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Assessing the Impacts of Land use/cover Change on the Hydrological Response of Temcha watershed, upper Blue Nile basin, Ethiopia

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ABSTRACT

Information on the relationship between hydrologic response and land use /cover change was vital for the proper management of water resources and land use planning across the world. The main objective of this study was to assess the impacts of land use/cover change on the hydrological response of Temcha watershed. ARC GIS did the hydrological modeling with an extension of ARC SWAT model and the model calibration and validation by SWAT CUP. The result in the calibration and validation period showed a good agreement between the observed and simulated data, both in the calibration and validation period respectively. the land use/ cover change had a significant impact on modeled watershed hydrologic response due to the transition from forest, grass, and shrub land to cultivated land areas resulted in annual and seasonal water yield, total aquifer recharge and surface runoff potential. These results demonstrate the usefulness of integrating remote sensing and distributed hydrologic models using GIS for assessing watershed conditions and the relative impacts of land cover transition on the hydrologic response continuous.

Keywords : ARC GIS, land use /cover, SWAT, Temcha Watershed

I. INTRODUCTION

Presently, fresh water becomes the main challenging resources in terrestrial ecosystem. The fact is that, each activity that has been on going in the world demands for fresh water. Freshwater availability at the global scale is an essential requirement and one of the most concerning challenges facing humanity at present and increasingly issue in the future (Vörösmarty et al., 2010). The other major global concerns, like food insecurity, human health problem, climate change, economic development crisis and, finally yet importantly, regional conflicts are not exclusively but to a considerable extent related to freshwater availability (Wackernagel and Rees, 1998).
The spatial and temporal variability of watershed resources (particularly land use/cover change) have a paramount impact on the presence of quantity and quality of river water flow (Mengistu, 2009). Land cover change, associated with the intensification of agriculture, cattle raising and urbanization, could have a profound influence on the hydrological processes in small Watersheds and at a regional level(Mengistu, 2009). Streamflow process plays an important role in establishing some of the critical interactions that occur between physical or ecological processes and social or economic processes(Choi and Deal, 2008).

The population in Ethiopia increased rapidly in the last century. This eventually resulted in large-scale land use changes, deforestation, overgrazing, and expansion of cropland too marginal and steeply sloping areas, poor soil management practices and unsustainable use of natural resources (Tesfahunegn *et al.*, 2012). These practices reduce rainwater infiltration resulting in more surface runoff and water erosion. This leads to exhaustion of the soil, decreasing soil quality and eventually a decline in soil productivity (Bewket, 2003). This study conducted on a Temcha catchment area that is located in upper Blue Nile basin (northern) part of Ethiopia. It is the major tributaries of upper Blue Nile river basin.

It is well-known that land use /cover change have an impact on changing variables, such as temperature, precipitation, evapotranspiration, water retention capacity of the soil, sediment loading, surface runoff potential and decrease in ground water recharge and soil infiltration capacity of the catchment area. Change in these variables have a direct impact on the hydrological cycle and water balance components of the area (Abebe, 2005). The area indicates that specific patterns of the land use changes in several years ago due to deforestation, conversion from grazing into farmland are some changes that have been taken place in the area (Mûelenaere *et al.*, 2014). There is a sensitivity of hydrological process system to land use/ cover variations .

The spatial-temporal variability of land use/cover, climate change and management practice in the watershed are extremely challenging to takes water resource management at the watershed level. The demand of water abstraction by ever-increasing number of human population or urbanization and development of irrigation, hydropower and other water projects at various scales within the river basin makes the problem worst. Hence, investigating the relationship between land use /cover and the hydrological condition (runoff volume, peak runoff rate, and total sediment yield) was a key attention for this study.

II. MATERIALS AND METHODS

2.1 Description of the study area

The study area has located in 10^0 23' to 10^0 41'N latitudes and 37^0 16' to 37^0 45' E longitude which constitute 108,976 ha of land. Concerning of administration, it is shared between Dembecha district (western Gojjiam) and Machakel district (Eastern Gojjiam) in Amhara regional state. It is about 345 km far from the capital city, Addis Ababa to the North West, 285 km from the regional city, Bahirdar to the southeast. The elevation ranges from 950 to 2800 mean sea level. The study area is bordered with 14 kebeles (small administration units in Ethiopia) on the side of west and eastern part of Gojjiam and shares boundaries with Debrealias on the south, west Gojjiam (Dembecha district) on the west district the north Senan district on the north-east (CSA, 2007).

