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Research Article

Modelling the Impacts of Land Use Land Cover Change on Hydrology and Sediment Yield in a Water Catchment in Central Uganda

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Abstract

This study investigated the influence of land use land cover change (LULC) on hydrology and sediment yield in a water catchment in Uganda. The Soil and Water assessment Tool (SWAT) model was used to assess the impacts of LULC on hydrology and sediment yield in upper Ssezibwa catchment. The calibrated and validated SWAT model based on observed streamflow data demonstrated good performance as indicated by the values during calibration (R^2=0.85, NSE=0.82, KGE=0.76, PBIAS = -18.5) and validation (R^2=0.72, NSE=0.66, KGE=0.66, PBIAS= -19.3). The model performance of for sediment yield is also good during calibration (R^2=0.80, NSE=0.81, PBIAS = -17) and validation (R^2=0.74, NSE=0.76, PBIAS= -19.7). Overall accuracy assessment of over 80% and Kappa statistics of 0.82, 0.84 and 0.80 for the years 2002, 2012 and 2022 respectively was satisfactory. Results indicated changes in the various LULC types in the catchment which increased the contribution to streamflow by surface runoff (130.2%) and 111.45% in 2002 - 2012, and 2012 – 2022 respectively, while Lateral flow and ground water flow decreased by -2.26% and -3.23% as well as -5.78% and -9.2% in 2002 - 2012, and 2012 – 2022 respectively. Sediment yield increased by 21.25% in 2002-2012 and 28.33% in 2012-2022. Results provide a solid foundation for better land use and water resource planning, monitoring and management as well as minimizing the costs of the impacts of flooding in Upper Ssezibwa catchment.

Keywords

Land Use, Land Cover Change, Hydrology, Sediment Yield, Swat Model

1. Introduction

Land use land cover change (LULC) change is the utmost symptomatic representation of anthropogenic interference in a basin [1]. Extant studies indicate that LULC change increases sediment yield in a catchment [2-5] but [6] projected that LULC will lead to a reduction in sediment yield in the future. Previous studies [7, 8] observe that changes in hydrology are a result of LULC changes. Land use change alters the flux of energy and mass influencing the river flow regimes and sediment loading [9]. Changes in LULC is a serious problem globally. Bouma and Batjes [10] revealed

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that 15% of the global land surface, 38% of the agricultural land, 21% of the land under permanent pasture and 18% of forest and woodlands are degraded as a consequence of antagonistic land use activities. Seventy five percent of the earth's environment has been transformed by humans in pursuit of socioeconomic benefits in the last millennium with serious consequences on the land and water resources [11, 12]. Changes in LULC resulting from settlement and encroachment on agricultural and forest land have significant impacts at the local level such as decreasing the water yield, altering the runoff pattern and stream flows, while increasing the sediment yield and risk of floods [13-16]. Understanding the impact of LULC change on various natural resources is important to achieve sustainable water and land management [17].

Changes in LULC can modify the natural hydrological environments within the basin [18]. Indeed, [19] reported that LULC change alter the hydrological response of a basin and the flow regime of a stream. The modification ensuing from the LULC change marks a decrease in baseflow and groundwater recharge as well as an increased rate and volume of surface runoff [1]. Additionally, [20] reveal that the adjustment of the stream flow regime resulting from LULC change leads to local flooding, increasing water level in wetlands and lakes, decreased baseflow into stream channels during dry seasons and increased erosion of river banks and channel beds. Recent studies [20, 21] highlighted the complexity of understanding the impact of LULC change on hydrology which calls for more novel studies to inform public policy planning and investment policies.

Land cover is an important determinant of the water balance [22]. A study by [23] indicated that changes in LULC such as afforestation may decrease water yield. Nyeko [24] observes that land cover controls the process of transpiration, evaporation, stream flow, groundwater flow and infiltration. Furthermore, [25] recognized that having fresh natural water in the area may indicate having vegetation cover because vegetation helps to control soil erosion which may help create a micro-climate where rainfall may be experienced in an area and at the same time lead to siltation of the water bodies. The consequences of LULC change are strong particularly in fragile ecosystems such as river basins and mountainous areas [17].

Information on influence of LULC change on hydrology in Uganda is fragmented yet understanding the causes, patterns and trends of long-term LULC change on water resources is vital for policy makers to address the growing challenges for local sustainability. In Uganda, land cover conversion was significantly hastened after 2000, and the most common land cover was switched from Open Grassland to Cropland [26]. This trend does not only amplify a persistent deficit in appropriate natural resource management practices but also has an impact on hydrology. While, [27, 28] claim that the influence of LULC change on hydrology is well understood does not hold for watershed with dynamic and fragmented land use patterns as documented in the tropical developing world of which Uganda is part.

The upper Ssezibwa catchment has experienced land use land cover conversion from forests to create more land for farming and built-up areas. Water catchments and agricultural areas in upper Ssezibwa catchment have been converted to settlement and the urban sprawl. The poor agricultural practices have led to increase in land degradation especially soil erosion and increased the deposition of sediments in the stream affecting the flow regimes resulting into flooding and the resultant destruction of property and loss of life. There is widespread degradation resulting from deforestation in pursuit of expansion of agriculture. The sustainability of land and water resources in upper Ssezibwa catchment has reached a critical point and requires decisive action. Although conversions in the LULC change are observed in Upper Ssezibwa catchment, the impact of land conversion on hydrology and sediment yield has not been quantified. The current study simulates the impacts of LULC on hydrology and sediment yield for effective planning and management of environment resources in the upper Ssezibwa.

2. Materials and Methods

2.1. Description of the Study Area

Upper Ssezibwa catchment is located in Central Uganda covering an area of 254.08 km^2, between 00°16′12″N, 33°00′18″E, and 01°24′00″N: 32°44′06″E (Figure 1). Upper Ssezibwa catchment is a valued ecosystem zone because of the ecosystem goods and services that support human life but has experienced huge ecological changes as a result of LULC change, destruction of wetlands, poor agricultural expansion and variation in climate parameters [24]. The catchment has clay loam soils which are extremely fertile and coupled with has tropical climate characterized by a bimodal distribution of rainfall that encompass two wet seasons i.e., March to May (Long rains) and September-November (short rains) attract small holding farmers who clear the vegetation cover and practice their agriculture. Located at the fringes of Kampala city, the area is increasingly undergoing urbanization and more area is being converted into built-up areas. The flows of River Ssezibwa fluctuate largely due to variation in rainfall and temperature. The catchment experiences low flows during the dry seasons ensuing droughts and water scarcity as well as high flows during the wet seasons resulting into floods. Upper Ssezibwa catchment experiences sediment loading resulting from soil erosion and floods [29]. However, there is need to adequately quantify the impacts of LULC on sediment yield and hydrology in the catchment.

