MODELING THE HYDROLOGY OF BORKENA WATERSHED, AWASH BASIN, ETHIOPIA

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Abstract— Human change the land cover for their own purpose and this change has effect on the water resource in any level but the level of impacts are different, so evaluating the level of impact is crucial. This study was conducted in Borkena River catchment, which is found in the Western highlands of Awash basin. The objectives of the study are to test the applicability of SWAT model for prioritizing micro watersheds for watershed development plan and to evaluate impact of land use change scenarios on flow of stream. SWAT model setup was carried out by Arc SWAT2012 interface in Arc GIS 10.1. DEM of 90m resolution, land use map of 2000, soil map and related user database, daily weather data for four stations were input data for model setup. After model setup, Sensitivity analysis calibration and validation were done by SUFI-2 algorism in SWATCUP until the statistical criteria for the model performance were met. Available soil capacity, Curve number II, Soil evaporation compensation factor, maximum canopy storage and base flow alpha factor are the most sensitive parameters among 10 selected sensitive parameters. During calibration 0.6, 0.5 and 36% were coefficient of determination, Nash-Sutcliffe model Efficiency and percent of bias respectively. Moreover, coefficient of determination, Nash-Sutcliffe model Efficiency and percent of bias respectively score 0.71, 0.54 and 16% respectively during validation period. The land use land cover change detection between 2000 and 2016 indicates that 5.86% and 14.12% expansion of cultivated land and grazing land respectively in the catchment. These resulted increments in sediment yield, Actual Evaporation and surface runoff. However ground water contribution and total water yield showed a decline trends. Therefore optimization of land use should be investigated during time of land use planning in the catchment.

Index Terms— Awash Basin, Borkena, Land use change, SUFI, SWAT, SWATCUP

I. INTRODUCTION

A. Background and justification

Human beings have modified a land cover for intended purpose for the last many years. High rate of population growth in Ethiopia highlands is one the main driving forces for the land use change [1-3]. This is because in Ethiopia, 85% of the population is employed in agricultural sector and it contributes 40% for the GDP of the country. In addition, Agricultural sector offers basic need and incomes for 90% of poor [4]. Moreover, [1]and [2] find out increase demand of land for cultivation, settlement and tree accelerate land use change. In addition, expansion of cultivated land and an increase trend of planting trees have been observed since second half of 20th century [5].

The change of land use influences the hydrology of the catchment by change the proportion of water balance. For instance, Evaporation and surface runoff response, which are the major water balance components, are changed [6]. [7] has revealed that the flow regime in Koga watershed (upper Blue Nile basin) has not changed, however, an increase in surface runoff and a decrease in evapotranspiration were observed due to removal of vegetation cover [8]. In addition, [9] found out an increase and a decrease of wet season and dry season flow respectively due to deforestation.

Studies revealed that land use and land

cover change affect sediment yield and soil erosion [3, 10]. Rapid population growth, less available lands for agriculture and high number of livestock cause expansion of cultivated land to marginal area and deforestation. When vegetation cover change to cultivated land, the protection of soil is reduced and it became vulnerable for erosion [11]. Since cultivated land is expanded to steeper slope, productivity of the land is dramatically declined [3]. Moreover, cultivated land and degraded land are very vulnerable for erosion threats [1]. Similarly high rate of soil erosion coupled with less sediment trapping efficiency produce high sediment yield at river basin [10].

Soil erosion, sedimentation and stream flow fluctuation are some of the environmental problems, which are caused by land use change and other factors. The intensity and the magnitude of the problems are site specific; it depends on the amount rainfall, intensity rainfall, soil type, topography, farming system, land management activity, conservation structure, and population growth. Therefore site specific studies should be conducted to understand the level of problems and suggest appropriate measures to different implementer in the area.

B. *Objectives*

1) *General objective*

The general objective of this research is to use SWAT model as a decision supporting tools by evaluate the impact of land use change on the hydrology of sub basin.

2) *Specific objectives*

- To Calibrate and validate SWAT models using river flow
- To identify sensitive parameters to river flow in the sub basin
- To Predict impact of land use change scenarios on the sub basin hydrology
- To identify critical watersheds for interventions

II. METHODOLOGY

A. *Description of Study Area*

Borkena is one of the tributary of Awash Basin in the western highland sub basin and the catchment is extend from $39^0 30'$E to $40^0 0'$ E and $10^0 15'$ to $11^0 30'$(Figure II:1) and the elevation is varies from 1417m to 3507m above sea level. From the catchment 50% of the catchment area lie below 1941 m which is less than the mean elevation of the catchment that is 2031m. The total drainage area of the watershed is 1702Km^2 and the total length of river is estimated to be 165km.

