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Impact of Land Use and Land Cover Changes on Surface Runoff and Sediment Yield in the Little Ruaha River Catchment

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Abstract

Little Ruaha River catchment (6370 Km^2) in the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), is one of the country's most significant waterways due to its ecological composition and economic value. Regardless of its ecological and economical value, the regional hydrologic condition has been tremendously affected due to land uses alteration, influenced by different socio-economic factors. This study aimed to understand the associated impacts of the present Land Use Land Cover (LULC) change on the surface runoff and sediment yield in the Little Ruaha River Catchment. Hydrological modelling using Soil and Water Assessment Tool (SWAT Model) was done to quantify the impact of land use and land cover dynamics on catchment water balance and sediment loads. The calibration and validation of the SWAT model were performed using sequential uncertainty fitting (SUFI-2). The results showed that, for the given LULC change, the average annual surface runoff increased by 2.78 mm while average annual total sediment loading increased by 3.56 t/ha, the average annual base flow decreased by 2.68 mm, ground water shallow aquifer recharge decreased from 2.97 mm and a slight decrease in average annual ground water deep aquifer recharge by 0.14 mm. The model predicts that in the future, there will be a further increase in both surface runoff and sediment load. Such changes, increased runoff generation and sediment yield with decreased base flow have implications on the sustenance flow regimes particularly the observed reduced dry season river flow of the Little Ruaha River, which in turn cause adverse impacts to the biotic component of the ecosystem, reduced water storage and energy production at Mtera Hydroelectrical dam also increasing the chances of flooding at some times of the year. The study recommends land use planning at the village level, and conservation agricultural practices to ameliorate the current situation. Developing multidisciplinary approaches for integrated catchment management is the key to the sustainability of Little Ruaha River catchment.

Keywords

Land Cover, Land Use, Sediment Loading, Surface Runoff, SWAT Model

1. Introduction

Land Use and Land Cover (LULC) are the important components of the terrestrial ecosystem that influence geomorphological, ecological and hydrological processes [1]. The changes in LULC call for special attention since humans have been modifying land to obtain food and other essentials for thousands of years, but current rates, extents and intensities of changes are far greater now compared to historically [2]. Day-to-day anthropogenic activities including expansion of agriculture, urbanization and deforestation activities have resulted in temporal and spatial changes in LULC which are argued to have contributed to change in hydrological regimes of many rivers and wetlands [3]. For instance, the conversion of tropical forest to grassland disrupts the hydrological cycle of a drainage basin, by altering the water yield of the area [4]. LULC change, particularly natural forest alteration, makes soils vulnerable to a massive increase in wind and water soil erosion, particularly on steep topography. When accompanied by fire, pollutants to the atmosphere are also released. Soil erosion over time may also cause damage to the land suitability for future farming, and releases a huge amount of phosphorus, nitrogen, and sediments to aquatic ecosystems, causing multiple harmful impacts of sedimentation and eutrophication.

The Little Ruaha River catchment in Tanzania, is one of the country's most significant waterways [5]. It provides irrigation and domestic fresh water services for many residents in the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) specifically in Ihemi cluster. Furthermore, it is the main source of water during the dry season, and so is vital for the ecology of the downstream Ruaha National Park. Additionally, the catchment contributes about 18% of flows to the Mtera Dam [6], which is an important source of hydro-electric power and the largest reservoir in Tanzania, with a surface area of 600 km^2 at the highest regulated water level. Despite its ecological and economical value, the regional hydrologic condition has been tremendously affected [7] due to LULC alteration [8]. However, there is a general understanding that the changes in catchment hydrology, occur mainly due to alteration in interception, infiltration, evapotranspiration and ground water recharge which are linked to LULC changes [9]. Estimating the effects of LULC changes on the hydrological response of Little

Ruaha River Catchment remains very important for integrated management and conservation strategies. A number of studies have been carried out in the LRRC, nonetheless, most of these studies have not focused on quantifying the contribution of LULC change on the hydrological components of the catchment. Thus, a gap exists in up-to-date information regarding the effects of LULC changes on stream flow and sediment yield. The amount of sediments generated from LULC changes in the catchment as well as the contribution of individual land covers to the major hydrological components of the LRRC are not clear.

This study employed the Soil and Water Assessment Tool (SWAT), a regional scale hydrological model, to simulate the impacts of LULC changes on the hydrological response of the LRRC. There are lots of evidences for the application of SWAT Model for hydrological response modeling under different land uses and related studies. Many studies [9]-[16] have applied the SWAT model to simulate the impacts of land use/cover changes on the hydrological ecosystem and shown successful results.

2. Materials and Methods

2.1. Study Location

Little Ruaha River is a tributary of the Great Ruaha River (GRR) that joins GRR just after the Ruaha National Park [17]. Little Ruaha River Catchment (**Figure 1**), is located in the Southern Highlands of Tanzania, within Ihemi Cluster, one of the six priority clusters for agricultural development within the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), which covers a larger part of Iringa and Njombe regions. The catchment has an estimated area of 6370 km^2 draining from Mafinga, Mufindi, Kilolo, Iringa municipal and Iringa districts in Iringa Region [18].

Geographically, the catchment lies between longitudes 35˚2'E and 35˚36'E and, latitudes 7˚11'S and 8˚36'S. The region's climate is unique in its heterogeneity, varying between the bimodal and unimodal rainfall patterns, with annual rainfall ranging from 600 mm in the lowlands to 1600 mm in the highlands which in turn results in diverse land uses [8]. The mean annual temperature varies with altitude from about 18˚C at high altitudes to about 28˚C at the lower altitudes. Elevation ranges from 698 m to above 2300 m above mean sea level. Dominant soils in the area include Cambisols, Fluvisols, Leptosols, Lixisols, Nitisols and Solonetz.

2.2. Model Description

The SWAT model is a continuous, long term, physical based distributed model developed by Agricultural Research Services of the United States Department of Agriculture to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large and complex watersheds with varying soil, land use, and management conditions over long periods of time [19]. It operates on a daily time step and is considered to be the most suitable model

