Impact of land use and land cover change on the magnitude of surface runoff in the endorheic Hayk Lake basin, Ethiopia

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Abstract

This study focused to analyze the main human-induced land use and/or cover changes and their impact on the response to surface runoff from the Hayk Lake endorheic basin between 1989 and 2015. The investigation of Landsat images of years 1989, 2000 and 2015 with the aid of ArcGIS 10.1 indicated an increase in cultivation land by 137.74% at the disbursement of a decrease of 1.34% in lake water, 49.48% in shrubland, 55.84% in plantation, and 17.32% in grassland. Overall accuracy (92%–96%) and kappa values (0.90–0.95) proved that the image classifications were accurate. The impact of the changed land use and/or cover on surface runoff was investigated by simulating the surface runoff for the years 1989, 2000 and 2015, and then quantifying the individual rate of contribution of land use and/or cover change on the magnitude of simulated surface runoff using HEC-HMS modeling tool. The analysis found that land use and cover change alone increased surface runoff by 20.18% and that climate change reduced surface runoff by 120.18%. The combined effect reduced surface runoff and caused a continued decline in water level at Hayk Lake. Therefore, this study advocated basin-based lake water management strategies linked to the negative impacts of land use and land cover, and climate change on the water balance of Hayk Lake for its sustainability.

Article highlights

- The major land use and cover changes undertaken in the endorheic Hayk Lake basin between 1989 and 2015 were detected and linked to changes in rainfall-runoff relationship using the HEC-HMS hydrological model.
- The simulation result indicated that the change in land use and cover raised surface runoff individually, but its combination with climate change had a negative impact on Hayk Lake's water level.
- Presented the scientific understanding of the integration of remote sensing, GIS, and the hydrological model at the local level can help to address the persistent threat of water level reduction in Hayk Lake.

Keywords Endorheic Hayk lake basin · Land use and cover change · Surface runoff · HEC-HMS model · Hayk lake water level

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1 Introduction

The progressing land use and cover (LU-LC) change induced by human beings is among the major factors responsible for water level changes of lakes as its change consequences changes in lake water balance components at a varying space and time dimensions [1, 2]. Ethiopia is a developing country where LU-LC change is intensified at a faster rate because of the fact that charcoal and firewood are the common sources of energy besides food and housing demands of the growing population [3–6]. Hence, in Ethiopia, the LU-LC change was mainly manifested by the conversion of forest land to agriculture and/or urbanization which influenced the hydrologic processes and consequently caused considerable water level fluctuations of lakes [7–9]. Hayk Lake basin, which is found in the northeastern Ethiopia has entertained the pronounced LU-LC changes of increased farmlands/settlement and shrublands; a decreased bush lands, grasslands, forestlands, and lake surface area during 1957–2007 [5]. However, the significance of the LU-LC change on the decrease in water surface area of Hayk Lake was the pending question that required attention and therefore, it became objective of this study.

The LU-LC change strongly influences the creation, progress, and concentration of surface runoff during hydrological transformation within the lake basin [10]. However, the relationship between LU-LC change and surface runoff is naturally complex as it also relies on other physical characteristics of a basin, such as the size, topography, and types of soils [11, 12]. Such kinds of hydrological problems with multitude relationships can be resolved through the use of hydrologic models like the Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) model with the integration of remote sensing and geographical information system [12, 13]. The HEC-HMS model is a powerful, widely applicable tool that is capable of solving wide ranges of hydrologic problems and also it is flexible, i.e., different combinations of model sets are possible for the loss, transform, routing, and baseflow separation methods based on the nature of the study [14]. Among the many alternative models under loss method package of the HEC-HMS, the soil conservation service- curve number (SCS-CN) loss method is the most relevant method to estimate the infiltration loss during the computation and modeling of surface runoff for small basins and local spatial scale studies [10]; even for those characterized by diverse LU-LC, soil, and physical conditions [15–17]. This is because of its simplicity and its capacity to offer results as good as those of complex models [18].

At various levels of space and time in Ethiopia, attempts have been made to calibrate and apply

HEC-HMS simulate runoff for different purposes [19–21] and they showed that the HEC-HMS model works well to simulate runoff in every climate zone in the country. However, rainfall-runoff modelling for the LU-LC impact assessment using the HEC-HMS model for the Hayk Lake basin has not yet been conducted. Thus, this study used remote sensing, geographic information system (GIS), and HEC-HMS in combination with HEC-GeoHMS and Arc-Hydro for rainfall-runoff modeling of Hayk Lake basin by adopting the SCS-CN method to assess the impact of LU-LC change on surface runoff between 1989 and 2015 to alleviate the declining water level problem of Hayk Lake in the endorheic lake basin. This provides a science-based understanding to set up a sound water management program for Hayk Lake which is jeopardized with the consistent water level reduction in the lake basin.

