Implications of Land Use and Climate Change on Water Balance Components in the Sigi Catchment, Tanzania

Mromba Clement[11] , Shadrack Mwakalila[12], Joel Norbert[13]

Abstract

Whereas normal water flow in a catchment is necessary for all forms of life, the hydrologic systems in the Sigi catchment is susceptible to land use and climate changes. Over the past three decades, water balance of the Sigi Catchment has indicated changes with unknown forms and magnitudes. To uncover the dynamics, this study used SWAT model to simulate water balance to a separate and combined impact of land-use and climate change. SWAT simulation showed good performance with NSE=0.58 and R^2=0.67 for calibration, and NSE=0.56 and R^2=0.64 for validation periods. Land use change scenarios indicated increase in surface runoff by 16.1mm, while base flow and water yield decreased by 23.1mm and 7.2mm, respectively. Climate change scenarios indicated an increase in surface runoff by 29.9mm, while base flow and water yield decreased by 36.1mm and 14.2mm, respectively. The combined land use and climate change scenarios indicated increase of surface runoff by 19.0mm, and decrease in base flow and water yield by 29.7mm and 10.7mm, respectively. From the study, it is clearly that the impacts of climate change on water balance components of the Sigi catchment are larger than land use change. Owing to the dilemma facing water resources in this era of climate change, long-term planning that balance households' livelihood options and water resources management option is needed.

Key words: land use change, climate change, modeling, SWAT, hydrology

Introduction

The influence of land-use and climate changes on the catchment's hydrology has been well established worldwide (Yao *et al.,* 2015; Wang *et al.* 2014; Khoi & Suetsugi, 2014). Climate change has been identified as the main contributor to changing streamflow volume, peak flow and flow routing time (Shi *et al.,* 2013). On the other hand, land use change has been found to have caused transformation in hydrologic systems and higher intensities of droughts (Wei *et*

[11] Assistant Lecturer, Geography Department,, College of Social Sceinces,University of Dar es Salaam
[12] Professor Mwalimu Nyerere Memorial University
[13] Senior Leuturer, Water Resources, College of Engineering and Technology, University of Dar es Salaam

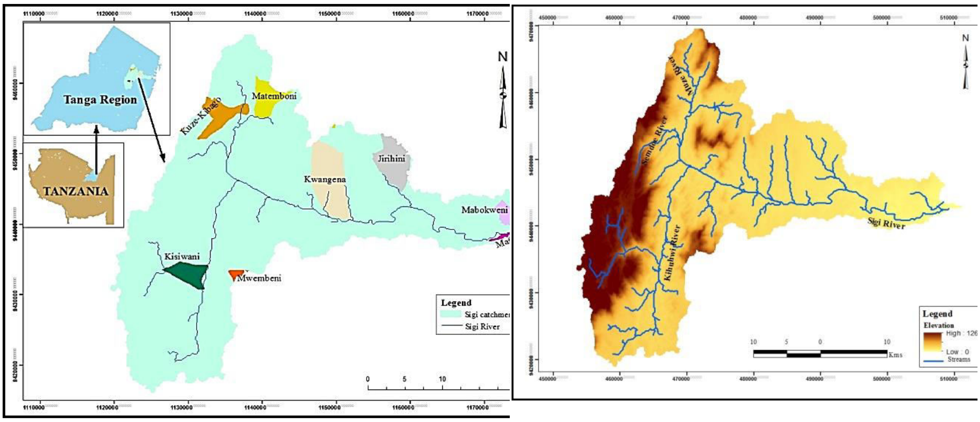
al., 2013). There has been an increase in the global mean near surface air temperature by $0.74^0 \pm 0.18^0C$ from 1906 to 2005 and 1.4^0C to 5.8^0C from 2005 onwards (IPCC, 2007). This has caused the global average streamflows to increase and decrease by 10-40% and 10-30%, respectively (Awotwi *et al.,* 2015). However, the hydrologic change cannot be explained by climate change alone, neglecting other factors like land use change (Mateus, 2015). The fact is that land use and climate changes which are linked through the hydrologic cycle form a complex and interactive system, and are very sensitive to both variables (Yao *et al.,* 2015). Thus changes in land use as a result of farming, grazing, logging, tree planting, and urbanization have affected the water balance and transformed the water-flow pathways (Crossman *et al.,* 2013).

Tanzania, as in many developing countries, is significantly affected by land use and climate change (Kashaigili et *al.,* 2015; Norbert and Jeremiah, 2012). Land use/ cover and climate change have deteriorated hydrologic systems thereby causing unpredictable change in stream flow. While several studies suggest land use change as a dominant factor (Gyamfi *et al.,* 2016; Zhang *et al.,* 2015), other studies points climate change as prominent factor in driving responses in water balance at catchment scale (Li *et al.,* 2015; Dile *et al.,* 2013). Both, climate and land use change are evident in the Sigi catchment (Shemdoe, 2015; Hepelwa, 2014). Yet, it is uncertain to what degree these environmental changes are likely to affect the water balance components in the Sigi catchment. It is essential, therefore, to understand the dynamics in water balance components to land use and climate change in the Sigi catchment as ways to reduce the related risk.