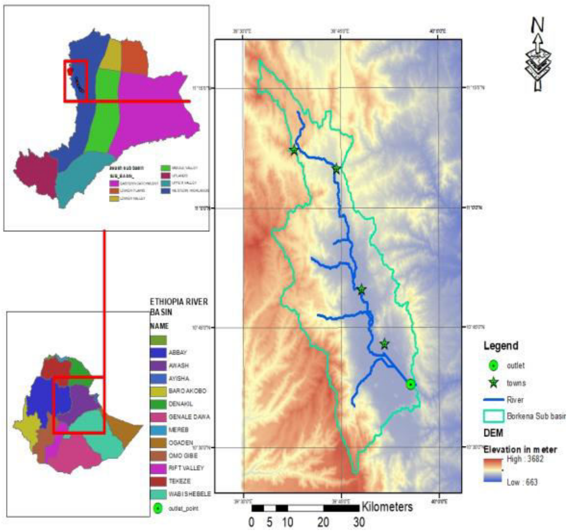

Figure II:1: Location and Elevation of study area

B. *Data Collection*

The SWAT model requires intensive data set for set up the model. Daily climatic data, soil data, land use and topographic data are basic as input for the model, moreover sediment and discharge data were collected for calibration and validation of the model. The data were collected from Ministry of Water Irrigation and Electricity, National Meteorological Agency (NMA), previous works and field survey data. Therefore the detail procedure is presented below under non spatial and spatial data set. All the collected data were subjected to different preprocessing analysis before using in SWAT model.

1) *Non Spatial data*

Non spatial data are data that don’t have a spatial component, so it includes daily metrological data and stream flow data. The daily metrological data were collected from five stations, those are Bati, Cheffa, Kabie, Kombolcha and Majete stations. The NMA provided 22 years data for the mentioned stations from 1995 to 2016 except for the station Cheffa, which have data from 2000 to 2016.

2) *Spatial Data*

a) *Digital Elevation model (DEM)*

One of spatial data that is required for model setup is a Digital Elevation Model (DEM). During the process of model setup the SWAT delineate a watershed, define stream lines and create slope of the basin by using this input spatial data. The DEM of 90m by 90m resolution for Awash basin was collected from Ministry of Water, Irrigation and Electricity. From the collected DEM, Elevation and slope map were created as indicated in Figure II:2, which shows 68% of the catchment area has an elevation less than 2300 m.a.s.l, but only 1.16% is lied on elevation greater than 3200 m.a.s.l. The slope map shows that 43.3% of the catchment area has slope less than 15% and most of this area is found a round stream network.

b) *Soil and Land Use land cover*

Soil texture, bulk density, soil depth, hydraulic conductivity, organic carbon, available water moisture at different soil layers are the required data for SWAT modeling. These data were collected from FAO soil map and harmonized world soil database. Soil was generated for the study area using the two sources and detail user soil database was created. Borkena catchment consists 16.85%, 56.05%, 17.97% and 9.13% of Euric Leptosol, Lithic Leptosol, Euric Vertisol and water respectively (Figure II:3).

Land use land cover data is a very important data to setup the model as well as to evaluate the impact of land use land cover change in the flow of the river. Two time steps, which are 2000 and 2016, land use land cover data were used (Figure II:4 and Figure II:5).