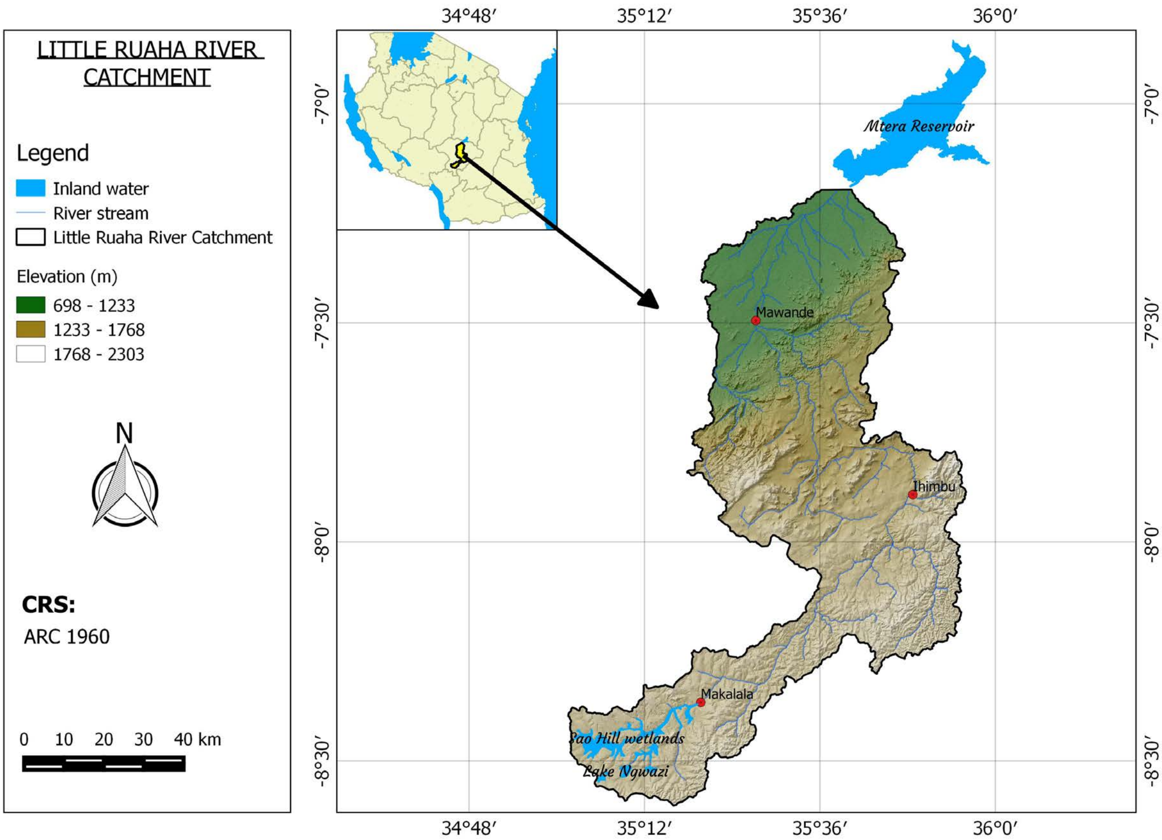


Figure 1. Little Ruaha River catchment.

to predict the impact of land use and management on water, sediment, and agricultural chemical yields in ungauged watersheds [20]. The model is capable of integrating different remote sensed spatial data and ground observation data sets (soil, land cover, weather data) describing the land surface to calculate the basin hydrologic water cycle [21], thus making it versatile in the area of watershed management and water resource planning [9]. The model is very useful because it has weather engine to generate the precipitation within an un-gauged watershed based on stochastic and probabilistic methods [21]. The basic operational of the model is the Hydrological Response Units (HRUs); the fundamental spatial unit that consist of homogeneous land use, management, topographical, and soil characteristics upon which SWAT simulates the water balance is the base of hydrologic cycle simulation in SWAT. Further reading on the SWAT model is accessed to the online resource at http://swat.tamu.edu/ and https://www.card.iastate.edu/swat_articles/.

2.3. SWAT Model Inputs

SWAT model used in this study was built on QGIS 2.6.1 interface. The inputs data collected to set up the model includes spatial data, hydrological data and meteorological data. Spatial data includes 30 m resolution digital elevation model (DEM) downloaded from NASA (https://reverb.echo.nasa.gov). The digital

LULC map (**Figure 2**) of the study area for 1990, 2015 and 2040 obtained from LULC change analysis reported by [22], mapped based on Landsat TM for 1990 and Landsat OLI for 2015 (http://earthexplorer.usgs.gov). Land use/land cover for the year 2040 was projected based on CA-Markov chain analysis. The Markov model is a theory based on the process of the formation of Markov random process systems for the prediction and optimal control theory method [23]. It tends to treat land use change as a stochastic process by assuming that rates of change between land use types are more or less constant from one period to the next.

Meteorological data comprised time series rainfall, relative humidity, solar radiation, wind speed and minimum and maximum temperature data for the period of 1976 to 2012, obtained from Tanzania Meteorological Agency and Rufiji Basin Water Office, Iringa. Hydrological data included time series river discharge, recorded from three different flow gauging stations, one located at the upper part of the catchment (Makalala station), one in the middle (Ihimbu station) and one in the lower part of the catchment (Mawande station). Soil data and information on related soil properties were obtained from the Food and Agriculture Organization (FAO) soil map [24].

2.4. SWAT Model Calibration and Validation Process

SWAT input parameters are process based and must be held within a realistic

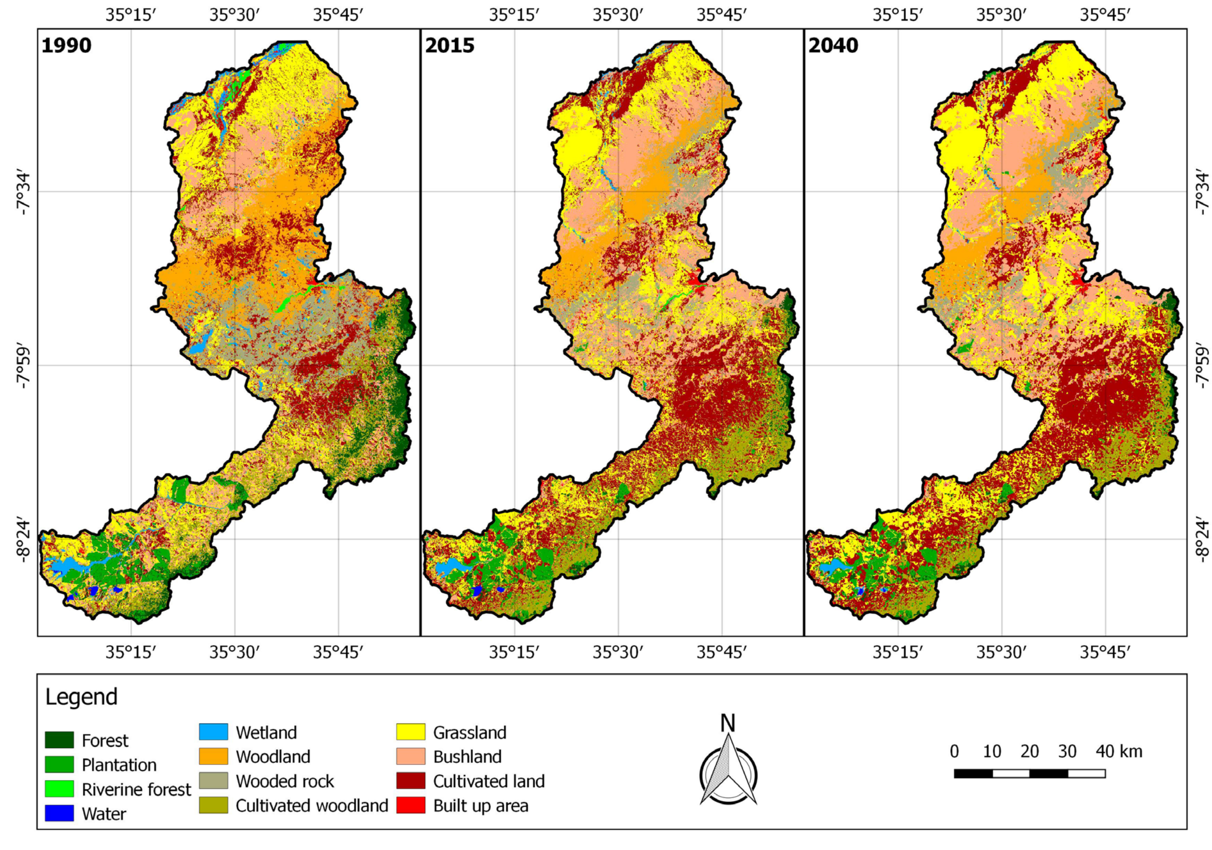


Figure 2. Land use/cover maps for LRRC year 1990, 2015 and 2040 (Source: Chilagane N, 2017).

uncertainty range. Model Calibration is to adjust a set of parameters so that the model agreement is maximized with respect to a set of experimental data. It is the process of turning model parameters based on checking results against observations to ensure the same response over time [25]. Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model [26]. Calibration and Validation process in SWAT model involves three steps which are Sensitivity and Uncertainty Analysis, Model Calibration and Model Validation.