Materials and Methods

Study area

Sigi catchment has a total area of $1100km^2$ and is 115km long (Hepelwa, 2011). It is located between latitude 4^0 48' and 5^0 13' S and longitude 38^0 32' and 39^0 10' E at altitudes between 1 and 1266m above sea level (Figure 1). Many rivers in the catchment are small and highly dependent on rainfall variability. All rivers flow from different sources and joins to form the main Sigi River which flows throughout the year to the Indian Ocean (Shemdoe, 2015). The average monthly flow peaks occur in the period of April-May and in October-November, and the annual average flow is 431mm. The area has a bi-modal rainfall pattern with two rain seasons. Long rains period is in March-May with annual average varying between 1000mm to 2000mm and short rain period is October-November. The maximum temperature ranges between 28^0C and 35^0C and the minimum temperature between 17^0C and 23^0C (Mashingia, 2011). The estimated population is 169, 220 in 2010, with a population density of about 153 inhabitants/km^2 (URT, 2012).



(a) Location of the Sigi catchment (b) Topography and stream networks

Figure 1: Location and river networks of the Sigi catchment (NASA-SRTM, 2016)

Model input data

Soil and Water Assessment Tool (SWAT) model requires Digital Elevation Model (DEM) file, and weather data with geographical coordinates, land use, and soil data in Database File (*.DBF*) as tabular file format stored in lookup tables. A 90m by 90m resolution DEM was downloaded from National Aeronautics and Space Administration (NASA) Shuttle Radar Topography Mission (SRTM) (NASA-SRTM, 2016). The land use data for two periods (1985 and 2015) were extracted by processing the Landsat 5 Thematic Mapper (TM), and Landsat 8 Enhanced Thematic Mapper Plus (ETM+) with spatial resolution of 90m. The two landsat imageries were downloaded from the United State Geological Survey (USGS) web available at https://earthexplorer.usgs.gov/. The soil data was obtained from the Harmonized World Soil Database (HWSD v1.2) developed in the Food and Agriculture Organization (FAO) web available at http://www.isric.org/isric/. Weather data (rainfall, and minimum and maximum air temperature) at daily step for three stations (Tanga Airport, Mlingano Agromet, and Amani Malaria Unit) were obtained from Tanzania Meteorological Agency (TMA) for a period from 1958 to 2015. Discharge data from Sigi at Lanzoni station (1C1) for the periods from 1958 to 2015 were collected from Pangani Basin Water Office (PBWO).

SWAT modeling

The hydrological analysis of the water balance components in the Sigi catchment based on the separate and combined land use and climate change scenarios was done using SWAT model as illustrated in figure 2. The fundamental water balance equation (Neitsch *et al.*, 2011) as presented in equation 1, guided SWAT modeling process.

$$SW_t = SW_0 + \sum_{i=1}^{t}\left[R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right] \qquad [1]$$

Where;

SW_t is the final soil water content at time t (mm), SW_0 is the initial soil water content on day *i* (mm H_2O), R_{day} is the amount of precipitation on day *i* (mm H_2O), Q_{surf} is the amount of surface runoff on day *i* (mm), E_a is the amount of evapotranspiration on day *i* (mm), W_{seep} is the total water entering the vadose zone from the soil profile (mm), Q_{gw} is the total return flow on day *i* (mm), and t is the time (days).