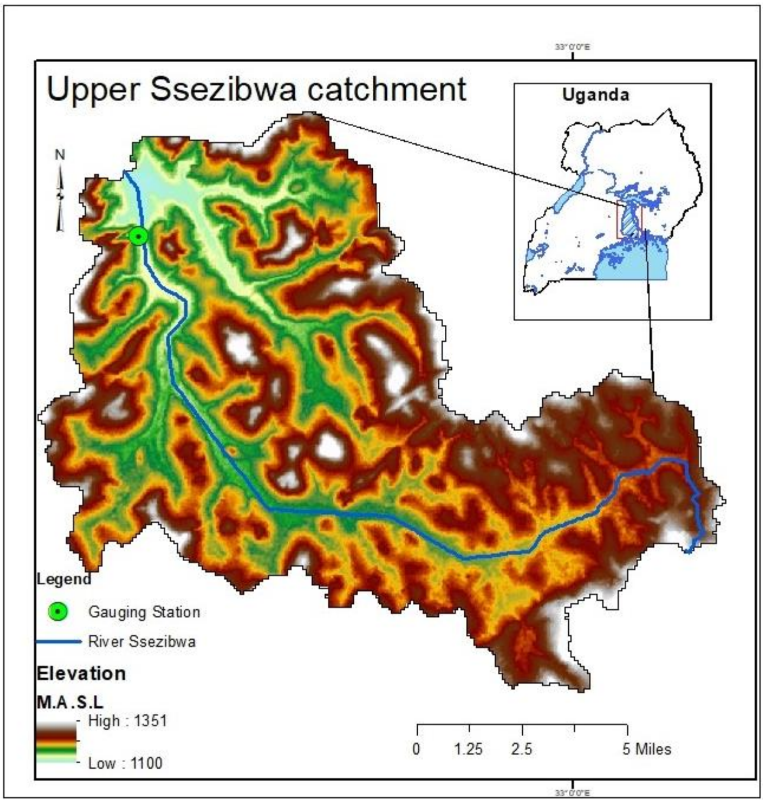

Figure 1. *Location map of Upper Ssezibwa catchment.*

2.2. Data Sources and Data Acquisition

Earth observation imagery were acquired from United states Geological Survey (USGS) data portal (https://earthexplorer.usgs.gov/). The Worldwide Reference System (WRS) was utilized to choose the area of interest. The Digital Elevation Models (DEM) with a spatial resolution of 30 m and decadal Shuttle Radar Topography Mission (SRTM) Landsat images for 2002, 2012 and 2022 were used. To maintain uniformity among data sets during analysis, all of the earth observation imagery was projected to the World Geodetic System 84 (WGS84) reference and the Universal Transverse Mercator (UTM) Zone 36S. The methodological flowchart for the study is shown in Figure 2.

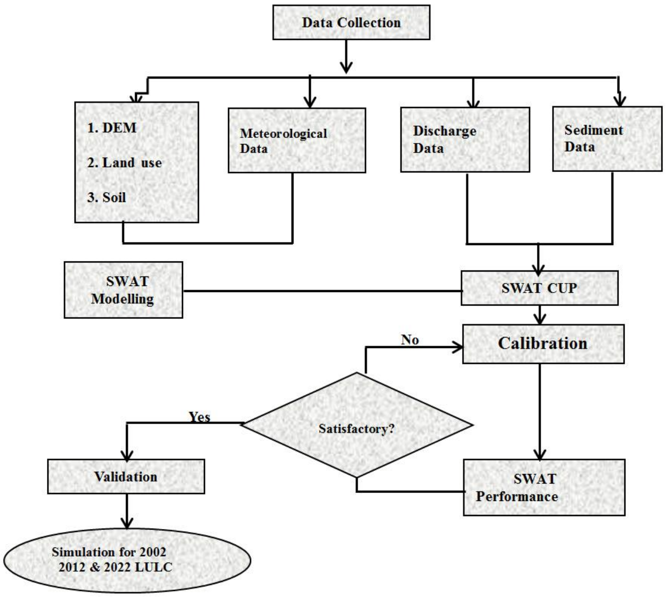

Figure 2. *Methodological framework of the study.*

2.3. Hydrological Model Setup and Data Inputs

The Soil and Water Assessment Tool (SWAT) a physically-based, continuous, semi-distributed parametric model was used to assess the impacts of LULC change on hydrology and sediment yield. The LULC change data of 2002, 2012 and 2022 was retrieved from https://earthexplorer.usgs.gov/ and used for LULC change analysis. The soil data was retrieved from FAO/UNESCO Soil Map which is clipped to the spatial extent of the analysis. Meteorological data such as daily minimum and maximum temperature, precipitation, solar radiation, wind speed and relative humidity data of the upper Ssezibwa catchment was accessed from National Aeronautics and Space Administration (NASA) portal for prediction of worldwide energy resources (https://power.larc.nasa.gov/). Hydrological data was obtained from Ministry of Water and Environment while sediment data was determined from records from the gauging station at Upper Ssezibwa. The catchment was delineated using ArcSWAT Automatic Watershed delineator based on the Digital elevation model.

The SWAT simulates the hydrologic model using the water balance equation:

$$SW_t = SW_o + \Sigma_{i=1}^{t} = \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \quad (1)$$

Where; SW_t = Final soil water content (mm), SW_o = Initial soil water content (mm), t = Time (days), R_{day} = Amount of precipitation on day i (mm), Q_{surf} = quantity of surface runoff (mm), E_a = Evapotranspiration (mm), W_{seep} = Seepage from the bottom soil layer (mm), and Q_{gw} = Ground water flow (mm). The SCS curve number procedure was used for calculating and analysis of surface runoff under the SWAT model. The Modified Universal Soil Loss Equation (MUSLE) embedded in SWAT was used for sediment flow analysis. The MUSLE equation used to calculate the sediment from the catchment is;

$$S=11.8(Q \times Area \times pr)^{0.56} \times K \times C \times P \times LS \times R \quad (2)$$

Where, S = Sediment load (mt), Q = Surface runoff (cu. m), pr = Peak runoff rate (cu. m), K = USLE soil erodibility factor, C = Cover and management factor, P = support practice factor, LS = Topographic factor (gradient, length).

2.4. Hydrologic Response Unit Analysis

Hydrologic Response Units (HRUs) are distinct combinations of land use, soil, and slope within each sub-basin that are thought to react similarly to weather inputs. Four GIS layers were needed to create HRUs: sub-basins, land use and cover, soils, and slope. The SWAT interface loaded these data in the projected grid file format. The look-up table was used to define the soil and land cover classes. The hydrologic response units were defined by integrating the land slope classes as well. The slope of the land surface directly correlated with the sediment transport capacity. The slope reclassification was done using the same DEM data that was used to delineate the watershed. Finally, the HRUs were created by superimposing the reclassified land use, soil, and slope grids. The last phase in the HRU study was the HRU definition. Multiple HRU were assigned to each sub-watershed in this study in order to create the HRU definition. To ensure that each distinct combination of land use, soil, and slope is regarded as a unique HRU, the HRU thresholds were maintained at zero in numerous HRU definitions. In our study area, 33 sub-basins and 321 HRUs were produced through the HRU defining process.

2.5. Land Use and Land Cover Change Analysis

Land use classification was done using maximum likelihood classification method because it takes into account the spatial information of Land cover classes and it is the most widely used per-pixel method [30]. Using the supervised classification based on [31] land use land cover classification system, the images were classified into six land use land cover types i.e. built-up areas, bushland, commercial farming, grassland, small scale farming, wetland and woodland.

2.6. Land Use Land Cover Accuracy Assessment

Following image classification, the level of acceptance and the process of change detection was determined using accuracy assessment. The confusion matrix method which is cross-tabulation of the mapped versus the reference class was used for accuracy assessment. Producers, users and overall accuracy as well as the Kappa statistics that removes the effect of random change on accuracy [32] were obtained from the error matrix.