2.4.1. Sensitivity Analysis

To understand how closely the model simulates the hydrological processes within a watershed, it is critical to examine the influence of different parameters. Sensitivity analysis is the computation of the most sensitive parameters for a given watershed. In this study a sensitivity analysis was conducted using the Sequential Uncertainty Fitting (SUFI-2) within the SWAT-CUP [27]. The advantage of using SWAT-CUP relies on the possibility of using different kinds of parameters including those responsible for surface runoff, water quality parameters, crop, parameters, crop rotation and management parameters, and weather generator parameters [21].

2.4.2. Model Calibration and Validation

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty and validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model [26]. Model calibration and validation were performed by using the Sequential Uncertainty Fitting (SUFI-2) within the SWAT-CUP [27].

Calibration and validated were conducted using monthly flow data for the period 1990-2000 and 2001-2010 respectively, using data recorded from three different flow gauging stations, one located at the upper part of the catchment (Makalala station), one in the middle (Ihimbu station) and one in the lower part of the catchment (Mawande station). Five years prior to 1990 were used as a warm up period to provide steady-state condition and mitigate unknown initial conditions to the model. The model performance was assessed based on four objective functions namely, Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2), Probability bias (PBIAS) and Root mean square error (RSR). The general performance rating statistics for NSE, R^2, RSR and PBIAS (**Table 1**)

Table 1. Recommended objective function statistics for monthly step.

Objective function	Performance rating for acceptable model
Nash-Sutcliffe Efficiency (NSE)	>0.5
Coefficient of determination (R^2)	>0.5
Root mean Square Error (RSR)	≤0.70
Probability BIAS (PBIAS)	≤±25%

as proposed by [28] and [9] were used to determine the performance of the model.

The Nash-Sutcliffe efficiency determines the relative magnitude of the residual variance compared to the measured data variance [29]. It used in the model to indicate how well the plot of observed versus simulated data fits the 1:1 line [28]. Nash-Sutcliffe efficiency range from −∞ to 1 where efficiency of one (E = 1) corresponds to a perfect match of modeled discharge to the observed data, efficiency of zero ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data, and efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model. Principally, the closer the model efficiency to 1, the more accurate the model is. The NSE is calculated by:

$$\mathrm{NSE} = 1 - \frac{\sum_i \left(Q_i - Q_s\right)^2}{\sum_i \left(Q_i - \bar{Q}_i\right)^2} \tag{1}$$

Coefficient of determination (R^2) is a measure of the strength of the linear correlation between the predicted and observed variables. It ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable [30]. It is calculated as:

$$\mathrm{R}^2 = \left[\frac{\sum_i \left(Q_i - Q_s\right)\left(Q_s - \bar{Q}_s\right)}{\left(\sum_{i=1}^n \left(Q_i - \bar{Q}_i\right)\right)^{0.5}\left(\sum_{i=1}^n \left(Q_s - \bar{Q}_s\right)\right)^{0.5}}\right]^2 \tag{2}$$

Root mean square error—observed standard ration (RSR) is the measure of goodness of fit between observed and simulated time series data, is the ratio of the Root Mean Square Error (RMSE) and standard deviation of measured data. According to [31], RSR standardizes RMSE using the observations standard deviation, and it combines both an error index and the additional information recommended. It is commonly accepted that, the lower the RMSE the better the model performance. RSR is calculated as:

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STD}_{\mathrm{obs}}} = \frac{\sqrt{\sum_{i=1}^n \left(Q_i - Q_s\right)^2}}{\sqrt{\sum_{i=1}^n \left(Q_i - \bar{Q}_i\right)^2}} \tag{3}$$

Probability BIAS (PBIAS) is the measure of how much (in percentage) the simulated variable to be larger or smaller than their observed counterparts [32]. The optimum value of PBIAS is zero, where low magnitude values indicate better simulations, positive value indicated model underestimation and negative values indicated model overestimation [32]. It is calculated as:

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^n \left(Q_i - Q_s\right)}{\sum_{i=1}^n Q_i} \times 100\% \tag{4}$$

where: Q_i is observed variable (e.g., discharge), Q_s is simulated variable and $\bar{Q}_i$ is the mean of observed variable, $\bar{Q}_s$ is the mean of simulated variable, RMSE is the root mean square error, $\mathrm{STD}_{\mathrm{obs}}$ is the standard deviation of the observed variable.

2.5. Simulation Analysis

To assess the impacts of LULC change on the hydrology of Little Ruaha River Catchment, the fix changing scenario was used [9] [33]. Under this scenario, the calibrated and validated model was used to simulate stream flows under changed land-use/cover condition for the year 1990/2015/2040, while maintaining the same weather data, meteorological data, soil data and digital elevation model. The influences of the land use land cover change on water resource and other hydrological components were quantified by comparing SWAT outputs for the two land use maps (1990/2015/2040). The differences between observed outputs represented the effects of land use and land cover changes on water resources in the catchment.

The SWAT model using the Modified Universal Soil Loss Equation (MUSLE) developed by [34] was used to simulate the sediment yield from the catchments [35]. The simulated sediment yield results for the time period 1990, 2015 and 2040 were compared, and the difference was deduced to reveal the impact of LULC change on sediment yields in Little Ruaha River Catchment.

3. Results

3.1. Sensitive Parameters

Table 2 shows list of parameters that were found to be most sensitive to flow prediction in the model. It was found that the runoff Soil Conservation Service runoff curve number (CN2) was the most sensitive parameter followed by Available Water Capacity of the Soil Layer (SOL_AWC), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQWN), Groundwater Delay Time (GW_DELAY), Base Flow Alpha Factor (ALPHA_BF) and Soil Evaporation Compensation Factor (ESCO). These results are in agreement with the study reported by [11] that mentioned parameters are most sensitive to flow

Table 2. Most sensitive parameters and their fitted values.

