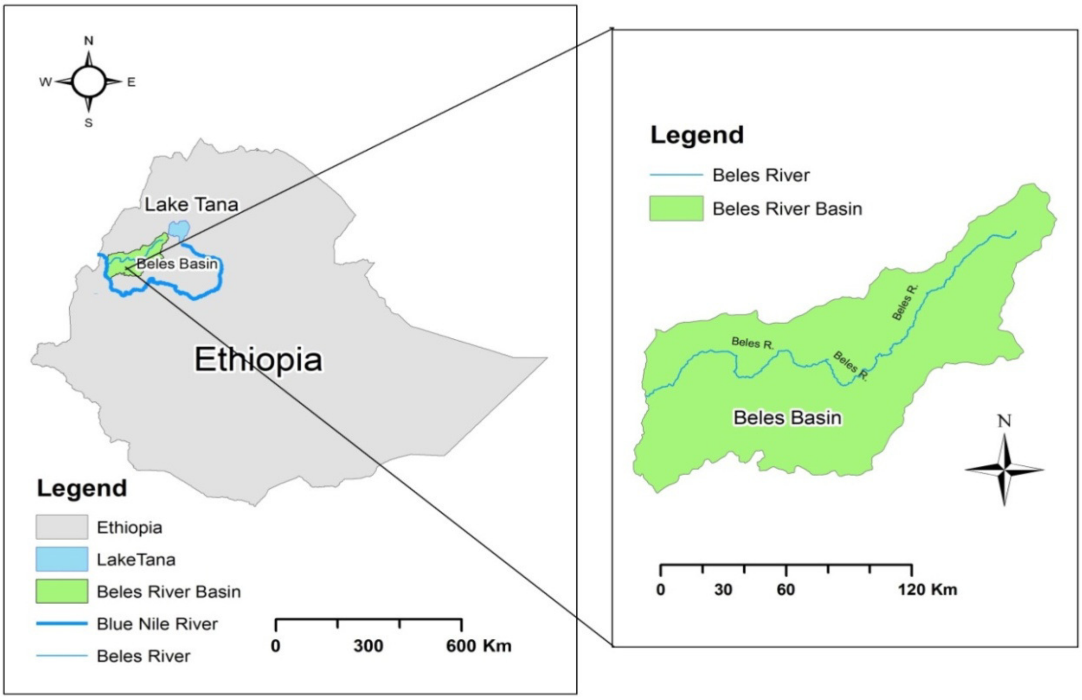


Figure 1. *Location of Beles River basin.*

The previous studies of the area (Ashebir (2017), Collick et.al (2008) and Conway (1997)), showed that the basin has a substantial potential for irrigated and hydropower development. According to the information from Euro consult Mott MacDonald, the total estimated irrigable area in the basin is about 260,000 ha. It represents some 50% of the total irrigable area in the Abbay (Blue Nile) basin. The area is suitable for growing industrial crops that have considerable export potential. There is also a possibility of groundwater availability in the area (World Bank 2015).

2.2 Data Description and Processing

The conceptual framework of this study indicated in the flow chart (Figure 2) starts with collection of hydrological and metrological data. Hydrological data of daily flow discharge was used for model calibration and validation for runoff simulation. Using metrological data total PET was calculated and with rainfall used as input for the model. Combination of Remote Sensing and GIS are the main tools used for terrain processing and watershed delineation in HEC-GeoHMS and digital map is produced as main input for the model. Land cover and soil data were also inputs for the model. Finally, model calibration is made and if its fitness is good model validation is undertaken; otherwise model calibration iteratively continues till the best fit is obtained. The final step of the overall process was a water balance assessment.