The catchment area was subjected to land use /cover change because of overgrazing, cutting and clearing vegetation, wood collection, land fragmentation, investment expansion, agricultural expansion, and settlement (Zeleke and Hurni, 2001). Due to land cover dynamics, surface runoff, Sediment accumulation, riverbank decrement, flood, river discharge capacity decrements are a cause and effect relationships. Generally, increase in sediment yield, the occurrence of high surface runoff, decrease in ground water level and others are problems caused by the land use land cover change of catchment area (Koch et al., 2012). This also affects hydraulic structures, which already built, and going to constructed in and around upper Blue Nile basin of Ethiopia by sedimentation and flooding. Human interference such as deforestation, urbanization and other land use activities can significantly alter the maximum and minimum flows of the river (Price, 2011)

Land use/cover changes in the area are a severe phenomenon and a great effect on mainly forest cover, grassland, shrubland and hydrology of Temcha watershed, the issue it might pose a serious impact on the future functioning of this fragile resource if urgent action taken in to consideration. So Understanding how these activities influence the hydrological response will enable planners to formulate policies towards minimizing the undesirable effects of future land use /cover changes on the hydrology of the river.

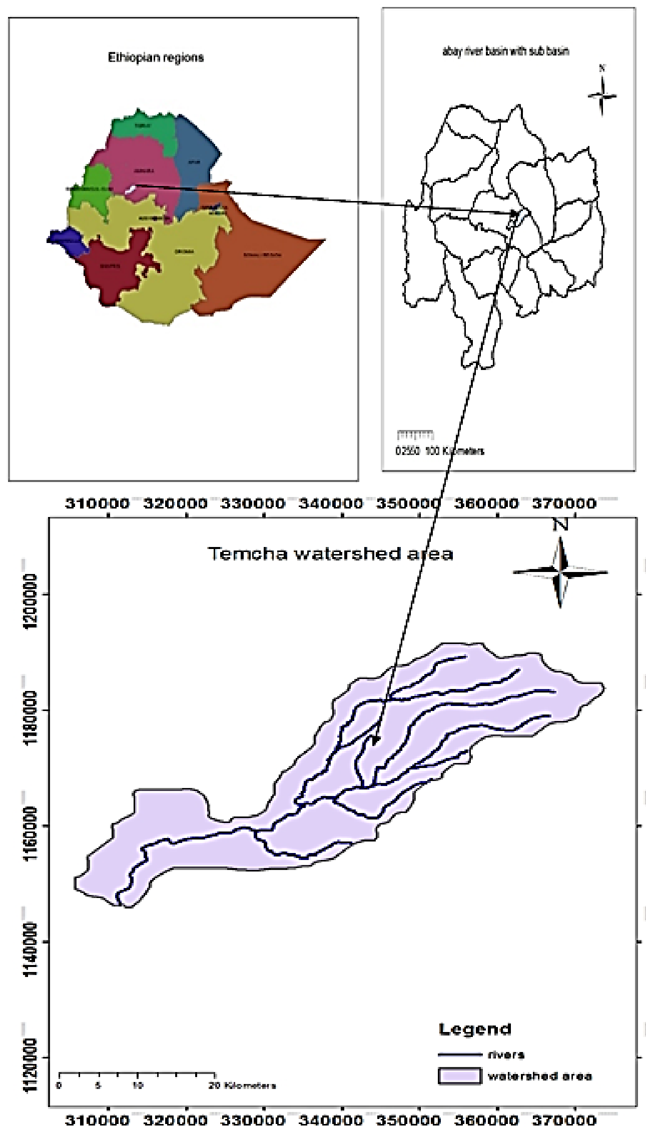


Figure 1: location map of Temcha watershed

2.2 Objective of the study

2.2.1 General objective

To quantify the impacts of land use land cover change on the hydrological response of Temcha watershed.