Rank	Parameter	Parameter definition	Fitted value
1	CN2.mgt	SCS runoff curve number	−0.226087
2	SOL_AWC.sol	Available water capacity of the soil layer	−0.743945
3	GWQWN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur	1212.925537
4	GW_DELAY.gw	Groundwater delay	146.182022
5	GW_REVAP	Groundwater "revap" coefficient	0.037623
6	RCHRG_DP	Deep aquifer percolation fraction	0.208973
7	ESCO.hru	Soil evaporation compensation factor	0.321092
8	SURLAG	Surface runoff lag time	6.335633
9	ALPHA_BF.gw	Baseflow alpha factor	0.11056

prediction. The most sensitive parameters were then considered for model calibration.

3.2. Model Accuracy

As mentioned, calibration was conducted in three sub-basins located in upstream, middle and downstream. The calibration process was done by comparing the simulated stream flows with the measured stream flows for each gauging station. Comparison of the results between the measured and calibrated stream flows show a good agreement with NSE, R^2, RSR and PBIAS statistical values falling within the range of a satisfactory to good model (**Table 3**).

The observed mean monthly streamflow for the calibration period (1990-2000) in the Little Ruaha River at Makalala station was 4.40 m^3/s while the simulated was 4.04 m^3/s. The difference was not significant for the downstream gauging stations as well, where the observed monthly stream flow was 16.80 m^3/s compared to the simulated 15.26 m^3/s at Ihimbu station and at Mawande station observed monthly stream flow was 32.50 m^3/s while simulated was 28.23 m^3/s.

Results for the validation period (2001-2010) show that the observed mean monthly stream flow was 4.25 m^3/s and simulated mean monthly flow was 3.89 m^3/s for Makalala gauging station, observed mean monthly flow of 16.06 m^3/s and simulated mean monthly stream flow of 14.38 m^3/s at Ihimbu station and observed mean daily stream flow of 28.46 m^3/s with simulated mean monthly flow of 26.20 m^3/s for Mawande gauging station. **Figure 3** and **Figure 4** below shows comparison of measure and simulated stream flow during model calibration and validation.

3.3. Land Use Land Cover Change Analysis

Results (**Appendix 1** and **Appendix 2**) indicate that land use and land cover change between 1990 and 2015 and the projected land use/cover for the year 2040 as reported by [22]. The report detailed the decrease in forest, riverine forest, water, wetland and woodland by 60%, 81.58%, 62.50%, 70.65%, and 46.62% respectively, while plantation, grassland, bushland, cultivated land and built up area increased by 17.71%, 25.27%, 43.90%, 34.36% and 46.31% respectively between 1990 and 2015.

Table 3. Evaluation statistics for calibration and validation.

Flow Station	Calibration				Validation				Calibration		Validation	
	NSE	R^2	RSR	PBIAS	NSE	R^2	RSR	PBIAS	Ob-flow (m^3/s)	Sim-flow (m^3/s)	Ob-flow (m^3/s)	Sim-flow (m^3/s)
Makalala	0.56	0.57	0.66	−5.9	0.50	0.51	0.71	8.5	4.40	4.04	4.25	3.89
Ihimbu	0.58	0.60	0.65	9.1	0.44	0.55	0.75	21.6	16.80	15.26	16.06	14.38
Mawande	0.64	0.65	0.60	−15.1	0.64	0.65	0.60	−8.6	32.50	28.23	28.46	26.20

Ob-flow; Observed flow; Sim-flow; Simulated flow.

3.4. Impacts of Land Use/Cover Change on Water and Sediment Yields

Table 4 below shows the annual averages hydrological summary for the Little Ruaha river sub-catchment under changing land use/cover. From the model, the change of land use/cover has contributed to the increase in average annual surface runoff by 2.78 mm and decrease in average annual base flow by 2.63 mm. Water percolation to soil profile decreased by 2.64 mm, ground water contribution

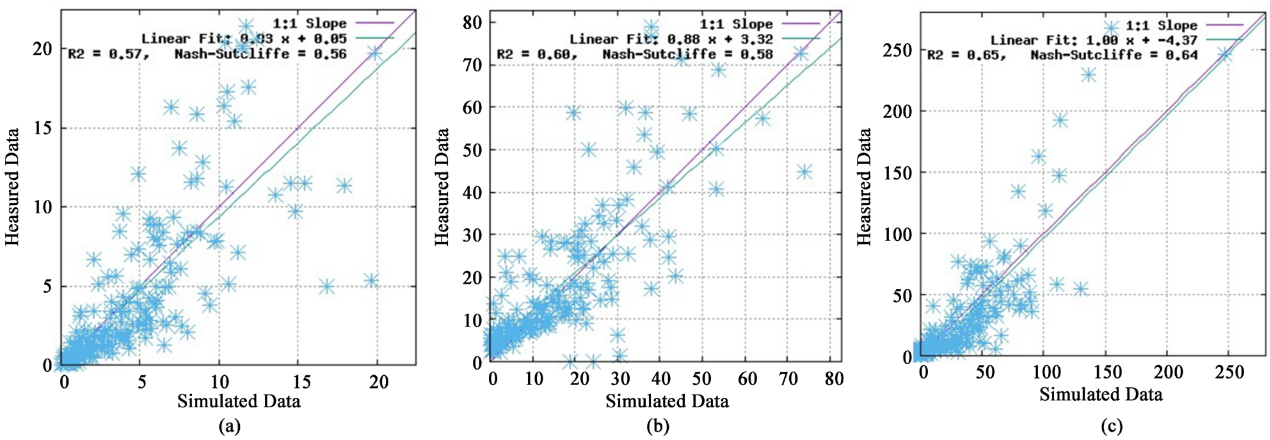


Figure 3. Comparison of measured and simulated stream flow during model calibration for (a) Makalala; (b) Ihimbu; (c) Mawande.

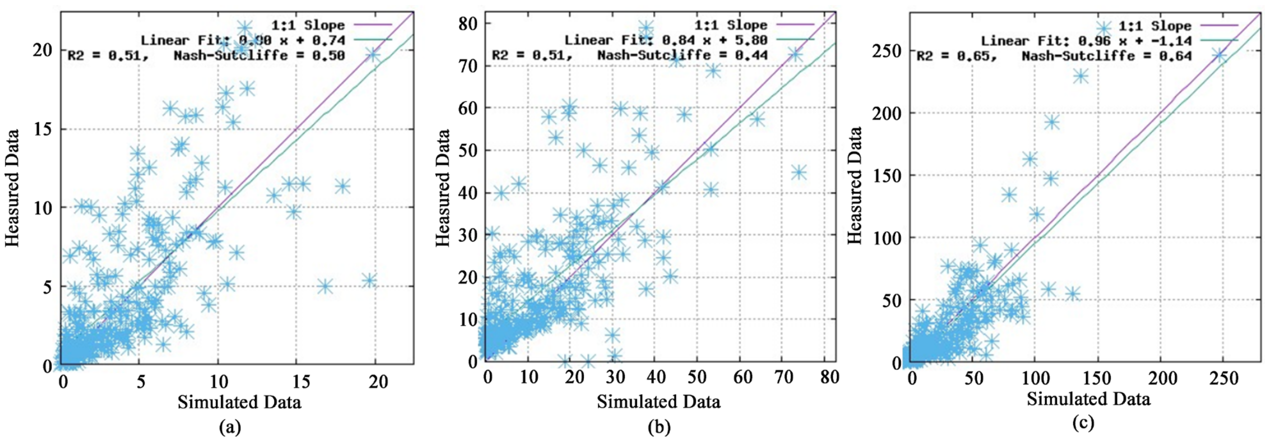


Figure 4. Comparison of measured and simulated stream flow during model validation for (a) Makalala; (b) Ihimbu; (c) Mawande.

