



A modeling approach for evaluating the impacts of Land Use/Land Cover change for Ziway Lake Watershed hydrology in the Ethiopian Rift

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Received: 6 May 2022 / Accepted: 17 July 2022 / Published online: 2 August 2022
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Abstract

Many parts of the Ethiopian Rift are undergoing significant Land Use/Land Cover (LULC) changes. In many places, the natural LULCs are converted into agricultural land to sustain the increasing food demand arising from a rapidly growing population. Modelling the responses of LULC changes on the hydrology of the area at the watershed scale is crucial for sustainable development of land and water resources. This study investigates the historic LULC change and its potential impacts on the hydrology of Ziway Lake Watershed in the Ethiopian Rift. Commonly, such assessments are accomplished by integrating physically based and semi-distributed hydrological model with Remote Sensing and Geographic Information System techniques. A hybrid LULC classification approach was applied to classify Landsat images of 1985, 1995, 2005 and 2020 and detect the LULC changes in the watershed. Subsequently, Soil and Water Assessment Tool was utilized to simulate the response of the hydrological process (water balance and stream flow) to LULC changes from 1985 to 2020. The image classifications of 1985, 1995, 2005 and 2020 revealed four LULC maps with eight LULC types. The relative change assessment results in the past 35 years from 1985 to 2020 revealed that the major expansion in Settlement, Cultivation and Agroforest resulting in a reduction of Woodlands. However, 58.3% of the watershed has remained intact while 41.7% has shown some degree of change. At the watershed level, these LULC changes had increased SURQ (87.07%), WYLD (31.86%) and ET (4.91%). Conversely, the observed change had reduced PERC (63.22%). But, the spatial analysis of the water balance components due to LULC changes were found to be non-uniform across the watershed. On the other hand, the seasonal stream flow analysis results indicated that Katar flow is increased by 15.36% and declined by 3.86% during the wet and dry seasons, respectively. Similarly, Meki flow showed a decrement during the dry seasons and an increment during the wet seasons by 7.04% and 20.66%, respectively. Beside the observed change, the results of the hypothetical LULC change scenarios justified a pronounced impact of historic LULC change on the water balance components of the watershed. These change in hydrological components and stream flow substantially attributed to the transformation of Woodland to agricultural land. Among the water balance components, the increment of SURQ may have a wider implication for increasing soil erosion and lake bed siltation. The continuous decline in PERC also highly affected the available groundwater resource of the watershed. The study will have significance for watershed managers and decision makers to improve the LULC and water management practices in the area by formulating mechanisms to maintain a sustainable hydrological balance in the watershed.

Keywords RS · GIS · LULC change · SWAT model · Hydrological response · ZLW · Ethiopian Rift

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Introduction

Starting from the ancient times to date, the natural Land Use/Land Cover (LULC) of our globe has been changing and expected to continue in the future (Lambin et al. 2003). Human activities and natural factors are the causes of this change which resulted a significant impact on the environment (Mulungu and Kashaigili 2012). The visibility of human impact was speedy while the natural impact

is gradual and takes extended periods. To satisfy the ever growing demand of human needs, land resources are intensively exploited rapidly, thereby modifying the natural landscapes of the earth over the past few decades (Bronstert 2004; Yanda and Munishi 2007). For example, clearing of forests for firewood, agricultural land expansion, urban sprawl and over grazing have brought significant LULC changes which has a direct impact on the hydrological dynamics, water resource availability, land productivity and ecosystems (Chhabra et al. 2006; Hamman et al. 2018).

In semi-arid and arid regions, such as the Ethiopian Rift, LULC change is a major environmental problem resulting a scarcity of water resources such as perennial rivers and aquifers (Jansen et al. 2007; Elias et al. 2019; Meshesha et al. 2012; WoldeYohannes et al. 2020). In the Ethiopian rift, there was a considerable expansion of an agricultural land at the expense of forests, grasslands, woodlands, wetlands and water bodies due to an increasing population which is heavily relying on an agriculture-based economy (Jansen et al. 2007; WoldeYohannes et al. 2018; Elias et al. 2019; Desta and Fetene 2020; Kuma et al. 2022). A few decades ago, the center of Ethiopian Rift was known for its dense acacia woodlands that have now been converted into cultivated lands (Garedew et al. 2009; Molla 2015; Kindu et al. 2015; Ariti et al. 2015; WoldeYohannes et al. 2018, 2020; Desta and Fetene 2020). Nowadays, there are few remnants of woodlands which were covering the vast portion of the valley floor. The expansion of an agricultural land was also extending to the natural forest in steepest and inaccessible mountains of the rift margin (Gebreslassie 2014; Fufa et al. 2015). Moreover, the Ethiopian government's future land use plan is also aiming to increase an agricultural land in order to satisfy the ever-growing demand of food which will in turn convert other LULC types into an agricultural land. This uninterrupted change in LULC is anticipated to impact the water resources of the region by altering the hydrological dynamics such as interception, surface runoff, evapotranspiration, water holding capacity of the soil and groundwater recharge.

In the Ethiopian Rift, many researchers have reported the considerable effect of these unstoppable LULC change on water resources. The drastic shrinkage of Lake Abijata (Teffaw et al. 2019) and the substantial decline in the areal extent of Awash valley swamp (EIB 2014) are the notable examples that showed the effect of LULC changes on water resources. Therefore, a comprehensive understanding and evaluation of LULC change impacts on hydrological processes of the region is essential to manage the water resource and environment in the face of future changes.

Ziway Lake Watershed (ZLW) is part of the Ethiopian Rift that faced the aforementioned challenges. The watershed is recognized to be the most productive region supporting the livelihood of more than 2 million people (CSA

2017). It comprises the second largest fresh water lake in Ethiopian Rift which is a source of water for domestic, irrigation and fish supply. Apart from its economic and livelihood importance, Lake Ziway and its watershed is a tourist attraction center with distinct ecological and hydrological characteristics (Vuik 2008). However, over the past few decades, the watershed suffered from human induced resource degradation mainly due to agricultural expansion and uncontrolled LULC changes arising from unprecedented population growth. Deforestation is a daily activity of the people residing in and around the watershed to satisfy the growing demand for agricultural land, charcoal, construction and grazing land (Hengsdijk and Jansen 2006; Jansen et al. 2007). This land degradation has diverse environmental consequences including loss of biodiversity (Islam et al. 2018), loss of top fertile soil (Morgan 1995), siltation of open water body (Kalsido and Berhanu 2020), low stream flow during dry season (Turner et al. 2001) which are common problems in the ZLW. Such multi-faceted problems have the potential to alter the hydrological and ecological integrity of ZLW and its environs.

The hydrology of the ZLW has been a focus of research in the past few decades. Most of the studies focus on water quality issues which are mainly associated with elevated fluoride level (Chernet et al. 2001; Rango et al. 2012), climate change (Zeray 2006; Musie et al. 2020) and lake level fluctuation due to anthropogenic activities near to the lake's region (Hengsdijk and Jansen 2006; Legesse et al. 2005; Ayenew and Legesse 2007; Seyoum et al. 2015; Gadissa et al. 2018). Recently, Abraham and Nadew (2018) highlighted the effects LULC change on the water balance components of Meki and Katar sub-watersheds. Despite the fact that Lake Ziway and its watershed have immense economic importance to the livelihood of millions of inhabitants in the watershed and the country at the larger scale, there is little information on past LULC changes and its subsequent impacts on the hydrology of ZLW. Therefore, there is an urgent need to investigate the impacts of LULC change on hydrological processes at the watershed to sub-watershed scale and also demonstrate their complex interrelationship.

Modeling and evaluating the impact of LULC change on the watershed hydrology requires an integrated application of Remote Sensing (RS), hydrological models and Geographic Information System (GIS). With the advent of satellite technology, RS is playing an important role in watershed hydrological studies (Leong et al. 2012; Ahn et al. 2014; Thakur et al. 2016) by providing spatio-temporal LULC change information, particularly over large and poorly monitored regions (Fortin and Bernier 1991; Di Gregorio and Jansen 2005; Zoungrana et al. 2015). Land Use/Land Cover Change information extracted from RS data has been utilized in different hydrological modeling studies such as water balance, streamflow, flood event and soil

erosion simulations (Du et al. 2012; Dang and Kumar 2017). Modeling the responses of LULC change on hydrological processes spatially and temporally requires the use of physically based and spatially distributed hydrological models (Paul et al. 2017; Boufala et al. 2022). Various hydrological models can be employed for assessing the impacts of LULC change on hydrological processes e.g., SWAT (Arnold et al. 1998), HBV (Bergström 1992), WetSpss (Batelaan and De Smedt 2001), VIC (Garg et al. 2017) and HEC-HMS (Chu and Steinman 2009). Among these models, SWAT has strong performance record in evaluating the effects of land management practices on hydrological processes in complex watersheds with varying LULC, soil, slope and management conditions over a long period around the world (Arnold et al. 1998; Neitsch et al. 2011). In conjunction with RS data and hydrological models, GIS provided a suitable platform for efficient management of large and complex data. In addition, it enhanced modeling capability and efficiency (Leong et al. 2012; Alexakis et al. 2014; Thakur et al. 2016). For instance, the integration of the SWAT with the GIS helped to understand the impacts of spatially explicit processes such as LULC change on the hydrological response (Yalew et al. 2013; Abbas et al. 2015). Therefore, the combined application of such techniques is appropriate to examine the impacts of LULC changes on the water resources of ZLW in the Ethiopian Rift.