Thus, the user's accuracy, producer accuracy and overall accuracy were computed using the following equations;

$$\text{User's accuracy} = \frac{aii}{dx\,\Sigma_{i-1}^{n}\,a+1} \quad (3)$$

$$\text{Producer's accuracy} = \frac{aii}{dx\,\Sigma_{i-1}^{n}\,ai+} \quad (4)$$

Where; aii: is the Number of Samples correctly classified, $ai+$: is the Column total for classes and $a+1$: is the Row total for classes.

2.7. Sensitivity Analysis

The calibration, validation and sensitivity analysis of the model was done using Semi-automatic Sequential Uncertainty Fitting 2 (SUFI-2) in SWAT Calibration and Uncertainty Procedures (SWATCUP) optimization programme. The Global Sensitivity Analysis (GSA) was used in sensitivity analysis because it allows investigating the whole assortment of parameters. Under this method, the entire parameters under consideration were concurrently perturbed permitting investigation of parameter connections and their impacts on model outputs [33, 34].

2.8. Model Performance Evaluation

Four major criteria were used to assess the evaluation of performance as suggested by [35, 36]; Nash–Sutcliffe efficiency (NSE), Coefficient of determination (R^2), Percent Bias (PBIAS) and the Kling–Gupta Efficiency (KGE).

1. Nash–Sutcliffe efficiency (NSE): Indicates the goodness of fit of the plot between the measures and simulated datasets

$$\text{NSE}= 1- \left[\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs}-Y^{mean})^2}\right] \quad (5)$$

where *Yi obs* is the *i*th observation for the constituent being evaluated, *Yi sim* is the *i*th simulated value for the constituent being evaluated, *Ymean* is the mean of observed data for the constituent being evaluated, and *n* is the total number of observations [35].

2. Kling–Gupta efficiency (KGE): It is metric for evaluating the goodness-of-fit of *the* model simulations and corresponding observations. Besides measuring the accuracy of the model predictions, it also measures the model's ability to reproduce the variability and timing of the observed data.

$$\text{KGE}=1-\sqrt{(r-1)^2+(\alpha-1)^2+(\beta-1)^2} \quad (6)$$

r is the Pearson correlation coefficient, α is a term representing the variability of prediction errors, β is a bias term. The term α and β are defined as follows; $\beta=\frac{\mu_s}{\mu_0}$ Where; μ_s is the mean of the simulated time series (e.g.: flows predicted by the model) and μ_0 is the mean of the observed time series [35].

3. Percent bias (PBIAS): Measures the tendency for observed to be greater (or lesser) than the simulated

$$\text{PBIAS}=\left[\frac{\sum_{i=1}^{n}\left((Y_i^{obs}-Y_i^{sim})\right)*1(100)}{\sum_{i=1}^{n}(Y_i^{obs})}\right] \quad (7)$$

Where: Y^{obs} is the measured data, Y^{sim} is the model simulation output, Y_0^{mean} *and* Y_s^{mean} *is* the observed data and simulated data for river flow, *i* is the *ith* measured of simulated data and *n* is the total number of observations [35].

4. Coefficient of determination (R^2): Describes the level of variance between the observed and simulated data. It is not recommended to use as a single criterion for evaluation of the model performance as it can give the same value for different magnitude data set.

$$R^2 = \frac{\sum_i [(Y^{obs}-Y_0^{mean})(Y^{sim}-Y_s^{mean})]^2}{\sum_i [(Y^{obs}-Y_0^{mean})^2 \sum_i [(Y^{sim}-Y_s^{mean})]^2} \quad (8)$$

Where: Y^{obs} is the measured data, Y^{sim} is the model simulation output, Y_0^{mean} *and* Y_s^{mean} *is* the observed data and simulated data for river flow, *i* is the *ith* measured of simulated data and *n* is the total number of observations [35].

3. Results and Discussion

3.1. Land Use Land Cover Change in Upper Ssezibwa Catchment

Upper Ssezibwa catchment has experienced significant changes in LULC (Figure 2) from 2002 to 2022 derived from the classification for the ten-year interval periods (2002 – 2012 and 2012 -2022). In 2002, Grassland covered 6052 ha (23.8%) which decreased to 5436 ha (21.4%) in 2012 and 4779 ha (18.8%) in 2022 (Table 1); Woodlands covering 5270 ha (21.1%) in 2002 declined to 3011 ha (11.9%) and 742 ha (2.9%) in 2002 and 2022 respectively. Wetlands declined from 5024 ha (19.8) in 2002 to 4539 ha (17.9%) in 2012 and 3116 ha (12.3%) in 2022. However, small scale farming expanded from 4831 ha (19.0%) in 2002 to 8402 ha (33.1%) in 2012 and 11242 ha (44.2%) in 2022. The expansion of small-scale farming could be as a result of demand for more land to grow more food for the families. The continuous conversion of wetlands, bushlands, woodlands and grassland could be a result of the existing "Mailo" land tenure system (exclusive individual ownership) that allows owners to exclusively use their land as they wish without consideration of the ecosystem health. These results are in agreement with the other study findings of [37, 38] who found changes in different LULC due to encroachment in the farm area resulting from inadequate monitoring of the conservation policies by National Environment Management.

Table 1. *Summary of LULC distribution and relative change between periods in upper Ssezibwa catchment.*

Land use Land cover	2002		2012		2022		Net Change (2002-2012)		Net Change (2012-2022)	
	Area (Ha)	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**
Built-up areas	1011	4	1324	5.2	3083	12.1	313	1.2	1759	6.9
Bushland	2013	7.9	1205	4.7	925	3.6	-808	-3.2	-280	-1.1
Commercial farming	1107	4.4	1491	5.9	1521	6	384	1.5	30	0.1
Grassland	6052	23.8	5436	21.4	4779	18.8	-616	-2.4	-657	-2.6
Small-scale farming	4831	19	8402	33.1	11242	44.2	3570	14.1	2841	11.2
Wetland	5024	19.8	4539	17.9	3116	12.3	-485	-1.9	-1423	-5.6
Woodland	5370	21.1	3011	11.9	742	2.9	-2359	-9.3	-2269	-8.9
TOTAL	25408		25408		25408					

