HYDROLOGICAL IMPACTS DUE TO LAND-USE AND LAND-COVER CHANGES OF KETAR WATERSHED, LAKE ZIWAY CATCHMENT, ETHIOPIA

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ABSTRACT

Human health and welfare, food security and industrial developments are dependent on adequate supplies of suitable water; however, water resources are finite in space and time and affected by many parameters. One of the parameters that affect the volume of water flowing in a watershed is land-use and land-cover of the watershed area. Having investigated the influence of human induced abstractions and its impact on the hydrology of the basin, it is also important to investigate of land-use/land-cover changes within the basin and their impacts on the hydrological regime. Based on this the main objectives of this study is to assess the temporal impacts of land-use and land-cover changes on stream flow of Ketar river which is located at south east central part of Ethiopia. The study also evaluated land-use and land-cover changes between 1986 and 2010 years and its impact on watershed hydrology. Classifications of historical land-use and land-cover changes occurred in the watershed were performed using 1986 and 2010 years satellite images with the help of ERDAS and GIS software. To investigate the impacts of land-use and land-cover change on stream flow, Semi-distributed hydrological model, Soil and Water Assessment Tool (SWAT) was applied. Following to model sensitivity analysis, calibration and validation was performed using historical recorded river flow data. The analysis result of land-use and land-cover change show that, an outspread of agricultural land and settlement and
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reduction of forest land and grass land in the study area. The evaluation of the SWAT model response to the land-use/land-cover change indicate that, the mean wet monthly flow for 2010 land cover increased by 3.8% compared to the 1986 land cover. On the other hand, average monthly flow in dry season is decreased by 12.3% in 2010 compared to 1986 land-cover. It is concluded that because of increasing number of population in alarming rates, it is expected that, the existing marginal lands at present will changed to agricultural lands which can affect health of hydrological process within the watershed and thereby threatens the livelihoods of the inhabitants.

Key words: Water resource, Ketar watershed, land-use/land-cover and SWAT 


1. INTRODUCTION

Human health and welfare, food security and industrial developments are dependent on adequate supplies of suitable water; however, water resources are finite in space and time and affected by many parameters. Establishing a relationship among these parameters is the central focus of hydrological modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations. One of the parameters that affect the volume of water flowing in a watershed is land-Use/Land-cover (LULC) of the watershed area. Land-Use/Land-Cover Change (LULCC) can be driven by multiple forces; demographic trends, climate variability, national policies, and macroeconomic activities which in turn have significant impact on hydrologic system both at a basin and regional scales [1, 2]. An evidence from several study show that high conversion of forest vegetation land to agricultural and pasture land in developing country, particularly in Africa including Ethiopia (for instance, [3, 1, 4]). For instance, in East Africa, nearly 13 million hectares of original forest were lost in 20 year period, and the remaining forest is fragmented and continually under threat [5]. In Ethiopia, the annual deforestation rate was calculated at 163,600 ha and the ongoing deforestation is a result of the very high human pressure on the natural resources [6]. However, Intensity of change may vary spatially as well as temporally due to the distribution and characteristic of population across the landscape. To visualize the future effects of LULCCs on river flow, it is important to have an understanding of the effects of historic land-use changes on the watershed hydrological system; because of direct and powerful linkages exist among spatially distributed watershed properties and watershed processes [7].

Having investigated the influence of human induced abstractions and its impact on the hydrology of the basin, it is also important to investigate of land-use/land-cover changes within the basin and their impacts on the hydrological regime. The spatio-temporal variability of LULCC, climate change and management practice in the watershed are extremely challenging to water resource management at watershed level. The demand of water abstraction by ever increasing number of human population and development of irrigation project at various scales within the river basin makes the problem more worsen. In addition, more mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion.
and degradation. Hence, investigating the relationship between land-use/land-cover and the hydrological condition (runoff volume, peak runoff rate, and total sediment yield) of the area enables us to know how the quantity of water flowing to the reservoir is changed with the change of land use. As a result, the need for scientific research that establishes the impact of land-use changes on stream flow is essential. The knowledge of the influence of land-use change on watershed hydrology are helpful for local governments and policy makers to formulate and implement effective and appropriate response strategies to minimize the adverse effects of future land-use change or modifications.

Hence the objectives of this study is to evaluate past land-use/land-cover change between two periods and assess the impact of land-use/land-cover change on stream flow of Ketar watershed by using a semi-distributed hydrologic model, Soil and Water Assessment Tool (SWAT) [8].