2.2.3 Specific Objectives

1. To model the flow of Temcha watershed by using ARC SWAT software.
2. To estimate land use /cover change impact on Temcha watershed runoff generation.
3. To estimate the sediment yield of Temcha watershed under land use /cover change

2.3 SWAT model set up

The ARC SWAT (soil and water assessment tool) watershed model is one of the most recent models developed at the USDA-ARS during early 1970 (Arnold et al., 2012). The model is semi distributed physically based simulation model and can predict the impacts of land use change and management practice on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool. The land phase of the hydrologic cycle modeled in SWAT based on the water balance equation

$$SW_t = SW_o + \sum (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

The model inputs are DEM (Digital elevation model), Land use/cover map, and Soil map and weather data. DEM of 30m by 30m downloaded from the http://earthexplorer.usgs.gov processed for watershed delineation and topographic characterization of the basin. For this study it was used the land use map of 1992, 2000 and 2010 were prepared from the land sat imagery of TM, ETM+ and TM respectively with the support of ERDAS Imagine 2014 and Arc GIS10.2. Six different classes of each map identified and assigned based on classification system. Then, the map integrated with the soil data that contain six major is soil groups. To integrate the soil map with the SWAT model, user soil database which contains textural and chemical properties of soil were prepared for each soil layers in SWAT2012 and added to the SWAT user database using the data management append tool in

ARCGIS. The overall SWAT model analysis looks like the chart below.

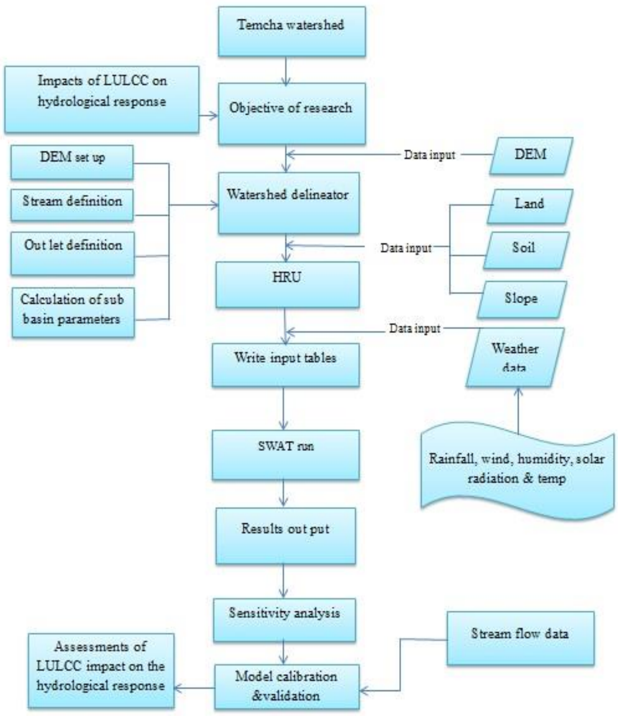


Figure 2 : work flow chart of SWAT model analysis

2.4 Sensitivity Analysis, Calibration and Validation of the SWAT Model

Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model parameters (Arnold *et al.,* 2012). The sequential uncertainty fitting (SUFI-2) found in SWATCUP was used to calibrate and validate the ARC SWAT model. The degree to which all uncertainties are accounted for were quantified by a measure of P-factor, which is the percentage of measured data bracketed by the 95% prediction percentage uncertainitiey-95PPU and Evaluate the model simulation outputs in relative to the observed data. The model performance evaluation is by coefficient of determination (R^2), Nash, and Sutcliffe simulation efficiency (ENS).

The determination coefficient (R^2) describes the proportion the variance in measured data by the model. It is the magnitude linear relationship between the data observed and simulated values. R^2 ranges from zero (which indicates the model is poor) to one (which indicates the model is good); with higher values indicating less error variance and typically greater than 0.6 considered acceptable the R^2 is calculated using the following equation.

$$R^2 = \frac{\sum[Xi - xav]\ [Yi - Yav]}{\sqrt{\sum[xi - xav]^2}\ \sqrt{[yi - yav]^2}} \qquad (2)$$

Where, xi – measured value (m^3/s), Xav – averaged measured value (m^3/s), Yi – simulated value (m^3/s) and Yav – averaged simulated value (m^3/s)

The Nash–Sutcliffe simulation efficiency (ENS) indicates that how well the plots of the observed versus simulated data fits 1:1 line ENS is computed using the following equation.

$$ENS = 1 - \frac{\sum(xi - yi)^2}{\sum(xi - xav)^2} \qquad (3)$$

Where, xi – measured value, Yi – simulated value and, Xav – averaged observed value

The model run using a daily data of 26 years (1990-2015) for the examination of the trend of hydrological process under a land use maps of 1992, 2000 and 2010. 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 stream flow due to land use and land cover change

