Hydrology Research

Hydrology Research Vol 54 No 6, 756 doi: 10.2166/nh.2023.121

Land-use and land-cover change and its impact on flood hazard occurrence in Wabi Shebele River Basin of Ethiopia

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ABSTRACT

Land-use and land-cover (LULC) changes can impact hydrological conditions such as land surface coefficient, runoff, and infiltration. This study investigates the changes in LULC and its impact on water resources of the Wabi Shebele basin using the soil and water assessment tool (SWAT) and a separation method. Surface and groundwater parameters in the northwestern; and soil and surface parameters in the eastern highland and southern lowland parts of the basin are identified as sensitive parameters in water production. The coverage of cropland was increased by 48.63% while forest and woodland decreased by 49.14 and 14.76%, respectively, between the 1980s and 2010. Streamflow simulated during this period indicates increases in those watersheds showing significant cropland increases and forest coverage decreases particularly in Wabi at Dodola, Maribo, Robe, and Erer watersheds. Flood indices (i.e., AMAX, SMW, SMSp, and SMSu) calculated from simulated daily streamflow under different LULC map indicates an increase in the middle and northwestern watersheds up to 1.83 and 0.44%, respectively. The impact level of LULC change on flood discharge shows a comparable level with climate change impact on flood hazard, particularly in the middle part of the basin.

Key words: flood hazard, LULC change, sensitive parameters, separation method, SWAT model

HIGHLIGHTS

- LULC shows a significant decrement in the last three decades.
- SWAT parameters sensitivity varies at upper, middle, and lower parts of the basin.
- Soil and surface parameters are the most sensitive parameters in flow production in eastern and lowland areas.
- The impact of LULC on flood hazard is significant in the middle and northwestern parts of the basin.
- LULC has a comparable impact level with climate change in the middle.

1. INTRODUCTION

The hydrological cycle is the phenomenon of the water recycling system on the earth, which is in the oceans, atmosphere, land surface, biosphere, soil, and groundwater systems. Water contained in the sea and the land surface can evaporate into the air and move up into the atmosphere directly and through vegetation as a process of evaporation and transpiration, which occurs through condensation, clouds, and rain as a process of precipitation (Yulianto *et al.* 2020). Rainfall that falls to the ground surface becomes runoff, and some water will be infiltrated into the ground and become groundwater. The surface of the earth on which the hydrological cycle process occurs continuously is a 'watershed'. It is an area bounded by surface topography and drainage or river patterns. Rainfall that accumulates in the watershed will flow through drainage or river to an outlet on the earth's surface (Marshall 2014; Yulianto *et al.* 2020). The characteristics and conditions of watersheds can be explained by conditions of landforms on the surface of the earth that include the nature of landforms, genesis, processes, and material composition.

Land-use/land-cover (LULC) changes can impact the hydrological conditions, such as land surface coefficient, discharge, and hydrographic characteristics and affect the related runoff and infiltration characteristics and hydrological patterns in a watershed. Land use means the use to which the land is being put or the utilization of land devoted to human activities and land cover is the physical surface of the earth (Tali & Kanth 2011). Land cover is continually molded and transformed by land-use changes; for example, when a forest is converted to pasture or cropland. Land-use change is the proximate cause of land-cover change.

The rapid increase in the human population and the activities they undertake have consequences for LULC in terms of fulfilling their needs, both socially and economically. The water resources development in the current and future conditions is sensitive to LULC changes and the intensification of human activities (Liu *et al.* 2017; Kundzewicz *et al.* 2018; Sutfin & Wohl 2019). Different human activities exert an influence on the hydrological cycle and water resources. LULC in watersheds exhibit differences in hydrologic runoff response, which can be linked to flood events. Increased runoff because of LULC changes can affect the frequency of flooding, base flow, and annual average flow in such a way as to alter the hydrological cycle (Sutfin & Wohl 2019; Yulianto *et al.* 2020). The types of LULC by themselves exhibit differences in hydrologic runoff response, which can be linked to flood events. Loss of land floor cover, thinner forest canopies, grasslands, and reduced infiltration of rainfall resulted in a rapid hydrologic response and increased flood magnitudes and frequency (Sutfin & Wohl 2019).

In the last 40 years, a significant deforestation process occurred in East African countries. For instance, Hailemariam *et al.* (2016) analyzed that a large area of forest land decreased due to farmland and urban settlement expansion in the Bale Mountain Eco-Region of Ethiopia from 1985 to 2015. Similarly, over-exploitation of resources due to an increase in population and demand for food supply has caused land degradation in western Kenya (Githui *et al.* 2009). However, deforestation and land development for agriculture has not necessarily led to an equal increase in food production but have often led to land erosion in the upstream area and triggered heavy floods in the downstream areas as presented in Vandaele & Poesen (1995) and Adnan (2010). In the Wabi Shebele basin, the extent of shrublands indicates significant increasing trends, while grassland and cultivated area showed decreasing trends from 1984 to 2004 (MoWR 2004).

Flooding is one of the most frequently occurring types of natural disaster in the Wabi Shebele basin of Ethiopia (Admassu *et al.* 2010). In the river basin, the magnitudes and frequency of flood events in middle watersheds indicate an increasing trend in recent decades (Wudineh *et al.* 2021). In mountainous zones, increased potential for intense convective storms, increased cultivated land, and more highly confined river valleys result in more rapid runoff response to precipitation and cause flood risks. Flood events can cause problems such as the inundation of settlements, damage to infrastructure, disruption to community activities, health problems, and loss of life, and can create economic losses.

Understanding LULC changes in the Wabi Shebele basin is important in the decisions of land planning in the region since it can reflect the dimensions, potential impacts, and interactions of the relationship between human activity and the environment. Thus, this study aimed to analyze land use/land cover change and relate those changes to flood occurrences in terms of magnitude and frequency of flood in the Wabi Shebele basin.

2. MATERIALS AND METHODS

2.1. Study area

The Wabi Shebele River Basin (WSRB) is a transboundary basin between Ethiopia and the Republic of Somalia in the horn of Africa. It originates from the Bale Mountain ranges of the Galama and Ahmar of Ethiopia, about 4,000 m above sea level, and drains a portion of Somalia before draining to the Indian Ocean. About 72% of the catchment (202,220 km^2) is lying in Ethiopia. In this study, the Wabi Shebele basin is used to represent the catchment that is lying in Ethiopia within 4° N 45′ to 9° 45′ N latitude and 38° 45′ E to 45° 45′ E longitude (Figure 1). The watershed is divided into three geographical areas: the upper valley, which is characterized by a mountainous area with abrupt valleys; the middle valley, which is wider and rainy; and the lower valley, which is an arid lowland area. The areal distribution of rainfall varies from 271 mm at the lower arid portion (Gode) to 1,320 mm in the upstream highlands of the basin (Seru), out of which a major portion is discharged to streams as runoff. The spatial variability of temperature is significant with maximum and minimum values of 27.1 and 12.6 °C, respectively. While having the largest area coverage, the basin water yield is only 0.43 l/s/km^2, which is exceptionally low relative to other basins in Ethiopia (MoWR 2003; Awass 2009).