2. STUDY AREA
2.1. Description of Study Area

Ketar watershed covers 3225.3 square kilometres (km²) is part of the Ziway–Shala basin, an internal drainage basin located in the central part of the Main Ethiopian Rift Valley (Figure 1). Geographically it is located between 7°21′33″–8°9′53″ north of latitude and 38°53′57″–39°24′46″ east of longitude. The latter is a NNE SSW structure down-faulted through the Ethiopian highlands. Ketar River and its tributaries drain from south east highland area to North West and enter Lake Ziway. This lake is the most northerly of the Main Ethiopian Rift Valley lakes, and is fed principally by rivers draining the south eastern and north western plateaux and escarpments. The over flow of Lake Ziway feeds Lake Abiyata to the south. Topographically, the Ketar catchment shows a well pronounced variation with the altitude ranging from around 1646 m amsl near Lake Ziway (at the outlet) to about 4171 m amsl, on the high volcanic ridges along the eastern watershed (chikalo and Galama Mountain).
3. METHODOLOGY

3.1. Procedures

The steps used for evaluating hydrological responses of watershed as a result of changes in land-use/land-cover are; first, data base for land-use/land-cover map of 1986 and 2010 were prepared in order to evaluating land-use/land-cover dynamics. Second, SWAT Simulation run of stream flow was carried out using set of variables (i.e. land-use and land-cover, soil, topography, and climate) and sensitivity analysis was conducted to identify the most sensitive flow parameter that affected stream flow. Third, performance evaluation of SWAT model was undertaken through Calibration and validation step using measured and simulated stream discharge on annual and monthly basis and simulation run for the response of stream flow based on calibrated parameter. Fourth, in order to test the assumption that, land-use/land-cover change has affected watershed stream flow, further simulations were performed using both land-use/land-cover maps of (1986 and 2010) for the same period.

3.2. Input Data Used

Hydrological modeling using SWAT requires the use of spatially explicit datasets for land morphology or topography, land-use and land-cover, soil parameters for hydrological characteristics, and climate and hydrological data on a daily time step [9]. The main input raw data required to develop an input data base for running the model and their sources are explained in Table 1.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land-use/land-cover map</td>
<td>Landsat 5 thematic mapper (TM), Mapping Authority of Ethiopia</td>
</tr>
<tr>
<td>Soil map</td>
<td>RVLB Master plan, Ministry of Water and Energy of Ethiopia</td>
</tr>
<tr>
<td>Digital Elevation Model</td>
<td>Ethiopia Mapping agency</td>
</tr>
<tr>
<td>Stream flow</td>
<td>Hydrology and irrigation department of Ministry of Water and</td>
</tr>
<tr>
<td></td>
<td>Energy of Ethiopia</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Relative humidity</td>
<td>National Meteorological Agency of Ethiopia, Addis Ababa</td>
</tr>
<tr>
<td>Wind</td>
<td></td>
</tr>
<tr>
<td>Solar radiation</td>
<td></td>
</tr>
</tbody>
</table>

DEM used to delineate the topographic features of Ketar watershed in order to determine the hydrological parameters of the basin such as, slope, flow direction and accumulation, outlet points and stream network. In order to assess the heterogeneity of the physical properties, the watershed divided in to 36 sub-basins and each of the sub-basin re-divided in to 325 HRU based on the homogenous land-use, management, soil and slope characteristics of the watershed.

3.3. Land-use/land-cover Data Base Establishment

Cloud free Land sat of ETM and ETM+ imageries (path 168; row 54 and 55) that were acquired in December 1986 and January 2010 were analyzed to classify the land-use/land-cover and its historical dynamics of the study area. The mosaics of the
two scenes (row 54 and 55) covering the whole extent of the study area was prepared. Generalized land-use/land-cover data generation by ERDAS software is summarized on the Figure 2 flow chart.

**Figure 2** Flow chart for land-use/land-covers change analysis using ERDAS2010.

The generic approach of land-use/land-cover change analysis used is based on post-classification comparison method, which is commonly employed in land-cover change detection studies [10]. Identified land-use type during field survey via supervised land sat satellite image classification by using maximum likelihood classification algorithm include Agricultural land, Afro-alpine vegetation, Grass land, Forest land, Shrub land, Built up area and wet lands. In order to evaluate stream flow variability in relation to land-use/land-cover change at watershed level the two 1986 and 2010 land-use/land-cover map are used.

