The Impact of Land Use/Land Cover Change on Hydrological Components due to Resettlement Activity: SWAT Model Approach

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ABSTRACT

Modification of land use systems constitute use/land cover and hydrology. Though the qualitative impact of disappearance of forest, agricultural expansion, and modifications of other land use systems is well understood, quantified results are necessary to understand the magnitude of the effect of a proposed action plan and make informed decisions based on them. Recent advances in distributed hydrological models integrated with Geographic Information Systems (GIS) are of great help in this regard since they overcome temporal and spatial limitations helping in quantifying these impacts for big watersheds for longer time periods. The results from the studied watersheds studied revealed that agricultural and forest covered areas significantly differed between years 1972 and 2007. A distributed hydrological model Soil and Water Assessment Tool (SWAT) is used in this study to quantify changes in land use/land cover that impacted hydrology of Anger Gutin resettlement area. Application of statistical analysis for fitness of observed and simulated flow values using the Nash- Sutcliffe coefficient (E_{NS}) and correlation coefficient (R^2) resulted 0.725 and 0.81 respectively while validation results for the two statistical measurements were 0.62 and 0.68 respectively. Land use land cover maps of 1972, 1986, and 2007 were used as input to quantify changes that occurred as result of land use changes. Analysis of Variance (ANOVA) carried out to assess significance of differences for means ($p \leq 0.05$) for outputs of SWAT in watersheds studied revealed that there is a significant difference within sub watersheds for all hydrological variables and sediment simulated except for potential evapotranspiration and sediment concentration. Sediment concentration in sub watersheds that are found in or around urban areas is found to be higher than other sub watersheds. Water yield also increased during wet seasons (May - September) by 42.61% and 40.18% in watershed one and two respectively while declined during the dry season (October – April) by 20.61 % and 24.18 % for watersheds one and two, respectively.

Simulated results for both watersheds supported the qualitative truth that modified land use/land cover affect hydrology. From the results of the analysis of SWAT, it is concluded that the model can be used as a decision support tool before such big schemes like resettlement projects commence.

Key Words: Hydrology, Land Use Change, Resettlement, SWAT

INTRODUCTION

Ethiopia is one of the most populous countries in Africa with over a population of 70 million people and an annual growth rate of 2.6 million people (CSA 2008). Eighty percent of the population lives in the northern highlands, which cover only 45 percent of the country and suffer from widespread erosion, deforestation, and loss of nutrients (Fitsum et al. 1999). The economy of the country is highly dependent on agriculture, which in turn is dependent on the availability of seasonal rainfall. Erratic rainfall patterns team up with an already present land degradation to put population in stress and experience drought at different times.

Result of these failures have led governing regimes at different times to take resettlement action plan as a solution to attain food security through population distribution from highly dense and degraded areas to less cultivated and high potential areas of the south west. But implementation of the resettlement measures raises practical problems because they were carried without proper preliminary study of the potential impact these resettles could cause on the environment and the long term consequences that befall on the population themselves, who in the first place were sought to be potential beneficiaries of the resettlement scheme (Belay 2004).

Related with this is the continued land use/land cover modification that happened at the area. A related study (Zelalem 2008) showed that during the 35 year period this study focused on (1972-2007) significant decline has occurred in wood land and forest coverage (41.79% and 7.03% respectively) while agricultural land increased by 41.35%. Changes in land use patterns certainly provide many social and economic benefits. However land use changes also have a direct impact on natural environment which affect natural resources availability such as soil and water negatively. For instance, clearing forest areas could contribute to climate change and to a loss of biological diversity (Lepers et al. 2005). By altering ecosystem functions, changes in land use/land cover affect the ability of ecological systems to support human needs and such changes also determine, in part, the vulnerability of places and people to climatic, economic, or socio-political perturbations. For example, biodiversity loss due to deforestation results in a decline in ecosystem integrity and may impact hydrological processes, leading to flooding and soil erosion (FAO, 2000, Millennium Ecosystem Assessment, 2005) and the degradation of water resources and water quality (USEPA 2001). Land use/land cover also impacts water balance of a watershed (Foher et al. 2001) and increases surface runoff while making ground water recharge and base flow to decrease (Pei-ju shi et al. 2006, Rongrong et al. 2007)

Effective management of water resources, therefore, requires understanding the hydrological component of an area and land management since they are intimately connected. In this regard, hydrological modeling is a great method of understanding hydrologic systems for the planning and development of an integrated water resources management. Recent developments of decision support systems based on GIS and a distributed hydrological model have provided practical and useful tools to achieve this goal. This study uses a distributed hydrological model SWAT to quantify land use land cover generated hydrological impact of the Anger Gutin resettlement area in eastern wollega of Ethiopia.

