The effects of land use land cover change on hydrological process of Gilgel Gibe, Omo Gibe Basin, Ethiopia

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Abstract

Land use change is one of the responsible factor for changing the hydrological process of watershed by altering the magnitude of surface runoff, aquifer recharge and river flows. Thus, effective information regarding the environmental responses of land use land cover changes are important to hydrologists, land use planners, watershed management and decision makers for sustainable water resource projects and planet ecosystem. Consequently, this study was aimed at assessing the effects the land use land cover changes have had on hydrological process of Gilgel Gibe catchment between the 1987, 2001 and 2010.Soil and Water Assessment Tool (SWAT) model was used to examine the effect land use land cove changes had on hydrological process. Simulation of SWAT is used in identifying the most vulnerable sub basin to the hydrological process changes. The model was calibrated and validated using the Stream flow of Gilgel Gibe at Asendabo station. The result of land use dynamics revealed the land use land cover change have significant effects on infiltration rates, runoff production, water yield, sediment loading, evapotranspiration and water retention capacity of the soil. The highest annual surface runoff was attributed by sub basin 43, 48 and 48 whereas sub basin 27, 27 and 41 contributes the highest ground water respectively for 1987, 2001 and 2010 land cover maps. In terms of sediment yield, sub basin 47 contributes a maximum load for the study periods. Sensitivity analysis shows curve number CN, ESCO and GWQMN are the top three sensitive parameters. The model was calibrated using stream flow data from 1990 to1995 and validated from 1996 to 2000. The R^2 and NSE values were used to examine model performance and the result indicates 0.84 and 0.90 to R^2 and 0.58 and 0.62 to NSE during calibration and validation respectively.

Key words:*hydrological process, land use land cover change, model performance, SWAT model*

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1. INTRODUCTION

Regardless of their existence, the connection and interaction of land and water with the natural ecosystem and catchment hydrology are intricate with a wide variety of spatial and temporal scales. This has contributed a great concern to the basic planet characteristics and process. Depending on the fact that the alteration of land surface will disturb the biophysical system, this in turn alters the global atmospheric circulation resulting in stream pattern shift. Thus, land use land cover change is the global phenomenon that affects the watershed hydrological process as it characterizes the catchments response to the event of rainfall-runoff relationship [1].

The severity of the dynamic land use changes as a result of population increment, expansion of the agricultural sector and climatic conditions were increasing in Ethiopia [2]. Expansion and intensification of agricultural lands, development of urban areas and the need of extracting timber and other products are accelerating over time to meet the needs of an increasing population. This results in the land use land cover change leading to a decreased availability of the products and services of the livelihood.Under such circumstance, handling the land and water resources in achieving high productivity would be difficult to be realized.

As water is a valuable part of our ecosystem that individuals has to be granted, predicting its availability for the next generation has become an essential task in a planning and resource management for hastily evolving area. This

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necessitates, exploring and integrating the significances of land-use change on hydrological processes, such as changes in water demand and supply with the emerging focus on land-change science. The evaluation of land use land cover change on hydrological process is vital to envisage reasonably the possible land-use changes at the individual cell level considering the dominant land use practices of the area.However, the hydrologic effect of alteration in land cover at a watershed scale is still an unresolved problem and is now a primary concern for most countries, which are commonly experiencing changes in land cover patterns caused by increasing populations and demand for accommodations [3].

Despite a strong potential for increased agricultural productivity, south-western Ethiopia is environmentally challenged mainly due to resource degradation, soil erosion and nutrient depletions. Gilgel Gibe catchment is one amongst such land resources which are subjected to the land use land cover dynamics [4]. One of the forms of this resource degradation is believed to follow from land cover changes which results in disturbance of stream flow regimes of watersheds. The basis will lead to the condition of land under little vegetative cover is subject to high surface runoff amounts, low infiltration rate and reduced groundwater recharge. This eventually, leads to lowering of water tables and intermittence of once-perennial streams [5].

Gilgel Gibe basin is found on the upper reach of the Gibe basin, contributing flow to the larger Omo Gibe basin consisting of Cascade Dams on the lower reach. Soil erosion from the upstream of the basin and the subsequent sedimentation in the downstream area is an immense problem threatening the existing and future water resources development of Gibe. Alleviating these multifaceted problems of the basin requires proper, coherent and organized land developments for which the land use land cover situation of the area was an input. However, the quantitative data on the land use land cover change and clear insight into the local contributions of the changes in the Gilgel Gibe catchment were absent. Consequently, research on land use land cover change is needed to explore how land use land cover change influences watershed hydrology. Besides, detecting and simulating the effects of land use land cover change on catchment hydrological process requires a new, strategic and improved procedure to conserve the catchment based on the hydrological sensitivity as a result of land use change at sub-watershed [6]. This enables local governments and policy makers to formulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use land cover change[7].