Simulation of the impacts of the land use/cover change on the hydrological response of the most significant parts of this study. As discussed above, Temcha watershed has experienced land use and land cover changes from 1992-2010. There was a high expansion of agricultural lands and settlement in the expense of other lands during the study periods considered. The study carried out through for three different year land use/cover maps i.e. 1992, 2000, and 2010. The three generated land use and land cover maps, soil, weather and stream flow data values were used to evaluate the impacts of land use and land cover change on the hydrological response. To evaluate the variability of stream flow due to land use /cover changes the 1992, 2000 and 2010 land use/cover maps used and three independent simulations conducted on a monthly basis. Using both land use and land cover maps for the period 1992-2010 keeping other input parameters unchanged. Hydrological response variability of 1992, 2000, and 2010 due to the land use /cover change was assessed and comparisons were made on surface runoff and sediment yield contributions to stream flow based on the three simulation outputs.

2.6 Evaluation of land use/cover change in the model

After flow, calibration and validation process by SWAT CUP software it was evaluate the land use/ cover change impact in the hydrological response of Temcha watershed area. During this time, it deeply analyze the outputs of SWAT CUP parameters after calibration and validation with varying use of land use and stream flow. Some parameters directly proportional with the varying impacts of land use/cover map such as ground water flow and land management.

III. Result and Discussion

3.1 Land use /cover change (1992, 2000 &2010) in Temcha watershed

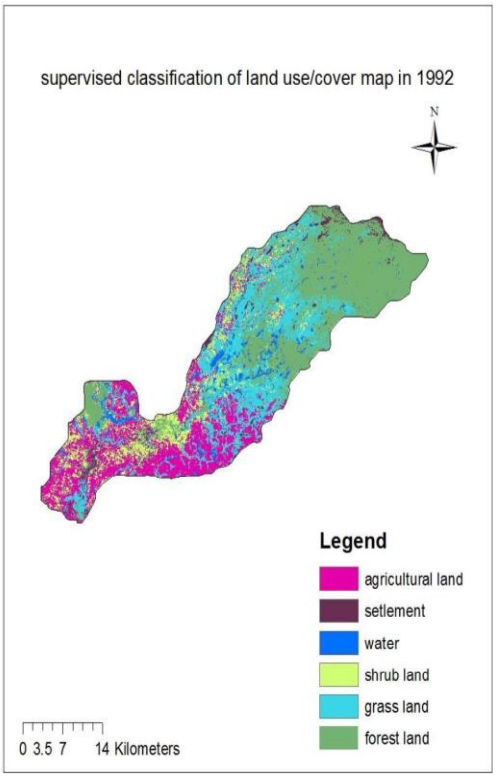
Based on the information from the classified image and inhabitants, cultivated land, shrub land and forestland where the major land use and land cover classes during the study periods. During the last several decades in Ethiopia, the population growth was lower with relative to the present time. In this period, it was highly likely that apportion of the land was left a banded. The human population was relatively low with lowed pressure on the land and associated resources in general and with the prevalence of fallow lands.

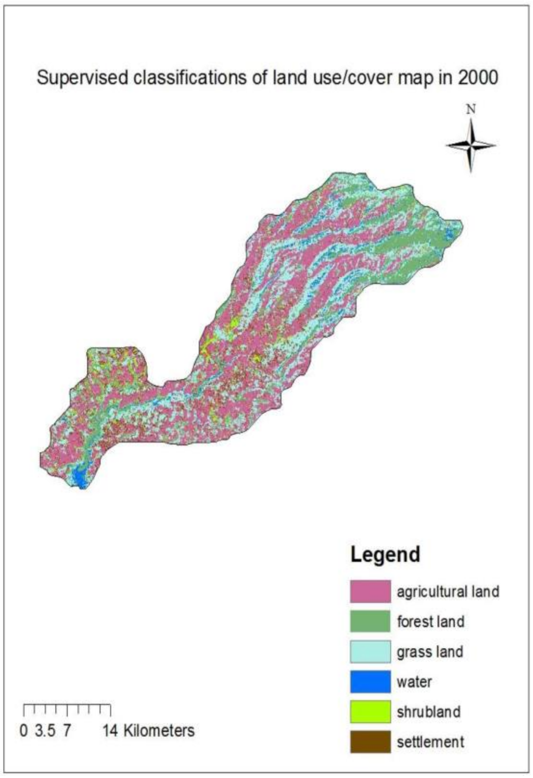
As in most parts of Ethiopia, dramatic forest cover decline occurred over the last decades. Forest cover in the Temcha catchment from (1992-2010) reduced in 22.27%, 15.067%, 8.70% respectively and also further forest cover decline was observed and reported in several parts of Ethiopia studies like (Dessie and Kleman, 2007) there was reported a relative forest decline from 16% to 2.8% in the Wondo Genet catchment in the period 1972-2000.