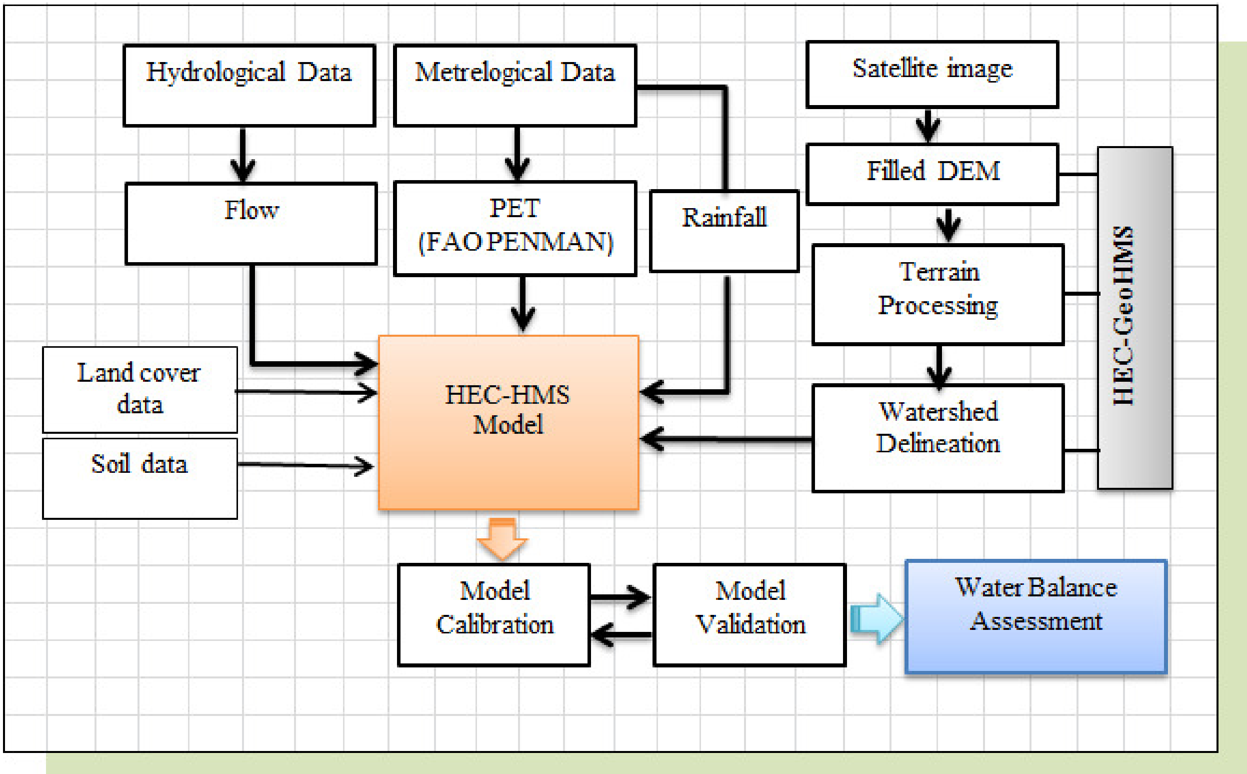


Figure 2. *Flow Chart Showing the Input Data.*

For this study, 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 to develop ASTER Global Digital Elevation Model (ASTER GDEM), DEM data which are acquired by the satellite-borne sensor "ASTER" to cover all the land of the earth (http://Earthexplorer.usgs.gov) finished with a resolution of 1 arc second (30*30 meters position) digital elevation raster that covers almost the entire globe.

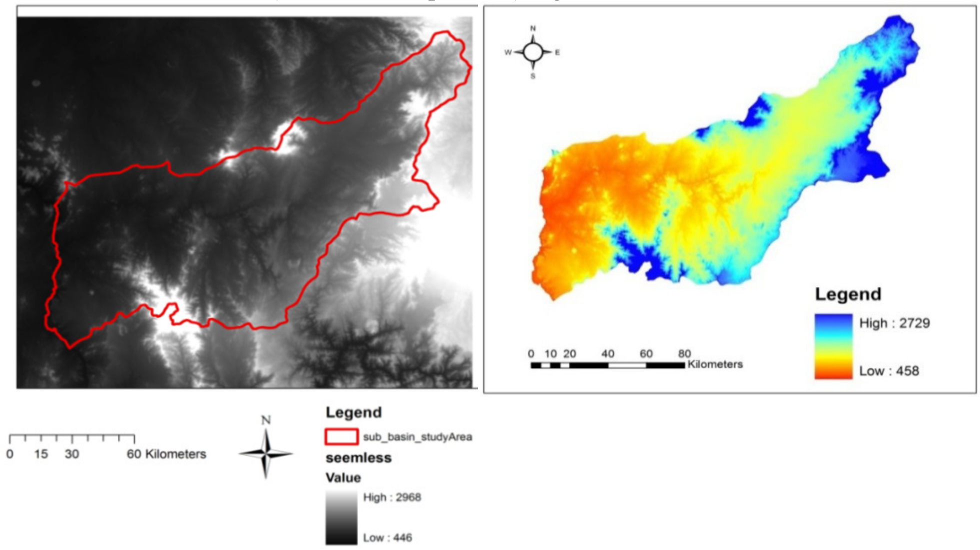


Figure 3 . *Delineation of River Basin from DEM using Buffer and Elevation Model.*