Therefore, this study was aimed at investigating the effect of land use and land cover changes on hydrological process of Gilgel Gibe catchment. Particularly, the trends of hydrological process under a varying land use land cover and the most vulnerable sub basins of the catchment to the yields of the hydrological process were investigated. Finally, the performance of the SWAT hydrological Model was assessed.

2. MATERIALS AND METHODS

2.1. Description of the study area

The study area was situated on the upstream of the large Omo Gibe basin in the south-western part of Ethiopia, in Oromia regional state at some 260km from Addis Ababa and about 70 km North-East of Jimma. Geographically, Gilgel Gibe lies between 7° 19′ 07.15″ and 8°12′09.49″ North latitudes and 36°31′42.60″ and 37°25′16.05″ East longitudes with the catchment area of 4225km^2.The basin is generally characterized by high relief hills and mountains with an average elevation of about 1700m above mean sea level and by a wet climate with an average annual rainfall of about 1550 mm and an average temperature of 19°c. The topography of the catchment is heterogeneous with upper plateaus that are cut by deep V-shape valleys in the flanks and flat terraces around the Gilgel Gbe River in the center of the catchment.

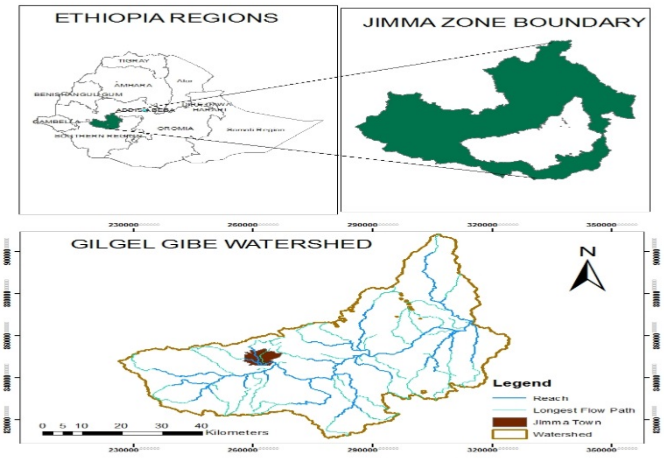

Fig 1: Location map of Gilgel Gibe catchment

2.2. Description of the SWAT model

SWAT model is the distributed rainfall-runoff model dividing the river into smaller discrete units for which spatial variations of the major physical properties are limited and treated as homogenous [8]. The maps of land cover, soil and slope in each sub basin would be used to define a unique combinations forming homogeneous unit (HRU) as a result basins having similar characteristics in land cover, soil and slope will be grouped into sub basins. Water balance components of each HRU are computed on daily time step. The hydrologic cycle as simulated by SWAT is based on the water balance equation.

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw)(1)$$

Where, SWt is the final soil water content(mm), SWo is the initial water content(mm), t is the time(days), Rday is the amount of precipitation on day I(mm),Qsurf is the amount of surface runoff on day I (mm), Ea is the amount of evapotranspiration on day I(mm), Wseep is the amount of water entering the vadose zone from the soil profile on day I(mm) and Qgw is the amount of return flow on day I (mm).

The SWAT 2009 model provides two options for surface runoff estimation: the soil conservation service (SCS) curve number method [9] and the Green and Ampt infiltration method [10]. In this study, SCS curve number method was adopted for runoff calculation. The SCS curve number is calculated as:

$$Qsurf = \frac{(Rday - Ia)^2}{(Rday - Ia + S)} \qquad (2)$$

Where, Qsurf is the accumulated runoff/excess rain fall (mm water), Rday is the rainfall depth for the day in (mm water), Ia is the an initial abstraction (mm water), s is the retention parameter (mm water)

The retention parameter s is calculated by

$$S = 25.4(\frac{100}{CN} - 10) \qquad (3)$$

Where, CN is the curve number for the day.