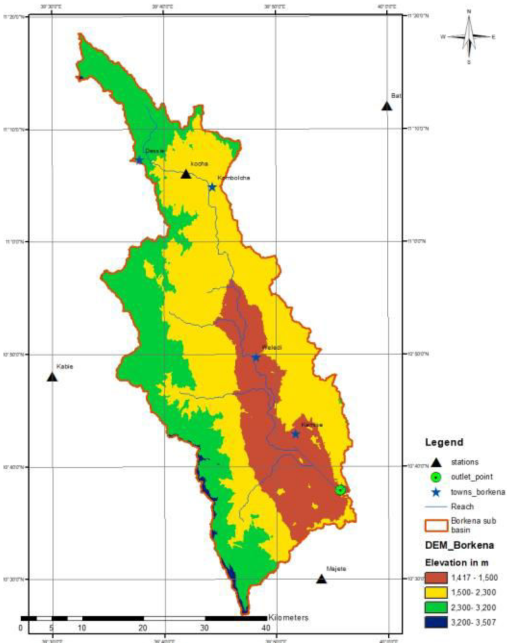

Figure II:2: Elevation Map of Borkena Watershed

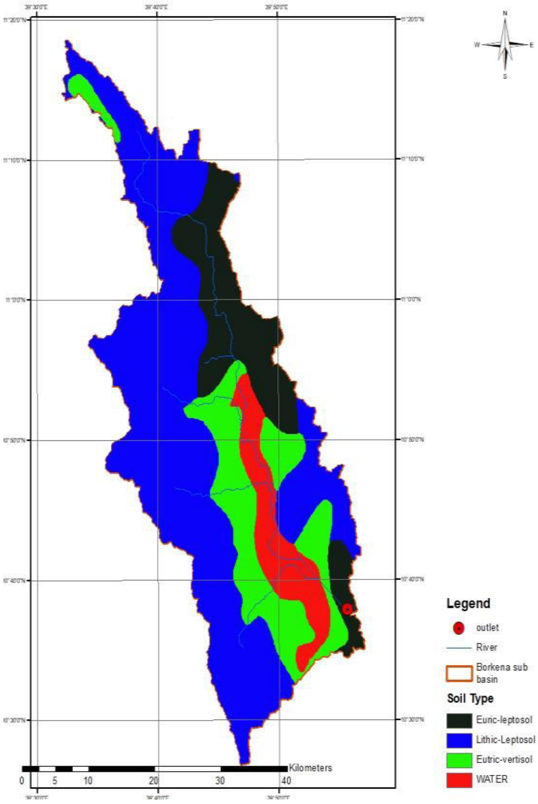

Figure II:3: Soil map of Borkena Watershed

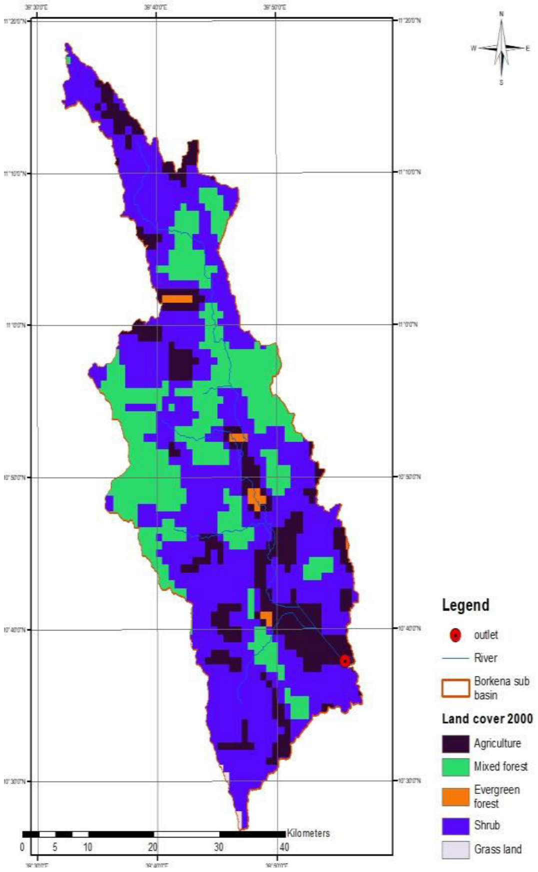

Figure II:4: land cover and land use map of Borkena Watershed in year 2000

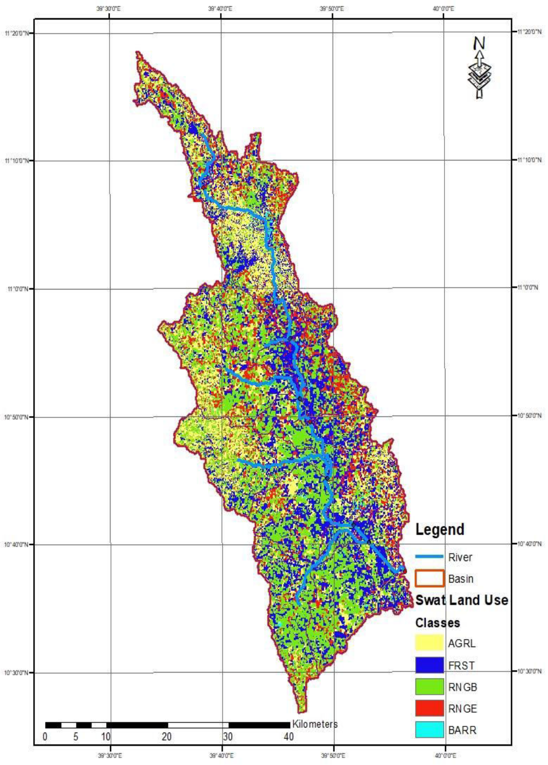

Figure II:5: land cover and land use map of Borkena Watershed in year 2016

C. *SWAT modeling*

1) *Model setup*

SWAT2012 with Arc GIS 10.1 interface was used to setup and run the SWAT model. Watershed delineation, HRU definition, weather data definition and define the management are key steps after SWAT project setup. A procedure presented in Figure II:6was used as a guideline for the model setup and evaluation of scenarios.