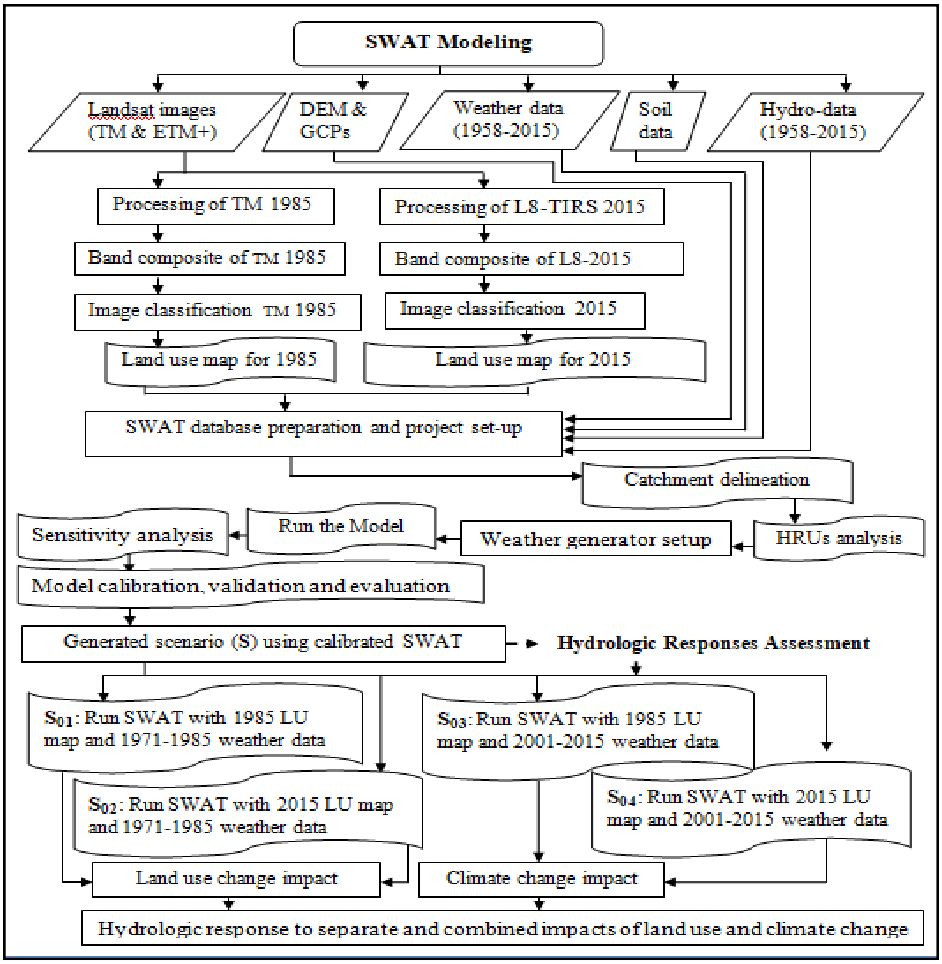


Figure 2: Flowchart of the SWAT modeling process for the study (Fieldwork, 2016)

Sensitivity analysis was performed to determine SWAT model parameters that are very sensitive to streamflow, and for an effective model calibration. The method algorithm for sensitivity analysis was defined in the SWAT project using the Latin Hypercube (*LH)* "One-factor-At-a Time" *(OAT*) for sensitivity analysis (Das *et al.,* 2013). In sensitivity analysis, the most sensitive parameters of the streamflow were ranked according to the magnitudes of response variable sensitivity to each of the model parameters, and divided in high and low sensitivities. Out of the streamflow parameters, the eight most sensitive parameters were chosen for model calibration processes.

Model calibration was performed to optimize internal parameters of the SWAT model in order to achieve a well representative hydrologic model results. Auto calibration was performed using sensitive flow parameters which produced medium, high, and very high mean sensitivity index values during sensitivity analysis. The average measured weather and stream flow data for the first three study years (1958-1960) were used as a "warming-up" period for the model in order to establish proper initial conditions and stabilize the model. Thereafter, the auto-calibration followed using the average measured weather and stream flow data from 1961-1966 and land use map of 1985. The model was then calibrated by adjusting related parameters such as the CN2, Alpha_BF, GW delay, GWQMN, and CH_K2.

Model validation and performance evaluation establishes goodness of fit between observed flow and predicted stream flow as a comparison of the model outputs with an independent data set without making further adjustment. The study used independent streamflow dataset recorded in the period 1967-1971 in the validation of the model. The model validation and performance evaluation was done using four graphic comparison and statistical indices namely; 1) Nash–Sutcliff Efficiency (NSE), 2) coefficient of the determination (R^2), 3) percentage bias (PBIAS), 4) ratio of the root mean square error to the standard deviation of measured data (RSR) as used in Neitsch *et al.* (2011).

The "*Nash-Sutcliff Efficiency*" (NSE) as presented in equation 2 describes how well the plot of observed values versus simulated values fits the 1:1 line that is accounted for by the SWAT model, and ranges from $-\infty$ to 1.

$$\boldsymbol{NSE = 1 - \left[\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}\right]} \qquad [2]$$

Where;

$\boldsymbol{O_i}$ is the observed flows in m^3s^{-1}, $\boldsymbol{P_i}$ is the simulated flows in m^3s^{-1}, $\bar{O}$ is the mean of the observed flows, and $\boldsymbol{n}$ is the number of observations.

The "*Coefficient of the Determination*" (R^2) as presented in equation 3 was used to assess whether the simulations reproduce observed variability of the natural hydrologic process while minimizing the overall deviation. The value of R^2 ranges from 0 to 1.

$$\boldsymbol{R^2} = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right]^2 \qquad [3]$$

Where;

$\boldsymbol{O_i}$ is the observed discharge at time $\boldsymbol{i}$, $\bar{O}$ is the average observed discharge, $\boldsymbol{P_i}$ is the simulated discharge at time $\boldsymbol{i}$, $\bar{P}$ is the average simulated discharge, and $\boldsymbol{n}$ is the number of registered discharge data.

The PBIAS as presented in equation 4, measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is < ±25%, with low-magnitude values indicating accurate model simulation, whereas positive PBIAS values indicate model underestimation and negative indicate overestimation.

$$\boldsymbol{PBIAS} = \left[\frac{\sum_{i=1}^{n}[O_i - P_i]}{\sum_{i=1}^{n}[O_i]}\right] * \mathbf{100} \qquad [4]$$

Where;

$\boldsymbol{O_i}$ is the observed discharge at time i, $\boldsymbol{P_i}$ is the simulated discharge at time i, and $\boldsymbol{n}$ is the number of observations.