### 3.4. Climate Data

The most important input climatic parameters used in the SWAT modeling includes, precipitation, maximum and minimum temperature, humidity, solar radiation and wind on daily time series of six stations (Areta, Asella, Bekoji, Kulumsa, Ogolcho and Sagure) found within the watershed were obtained from National Meteorology Agency of Ethiopia (NMAE). However; these climatic variables are the most sensitive elements in hydrologic process, they are kept
unchanged during simulation of stream flow to analyze impact of land-use/land-cover changes on water resource availability.

3.5. Soil and Flow Data

Similarly soil digital map is obtained from Ministry of water resource GIS section and soil physical and chemical properties at different layer were collected from rift valley lake basins master plan documented by the Ministry of water resources of Ethiopia. Accordingly, soil data-base of the study area was prepared in suitable format and appended in SWAT data-base.

Daily time series of stream discharge between 1970–2010 years were collected from Ministry of Water Resource, Hydrology section, Ethiopia that has been gauged at the outlet of the catchment. This data mainly used to evaluate the predictive capacity of SWAT model through calibration and validation procedures against measured stream discharge. The data of 1983–2010 years was divided in to two sets of period 1983–1994 and 1995–2010 corresponding to the land-use/land-cover map of 1986 and 2010 respectively. These sets of data again divided in to two for calibration and validation period.

3.6. Stream Flow Change Analysis

For the assessment of stream flow change in the watershed due to land-use/land-cover changes, land-use/land-cover map of 1986 and 2010 were used while sets of all other input variables are kept unchanged for both simulations [11]. The parameter sensitivity analysis was conducted using a combined method of Latin Hypercube (LH) sampling and One-Factor-At-a-Time (OAT), a LH-OAT that is integrated to SWAT2009. Following to sensitivity analysis, calibration and validation of the model was carried out by the Sequential Uncertainty Fitting version 2 (SUFI-2) algorithms of SWAT Calibration and Uncertainty Programs (SWAT-CUP) an interface that was developed for SWAT [12]. The evaluation of model performance assessment was applied using Nash-Sutcliffe model efficiency, Coefficient of determination and root mean square error. After calibrating and validating the model using the two land use/cover maps for their respective periods, the model was also run using both the 1986 and 2010 land use/cover maps for the period of 1995–2010 to find out the impacts introduced on the stream discharge due to the land use/cover change.

4. RESULTS AND DISCUSSIONS

The result part of this section reports land use change from 1986 to 2010, hydrological modeling, and change of stream discharge as a result of change in land-use/land-cover. Calibration, sensitivity analysis and model performance capacity are also presented.

4.1. Land Use Change

The result obtained from land-use/land-cover analysis indicated that, agricultural and built up land-use is increased while grass land and natural forest cover is decreased. As indicated in Table 2, agricultural land was increased by 27.7% between 1986 and 2010, with annual rate of (15.5 km²/year). Built up area was increased by 211.3%, while grassland, Natural forest, Afro-alpine vegetation and wet land decreased by 33.7 %, 53 %, 6.2 and 15% respectively. In contrast, plantation forest is increased by 117 % with 1.4 km² annual rate of change. In both periods agricultural
land is the dominant land use type in the study area, which constitutes 42.6% and 54.5% in 1986 and 2010 respectively.

<table>
<thead>
<tr>
<th>Land-use type</th>
<th>LULC 1986</th>
<th>LULC 2010</th>
<th>LULCC (1986-2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (Km²)</td>
<td>Area (%)</td>
<td>Area (Km²)</td>
<td>Area (%)</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>1401</td>
<td>42.6</td>
<td>1789</td>
</tr>
<tr>
<td>Grazing/Grassland</td>
<td>682</td>
<td>20.8</td>
<td>452</td>
</tr>
<tr>
<td>Afro-alpine vegetation</td>
<td>598</td>
<td>18.2</td>
<td>561</td>
</tr>
<tr>
<td>Natural Forest land</td>
<td>499</td>
<td>15.2</td>
<td>235</td>
</tr>
<tr>
<td>Built up land</td>
<td>53</td>
<td>1.6</td>
<td>165</td>
</tr>
<tr>
<td>Plantation forest land</td>
<td>29</td>
<td>0.9</td>
<td>63</td>
</tr>
<tr>
<td>Wetland</td>
<td>20</td>
<td>0.6</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total area</strong></td>
<td>3282</td>
<td>100</td>
<td>3282</td>
</tr>
</tbody>
</table>