a) *Watershed delineation*

After SWAT project setup, watershed delineation was carried out. DEM setup for the study area is first step under watershed delineation. Therefore 90 m resolutions DEM was used for this study and mask of the study area was manually drawn. After setup of the DEM, calculation of flow direction and accumulation were executed under stream definition. Moreover, stream and outlets were created depend up on threshold area, that is the minimum sub basin area. 60 km2 was used as threshold drainage area to distribute the model output as much as possible and some critical sub basin outlets were edited manually. After creating stream network, outlet of the sub watershed was defined and the total area of 1702km^2 was taken for this study. Calculation of sub basins parameters were carried out to calculate geomorphic parameters of each sub basins and relative reaches.

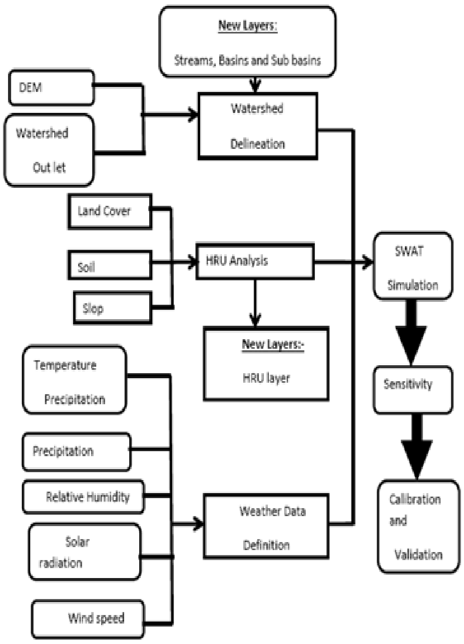

Figure II:6: SWAT Model Setup procedure

b) HRU Analysis

During HRU analysis two steps were performed. First definition of land use, soil and slope were carried out to define the land cover, soil property and topography of sub basin respectively. Definition of land use was done based on the land use of 2000 and the map was reclassified in five classes that was presented in Figure II:4. The Soil map that was created from FAO 1986 soil map of East Africa for the basins (Figure II:3) and property of four user soil data were edited in SWAT database. The slope discretization was done in multiple slopes; therefore 4 slope classes were created.

HRU definition was performed in order to establish hydrological response unit for each sub basin. The definition of HRUs was based on assigning a threshold values for land use, soil and slope under multiple HRUs option. Even though user guide of ArcSWAT suggest 20%, 10% and 20% threshold level for land use, soil and slope respectively, for this study threshold level of 10% were assigned for land use, slope and soil to consider all small unit of soil, slope and land use.

c) Write Input tables

Write input tables menu comprises two commands that are weather station and write command. Daily precipitation, daily minimum temperature and daily maximum temperature data are minimum weather data that are required by SWAT modelling, therefore observed daily rainfall, daily minimum and maximum temperature from four stations and Wind speed, Relative humidity and solar radiation from two stations were arranged and location of stations were prepared, moreover user weather generator was adapted to a local condition, by preparing a user weather generator from three stations. The location tables were loaded in SWAT database by following weather station command. Once the weather data were loaded successful, the write command became active and input database were built. At this stage, the model build input database sequentially, therefore some tables were not created until others have been completed.

d) Edit SWAT Input

Edit SWAT menu allows the user to edit and re write input data. Under edit menu point source discharge, inlet discharge, reservoirs, sub basins and watershed data are edited. In this study, sub basins and watershed data were edited for this study. General watershed parameters and method of estimation were adjusted. In this study, Hargreaves, SCS CN and variable storage method were applied for estimation of potential evapotranspiration, surface runoff and channel routing respectively.

D. Sensitivity analysis

Not all input parameters have equal influence on output of the model. If relative change of the model output to input parameter is high compare to others, the output is sensitive to those input parameters comparing to others[16]. Therefore sensitivity analysis was carried out to understand the influence of input parameter to output of the model.

Flow and sediment related parameters were collected from previous SWAT modelling studies and SWAT manual [14, 17, 18] and . In Table II-1, 30 parameters were selected for sensitivity Analysis that was carried out by using Sequential uncertainty fitting version two (SUFI-2) algorism in SWATCUP 2012 version5.1.6.2. Therefore a global sensitivity analysis was performed for this study. A multiple regression between parameters that were generated by Latin Hypercube(LH) random sampling method against objective function determined sensitivity of parameters [19]. The sensitivity and significance of sensitivity were known by t test and p values. The higher absolute value of t shows the sensitivity of parameters.