THE STUDY AREA

Anger Gutin settlement area is situated in Oromia region, Eastern wollega zone about 45-50 km north of Nekemte Town (Figure 1). The resettlement is on a low land area and is located north of the river Anger extending up to the southern foots of the Dicho escarpments. It lies between 36° 80' 26.31"E to 36° 31' 38.05" E longitude and 9° 71' 13.23" N to 9° 39' 88.11" N latitude. The resettlement area has an area of 857 km^2 out of which two watersheds with an area of 109.5 and 147.3 km^2 were selected to quantify the impact that land use/land cover change of the resettlement has caused on water resources in this study as shown in the figure below. Much of the area is gently undulating to rolling terrain, gradually descending from 1400 m above sea level (ASL) in the east to about 1250 m ASL in the west. Average monthly temperature range from 19–20 °C during the main rainy period (June – September) to 24 – 25 °C (March and April). Rainfall has a uni-modal distribution pattern, with five rainy months from May to September. This period accounts for 86% of precipitation while July and August have the highest and most dependable rainfall depths. The average annual rainfall is 1305 mm, and the estimated potential evapotranspiration (PET) (for a year) is 1362 mm. PET exceeds rainfall during seven months of the year.

METHODS

We adopted a holistic approach to study the impact of land use/land cover on the hydrological components, using SWAT model..

The Soil and Water Assessment Tool (SWAT) model was developed by the U.S. Department of Agriculture and Agricultural Research Service (USDA-ARS). It is a theoretical model that functions on a continuous time step developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soil, land use and management conditions over long periods of time. It is a physically based model that uses readily available inputs to make a run. The model is compu-tationally efficient and enables users to studying long term impacts that cover large areas. This study used the recent version of SWAT called "*AVSWAT-X for SWAT 2005 – Blackland Research Center – Ver.Beta 0.04*" which uses the Arc View graphical user interface (GUI).