Poorly drained and shallow profile soils are distributed upstream of the basin and highly drained soils formed from limestone and gypsum are highly distributed over flat and gently undulating lands of the middle and downstream of the basin (MoWR 2003). Geologically, the basin falls into three major categories: Precambrian crystalline basement rocks in the northern and valleys of the upper tributaries main river, late–Paleozoic to Early Tertiary Sedimentary rocks in the southeastern sector of the Ogaden Sedimentary Basin and Tertiary to Quaternary Volcanic rocks in the most north western fringe of the basin. The land use and land cover in the basin is highly dependent on climatic, topographic and edaphic factors (MoWR 2004). Cultivated land units are dominated in the upstream part of the basin, whereas grasses and shrubs are common in the arid and semi-arid areas of the basin which cover more than 67.8% of the basin land use/cover (MoWR 2004).

2.2. LULC information

The input data for this study, comprising LULC maps information for 1986, 1997, and 2016, were collected from various sources (Table 1). Landsat Image was the principal source to delineate the land use/cover map of the basin in all maps. Satellite images taken at a scale of 1:250,000 were used for the interpretation of land use/cover in all sources. Landsat images are medium-resolution remote sensing tools that are used for land use and land cover change analyses. There are ten major

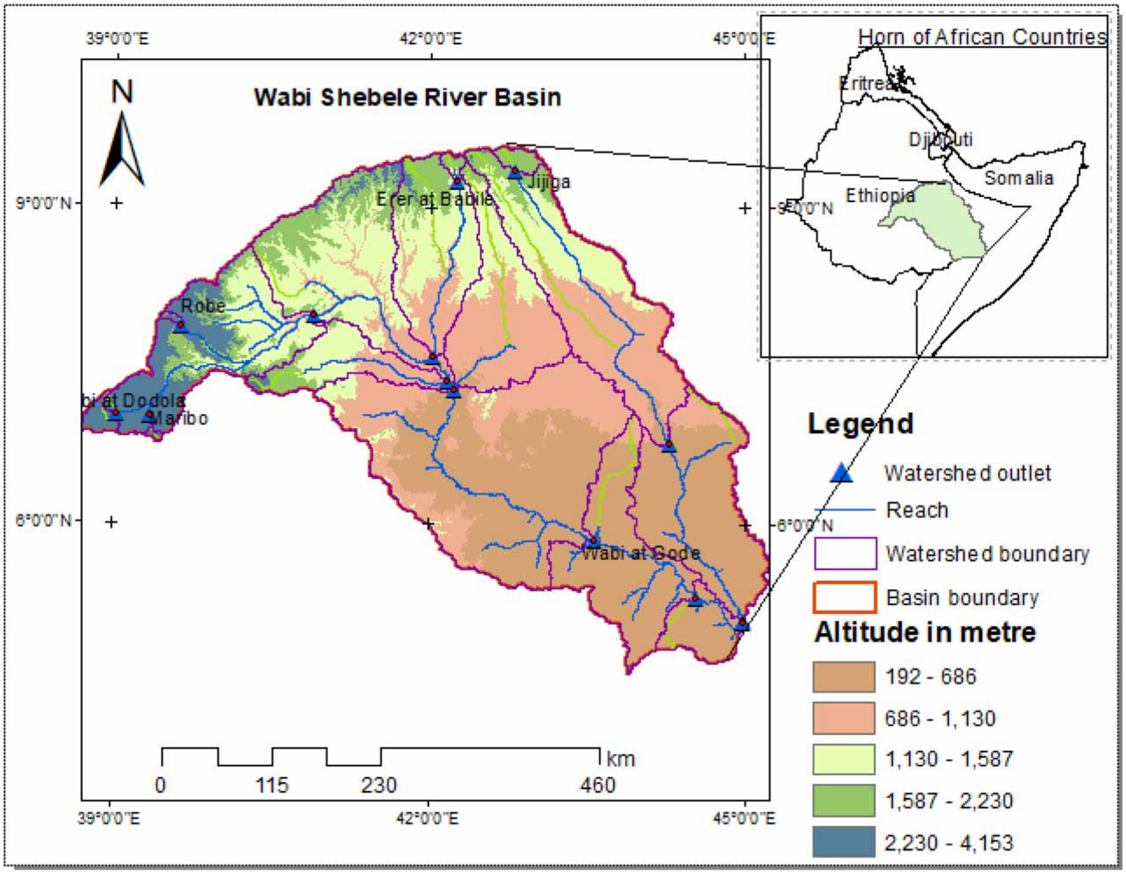

Figure 1 | Study area map.

Table 1 | LULC maps information, sources, and required parameter

Dataset	Resolution/ scale	Source	Required parameter
LULC map of 1986	1:250,000	Water and Land Resource Center (WLRC), Addis Ababa University, Ethiopia	Area (ha), LULC classes
LULC map of 1997	1:250,000	Ethiopian Ministry of Water, Irrigation and Energy (MoIE)	Area (ha), LULC classes
LULC map of 2016	1:250,000	Water and Land Resource Center (WLRC), Addis Ababa University, Ethiopia	Area (ha), LULC classes