Table 4. Annual average hydrological summary for the watershed.

Year	SURQ	PERCQ	GWQ	Shall AQ	Deep AQ	ET	Water Yield (mm)	Sediment Yield (t/h)
1990	45.83	346.03	351.24	297.97	17.66	272.4	375.52	9.397
2015	48.61	343.4	348.56	295.42	17.52	272	375.74	12.958
Change	2.78	−2.63	−2.68	−2.55	−0.14	−0.4	0.22	3.561

SURQ: Surface runoff contribution from stream flow from HRU (mm); PERCQ: Water percolation past bottom of soil profile (mm); GWQ: Ground water contribution to stream in watershed on day, month, year (mm); SHALL AQ: Ground water contribution to shallow aquifer (mm); DEEP AQ: Ground water contribution to deep aquifer (mm); ET: Actual evapo-transpiration in watershed (mm).

to shallow and deep aquifer decreased by 2.55 mm and 0.14 mm respectively. Actual evapotranspiration decreased by 0.4. mm. The average annual water yields to stream flow and sediment yield from Hydrological Response Unit (HRU) in watershed has increased by 0.22 mm and 3.561 ton/h respectively.

SWAT simulations of the future scenarios showing expected changes in water and sediment yields in Little Ruaha River Catchment for the next 25 years from 2015 (Table 5). Results show the average annual surface runoff or overland flow will increase by 1.04 mm, Water percolation to soil profile decreased by 0.81 mm, ground water contribution to stream will decrease by 0.83, ground water contribution to shallow and deep aquifer decreased by 0.83 mm and 0.04 mm respectively. Annual average actual evapotranspiration will decrease by 1 mm. At the same time, the average annual water yield will increase by 0.12 mm which will raise soil loss from 12.958 t/ha to 13.797 t/ha.

Furthermore, the model revealed the LULC changes have also impacted dry seasonal flow of Little Ruaha river. SWAT scenario revealed decline of average dry season flow (July-October) in three-gauge stations of Little Ruaha river namely Makalala (Upper), Ihimbu (Middle) and Mawande (lower) following LULC transformation (Figures 5-7). Dry season monthly averages at different land use scenario for Makalala, Ihimbu and Mawande gauge stations are represented in Tables 6-8 respectively.

Table 5. Annual average hydrological summary for the watershed for the year 2040.

Year	SURQ	PERCQ	GWQ	Shall AQ	Deep AQ	ET	Water Yield (mm)	Sediment Yield (t/h)
2015	48.61	343.4	348.56	295.42	17.52	272	375.74	12.958
2040	49.65	342.59	347.73	294.6	17.48	271	375.86	13.797
Change	1.04	−0.81	−0.83	−0.82	−0.04	−1	0.12	0.839

SURQ: Surface runoff contribution from stream flow from HRU (mm); PERCQ: Water percolation past bottom of soil profile (mm); GWQ: Ground water contribution to stream in watershed on day, month, year (mm); SHALL AQ: Ground water contribution to shallow aquifer (mm); DEEP AQ: Ground water contribution to deep aquifer (mm); ET: Actual evapo-transpiration in watershed (mm).

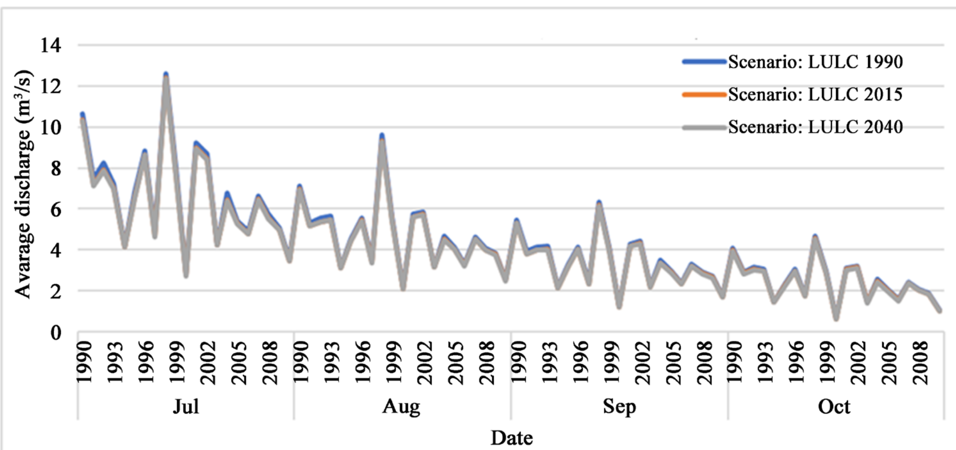


Figure 5. Dry season average discharge at Makalaka gauge station.

Table 6. Dry season monthly averages at different land use scenarios for Makalala station.

Month	Average discharge (m^3/s) Scenario: LULC 1990	Average discharge (m^3/s) Scenario: LULC 2015	Average discharge (m^3/s) LULC 2040
Jul	6.76	6.57	6.53
Aug	4.74	4.63	4.61
Sep	3.41	3.33	3.31
Oct	2.45	2.38	2.37
Total	4.34	4.23	4.20

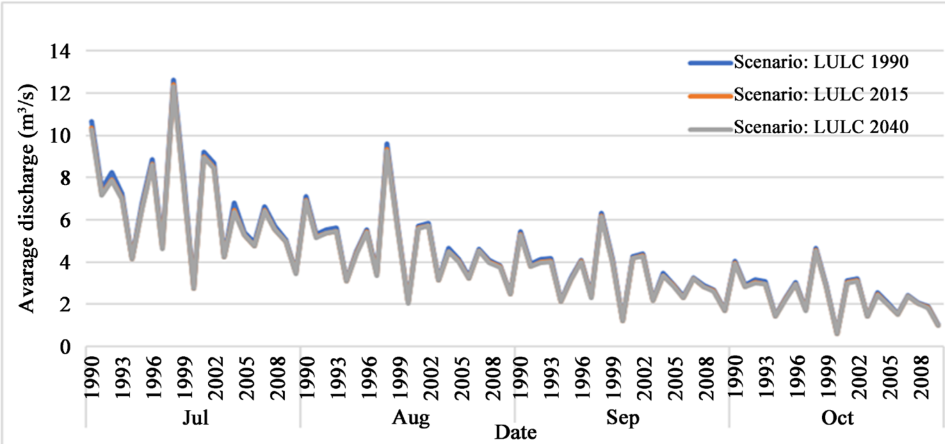


Figure 6. Dry season avarage discharge at Ihimbu gauge station.

Table 7. Dry season monthly averages at different land use scenarios for Ihimbu station.