To accomplish SWAT simulation process, four hypothetical scenarios (S_{02}, S_{02}, S_{03}, and S_{04}) were created using changing one factor at a time while keeping others constant scenario, commonly known as "the one-factor-at-a-time approach" as used in Khoi and Suetsugi (2014). The scenarios were as follows; S_{01} (baseline scenario): a combination of climate data for 1971-1985 and land use map for 1985 assuming that there were no land use and climate changes. S_{02} (land-use change scenario): a combination of climate data for 1971-1985 and land use map for 2015 assuming that there were no climate changes. S_{03} (climate change scenario): a combination of climate data for 2001-2015 and land use map for 1985 assuming that there were no land use changes. S_{04} (combined land use and climate changes): a combination of climate data for 2001-2015 and land use map for 2015 assuming that there were both, land use and climate changes. The difference in outputs between S_{02}, S_{03}, and S_{01} reflected the separate impact of land use and climate change on hydrology. The difference in outputs between S_{01} and S_{04} reflects the combined impacts of land use and climate changes for entire study period. The annual values of water balance components for simulated surface runoff, baseflow, and total water yield of S_{02}, S_{03}, and S_{04} were subtracted from those in S_{01} and converted into percentages to determine the total water balance components.

Results and Discussion

3.1 Sensitivity analysis results

The result of sensitivity analysis indicates that eight parameters namely; Curve number (CN2), Base flow alpha factor (Alpha_BF), Groundwater delay time (GW_delay), Threshold water depth in shallow aquifer for flow (GWQMN), Effective hydraulic conductivity in main channel alluvium (CH_K2), Soil Evaporation Compensation factor (ESCO), Surface runoff lag time (SURLAG), and Groundwater_revap coefficient (GW_REVAP) were the most sensitive parameters for the Sigi catchment (1). However, CN2, Alpha_BF, and GW_delay were found to be highly sensitive than other parameters.

Table 1: Best parameters sensitivity ranking

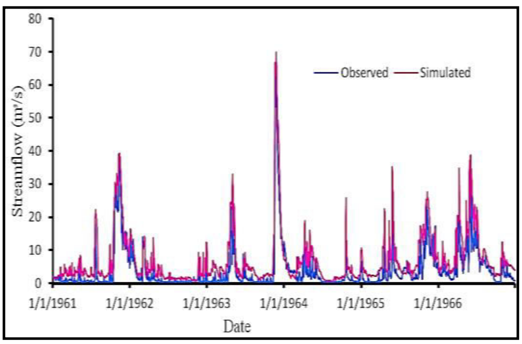
Parameter description	**Parameter code**	**Rank**	**P-value**	**File**
SCS runoff curve number for moisture condition II	CN2	1	Very high	*.mgt
Baseflow alpha factor (days)	Alpha_BF	2	Very high	*.gw
Groundwater delay time (days)	GW_delay	3	High	*.gw
Threshold water depth in shallow aquifer for flow	GWQMN	4	High	*.gw
Effective hydraulic conductivity in main channel alluvium	CH_K2	5	High	*.rte
Soil evaporation compensation factor	ESCO	6	High	*.hru
Surface runoff lag time (days)	SURLAG	7	High	*.bsn
Groundwater "revap" coefficient	GW_Revap	8	High	*.gw

Source: Fieldwork Survey 2016

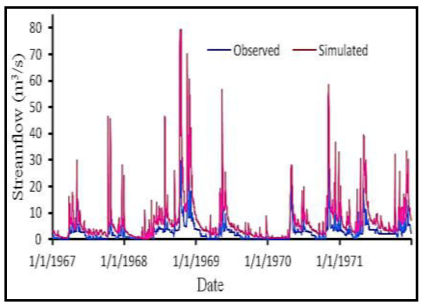
Sensitivity analysis results from the current study when compared with previous works indicate some similarities. Similar sensitivity ranking were reported by Pandey *et al.* (2016) in the Armur watershed in India where CN2 and Alpha-BF were the most sensitive parameters while disparities in ranking were in other parameters. However, the differences can be seen for example, in the studies by Norbert and Jeremiah (2012) in Wami basin in Tanzania, Mango *et al.* (2011) in Nyangores sub-basin of Mara basin in Tanzania, and Shi *et al.* (2013) in an Upstream Catchment of Huai River in China. These studies found soil available water capacity (SOL_AWC), soil depth (SOL_Z), and saturated hydraulic conductivity (SOL_K) as among the five highly sensitive parameters, which is not the case in the Sigi catchment. Therefore, it can be established that parameter sensitivity is site specific and sensitive to different land use, topography and soil types.

Model calibration and validation results

Comparison was made between the observed and simulated streamflow. The values of observed and simulated flows changed in the same way indicating presence of similarities and reasonable agreement between the measured and simulated values in both calibration period (1961-1966) and validation period (1967-1971) (Figure 3). The implication of the results regarding to SWAT model performance is that the physical processes involved in the generation of streamflow in the Sigi catchment were adequately captured by the model. Additionally, the flow hydrographs for model calibration and validation show SWAT simulations to be realistic and captured quite well the seasonal changes in observed flows, with exception of very few peaks. For example, a slight variation between observed and simulated flows are indicated by calibrated hydrograph in June to July, 1963 and January to march 1965.