Therefore, the aim of the present research was to (1) analyze the historic LULC changes of ZLW in the periods between 1985 and 2020 and (2) evaluate its subsequent impact on the water balance components and stream flow. As suggested by many researches (e.g., Leong et al. 2012; Thakur et al. 2016; Hachemaoui et al. 2022), RS-GIS techniques and hydrological modeling was integrated to produce the LULC maps of 1985, 1995, 2005 and 2020 in order to analyze the LULC dynamics of the watershed. The impact of LULC changes on the hydrology of this watershed was studied by hydrological modelling and statistical analysis (Elfert and Bormann 2010). For this study, a physically based and semi-distributed hydrological model called SWAT (Neitsch et al. 2011) was applied for this study.

Study area: geographical overview

Ziway Lake Watershed (ZLW) is situated in the northern parts of the Ethiopian Rift (Fig. 1). The watershed covers an area of about 7,300 Km² and is bounded between latitudes of 7° 20' 54" N and 8° 02' 56" N and longitudes of 38° 13' 02" E and 39° 24' 01" E. The area extends from the Gurage Mountains in the west via the rift floor to Arsi mountains in the eastern side. Ziway Lake Watershed comprises two major sub-watersheds namely; Meki and Katar situated at

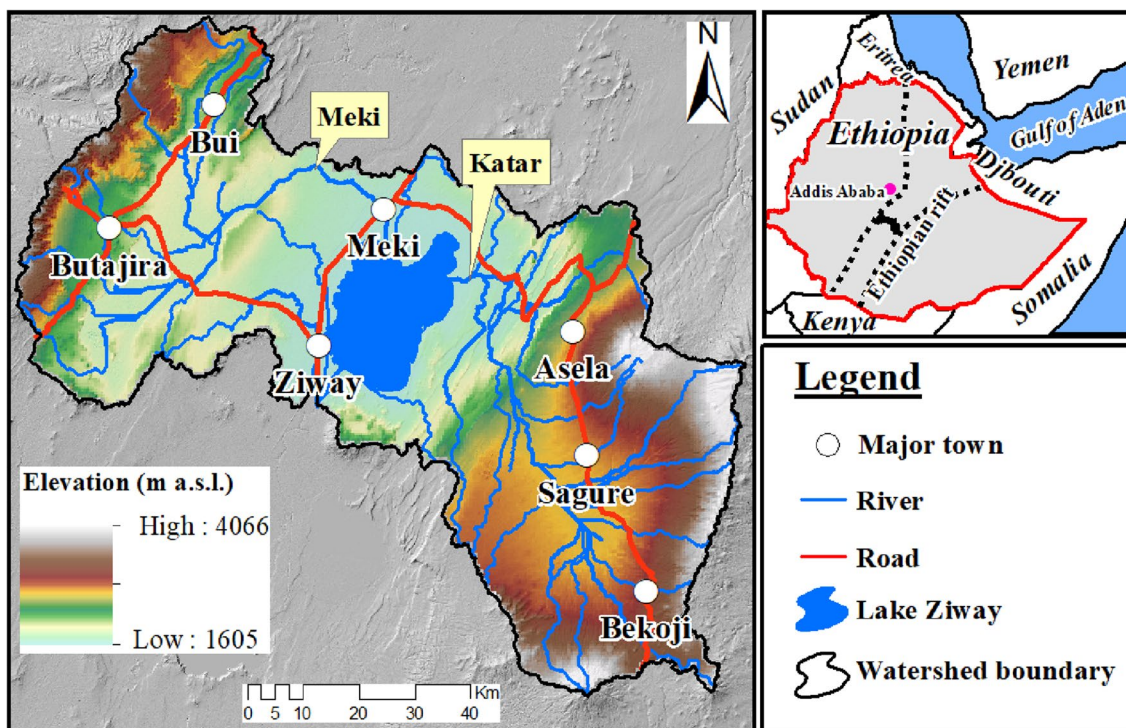


Fig. 1 Location map of ZLW depicting the major towns, drainage networks and topographic variability in the watershed. The inset map shows the location of ZLW (black polygon) within the Ethiopian Rift

the western and eastern flanks of the study area, respectively. Katar and Meki are the major feeder rivers of Lake Ziway (Fig. 1).

Ziway Lake Watershed is characterized by rugged terrain and geological and structural complexities in which the principal features in the rift margin are dominated by chains of mountains, step faults, horst-graben structures and river channels. The western and eastern part of the watershed are mainly dominated by volcanic mountain chains and a series of step faults. However, the rift center is characterized by gentle slope and flat land decorated by volcanic hills and closely spaced horst-graben structures. Similar to the other sectors of the Ethiopian Rift, the area can be subdivided in to three major physiographic regions, as follows: the rift floor [< 1800 m above sea level (m. a.s.l)], the transitional escarpment (1800–2400 m a.s.l.), and the highland (2400–4066 m a.s.l) (Fig. 1). There is elevation difference above 2400 m between the rift floor and the highland. Even though, the elevation shows wide variations, the majority (60%) of the watershed area belongs to the rift floor whereas the rest 40% belongs to the bordering monotonous escarpment on either side of the rift floor.

The climate of ZLW varies from humid in the mountains of the escarpments to semi-arid in the rift floor (Makin et al. 1976). The long term (2003–2015) average annual rainfall of the study area was 1,355 mm. However, in the mountains of the escarpments bounding the rift floor, rainfall surpasses 1600 mm/year, whereas at the lowest elevation in the rift floor, rainfall is often < 800 mm/year. The watershed has a bi-modal rainfall pattern where about 55% and 30% belong

to summer (June–September) and autumn (March–May) seasons, respectively. The remaining 25% falls between October and February. The mean monthly temperature ranges between 19 and 22.5 °C in the rift floor while in the high altitude plateau, it varies from 14.08 to 16.92 °C.

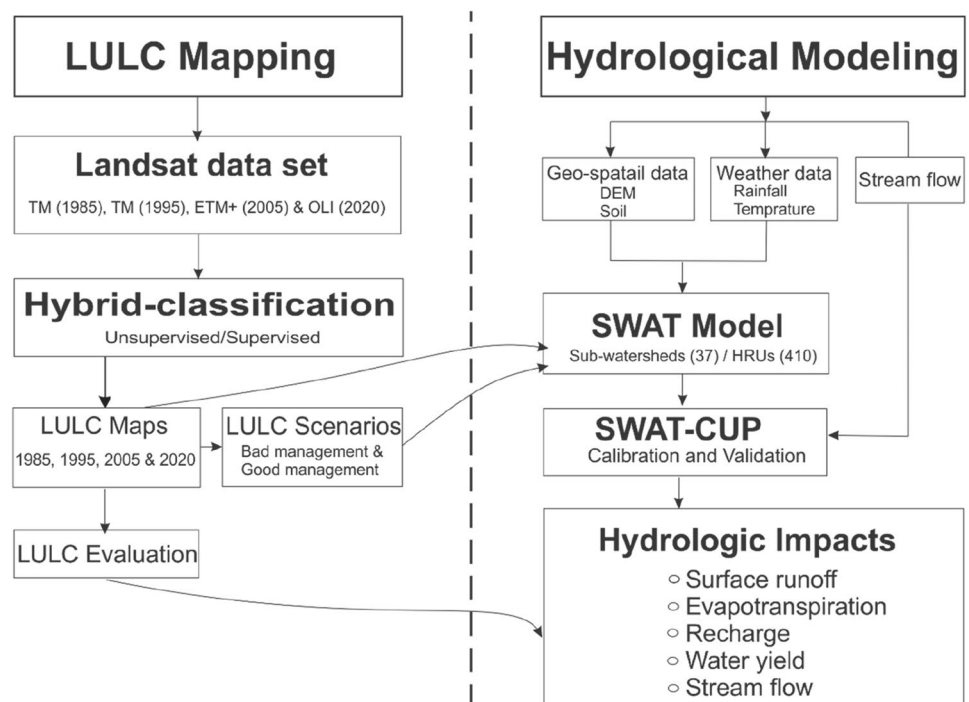
Materials and methods

Modeling approach

Figure 2 illustrates the modelling approach and the work flow of this study. It presents the application of RS-GIS techniques for mapping the LULC and hydrological modeling for the responses of these LULCs using the combined application of SWAT model and SWAT-CUP.

To achieve the stated modeling objectives, four steps were followed. In the first step, the observed LULCs in 1985, 1995, 2005 and 2020 were mapped which are then compared to evaluate the LULC dynamics of the area. Beside the real observed LULC, hypothetical (Bad and Good management) LULC scenarios were created in this step. In the second step, a hydrological model, SWAT was developed for the time periods between from 1985 to 2020. This step permits the determination of the most sensitive model parameters and model calibration and validation considering the 1985 LULC scenario. Subsequently, the hypothetical LULCs were incorporated in the calibrated model. Finally, in the fourth step, the hydrological responses of the LULC scenarios were analyzed, compared and correlated with LULC changes that

Fig. 2 Flowchart showing the modeling approach of this study



have been already emphasized in the first step of the modeling procedure (Fig. 2).