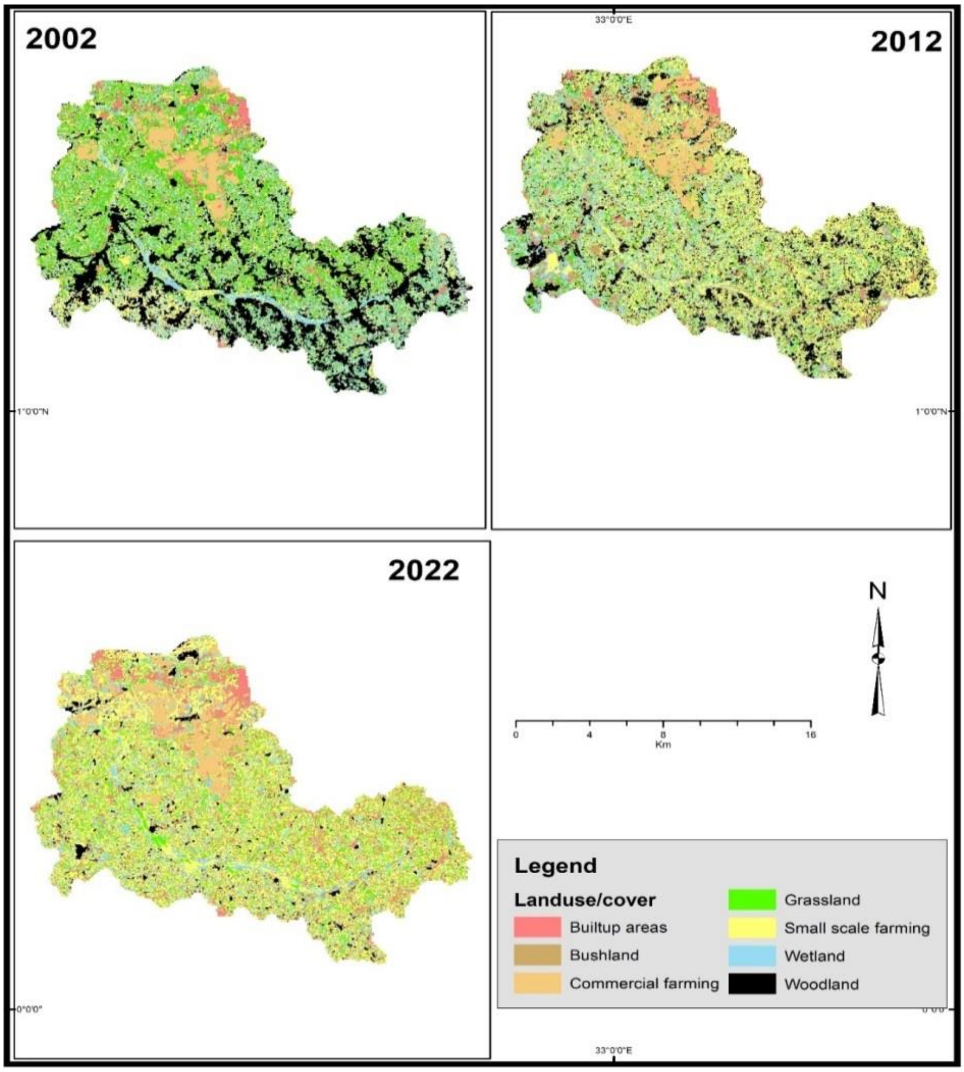

Figure 2. *Spatial temporal distribution of land use/cover in 2002, 2012 and 2022 in Ssezibwa catchment.*

3.2. Land Use Land Cover Accuracy Assessment

Land use land cover accuracy assessment was based on LULC classification imagery in the catchment. Accordingly, the user accuracy ranges between 66.2%-94.9%, and producer accuracy ranges between 64.7% - 94.9% within the temporal trend of 2002, 2012, and 2022 (Table 2). Built-up areas were found to be more reliable with 90.9% of user accuracy in 2002, Commercial farming had 94.9% of user accuracy in 2012 and grassland was more reliable with 92.2% of user accuracy in 2022. An overall accuracy (OA) of over 80% was obtained for the images of 2002, 2012, and 2022. The overall accuracy of this study is consistent with that of [39, 40] who reported a satisfactory overall accuracy of 80.0%.

Table 2. *Accuracy assessment 2002, 2012 and 2022.*

Year	2002		2012		2022	
Land use land cover	**Producer Accuracy**	**User Accuracy**	**Producer Accuracy**	**User Accuracy**	**Producer Accuracy**	**User Accuracy**
Built-up areas	82	90.9	94.9	91.8	92.9	88.6
Bushland	79.7	87.9	90.7	90.7	89.7	82.4
Commercial Farming	84.3	74.1	74.7	94.9	73.4	66.2
Grassland	75	83.8	83.3	75	86.6	92.2
Small scale farming	90.5	83.8	85.9	93.2	83.3	90
Wetland	91.5	89	93.1	89.3	90.3	79.3
Woodland	87.5	80	83.3	72.6	64.7	84.6
Year	2002		2012		2022	
Overall Accuracy (OA)	84.2		86.2		82.7	
Kappa statistics	0.82		0.84		0.8	

The Kappa coefficients of 0.82, 0.84, 0.80 for 2002, 2012 and 2022 respectively were achieved. These findings are in agreement with [41] who defined the agreement criteria for Kappa coefficients as poor when Kappa<0.4, good when 0.4<Kappa<0.7 and excellent when K>0.75. Accordingly, the LULC classifications for 2002, 2012, 2022 denotes excellent with a Kappa statistics which showed a strong agreement for all the classified images and the overall accuracy that was within the acceptable range for further LULC changes analysis [42].

3.3. Hydrological Model Performance Evaluation

The comparisons between the simulated and observed stream flow (Q) from ArcSWAT for the period 2002-2022 at the catchment outlet (Figure 3) shows good accordance between the simulated and observed stream flow although some high flows and low flows are overestimated by the model. However, the simulated daily stream flow derived from the model matched well with the observed stream flow during calibration (R^2=0.85, NSE=0.82, KGE= 0.76, PBIAS = -18.5) and validation (R^2=0.72, NSE=0.66, KGE= 0.66, PBIAS= -19.3) as shown by Table 3. The performance of ArcSWAT is considered to be acceptable for the stream flow calibration and validation at the catchment outlet as recommended by [35]. The model performance for sediment yield is also good during calibration (R^2=0.80, NSE=0.81, PBIAS = -17) and validation (R^2=0.74, NSE=0.76, PBIAS= -19.7) as shown by Table 3.

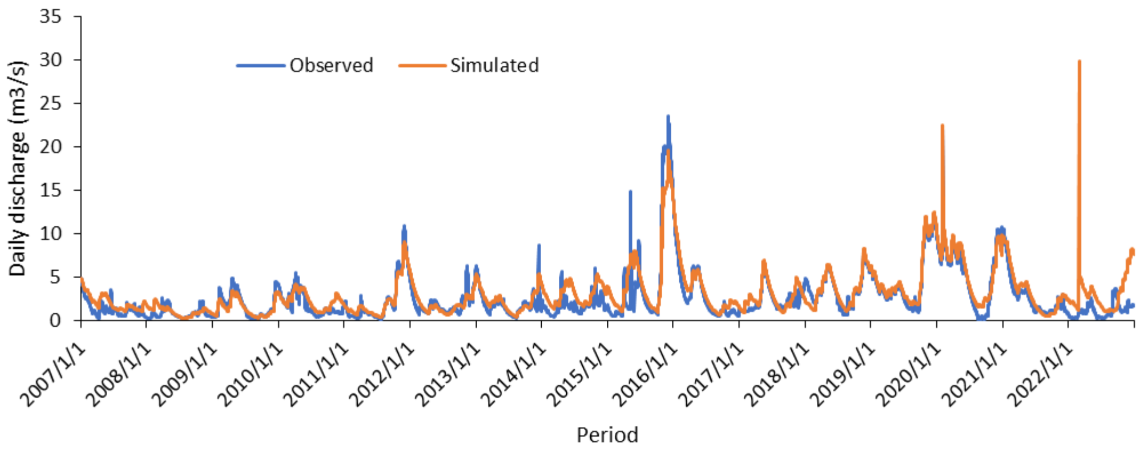

Figure 3. *Observed and simulated discharge for the calibration (2007-2016) and validation (2017-2022) periods at the catchment outlet.*

Table 3. *Model performance indicators for discharge and sediment yield at the catchment outlet.*

	Discharge							**Sediment yield**		
Simulation period (Daily)	**P-Factor**	**R-Factor**	**R^2**	**NSE**	**KGE**	**PBIAS**	**Mean Flow (simulated)**	**R^2**	**NSE**	**PBIAS**
Calibration (2007-2016)	0.62	0.38	0.9	0.82	0.76	-18.5	2.65(3.15)	0.8	0.81	-17
Validation (2017-2022)	0.59	0.45	0.7	0.65	0.66	-19.3		0.7	0.76	-19.7

3.4. Sensitivity Analysis of LULC Components That Affect the Hydrological Response in River Ssezibwa Basin

Ten sensitive parameters influencing hydrology and their ranking was done using SUFI-2 procedure in SWATCUP. The parameters were ranked in terms of their sensitivity to the SWAT model calibration (Table 4).