The simulation of ground water is partitioned into two aquifer systems: a shallow, unconfined aquifer contributing flow to the main channel and deep, a confined aquifer contributing flow outside the watershed [8]. In SWAT water balance for shallow aquifer is calculated as

$$aq_{sh,i}=aq_{sh,i-1}+w_{rchrg}-q_{revap}-w_{revap}-w_{deep}-w_{pump},sh \qquad (4)$$

Where: $aq_{sh,\ i-1}$ is the amount of water stored in shallow aquifer on day i-1(mm), w_{rchrg} is the amount of water recharge entering the aquifer on day i(mm), $q_{revap}$is the ground water flow or base flow, into the main channel on day i(mm), w_{revap} is the amount of water moving into soil zone in response to water deficiencies on day i(mm), w_{deep} is the amount of water percolating from the shallow aquifer into deep aquifer on day i(mm), w_{pump},sh is the amount of water removed from shallow aquifer by pumping on day i(mm).

There are two options for routing the flow in the channel network by SWAT model: the variable storage and Muskingum methods. The variable storage method was used in this study.

The variable storage method uses simple continuity in routing the storage volume as:

$$\Delta V_{stored}=V_{in}-V_{out} \qquad (5)$$

Where, ΔV_{stored} is the change in volume of storage during the time step (m^3 water), Vin is the volume of inflow during tie step (m^3 water), and Vout is the volume of outflow during time step (m^3 water),

2.3. SWAT Model Set Up

SWAT model inputs are DEM (Digital elevation model), Land use Map, Soil Map and weather data. DEM of 30m by 30m downloaded from the United States Geological Survey (USGS) was processed for watershed delineation and topographic characterization of the basin. The delineated watershed was discretized into 48 sub-basins to capture the heterogeneity in physical properties. Each one of the sub-watersheds was partitioned into hydrologic response units (HRUS) that consist of homogeneous land use, management and soil characteristics.

Aland use map of 1987, 2001 and 2010 were prepared from the land sat imagery of TM, ETM+ and TM respectively with the aid of ERDAS Imagine 9.1 and Arc GIS10. Five different Land use classes of each map were identified and assigned based on [11] land use classification system. The classes are coded according to the SWAT database as forest lands (FRST), urban and built up areas (URBN), range land (RNGB), agricultural land (AGRL) and water body (WATR).

Soil found from FAO data base [12] was over lapped with the shape file of the study area to match and get the nomenclature of the soil class. Then, the map was integrated with the soil data obtained from the water base. Some of the soil data variables were extracted and computed from the digital soil and terrain database of East Africa (SOTER) and compared with, digital soil map of the world database and derived soil properties from FAO database. With the identified nomenclature, soil class was taken from the user soil of the map window SWAT and copied to the SWAT data base. The two dominant soil classes of the basin, Nitosols and Vertisols were loaded in to the SWAT data base. In this study, multiple HRU option was selected to assign each sub watershed based on a thresh hold values of 10%, 10% and 20% for land use, soil and slope respectively to divide the Gilgel Gibe watershed in to HRUs having unique land use, soil and slope combinations.

The daily weather data of precipitation, maximum and minimum temperature, relative humidity and wind speed of Jimma and Sokeru station obtained from National Meteorological Agency (NMA) were used for the SWAT setup. For this study, multiple linear regression analysis was found to be the best fitting method to fill the missed data based on the available daily data of rainfall and air temperature. Whereas, the missed sunshine data, wind speed and relative humidity were filled with the nonlinear regression analysis. As Jimma station have daily data on sunshine hours, the Angstrom formula which relates solar radiation with the extraterrestrial radiation and relative sunshine duration was used to estimate the daily solar radiation to be used in the model. Prior to using the filled data, Double mass Curve analysis was used for checking the data consistency and correction. Weather data used in watershed simulation was imported once HRU distribution was carried out using the first command in the write input table's menu item of the Arc SWAT. The weather generator data containing the location of the weather generator station (WGEN user) was loaded first followed by the weather stations location into the current project and assign weather data to the sub watersheds. The write command becomes active after weather data is successfully loaded.

After importing the weather data, the initial watershed input values has been defined. These values are set automatically based on the watershed delineation and land use/soil/slope characterization.

2.4. Sensitivity Analysis, Calibration and Validation of the SWAT Model

Sensitivity analysis was used to recognize the parameters that do or do not have significant influence on the model simulation and identify the most sensitive parameter for model calibration. The sequential uncertainty fitting (SUFI-2) found in SWATCUP was used to calibrate and validate the SWAT model. The sequential uncertainty fitting (SUFI-2) parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables, conceptual model, parameters and measured data [13]. The degree to which all uncertainties are accounted for is quantified by a measure of P-factor which is the percentage of measured data bracketed by the 95% prediction uncertainitiey-95PPU. The 95PPU is calculated at 2.5% and 97.5%levels of the cumulative distribution of an output variable obtained through Latin Hypercube sampling.