Month	Average discharge (m^3/s) Scenario: LULC 1990	Average discharge (m^3/s) Scenario: LULC 2015	Average discharge (m^3/s) LULC 2040
Jul.	22.51	21.62	21.34
Aug.	15.68	15.15	14.99
Sep.	11.03	10.62	10.49
Oct.	7.69	7.36	7.25
Total	14.23	13.69	13.52

3.5. Contribution of Individual Land/Cover to the Surface Runoff and Sediment Yield

The proportional contribution of individual LULC to surface runoff and sediment yield is summarized in Figure 8 below. Results found that cultivated woodland and cultivated land are the main contributors to both surface runoff and sediment yields followed by built up area which has high contribution to surface runoff but very little contributions to sediment yield. Forest, woodland and wetland were found to have very little contributions to sediment yield but showing a variation on their contribution to surface runoff.

Figures 9(a)-(c) below shows the spatial annual means contribution to hydrologic component of the Little Ruaha river catchment.

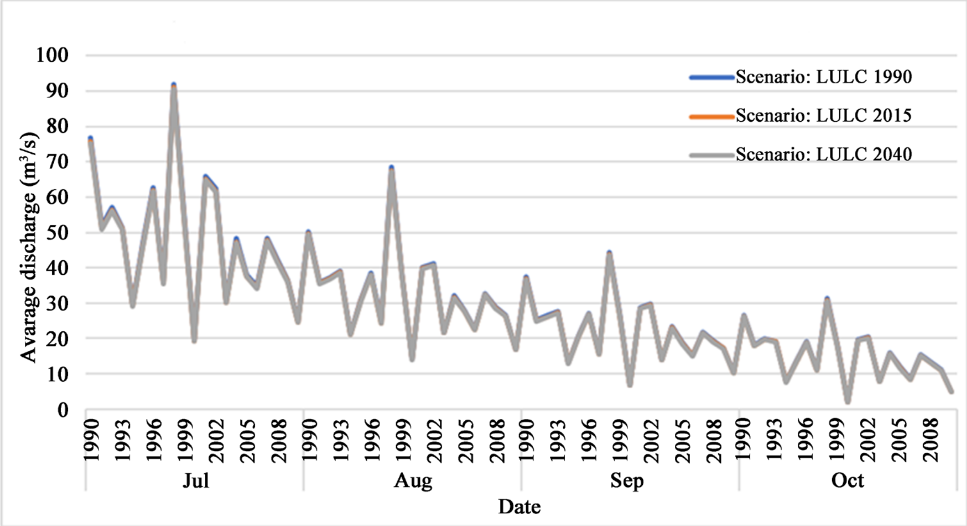


Figure 7. Dry season avarage discharge at Mawande gauge station.

Table 8. Dry season monthly averages at different land use scenarios for Mawande station.

Month	Average discharge (m^3/s) Scenario: LULC 1990	Average discharge (m^3/s) Scenario: LULC 2015	Average discharge (m^3/s) LULC 2040
Jul	48.18	47.56	47.33
Aug	32.91	32.54	32.39
Sep	22.45	22.16	22.05
Oct	15.04	14.82	14.73
Total	**29.64**	**29.27**	**29.12**

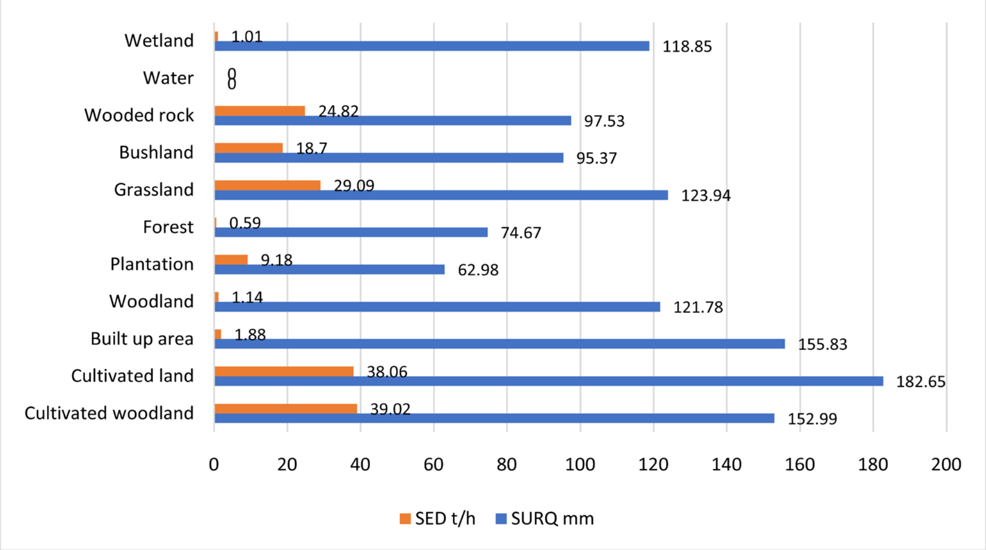
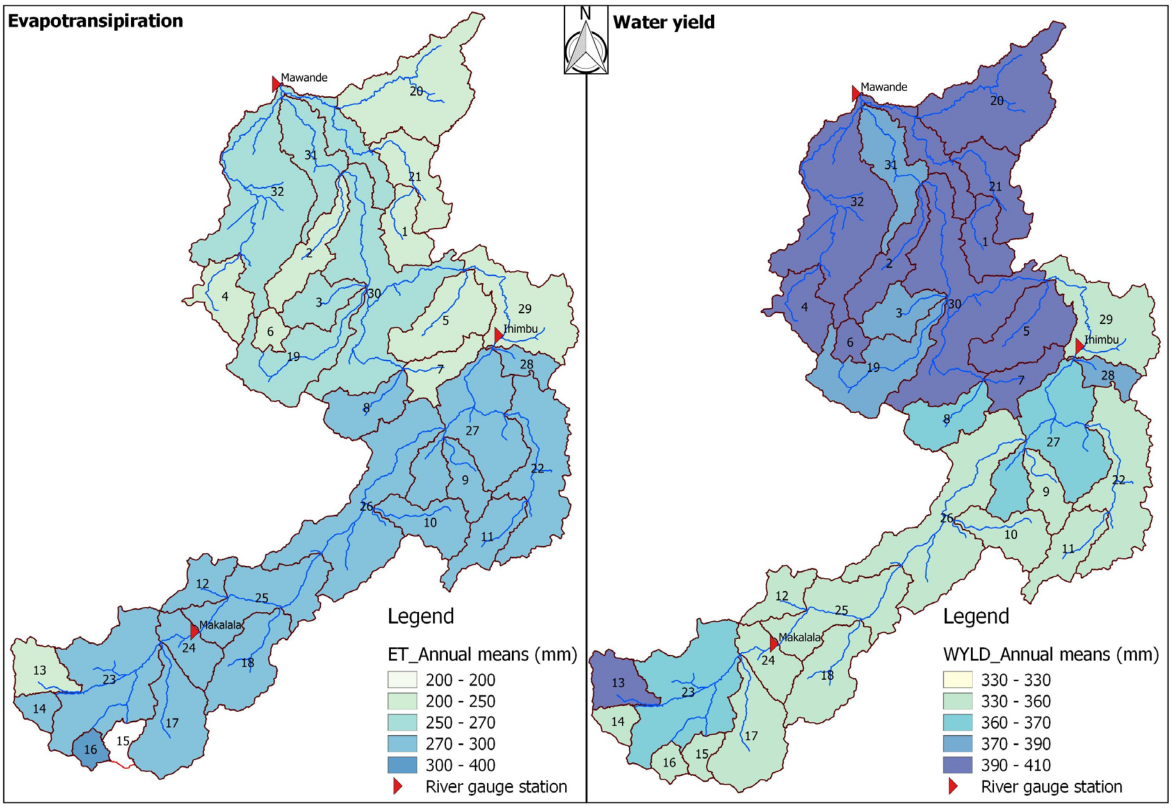
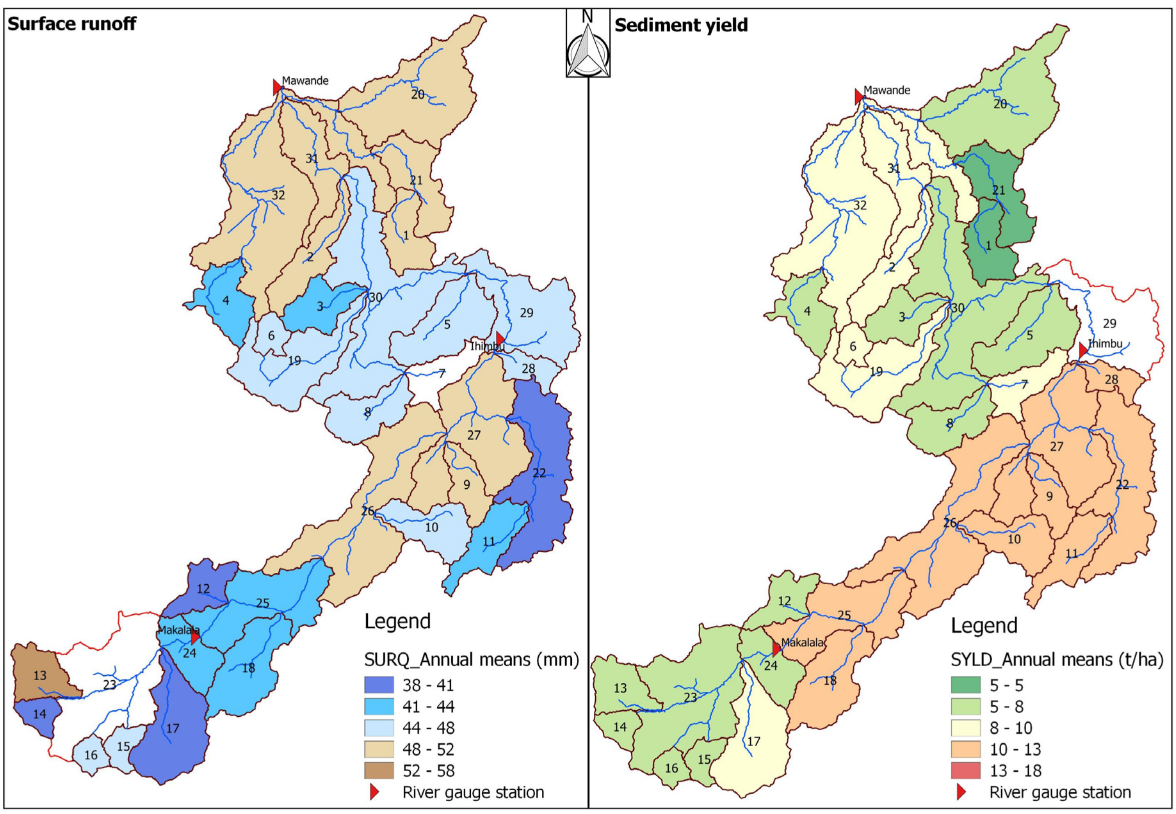