Table 4. *Ranking of the calibrated parameters, according to their sensitivity and significance.*

Rank	**Parameter**	**Description**	**Final Range**	**Method**
1	Sol_AWC. sol	Available water capacity of the soil layer	-0.12315	R
2	CN. mgt	SCS runoff curve number	-1.223492	R
3	HRU_SLP. hru	Average slope steepness	0.0 - 0.010634	V
4	ESCO. hru	Soil evaporation compensation factor	0.0 - 0.166683	V
5	SURLAG. bsn	Saturated hydraulic conductivity	0.060713 - 0.182883	V
6	GWQMN. gw	Threshold depth of water in the shallow aquifer required for return flow to occur	316.3638 - 428.2069	V
7	GW_DELAY. gw	Groundwater Delay	20.724407 - 62.389194	V
8	ALPHA_BF. gw	Base flow alpha factor (days)	0.383230 - 0.453092	V
9	SLSUBBSN. hru	Average slope length	11.305268- 21.171534	V
10	RCHRG_DP. gw	Deep aquifer percolation fraction	0.128689 - 0.192655	V

Note: “v” indicates a replacement method of the initial parameter value with the given value in the final range. “R” means a relative change to the initial parameter value.

Global Sensitivity Approach of the flow parameters was performed for calibration of the SWAT model using SWAT-CUP. The parameter that induced the most output is the most sensitive as recommended by [43]. The Available Water capacity of the Soil Layer (Sol_AWC. sol), SCS runoff curve number (CN. Mgt), Average slope steepness (HRU_SLP. hru), Soil evaporation compensation factor (ESCO. hru) and Saturated hydraulic conductivity (SURLAG. bsn.) were the most sensitive respectively. Generally, surface runoff parameters (Sol_AWC. sol, CN. Mgt, HRU_SLP. hru, ESCO. hru and SURLAG. bsn) are most sensitive to hydrological response in Upper Ssezibwa catchment.

3.5. Impacts of LULC Change on Hydrology (River Discharge) in Upper Ssezibwa Catchment

Results indicate an increase in monthly discharge from the LULC scenario of 2002 to LULC for the year 2022 (Figure 4). However, all the LULC scenarios indicate a decline in monthly discharge during June to September which are dry months in the catchment while the wet months, show an increase in discharge. This is related to the poor management of land and forest resources in the catchment, resulting into conversion of vegetation to small-scale farming and urbanization affecting precipitation and temperature patterns.

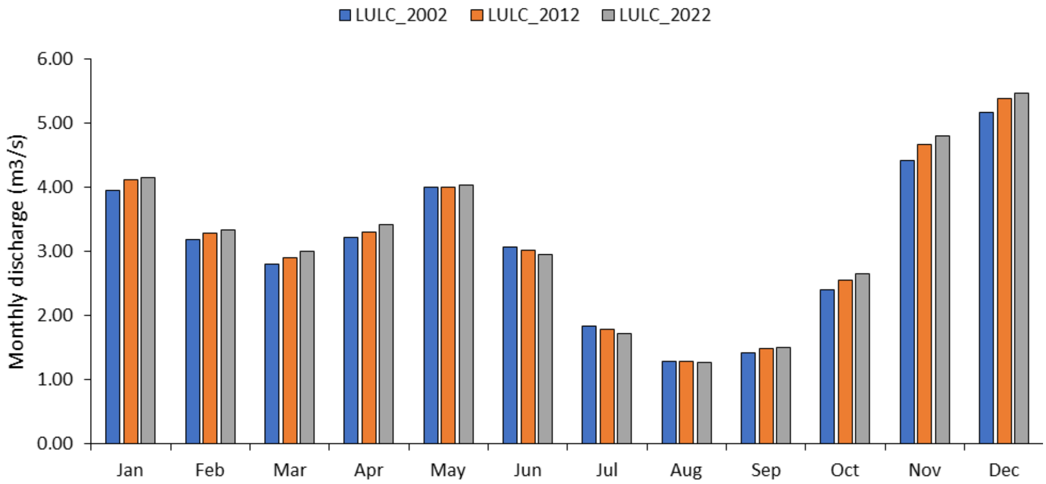

Figure 4. *Monthly discharge according to the land use/cover scenarios in the catchment.*

Between 2002 and 2012 there was a general increase in monthly discharge based on the seasons except for June – July, which showed a decline of -1.8% and 2.8%, respectively. The greatest increase in discharge was observed in October (6.2% increase) and the wet seasons in the year i.e. March –May and September – December showed an increase in discharge. This is the period floods are experienced in the catchment. Conversely, between 2012 and 2022, the LULC changes showed an increase in monthly discharge for the wet seasons/months, with the greatest increase observed in April (3.8%) and October (3.9%). This suggests an increase in flood magnitude and frequency leading to severe loss of property and lives. This finding is consistent with [44, 45] who observed that catchments with forests or thick vegetation exhibit smaller river flow rates than catchments dominated by other managed land uses as the vegetation cover loss results in decrease in aerodynamic roughness, changes in albedo and reduction in rooting depth subsequently leading to a cutback in Evapotranspiration which consequently affects river flow.

However, during the dry months of June, July and August, a decrease in discharge due to LULC was observed at -2.4%, -3.2% and -1.6%, respectively (Figure 5). These low flows curtail the flooding in the area but instead, lead to water scarcity for livestock and humans affecting various aspects of livelihoods. The decrease in discharge during these months due to LULC between the year 2012 and 2022 indicates degradation in land use landcover of the catchment. Earlier studies, [46-48] observed that a decrease in discharge in dry months is an indication of conversion of forest land to agricultural and settlement land.