Before using the model simulation outputs adequacy under different circumstances, the models out puts were evaluated relative to the observed data. Coefficient of determination (R^2) and Nash and Sutcliffe simulation efficiency (ENS) were used for performance evaluation. The coefficient of determination (r^2) indicates the strength of the relationship between the observed and simulated values. The value of r^2 ranges between 0 and 1, with higher value indicating less error variance and typical values greater than 0.6 are considered acceptable [14].

The r^2 is calculated using the following empirical:

$$R^2 = \frac{\sum[Xi-Xav][Yi-Yav]}{\sqrt{\sum[Xi-Xav]^2}\sqrt{[Yi-Yav]^2}} \qquad (6)$$

Where: xi is the measured value (m^3/s), xav is the average measured value (m^3/s), yi is the simulated value (m^3/s) and yav is the average simulated value (m^3/s).

The Nash-Sutcliffe efficiency (NSE) is measured as the ratio of the residual variance to the measured data variance. NSE indicates how well the plots of observed versus simulated data fits the 1:1 line. It is calculated by the following equation:

$$NSE = 1 - \frac{\sum[Xi-Yi]^2}{\sum[Xi-Xav]^2} \qquad (7)$$

Where, xi is the measured value (m^3/s), Xav is the average measured value (m^3/s) and Yi is the simulated value (m^3/s). The general performance of NSE in SWAT according to (Moriasi, *et al.*,2007) is NSE>0.65 is very good, NSE between 0.5 and 0.65 is adequate, NSE >0.5 is satisfactory and NSE<0.5 is unsatisfactory both for calibration and validation.

Flow data of Gilgel Gibe River measured near to Asendabo obtained from Ministry of Water, Irrigation and Energy was used for model calibration and validation. The model was run using a daily data of 26 years (1985-2010) for the examination of the trend of hydrological process under a land use maps of 1987, 2001 and 2010. For evaluation of SWAT model performance, the model runs with a daily data of 3years for warm up period (1987-1989), 6 years for calibration (1990-1995) and 5 years for validation (1996-2000). The choice of stream flow for the calibration and validation was preferred with a period of relatively free gaps carefully attempting similar dry and wet years of both periods.

2.5. Evaluation of the Hydrological Process due to Land Use Land Cover Change

As Gilgel Gibe has experienced land use changes from 1987 to 2001 and from 2001 to 2010, three independent simulations were carried out to examine the effects of the LULC change on the hydrological process. The result of the three generated land use maps, soil, climate and stream flow data values were used to evaluate the impacts. The simulation runs were conducted on annual and monthly basis using the three land use maps of 1987, 2001 and 2010 keeping the other input parameters unchanged to evaluate the variability of hydrological process due to the land use changes. Based on the three simulation outputs, the periodic variability of the hydrological process due to the LULC changes were assessed and compared on surface flow, ground water flow, sediment yield, water yield contributions to stream flow.

3. **RESULT AND DISCUSSION**

3.1. Effects of LULCC on Hydrological Process of the Catchment

The analysis of the LULCC contribution were made on surface runoff, lateral flow, total aquifer recharge, percolation out of soil, total water yield, sediment loading, evapotranspiration and potential evapotranspiration as characteristics of the hydrological process of the catchment. Average annual comparisons of land use land cover effects on the hydrological process are presented in **table 1.**

Table 1: Hydrological process from annual simulations of 1987, 2001 and 2010 land covers

Item	Lulc_1987	Lulc_2001	Lulc_2010
Surface runoff, mm	388.04	378.79	394.07
Lateral flow, mm	67.75	71.91	67.44
Total aq recharge, mm	567.27	563.22	555.8
Total water yield, mm	1008.5	999.09	1002.86
Sediment yield/ha	346.701	355.355	364.524
Percolation, mm	567.24	564.19	555.78
Et, mm	475.3	485.4	479
Pet, mm	729.9	744.4	735.6

The contribution of surface runoff, total aquifer recharge and water yield has decreased from 1987 to 2001 and increased from 2001 to 2010. This was related to the surface cover of the catchment. From the result of land cover map, areas of forest have increased from 1987 to 2001 which has contributed to the decreasing surface run off contribution. On the other hand, the rate of evapotranspiration and potential evapotranspiration has increased from 1987 to 2001 indicating losses are mainly through evapotranspiration resulting in decreased water yield. The increased water yield from 2001 to 2010 was due to the creation of reservoir in the catchment. Sediment yield has increased from 1987 to 2001 and from 2001 to 2010. As a result of continuous agricultural land increment, sediment loadings of the area is increasing contributing maximum sediment rate. The study also revealed that, the expansion of farm land has attributed to the increased sediment load.