**LULC**: Land-use/land-cover, **LULCC**: Land-use/land-cover change

### 4.2. Model Sensitivity Analysis, Calibration and Validation

The results of the sensitivity analysis indicate that, twelve parameters viz, Curve Number (CN2), Ground flow recession factor (ALPHA_BF), Soil Evaporation Compensation coefficient (ESCO), Plant Evaporation Compensation Coefficient (EPCO), Soil Available Water Capacity (SOL_AWC), Soil Hydraulic conductivity (SOL_K), Hydraulic conductivity in main channel (CH_K2), Surface runoff lag coefficient SURLAG, Average slope steepness (HRU_SLP), Groundwater “revap” coefficient (GW_REVAP), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) and Ground water Delay (GW_DELAY) are the most essential parameters for the studied watershed. The sensitivity analysis indicated the overall importance of the twelve parameters in determining the stream flow at the study area, but CH_K2, CN2 and SOL_K were found to be the most sensitive parameters than others.

The simulated stream flow was calibrated and validated against measured stream discharge on annual and monthly basis. The result revealed that, monthly coefficient of determination ($R^2$) varied between 0.71 and 0.82 with the highest value is 0.82 during calibration time step. Similarly, Nash-Sutcliffe coefficient ($NS_E$) varied between 0.65 to 0.82 with the highest value of 0.82 during calibration of 2010 land-use map with respect to measured and predicted stream discharge on monthly calibration and validation time period as shown on Figure 3. This model test values in both calibration and validation period prove that, SWAT model simulated monthly stream flow quite satisfactorily against measured stream flow.

### 4.3. Hydrological Responses to Changes in Land Use/Cover

As the results of stream flow variability indicate that mean monthly stream flow during dry season decreased by 12.3%, while during wet season increased by 3.8% due to land-use/land-cover change in the 1997–2010 period. The SURQ, GWQ and LATQ components of the stream simulated using the 1986 land-use and land-cover map for 1997–2010 period are 40.6%, 56.4% and 4.1% while using the 2010 land-
use and land-cover map are 45.0 %, 51.7% and 4.5 % respectively. The contribution of surface runoff has increased from 40.6 % to 45.0 % due to the LULCC occurred between the period 1986 to 2010.

![Figure 3](image)

**Figure 3** Monthly calibration and validation of stream discharge for the period of (1997–2005)

On other hand, the contribution of ground water flow decreased by 4.8 % due to land-use/land-cover change between 1986–2010. Figure 4, shows mean monthly hydrographs of stream flow changes as a result of LULCC in three decades.

![Figure 4](image)

**Figure 4** Mean monthly stream flow variation due to LULCC at gauging station

5. CONCLUSIONS

From this study, it can be concluded that, land-use/land-cover change in Ketar watershed is experienced before 1970 and highly significant for the past three decades. It can be presumed that deforestation natural forest and increase in farmland that was manifested by the rapid increase in human population has altered the whole Ketar watershed. The identified land-use/land-cover change during (1986–2010) study period, are the overall increase of farmland and built up area over the reduction of grass land and natural forest area at Ketar watershed.
Over all, the result of analysis indicated that changing of forest land and grassland to agricultural land and urban area has altered rainfall-runoff relationship and resulted in increase wet season surface flow and reduction of dry season water flow. As explained in the methodology, all input parameters (including climatic, soil, and slope) are kept unchanged during the simulations so that only the impacts of LULCC are recognized. It also identified that one of the most important concerns regarding the conversion of forest to farmland land-use change relates to water availability during the dry season that reduced the contribution of ground water flow at critical time. Therefore, as a result of increasing number of population in the study area (Ketar watershed), it is expected that, existing marginal lands at present will changed to agricultural lands which can affect health of hydrological process within the watershed and thereby threatens the livelihoods of inhabitants. Hence the land-use/land-cover change should be controlled in the watershed and some measures should be taken for the stabilization of the land cover change to sustain the contribution of groundwater in dry season and ecological bio-diversity within the basin.

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Hydrological Impacts due to Land-Use and Land-Cover Changes of Ketar Watershed, Lake Ziway Catchment, Ethiopia