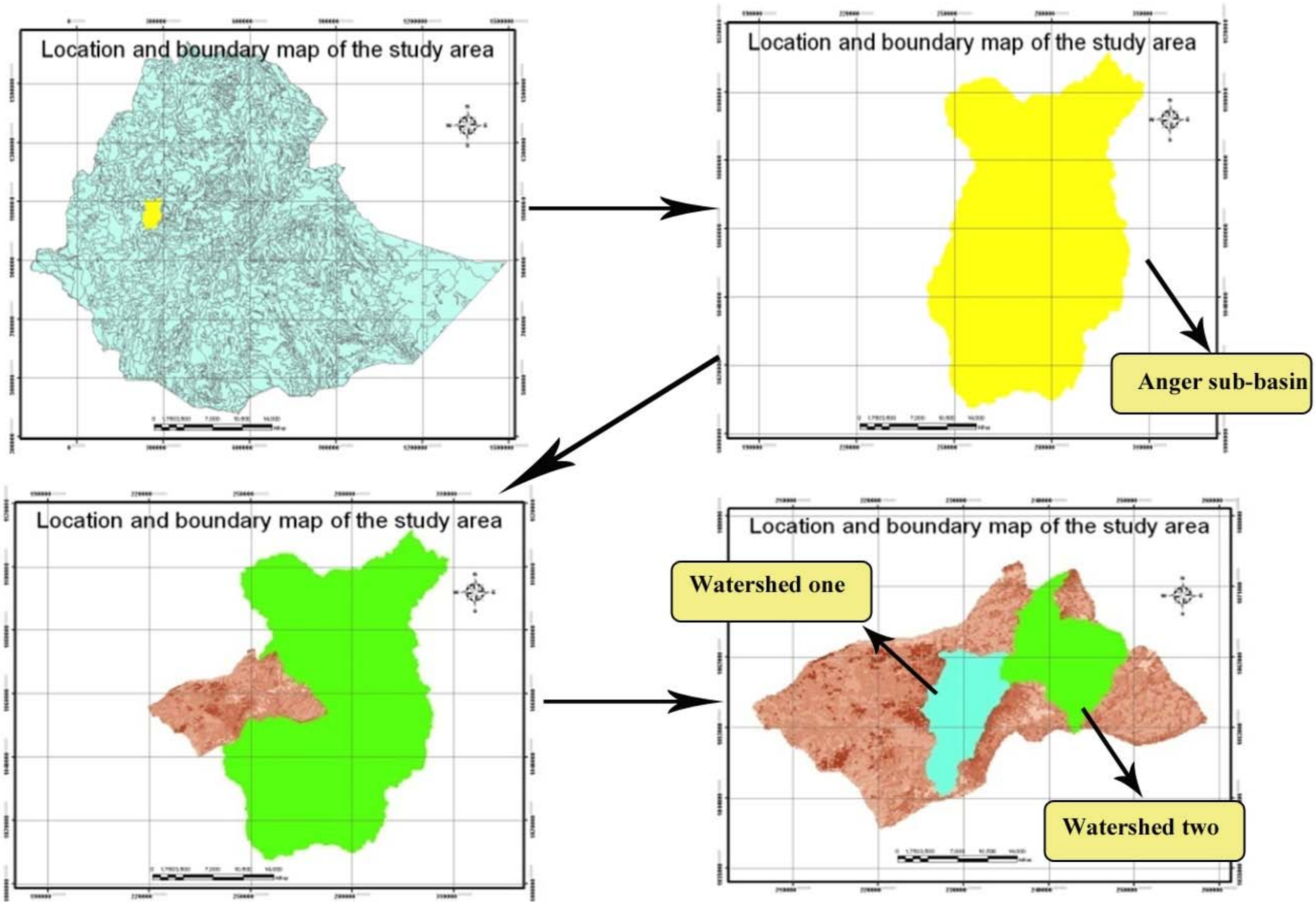

Figure 1. Location and boundary map of the study areas

INPUT DATA

Digital Elevation Model

Digital Elevation Model (DEM) which used in this study was the NASA Shuttle Radar Topographic Mission (SRTM) 3 arc second (≈90m) resolution Digital Elevation Data. Using 3DEM software the DEM was checked for holes and tiff format was exported. A 20m contour was created out of the DEM using the software global mapper 7 and this is exported to Arc View where the next steps were creating TIN and then Grid of the DEM to be used by the SWAT model.

Digitized Stream Networks

Stream networks used in this study were digitized from a 1: 50,000 scale topographic map of the study area (Figure 2). The streams were prepared in a shape file format and after being checked for topology were given, together with the DEM , as an input to the model to be "burnt" during the delineation process.

Land Use / Land Cover Maps

Land use/land cover maps of the area were acquired from one division of this research project which studies the land use/land cover change pattern for the years 1972, 1986, and 2007. Additional supervised and unsupervised land use classification of image of Anger sub-basin is done using ERDAS Imagine software on a 1986 Landsat image due to the fact that the outlet point for the calibration actually covers an area that is bigger than the actual resettlement area (Figures 3 and 4). Land use names have been made to agree with the requirements of SWAT (Table 1).

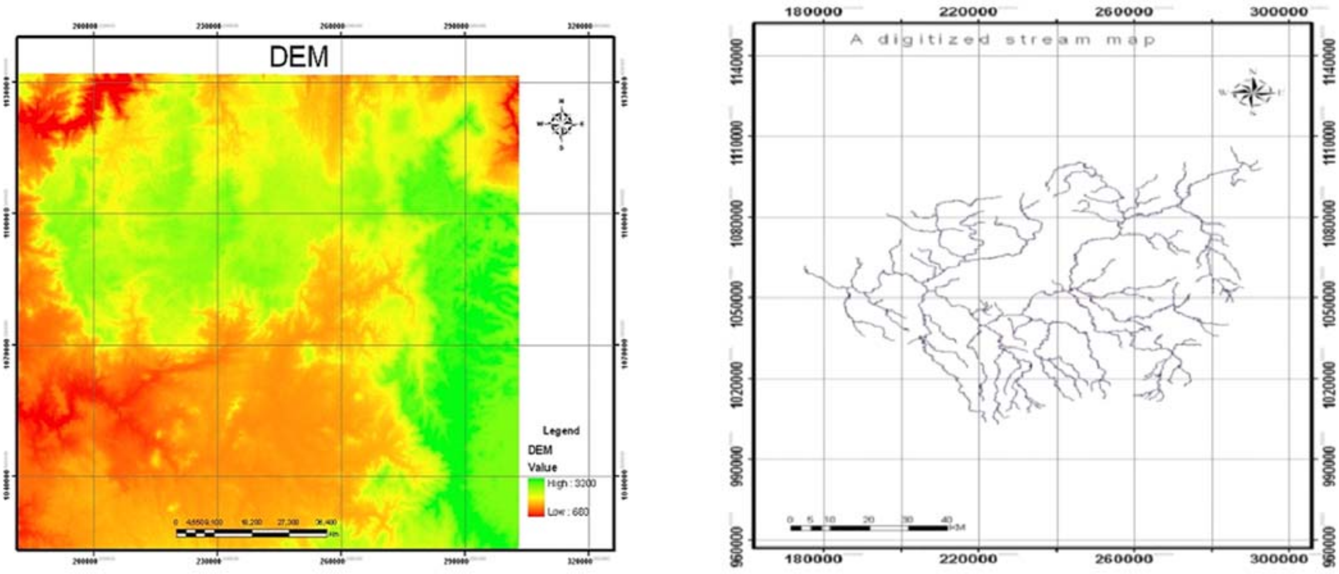

Figure 2. Digital elevation model (DEM) and digitized stream network used in the study

Table1. Original LULC cover types redefined according to the SWAT code.

Original Land use	Redefined Land use	SWAT Code
Wet/marsh land	Wetland non forested	WETN
Settlement	Urban low density	URLD
Bush/wood land	Range brush	RNGB
Grass land /savannah	Range grass	RNGE
Mountainous and riverine vegetation	Forest evergreen	FRSE

Soil Map and Properties

Soil samples collected from the field and brought to laboratory are analyzed for texture, carbon content, and bulk density. Missing data were calculated using available pedotransfer functions using the Soil texture triangle - Hydraulic Properties Calculator developed by the USDA and Washington state university (Saxton, 2006). The technique is a set of generalized equations which describe soil tension and conductivity relationships versus moisture content as a function of sand and clay textures and organic matter. Additional to this the soil and terrain map of east Africa (SOTER) which is a 1:1000000 resolution is used.