These facilities allowed downloading a DEM date for the study area (Figure 3) 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.

2.3 Model Calibration and Validation

Calibrating the model was done separately for gauged Beles sub basin. Two years (2003 & 2004) daily recorded data was taken for calibration. During calibration of the models a simple sensitivity analysis was simply observed to have understanding and simply identifying the most sensitive model parameters which mead the processes easy. This was followed by a manual trial and error procedure until the result of the calibrated model was considered acceptable.

But for the model validation, the degree of accuracy of parameter estimates was assessed by applying the model to different data set (2005) which was not used for calibration. Thiemig et al. (2014) defines validation as a process of demonstrating capability of a given site-specific model to make predictions satisfactorily accurate at other site and/or outside the calibration period. Model performance was evaluated by percentage Relative Error (RE) which is expressed by the ratio of the difference of simulated and observed flow to the observed flow as indicated by the following parameter (Equation 1).

Equation 1 . Percentage of Relative Error.

$$RE(\%) := \left(\frac{Simulated - Observed}{Obseved\ flow}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2.4 Water Balance Model Simulation

Water balance model simulation is the most common method of water assessment in those areas where there is lack of availability data and also the input parameters are very limited to assess water availability in the entire Beles River Basin (Rybak and Volodin, 2015). In Beles River Basin there is no surface inflow and irrigation in the 2003 to 2005 inflows and outflows in the system. The major components for water balance assessment of surface storage was included as precipitation (P), Losses (precipitation loss due to Evapo-transpiration (ET), interception, infiltration river outflow (Q) and change in surface storage (ΔS) as indicated in equation 2.

Equation 2. Water Balance Model.

ΔS = **P – Losses** (Evapotranspiration + Infiltration + Interception) **– Q** ………… (2)

Precipitation and Discharge data in river was acquired from the rain gauge information monitored by the Ethiopian Metrological Agency and form the Ethiopian Ministry of Water Resources of Ethiopia respectively. The assessment was done for each sub basin and the availability of water has been compared.

3. RESULTS AND DISCUSSION

3.1 Cover Monthly Evapotranspiration of Beles Sub-Basin

The monthly evapotranspiration for each station in the basin is estimated using the standard method and the data used to determine ET of the basin is minimum and maximum temperature, Relative Humidity, Wind Speed and Sunshine hour. The stations used are Pawe, Bullen, Mandura and Dangilla.