Land Use/Land Cover mapping and change analysis

Data source and image classification

Land Use/Land Cover assessments were carried out using four Landsat images (Table 1): Landsat-5 thematic mapper (TM) 1985, Landsat-5 TM 1985, Landsat-7 Enhanced Thermal Mapper Plus (ETM+ 2000) and Landsat-8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) 2020. Images with 30 m resolution and less than 10% cloud cover were obtained from US Geological Survey website using earth explorer (<http://earthexplorer.usgs.gov>). Prior to image classification, the standard image pre-processing techniques (Temesgen et al. 2017) such as layer stacking, geometric correction, geo-referencing, haze reduction and mosaicking were applied on the Landsat images using ERDAS imagine. The hybrid classification approach (Teferi et al. 2010; Gashaw et al. 2018) which combines unsupervised and supervised classification methods, was applied in classifying the Landsat images. Initially, the unsupervised classifications were performed using Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithm (Teferi et al. 2010). Subsequently, the supervised classifications was carried out with Bayesian Maximum Likelihood Classifier (BMLC) algorithm (Temesgen et al. 2014) based on ground truth points from each LULC types collected during the field survey. A total of 350 ground truth points were collected and utilized for supervised classification and accuracy test.

Accuracy assessment and change detection

Accuracy assessment was carried out to evaluate the quality of the LULC classification. For this purpose, an error matrix was created by cross-tabulating the mapped classes versus the reference class (Congalton and Green 2009). For 1985, 1995 and 2005, the reference points were obtained from historical Google Earth images, interviews, earlier reports and maps. Likewise, for the 2020 image, the references points were collected from Google Earth

images and field survey including field observation and interviews conducted in random reference points of various LULC types using GPS. Accuracy measurement indices (Foody 2002; Fayaz et al. 2020) such as Overall Accuracy (OA) and Kappa coefficient (Kc) were determined from the confusion matrix. Moreover, User Accuracy (UA) and Producer’s Accuracy (PA) were also determined for each class which measure the commission and omission errors, respectively. The value of OA above 70% is considered as satisfactory classification accuracy (Foody 2002). According to Mishra and Rai (2016), for many applications, values of Kc above 0.8 can be recognized as strong agreement, values between 0.4 and 0.8 as moderate agreement and values below 0.4 represent poor agreement.

The LULC change detection was conducted using Post-Classification Comparison (PCC) approaches (Foody 2002; Lu et al. 2004). Images of different reference years were first separately classified and then compared into three periods (1985–1995, 1995–2005 and 2005–2020). Beside visual inspection, quantitative change indicators were computed using image values of one data set with the corresponding value of the second data set in each period (Yanda and Munishi 2007). Accordingly, to elucidate the areal extent of changes experienced between the successive periods (1985–1995, 1995–2005 and 2005–2020) and overall change (1985–2020), the magnitude change (MC), percent of change (P) and annual rate change (ΔR) (Temesgen et al. 2014, 2017) were calculated using Eqs. (1–3), respectively and their values are presented in Km² and percentages (%).

$$MC(km^2) = A_i - A_f, \tag{1}$$

$$P(\%) = \left(\frac{A_i - A_f}{A_i} \right) \times 100, \tag{2}$$

$$\Delta R(km^2/year) = \left(\frac{A_i - A_f}{n} \right) \times 100, \tag{3}$$

where A_i is the LULC class areal extent (Km²) at the previous time, A_f is the LULC class areal extent (Km²) at recent time, and n is the number of years of the time period.

Table 1 The detail features of satellite images utilized in this study

Year	Satellite	Sensor	Acquisition date	Path/Row	Resolution	Cloud cover (%)
1985	5	TM	1985/01/18	168/55–54	30 m	< 10
1995	5	TM	1995/01/14	168/55–54	30 m	< 10
2005	7	ETM+	2005/01/04	168/55–54	30 m	< 10
2020	8	OLI	2020/01/29	168/55–54	30 m	< 10

TM thematic mapper, ETM+ enhanced thermal mapper plus, OLI/TIRS operational land imager and thermal infrared sensor

Hydrological modeling

SWAT model overview

The “Soil and Water Assessment Tool” SWAT (2012) (Neitsch et al. 2011) and the Calibration and Uncertainty Program “SWAT CUP” (Abbaspour et al. 2011) were utilized to simulate and assess the impacts of LULC changes on the ZLW. SWAT is a semi-distributed and physical-based hydrological model that has been commonly used for investigating the impacts of LULC change on water resources in every corner of the world (Garg et al. 2019). SWAT operates at a daily time step with complex terrain conditions including different LULCs, soils, and management practices. During model development, SWAT partition a watershed into multiple sub-watersheds. Subsequently, these sub-watersheds are further sub-partitioned into Hydrologic Response Units (HRUs). HRUs are portion of areas within the sub-watershed that comprise of unique combination of LULC, soil and slope (Setegn et al. 2009; Arnold et al. 2012) which can be defined by means of a coupled GIS tool. The division of sub-watersheds into HRUs is quite helpful to simulate high level of spatial variability that arose from spatial heterogeneity in terms of LULC, soil and slope within a watershed. The simulated hydrological components from each HRU are routed back to obtain the total value of these elements for the sub-watershed and watershed scale (Neitsch et al. 2011; Arnold et al. 2012). Often, these components simulated by SWAT model include precipitation, interception, infiltration, surface runoff, evapotranspiration, percolation and lateral subsurface flow within the soil and aquifer (Arnold et al. 2012). The hydrological components are simulated based on the water balance equation on a daily time step (Neitsch et al. 2011) as shown in Eq. (4).

$$SW_t = SW_0 + \sum_{i=1}^t (R_{\text{day}} - Q_{\text{surf}} - E_a - W_{\text{seep}} - Q_{\text{gw}}), \quad (4)$$

where SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of Rainfall on day i (mm), Q_{surf} is the amount of Surface Runoff on day i (mm), E_a is the amount of Evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

The SWAT model provides users with different options to choose for the simulation of the hydrologic process. Surface runoff in SWAT model can be estimated either with the modified Soil Conservation Service (SCS) Curve Number (CN) (USDA-SCS 1972) or the Green and Ampt infiltration method (Green and Ampt 1911). In the present study, the SCS-CN method was preferred. It is the most popular and computationally efficient approach which determines

surface runoff based on a given rainfall event under different LULC, soil properties and hydrologic conditions (Arnold et al. 2012). Due to the lack of sufficient weather data, Hargreaves and Samani 1982 method was applied to estimate the potential evapotranspiration (PET) instead of the more data-demanding Penman–Monteith (Monteith 1965) and Priestley–Taylor (Priestly and Taylor 1972) methods available in SWAT. The detailed description of the hydrological equations used and different model components can be referred in the SWAT documentation (Arnold et al. 2012) and online resources at <http://swat-model.tamu.edu/>.

In the present study, Sensitivity, Calibration and Validation analysis were conducted by SWAT–CUP which is a separate software that has been increasingly used by SWAT users to conduct an automatic calibration with comfort and efficiency (Arnold et al. 2012). Therefore, the SWAT model simulation output was imported to SWAT-CUP for Sensitivity, Calibration and Validation analysis using the Sequential Uncertainty Fitting Algorithm version II “SUFI-II” which is known to achieve a good calibration result in limited number of iterations (Young et al. 2008).

SWAT data required and model set up

Developing a reliable SWAT model which can simulate different hydrological processes depends mainly on the availability of high-quality input data including Digital Elevation Model (DEM), weather, soil and LULC. Stream flow data are also required for calibration and validation purposes.

Geo-spatial datasets

A 12.5 m × 12.5 m resolution DEM was obtained from earth data sources (<https://earthexplorer.usgs.gov/>) for free in this study to delineate the ZLW and discretize the entire watershed into 37 sub-watersheds (Fig. 3). Moreover, the DEM was used to obtain the topographic features of the study area such as slope, flow direction and accumulation, outlet points and stream network. Slope was classified based on the elevation variability of the DEM used during watershed delineation. As ZLW is characterized by wide topographic differences, the area is classified in to variable slope classes (Fig. 3). The higher proportion of the rift floor is plain land and it is categorized under gentle slope class while both the western and eastern mountainous escarpments of the area are classified under steep and gentle slope classes.

One of the key inputs that the SWAT model needs is the soil map including the physical and chemical properties of the soil units in the watershed. The physical and hydraulic properties of the soil map which contain seven soil units were obtained from Halcrow (2008) (Figs. 3, 4). However, the physical and hydraulic properties of the soil units are characterized by limited data points. For better

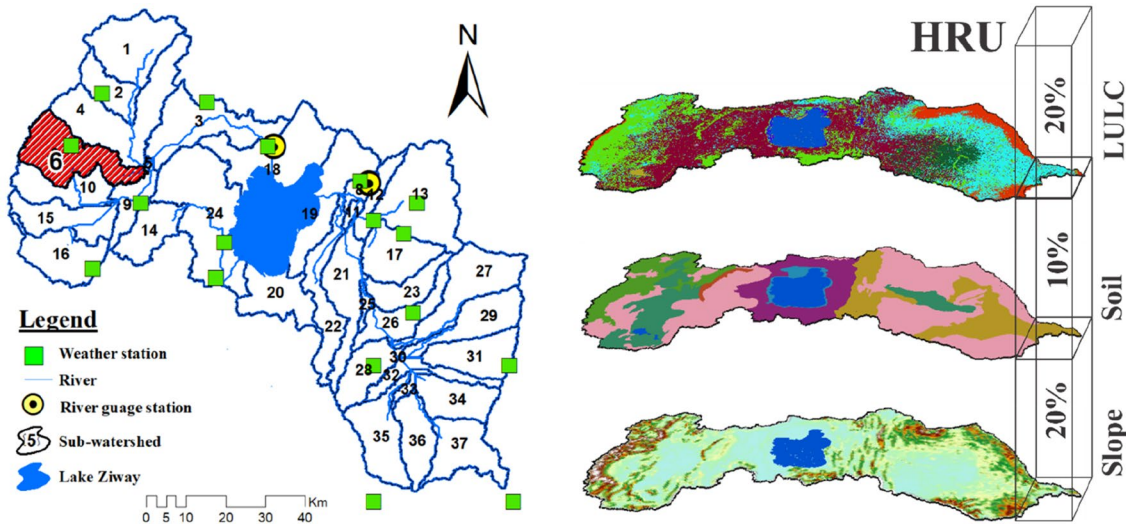


Fig. 3 SWAT model building of the ZLW: Watershed discretization, gauging stations (weather and stream flow) and multiple model inputs (slope, soil and LULC) used to generate hydrologic response unit