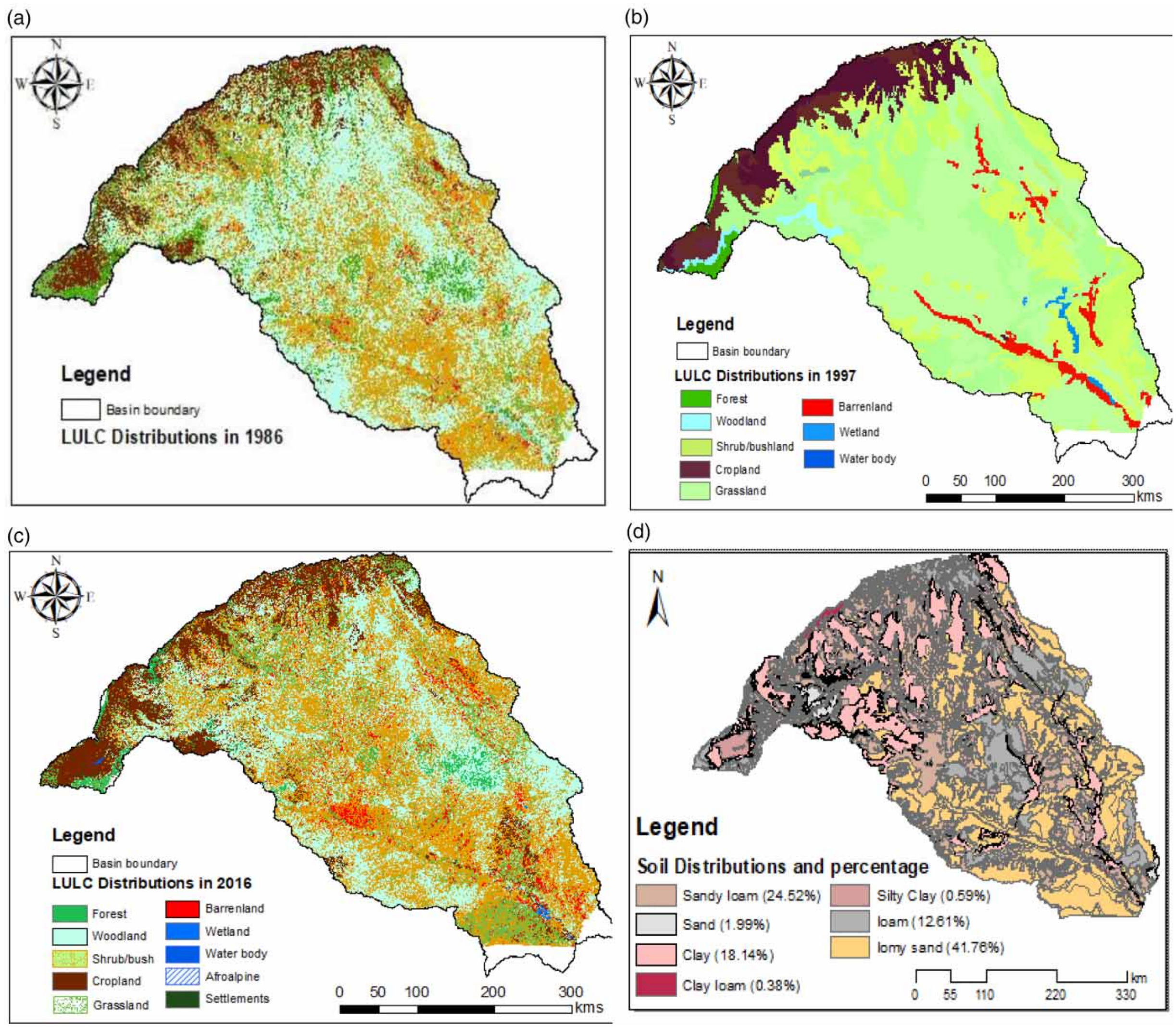

Figure 2 | Distributions of land use/land cover from 1986, 1997, and 2016 (a–c) and soil distributions (d) in the Wabi Shebele River basin (Source: WLRC).

Table 2 | Land use/land cover classification (%) of the Wabi Shebele basin in 1986, 1997 and 2016

Year	Forest	Woodland	Shrubland	Cropland	Grassland	Bare land	Wetland	Water body	Afroalpine	Settlement
1986	5.21	43.30	31.56	8.41	9.06	1.95	0.23	0.00	0.21	0.05
1997	0.71	1.13	28.20	12.41	42.74	14.08	0.55	0.01	0.15	0.07
2016	2.65	31.69	36.90	12.50	11.40	4.49	0.10	0.02	0.17	0.08

classes of LULC information identified in the Wabi Shebele basin. It is found that the main categories are shrubs, grassland, and agricultural land. The maps and classes are presented in Figure 2 and Table 2, respectively.

2.3. SWAT model and separation strategy

2.3.1. Soil and water assessment tool

Soil and water assessment tool (SWAT) is a physically based distributed hydrological model (Arnold *et al.* 1998; Neitsch *et al.* 2005; Abbaspour *et al.* 2007) that was developed by the United States Department of Agricultural Research Service to simulate the impact of land management practices on hydrology and water quality under complex watersheds with heterogeneous soil and land use conditions. In recent decades, it has been widely used for water cycle simulation and water resources management, especially for the analysis of streamflow variation under climate change and LULCC (Adamu 2014; Guo *et al.* 2016; Näschen *et al.* 2019). In addition, SWAT can also be used to predict the impact of future climate on the evolution of water resources and streamflow under different preset scenarios of climate (Schulze 2000; Camici *et al.* 2014; Gaur *et al.* 2020). The future climate conditions can be obtained from the general circulation models (GCMs) developed by the Intergovernmental Panel on Climate Change (IPCC) (Schulze 2000; Gaur *et al.* 2020), thus the effects of different future climate conditions can be further discussed for different drainage basins.

The SWAT model proceeds in two steps to simulate the hydrological cycle (Guo *et al.* 2016): runoff generation and its confluence in the river channels. To generate runoff, a watershed is firstly divided into several sub-basins, each of which is composed of one to several hydrological response units (HRUs) that consist of homogeneous land use, topographical, and soil characteristics. Threshold values for land use, soil types, and slope are set up to remove the insignificant land use, soil type, and slope in each sub-basin, thereby avoiding the generation of many HRUs. Next, the river network connects the discharge produced in sub-basins based on the water balance equation and water flows through the river channels and toward the basin outlet (Neitsch *et al.* 2005; Guo *et al.* 2016). The surface streamflow was calculated by a modified Soil Conservation Service (SCS) curve number method (USA_SCS 1972). The potential evapotranspiration and channel routing were estimated and simulated by the Penman–Monteith method and a variable storage method, respectively.

The optimum parameters of the SWAT model can be determined by sensitivity analysis, which assesses the sensitivity between a parameter and other parameters in different areas. Based on parameters available for water production identified by Arnold *et al.* (2012) and preliminary identification in the SWAT model, SWAT-CUP global sensitivity analysis is conducted to identify the most sensitive parameters for watersheds. The *p*-value and *t*-statistic are used to eliminate nonsensitive parameters from the calibration process. The higher the absolute value of the t-stat and the smaller the value of the *p*-value, the more sensitive is the parameter (Abbaspour *et al.* 2007; Moreira *et al.* 2018).