Table 1. *Monthly Potential Evapotranspiration of Beles River Basin*

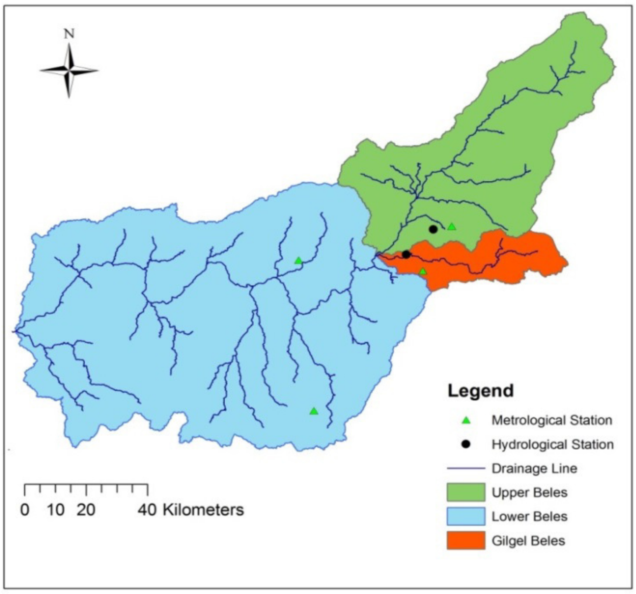
	Upper Beles											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2003	115.6	115.1	138.3	153.1	160.3	109.4	89.3	91.8	101.4	111.9	104.8	107.6
2004	116.6	119.7	143.4	144.2	153.3	105.0	100.8	94.0	101.7	107.0	100.0	106.0
2005	112.7	120.8	137.5	147.0	142.0	111.7	84.4	95.5	102.0	103.5	101.5	104.0
	Gilgel Beles											
2003	125.5	123.7	140.0	154.4	154.7	99.4	87.4	87.8	94.2	109.1	112.1	118.0
2004	128.4	124.1	153.8	138.0	143.0	93.2	90.0	86.5	88.0	106.9	104.5	115.5
2005	123.6	130.7	143.9	149.6	144.8	100.0	82.0	85.8	91.5	95.8	105.9	119.2
	Lower Beles											
2003	130.0	135.1	170.1	174.1	163.3	138.7	101.8	101.4	107.7	123.6	117.6	122.5
2004	128.0	135.6	158.9	155.2	161.2	119.3	111.7	109.1	117.3	120.4	121.0	117.4
2005	124.1	134.4	154.1	159.2	155.7	127.3	106.3	115.1	112.4	116.3	116.9	115.1

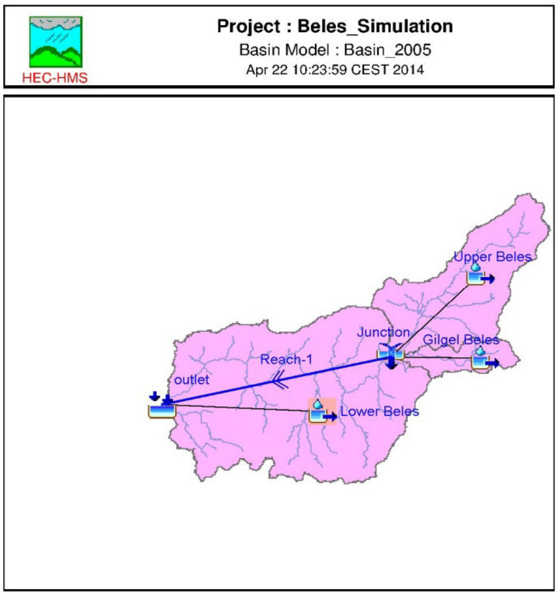
The mean monthly evapotranspiration of three year doesn't show a significant different but it is increasing from upper sub basin to lower sub basin. The lower Beles is found in lower elevation and it has higher monthly evapotranspiration. In most cases the lowest is estimated from July to September which is wet season in the study area. This calculated PET was used as the input for the calibration of the HEC-HMS model.

3.2 Map of Basin Processing and Sub-Watershed Delineation

After Basin processing in HEC-GeoHMS three sub basin has been delineated and having the following information and used as a digital map for simulation of runoff in HEC-HMS. The drainage areas are 9078.20 km2, 3461.80 km2, and 747.11 km2 for the sub watershed Lower, Upper, and Gilgel Beles respectively. The results of the delineation the sub-watershed are indicated in Figure 6 below.

Figure 4. *Map of Sub-watershed (bottom Left) and* ***Figure 5.*** *HEC-HMS Runoff Simulation Model for the Beles for 2005 (bottom right).*





All the hydrological elements and characteristics generated was mainly Basin model, Metrological model and control specification had been created is HEC-GeoHMS in GIS was exported to HEC-HMS model, then the background map of the basin and river network is imported to the model separately. All the data is exported with the name of basin model and the life of GeoHMS and GIS terminated in this phase as indicated Figure 7 above.