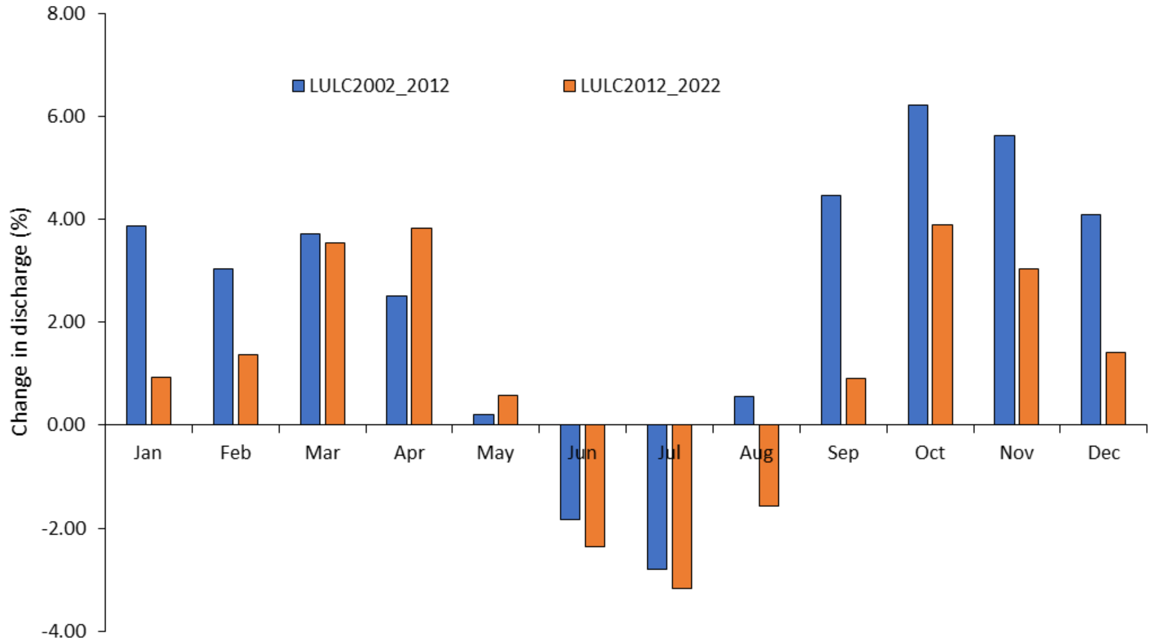

Figure 5. *Percentage changes in monthly discharge in the catchment according to land use/cover scenarios.*

Results about the changes in the annual water balance between 2002 and 2012, and 2012 and 2022 of the catchments due to LULC change (Table 4) indicate that discharge was 0.08 m^3/s for the period 2002 and 2012 and 0.04 m^3/s for the period 2012 to 2022 in the catchment due to LULC. These results are similar to observed discharge data in the catchment. Accordingly, an increase in annual discharge for both the LULC change periods was observed although LULC change between the years of 2002 and 2012 was higher (2.8% increase) than the change between 2012 and 2022 (1.4%). Further, surface runoff significantly increased by 17.84 mma^{-1} due to LULC changes between the study periods with a period between 2002 and 2012 causing the highest increase of 130.2% than for 2012 and 2022 of 21.64 mma^{-1} representing an increase of 111.45%. These results explain the flooding experienced in the catchment between 2002-2012 and 2012-2022. This indicates that LULC degradation was highest from 2002 to 2012, compared to that of 2012 to 2022, leading to higher runoff in the catchment. These changes are attributed to anthropogenic activities in the catchment. Similarly, the higher runoff can explain the occurrence of floods in the study area. The floods in the study area were more severe between 2002 – 2012 [49] compared to 2012-2022 [50-54]. LULC changes for both study periods led to a negative trend in the lateral flow -0.00092 mma^{-1} (-2.26%), -0.0023 mma^{-1} (-5.78%);, Base flow/Groundwater flow -7.79 mma^{-1} (-3.23%), 21.64 mma^{-1} (-21.35%) and percolation -9.664 mma^{-1} (-3.33%), -25.97 mma^{-1} (-9.26%) for the period 2002 -2012 and 2012-2022 respectively–in the catchment. Various studies found similar results of a decline in lateral flow and ground water flow [55-57] which was attributed to high surface runoff and low infiltration arising from changes in land use and land cover.

On the contrary, LULC changes showed a mixed impact on actual evapotranspiration, annual water yield, and deep aquifer recharge for the two study periods. For instance, LULC changes between the years 2002 and 2012, led to an increase in actual ET (1.6%) and annual water yield (4.2%) while a decrease in deep aquifer recharge (-34%) was observed during this period. Furthermore, LULC changes for 2012 and 2022 caused a decrease in actual evapotranspiration (-1.9%) and annual water yield (-16%). The decrease in ET during 2012-2022 could be due to a decline in bushlands, woodlands, wetlands, and grasslands as observed. These results are similar to the findings by [55] who detected changes in ET in the period 1994 and 2022 due to a decline in shrubland and forests in Muga watershed, Abiy River Basin, Ethiopia.

The increase in surface runoff contribution to river flow in the Upper Ssezibwa catchment by 130.2% and 111.45% from the point of reference in the years 2002 and 2012; and 2012 and 2022 respectively explains the emergency and occurrence of the floods in the catchment in the period under study. The decline in woodlands, grasslands, wetlands- and bushlands at the expense of small-scale farming, commercial farming and built-up areas may be the reason for the increased rate of surface runoff in upper Ssezibwa catchment. The increase in surface runoff and at the same time decrease in the rate of river discharge from 0.08 m/s (2.76%) in 2002 to 2012, to 0.04 m/s (1.37%) is due to loss of grassland, woodlands, wetlands and bushlands and the expansion of small-scale farming, commercial farming and built-up areas. These findings are similar to the results of [58, 59] which reported that stream flow decreased while surface runoff increased due to the expansion of farmland and rapid deforestation of natural forests at the expense of grassland and shrubland.

Table 5. Changes in annual water balance due to LUCC scenarios.

Water balance components	*LULC_2002-2012*	*LULC_2012-2022*
Surface runoff [mma^{-1}]	17.84 (130.2)	21.64 (111.45)
Lateral flow [mma^{-1}]	-0.00092(-2.26)	-0.0023 (-5.78)
Groundwater flow [mma^{-1}]	-7.79 (-3.23)	-21.35(-9.2)
Water yield [mma^{-1}]	10.05 (4.15)	-40.81 (-16.2)
Deep aquifer recharge [mma^{-1}]	-29.01 (-34.6)	65.44 (119.3)
Evapotranspiration [mma^{-1}]	18.96(1.55)	-24.22 (-1.95)
Percolation [mma^{-1}]	-9.66 (-3.33)	-25.97 (-9.26)
Sediment yield (t/ha)	0.0016 (21.25)	0.0025 (28.33)
Discharge (m^3/s)	0.08 (2.76)	0.04(1.37)

Note: Brackets indicate percent change from the reference

Figure 6 shows the monthly changes in the water balance components specifically, ET, WYLD, LATQ and GWQ due to LULC scenarios in the catchment. In general, GWQ and LATQ showed a decrease across the months in the year in the catchment for the two LULC change periods.