To evaluate the errors between the simulation results and measured streamflow data that may be introduced by the initial model structure and input data, the performance of the SWAT model can be evaluated based on the visual comparison and statistical criteria such as coefficient of determination (R^2), percent bias (PBIAS) and the Nash and Sutcliffe model efficiency coefficient (NSE). R^2 is the square of the correlation coefficient between the observed and modeled data and values greater than 0.5 are considered acceptable. PBIAS ranges between $-\infty$ and ∞, with 0 as an optimum value. NSE is a normalized statistic, that ranges from $-\infty$ to 1, used to indicate the relative value of residual variance compared to the variance of the observed data and values close to one show a perfect match of the modeled with the observed data (Nash & Sutcliffe 1970).

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{N} (X_i - Y_i)^2}{\sum_{i=1}^{N} (X_i - \bar{X})^2} \tag{1}$$

$$R^2 = \left[\frac{\sum_{i=1}^{N} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{N} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{N} (Y_i - \bar{Y})^2}} \right]^2 \tag{2}$$

$$\mathrm{Pbias} = \frac{\sum_{i=1}^{N} (Y_i - X_i}{\sum_{i=1}^{N} X_i} * 100 \tag{3}$$

where x and y are observed and modeled streamflow, respectively, N is the number of data pairs.

2.3.2. Separation method

In this paper, the SWAT model is combined with a separation method which is used to separate the contributions of LULC change and climate change to the streamflow as proposed by Guo *et al.* (2016). Simulation results and measured data under different conditions of climate and land use can be compared using this strategy. For instance, taking two conjoint periods (defined as periods I and II) and two land use conditions (defined as land use A and B) into consideration, four annual streamflows can be obtained under four conditions with different climate change and LULC change in the SWAT simulation, as follows: Q_1 for period I and land use A; Q_2 for period I and land use B; Q_3 for period II and land use A; Q_4 for period II and land use B. Therefore, the difference between Q_1 and Q_2 is caused by the different conditions of land use, defined as ΔQ_L, the difference between Q_1 and Q_3 is caused by the different conditions of climate, defined as ΔQ_C, and ΔQ is used to evaluate the difference caused by both climate and land use change, here the difference between Q_1 and Q_4 is used, and yields:

$$\Delta Q_L = Q_2 - Q_1 \tag{4}$$

$$\Delta Q_C = Q_3 - Q_1 \tag{5}$$

$$\Delta Q = Q_4 - Q_1 \tag{6}$$

$$\Delta Q_\mathrm{m} = Q_\mathrm{L} + Q_\mathrm{C} \tag{7}$$

Theoretically, $\Delta Q = \Delta Q_\mathrm{m}$. Subsequently, the impact of climate change on streamflow η_C and that of land use change η_L can be separately calculated by:

$$\eta_\mathrm{C} = \left(\frac{\Delta Q_\mathrm{C}}{\Delta Q_\mathrm{m}}\right) * 100\% \tag{8}$$

$$\eta_\mathrm{L} = \left(\frac{\Delta Q_\mathrm{L}}{\Delta Q_\mathrm{m}}\right) * 100\% \tag{9}$$

2.4. Flood indices

In this study the separation method is applied to extreme high flows since it focuses on the impact of LULC change on flood occurrence. Six extreme high flow indices (flood indices) are extracted from simulated streamflow under different climate change and LULC change conditions and the impact level of climate change and LULC change are analyzed in each index. These flood indices are: annual maximum discharge (AMAX), peak over the threshold (third quartile) frequency (POTF), peak over the threshold (third quartile) magnitude, seasonal maximum discharge for winter (SMW), seasonal maximum discharge for spring (SMSp), and seasonal maximum discharge for summer (SMSu) are used to define extreme high discharges.

In extreme value analysis ensuring the independence of samples is an initial task. In this study, the time interval approach is used to ensure the independence of flow discharges. Time intervals between 5 and 14 days between successive peaks; 5 days for catchments $<$10,000 km^2 and 14 days for catchments $\geq$10,000 km^2, are used. This approach is reported as a strong flood-frequency estimations approach (e.g., Malamud & Turcotte 2006; Keast & Ellison 2013).

3. RESULT AND DISCUSSION

3.1. Calibration and validation of SWAT model

In data-sparse watersheds, like Wabi Shebele River Basin, developing a representative hydrological model (e.g., in generating the observed streamflow) is challenging but it is a prerequisite to accurately assess variabilities in extreme flows. In this study, we used a combination of datasets to calibrate and validate the hydrological model. In addition to the field-based ground stations, some weather data like relative humidity, solar ratio, and wind speed data from Climate Forecast System Reanalysis (CFSR) climate data to improve the hydrological model accuracy during both calibration and validation.

In detail, the Wabi Shebele River Basin was divided into 14 sub-basins and 311 HRUs. To define HRUs, threshold values of 10% were chosen for land use/soil type and slope, respectively. Meteorological data from the period of 1988–2000 and land use data from 1997 were used for the calibration and validation of the SWAT model with 3 years warming period. Seven hydrologic stations were selected for calibration and validation in the basin. To evaluate the model performance, three parameters have been used, namely R^2 and NSE and P-bias, and are estimated as presented in Table 3.

Table 3 | Evaluation of model performance

Stations	Area (km^2)	Location		Average annual flow (mm^3)	Calibration			Validation		
		Lat	Long		R^2	NSE	P- bias (%)	R^2	NSE	P- bias (%)
Wabi at D/Bridge	1,040	7.01	39.02	230.9	0.74	0.74	−3.0	0.74	0.74	−2.1
Maribo	192	7.00	39.20	100.2	0.66	0.62	−18.5	0.55	0.47	−28.7
Robe	169	7.51	39.38	48.5	0.57	0.56	12.4	0.42	0.39	−20.8
Wabi at L/Hida	19,793	7.58	40.54	1,848.5	0.64	0.61	−0.87	0.62	0.65	−0.27
Erer	494	9.14	42.15	87.5	0.43	0.42	−4.3	0.11	−0.4	−53.6
Jijiga	731	9.21	42.48	35.4	0.41	0.40	11.2	0.02	0.16	−59.1
Wabi at Gode	124,108	5.56	43.33	4,523.2	0.40	0.20	−29.4	0.16	0.01	−37.6