Table 1. The statistical summaries of the different land use/cover maps

Land use type	Area (ha)	1992 In (%)	Area (ha)	2000 In (%)	Area (ha)	2010 In (%)
Agricultural land	55987	34.55%	76705	61.86%	92133	85.384%
Forest Land	27979	30.73%	19063	15.067%	10944	8.70%
Grass Land	32335	27.27%	25229	20.08%	20883	4.61%
Shrub Land	8228	6.54%	2580	2.003%	157	0.12%
Water body	1078	0.85%	249	0.19%	33	0.026%
Settlement	78	0.06%	1127	0.8%	1452	1.16%
Total	125685	100%	124953	100%	125602	100%

The following figure shown below the supervised land use/cover map classification systems of the watershed area. It also express the variations of land use/cover maps in different years.





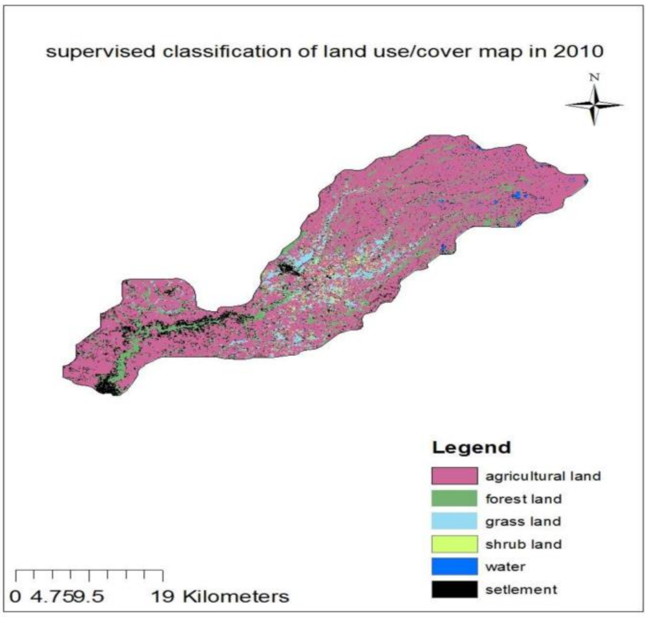


Figure 3. Classified land use/cover map of the study area (1992-2010)

3.2 Model Calibration and validation by SWAT- CUP

For the model calibration, 27 parameters considered and the calibration and validation performed in three land use/cover maps. Eight sensitive parameters identified and tabulated in the table with an order of decreasing sensitivity.

Table 2. The most sensitive parameters in the calibration period

Rank	Sensitive parameter	Min & max range	t-stat value	p-value	Fitted value
1	CN2	-0.2 to 0.2	2.77	0.00032	0.19
2	ALPHA_BF	0 to 1	2.54	0.0057	0.11
3	SOL_BD	-0.5 to 0.6	2.34	0.013	-0.22
4	SOL_K	-0.8 to 0.8	1.60	0.113	-0.44
5	EPCO	0 to1	-1.36	0.175	0.12
6	CANMX	0 to 100	-1.13	0.262	10.50
7	GWQMN	0 to 2	1.00	0.316	1.49
8	REVAPMN	0 to 0.25	0.434	0.665	0.02

After the calibration model again run with the calibrated parameters and the simulated flow compared with the observed flow. The graphical (visual observation) method and values of statistical parameters used as an indication of calibration acceptance. Due to the absence of observed stream flow data the calibration period were limited in the period of 1992-1997 for six years with two years (1990-1991) keeping for model warm up for model validation it was taken (1998-2002). The result of model calibration and validation process indicated good agreement between monthly measured and simulated flow with the R^2 and ENS values of 0.84 and 0.73 respectively. This result shows that there is a good model fit in the calibration and validation period.