(HRU). The shaded (red) region shows sub-watershed-6 which represent the Woodland dominated area

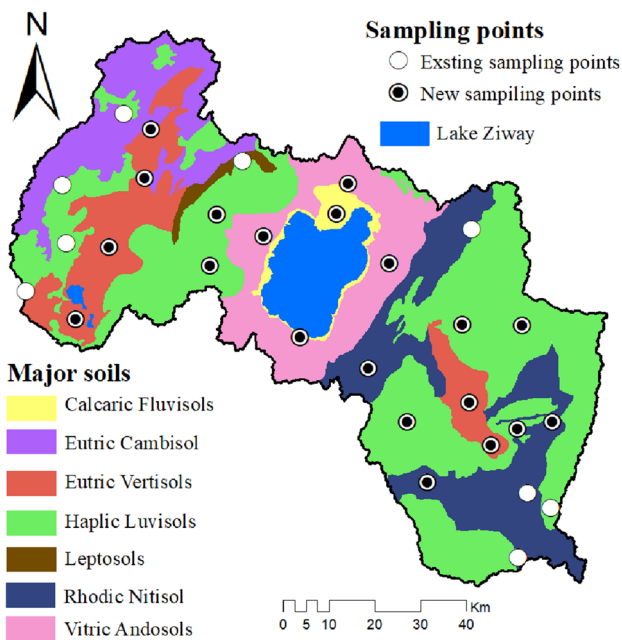


Fig. 4 Soil map (Halcrow 2008) and sampling points of the study area

representation of the soil in the model, new soil samples were collected from a soil survey campaign of 20 cores, sampled on a 2 m × 1 m soil pit in the catchment. The soil samples were taken from the major soil units at multiple depths representing each soil layers. The soil sample analyses were performed at Addis Ababa Science and Technology University (AASTU) soil mechanics laboratory to determine

the texture (silt, clay and sand percentages), Bulk Density (BD), Saturated Hydraulic conductivity (Ks) and Available Water Capacity (AWC). The soil properties from the soil samples were averaged for each respective soil unit in the soils map. Finally, seven soil types were fully characterized and used for the study as an input soil data. These are Leptosols (0.95%), Calcaric Fluvisols (1.92%), Water body (6.14%), Eutric Cambisols (9.97%), Eutric Vertisol (11.78%), Vitric Andosols (12.65%), Rhodic Nitisols (15.53%) and Haplic Luvisols (41.07%). The summarized soil properties at various depths are shown in Table 2.

The LULC data are essential for hydrological modeling as it determines the water quantity and quality of a watershed (Lerner and Harris 2009). Hence, the classified LULC maps of 1985, 1995, 2005 and 2020 and the hypothetical LULC change scenarios were deployed separately to evaluate the hydrological responses to changes of LULC in the ZLW. SWAT model requires predefined four-letter codes for each LULC types to link the identified LULC type with to SWAT LULC databases. Therefore, conversion of the mapped LULC types into the SWAT code is a prerequisite in the modeling process. Hence, the SWAT codes given for Afro-alpine, Agro-forest, Cultivated land, Plantation, Settlement, Water body, Wetland and Woodland were RNGE (Range-Grasses), FRST (Forest-Mixed), AGRL (Agricultural Land-Generic), EUCA (Eucalyptus trees), URML (Residential-Med/Low Density), WATR (Water), WETN (Wetlands-Non-Forested) and RNGB (Range-Brush), respectively.

The above mentioned geo-spatial data sets such as DEM, LULC, soil and slope were imported, overlaid and linked

Table 2 The physical and hydraulic properties of the soil units

Soil type	D_{\max} (m)	N_L	Z_L (m)	BD (g cm^{-3})	AWC ($\text{cm}^3 \text{cm}^{-3}$)	Ks (mm h^{-1})	Clay (%)	Silt (%)	Sand (%)
Leptosols	1.65	1	0.35	0.95	0.21	42.21	6.70	85.00	8.40
		2	0.40	1.32	0.21	38.34	8.7	84.4	6.8
		3	0.90	1.32	0.17	3.75	37.5	52.2	9.9
Vitric Andosols	1.00	1	0.15	1.46	0.13	13.32	15.6	36.3	48.2
		2	0.70	1.43	0.13	9.10	18.9	33.7	47.4
		3	0.15	1.54	0.15	32.56	8.3	49.8	42
Calcaric Fluvisols	2.00	1	0.40	1.79	0.13	55.96	2.00	34.70	63.30
		2	1.60	1.507	0.187	34.40	8.3	66.6	25
Eutric Cambisol	2.10	1	0.75	1.31	0.19	19.00	15.59	70.25	14.17
		2	1.35	1.41	0.18	17.24	16.03	65.85	18.12
Rhodic Nitisol	2.10	1	0.85	1.20	0.21	39.09	8.52	85.17	6.30
		2	1.25	1.29	0.18	5.21	33.15	60.80	6.05
Eutric Vertisol	1.40	1	0.15	1.27	0.15	2.26	41.35	33.75	24.95
		2	0.75	1.20	0.15	2.24	56.70	31.23	12.10
		3	0.50	1.25	0.13	1.69	49.00	23.93	27.05
Haplic Luvisols	1.45	1	0.20	1.37	0.17	9.40	21.41	55.04	23.58
		2	0.45	1.32	0.16	4.94	29.07	48.34	22.57
		3	0.80	1.31	0.14	2.87	34.86	35.16	30.00

D_{\max} , N_L , Z_L , BD, Ks and AWC refer to Soil maximum thickness, Number of sub-soil layers, Thickness of sub-soil layers, Bulk Density, Saturated hydraulic conductivity and Available Water Capacity, respectively. Percentage Clay, Silt and Sand refer to textural classes

with the SWAT databases to build the sub-watersheds and define the HRUs (Fig. 3). The multiple HRU was preferred for this study in order to consider the heterogeneity in LULC, soil and slope in sub-watersheds. As suggested by Setegn et al. (2009) in Ethiopian regions, HRU definition with threshold values of 20% slope, 10% soil and 20% LULC were used to discretize the sub-watersheds in to HRUs (Fig. 3).

Hydro-meteorological data

Beside the geo-spatial data sets, SWAT model requires long-term daily weather data which includes rainfall, temperature, solar radiation, wind speed and relative humidity. Due to lack of long-term data, only daily rainfall and minimum and maximum temperature for the period from 1979 up to 2014 were used in this study. These data were collected from the National Meteorological Agency of Ethiopia (NMA) for weather stations situated within and nearby the watershed (Fig. 3). In order to fill the data gaps arising from uneven distribution of the weather stations, weather data from the Climate Forecast System Reanalysis (CFSR) website (<http://globalweather.tamu.edu/>) was utilized for this study. During model simulation each sub-watershed is linked to the nearby weather station. Daily stream flow data of two gauging stations (Meki and Katar) (Fig. 3), which was collected from the Ministry of Water and Energy of Ethiopia (MoWE), was utilized for model calibration and verification.

Sensitivity analysis, calibration and validation (SWAT-CUP)

Sensitivity analysis determines the most critical model parameters which control the specific model outputs by weighing and ranking (Arnold et al. 2012). It is a first step in model calibration and reduces the computation time by determining the most sensitive input parameters to be adjusted. To determine the utmost sensitive parameters, 28 flow SWAT parameters were tested using the default upper and lower bound values as recommended by Neitsch et al. (2011). For this purpose, Global sensitivity analysis, which involves changing parameter All-At-a Time (AAT) was applied in SWAT-CUP instead of the Local sensitivity analysis which considers changing values One-At-a Time (OAT) (Abbaspour 2011, 2013). Indices such as p value and t Stat were utilized to provide the significance and measure of sensitivity of the parameters, respectively (Abbaspour 2013). Therefore, a p value of 0 is more significant while higher t test in absolute values measure high sensitivity. Based on the sensitivity analysis, 14 model parameters showed considerable effect on stream flow (Table 3). These parameters were considered for further calibration process.