As a result of decreasing percolation rate, total aquifer recharge has decreased throughout the study period from 1987 to 2010. But, the rate of decreasing is maximum from 2001 to 2010 when compared with the rate of 1987 to 2001. The decreasing rate would be related with increasing agricultural land, settlement and bare land. The perviousity of lands are getting changed affecting capacity of soil mass to attain large moisture (reducing infiltration rate) as a result the coming precipitation will be subjected to losses. This indicates that the rain fall runoff relationship has altered as a result of land use land cover change.

From 2001 to 2010 surface runoff was increased while lateral flow and total aquifer recharge has decreased. This attributed by the expansion of agricultural was directly land over forest causing the variation of soil moisture condition and ground water storage. The change in of forest/range land cover results in the reduction of water infiltrating in to the ground, changing the infiltration rate, affecting the retention capacity of soils, contributing flow to runoff, increasing the rate of sediment yields. These result revealed that the land use land cover change have significant effects on infiltration rates, on runoff production, water yield, sediment loading, evapotranspiration and water retention capacity of the soil. The changes of hydrological process under the land use land cover changes are summarized in **figure 2.**

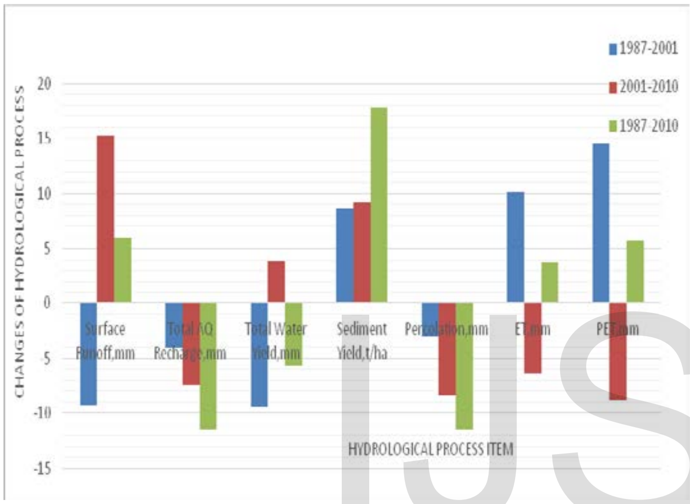

Fig 2: Changes of hydrological process over the period of study time

It is also important to know the monthly contribution of land use land cover changes on hydrological process under the same wet and dry season for the 1987, 2001 and 2010 study periods. This is essential mostly for decision makers, hydrologists, water resources planners, flood protection, agriculturists and the community at large to know the seasonal variation of the hydrological process as it provides information on the occurrence of minimum and maximum value of the event. The figure 3 below shows comparison of the surface runoff, lateral flow, water yield and sediment yield under similar season.