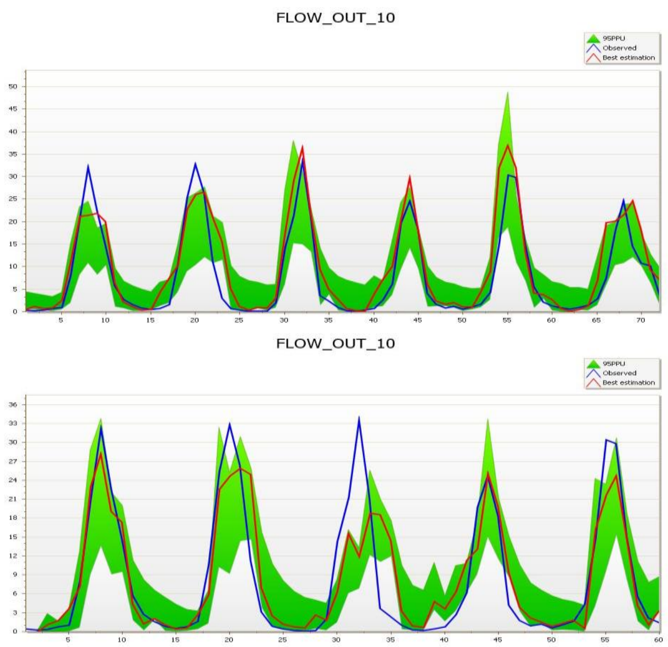


Figure 4 : Hydrographs of calibration and validation period

3.3 Hydrological response to different land use/cover change scenarios

As a result from after model calibartion and validation a unique trend of continuous groundwater decline was noticed in the (table 2) From 1992 to 2000, the annual groundwater recharge decreased. The further decline in groundwater recharge of 22.85 mm was observed in 2010. The similar decline in groundwater recharge has been reported by other studies shows a higher surface runoff increment and a reduction of ground water recharge in gedeb catchemnt upper blue Nile basin. The declining trend seen in the average groundwater recharge can be attributed to increase in surface runoff potential, less soil infiltration capacity and higher evapotranspiration. It is also the case that groundwater resource within the basin is sourced for several activities.

Table 3. Hydrological process of 1992, 2000, 2010 LULC

Hydrologic process	1992	2000	2010
Surface Runoff	319.61 mm	329.06 mm	347.14 mm
Lateral flow	76.55 mm	73.25 mm	71.88 mm
Ground Water Shal AQ	429.9 mm	416.91 mm	411.35 mm
Ground Water Deep AQ	26.82 mm	22.82 mm	21.95 mm
Deep Aquifer Recharge	27.85 mm	25.40 mm	22.85 mm
Total Aquifer Recharge	516.99 mm	507.98 mm	456.92 mm
Total Water Yield	743.60 mm	733.22 mm	710.87 mm
Percolation Out of Soil	516.99 mm	507.98 mm	425.41mm
ET	605.9mm	668.5mm	677.1 mm
Sediment loading	7.89 t/ha	15.59 t/ha	16.31 t/ha

A resulting effect of these uses of water may account for the continuous decline in groundwater recharge as depicted by the model results be consistent with the findings of water. Where, they asserted that ground water is a preferred source of water over surface water due to the high inter annual variation in precipitation that tend to affect surface water availability. This is particularly the case in semi-arid environment in Africa and so is the case of the Temcha watershed. A comparison of the variations in surface runoff under the land use /cover change scenarios show the surface runoff increase in a large extent in several years ago. The increase in surface runoff are linked to the significant changes in watershed land use/cover, resulting mainly from the conversion of forest land and grassland to agricultural land and urban land areas and consequently causing an increase in impervious surface covers. In subsequent years surface runoff increased for all the land use/cover change scenarios, water yield reduced in year to year probably due to the reduction in both ground water deep and shallow aquifer recharge and lateral flow.

Such enhanced sources of sediment in a watershed include unvegetated stream banks and uncovered soil regions, including construction sites, deforested areas, and croplands. Changes in land use/cover, stream flow characteristics and drainage patterns can alter the natural sediment rate. Historically, intensive agricultural activities have been the main source of human-enhanced sediments in water bodies US farming, for instance, accounts for an annual erosion loss of over 3 billion metric tons of soil. The conversion of marshlands (wetlands) or woodlands to cropland can increase soil erosion and the associated sedimentation in streams, particularly when bare soil is exposed.