Model calibration is a procedure of altering or modifying model parameters, within the proposed ranges, with reference to observed dataset to provide similar/the same response over time (Arnold et al. 2012). While, validation refers to a demonstration of evaluating the model outputs

Table 3 The most sensitive model parameters (14) with their relative sensitivity, parameter ranges and calibrated values used during the calibration procedure

Parameter	Definition	Rank sensitivity	Parameter range	Calibrated value
CN2	SCS runoff curve number for moisture condition II (–)	1	±0.25%	– 0.19%
SOL_K	Saturated hydraulic conductivity (mm/h)	2	±0.25%	0.00%
SOL_Z	Soil thickness (mm)	3	±0.25%	0.19%
ESCO	Soil evaporation compensation coefficient (–)	4	0.7–1	0.59
ALPHA_BF	Base flow recession constant (1/day)	5	0–1	0.57
REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm H ₂ O)	6	1–500	307.65
CANMX	Maximum canopy storage (mm H ₂ O)	7	0–10	0.23
EPCO	Plant uptake compensation factor (–)	8	0–1	
RCHG_DP	Deep aquifer percolation coefficient (–)	9	0–1	0.14
GW_REVAP	Groundwater revap coefficient (–)	10	0.02–0.2	0.10
GW_DELAY	Groundwater delay (days)	11	0–500	37.76
SOL_AWC	Soil available water capacity (mm H ₂ O/mm soil)	12	±0.25%	– 0.19%
GWQMN	Threshold water level in shallow aquifer for base flow (mm H ₂ O)	13	0–5000	1306.61
CH_K2	Effective hydraulic conductivity of channel (mm/h)	14	0–250	1.94

obtained using the calibrated model without further adjustment matches with an independent data sets. In this study, both calibration and validation were performed for Meki and Katar rivers using 35 years data (1981–2014) of monthly measured stream flow data to evaluate the reliability and accuracy of the SWAT model simulation. The stream flow data were divided into warm-up (1979–1980), Calibration (1981–2000) and Validation (2001–2014) periods.

As suggested by Musyoka et al. (2021), manual followed by automatic calibration procedures were applied. The SWAT model was calibrated manually following step by step approach as commended by Neitsch et al. (2011). Primarily, the western sub-watersheds (Meki) were independently calibrated, and the parameters in these sub-watersheds were then kept constant while the eastern sub-watershed (Katar) was calibrated. During the manual calibration process, the parameters were allowed to vary within the given ranges to obtain the optimal parameter values to reduce the differences between measured and simulated stream flows and to mimic the seasonal signature. Subsequently, the SUFI-II of the SWAT-CUP package was utilized for further parameter optimization/automatic calibration. During the automatic calibration procedures, the parameters were allowed to vary within given ranges to obtain the optimal parameter values (Table 3). The parameter ranges are based on the references provided in the SWAT documentation.

The performance of the SWAT model was evaluated by using various statistical techniques to evaluate the reliability and quality of predictions when compared with observed values. In this study, three model evaluation indicators such as Correlation Coefficient (R^2), Nash–Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970) and Percent Bias (PBIAS)

(Gupta et al. 1999) were used. The R^2 refers the strength of the observed and simulated data relations and the value varies from 0 to 1. The relation between observed and simulated data is best when R^2 is closer to 1; conversely when it approaches 0 the relationship appears to be poor. The NSE measures the degree of fitness (1:1 line) of plot for the observed versus simulated values and ranges from $-\infty$ to 1; in which higher values approaching 1 indicates that the model performs well. The PBIAS is a measure of tendency of the simulated data to be higher or lower than the measured data, expressed as a percentage. A positive and negative value of PBIAS shows a model toward underestimation and overestimation, respectively. The absolute low values of PBIAS designates better simulation; while 0 is an optimal value.

Results and discussion

LULC change analysis

Accuracy evaluation

The accuracy evaluation of the 1985, 1995, 2005 and 2020 classified images are shown in Table 4. An Overall Accuracy (OA) of 90.24%, 89.16%, 86.72% and 91% were achieved for the 1985, 1995, 2005 and 2020 classified images, respectively. A Kappa coefficient (K_c) of 0.74, 0.94, 0.71 and 0.87, respectively, were also attained for the 1985, 1995, 2005 and 2020 LULC maps. Based on Foody (2002) and Mishra and Rai (2016), the validation data set showed a very good agreement of the classified image with the ground truths.

Table 4 Users (UA), producers (PA), overall (OA) accuracies and Kappa coefficient (Kc) for the 1985, 1995, 2005 and 2020 images

LULC type	1985		1995		2005		2020	
	UA	PA	UA	PA	UA	PA	UA	PA
Afro-alpine	90.9	100	83.3	100	93	100	82	100
Ago-forest	82.2	90.9	90.7	96.1	92	92	96	86
Cultivated land	98	96.1	97.2	77.8	80	72	83	90
Plantations	100.0	100	100	84	100	89	94	91
Settlement	96.2	73.5	75	98.3	100	100	97	88
Water body	100	87.9	96.1	74.2	100	67	92	89
Wetland	90.9	81.1	100	100	79	100	100	87
Woodland	81.3	96.8	84.6	90.2	88	76	88	97
OA (%)	90.24		89.16		86.72		91	
Kc	0.74		0.94		0.71		0.87	

Hence, the mapped LULC types can be utilized as an input data for setting the SWAT model. The LULC data of the years 1985, 1995, 2005 and 2020 were used to represent different LULC classes of the study area for the following three distinct periods: 1985–1995, 1995–2005 and 2005–2020, respectively.

Historical (1985–2020) LULC change

The LULC conditions of the ZLW in the period between 1985 and 2020 are depicted in Fig. 5. Over the past three decades (1985–2020), the study area has experienced major LULC changes. The comparison of LULC maps for the years 1985, 1995, 2005 and 2020 indicates that substantial changes had occurred in Settlement, Cultivated land and Woodland LULC classes. The areal extent of the Cultivated land increased from 35.59% in 1985 to 40.1% in 1995 to 46.38% in 2005 and to 49.16% in 2020 (Figs. 5, 6). Like the Cultivated land, the Settlement area is also successively increased in the period between 1985 and 2020 from 0.5% initial areal share to 1.38%, respectively. Both LULC classes have simultaneously grown in the study period; however, the annual expansion rate of the Settlement (1.8 Km²/annum) is much lower as compared to the Cultivated land (27 Km²/annum). On the contrary, areas covered by Woodland progressively diminished from 23.54% in 1985, to 22.28% in 1995, to 6.21% in 2005, and to 3% in 2020 with negative annual rate change of 41.9 Km²/annum. In the study period, Woodlands showed a drastic shrink in spatial coverage and eventually close to 1500 Km² were lost by the year 2020 which accounts 87.34% of its original area coverage.

The Agro-forest and Afro-alpine classes exhibited moderate change during the study period (1985–2020). Over the first period (1985–1995), the Agro-forest cover showed a decreasing signature from 21.6% to 16.17% of the total watershed. However, its proportion increased to 26.76% in 2005 and then remained almost unchanged till 2020 (26.07%). On the other hand, Afro-alpine accounted for

6.94% of the total watershed area in 1985. In 1995, 2005 and 2020, it accounted 8.38%, 7.12% and 8.60%, respectively, which showed a slight increase during the first and third periods but with a declining signature in the second period. However, over the entire periods, it has grown by about 1.16% in the watershed. Between 1985 and 2020, Agro-forest showed an annual rate of increase by 9.5 Km²/annum while Afro-alpine continued to increase with a rate of 3.3 Km²/annum.

Relative to other LULC classes, Plantation, Water body and Wetland showed a slight modification during the study period (1985–2020). Plantation cover accounted for less than 4.29% of the watershed in 1985. In 1995, 2005 and 2020, it accounted for 4.96%, 5.07% and 4.31%, respectively, which showed a steady growth during the first and second periods but declined in the third period. Similarly, the change observed in the size of the Waterbody was not significant during the study periods but characterized by slight fluctuation. Quantitatively, the Water body declined from 6.01% in 1985 to 5.93% in 1995 and later increased to 5.95% and 6.02% in 2005 and 2020, respectively. Like Water body, the Wetland did not exhibit considerable change. However, the extent of the Wetland was steadily increasing during the study period: 1985 (1.32%), 1995 (1.47%), 2000 (1.5%) and 2020 (1.59%) (Figs. 5, 6). The estimated annual rates of change of the Plantation, Water body and Wetland are shown in Table 7. The results depicted that about 1.2 and 0.1 Km²/annum decrease in Plantation and Water body occurred during the period between 1985 and 2020 while the Wetland has increased by about 0.3 Km²/annum over the same period.