2 Materials and methods

2.1 Study area

The Hayk Lake basin is located in the northeastern part of Ethiopia, extending from 39.68°E to 39.81°E, 11.24°N to 11.39°N. Its total area is $85926.8 \times 10^3 \text{ m}^2$, of which $21,567.6 \times 10^3 \text{ m}^2$ is a lake. The Hayk Lake basin is naturally endorheic, where there is no water outflowing from it. Hayk Lake is a sink in the lake basin. Seventeen ephemeral streams in the upper catchment transport surface runoff and discharge it into the Hayk Lake (sink of the lake basin) through their individual outlets. Total surface runoff in the Hayk Lake was then obtained from the lake water level reading of a gauge on the southwest shore of the lake (Fig. 1). This gauge was used to run hydrological models in the lake basin to simulate total surface runoff at Hayk Lake. Simulation of this challenging lake basin hydrology may be the novelty of the study.

The sub-humid tropical climate with bimodal rainfall pattern (the long rainfall season from June to September and the short rainfall season, which lasts from March to May) characterizes the lake basin. The basin has 5 dry months from October to February. It received an average annual precipitation of 1.19 m, with an average annual temperature of 17.58 °C. The basin is also characterized by uneven topography with an elevation ranging from 1878 to 2817 m asl.

2.2 Data used

The datasets required to carry out this study were daily hydro climate (precipitation, temperature and water level) and Landsat images for the years 1989, 2000, and 2015;

Fig. 1 Map showing location and subbasins of Hayk Lake basin. (The subbasins and their associated stream networks for each outlet point were delineated in batch following terrain preprocessing of the DEM using Arc Hydro)

soil data, and Digital Elevation Model (DEM) data. The years 1989, 2000, and 2015 were chosen because of the lack of pre-1989 lake water level data and the adequacy of the time gap to perform LU-LC change analysis.

Only the Hayk Meteorological Station (11.31°N, 39.68°E; 1984 m asl) (Fig. 1) was a source of daily climate data. It was chosen for 3 reasons. Its proximity to Hayk Lake provides measured data that are almost the same as the actual data received by the lake and surroundings. It contains sufficient historic climate data for this study and an adequate density of meteorological stations (85.93 square kilometer per station) to adequately represent the Hayk Lake basin as per the WMO recommendation: 300–1000 square kilometer per station in mountainous regions of temperate, Mediterranean and tropical zones [22].

The Hayk Lake water level (LWL) time series for the years 1989, 2000 and 2015 was collected from the gauge situated on the southwest shore of Hayk Lake (Fig. 1). The daily LWL data were used to estimate surface runoff for calibrating and validating the HEC-HMS model. In the absence of inflow of natural water sources (such as springs) to the lake and any nonnatural diversion of water into the lake and/or out of the lake, the surface runoff is calculated from the water balance equation of endorheic or terminal lakes as shown in Eq. (1) [23].

$$\Delta H = P + Q - PET \quad (1)$$

where ΔH is the change in lake water level; P is precipitation on the lake; Q is surface runoff; PET is the lake evapotranspiration or potential evapotranspiration.

The Landsat image Multispectral Scanner (MSS) acquired on 21 November 1989, Thematic Mapper (TM) image on 28 January 2000, and Enhanced Thematic Mapper Plus (ETM+) on 29 January 2015 were obtained from the archiving system of Earth Explorer (<http://earthexplorer.usgs.gov/>) to generate the LU-LC map. The Hayk Lake basin was entirely covered by a single image of Landsat that did not display any spatial asymmetry with the basin meteorological station.

The soil data for the Hayk Lake basin were extracted from the FAO soil shapefile of the Amhara region (a region where the study area is located). It was used to obtain the Hydrologic Soil Group (HSG) data that assisted in the curve number calculations.

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a spatial resolution of 20 m was used to delineate subbasins and stream networks in the basin and to extract their physical features.

The tools employed for the analysis were ArcGIS 10.1 to determine the topographic features from DEM, LU-LC maps from Landsat images, and HSGs from soil data; Arc Hydro 1.0 beta 2 to delineate subbasins and their associated streams in batch following preprocessing the DEM; HEC-GeoHMS 10.1 to estimate the model parameters (CN, lag time, and initial abstraction) from physical properties of subbasins and streams, LU-LC maps, and

soil data; and HEC-HMS 4.0 to calibrate and validate model parameters using initial model parameters, daily precipitation, and daily surface runoff. The calibrated HEC-HMS model was then used to simulate surface runoff and quantify the impact of the LU-LC change on the magnitude of surface runoff.

2.3 Methods of data analysis

The research methodology is summarized according to the conceptual framework presented in Fig. 2.

2.3.1 Classifying landsat images of Hayk Lake basin

The LU-LC maps of the lake basin were produced from Landsat images using ArcGIS 10.1 software. The maximum likelihood supervised classifier classified the images [24]. The LU-LC classes were categorized into five types, including water body (lake), shrubland, plantation, cultivation, and grassland. The accuracy of the classification was evaluated using the overall accuracy (OA) and kappa coefficient derived from the error matrix [25, 26]. Overall accuracy is the ratio of the total number of correctly classified pixels to the total number of sample data, while the KAPPA coefficient is computed from Eq. (2) [26].