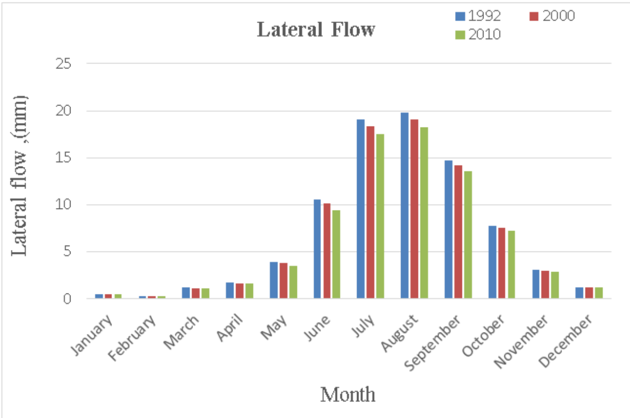
3.4 Sub basin contribution sediment and surface runoff in three land use maps

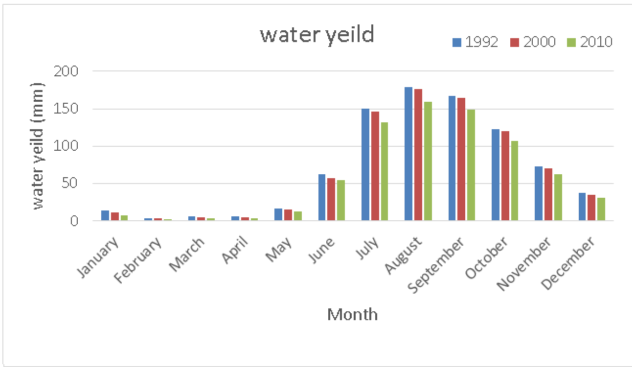
Table 4. Sediment and surface runoff yields

Land use/cover map	Sediment	Yield (t/ha)		Surface	Runoff (mm)	
Range	max	min	Sub basin	max	min	Sub basin
1992	21.8	11.7	6 , 5	322	62	8 , 12
2000	16.7	10.5	17 , 14	300	56	10 , 13
2010	27.81	12.5	2 ,3	391	42	21 , 17

In table 4 the subasin contributes this yield during the dry months. During this month after rainfall reaches in the surface of the earth, directly it contributes immediate surface runoff. This sudden surface runoff it makes also immediate and high yield sediment contribution. The sediment yield contribution is varied from sub basins to subasin, for elaborating this study I was selected the maximum and minimum values and their contributor subasin. In addition to simulating surface runoff, water yield and groundwater, the SWAT model also gave a good prediction of evapotranspiration (ET). Several factors other than physical characteristics of the water, soil, and plant cover also affect the evapotranspiration and potential evapotranspiration process.

The change in more important factors include net solar radiation, surface area of open bodies of water, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics, and season of year a greater impact on this process. Thus, from table 2 and figure 4 ET increased from 605.9 mm in 1992 to 668.5 mm in 2000, and also after 2000 years saw that a continued increase in ET from 668.5 mm to 677.1 mm in 2010. The increase in ET potential in the catchment area coincide with decrease or decline in forest cover and water for the same period. Under consideration this is so because trees that makes generally have the ability to access soil moisture from greater depths for transpiration and also have greater canopy cover for interception of precipitation which eventually culminates into higher observed ET.