3.2. Parameter sensitivity analysis

The sensitivity of the discharge to the model parameters was checked through global sensitivity analysis performed using SUFI-2 of SWAT-CUP out of 20 model parameters identified for streamflow prediction in literature (Neitsch *et al.* 2005; Narsimlu *et al.* 2015; Moreira *et al.* 2018). Based on the results obtained from the global sensitivity analysis, the first six parameters categorized as especially important and important were found to be sensitive (p-value < 0.05) in Wabi Shebele River Basin (Table 4). Griensven *et al.* (2006) classified parameters regarding their sensitivity based on their increasing hierarchical position of the parameters. They categorized parameters as especially important (1st), important (2nd–6th), slightly important (7th–14th), and not important (15th–20th). From Table 4, it is evident that there is a spatial distribution of parameters contributing to water production at three parts of the Wabi Shebele basin watersheds: at the northwestern highland, middle to the northeastern basin, and lower downstream of the basin. In the northwestern highland of the basin surface parameters (SLSUBBSN.hru, HRU_SLP.hru, CANMX.hru) and groundwater parameters (i.e., GWQMN.gw, RCHRG_DP.gw and GWREVAP.gw) are the most significant parameters in water production, in the middle and northeastern part of the basin soil parameters (i.e., ESCO.hru, SOL_K sol and SOL_Z.sol) and surface parameters (i.e., SLSUBBSN.hru and HRU_SLP.hru) are the most significant parameters and in the lower downstream part of the basin surface parameters (i.e., SLSUBBSN.hru, HRU_SLP.hru, CANMX.hru) and soil parameters (i.e., SOL_K sol and SOL_Z.sol) are the most significant water production parameters identified in this study.

3.3. Impacts of LULC change on flood occurrence

The effects of LULC change on streamflow were distinguished by simulations of multi-year daily catchment stream flows using 1986, 1997, and 2016 land covers, respectively, as presented in Table 5 and Figure 4. We used two different conditions to see the effects of land use and cover changes on streamflow: condition one, stream flow change under LULC change at small period of 12 years between 1986 and 1997; and condition two, stream flow change under LULC change prolonged period of 31 years in between 1986 and 2016.

3.3.1. Condition one: change in LULC between 1986 and 1997 and its impact on stream flow

During the 12-year period of LULC observation from 1986 to 1997 (Figure 3(a) and 3(c)), LULC was dominated by grassland, shrubland, bare land, and forest in the entire basin. Increases in LULC during this period occurred in grassland, cropland, and barren land. This LULC increases in three watersheds: Wabi at Dodola, Wabi at Lege Hidha, and Wabi at Gode. Exceptionally, the coverage of cropland increases in all sub-basins of the Wabi Shebele river basin during this period. However, the coverage of forest and woodland, and shrubland steeply decreased in this period. The coverage of the forest is significantly dropping in Erer watersheds (Figure 3(c)). Erer watershed is one of the major sub-basins which contributes many annual floods to the Wabi Shebele River basin (MoWR 2003). From Table 5, it is evident that flow simulated under condition one indicates increases in those watersheds' coverage of cropland increases and forest coverage decreases particularly in Wabi at Dodola, Maribo, Robe, and Erer watersheds. In the upper Wabi Shebele basin at Dodola watershed alone, annual streamflow increased by 7% when LULC changed from 1986 to 1997 land use map.

Table 4 | Sensitive parameters at watersheds

Station	Rank of parameter	Parameter	Fit	Minimum	Maximum	*t*-stat	*p*-value
Wabi at Dodola	1	V__SLSUBBSN.hru	108.68	81.81	130.52	11.03	0.00
	2	V__RCHRG_DP.gw	0.13	0.11	0.34	−6.09	0.00
	3	R__HRU_SLP.hru	0.53	0.19	0.56	−4.01	0.00
	4	V__CANMX.hru	0.05	0.00	1.57	−3.25	0.00
	5	R__SOL_K(..).sol	0.08	0.03	0.25	−3.04	0.00
	6	R__CN2.mgt	−0.07	−0.16	0.02	−2.21	0.03
Maribo	1	A__GWQMN.gw	−347.46	−659.74	21.60	−18.40	0.00
	2	V__ESCO.hru	0.99	0.71	1.00	7.65	0.00
	3	V__ALPHA_BNK.rte	0.21	0.00	0.45	7.09	0.00
	4	V__SLSUBBSN.hru	142.52	80.97	150.00	−4.06	0.00
	5	R__SOL_AWC(..).sol	−0.15	−0.16	0.01	−4.03	0.00
	6	V__CANMX.hru	2.57	1.91	7.30	−2.16	0.03
Robe	1	V__SLSUBBSN.hru	53.95	25.53	78.00	4.19	0.00
	2	V__CH_N2.rte	0.28	0.14	0.42	2.16	0.03
	3	V__ALPHA_BNK.rte	0.90	0.67	1.00	1.84	0.07
	4	V__RCHRG_DP.gw	0.02	0.00	0.28	1.56	0.12
	5	A__GWQMN.gw	−363.99	−1,000.00	−324.60	−1.25	0.21
	6	A__GW_REVAP.gw	0.00	−0.01	0.02	−1.19	0.23
Wabi at Lege Hida	1	R__SOL_AWC(..).sol	−0.02	−0.16	0.02	23.39	0.00
	2	V__SLSUBBSN.hru	140.29	125.20	150.00	9.09	0.00
	3	V__RCHRG_DP.gw	0.00	0.00	0.15	−8.57	0.00
	4	R__SOL_K(..).sol	−0.03	−0.07	0.07	−7.73	0.00
	5	R__HRU_SLP.hru	0.05	0.00	0.16	−7.17	0.00
	6	V__ESCO.hru	0.07	0.00	0.16	−2.87	0.00
Erer	1	V__ESCO.hru	0.04	0.00	0.27	−10.46	0.00
	2	R__SOL_Z(..).sol	0.20	0.06	0.24	7.84	0.00
	3	R__HRU_SLP.hru	0.01	0.00	0.32	−5.95	0.00
	4	V__RCHRG_DP.gw	0.54	0.02	0.55	−5.22	0.00
	5	V__SLSUBBSN.hru	99.11	77.07	125.52	5.15	0.00
	6	R__SOL_AWC(..).sol	0.21	0.12	0.25	3.78	0.00
Jijiga	1	R__SOL_Z(..).sol	−0.08	−0.11	0.03	7.35	0.00
	2	V__ESCO.hru	0.13	0.09	0.27	−5.75	0.00
	3	R__SOL_AWC(..).sol	−0.14	−0.21	−0.12	4.52	0.00
	4	V__SLSUBBSN.hru	144.51	118.84	150.00	3.78	0.00
	5	V__ALPHA_BF.gw	0.39	0.28	0.53	−2.34	0.02
	6	A__REVAPMN.gw	−8.13	−28.99	11.32	1.78	0.08
Wabi at Gode	1	V__SLSUBBSN.hru	140.81	112.98	150.00	24.01	0.00
	2	R__HRU_SLP.hru	0.21	0.00	0.32	−18.34	0.00
	3	R__SOL_K(..).sol	−0.25	−0.25	−0.11	−13.25	0.00
	4	V__CANMX.hru	2.77	0.00	3.33	6.13	0.00
	5	R__SOL_Z(..).sol	0.18	−0.07	0.19	4.05	0.00
	6	R__SURLAG.bsn	−0.10	−0.19	0.01	2.20	0.03

V is the existing parameter value to be replaced by a given value. R is the existing parameter value * (1 + a given value) whereas A represents an additional value to be added to the existing parameter value (Abbaspour *et al.* 2007).