Weather Data

Five years of daily climatic data (1983-1987) were collected from the National Meteorological Services Agency (NMSA) of Ethiopia. Data for precipitation, maximum and minimum temperature, sunshine hours, relative humidity, and wind speed were collected for three meteorological stations within the study area. Additional data required by the model to generate missing weather data were calculated using the DOS-based programs PCPSTAT.exe and DEW02.exe.

River Flow Data

Anger River flow data for the years between 1983 and 1987 were used for the study that fit well with the weather data. Since total flow is combination of surface and base flow, the total volume of flow is separated into its components using Web Based Hydrograph Analysis Tool (WHAT) and used in the calibration and validation procedures.

MODEL APPLICATION

Watershed Delineation and Stream Definition

DEM, mask, and digitized stream network were loaded

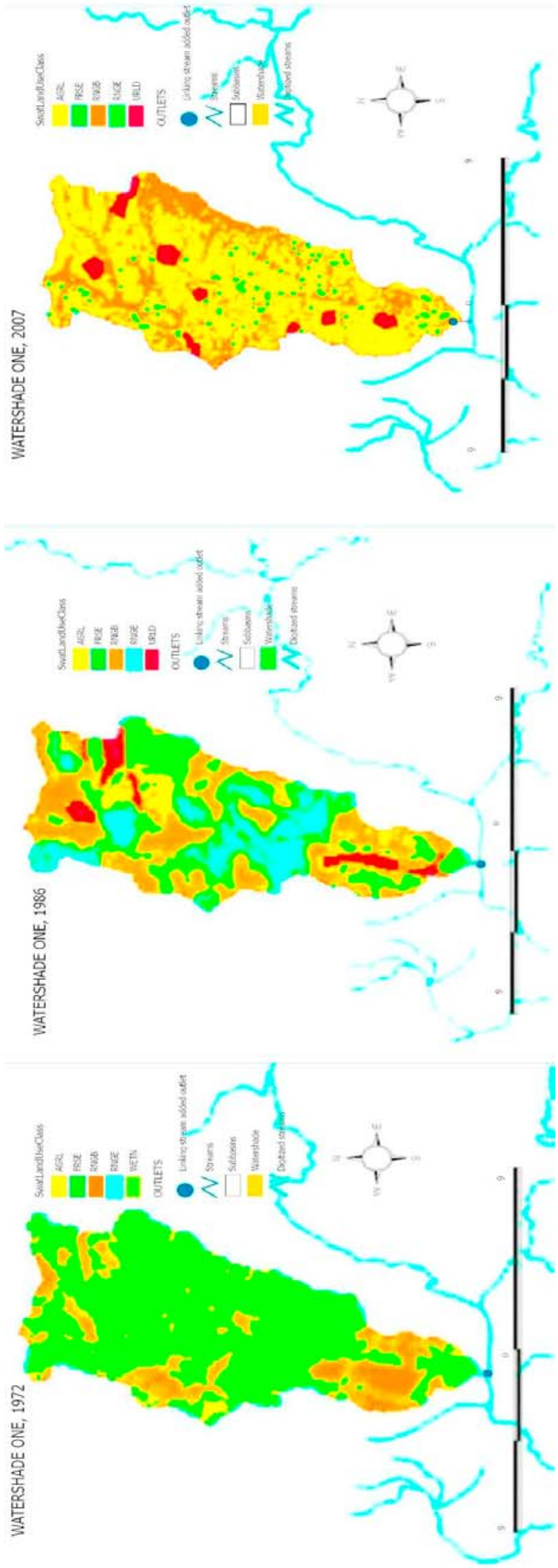

Figure 3. Land use / land cover map of watershed one.