The overall change from 1985 up to 2020 showed that the Settlement, Cultivated land, Afro-alpine, Agro-forest and Wetland LULC types increased by 175.09%, 37.25%, 23.17%, 21.86% and 11.18%, respectively. The highest increment in Settlement and Cultivated land is due to rapid population growth thereby demanding large area for housing and farming to meet their basic needs. The major reason for the expansion of Agro-forest and Afro-alpine LULC

Fig. 5 LULC maps of the ZLW: LULCs for **a** 1985, **b** 1995, **c** 2005 and **d** 2020

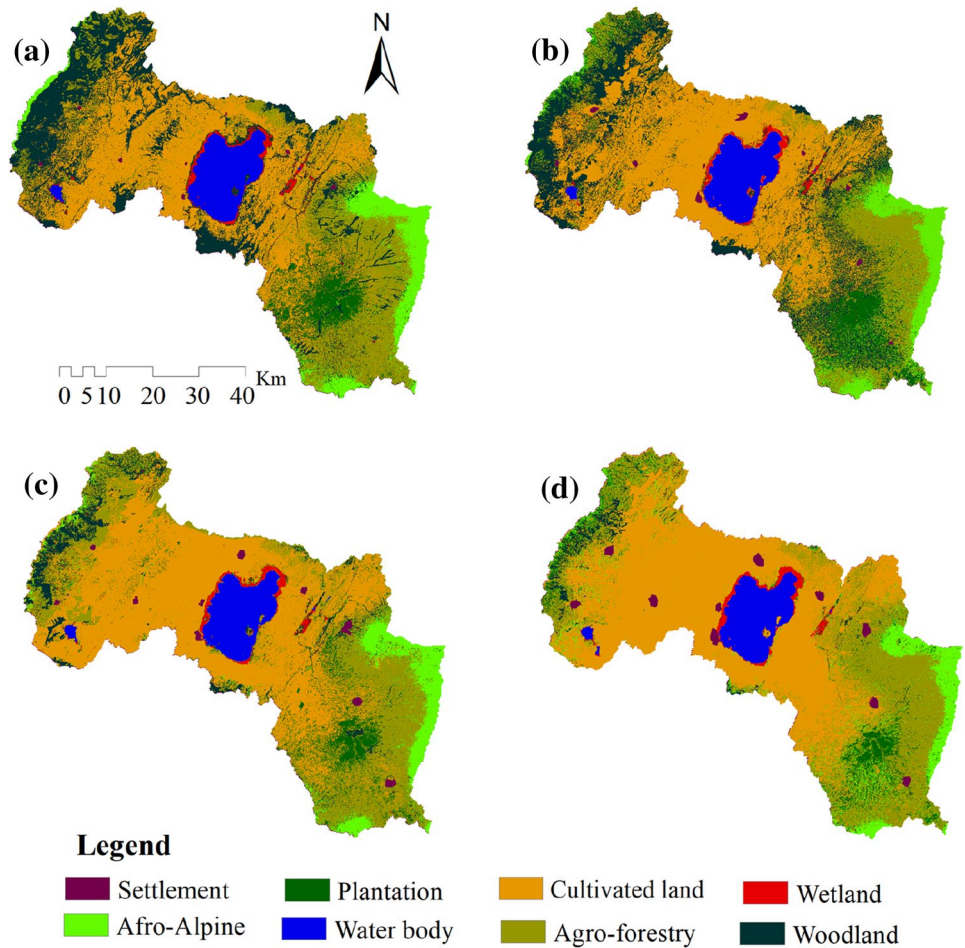
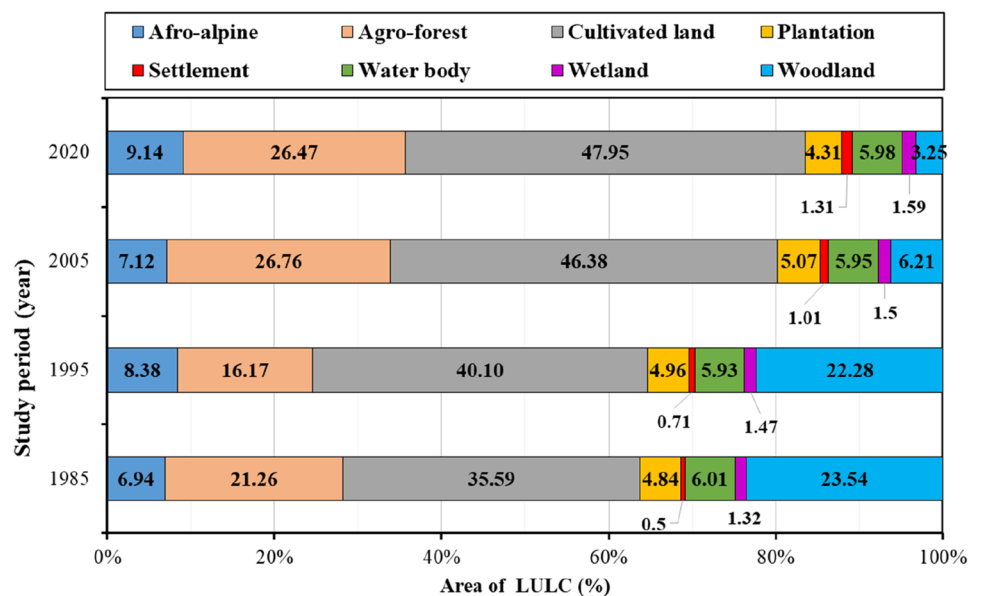


Fig. 6 Percentage areal coverage of each LULC type in the ZLW in the period between 1985 and 2020



categories is the increasing demand for mixed cultivation of crops and commercial wood lots. Due to the unfavorable climatic condition and less accessibility of the steep slopes

of mountainous escarpments both in the western and eastern parts of the watershed, Afro-alpine seems unaffected by human interference. The slight increment in the Wetland has

resulted from the shrinkage of the lake's surface area. Like the rest of the Ethiopian Rift areas where agriculture is the only means of income generation and food supply, agricultural land (Cultivated land and Agro-forest) and Settlement areas are expected to increase in the future if the existing causes of LULC changes are not controlled.

Conversely, Woodland, Water body and Plantation decreased by 87.34%, 1.2% and 0.1%, respectively, in the past 35 years between 1985 and 2020 (Fig. 5). The Woodland is the most significantly degraded LULC type and almost has undergone a dramatic depletion since 1985 (Figs. 3, 4, 5). This can be mainly attributed to intensive and unplanned expansion of an agricultural land in the study area. Moreover, the removal of Woodlands could also be associated with the increased demand for more fuel wood and construction (Desta 2016). In comparison with the other LULC classes, Plantation and Waterbody have shown unnoticeable changes. According to the local elders, the preservation of the Plantation might be due to natural regeneration after cutting and the habit of the community for replantation. In contrast to other Ethiopian rift lakes (Belete et al. 2015; Seyoum et al. 2015), the maintenance of Lake Ziway surface area might be associated with sedimentation processes that have been taking place though this explanation requires further research (Fig. 7).

The outcome of this research is in line with earlier studies done in the central Ethiopian Rift. For instance, an increase in the Cultivated land and a decline in Woodland were also reported by many scholars (Garedew et al. 2009; Meshesha et al. 2012; Gebresslassie 2014; Kindu et al. 2015; Ariti et al. 2015; Elias et al. 2019; WoldeYohannes et al. 2018, 2020; Desta and Fetene 2020). Similarly, recent studies (WoldeYohannes et al. 2020; Desta and Fetene 2020) also found minor fluctuation in the Water body and Plantation areas. On the other hand, Garedew et al. (2009) and Kindu et al. (2015) also documented a decline in Agro-forest and Afro-alpine. The increase in Settlement areas in ZLW is consistent

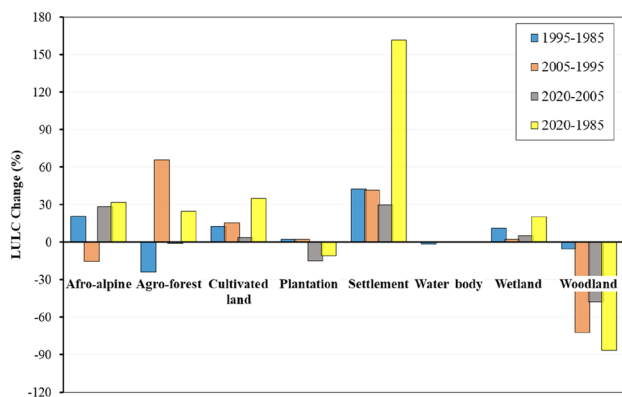


Fig. 7 The percentage area changes for every LULC classes for four periods (1985–1995, 1995–2005, 2005–2020 and 1985–2020)

with other studies in different parts of Ethiopia (Gete and Hurni 2001; Getachew and Melesse 2012) and elsewhere in the world (Gyamfi et al. 2016; Karamage et al. 2017). The performance of the SWAT model was evaluated by using various statistical techniques.

SWAT model performance

The visual inspection of the measured and simulated hydrographs for the calibration (1981–2000) and validation (2001–2014) periods showed that the seasonal variability of the stream flows is well identified by the model (Fig. 8). Besides the visual observation, the performance of the model was evaluated statistically against R^2 , NSE and PBIAS for the monthly calibration and validation periods as presented in Table 5. The goodness of fit measures is well beyond the suggested minimum values ($R^2=0.60$, $NSE=0.50$ and $15 < PBIAS < -15$) (Gupta et al. 1999; Krause et al. 2005). Although the performance of the model was satisfactory, still relatively low association was detected. This might be related with the quality of input data sets, particularly

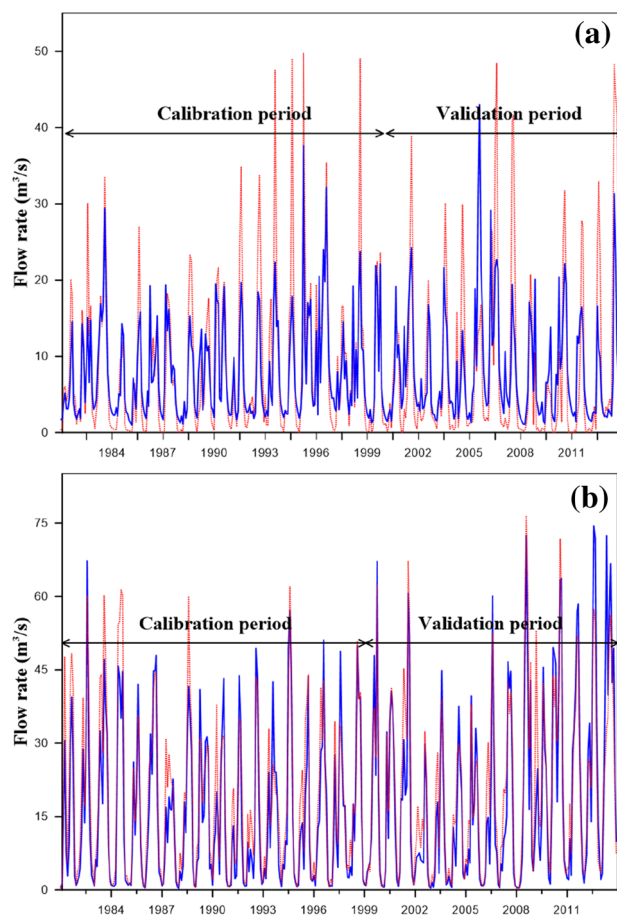


Fig. 8 Measured versus simulated flow for **a** Meki and **b** Katar rivers for calibration and validation phases