Table II-1: Selected parameters for sensitivity analysis

No	parameter	Descriptions
1	CN2	Moisture condition II curve number
2	USLE_p	USLE management support for different management
3	Gwqmn	Thresh hold water depth in the shallow a aquifer for flow (mm)
4	Alpha_bf	Base flow alpha factor (days)
5	Rchrg_DP	deep aquifer percolation fraction
6	Gw_delay	Ground water delay (days)
7	Revapmn	threshold water depth in the shallow aquifer for "revap" (mm)
8	Sol_k	hydraulic conductivity (mm/hr)
9	Sol_AWC	available water capacity (mm)
10	USLE_K	soil erodibility (K) factor
11	Sol_alb	moist soil albedo
12	Sol_z	soil depth (mm)
13	Surlag	surface runoff lag time (days)
14	Spcon	Linear re-entrainment parameter for channel
15	Spexp	Sediment routing
16	Ch_K2	Channel effective hydraulic conductivity(mm/hr))
17	Ch_N2	Channel manning coefficient
18	Ch_ERODMO	channel erodiblity fact
19	CH_COV1	Channel erodibility factor
20	CH_COV2	Channel cover factor
21	CH_W2	Average width of main channel
22	CH_D	Average depth of main channel
23	USLE_ C	Minimum USLE cover factor
24	HRU_Slp	average slope steepness (m/m)
25	LAT_SED	Sediment concentration in lateral flow and groundwater flow
26	Slsubbsn	average slope length (m)
27	Canmx	maximum canopy storage (mm)
28	Epco	plant up take compensation factor
29	Esco	Soil evaporation compensation factor
30	Tlaps	Temperature laps rate

E. *Calibration and validation*

Calibration is the process of changing sensitive parameters to adopt the model in the local condition through comparing model outputs to the measured data. Daily average stream flows from 1996 to 2003 were utilized for calibration and validation of the model. The first five years (1996 to 2000) and the second three years (2001-2003) data were used for calibration and validation respectively. In addition, the data for 1995 was skipped for warming up. Finally, the calibration was carried out by SUFI-2 algorism in SWATCUP [19].

The validation of the model was done after calibration. From the calibration result, the values of fitted parameters were edited in SWAT model was run for daily stream flow during the validation period.

F. *Evaluate model performance*

In this study, the performance of model was evaluated by comparing the output to measured data of daily stream flow. According Santhi, Arnold, Williams, Dugas, Srinivasan and Hauck [20] and Moriasi, Arnold, Van Liew, Bingner, Harmel and Veith [21] four model evaluation statistics with the corresponding rating criteria were applied. In addition graphical evaluation, which are comparison of hydrographs and scatter plot, were carried out.

1) *Coefficient of determination (R^2)*

Coefficient of determination (R^2) shows the degree of correlation between predicated and measured values. Its value ranges from 0 to 1. Higher value in R^2 shows less error in variance and high model performance therefore R^2 Value greater than 0.5 is considered as acceptable [20]. Equation 1 is used to compute R^2.

$$R^2 = \left[\frac{\sum_{i=1}^{N}(O_i - O)(P_i - P)}{\sqrt[2]{\left(\sum_{i=1}^{N}(O_i - O)^2\right)\left(\left(\sum_{i=1}^{N}(P_i - P)^2\right)\right)}}\right]^2$$

Equation 1

Where:

R^2- coefficient of determination
O_i is the ith observed value,
P_i is the ith predicted value
O is the mean of the observed data;
P is the mean of the predicted values and
N is the number of compared values

2) The Nash-Sutcliffe model Efficiency (NSE)

Nash-Sutcliffe efficiency(NSE) describes relative magnitude of residual variance to measured data variance [21]. The Value of NSE ranges from −∞ to 1, negative value shows the mean of measure data is better to predict the data than the model output whereas 1 is the optimum value and indicate the highest level of fit between measured and predicted values. NES is computed by Equation 2

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - O)^2}$$

Equation 2

Where:

NSE is Nash-Sutcliffe model efficiency
O_i is the ith observed value,
P_i is the ith predicted value
O is the mean of the observed data;
N is the number of compared values

3) Percent bias (PBIAS)

Model simulated values may be smaller or greater than observed values. Therefore average tendency of overestimation or under estimation is measured by percent of bias. Negative and positive values of PBIAS indicate overestimation and underestimation of model respectively; 0 is optimal value for model performance[22]. PBIAS is calculated by Equation 3

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{N}(O_i - P_i)}{\sum_{i=1}^{N} O_i} * 100$$

Equation 3

Where:

PBIAS is percent of bias
O_i is the ith observed value,
P_i is the ith predicted value
O is the mean of the observed data;
N is the number of compared values

4) RMSE-observations standard deviation ratio (RSR)

RSR is the ratio of root mean square error to the standard deviation of observed data as shown in Equation 4. Its value varies from 0 to large positive number. A large positive value for RSR indicates the less performance of the model whereas 0 is an optimum value, which indicates 0 RMSE [21].