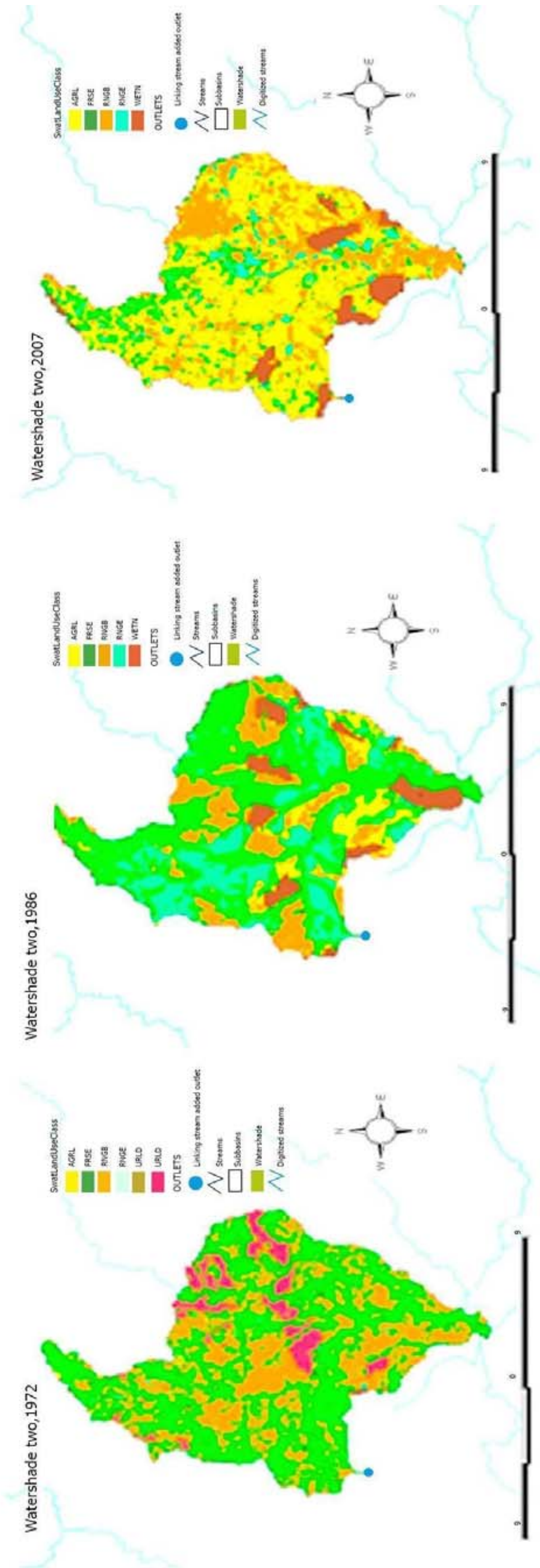

Figure 4. Land use / land cover map of watershed two

into the watershed delineation box. Stream definition was carried out using suggested threshold area of 15500ha for calibration and validation purposes and 1200 ha for simulation inside the two watersheds studied (watershed one and watershed two).

Six simulations have been done using LULC maps for the years 1972, 1986 and 2007 while in all simulations weather data is kept constant to compensate for the effect that change in climate could have on the hydrology.

Model Calibration

Manual calibration for flow is done to make fit the actual stream flow with the simulated flow and to this end different flow parameters were changed according to the SWAT user manual.

RESULTS AND DISCUSSION

According to the suggested 15500 ha threshold value for delineation, 17 watersheds were delineated where flow information at the out let, at watershed seventeen, has been used (Figure 5).

Base flow separation using the web-based hydrographic analysis tool showed that 90.3% of flow during dry periods (November-may) is generated from groundwater whereas in the wet season flow is dominated by direct runoff (83.2 % of total volume) where the contribution of base flow become less significant.

Simulation of runoff for the period of five years (1983-1987) has been done where the first year was considered a warm up period and discarded from the calibration and validation process. Simulation by SWAT fairly predicted the base flows but over-predicted peak period flows and a seasonal shift also occurred in the simulated flow amount. This was expected before the run of the simulation since DEM resolution, for the sake of accurate stream definition, has been made high (30 m) making the simulated runoff to be higher than the actual (Figure 6). Therefore surface runoff parameters are manipulated through a repeated trial to better fit the simulation results with the hydrograph shape.