Table 5 Goodness fit for stream flow calibration and validation phases

Gauging station	Model stage	Objective functions		
		R ²	NSE	PBIAS
Katar	Calibration (1981–2000)	0.86	0.84	– 3.7
	Validation (2001–2014)	0.85	0.83	3.2
Meki	Calibration (1981–2000)	0.73	0.67	– 12.0
	Validation (2001–2014)	0.79	0.78	5.9

the rainfall used during the modelling process. Rainfall is strongly variable across the watershed (Hordofa et al. 2022); however, this variability is poorly represented in the model due to uneven distribution of rainfall stations (Fig. 3) which might be a cause of deviation. The errors in river discharge measurements can also contribute to uncertainties. However, the overall model fit was found to be beyond satisfactory for both stations during calibration and validation phases which can be used for impact studies.

Impacts of LULC change on the hydrology of ZLW

Historic impacts of LULC change on hydrologic parameters at watershed and sub-watershed scale

The impact of LULC changes on the water balance components of the ZLW was examined by running the SWAT model after successful calibration and validation processes. To simulate the impact, SWAT input parameters were held constant except LULC maps following many researchers (Getachew and Melesse 2012; Gebremicael et al. 2013; Gwate et al. 2015). Based on this, the simulated results of 1985, 1995, 2005 and 2020 LULC maps/scenarios were used to evaluate the hydrological response of the major water balance components: Surface runoff (SURQ), Groundwater recharge (PERC), Evapotranspiration (ET) and Water yield (WYD). Table 6 and Fig. 9 depict the average annual watershed scale values for these water balance components. With this representation, SURQ and PERC showed noteworthy changes relative to other water balance components under each LULC scenarios.

With reference to the respective LULC scenarios, it was observed that SURQ showed a consistent increment from 131.77 mm in 1985 to 155.41 mm in 1995 and 168.19 mm in 2005 to 246.51 mm in 2020 (Table 6; Fig. 9). The overall change between 1985 and 2020 indicated that the mean annual SURQ from the watershed increased by 87.07% (Fig. 10). The uninterrupted rise in the annual SURQ can be associated with the fact the soil was poorly covered between 1985 and 2020 or even barely showing a lower interception and higher CN than in the reference year 1985. The poor cover of the soil in the area is directly linked with

Table 6 The average and percentage change of the water balance components representing the four historic LULC periods in the ZLW

Year	Water balance components (mm/year)			
	ET	PERC	SURQ	WYLD
1985	564.83	197.47	131.77	238.42
1995	552.40	187.81	155.41	256.68
2005	588.04	149.86	168.19	245.16
2020	592.56	72.63	246.51	314.38
<i>Estimated change (%)</i>				
1995–1985	– 2.20	– 4.89	17.94	7.66
2005–1995	6.45	– 20.21	8.23	– 4.49
2020–2005	0.77	– 51.53	46.56	28.23
2020–1985	4.91	– 63.22	87.07	31.86

the unstoppable conversion of Woodland and Plantation to an agricultural land (Cultivation and Agro-forest) and the increase in Settlement areas in the watershed since 1985. Similar results were reported in earlier studies elsewhere in the Ethiopian Rift (Belihu et al. 2020; Kalsido and Berhanu 2020; Bekele et al. 2021; Nigusie and Dananto 2021; Sulamo et al. 2021). On the contrary, PERC was observed to have shown a continuous drop under all scenarios. It reduced from 187.81 mm in 1985 to 19.89 mm in 1995 and further declined from 149.86 in 2005 to 72.63 mm in 2020 thereby representing a total reduction of 37.63% during the

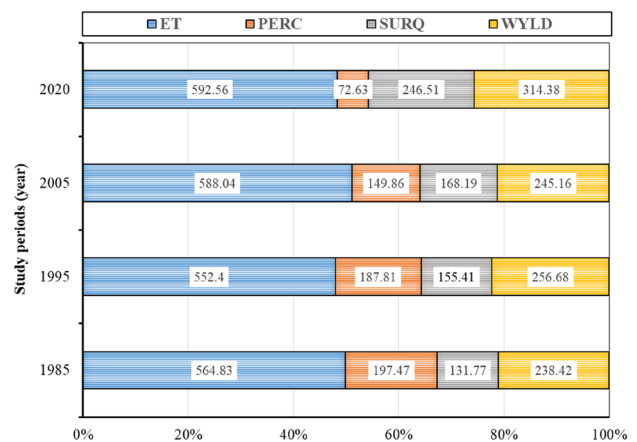


Fig. 9 The average annual water balance components representing 1985, 1995, 2005 and 2020 LULC of ZLW. In addition to the major water balance components, SWAT simulated a reasonable estimate of WYLD (Table 6 and Figs. 9, 10). The WYLD increased from 238.42 to 256.68 mm in the first period (1985–1995), reduced from 256.68 to 245.16 mm in the second period (1995–2005) and finally rose from 245.16 mm to 314.38 mm in the third period (2005–2020). The overall relative changes from 1985 up to 2020 in the study periods revealed that WYD has increased by 31.86%. This is mainly associated with the decline of Woodland and Plantation and intensification of agriculture practices which resulted in high SURQ in the watershed over the past 35 years

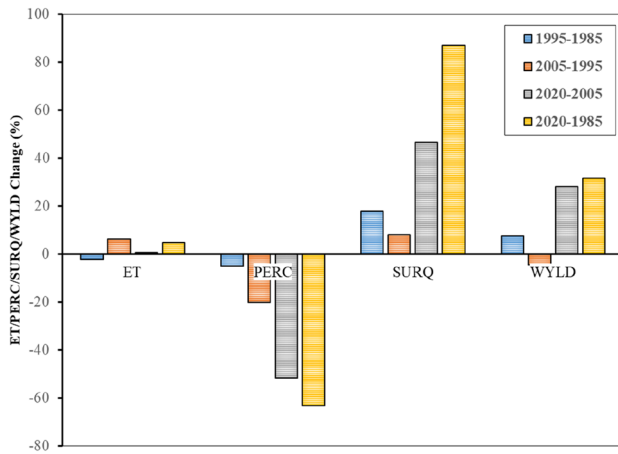


Fig. 10 The percentage change of the water balance components (ET, PERC, SURQ and WYLD) between 1985 and 2020 in the ZLW

study period. The aforementioned studies in Ethiopian Rift also have confirmed a similar trend in PERC. The decline in annual PERC can be attributed to a lesser soil infiltration and higher SURQ and higher ET in the study periods.

The impact of LULC change is also visible on the annual ET though the change is not substantial (Table 6 and Figs. 9, 10). Evapotranspiration showed a decreasing trend in the first period from 564.83 mm (1985) to 552.40 mm (1995). However, in the next periods, it is observed to rise from 552.40 mm (1995) to 592.56 mm (2020). The overall relative change (1985–2020) in the entire study periods indicated that ET has increased by 4.91%. The slight increment in ET is associated with the increase in agricultural land (Cultivated land and Agro-forest) as well as a slight increase in Afro-alpine and a decline in the Water body which leads to an increase in the rate of transpiration and evaporation.

Besides the watershed scale, the spatial distribution of the annual water balance components (ET, PERC, SURQ and WYLD) due to LULC changes over the entire study period (1985–2020) are shown in Fig. 11. The result of the LULC changes showed an increase in the WYLD (Fig. 11a) and SURQ (Fig. 11b) although the relative change is variable across the watershed. The most significant change in WYLD is exhibited in the eastern part of the watershed (Katar sub-watershed) while high SURQ occurred in the western part of the study area (Meki river sub-watershed) where extensive conversion of Woodland to Cultivated land is visible (Fig. 5). On the contrary, PERC generally showed a decrement in the entire watershed between 1985 and 2020 (Fig. 11c) which can be attributed to high SURQ and ET in the study periods. The increase in PERC which was observed in the head water of Katar sub-watershed might be related with the growing size of Afro-alpine by 8.6% between 1985 and 2020 which lowers the rate of SURQ. The maximum changes of PERC which was seen in the Meki sub-watershed is associated with

the expansion of agricultural land in the area (Fig. 5) which leads to higher SURQ. Evapotranspiration (Fig. 11d) showed a relatively slight change as compared to other water balance components. Even though the relative change during the study period seems to be lower, a slight change in ET can bring a significant change on the other water balance components. Hence, besides rainfall, ET has also a major control on the distribution of other water balance components in the ZLW. The spatially distributed map for average annual ET in the watershed indicated that an increase in ET was significantly observed at the western (Meki sub-watershed) part of the study area. The upsurge in ET around the intensively cultivated regions could be attributed to an increase in both transpiration and soil evaporative demand arising from a net increment in an agricultural land.