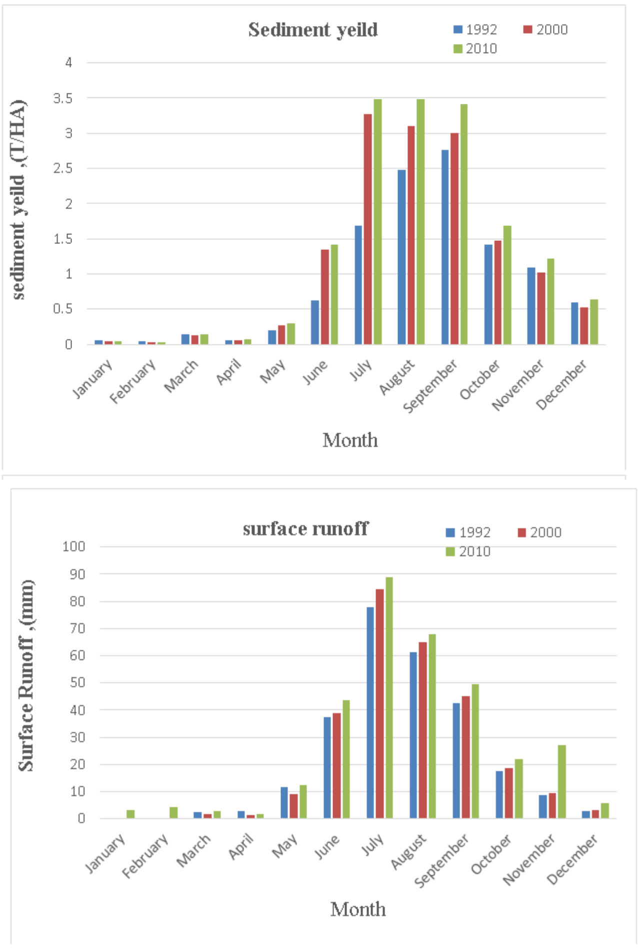


Figure 5 : Calibrated mean monthly yields of, lateral flow, water yield and sediment yield and surface runoff

3.5 Discussion

There are a number of reasons, which prevent the model result being highly accurate. The lack of actual, necessary data, such as precipitation, discharge, and soil are some of these reasons. As mentioned above, filling in the missing precipitation and observed data attained by using interpolated data. Using interpolated data does not provide the actual result data. Furthermore, it is common that measured discharge and precipitation data contain errors, which sourced from either measuring instrument, or crew error in a measuring station. Therefore, It is clear that these kinds of errors be propagated in a modeling process and could affect the model result.

Some GIS-based errors could affect the model result. These kinds of errors mostly introduced while data processing and analysis of geospatial SWAT input data. The possible GIS based error results shown that expected from this study, mainly generated from the combining process of similar land use/cover attributes and the reclassifying process of land use/covers and soil class analysis these include some other errors, which be created while using GIS data managing process such as digitizing, extracting and georeferencing. All these kinds of errors could have an effect on the accuracy of the model results

IV. CONCLUSION AND RECOMMEDATION

Understanding how the land use and land cover changes influence the catchment hydrological system will enable planners to formulate policies to minimize the undesirable effects of future land–use /cover changes. Land use/cover changes as noted in this study increases impervious ground surfaces, decrease the infiltration rate and increase runoff rate, hence causing low base flow during the dry seasons. It is evident that the catchment hydrology is currently under pressure following the rapid land-use change that was taking place in Temcha River. The study revealed that there are major land use and land cover changes in Temcha watershed.

The results also revealed that most land use/cover changes were directly to take place as more land converted over time, especially forestland to agricultural land and settlements, which threatens the existence of water resources in the future. Efficient tools such as satellite remote sensing and geographic information system are currently manage the limited water resources. In addition, this method implemented in the land-use scenarios to predict the changes that may happen to the river flow regimes. The GIS software provides a powerful tool for assessing the effects of land-use and land-cover on the river hydrology.

The changes of land-use are complex, dependent on the history, and important for managing current and future land-use, however, using remotely sensed data and GIS to simulate the land-use /cover changes and *their effects on the hydrology of the river are more advantageous when the study area is large. On the other hand, data preparation, sensitivity analysis, calibration, validation and evaluation of model performance on the selected, SWAT model. These analyses done before the evaluation of the impacts of land use /cover changes in the hydrological response of the watershed analyzed. The GIS environment used for the processing of DEM, Land use and land cover, soil data layers and displaying model results. Based on the results, the following conclusions are drawn.*

V. RECOMMENDATION

From this specific study, the following recommendation could improve; Integrating land/cover change map with hydrological models applied to predict the potential impacts of land use change on the hydrological response, vital ecosystem services in the watershed and the country in general. This helps for stakeholders and decision makers make better choices for land and water resource planning and management. It applied to a variety of watersheds, where the time-sequenced digital land cover is available, to predict hydrological consequence for land use /cover change in the area.

Due to land, use/cover change in the area surface runoff increased in the last 26, years so that a great attention on this because it may occur sudden runoff in the area and it may make undesirable influences human, animals, and crops. Land use planning considered an integral planning from the outset. Integration is necessary for the environmental perceptions of planners and water managers to ensure that management adopt holistic, basin-wide planning strategies capable of dealing with the diversity of resources and problems confronting Temcha watershed. Zoning applied to separate incompatible change of land use/cover and protect the water sources like springs, rivers, and forests. Soil protection and erosion control measures, such as ploughing parallel to contour lines, or the prescribed planting of trees should also be encouraged in the catchment.

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