Fig. 2 Conceptual framework of the research methodology

$$\hat{K} = \left(N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} \cdot x_{+i}) \right) / \left(N^2 - \sum_{i=1}^r (x_{i+} \cdot x_{+i}) \right) \quad (2)$$

where r is number of rows and columns in error matrix; N is total number of observations (pixels); x_{ij} is the number of observations in row i and column j ; x_{i+} is marginal total of row i , and x_{+i} is marginal total of column i . [27] indicated that the minimum level of interpretation accuracy should be at least 85%.

2.3.2 Estimating model parameters of the lake basin

The physical characteristics of subbasins (basin slope, longest flow path, basin centroid, centroid elevation, and centroidal longest flow path) and streams (river length, upstream and downstream elevations, and river slope) were extracted from terrain data using HEC-GeoHMS. HEC-GeoHMS used these data with LU-LC and soil data to generate the model parameters (CN, lag time, and initial abstraction) in each subbasin of the lake basin. The model parameters of the lake basin, daily precipitation, and daily observed surface runoff were used to calibrate and validate the HEC-HMS model. The calibrated HEC-HMS model was used to simulate surface runoff and quantitatively assess the impact of LU-LC on surface runoff.

2.3.3 Runoff simulation using HEC-HMS modeling tool

The four model components of HEC-HMS known as basin models, meteorologic models, control specifications, and input data should be first created properly to execute simulation and interpret results of simulation [13]. The subbasin hydrologic element of the basin model was used for runoff simulation. The meteorologic model links the daily precipitation input time series (in this case, time series of years 1989, 2000, and 2015) to the subbasin hydrologic element. The control specification model controls the start and end dates of the simulation and the time interval of the simulation. The simulation time interval must be less than 29% of lag time for a satisfactory definition of the ordinates on the rising limb of the SCS Unit Hydrograph (SCS UH) [28]. A simulation time interval of 15 min was therefore set for this study.

Methods to assess the impact of LU-LC on the magnitude of surface runoff in 1989, 2000, and 2015 in the endorheic lake basin were the loss method and the transformation method. The SCS-CN loss model defines the rainfall-runoff relationship based on Eq. (3) to determine the infiltration loss of the lake basin.

$$Q = (P - I_a)^2 / (P - I_a + S) \quad (3)$$

where Q is precipitation excess in mm; P is total rainfall in mm; S is potential maximum soil moisture retention in mm and I_a is initial abstraction of rainfall in mm. Taking $I_a = 0.2S$ and substituting in Eq. (3), it gives:

$$Q = (P - 0.2S)^2 / (P + 0.8S), P \geq 0.2S \quad (4)$$

$$S = (24500 / CN) - 254 \quad (5)$$

CN is a dimensionless parameter that is dependent on the LU-LC class, HSGs, and the antecedent soil moisture condition (AMC). The AMC is the wetness condition of the soil based on total precipitation 5 days antecedent to the storm [29]. In practice, CN values range from 100 for water bodies to about 30 for permeable soils with high infiltration rates [30]. The weighted average CN (CN_w) value of the basin can be calculated using Eq. (6).

$$CN_w = \left(\sum_{i=1}^n CN_i A_i \right) / A \quad (6)$$

where i is an index of the basin subdivisions of uniform LU-LC and soil type; CN_i is the CN for subdivision i ; and A_i is the basin area of subdivision i .

The SCS UH then transforms the precipitation excess to produce direct runoff hydrograph in which the hydrograph is scaled by the parameter called lag time to produce unit hydrograph. A negligible baseflow is assumed in the absence of net ground flow data around the lake [31]. The basin lag time (T_{lag}) of each subbasin in the lake basin is highly related to the characteristics of the main stream (length, slope, and roughness) as shown in Eq. (7) [32].

$$T_{lag} = 0.0057 \left(\frac{100}{CN} - 9 \right)^{0.7} \frac{L^{0.8}}{\sqrt{S}} \quad (7)$$

where L denotes the longest stream flow path in kilometers and S is the average basin slope in m/m. On the other hand, in a basin with a more or less uniform runoff distribution, lag time can be related to time of concentration (T_c) as follows:

$$T_{lag} = 0.6T_c \quad (8)$$

2.3.4 Sensitivity analysis

The sensitivity of the model parameters (SCS CN, initial abstraction, and lag time) on the runoff volume, peak discharge, and time to peak runoff characteristics were analyzed using HEC-HMS. The initial parameter values were used as base values for the evaluation and one parameter at a time was analyzed between $\pm 20\%$ ranges at 5% intervals while the other parameters were held constant.