3.3.2. Condition two: change in LULC between 1986 and 2016 and its impact on stream flow

In a prolonged period of 31 years of LULC observation from 1986 to 2016 (Figure 3(b) and 3(d)), LULC was dominated by woodland, shrubland, cropland, grassland, bare land, and forest in the entire basin. Increases in LULC during this period occurred in shrubland, cropland, grassland, and barren land whereas forest and woodland are LULC which show decreases in this period. The basic change in this condition is observed in shrubland coverage. Shrubland indicates increases in a prolonged period from 1986 to 2016 while it showed decreases during a small period between 1986 and 1997. But other LULCs follow similar trends as condition one.

Table 5 | Simulated average annual surface runoff (m^3/s) from 1986, 1997 and 2016 land use/land cover and changes under two conditions: condition one (in between 1986 and 1997) and condition two (in between 1986 and 2016)

		Condition one				Condition two			
S. No	Sub-basin	1986	1997	Change (m^3/s)	Percentage change (%)	1986	2016	Change (m^3/s)	Percentage change (%)
1	Wabi at Dodola	3.76	4.04	0.28	7	3.76	3.82	0.06	2
2	Maribo	2.59	2.68	0.09	3	2.59	2.58	−0.01	0
3	Robe	1.59	1.61	0.02	1	1.59	1.6	0.01	1
4	Wabi at Lege Hida	65.56	65.77	0.21	0	65.56	67.18	1.62	2
5	Erer at Babile	3.07	3.10	0.03	1	3.07	3.07	0.00	0
6	Jijiga	3.90	3.90	0.00	0	3.90	3.91	0.01	0
7	Wabi at Gode	1,215	1,197.05	−17.95	−1	1,215	1,214.67	−0.33	0

Out of the 10 LULC types analyzed in the study area, 3 of them, namely cropland, grassland, and, bare land, showed growth in both conditions. The coverage of cropland was increased by 47.56% in condition one and by 48.63% in condition two. Contrarily, the coverage of forest and woodland were decreased by 86.37 and 97.39%, respectively, between 1986 and 1997 (Figure 3(a)). Between 1986 and 2016, large areas of forest (49.14%) and woodland (14.76%) were converted to other LULC types (Figure 3(b)). Similarly, an IWMI (2015) study report indicates forest degradation in the western upper Wabi Shebele basin by an average annual deforestation rate of 0.25%. The recent data analysis in Bale Eco-Region (i.e., upper Wabi Shebele basin) indicates a reduction in forest area (forest, woodlands, Erica Forest) of about 2.3% between 2010 and 2014 (IWMI 2015). It is known that deforestation and forest degradation in Ethiopia are for the expansion of subsistence agriculture and grazing lands implies that the land use and land cover change over the middle and northern parts of the Wabi Shebele basin from the forest, woodland, grassland, and shrubland to agricultural land (cropland) is one of the causes of streamflow increases. The reduction of forest cover amplifies flood events, as more rainfall directly turns into runoff instead of being slowed down or buffered by forests (Bradshaw *et al.* 2007; IWMI 2015). In the northeastern downstream of the Wabi Shebele basin (Erer and Wabi at Gode watersheds) simulated streamflow did not show significant changes with land use change in both conditions as presented in Table 5 and Figure 4. Flood indices calculated from simulated daily streamflow under different land use and cover map indicate comparable situations with annual average flow variations in the basin. In the middle and northwestern basin flood indices like AMAX, SMW, MSp, SMSu, and volume of discharge indicate increasing as forest coverage indicates decreasing trends (Table 6).

3.4. Quantitative measure of the influence of LULC change and climate change on flood occurrence

The influence level of LULC change and climate change on the stream flow of the Wabi Shebele basin is estimated using the separation method. As presented in Table 7, the response of the streamflow to climate change is higher than that of LULC change in the Wabi Shebele basin. However, LULC change also has a significant impact on watersheds like Wabi at Lege Hida, Wabi at Dodola, Maribo and Robe. Annual maximum discharge (AMAX) decreases in watersheds where forest and shrubland coverage increases in the study period. For instance, in Wabi at Lege Hida and Erer watersheds, the magnitude of floods decreases while the coverage of forest increases in condition one. In north western watersheds like Wabi at Dodola, Maribo, Robe, and Wabi at Lege Hida flood discharge estimated using LULC of 2016 is greater than flood estimate using LULC of 1986 by 3.91, 2.33, 1.92, and 128.66 m^3/s and as a result, flood magnitude increases by 0.18, 1.83, 0.57, and 0.44% in watersheds, respectively. In Wabi at Gode watershed flood magnitude under condition one is greater than flood magnitude in condition two by a value of 1,285.18 m^3/s, which is contributed by both climate change and LULC, accounting for 105.12 and 5.12%, respectively. The results indicated that climate change is the major factor influencing the streamflow and flood values in Wabi Shebele River Basin in the period from 1980 to 2010, which is like the conclusion drawn by Akola *et al.* (2018).