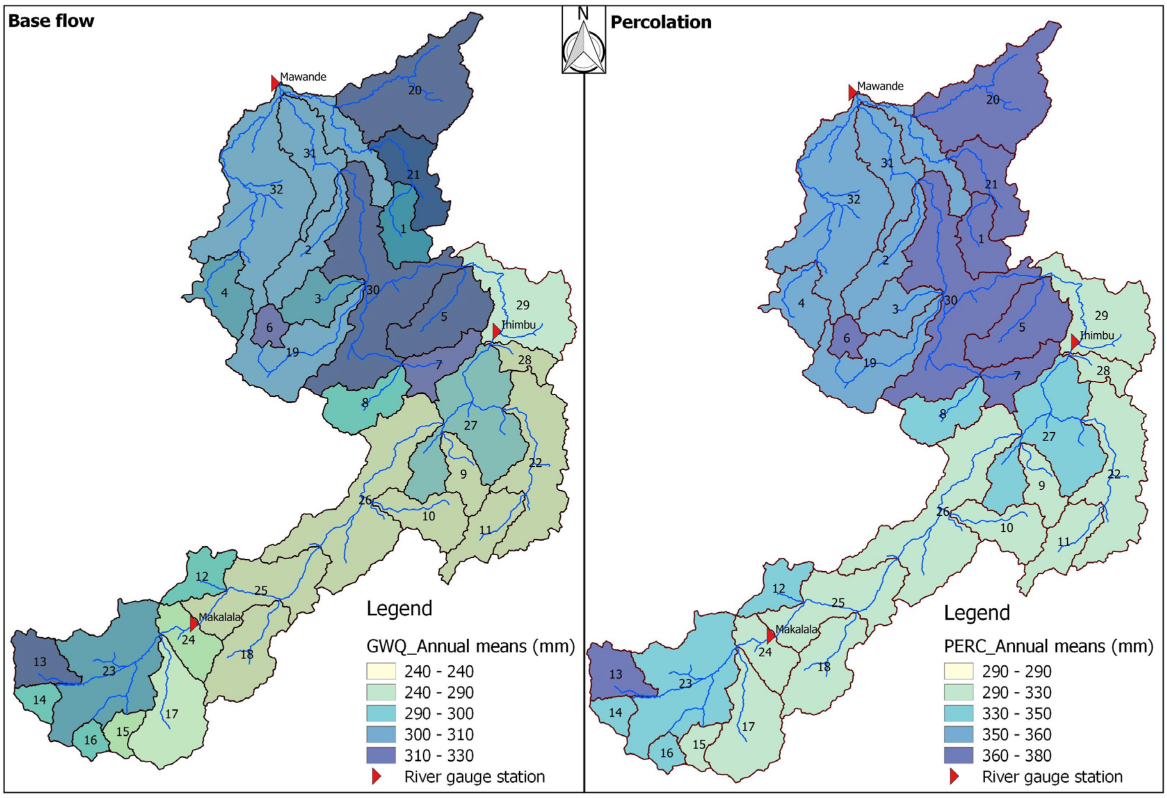
Figure 8. Contribution of individual land use/cover on surface runoff and sediment yield.