The $\pm 20\%$ range was chosen because the estimated initial CN values were 80 and greater, which can reach a maximum of 100. The absolute average sensitivity index is a value used to rank parameters based on their sensitivity status, from the most to the least sensitivity to model output. It is calculated on the basis of the sensitivity index [33] by:

$$R_p = \frac{1}{n} \left(\sum_{i=1}^n |S_i| \right) \quad (9)$$

$$S_i = (I_{avg}/I_2 - I_1) (O_2 - O/O_{avg}) \quad (10)$$

where S_i is the sensitivity index; O_1 is the model output value corresponding the smallest input value (I_1); O_2 is the model output value corresponding the largest input value (I_2); I_{avg} is the average of I_1 and I_2 ; O_{avg} is the average value of O_1 and O_2 . In this study, the I_1 and I_2 values are $\pm 20\%$ for a given parameter.

2.3.5 HEC-HMS calibration and validation

The daily precipitation and observed surface runoff from 01 January to 31 August of the years 1989, 2000, and 2015 were used to calibrate a model and the values from 01 September to 31 December of the same years were used for validating a model. The univariate gradient search algorithm and the peak weighted root mean square error (PWRMSE) objective function were used to optimize the model parameters. The objective function PWRMSE is expressed [13] as:

$$PWRMSE = \sqrt{\frac{\sum_{t=1}^N (Q_0(t) - Q_s(t))^2 \frac{Q_0(t) + Q_a}{2Q_a}}{N}} \quad (11)$$

$$Q_a = \frac{1}{N} \sum_{t=1}^N Q_0(t) \quad (12)$$

where $Q_0(t)$ and $Q_s(t)$ are respectively the observed and simulated flows at time t , and Q_a is the average observed flow [34]. Using a weighting factor, the PWRMSE measure gives a greater overall weight to error near the peak discharge. It implicitly measures the comparison of peak values, volumes, and peak times of the two hydrographs [13].

The performance of the model was assessed by visual hydrograph comparison and use of the goodness of fit measures. The known goodness of fits in HEC-HMS tool version 4.0 are mean absolute error (MAE), root mean square error (RMSE), and Nash Sutcliffe efficiency (NSE).

$$MAE = \frac{1}{N} \sum_{i=1}^N |O_i - S_i| \quad (13)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (O_i - S_i)^2} \quad (14)$$

NSE evaluates the overall model performance [35] and it is defined based on Eq. (15).

$$NSE = 1 - \left(\sum_{i=1}^N (O_i - S_i)^2 / \sum_{i=1}^N (O_i - \bar{O})^2 \right) \quad (15)$$

The performance ratings of NSE recommended by [36] are very good for $0.75 < NSE \leq 1.0$; good for values $0.65 < NSE \leq 0.75$; satisfactory for $0.50 < NSE \leq 0.65$ and unsatisfactory for $NSE \leq 0.50$.

2.3.6 Contribution of land use and cover change to surface runoff generation

The HEC-HMS used the historical scenario simulation method to separate the contribution of LU-LC change from the combined LU-LC and climate change effects on surface runoff generated in the lake basin [37]. Precipitation variation is the prominent and the only climate factor to significantly affect runoff and all other elements of water balance [38]. Therefore, 12 scenarios were developed by combining different LU-LC and precipitation data to separate the contribution rate of LU-LC change from climate change as shown in Table 1.

The scenarios created were used to determine the rate of impact of LU-LC change (L) and climate change (C) on

Table 1 Scenarios used for quantitative impact analysis

Scenarios	LU-LC data	Precipitation data	Simulated annual runoffs (Qs)
1	1989	1989	Q1
2	1989	2000	Q2
3	2000	1989	Q3
4	2000	2000	Q4
5	2000	2000	Q5
6	2000	2015	Q6
7	2015	2000	Q7
8	2015	2015	Q8
9	1989	1989	Q9
10	1989	2015	Q10
11	2015	1989	Q11
12	2015	2015	Q12

the generation of surface runoff in the Hayk Lake basin as shown below.

- (i) Calculating the contribution rate between 1989 and 2000 based on the 1989 reference period

$$L_{1989-2000} (\%) = ((Q_3 - Q_1) / (Q_4 - Q_1)) \times 100\% \quad (16)$$

$$C_{1989-2000} (\%) = ((Q_2 - Q_1) / (Q_4 - Q_1)) \times 100\% \quad (17)$$

- (ii) Calculating the contribution rate between 2000 and 2015 based on the 2000 reference period

$$L_{2000-2015} (\%) = ((Q_7 - Q_5) / (Q_8 - Q_5)) \times 100\% \quad (18)$$

$$C_{2000-2015} (\%) = ((Q_6 - Q_5) / (Q_8 - Q_5)) \times 100\% \quad (19)$$

- (iii) Calculating the contribution rate over the study period based on the 1989 reference period

$$L_{1989-2015} (\%) = ((Q_{11} - Q_9) / (Q_{12} - Q_9)) \times 100\% \quad (20)$$

$$C_{1989-2015} (\%) = ((Q_{10} - Q_9) / (Q_{12} - Q_9)) \times 100\% \quad (21)$$