(a) Calibration period (1961-1966)

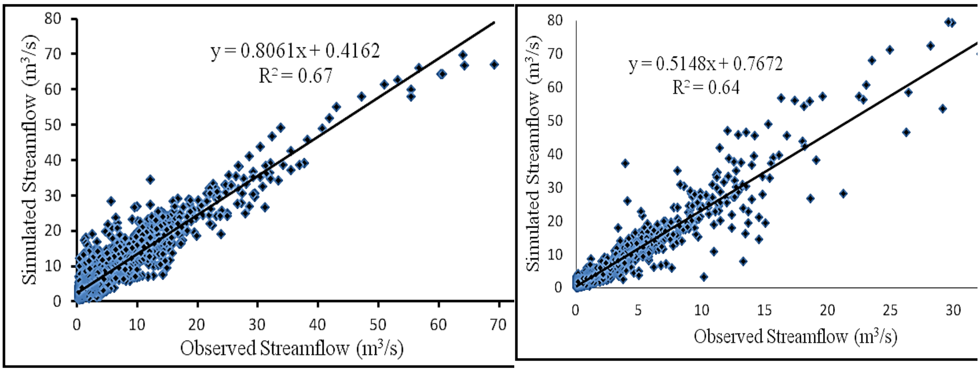


(b) Validation period (1967-1971)

Figure 3: Observed and simulated streamflow for calibration and validation period

Source: Fieldwork Survey 2016

Results of coefficients of determination (R^2) obtained from measured and simulated values of daily streamflow for the Sigi catchment were 0.67 and 0.64 for calibration and validation periods, respectively (Figure 4). All the two coefficients of determination indicated good performance of the model although the coefficient for calibration is higher than validation period. The difference can partly be contributed by different dataset of the measured values used for the calibration and validation.



(a) Calibration period (1961-1966) (b) Validation period(1967-1971)

Figure 4: Coefficients of determination for calibration and validation periods

Source: Fieldwork Survey 2016

The results of model calibration (1961-1966) and validation (1967-1971) with NSE=0.58 and 0.56, respectively, indicated satisfactory fits between measured and simulated streamflow. Other values of model calculated during calibration are; RSR (0.79) and PBIAS (-13.8%) for calibration period and RSR (0.77) and PBIAS (-15.2%) for validation period (Table 2). The simulated statistics of the mean (8.57) and standard deviation (10.26) do not deviate much from mean (5.23) and standard deviation (11.26) of observed flows for the station (1C1) studied. The range of standard deviations for both observed and simulated streamflow is within acceptable values (9.3%), although range of their means are slightly larger for the simulated than the observed streamflow with a difference of 3.34 (48.4%). The larger differences in their means can partly be attributed to high variability in rainfall amount, thus leading to high variance in the simulated streamflow.

Table 2: Daily time step calibration and validation performance assessment

Model stage	Model evaluation statistics					
	NSE	R^2	RSR	PBIAS (%)	Mean (obs_sim)	SD (obs_sim)
Calibration	0.58	0.67	0.79	-13.8	5.23 (8.57)	11.26 (10.26)
Validation	0.56	0.64	0.77	-15.2	6.23 (8.77)	12.26 (11.26)

Source: Field Survey 2016

The study results can be used to provide consistent information of analyzing discharge on temporal and spatial dimensions, thus become superior when compared with other previous studies. For example, a study by Mengistu (2009) in Hare watershed, Ethiopia simulated at daily resolution generated $R^2 > 0.6$ and NSE > 0.5. Related model performance with statistical values of NSE= 0.43 and R^2= 0.56 and NSE= -0.53 and R^2= 0.085, respectively, were observed in a study by Mango *et al.* (2011) in the Nyangores sub-basin of Mara river basin, Tanzania. From the above previous studies, it is very clear that the model performance statistics for Sigi catchment were satisfactory.

Water balance components of streamflow

The impact of climate change and land use change on the water balance components of the Sigi catchment showed great variation in streamflow (Figure 5). For the land use map of 1985, daily streamflow were in the range of $8.02m^3s^-$ in February, 2012 while peaking to $98.4m^3s^{-1}$ in October, 2012. On the other hand, simulation of 2015 land use map produced streamflow with a range of $9.31m^3s^{-1}$ in September 2012 while peaking to $69.9m^3s^{-1}$ in March 2015. Results show the land use map for 1985 yielding more high flows than the land use map for 2015. Majority of the peak flows were depicted during the months of March to May and later in the month of November when rainfall is at its peak. Low flows are mostly experienced during the months of February and July to August when rainfall is low in the Sigi catchment. For each year of simulation, the daily streamflow in the catchment indicate high flow peaks several days after rain season has began implying the time when the soil is saturated.