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV}_{\mathrm{obs}}} = \frac{\sqrt{\sum_{i=1}^{n}(O_i - p_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - O)^2}}$$

Equation 4

Where:

RSR is ratio of square roots
O_i is the ith observed value,
P_i is the ith predicted value
O is the mean of the observed data;
N is the number of compared values

G. Evaluate Impact of LULC

In this study, two LULC maps, which are 2000 and 2016, were used to show impact of land use land cover on the hydrology of the catchment. Once the model was calibrated and validated, the land use land cover evaluation was done from year 2006 to 2016 for two different land use based on the validated model. Major water balance components were compared during the change in land use land cover.

III. RESULT AND DISCUSSION

A. Watershed configuration and HRU analysis

Spatial data are important for watershed delineation, stream network and HRU definition. For this study Borkena river watershed is divided in to 13 sub catchment (Figure III:1) and 153 HRU (Figure III:2)

B. Sensitivity analysis

All input parameters did not have equal influence on the output parameters, therefore selecting a significant parameter from the input parameter is crucial and the process is sensitivity analysis. In this study the output variable is stream flow (Daily, monthly and yearly) and there are many parameters that affect the flow of the river. 30 parameters were selected from different studies and their level of significance and sensitivity are indicated by T-stat and p-value.

Figure III:1: Map of Borkena Catchment Sub watersheds

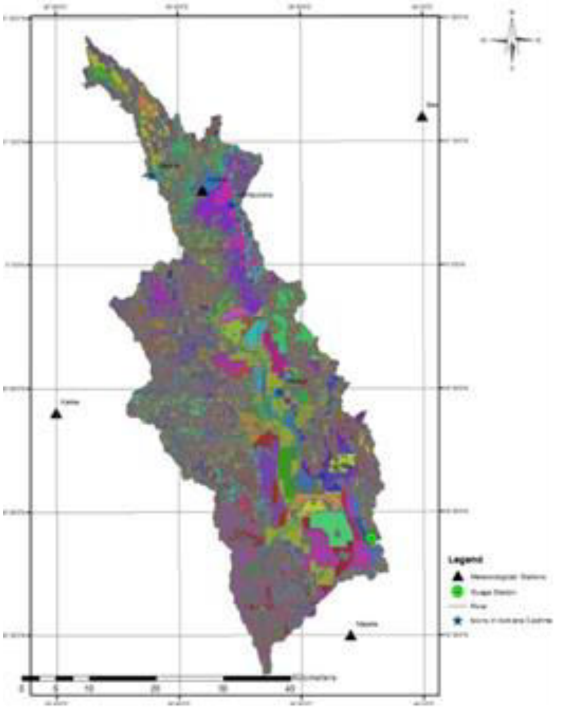

Figure III:2: Map of Borkena Watershed Hydrological Response units

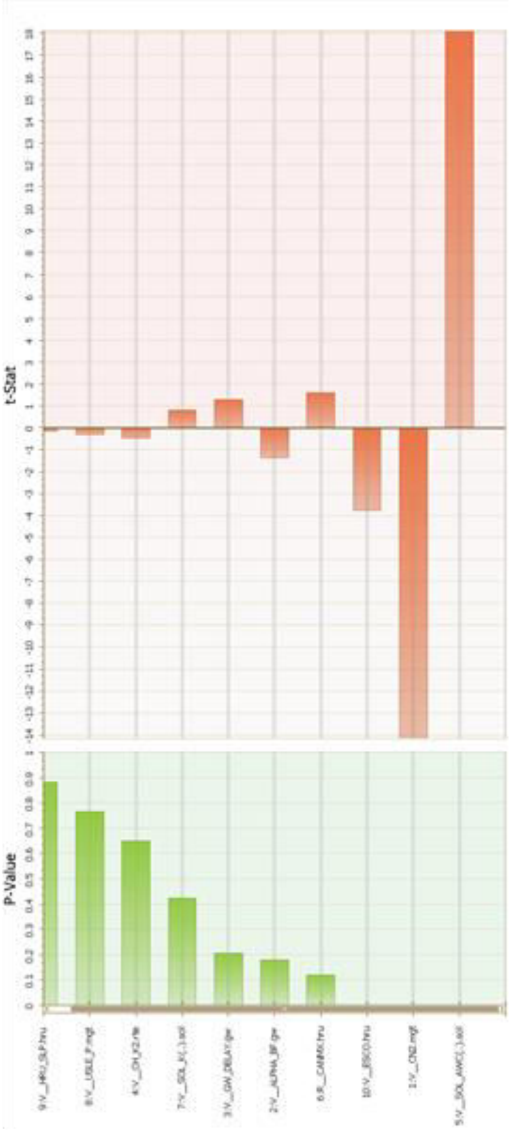

Figure III:3: sensitive parameters

To avoid over model parameterization only 10 most sensitive parameters (Figure III:3) were selected. Therefore Moisture condition II curve number, plant up take compensation factor, Base flow alpha factor, Slope Steepness, USLE management support for different management, hydraulic conductivity, maximum canopy storage, available water capacity and Channel effective hydraulic conductivity are considered as a very significant and sensitive and parameters in this study. Those selected parameters are highly sensitive to flow.