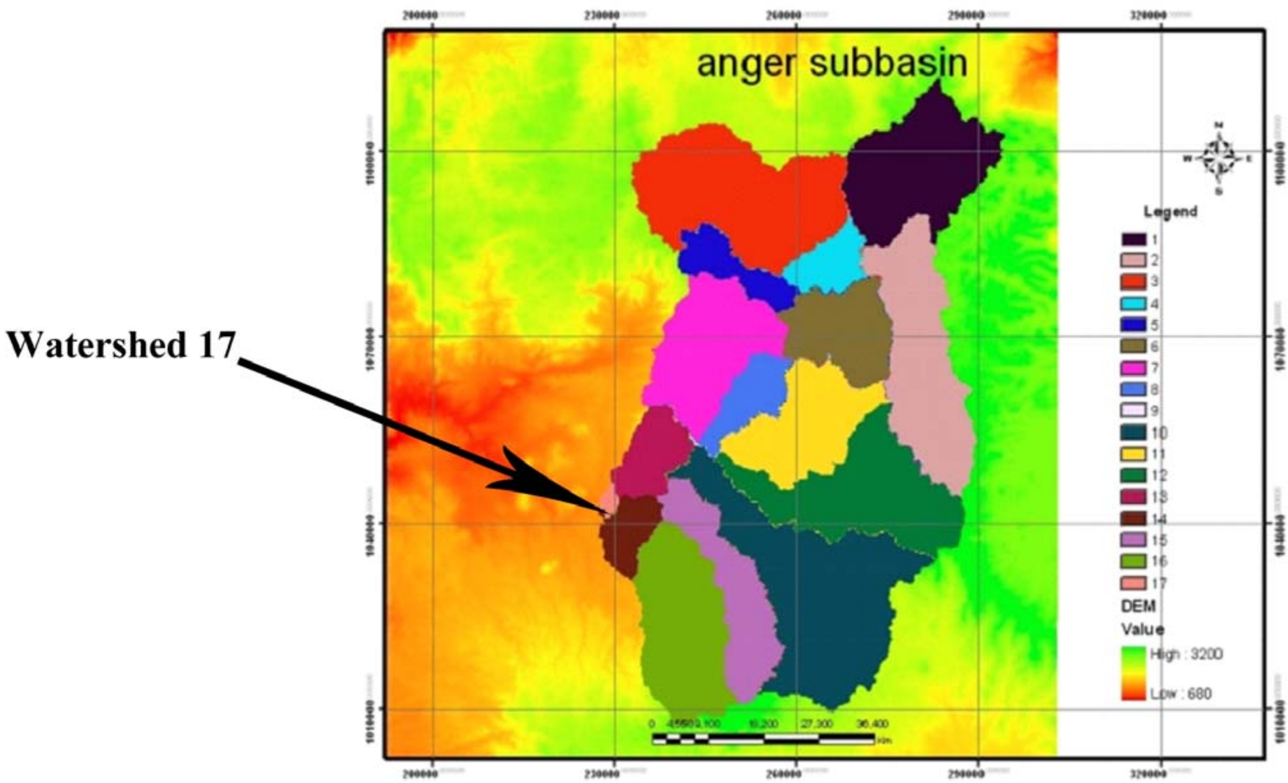

Figure 5. Watershed delineated for calibration and validation purpose.

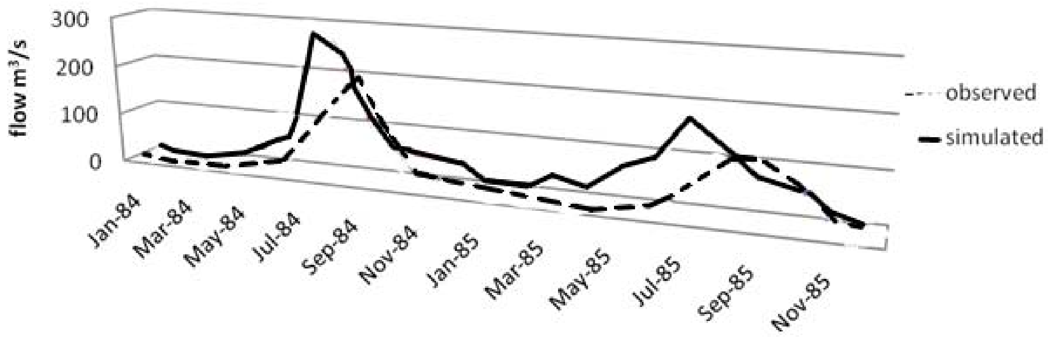

Figure 6. A hydrograph showing observed and simulated values of flow

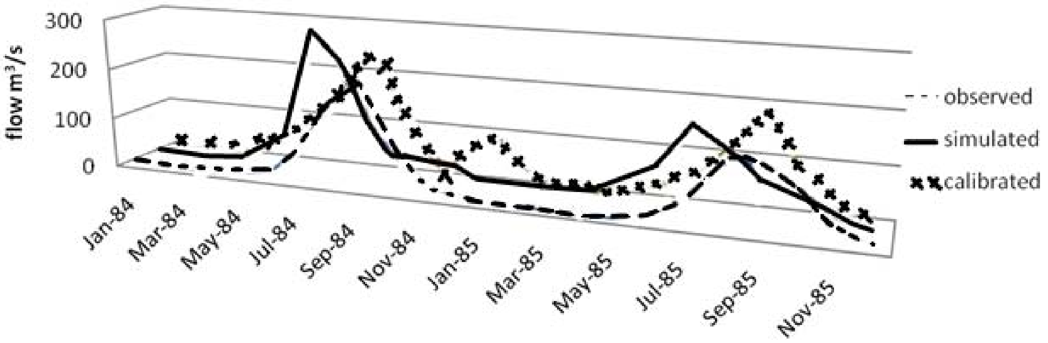

Figure 7. Adjusted hydrograph shape after calibration of model parameters

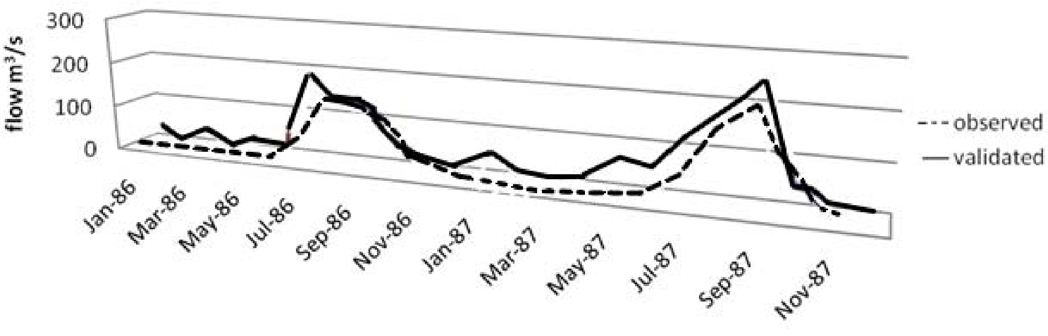

Figure 8. A hydrograph showing fitness for observed and validated runs.