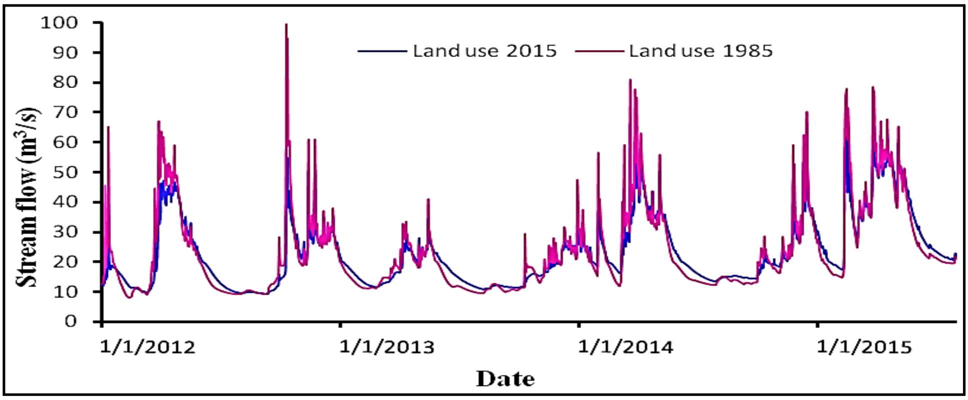


Figure 5: Simulated hydrograph of daily streamflow
Source: Field Survey 2016

The comparison of water balance components made between the years 1971-1985 and 2001-2015 shows a considerable changes in surface runoff, baseflow and water yield over time in the Sigi catchment (Table 3). The simulated SWAT model results under baseline period (S_1) indicated surface runoff amounting to 208.4mm, while baseflow and water yield were 123.3mm, and 331.7mm, respectively. Under land use change scenario (S_2), surface runoff increased to 216.3mm while baseflow and water yield decreased to 110.6mm and 326.9mm, respectively. With climate change scenario (S_3), surface runoff increased to 219.3mm while baseflow and water yield decreased to 104.1mm and 323.4mm, respectively. The combined land use and climate change scenario (S_4) indicated significant increase in surface runoff (227.4mm), while baseflow and water yield decreased to 93.7mm and 321.1mm, respectively.

Table 3: Simulated annual water balance under different scenarios

Hypothetical scenarios	Study period	Base map year	Surface runoff (mm)	Baseflow (mm)	Water yield (mm)
S_1 (Baseline)	1971-1985	1985	208.4	123.3	331.7
S_2 (Land use change)	1971-1985	2015	216.3	110.6	326.9
S_3 (Climate change)	2001-2015	1985	219.3	104.1	323.4
S_4 (Combined)	2001-2015	2015	227.4	93.7	321.1

Source: Field Survey 2016

Implication of the results is that land use and climate change have significant influence on water balance components in the Sigi catchment. This is because the expansions of cultivated and built-up lands increased area coverage of open forests. This reduced water soaking time in the soil thus increased surface runoff during rainfall events. Cultivated lands and open forests retain less soil moisture than closed forest lands, consequently rainfall satisfies the soil moisture deficit in the former more quickly than in the later, thereby inducing more surface runoff. Bare lands have strong effects by promoting rapid surface runoff, reducing water concentration time and reduce percolation. In turn, increased surface runoff cause the variation in infiltration into the ground, soil moisture contents and groundwater storage which reduces baseflow and water yield components of the catchment.

To compliment the current study findings, many studies have been conducted elsewhere to evaluate the effects of land use and land cover changes on the streamflow. For example, Brook *et al*. (2011) who modeled Anger watershed in Ethiopia, found surface runoff and baseflow to have increased and decreased, respectively, due to the expansion of agricultural land and decline of forest land. Another study by Tadele (2007) in Hare watershed, Southern Ethiopia, found replacement of natural forest into farmlands and built-up lands to have decreased mean monthly river discharge for wet months although in the same case the dry season flows indicated an increasing trend.

Water balance under land use change scenario

Very interesting results of water balance components of the Sigi catchment based on the hypothetical scenarios showed increase in surface runoff and decrease in baseflow and water yield. Results of the two hypothetical land use change scenarios, i.e. S_2 - S_1 and S_4 - S_3 are presented in table 4. The earlier land use change scenario increased surface runoff by 7.9mm (3.8%), reduced baseflow and water yield by 12.7mm (10.3%) and 4.9mm (1.5%), respectively. The later land use change scenario increased surface runoff by 8.2mm (3.9%), reduced baseflow and water yield by 10.4mm (10.4%) and 2.3mm (0.7%), respectively. The two land use change scenarios when combined together indicated overall increase in surface runoff by 16.1mm (7.7%), while baseflow and water yield decreased by 23.1mm (20.7%) and 7.2mm (2.2%), respectively.

Table 4: Water balance under land use change scenarios

Hydrologic response	Detectionscenarios	Surface runoff in mm (%)	Baseflow in mm (%)	Water yield in mm (%)
Land use change	S_2 - S_1	7.9 (3.8)	-12.7 (10.3)	-4.9 (1.5)
	S_4 - S_3	8.2 (3.9)	-10.4 (10.4)	-2.3 (0.7)
	(S_2 - S_1) + (S_4 - S_3)	16.1 (7.7)	-23.1 (20.7)	-7.2 (2.2)

Source: Field Survey 2016

The observed dynamics in water balance components are directly attributed to the expansion of cultivated land, built-up lands and open forests over closed forests resulting in the increase of surface runoff. These expansions have also reduced water infiltration, thus diminishing groundwater supply in the shallow aquifer which has lead to the decrease in baseflow. Thus dry season streamflow which mostly comes from baseflow is the most important component of hydrologic response which is at risk. As already reported in previous sections, there is an immediate streamflow response to rainfall due to the significant decrease in forest. The main reason is that closed forest litters have a great influence on overland flows thereby absorbing direct rainfall inputs and increases water soaking time into the soil which finally increases soil water storage.

Water balance under climate change scenario

On the other hand, the differences between the two hypothetical climate change scenarios, i.e. S_3 - S_1 and the scenario S_4 – S_2 produced the following results (Table 5). The former climate change scenario increased surface runoff by 10.8mm (5.2%), reduced baseflow and water yield by 19.2mm (15.6%) and 8.4mm (2.5%), respectively. The later climate change scenario increased surface runoff by 11.1mm (5.3%), reduced baseflow and water yield by 16.9mm (13.7%) and 5.8mm (1.8%), respectively. The two climate change scenarios together indicated an overall increase in surface runoff by 29.9mm (10.5%), while baseflow and water yield decreased by 36.1mm (29.3%) and 14.2mm (4.3%), respectively.