C. Model Calibration and Validation

Model calibration was done from 1996 to 2000 for five years. AS we see from Figure III:4 the model performance for mean monthly flow is sufficient coefficient determination (R2), which rate 0.6. Even though the coefficient of determination is under the accepted range other statistical parameter indicates the need of improvement in model performance.

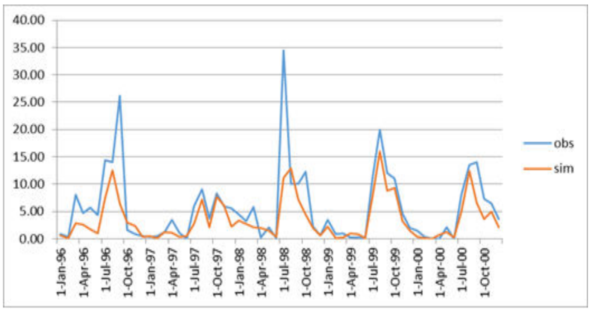

Figure III:4: Monthly average observed and simulated Stream flow before calibration (1996-2000)

Since calibration is a process of optimizing sensitive parameter to get the outflow for the basin, this process will continue to improve the model performance. The calibration result was presented in Figure III:5. Moreover the performance tests were satisfactory and the values are indicated below in Table III-1.

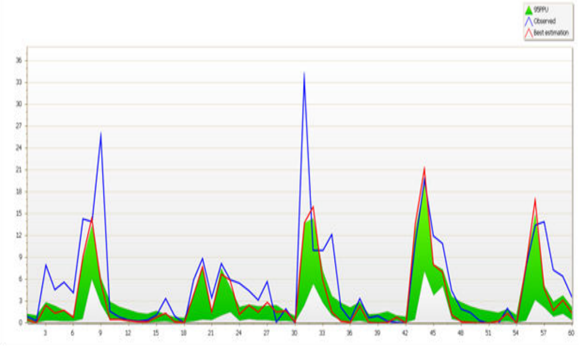

Figure III:5: Model performance during calibration (1996-2000)

Table III-1: Calibration and validation statistics

Monthly time step	Period	Model performance Evaluation statistics		
		R^2	NES	PIBAS
Calibration	1996-2000	0.6	0.5	35%
Validation	2001-2003	0.71	0.54	16%

Validation was carried out without changing the parameters that were fitted during calibration and it was run for three years from 2001 to 2003. The result in the Figure III:6 show the model performance was better during validation, which also supported by the model performance statics in Table III-1.

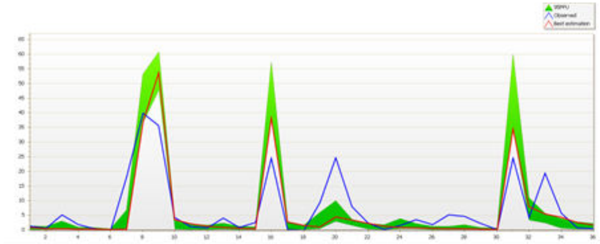

Figure III:6: model performance during validation (2001-2003)

D. Impact of LULC change

Table III-2 shows an alternation of land use change in 16 years period. Grass land, Agricultural land, mixed forest and Bar land were increased by 14.12%, 5.86%, 1.27% and 0.7% respectively whereas the forest land and mixed shrub & grass lands were declined by 21.95 % in the catchment.

Table III-2: Land Use land cover change between the year 2000 and 2016

No	Land Use land Cover	Percentage of Area coverage (2000)	Percentage of Area coverage (2016)	Percentage of change b/n 2000 to 2016
1	Cultivated land	17.1	22.96	5.86
2	Mixed forest	25.83	27.10	1.27
3	Forest	0.89		-0.89
4	Mixed shrub and grass land	56.06	35.00	-21.06
5	Grass land	0.12	14.24	14.12
6	Bar land		0.70	0.7
	Total	100	100	

Assess impact of land use land cover change was conducted in SWAT model during the period 2004 to 2016. 10 years period was used to evaluate the change in different component of flow and the rest three years were utilized for model warming up. For this study, five output parameters were selected to evaluate the impact of LULC, these are Actual Evaporation, Surface runoff, Water yield, Sediment yield and Groundwater contribution to streamflow.