Accordingly the curve number (CN2), reduced by an amount of 21%, better fits the observed flow by reducing the amount of runoff produced (Figure 7). The soil evaporation compensation factor (ESCO) is also reduced from a default set value of 0.95 to 0.2. The next step taken is to adjust the temporal shift in flow and this is achieved by manipulating the Manning's roughness coefficient (OV_N) from a default set value of 0.014 to 0.018. Though the soil available moisture (SOL_AWC) has an effect on determining flow generation, it is not changed because it is directly estimated from the Saxton hydraulic parameter calculator using laboratory-measured soil texture, bulk density (BD) and amount of organic matter and it is assumed that an accurate measurement has been derived.

Application of statistical analysis for fitness of measured and calibrated flows returned values of 0.725 and 0.810 for Nash-Sutcliffe and correlation coefficient (R^2) respectively.

Validation of model was carried out for two years (1986-1987) where fitness check resulted 0.62 and 0.68 for Nash-Sutcliffe coefficient and correlation coefficient respectively (Figure 8).

Assessment of Parameters: Effect of Land Use Change on Studied Watersheds

ANOVA carried out to assess significance of differences for means ($p \leq 0.05$) within sub watersheds for outputs of SWAT in both watersheds revealed that there is a significant difference within sub watersheds for all hydrological variables and sediment simulated except for potential evapotranspiration and sediment concentration. This is expected as the important factors like solar radiation, temperature, precipitation and wind speed used were the same in all the simulations for the different years making differences in evapotranspiration and total volume of flow insignificant. Insignificant difference in sediment concentration could be due to the coarse nature of the soil data not accounting to an acceptable degree the variations in soil type for the resettlement area.

Mean sediment concentration increased significantly for all sub-watersheds in both watersheds for the year 2007 and this is believed to have been caused by the rapidly urbanizing areas of Anger Gutin and Tulu Gana areas combined with the intense expansion of agricultural activity around these towns. Comparing means of sediment concentration for the sub-watersheds it is found that the upstream lands have a high sediment generation potential than the downstream areas. According to the 2007 land use simulation sub-watershed two has a higher sediment yield (6.31 Mg ha) compared with sub-watersheds one and three. In watershed two sub-watershed three has higher sediment yield (1296.65 Mg ha^{-1}) than the remaining watersheds.

Comparing mean water yield for dry and wet seasons between years 1972 and 2007 for each sub watershed, it is found that while water yield increased during wet seasons (May–September), it declined during dry seasons (October–April). Watershed one has average increase of 42.61% on wet season while decreased by 20.61 % in the dry season. Focusing on watershed two it was found out that water yield, while showing an increase of 40.48 % in the wet season, dry season water yield show a decrease of 24.18 %. This result goes hand in hand with the result found for decline in return base flow and amount that percolates. Since the amount of water yield is directly connected with agricultural production, household and animal consumption, its unbalanced variation decrease could really pose a looming threat to this socioeconomic aspects.

The comparison of datasets between 1972 and 2007 has been done to assess the impact of LULC at a watershed scale in both watersheds. Dataset 1986 is not used in the paired-samples t-test analyses because it is believed differences between 1972 and 2007 are enough to quantify impacts of LULC (Tables 2 and 3).

Table 2. Result of a paired-samples t-test for watershed one

Variables	1972 Mean	2007 Mean	Stdev	95% confidence interval of the difference Lower	Upper	t	Sig (2-tailed)
PET	84.19	84.19		-0.14	0.15	0.7	0.95
ET	48.12	43	0.52	2.84	7.37	0.71	0.01
SW	286.86	289.68	1.62	-6.84	1.19	-3.02	0.094
PERC	66.09	41.92	1.63	20.1	28.22	25.62	0.002
SURQ	10.61	39.78	2.06	-34.29	-24.47	-24.4	0.002
GWQ	60.48	38.22	1.51	18.49	26.01	25.45	0.002
WYLD	71.66	78.37	0.94	-9.06	-4.36	-12.2	0.007
SYLD	0.23	4.47	0.94	-8.32	-0.17	-4.49	0.046
SEDCONC	482.68	1504.21	897.04	-3249.9	1206.83	-1.97	0.187

Table 3. Result of a paired-samples t test for watershed two

Variables	1972 Mean	2007 Mean	Stdev	95% confidence interval of the difference		t	Sig (2-tailed)
				Lower	Upper		
PET	84.11	84.2	0.12	-0.21	0.02	-1.9	0.106
ET	48.08	42.38	1.9	3.93	7.4	7.9	0
SW	287.2	291.81	4.07	-8.32	-0.79	-2.9	0.025
PERC	67	48.84	5.43	13.13	23.18	8.83	0
SURQ	10.11	32.59	4.97	-27.07	-17.89	-11	0
GWQ	61.32	44.76	4.99	11.94	21.18	8.76	0
WYLD	71.66	77.51	2.01	-7.72	-3.99	-7.6	0
SYLD	0.008	1.83	0.91	-2.66	-0.98	-5.3	0.002
SEDCONC	4.45	694.31	627.12	-1269.8	-109.8	-2.91	0.027

Averaged datasets of 1972 and 2007 were subjected to paired-samples t test procedure for all variables tested. Since climatic parameters are made to be constant in all the simulations, the difference found is only due to LULC changes.