3 Results

3.1 The land use and cover mapping and change analysis

Five LU-LC classes (water body, shrubland, plantation, cultivation and grassland) were produced using Landsat images for the years 1989, 2000, and 2015. To assess the accuracy of the classification, 170 observations were used, covering 20, 30, 30, 50, and 40 points of the lake, shrubland, plantation, cultivation, and grassland respectively. The ground truth data were collected with reference to the previous topographic map (scale 1: 50,000), regional LU-LC maps and Google Earth. Most importantly, the good knowledge of the researchers in the study area ensured that historical data were easily obtained for each year 1989, 2000 and 2015. The error matrix was used to determine the overall and kappa accuracies (Tables 2, 3, 4). It

Table 2 Classification accuracy (1989)

		Reference data					Row total	User's accuracy
		Lake	Shrubland	Plantation	Cultivation	Grassland		
Classified data	Lake	20	0	0	0	0	20	100
	Shrubland	0	25	3	0	2	30	83
	Plantation	0	5	27	0	0	32	84
	Cultivation	0	0	0	48	1	49	98
	Grassland	0	0	0	2	37	39	95
Column total	20	30	30	50	40	170		
Producer's accuracy	100	83	90	96	93			
OA						92		
Kappa						90		

Table 3 Classification accuracy (2000)

		Reference data					Row total	User's accuracy
		Lake	Shrubland	Plantation	Cultivation	Grassland		
Classified data	Lake	20	0	0	0	0	20	100
	Shrubland	0	27	2	2	0	31	87
	Plantation	0	3	28	0	0	31	90
	Cultivation	0	0	0	47	2	49	96
	Grassland	0	0	0	1	38	39	97
Column total	20	30	30	50	40	170		
Producer's accuracy	100	90	93	94	95			
OA						93		
Kappa						93		

has been identified that out of the 170 points collected, 157 in 1989, 160 in 2000 and 163 in 2015 were classified correctly showing an overall accuracy of 92%, 93% and 96%; and a Kappa coefficient of 0.90, 0.93, and 0.95 respectively for the 3 years. This indicates a high degree of agreement between the classified LU-LC and the ground truth data. Accordingly, the LU-LC maps produced were correct and adequate for further analysis.

The spatial coverage and change patterns of the LU-LC types are shown in Tables 5 and 6 and Fig. 3. During 1989–2000, there was a reduction in shrublands from 13,318.7 to 4210.4 $\times 10^3$ m² (68.39%), plantation

from 21,266.9 to 11,875.1 $\times 10^3$ m² (44.16%), grassland from 14,092.0 to 9503.5 $\times 10^3$ m² (32.56%), and lake water from 21,859.8 to 21,619.2 $\times 10^3$ m² (1.10%). Conversely, cultivation land increased from 15,389.5 to 38,718.6 $\times 10^3$ m² (151.59%). Between 2000 and 2015, cultivation land decreased by 5.5%, plantation by 20.91% and lake water by 0.24%. However, shrubland and grasslands increased to 59.8% and 22.6% respectively over 15 years, from 2000 to 2015. Over the 1989–2015 period, shrublands decreased by 49.48%, plantation by 55.84%, grassland by 17.32% and lake water by 1.34%. In contrast, the cultivation land was increased by 137.74%.

Table 4 Classification accuracy (2015)

		Reference data					Row total	User's accuracy
		Lake	Shrubland	Plantation	Cultivation	Grassland		
Classified data	Lake	20	0	0	0	0	20	100
	Shrubland	0	27	2	0	0	29	93
	Plantation	0	2	28	0	0	30	93
	Cultivation	0	0	0	49	1	50	98
	Grassland	0	1	0	1	39	41	95
Column total	20	30	30	50	40	170		
Producer's accuracy	100	90	93	98	98			
OA						96		
Kappa						95		

NB: The bold numbers along the diagonals in Tables 2, 3 and 4 denote points that have been appropriately categorized using reference data

Table 5 Spatial coverage of land use and cover classes of Hayk Lake basin

S. no	List of classes	Covered area and the corresponding percentage					
		1989		2000		2015	
		($\times 10^3$) m ²	(%)	($\times 10^3$) m ²	(%)	($\times 10^3$) m ²	(%)
1	Lake	21,859.8	25.44	21,619.2	25.16	21,567.6	25.10
2	Shrubland	13,318.7	15.50	4210.4	4.90	6728.1	7.83
3	Plantation	21,266.9	24.75	11,875.1	13.82	9391.8	10.93
4	Cultivation	15,389.5	17.91	38,718.6	45.06	36,587.6	42.58
5	Grassland	14,092	16.40	9503.5	11.06	11,651.7	13.56
	Total	85,926.8	100	85,926.8	100	85,926.8	100