Evapotransipiration
N
Water yield
Mawande
Ihimbu
Makalala
Legend
ET_Annual means (mm)
200 - 200
200 - 250
250 - 270
270 - 300
300 - 400
River gauge station
Legend
WYLD_Annual means (mm)
330 - 330
330 - 360
360 - 370
370 - 390
390 - 410
River gauge station

(a)


Surface runoff
N
Sediment yield
Mawande
Ihimbu
Makalala
Legend
SURQ_Annual means (mm)
38 - 41
41 - 44
44 - 48
48 - 52
52 - 58
River gauge station
Legend
SYLD_Annual means (t/ha)
5 - 5
5 - 8
8 - 10
10 - 13
13 - 18
River gauge station

(b)



(c)

Figure 9. Subbasin contribution on hydrological component of the catchment.

4. Discussion

The study findings indicate that the change in the LULC has a significant impact on the hydrological response of Little Ruaha River Catchment. The expansions of agricultural activities and built-up areas are directly linked with increased water use for irrigation and domestic use. The land use changes, particularly, conversion of forest covers (natural forest, woodland and riverine forest) between 1990 and 2015, are associated with the increased runoff. Increase in storm runoff is mainly due to the reduced infiltration rate when forest is converted to other land uses [36] [37]. These changes in runoff generation are in agreement with the general knowledge that reducing forest cover decrease opportunity of infiltration which in turn leads into an increase in water yield due to increased surface runoff [38] [39], has reported that the increased water yield and surface runoff in the catchment bring environmental problems including soil erosion and siltation of water bodies. Furthermore, the decrease in base flow and evapotranspiration observed in the study is accompanied with the alteration of forest covers. This was highlighted in [40], as cited in [38] that forest cover removal decreases the opportunity of infiltration to the extent that surface flow exceeds the gain in base flow which results in diminished dry seasonal flow. Studies from Tanzania and other different countries have also shown the influence of land use changes on runoff generation [41] [42] [43]. According to this study, it is apparently clear that, land use and cover changes impact on the water yield and sediment yield and have implications on the sustenance flow regimes particularly dry season river flows which in turn cause adversely impacts not only to biotic component of ecosystem found within and outside the catchment but also hydropower generation.

It is also important noting that much of the planned development investments in the Ihemi Cluster including agriculture, tourism, and energy production depends much on the Little Ruaha River, therefore decrease in river flow can be a very challenging factor for agricultural development for small holders' farmers in the SAGCOT as well as tourism activities in the Ruaha Natinal park. Little Ruaha river is essential sources of surface water for wildlife during 'dry' seasons when rainfall is limited or absent, particularly for species whose resilience to water scarcity is low. The decreased flow in this river jeopardizes the survival of these wild animals especially during dry season which in turn have negative implication in tourism industry. Increase sediment generation represents a serious threat to the sustainability of Mtera hydropower. Sedimentation may affect the safety of dams and reduces energy production, storage, discharge capacity and flood attenuation capabilities which threaten security to downstream user.

5. Conclusions

This study has examined the impact of land use and land cover changes on hydrological response with a strong focus on water quantity and sediment yield in Little Ruaha River Catchment. The results indicate that changes in land use and land cover have a significant impact on the hydrological response of the catchment. An increase in sediment yield and surface runoff along with a decrease in base flow and lateral flow were directly associated with the transformation of land use and land cover in the catchment. Such changes, increased runoff generation and sediment yield with the decreased base flow have implications on the sustenance flow regimes particularly diminish dry season river flows, which in turn cause adverse impacts to a biotic component of the ecosystem and reduced water storage and energy production at Mtera Hydroelectrical dam.

Therefore, to ensure the sustainability of water resources in the Little Ruaha River Catchment, the study recommends the need for an appropriate intervention including implementation of sustainable land use planning at the village level, and conservation agriculture practices to ameliorate the current situation. According to the model results, it is necessary to prescribe appropriate soil and water conservation practices to all subbasins with high runoff and sediment generation identified in the model results (**Figure 9(b)**). Subsequent land development should avoid such areas because of the need to adequately protect them with appropriate conservation strategies.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Appendix 1. Land Use Land Cover Change Analysis 1990-2015 (Chilagane, 2020)

Years	1990		2005		2015		1990-2005			2005-2015			1990-2015		
LULC	Cover area (ha)	%	Cover area (ha)	%	Cover area (ha)	%	Change area (ha)	% Change	Annual rate of change	Change area (ha)	% Change	Annual rate of change	Change area (ha)	% Change	Annual rate of change
FR	39,872	6.26	22,957	3.6	15950	2.5	−16915	−42.42	−1127.67	−7007	−30.52	−700.70	−23922	−60.00	−956.88
PL	20,632	3.24	34,068	5.35	24285	3.81	13436	+65.12	+895.73	−9783	−28.72	−978.30	+3653	+17.71	146.12
RF	5878	0.92	2746	0.43	1083	0.17	−3132	−53.28	−208.80	−1663	−60.56	−166.30	−4795	−81.58	−191.80
WTR	1752	0.28	1202	0.19	657	0.1	−550	−31.39	−36.67	−545	−45.34	−54.50	−1095	−62.50	−43.80
WET	19,157	3.01	11,785	1.85	5622	0.88	−7372	−38.48	−491.47	−6163	−52.30	−616.30	−13535	−70.65	−541.40
WD	109,692	17.22	72,809	11.43	58554	9.19	−36883	−33.62	−2458.87	−14255	−19.58	−1425.50	−51138	−46.62	−2045.52
WR	60,288	9.46	75,121	11.79	43767	6.87	+14833	+24.60	+988.87	−31354	−41.74	−3135.40	−16521	−27.40	−660.84
CW	57,368	9.01	54,517	8.56	55300	8.68	−2851	−4.97	−190.07	+783	+1.44	+78.30	−2068	−3.60	−82.72
GR	118,784	18.65	129,797	20.38	148795	23.36	+11013	+9.27	+734.20	+18998	+14.64	+1899.80	+30011	+25.27	+1200.44
BS	87,394	13.72	111,284	17.47	125759	19.74	+23890	+27.34	+1592.67	+14475	+13.01	+1447.50	+38365	+43.90	+1534.60
CLT	106,782	16.76	109,047	17.12	143470	22.52	+2265	+2.12	+151.00	+34423	+31.57	+3442.30	+36688	+34.36	+1467.52
BLT	9408	1.48	11,674	1.83	13765	2.16	+2266	+24.09	+151.07	+2091	+17.91	+209.10	+4357	+46.31	+174.28
Total	**637,007**	**100**	**637,007**	**100**	**637007**	**100**									

FR: Forest; PL: Plantation; RF: Riverine forest; WTR: Water; WET: Wetland; WD: Woodland; WR: Wooded rock; CW: Cultivated woodland; GR: Grassland; BS: Bushland; CLT: Cultivated land; BLT: Built up area

Appendix 2. Predicted Land Use/Cover Based on CA-Markov Model (Chilagane, 2020)

LULC	2040	
	Area (Ha)	Coverage (%)
Forest	11,936	1.87
Plantation	22,950	3.60
Riverine forest	461	0.07
Water	211	0.03
Wetland	3183	0.50
Woodland	50,158	7.87
Wooded rock	35,387	5.56
Cultivated woodland	49,901	7.83
Grassland	160,422	25.18
Bushland	130,023	20.41
Cultivated land	158,132	24.82
Built up	14,242	2.24
Total	637,007	**100**