4. CONCLUSION AND RECOMMENDATIONS

Land-use and land-cover (LULC) changes can impact hydrological conditions such as land surface coefficient, discharge, and hydrographic characteristics and can affect the related runoff and infiltration characteristics and hydrological patterns in a

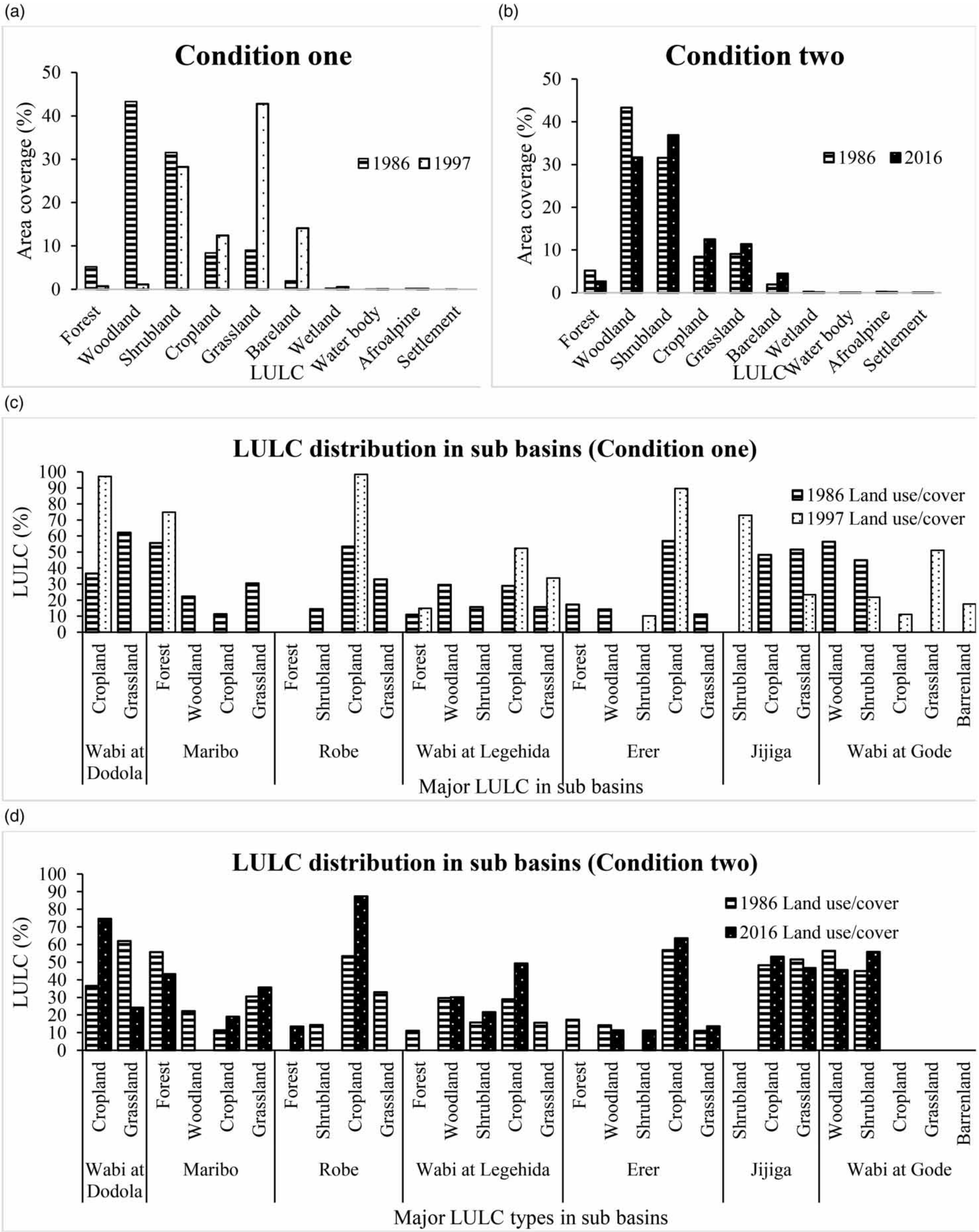

Figure 3 | Major LULC distribution in Wabi Shabelle basin and its sub-basins at two different conditions: condition one (a,c) in the small period between 1986 and 1997 and condition two (b,d) in the prolonged period between 1986 and 2016.

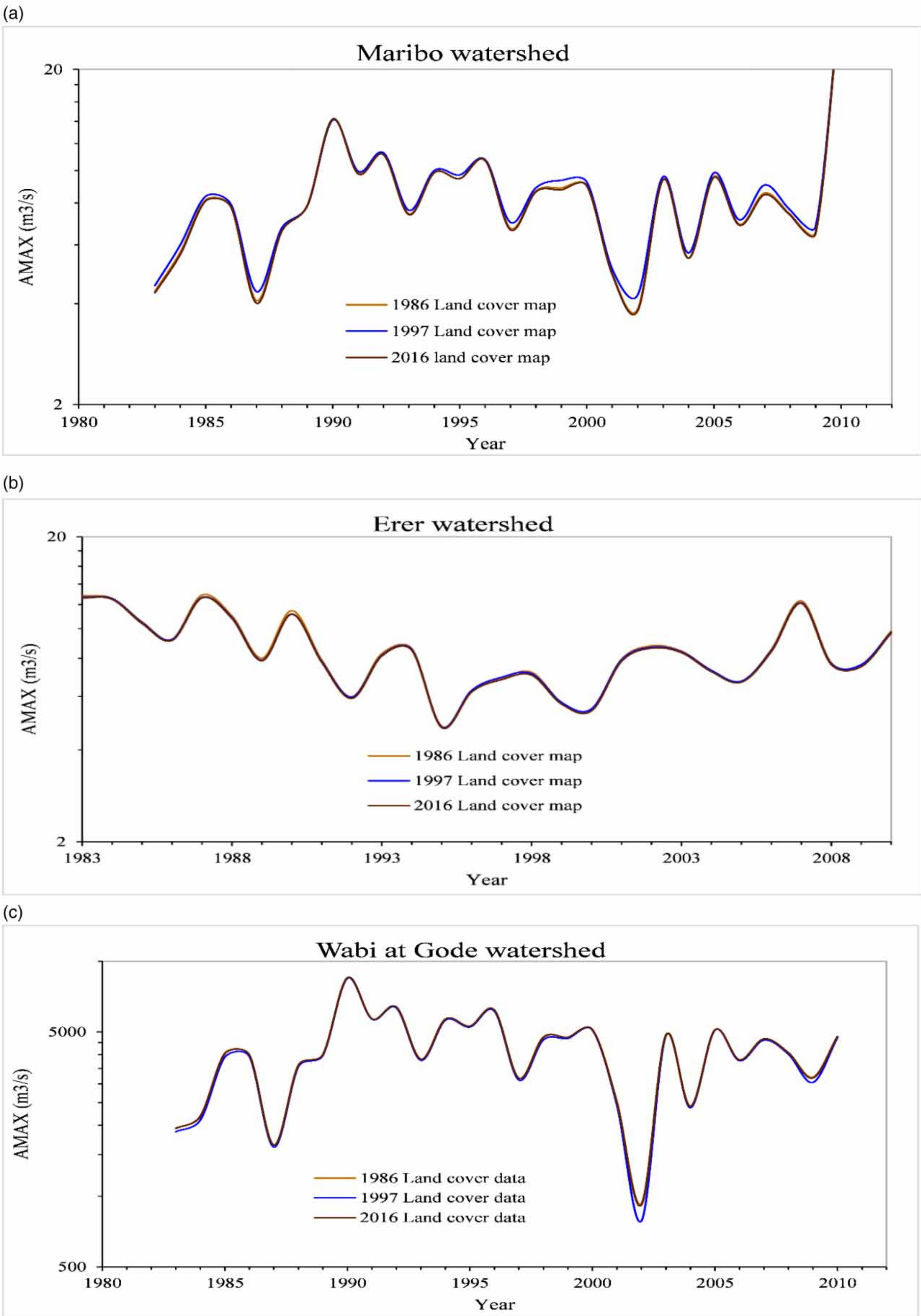

Figure 4 | Comparison of simulated maximum daily discharges for 1986, 1997, and 2016 land cover data at three gauging stations: (a) western upper basin (Maribo watershed), (b) eastern upper basin (Erer watershed), and (c) downstream lower basin (Wabi at Gode watershed).