Analysis of the paired samples t-test result showed that there is a significant difference in all the variables measured in both watersheds except PET (Tables 4 and 5).

Table 4. Means of simulated variables for three years for watershed One.

Variables	1972	1986	2007
PET (mm)	84.383	84.383	84.383
ET (mm)	47.611	44.613	42.584
SW (mm)	285.658	290.672	288.529
PERC (mm)	64.744	61.110	41.070
SURQ (mm)	10.398	16.987	38.969
GW_Q (mm)	59.689	56.330	37.659
WYLD (mm)	70.656	73.859	77.002
SYLD (mg ha^{-1})	0.226	0.797	4.388
SEDCONC (mg L^{-1})	472.833	1067.695	1473.520

Though PET did not vary significantly, there is a significant difference in ET. Looking at the trend of mean ET variation across watersheds for the years 1972 and 2007, there was a 10.5 % and 10.7% decline in watershed one and watershed two respectively which could be attributed to the fact that 52.33 % cover of forest reduced to only 9.68 % cover in watershed one and from 54.34 % cover to 7.73 % in watershed two through years 1972-2007. Since forests with bigger plant cover have high water evaporative power over other type of land uses, decline in evapotranspiration could be due to decrease in forest cover.

Table 5. Means of simulated variables for three years for watershed two

Variables	1972	1986	2007
PET (mm)	84.304	84.304	84.158
ET (mm)	47.574	47.652	42.448
SW (mm)	286.078	286.165	291.410
PERC (mm)	65.639	63.116	48.973
SURQ (mm)	9.907	12.350	32.723
GW_Q (mm)	60.523	58.176	43.963
WYLD (mm)	70.653	70.743	76.839
SYLD (Mg ha^{-1})	0.008	0.011	1.835
SEDCONC (mg L^{-1})	4.357	7.993	688.438

The decrease in forest cover also has relation with the increase in surface runoff and decline in percolation. A reduced forest cover significantly reduces flow abstraction and time for percolation at an area adding more to the volume of flow generated and also lessening the volume of water that percolates (Hollis et al. 2003, Palmer 2003). Comparisons of the two parameters during these years showed a 375% increase in the amount of runoff generated in watershed one (increase from 10.39 mm to 38.969 mm) and a 330.31 % increase in watershed two (increase from 9.91 mm to 32.72 mm) between years 1972 and 2007. This is believed to have been caused by an ever-continuing decline in forest cover in the area and this result parallels other studies of this kind (Rice et al. 1988). Related with this is a reduced amount of percolation. Water that percolate declined by 36.56 % from 64.74 mm to 41.07 mm in watershed one while it declined by 25.39 % from 65.64 mm to 48.97 % in watershed two. This is attributed to the declined forest cover and increased runoff.

Increase in surface runoff together with agricultural expansion can also lead to a substantial redistribution of soil materials leading to erosion and sedimentation of water bodies. The sediment yield variation for the years 1972 and 2007 showed that the sediment loss increased from 0.226 Mg ha^{-1} as a loss of sediment in 1972 rose to be 4.39 Mg ha^{-1} in 2007 in watershed one. Sediment yield also increased in watershed two from 0.008 Mg ha^{-1} in 1972 to 1.835 Mg ha^{-1} in 2007. This can be attributed to the fact that expansion of agricultural fields contributing to generation of sediment. This is a well known situation studied by various researchers (Harned 1995, Seeger 2007).

The results of mean soil water content showed increment from 1972 to 2007 and this is an unlikely situation where clearance of forest cover has taken place. But this study revealed that the area is undergoing change in terms of hydrological components and because of increased radiation received by land surface due to forest clearance and nature of shallow aquifers it is possible that capillary action may contribute the water table to move up to the top surface making an increase in the amount of soil water.

CONCLUSION

Result of the study has shown that there has been considerable degree of changes to the land use/land cover of the area. Forest cover has declined whereas the proportion of agricultural land has increased. Results of the SWAT modeling have shown that there have been significant changes in hydrological parameters throughout the thirty five years that this study focused.

Decline in mean evapotranspiration, percolation, and return base flow is seen in both watersheds studied whereas increases have been observed for surface runoff, water yield, sediment yield, and sediment concentration.

Finally considering sediment yield, the study has prioritized sub watersheds that need intervening to control of erosion according to their sediment generation potential. The order of need is put for sub-watersheds in both watersheds according to their sediment yield during year 2007.

Watershed one: 2 > 1 > 3

Watershed two: 4 > 3 > 2 > 1 > 5 > 7 > 6

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