However, it should be made clear that the changes contributed by climatic changes of rainfall and temperature are high during the wet month of March to May and between September and December when the rainfall amounts are at the peak. The combined impact of both land use and climate change scenarios, i.e., S_4 - S_1 indicated increase in surface runoff by 19.0mm (9.1%), and decrease in baseflow and water yield by 29.7mm (24.1%) and 10.7mm (3.2%), respectively. The result explains why observed annual streamflow has decreased over time in the Sigi catchment. When all the hypothetical scenarios of this study (S_1, S_2, S_3, and S_4) are compared, the results indicate remarkable differences in values produced between S_1 and S_2 and those of S_3 and S_4. The difference shows clearly the influence of land-use change during the two time windows under study to be relatively small compared to climate change. The results suggest that climate change was the predominant factor that changed the water balance components in the Sigi catchment.

Table 5: Water balance under climate change scenarios

Hydrologic response	Detection scenarios	Surface runoff in mm (%)	Baseflow in mm (%)	Water yield in mm (%)
Climate change	$S_3 - S_1$	10.8 (5.2)	-19.2 (15.6)	-8.4 (2.5)
	$S_4 - S_2$	11.1 (5.3)	-16.9 (13.7)	-5.8 (1.8)
	$(S_3 - S_1) + (S_4 - S_2)$	21.9 (10.5)	-36.1 (29.3)	-14.2 (4.3)
Combined	$(S_4 - S_1)$	19.0 (9.1)	-29.7 (24.1)	-10.7 (3.2)

Source: Field Survey 2016

In fact, the dynamics of surface runoff, baseflow and water yields have been frequently mentioned in various studies conducted in many basins. For example, findings from Iberian Peninsula (Lopéz-Moreno *et al.,* 2014), and in the Mediterranean (Lespinas *et al.,* 2014) found a decrease in precipitation due to climate changes as the main cause of reduced surface water availability. In these basins, as in the present study, the decrease in precipitation caused decrease in streamflows, surface wells and water spring total yields.

Conclusion

The water balance components of the Sigi catchment have significantly changed as most of the average annual flow values are below the long term mean. Spatial analysis from the model has revealed that the land use in the Sigi catchment has significantly changed flow regime of the Sigi river. Again, it is apparent to conclude that the impacts of climate change on hydrologic processes of the Sigi catchment are larger than those of land use change. With the observed tendency of increased surface runoff and reduced baseflow and water yields, it may not be surprising for Sigi river which is currently perennial, to become one of the seasonal rivers in the Pangani basin in the near future. The fact is that, land use and climate are increasingly changing and causing reduction of baseflow which is the most important water balance component of dry season streamflow.

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References

Awotwi, A., Kumi, M., Jansson, P.E., Yeboah, F. and Nti, K (2015), "Predicting Hydrological Response to Climate Change in the White Volta Catchment, West Africa, Earth Science and Climatic Change", Volume 6:1, doi: 10.4172/2157-7617.1000249

Brook, H., Argaw, M., Sulaiman, H. and Abiye, T. A (2011), "The Impact of Land Use/Cover Change on Hydrology Components due to Re-settlement Activity: SWAT Model Approach", *International Journal of Ecology and Environmental Sciences,* Volume 37 (1): 49-60

Crossman, D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K. and Evangelia, P (2013), "A Blue Print for Mapping and Modeling Ecosystem Services", *Journal of Ecosystem Services*, Volume 4:4–14

Das, S.K., Nga, A.W.M. and Perera, B.J.C (2013), Sensitivity Analysis of SWAT Model in the Yarra River Catchment, A Paper presented in the 20th International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia, Adelaide, Australia

Dile, Y.T., Berndtsson, R. and Setegn, S.G (2013), "Hydrological Response to Climate Change for Gilgel Abay River, in the Lake Tana Basin-Upper Blue Nile Basin of Ethiopia", *Public Library of Science Journal,* Volume 8:10

Dwarakish, G.S. and Ganasri, B.P (2015), "Impact of Land Use Change on Hydrological Systems: A Review of Current Modeling Approaches", *Journal of Cogent Geoscience,* Volume 1

Gyamfi, C., Ndambuki, J.M. and Salim, R.W (2016), "Hydrological Responses to Land Use/Cover Changes in the Olifants Basin, South Africa", *Journal of Water*, Volume 8:588

Hepelwa, A.S (2011), "Environmental Resources Sustainability Indicators: An Integrated Assessment Model for Tanzania", A Thesis Submitted in Fulfilment of the Requirements for the Award of the Doctor of Philosophy Degree of the Vrije Universiteit Brussel, Belgium

Intergovernmental Panel for Climate Change, IPCC (2007), *Climate Change, the Physical Science Basis*, Cambridge University Press, Cambridge and New York, p 996

Kashaigili, J.J., Zziwa, E., Siwa, E., Laswai, E., Segatagara, B.M., Mpairwe, D., and Kadigi, R.M.J (2015), "Implications of Land Use Land Cover Change and Climate Variability on Future Prospects of Beef Cattle