Table 6 | Flood indices obtained from daily simulations for 1986, 1997 and 2016 land cover

Item	Maribo watershed			Wabi at Lege Hida watershed			Erer watershed			Wabi at Gode watershed		
	1986	1997	2016	1986	1997	2016	1986	1997	2016	1986	1997	2016
Maximum daily flow (m^3/s)	8.9	9.1	8.8	281	273	286	8.59	8.53	8.47	4,181	4,120	4,176
Seasonal maximum discharge for Winter (m^3/s)	2.7	2.8	2.7	68.1	70.5	70.8	3.20	3.23	3.22	1,459	1,454	1,462
Seasonal maximum discharge for Spring (m^3/s)	1.8	1.9	1.9	60.5	59.5	60.9	3.38	3.36	3.34	786	671	680
Seasonal maximum discharge for Summer (m^3/s)	5.9	6.2	5.9	161	158	164	5.96	5.97	5.91	2,782	2,828	2,881
Frequency of Peak over threshold (3rd quartile) (POTF)	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.00	95.0	95.0	95.0
Volume of discharge (BMC)	0.8	0.9	0.9	2.1	2.1	2.2	0.96	0.98	0.97	38.3	37.8	38.3

Table 7 | Impact of LULC and climate change on annual maximum streamflow in Wabi Shebele River Basin under two different conditions of climate and land use defined by the preset scenario

Sub-basin	Condition one (1980–1999)			Condition two (1980–2010)		
	Variation in AMAX (m^3/s)	Impact of LULC change (ηL) (%)	Impact of Climate change and others (ηc) (%)	Variation in AMAX (m^3/s)	Impact of LULC change (ηL) (%)	Impact of Climate change and others (ηc) (%)
Wabi at Dodola	1.86	2.55	**97.45**	3.91	0.18	**100.18**
Maribo	1.94	**6.45**	**93.46**	2.33	1.83	**101.83**
Robe	0.95	0.66	**99.34**	1.92	0.57	**100.57**
Wabi at Lege Hida	−14.37	**45.95**	**54.05**	128.66	**0.44**	**99.56**
Erer	−4.51	**3.07**	**96.63**	−2.71	**6.44**	**93.56**
Jijiga	−18.57	0.54	**100.54**	−12.31	0.11	**99.89**
Gode	1,285.18	5.12	**105.12**	−115.08	**3.37**	**96.63**

Bold number indicates the significance of drivers influences on streamflow.

watershed. The impact of land use and land cover on flood occurrence is investigated. To identify the most sensitive parameters to water production, the hydrological model is performed in this study. Furthermore, which share LULC and/or climatic changes cause the increase of flooding in the Wabi Shebele basin is answered partly by this study.

In Wabi Shebele basin parameters contributing to water production are spatially distributed over the basin at three different parts: at northwestern highland, surface and groundwater parameters (i.e., SLSUBBSN.hru, HRU_SLP.hru, CANMX.hru, GWQMN.gw, RCHRG_DP.gw, and GWREVAP.gw); at the north eastern and southern lowland parts of the basin, soil and surface parameters (i.e., ESCO.hru, SOL_K sol and SOL_Z.sol, SLSUBBSN.hru and HRU_SLP.hru) are the most sensitive parameters identified for water production. These parameters are directly and indirectly based on land use and land cover in the watersheds. For instance, CANMX.hru is maximum canopy storage (mm H_20) which can significantly affect infiltration, surface runoff, and evapotranspiration. The influence the canopy exerts on these processes is a function of the density of plant cover and the morphology of the plant species (Neitsch *et al.* 2005).

Out of the 10 LULC types analyzed in the study area, three of them, namely cropland, grassland, and bare land, showed growth in both short and long period conditions. The coverage of cropland was increased by 47.56% in condition one and by 48.63% in condition two. Contrarily, the coverage of forest and woodland decreased by 86.37 and 97.39%, respectively, between 1986 and 1997. Between 1986 and 2016, large areas of forest (49.14%) and woodland (14.76%) were converted to other LULC types mainly to cropland and shrub land. Streamflow simulated under condition one indicates that increases in those watersheds show significant cropland increases and forest coverage decreases particularly in Wabi at Dodola, Maribo, Robe, and Erer watersheds. In the upper Wabi Shebele basin at Dodola watershed alone, annual streamflow increased by 7% when LULC changed from 1986 to 1997 land use map. Flood indices (i.e., AMAX, SMW, SMSp, and SMSu) calculated from simulated daily streamflow under different land use and land cover map indicates an increase in watersheds located in the middle and north western part of the basin where most of the forest coverage decreases.

The influence level of LULC change and climate change on streamflow analyzed using the separation method indicates that climate change is the major factor influencing the streamflow and flood values in Wabi Shebele River Basin. However, LULC change also has a significant impact in middle and upper watersheds like Wabi at Lege Hida, Wabi at Dodola, Maribo, and Robe. In north western watersheds like Wabi at Dodola, Maribo, Robe, and Wabi at Lege Hida flood discharge estimated using LULC of 2016 is greater than flood estimate using LULC of 1986 by 3.91, 2.33, 1.92, and 128.66 m^3/s and as a result, flood magnitude increases by 0.18, 1.83, 0.57, and 0.44% in watersheds, respectively.

Separation was a useful approach to differentiate the impact level of LULC change from other potential drivers like climate change. Finally, I recommend a better determination of historical land-use changes in high-resolution hydrological rainfall–runoff models and validation of special hydrological parameters, which are capable of reproducing those land-use changes and their impact on flood conditions.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 12 November 2022; accepted in revised form 4 May 2023. Available online 22 May 2023