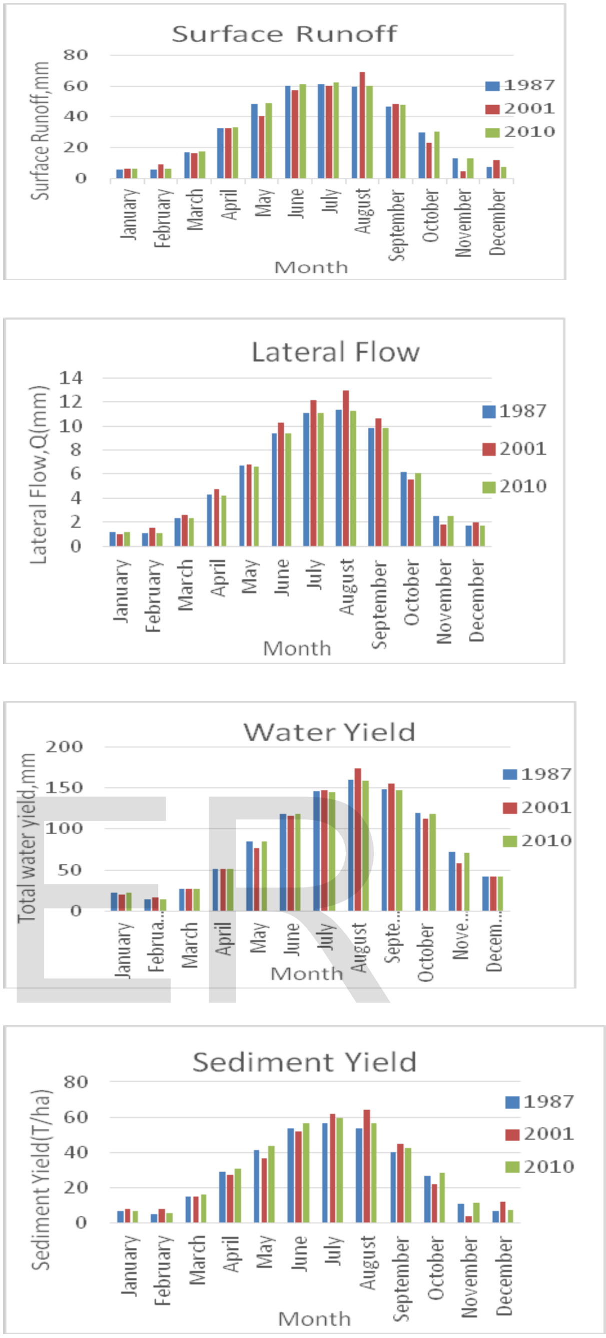

Fig 3: Simulated mean monthly yields of surface runoff, lateral flow, water yield and sediment yield of 1987, 2001 and 2010.

3.2. Contribution of Sub Basins to the Hydrological Process

The examinations of different sub basins on their percentage contribution to the changes of the hydrological process were evaluated to get the prominent sub basin contributor of the catchment. The highest annual surface runoff was attributed by sub basin 43, 48 and 48 for 1987, 2001 and 2010 land cover maps respectively and the lowest surface runoff was contributed from sub basin 4, 9 and 5, 9 for 1987, 2001 and 2010 maps respectively. The contribution of ground water flow is maximum for sub basin 27, 27, and 41 respectively for 1987, 2001 and 2010 and minimum from sub basin 13, 13 and 5, 9 for 1987, 2001 and 2010 respectively. In terms of sediment yield, sub basin 47 contributes a maximum load whereas sub basin 9 contributes a minimum sediment load for the study periods.

Table 2: Summary of sediment yield contribution of sub basins

Year	Very high SYLD >400	High 300< SYLD <400	Medium 200< SYLD <300	Low 100< SYLD >200	Very low SYLD <100
1987	43,48,47	35,13,34,1,45,11,16,14,25,40,46,42,44	6,10,28,33,27,41,30,3,23,22,37,2,38	32,24,31,17,26,36,19,20,39	4,5,21,7,8,12,18,15,29
2001	40,48,43	45,29,13,24,2716,14,25,1,26,31,44,46	30,22,15,3,10,7,9,4,42,35,28,38	33,11,20,34,39,37,2,41	18,6,23,8,17,19,12,36,5,21,32
2010	46,47,43	35,28,32,39,40,27,37,2,16,41,14,25,38,1,48,26,31,44	9,12,36,5,4,42,21,24	22,45,15,34,3,10,29,7,13	6,23,8,30,33,17,19,11,20,18