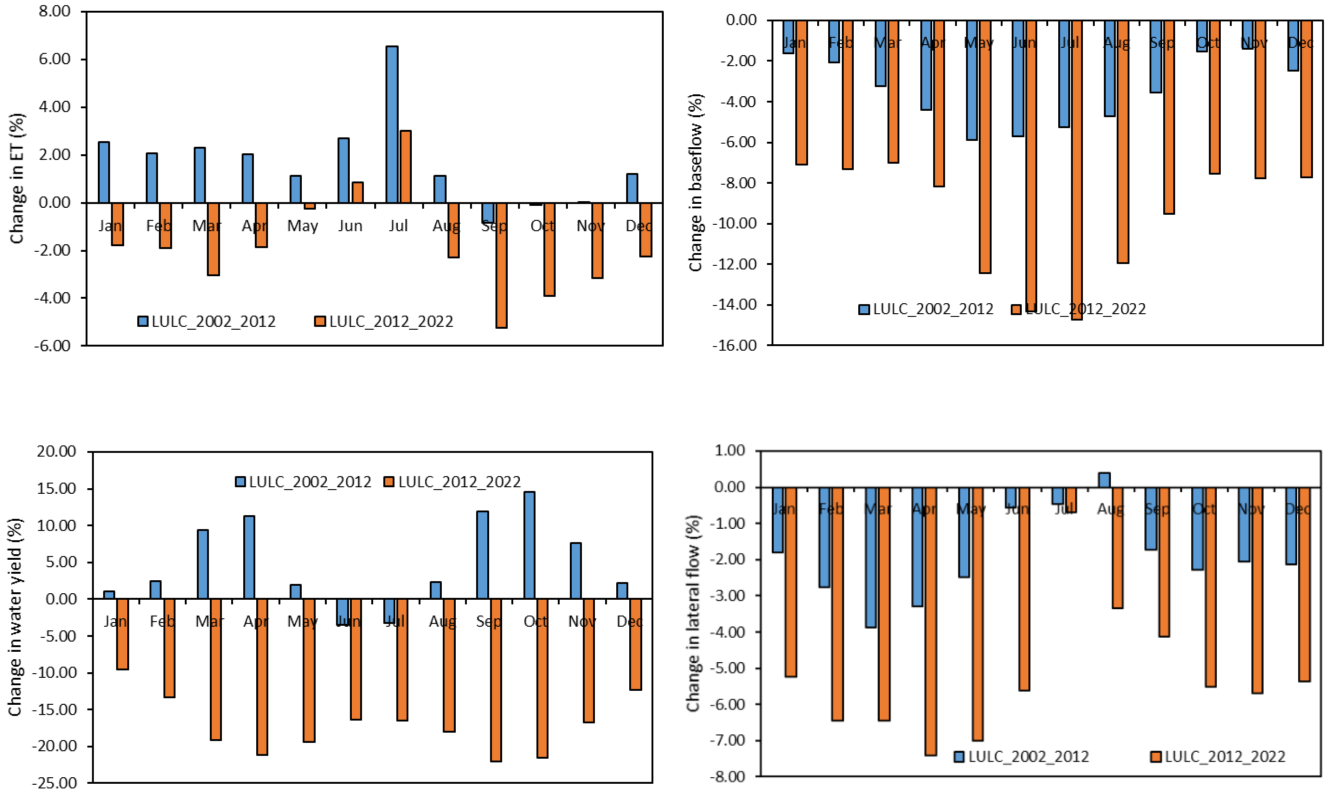

Figure 6. Monthly changes (%) in water balance components under different land use/cover scenarios.

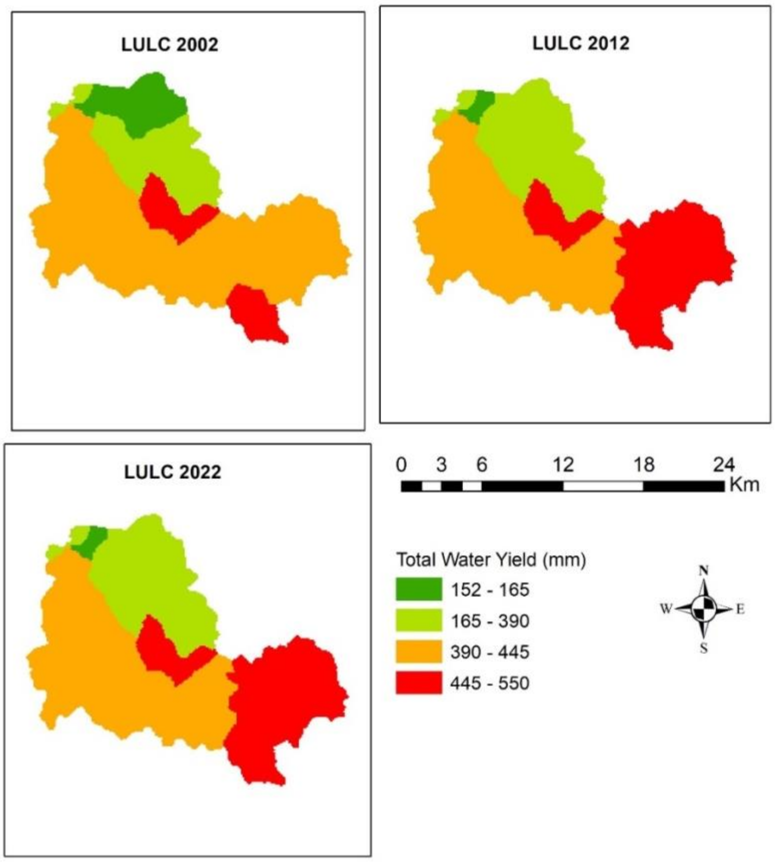

Figure 7. *Spatial distribution of water yield according to land use/cover scenarios.*

Figure 7 indicates the spatial changes in water yield due to LULC scenarios. The change in LULC for the periods 2002, 2012 and 2022 show impacts on the annual water yield within the catchment with the lower and upper right section of the sub-catchment being highly sensitive to LULC changes. Accordingly, annual water yields highly increased at the lower section from the LULC period of 2002 to 2012 although there was no observable change in water yield between the years 2012 and 2022. This indicates that LULC change from 2002 to 2012 had a greater impact on water yield than 2012 to 2022.

3.6. Impacts of LULC Change on Sediment Yield in Upper Ssezibwa Catchment

Sediment yield increased in the catchment for the two LULC change periods with the highest change of 28.3% (0.0025 t/ha) between the years 2012 and 2022 than that of 21.3% (0.0016 t/ha) for the years 2002 and 2012. Observed data equally indicate that sediment yield in the catchment was higher in the period 2012 – 2022 than in 2002 – 2012. The increase in sediment yield has resulted in the silting of the river channel making flooding possible in the lower part of the upper catchment and downstream. This finding amplifies the increased degradation of natural resources resulting from LULC change. This finding is in agreement with [60, 61] who observed that an increase in sediment yield in the Hatila Valley Natural Protected Area in Turkey and Mazowe catchment in Zimbabwe respectively was a result of LULC change and affected river flows leading to floods. Relatedly, [38] concluded that the increase in sediment yield in Muzizi River catchment in Uganda was a result of LULC.

Sediment yield showed an increase across the months with no significant difference between the LULC change periods (Figure 8). These results could be a consequence of other factors in the catchment especially increased amounts of rainfall. However, a mixed trend in the change is simulated for ET and WYLD for the two LULC change periods. In fact, an increase in ET and WYLD is simulated under the LULC change between the year 2002 and 2012 while a decrease in these processes is observed under the LULC change for the period of 2012 and 2022 across all the months of the years. This equally explains the increased water availability and eventual occurrence of floods observed by the communities in recent years that were not occurring in the past in the upper catchment and the downstream.