3.3. Total Loss in the Beles River Basin

The result showed that HEC-HMS model take in to account loss as precipitation a loss which is mainly influenced by Evapo-transpiration, plant interception and depression storage**.** For estimation of surface runoff the model uses total monthly Evapo-transpiration which may influence the result of surface runoff simulation. Hence, the simulation results of surface runoff from 2003 to 2005 show that the mean monthly loss values are higher during May to October and lower values are at September to January for each sub basin. The mean annual loss was 48 % of total annual precipitation loss but in 2005 from total annual rainfall 55 % was lost in Gilgel Beles. 29% of mean loss was from total annual precipitation in Upper Beles but only 19% of mean loss was from total annual rainfall in Lower Beles but about 64% of mean annual runoff came from total annual rainfall in this sub basin. Form the result it can be conclude that the highest loss was from agricultural land, forest and settlement or urban areas since the urban areas are mainly impervious surface with lower losses.

3.4. Water Balance Assessment of Beles River Basin

Based on the assessment result of daily simulation of the hydrological components of the Beles River Basin from 2003 to 2005 for each sub basin, showed that losses exceed precipitation in most of months in the year of sub basin which makes a deficit year of soil moisture.

Table 2.*Total summery of water balance assessment calculation in the Beles River Basin*

	Gilgel Beles				Upper Beles				Lower Beles			
Year	**(P) (mm)**	**(L) (mm)**	**(Q) (mm)**	**(ΔS) (mm)**	**(P) (mm)**	**(L) (mm)**	**(Q) (mm)**	**(ΔS) (mm)**	**(P) (mm)**	**(L) (mm)**	**(Q) (mm)**	**(ΔS) (mm)**
2003	1507	828	808	**-128**	1782.03	1209.53	648.4	**-75.9**	1346	1132	394	**-180**
2004	1737	965	644	**129**	2159.64	1454.82	643.58	**61.24**	1374	1194	643	**-463**
2005	1964	877	1088	**-1**	1759.82	1326.65	433.29	**-0.12**	1303	921	382	**0**

***N.B. P** is precipitation, **L** is loss, **Q** is discharge and **ΔS** is change is soil moisture.*

The highest water deficit was found in the lower basin in 2004 (-463 mm) and 2003 (-180 mm) of Lower Beles which could support that increase precipitation and temperature drop with increasing the elevation besides the high temperature and vegetation cover type of the area results in high loss especially Evapo-transpiration (Usmanov *et.al*, 2015). Therefore, the simulated result of water balance assessment summery showed that 2004 for Gilgel Beles (129 mm) and Upper Beles (61.24 mm) found to be a water surplus year were as 2003 showed the deficit year in the basin but 2005 was found almost balanced soil moisture storage in the River Basin. Based on the result of water balance assessment it can be concluded that there was variation of water availability from 2003 to 2005 and this assessment is done with the relative error of HEC-HMS model simulation and according to Gebreyohannes *et.al* (2013) suggested that this error could be subtracted from the runoff.

4. CONCLUSION AND RECOMMENDATION

From this study, comparison of observed and simulated river discharge at two gauging station in the basin showed that the model under predictions for Gilgel and over prediction for upper Beles but different literature showed it is reasonably accepted.

Hence water balance assessment indicated that loss constitutes high percentage of total annual precipitation and it is mainly influenced by precipitation and potential Evapo-transpiration and to some extent soil type and vegetation cover. The monthly surface runoff from 2003 to 2005 in the Beles River Basin ranges from 0 to 440.2 mm (mean of 76 mm) for Gilgel Beles, 0 to 281.1mm (mean of 55.7 mm) for upper Beles and 0 to 283.7 mm (mean of 42.4 mm) for lower Beles. Bare land, cultivated land and urban land uses on sandy clay soil produced the highest surface runoff in the basin. According to water balance assessment, the highest water deficit was observed in 2003 and 2004 of Lower Beles but 2004 for Gilgel Beles and Upper Beles was found to be a water surplus year were as 2003 showed the deficit year. There is no significant change in soil moisture storage in Beles River Basin in 2005.

From this study, it is recommended that water balance assessments have the ability to compare river discharged in the areas where there is limitation of measured data because it doesn't require lot of input data. Therefore, the hydrological findings and information generated on surface water balance assessment of this study can be used in planning of water resource management in Beles River Basin. Efficiency of the model may increase if the model application is done in seasonal basis or less like wet or dry season for this study area because there is erratic annual rainfall in the basin. Hence; in order to mitigate the especially social, economic and environmental challenges which may directly related to water issues and which could be a major limitations in the near future in Africa especially Ethiopia, it would be advisable to consider immerging 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.

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