Table 6 Change pattern in land use and cover classes of Hayk Lake basin

S. No	List of classes	Change pattern in land use and cover classes					
		1989–2000		2000–2015		1989–2015	
		($\times 10^3$) m ²	(%)	($\times 10^3$) m ²	(%)	($\times 10^3$) m ²	(%)
1	Lake	– 240.6	– 1.10	– 51.6	– 0.24	– 292.2	– 1.34
2	Shrubland	– 9108.3	– 68.39	2517.7	59.80	– 6590.6	– 49.48
3	Plantation	– 9391.8	– 44.16	– 2483.3	– 20.91	– 11,875.1	– 55.84
4	Cultivation	23,329.1	151.59	– 2131	– 5.50	21,198.1	137.74
5	Grassland	– 4588.5	– 32.56	2148.2	22.60	– 2440.3	– 17.32

Fig. 3 LU-LC map of Hayk Lake basin for years (a) 1989 (b) 2000 (c) 2015

3.2 Soil data of Hayk Lake basin

Soil texture classes of the lake basin are shown in Fig. 4. They were grouped into HSG B and HSG D according to infiltration rate criteria (Fig. 5). HSG B soils have moderate runoff potential, while HSG D soils have high runoff

potential due to low infiltration rates. The textural classes of loam, silty loam, and sandy loam are predominantly found in the northeastern and southeastern parts of the basin. These soils were grouped under GHG B, which represents 9.57% coverage. Most parts of the lake basin are

Fig. 4 Soil texture classes in Hayk Lake basin

Fig. 5 HSG classes of Hayk Lake basin

dominated by HSG D (90.43%) which are attributes of clay, clayey loam and heavy clay soils.

3.3 Model parameters of Hayk Lake basin

HEC-GeoHMS was employed to generate the model parameters (CN for AMC II, lag time, and initial abstraction) of each of the 17 subbasins pre delineated in batch in the Hayk Lake basin using hydro DEM (filled DEM), merged features of LU-LC and soil data, and CNLookUp table input datasets (Table 7).

The weighted CN (AMC II), the lag time, and the initial abstraction values representing the entire lake basin were the initial input model parameters for HEC-HMS modeling (Table 8).

3.4 HEC-HMS modeling

3.4.1 Sensitivity analysis

The runoff model output for the Hayk Lake basin was less sensitive to the initial abstraction loss parameter during all simulation periods (Table 9). On the contrary, SCS CN and lag time, in their order of listing, have a very significant impact on runoff volume and peak discharge in the Hayk Lake basin.

3.4.2 Calibration and validation of model parameters

The results of the calibration and validation of the model parameters (SCS CN, initial abstraction, and lag time) for the years 1989, 2000, and 2015 are shown in Table 10 and Figs. 6 and 7. Calibration and validation results confirmed the adequacy of the HEC-HMS model for rainfall-runoff simulation in the Hayk Lake basin. This result agrees with the findings of [19–21] that ensured the applicability of the HEC-HMS model at various spatiotemporal scales in Ethiopia for various purposes such as water availability assessment and flow forecasting.

3.4.3 Evaluating the level of impact of land use and cover change on surface runoff

To determine the combined and isolated contributions of the LU-LC and climate change on runoff, along with LU-LC data, it is important to analyze trends of climate change indicators briefly to find out if the climate change signal is revealed within the study area. At the same time, the monotonic trend direction and magnitude of change of the observed surface runoff for the same period was analyzed. Therefore, trend analysis of the mean annual precipitation, temperature and observed surface runoff time series at the local level in the Hayk Lake basin during the

Table 7 Model parameters of Hayk Lake basin (1989, 2000, and 2015)

Subbasin	Area ($\times 10^3 \text{ m}^2$)	Basin slope (%)	1989		2000		2015	
			Basin CN	Lag time (s)	Basin CN	Lag time (s)	Basin CN	Lag time (s)
Subbasin1	349.6	24.19	81.55	576	83.88	540	83.88	540
Subbasin2	728	31.44	70.47	1116	74.92	972	76.93	936
Subbasin3	417.6	29.04	74.02	972	75.73	900	76.64	900
Subbasin4	1302.8	30.76	73.37	1332	74.81	1260	76.33	1224
Subbasin5	431.6	42.28	72.73	792	73.34	756	74.40	756
Subbasin6	1373.6	22.53	77.35	1260	79.48	1188	78.07	1224
Subbasin7	574.8	15.30	81.77	1044	83.50	972	83.81	972
Subbasin8	29,866	23.61	80.36	5796	80.76	5688	79.91	5868
Subbasin9	11,493.2	23.32	82.18	2844	83.14	2772	83.18	2772
Subbasin10	741.6	12.20	83.23	1332	83.12	1332	81.68	1404
Subbasin11	1824.8	21.16	82.25	1548	83.51	1476	83.32	1476
Subbasin12	503.2	16.74	83.34	756	83.82	720	83.47	756
Subbasin13	422.8	19.52	83.36	900	83.65	900	83.36	900
Subbasin14	701.6	23.68	83.12	864	83.55	864	83.49	864
Subbasin15	766.4	20.00	82.60	1152	83.78	1080	83.58	1116
Subbasin16	428.8	20.88	82.75	864	83.75	828	83.45	828
Subbasin17	372.8	19.09	81.87	648	83.54	612	83.29	612
Total	52,299.2							
Weighted average			80.54		81.28		80.81	