Note: SYLD is measured in ton per ha

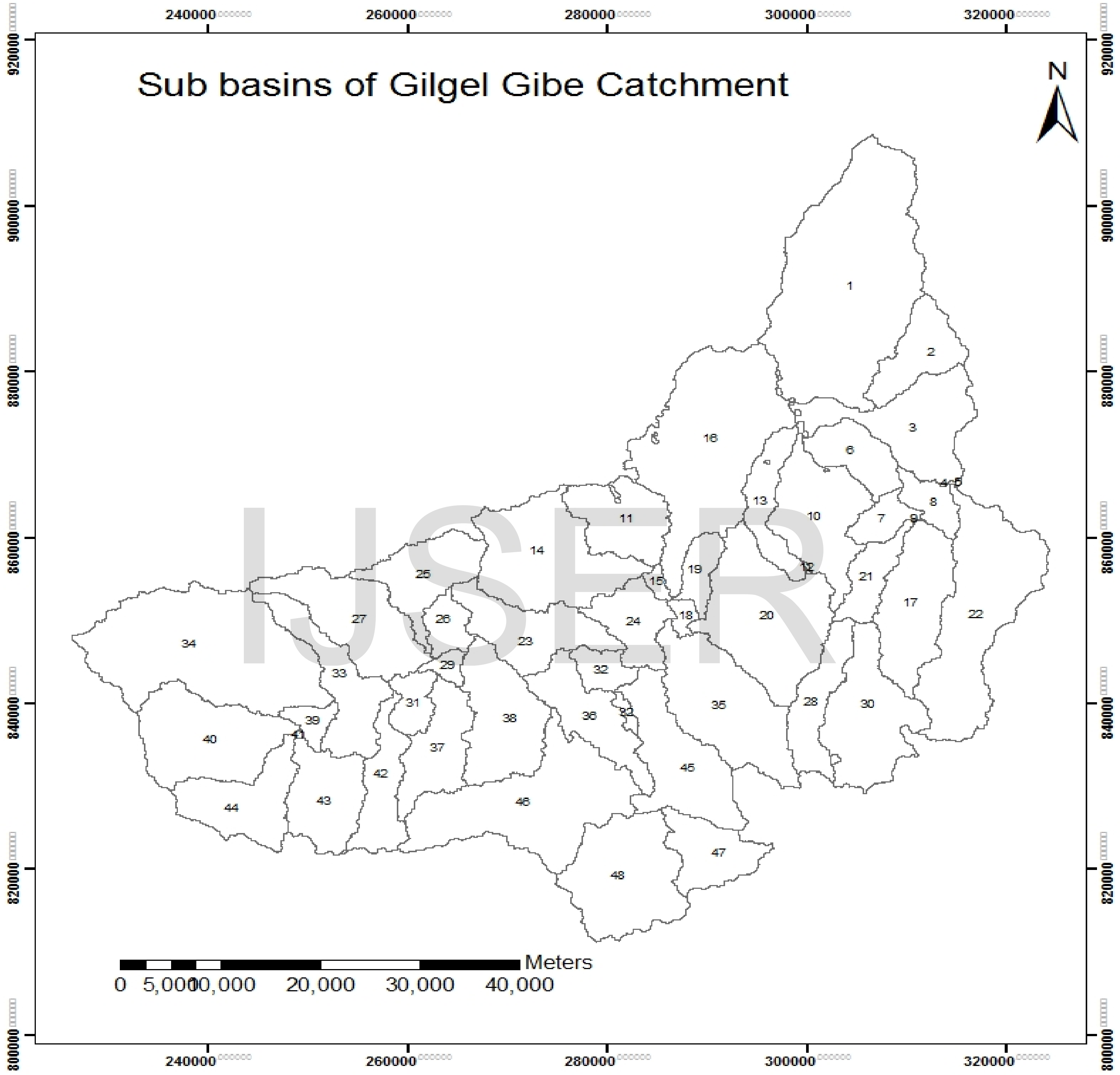

Fig 4: Sub basins of Gilgel Gibe Catchment

3.3. Model Calibration and Validation

The most top five sensitive parameters for flow prediction were CN2 (Curve number), ESCO (Soil evaporation compensation factor), GWQMN (Threshold depth in shallow aquifer for return flow), (SOL_AWC) Available soil water capacity and CANMX (maximum canopy storage). Table 4 shows all the most sensitive parameters and fitted values. These flow parameters were adjusted with in the given limit for the auto calibration initiation.

Table 4: Flow sensitive parameters and their fitted value in SUFI2

No	Sensitive Parameter	Lower and upper Range	Fitted Value
1	CN2	-0.25 to 0.25	-0.22
2	ESCO	0.8 to 1	0.13
3	GWQMN	0 to 2	0.99
4	SOL_AWC	-0.2 to 0.4	0.39
5	CANMX	0 to 100	90.4
6	BLAI	0.5 to 10	4.34
7	EPCO	0 to 1	0.95
8	ALPHA_BF	0 to 1	0.82

Table 3: Summary of sub basin surface runoff contribution

Year	Very high SRQ>450	High 400<SRQ<450	Medium 350<SRQ<400	Low 300<SRQ>350	Very low SRQ<300
1987	43	13,14,25,40,42, 44,45,46,47,48	11,12,16,33, 35,37,38	1,2,3,6,10,15,18,19, 20,22,23,24, 26,29, 30,31,32,34, 36,39	17,21,27, 28,41,7,8,9
2001	43,48	13,42,43	14,25,40,44,45, 46,19,11,16,35,3,38	1,2,3,6,10,15,18,20, 22,24,26,29, 30,31, 32,36,39,27	23,34,12, 33,4,5, 17,21,28, 41,7,8,9
2010	48	13,42,47,40,44, 46,25,37,38,43	26,14,45,11,16,35	1,2,3,6,10,15,18,20,22, 24,29,30,31, 32,36,39, 27,19,23,34, 33,4,28,41	12,5,17,21,7,8,9

Note: SRQ is measured in mm

After the calibration model was run with the calibrated parameters and the simulated flow was compared with the observed flow. The graphical (visual observation) method and values of statistical parameters were used as an indication of calibration acceptance. The calibration was done for the period of 1990-1995 for six years with three years (1987-1990) keeping for model warm up. The result of model calibration indicated good agreement between monthly measured and simulated flow. The R^2 value of 0.84 obtained indicate a good model fit during calibration. In addition the objective function NSE of 0.58 indicates the model performance during calibration is satisfactory.