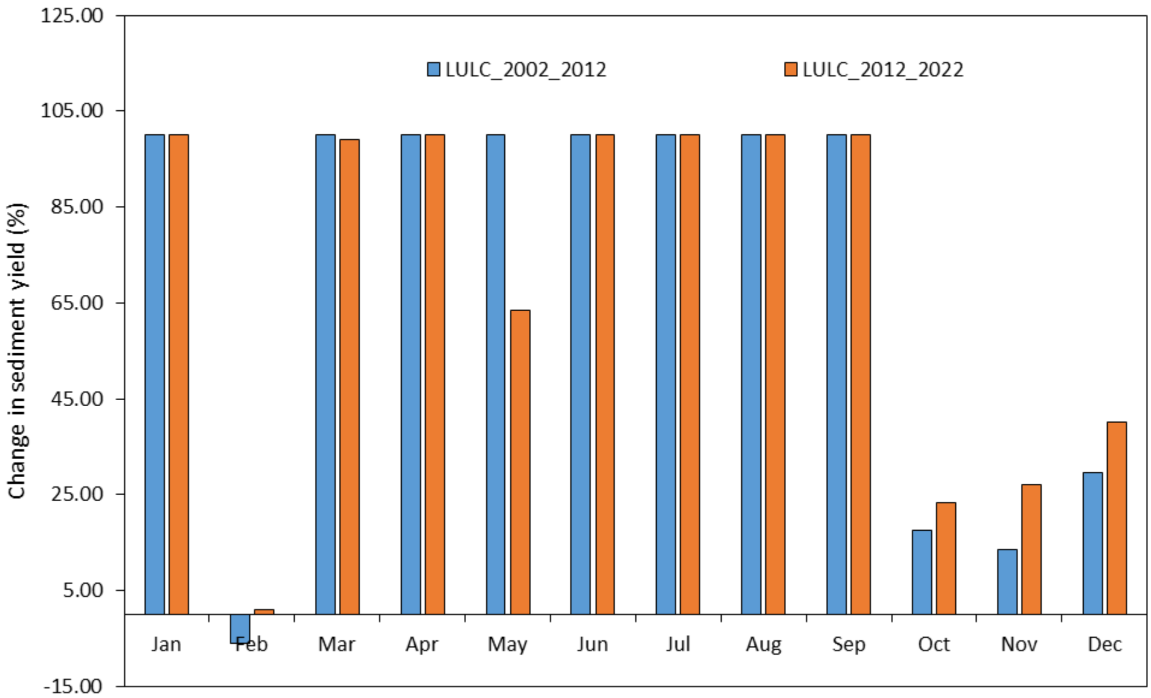

Figure 8. *Percentage change in sediment yield according to land use land cover scenarios.*

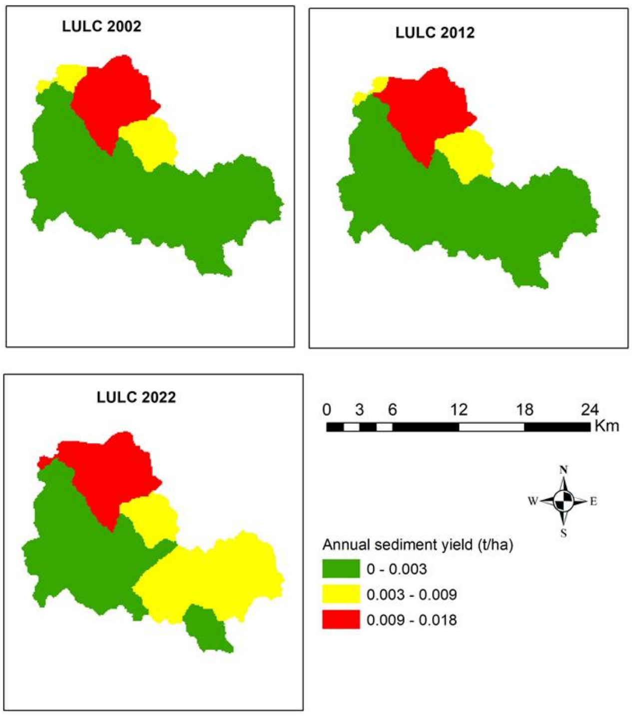

Figure 9. *Spatial distribution of sediment yield according to land use land cover changes.*

On the other hand, possible areas of eroded soil across the catchment were higher in the upper right section of the catchment, indicating a high degradation level in this section of the catchment (Figure 9). However, in the year 2022, sediment yield increased at the lower section of the catchment, showing an increase in vegetation degradation in the lower part of the catchment during this year compared to the previous years. Similar findings to the results of this study were reported by [62] in their study on the LULC change on stream flow and sediment yield of Gojeb watershed, Omo-Gibe basin, Ethiopia using the SWAT model who concluded that between 1989 and 2013 an increase in cultivated land by 14.97% and conversion of most parts of the forest land resulted into an increase in sediment yield and stream flow by 41.07-ton/km^2 and 8.6 m^3/s respectively. In addition, [63] study on modelling runoff- sediment response to land use/land cover changes using integrated GIS and SWAT model in Bewessa Watershed, Ethiopia between 1980-2015 found that changes in LULC significantly affect runoff and sediment yield.

4. Conclusion

The upper Ssezibwa catchment has undergone land use land cover changes over the last twenty years. The major changes have been the increase in built-up areas and small-scale farming while consistent decline of bushland, woodland, wetland and grassland has been recognized. The changes in land use land cover have been attributed to the increasing surface runoff and sediment yield in the catchment due to decline in infiltration capacity and poor natural resource management practices. The increase in sediment yield and surface runoff poses floods risks, loss of life and destruction of property. The government of Uganda should embark on sensitization and restoration of catchment ecosystem of human induced LULC changes to check sediment production and at the same time improve water retention capacity. Monitoring and enforcement of environment as well as sensitization of masses about sustainable environmental management should be prioritized to regulate the use of the environmental resources in catchment.

Abbreviations

DEM	Digital Elevation Model
ET	Evapotranspiration
FAO	Food and Agriculture Organisation
GSA	Global Sensitivity Analysis
GWQ	Ground Water Flow
HRUs	Hydrologic Response Units
KGE	Kling - Gupta Efficiency
LATQ	Lateral Flow
LULC	Land use land cover
MUSLE	Modified Universal Soil Loss Equation
NASA	National Aeronautics and Space Administration
NSE	Nash–Sutcliffe efficiency
OA	Overall Accuracy
PBIAS	Percent Bias
R^2	Coefficient of Determination
SRTM	Shuttle Radar Topography Mission
SUFI-2	Semi-automatic Sequential Uncertainty Fitting 2
SWAT	SWAT Soil and Water Assessment Tool
SWATCUP	SWAT Calibration and Uncertainty Procedures
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United states Geological Survey
UTM	Universal Transverse Mercator
WGS84	World Geodetic System -84
WRS	Worldwide Reference System
WYLD	Water Yield

Ethical Approval

No parts of the study that concern human and/or animal lab.

Author Contributions

Alex Ronald Mwangu: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing

Boniface Oindo: Conceptualization, Data curation, Formal Analysis, Methodology, validation, Writing – review & editing

Denis Masika: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Validation, Writing – review & editing

Data Availability Statement

All data generated and analyzed during this study are included in this published article.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Fields

Alex Ronald Mwangu: Earth surface processes, climate change, hydrology and water resource management, GIS and remote sensing, natural resources management

Boniface Oindo: Biogeography, environmental science, species distribution modeling, ecology, conservation and invasive biology, GIS and remote sensing

Denis Masika: Hydrology and water resource management, GIS and remote sensing, business analytics and machine learning, water quality monitoring, and hydrological and hydraulic modeling