Production in the Lake Victoria Basin", *American Journal of Climate Change*, Volume 4:461-473

Khanal, S. and Parajuli, P.B (2014), "Sensitivity Analysis and Evaluation of Forest Biomass Production Potential Using SWAT Model", *Journal of Sustainable Bioenergy Systems*, Volume 4: 136-147

Khoi, D.N. and Suetsugi, T (2014), "Impact of Climate and Land-Use Changes on the Hydrological Processes and Sediment Yield – A Case Study for the Be River Catchment, Vietnam", *Journal of Hydrological Sciences*, Volume 32

Lespinas, F., Ludwig, W. and Heussner, S (2014), "Hydrological and Climatic Uncertainties associated with Modeling the Impact of Climate Change on Water Resources of Small Mediterranean Coastal Rivers", *Journal of Hydrology*, Volume 511:403–422

Li, Z., Deng X., Wu, F. and Hasan, S.S (2015), "Scenario Analysis for Water Resources in Response to Land Use Change in the Middle and Upper Reaches of the Heihe River Basin", *Journal of Sustainability*, Volume *7*:3086-3108

Mango, L.M., Melesse, A.M., McClain, M.E., Gann, D. and Setegn, S.G (2011), "Land Use and Climate Change Impacts on the Hydrology of the Upper Mara River Basin, Kenya: Results of Modeling Study to Support better Resource Management", *Journal of Hydrology and Earth System Sciences*, Volume 15(7): 2245

Mateus, C., Tullos, D. and Surfleet, C.G (2015), Hydrologic Sensitivity to Climate and Land Use Changes in the Santiam River Basin, Oregon, *Journal of the American Water Resources Association*,Volume 51(2): 400-420

Molina-Navarro, E., Trolle, D., Martinez-Perez, S., Sastre-Merlin, A. and Jeppesen, E (2014), "Hydrological and Water Quality Impact Assessment of a Mediterranean Limno-Reservoir under Climate Change and Land Use Management Scenarios", *Journal of Hydrology*, Volume 509: 354–366.

National Aeronautics and Space Administration-Shuttle Radar Topographic Mission, NASA-SRTM (2016), SRTM 90m Digital Elevation Data for the entire World, Consortium for Spatial Information (CSI), http://srtm.csi.cgiar.org/

Neitsch, S.L., Arnold J.G., Kiniry, J.R. and Williams J.R (2011), *Soil and Water Assessment Tool, Theoretical Documentation Version 2009*, Texas Water Resources Institute Technical Report No. 406

Nobert, C. and Jeremiah, J (2012), "Hydrological Response of Watershed Systems to Land Use/Cover Change, A Case of Wami River Basin", *the Open Hydrology Journal,* Volume *6:*78-87

Pandey, B.K., Gosain, A.K., Paul, G. and Khare, D (2016), "Climate Change Impact Assessment on Hydrology of a Small Watershed using Semi-Distributed Model", *Journal of Applied Water Science*, Volume 7(4):2029-2041

Shemdoe, Z (2015), "Towards Integration of Sustainable Environmental and Biodiversity Conservation in Secondary Schools Students Extra-Curricular in Tanzania, Where do We Start"? *International Journal of African and Asian Studies*, Volume 16

Shi, P., Ma, X., Hou, Y., Li, Q., Zhang, Z., Qu, S., Chen, C., Cai, T. and Fang, X (2013), "Effects of Land-Use and Climate Change on Hydrological Processes in the Upstream of Huai River, China", *Journal of Water Resource Management*, Volume 27:1263-1278

Tadele, K (2007), *Impact of Land Use/Cover Change on Streamflow: The Case of Hare River Watershed, Ethiopia,* Arba Minch Water Technology Institute, Arba Minch University

United Republic of Tanzania, URT (2012), *The 2012 Population and Housing Census General Report*, National Bureau of Statistics, Dar es Salaam, Government Printer

Vargas-Amelin, E and Pindado, P (2014), "The Challenge of Climate Change in Spain: Water Resources, Agriculture and Land", *Journal of Hydrology*, Volume 518:243-249.

Wang, J., Ishidaira, H. and Xu, Z. X (2014), "Effects of Climate Change and Human Activities on Inflow into the Hoabinh Reservoir in the Red River basin," *Journal of Environmental Science*, Volume 13: 1688–1698

Wei, X.H., Liu, W.F. and Zhou, P.C (2013), "Quantifying the Relative Contributions of Forest Change and Climatic Variability to Hydrology in Large Watersheds: A Critical Review of Research Methods", *Journal of Water,* Volume 5:728-746

Yao, X., Cui, X., Yu, J and Sun, W (2015), "Response of Hydrological Processes to Climate Change in the Middle Reaches of the Yellow River, China", *Journal of, Remote Sensing and GIS for Hydrology and Water Resources,* Volume 368, doi:10.5194/Piahs-368-293-2015

Zhang, L., Nan, Z., Yu, W. and Ge, Y (2015), "Modeling Land-Use and Land-Cover Change and Hydrological Responses under Consistent Climate Change Scenarios in the Heihe River Basin", China, *Journal of Water Resources Management*, Volume 29:4701–4717