Table 8 The initial model parameters of Hayk Lake basin

Year	CN (AMC II)	Initial abstraction ($\times 10^{-3}$) m	Lag time (s)
1989	80.54	10.04	5796
2000	81.28	9.49	5688
2015	80.81	9.84	5868

Table 9 Parameter sensitivity analysis and parameter sensitivity ranking

Year	Element	Parameter	Average sensitivity index	Absolute Sensitivity index	Rank
1989	Subbasin	SCS CN	0.56	0.56	1
	Subbasin	Initial abstraction	−0.01	0.01	3
	Subbasin	Basin lag	0.45	0.45	2
2000	Subbasin	SCS CN	0.48	0.48	1
	Subbasin	Initial abstraction	−0.01	0.01	3
	Subbasin	Basin lag	0.47	0.47	2
2015	Subbasin	SCS CN	0.50	0.50	1
	Subbasin	Initial abstraction	−0.01	0.01	3
	Subbasin	Basin lag	0.47	0.47	2

Table 10 Model performance measurements during runoff simulation

Year	Period	Objective function		
		MAE	RMSE	NSE
1989	Calibration	0.3	0.9	0.91
	Validation	0.2	0.9	0.84
2000	Calibration	0.4	1.5	0.93
	Validation	0.4	1.3	0.82
2015	Calibration	0.3	1.2	0.92
	Validation	0.2	0.7	0.87

study period 1989–2015 was performed by the nonparametric methods of Mann–Kendall and Sen to test the trend and the magnitude of the trend respectively. A Mann–Kendall test for trend and Sen's slope estimates (MAKESSENS) Excel model was used for the analysis. The details of these theories are presented in [39].

The result of the statistical calculation of trends is presented in Table 11. The Z test statistic values for each parameter indicated a statistically significant downward trend in precipitation and surface runoff at the 0.1 level of significance and a statistically significant upward trend in temperature at the 0.05 level of significance. The precipitation and surface runoff decreased at a rate of approximately 69 mm and 54 mm per decade. On the contrary, the mean temperature has warmed at a rate of 0.28 °C

Fig. 6 Calibration of HEC-HMS model (01 Jan to 31 Aug) (a) 1989 (b) 2000 (c) 2015

per decade. Similar findings were reported by the Federal Democratic Republic of Ethiopia [40] in its Climate Resilient Green Economy National Adaptation Plan document.

Then, the individual rates of impacts of LU-LC and climate change on the generation of surface runoff in the Hayk Lake basin for the period 1989–2015 were calculated

based on Table 12 using Eqs. (16–21) and the analysis result is shown in Table 13. As shown in Table 13, during the period 1989–2000, there was an increase in the total surface runoff of 0.54 m resulted from the combined effects of LU-LC and climate changes. The isolated contribution of each of the LU-LC or climate changes indicated

Fig. 7 Validation of HEC-HMS model (01 Sep to 31 Dec) (a) 1989 (b) 2000 (c) 2015

Table 11 Trend statistics of mean precipitation and temperature in Hayk Lake basin

Time series	First year	Last year	n	Mann–Kendall trend		Sen's slope
				Test S	Test Z	
P (mm)	1989	2015	27		− 1.67 ⁺	− 6.891
T (°C)	1989	2015	27		2.25 [*]	0.028
Observed surface runoff (mm)	1989	2015	27		− 1.67 ⁺	− 5.406

⁺Statistically significant at 0.1 level of significance. ^{*}Statistically significant at 0.05 level of significance.

Table 12 Simulated annual surface runoff in different scenarios

S. No	Land use and land cover data	Precipitation data	Peak flow (m ³ /s)		Runoff depth (× 10 ^{−3}) m	
			Simulated	Observed	Simulated	Observed
1	1989	1989	19.9	19.5	809.16	676.17
		2000	31.1	19.5	1337.97	676.17
		2015	28	19.5	765.54	676.17
2	2000	1989	20	30.7	817.75	1166.81
		2000	31.3	30.7	1346.92	1166.81
		2015	28.2	30.7	774.09	1166.81
3	2015	1989	19.9	27.4	816.49	648.67
		2000	31.3	27.4	1345.59	648.67
		2015	28.2	27.4	772.83	648.67

Table 13 Impact proportions on surface runoff (1989–2015)