Table III-3 shows the mean annual value of each parameter during the two LULC period and relative change in percentage. From all parameters an average sediment yield from the catchment is dramatically increased, but the ground water contribution and the total water flow were declined by 9.21% and 1.01% respectively. On the other hand actual evaporation and surface runoff were increased by 2.49% and 1.2% respectively.

Table III-3: Impact of land use change on main hydrology components and sediment yield

No	Hydrology components	2000_LULC (2007-2016)	2016_LULC (2007-2016)	(i
1	Actual Evaporation (mm)	568.04	582.16	2
2	Surface runoff (mm)	996.33	1008.30	1
3	Water yield (mm)	1341.81	1328.23	-
4	Sediment yield (metric tons/ha)	13.0	135.5	9
5	Groundwater contribution to streamflow (mm)	321.99	292.34	-9.21

The result revealed that sediment yield is a very significant output parameter, which is affected by the change in land use land cover. Therefore, prioritizing watersheds for intervention is important to tackle the problem, so sub watersheds are prioritized based on mean annual sediment yield from each sub watershed in the catchment and the annual sediment yield in metric tons per ha was mapped for the two LULC Scenarios (Figure III:7 and Figure III:8). The map clearly shows the expansion of critical sub catchments during 16 years period.

Figure III:7: simulated sediment yield for Borkena Watershed during 2000

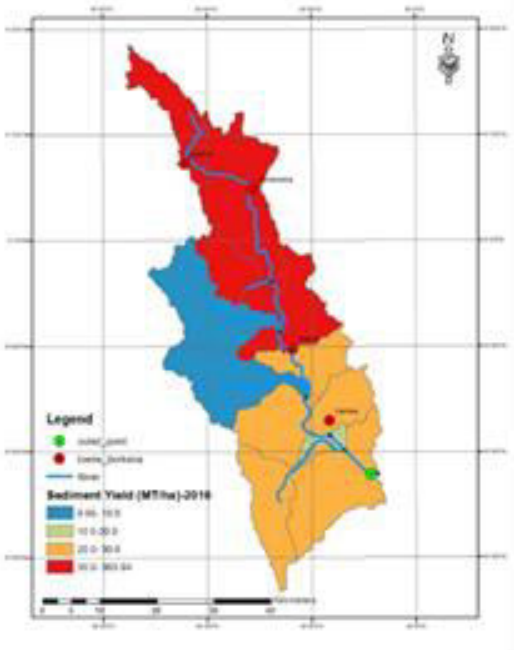

Figure III:8: simulated sediment yield for Borkena Watershed during 2016

IV. CONCLUSION AND RECOMMENDATION

A. Conclusion

The main objective of this study is assessing the impact of land use land cover change on the hydrology of Borkena Catchment using 2000 and 2016 LULC map by SWAT model, which is a semi distributed model. The Result revealed that available soil capacity, Curve number II, Soil evaporation compensation factor, maximum canopy storage and base flow alpha factor are the most sensitive parameters which control the flow among the sensitive parameters. The SWAT model were calibrated and validated by using 8 years flow data of Borkena River from 1996 to 2003. During calibration the model performance evaluation was 0.6, 0.5 and 36% in coefficient of determination, Nash-Sutcliffe model Efficiency and percent of bias respectively. Moreover, coefficient of determination, Nash-Sutcliffe model Efficiency and percent of bias respectively score 0.71, 0.54 and 16% respectively during validation period. Therefore, the model was used to evaluate the impact of land use land cover.

The land use land cover change detection between 2000 and 2016 indicates that 5.86% and 14.12% expansion of cultivated land and grazing land respectively in the catchment. Therefore other major land use land cover classes such as forest and shrub lands were declined by 9 to 21%. These resulted increments in sediment yield, Actual Evaporation and surface runoff. However ground water contribution and total water yield showed a decline trends. From this study we can conclude that land use land cover change increases the sediment yield by more than nine fold that indicate the catchment needs high level of innervation based on the level of severity in the catchment.

B. Recommendation

The author draw recommendation to improve future works and applicability of SWAT model for the users

- Since SWAT is a distributed model that requires good quality and quantity data, but the data availability in quality, spatial and temporal scale are limited in our country. Therefor the government, research institutes, higher educational institute, other interested NGOs should invest on data collection and distribution infrastructure.
- Development office should apply calibrated model for the watershed level for different purpose such as design and watershed planning.
- Implementation of land use planning at catchment level should be optimized with its impact.

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