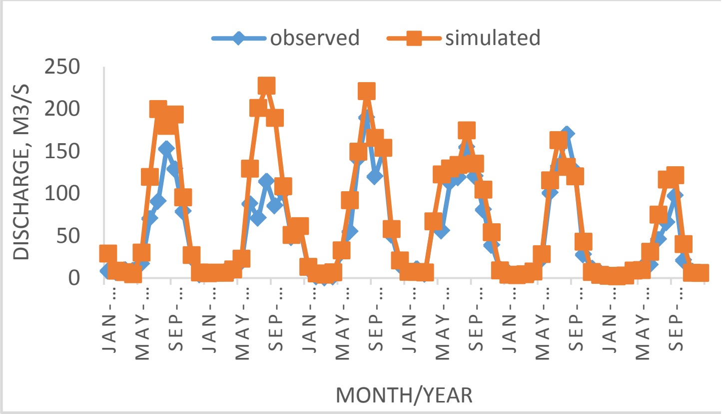

Fig 5: Hydrograph of observed and simulated monthly stream flow during calibration.

The model validation was conducted using climatic data set for the period of five years (1996-200). The same number of simulation was used during validation process. Statistical analysis of model performance during validation using regression plot indicates a good relationship between simulated and measured stream flow. The R^2 value of 0.84 obtained indicate a good model fit during validation. In addition the objective function NSE of 0.62 indicates the model performance during validation is satisfactory.

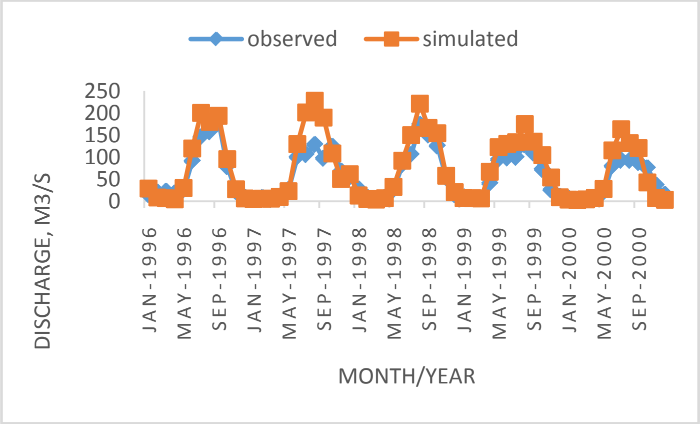

Fig 6: Hydrograph of observed and simulated monthly stream flow during validation

4. CONCLUSION

The advancement of computational power and the availability of spatial and temporal data have made hydrological models being attractive tools to examine and analyze how the hydrological process of the catchment functions under a varying land use dynamics. Particularly, in this study hydrological modelling is found to be useful tool for investigating interactions among the watershed components and hydrologic response analysis to LUCC at various spatial and temporal scales. As none of the hydrological models can be thought as perfect, models representing a better way were considered as essential criteria on the basis of data availability and the ease and purpose of modelling to evaluate the effects of land use land cover change on hydrological process.

The simulation of hydrological process has quantified the hydrological process in the basin using the reference conditions, defined in this study as the 1987, 2001 and 2010 scenarios. The result of land use dynamics revealed that the land use land cover change have significant effects on infiltration rates, runoff production, water yield, sediment loading, evapotranspiration and water retention capacity of the soil. The results of model calibration and validation have exposed the phenomena of the catchment. The result of SWAT model performance during calibration and validation was found to be 0.84, 0.90 and 0.58, 0.62 respectively for R2 and NSE. This shows good agreement between the simulated flow and observed stream flow.

Land use dynamics and hydrological process are systematically linked. This link provides an opportunity for manipulating the hydrological process if land use are controlled and managed. The study indicates that the out looks into future sustainable land and water resources of Gilgel Gibe catchment shall depend on the spatial planning of land use with the objective of optimizing the environmental benefit through surface runoff control, erosion protection, flood protection and water availability. Finally, educating the community the effect the unplanned land use practices had on the environment, natural resources and ecosystem is of paramount importance for the catchment management.

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