Comparison with reference to	Year	Simulated annual runoff (× 10 ^{−3}) m	Total change (× 10 ^{−3}) m	Impact of land use and cover change on surface runoff		Impact of climate change on surface runoff	
				Proportion (%)	Change (× 10 ^{−3}) m	Proportion (%)	Change (× 10 ^{−3}) m
1989	1989	809.16					
	2000	1346.92	537.76	1.60	8.60	98.40	529.16
2000	2000	1346.92					
	2015	772.83	574.09	0.23	1.33	99.77	572.77
1989	1989	809.16					
	2015	772.83	36.33	20.18	7.33	− 120.18	− 43.66

only 1.6% of the increase (8.6×10^{-3} m) was due to human effects (change in LU-LC), whereas 98.4% of the increase (0.53 m) was caused by climate change. Between 2000 and 2015, simulated surface runoff was decreased by 0.57 m. The 0.23% decrease was attributable to the LU-LC change, while 99.77% of the decrease in surface runoff was attributable to climate change. Over the three decades (1989–2015), there was an average decrease in simulated surface runoff of 3.63×10^{-2} m. The LU-LC change increased it by 7.33×10^{-3} m, representing 20.18% of the total surface runoff change. In contrast, climate change decreased surface runoff to 4.37×10^{-2} m, or 120.18% of the total change.

4 Discussion

The combined and isolated impacts of LU-LC and climate change on surface runoff between 1989 and 2015 were quantified after the detection and simulation of LU-LC change and climate trend analyzes were carried out. The trend analysis of the two key indicators of climate change (precipitation and temperature) demonstrated that the climate in the Hayk Lake basin has warmed and become slightly drier over the time frame studied. This meant that the change in runoff in the lake basin was directly linked to changes in LU-LC and climate change. Therefore, the combined and isolated impacts of LU-LC and climate change

on surface runoff for the periods 1989–2000, 2000–2015 and 1989–2015 were quantified through scenario simulations using the HEC-HMS model.

During the period 1989–2000, the major LU-LC changes were a change in cultivation land that changed positively (151.59%), while other LU-LC types changed negatively with the highest negative change in shrubland (68.39%). These changes increased surface runoff by 8.6×10^{-3} m, representing 1.6% of the overall surface runoff change (0.54 m). Between 2000 and 2015, the major LU-LC changes were an increase in shrubland (59.8%) and grasslands (22.6%) with the expense of a decrease in cultivation (5.5%), plantation (20.91%), and lake water (0.24%). This LU-LC change reduced surface runoff by 1.33×10^{-3} m, representing 0.23% of the total surface runoff change (0.57 m) from 2000 to 2015. Over the study period (1989–2015), the cultivation land use was expanded by 137.74% with the expense of a decrease in other LU-LC types. This change increased the surface runoff by 7.33×10^{-3} m, representing 20.18% of the total surface runoff change (3.63×10^{-3} m). Conversely, climate change alone reduced it by 120.18%.

The change in the magnitude of surface runoff depends upon the characteristics of the LU-LC to affect infiltration and evapotranspiration processes. LU-LC increases surface runoff by decreasing infiltration and evapotranspiration [7–9]. The expansion of cultivation disturbs the soil structure and reduces surface roughness, eventually increasing surface runoff by decreasing infiltration and evapotranspiration processes. Decrease in plantation decreases the canopy cover causing reduced interception, loss of permeability (due to exposure of soil particles to raindrop impacts), and decreased surface roughness that reduces interception, infiltration, and evapotranspiration to increase surface runoff.

The possible reason for the expansion of cultivation land at the cost of reduction on plantation, shrubland, and grasslands may be the increasing population growth and its associated increase in demand for new cultivation land and settlement in the lake basin. Similarly, [3–6] indicated the increment of cultivation land at the expense of other LU-LC types is the common trend of LU-LC changes in Ethiopia to satisfy the demand for more agricultural lands and settlements of the growing population in the country.

5 Conclusion

The study analyzed the LU-LC change pattern and its impact on the magnitude of surface runoff generated in the endorheic Hayk Lake basin for the period 1989–2015. It has also identified warmed and slightly drier climate change signals dominating the Hayk Lake basin to affect

the runoff in the lake basin. The LU-LC change alone was found to increase surface runoff by 20.18% and climate change decreased it by 120.18%. The increase in the magnitude of surface runoff was related to the conversion of shrubland, plantation, and grasslands to cultivation land, whereas the decreased surface runoff amount was related to the decreased precipitation. The combined impact of LU-LC and climate change has caused Hayk Lake's water level to continue to fall. Therefore, this hydrological disturbance of Hayk Lake requires immediate and appropriate water management of Hayk Lake to ensure that the water resource of Hayk Lake in the endorheic Lake basin is sustainable.

Authors' contribution MM, AA, ST, and ZA conceived and planned the idea of the study. MM collected the data. All authors conducted the analysis and contributed to the interpretation of the findings. MM drafted the manuscript in consultation with the other three authors. All authors read and approved the final manuscript.

Availability of data and materials The three Landsat scenes of the Hayk Lake basin for years 1989, 2000, and 2015 were acquired from the data source <https://earthexplorer.usgs.gov/>. The climate and hydrology data that support the findings of this study are available in the National Meteorological Agency and the Ethiopian Water Resources, Irrigation, and Electricity Ministry repositories. Access to these data can be allowed based on reasonable requests submitted to the respective organizations. However, all the generated data during the analysis process are available in this manuscript.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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