In order to elucidate the role of individual LULC types on water balance components, Pearson correlation coefficient of the LULC types with the water balance components of the ZLW was determined (Table 7). It is evident that a strong relationship exists between the LULC types and water balance components. Cultivated land and Settlements were found to have significant negative correlations with PERC and positive correlations with SURQ and WYLD. On the other hand, Woodland and Plantation have positive correlation with PERC and negative correlations with SURQ and WYLD. This suggests that increase in Cultivated land and Settlements areas within the watershed causes increase in WYLD and SURQ while decrease in PERC. Agro-forest, Cultivated land and Settlements were found to have a positive correlation with ET. Similarly, the correlation test was carried among the water balance components (Table 7). A significant positive correlation exists between SURQ, WYLD and ET; however all these water balance components showed a negative correlation with PERC. The association between these water balance components suggest that the change in LULC of the area gradually impacted the available groundwater resources in the study area since 1985.

Impact of LULC change on river discharge

Alongside with water balance components, this study evaluated the impact of LULC change on the flux of Meki and Katar rivers which are the major rivers draining the ZLW. The seasonal variation of stream flow was appraised on wet (July, August and September) and dry (January, February and March) months. The wet and dry mean monthly stream flow of 1985, 1995, 2005 and 2020 and also the change with each and overall periods are displayed in Table 8. Moreover, the mean monthly stream flow for 1985, 1995, 2005 and 2020 are shown in Fig. 12. These results have depicted that there was a change in river flows over 35 years. Meki river discharge showed a decrement throughout the simulation periods of dry seasons (1995–1985, 2005–1995 and

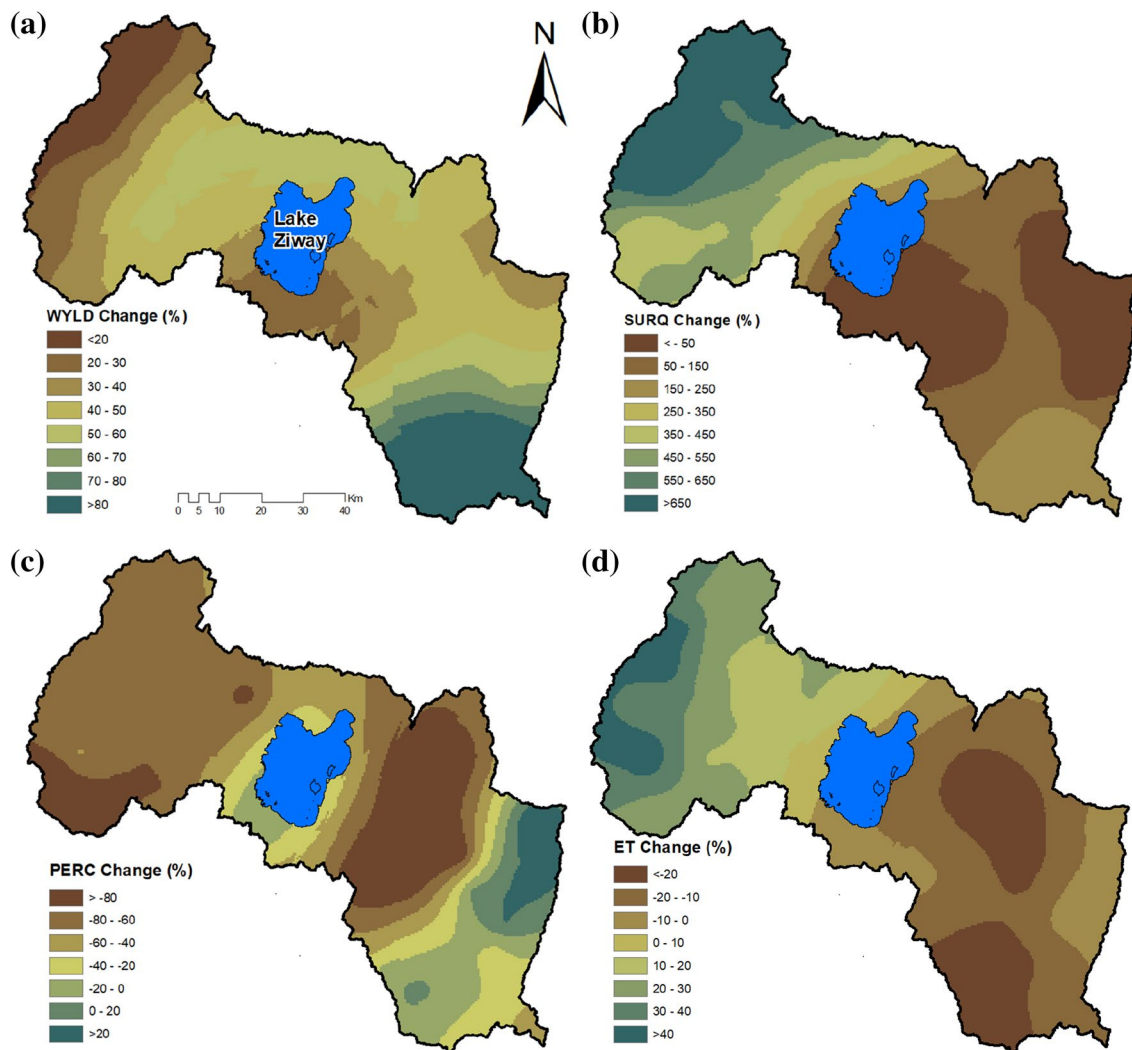


Fig. 11 The spatial distribution of percentage change in WYLD (a), SURQ (b), PERC (c) and ET (d) between the period 1985 and 2020

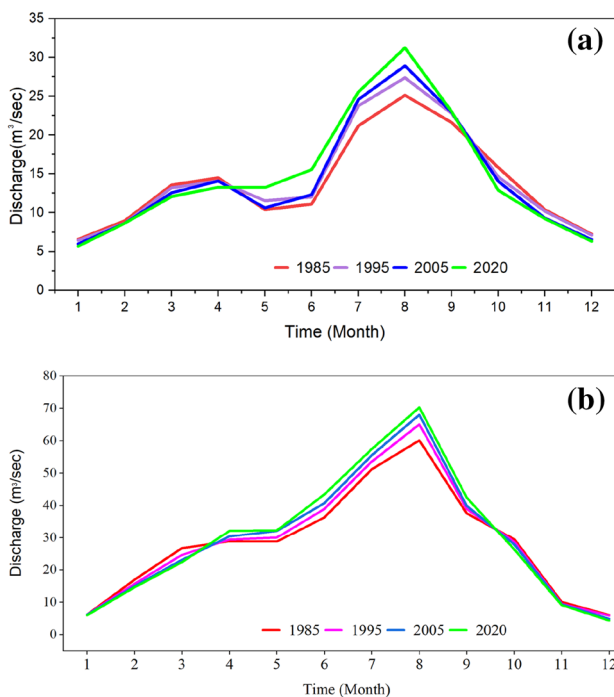
Table 7 Pearson correlation established for seven LULC types and water balance components

	RNGE	FRST	AGRL	EUCA	URML	WETN	RNGB	ET	PERC	SURQ	WYLD
RNGE	1.00										
FRST	-0.24	1.00									
AGRL	0.45	0.70	1.00								
EUCA	-0.59	-0.33	-0.46	1.00							
URML	0.54	0.68	0.97	-0.66	1.00						
WETN	0.52	0.26	0.80	0.00	0.68	1.00					
RNGB	-0.24	-0.86	-0.96	0.47	-0.94	-0.65	1.00				
ET	0.00	0.97	0.83	-0.48	0.83	0.39	-0.95	1.00			
PERC	-0.54	-0.68	-0.89	0.81	-0.97	-0.50	0.89	-0.83	1.00		
SURQ	0.68	0.54	0.86	-0.84	0.96	0.53	-0.82	0.72	-0.98	1.00	
WYLD	0.79	0.33	0.71	-0.92	0.85	0.39	-0.64	0.54	-0.91	0.96	1.00

RNGE (Woodland), FRST (Agro-forest), AGRL (Cultivated land), EUCA (Plantation), URML (Settlement), WATR (Water body), WETN (Wetland), RNGB (Afro-alpine), ET (Evapotranspiration), SURQ (Surface Runoff), PERC (Groundwater recharge), WYD (Water yield). Significant value at $P=0.05$ are shown in Bold

Table 8 Dry and wet period seasons' average stream flow results of 1985, 1995, 2005 and 2020

Year	Dry month		Wet month	
	Katar	Meki	Katar	Meki
1985	19.15	10.94	46.29	19.75
1995	18.74	10.72	49.13	21.49
2005	18.60	10.23	51.04	22.18
2020	18.41	10.17	53.40	23.83
<i>Change detection (%)</i>				
1995–1985	– 2.14	– 2.01	6.14	8.81
2005–1995	– 0.72	– 4.57	3.89	3.21
2020–2005	– 1.05	– 0.59	4.62	7.46
2020–1985	– 3.86	– 7.04	15.36	20.66

**Fig. 12** Seasonal Meki (a) and Katar (b) rivers flow due to LULC changes between 1985 and 2020

2020–2005) by 2.01, 4.57 and 0.59%, respectively. However, it showed an increment during wet seasons of the study periods by 8.81, 3.21 and 7.46%, respectively (Table 8 and Fig. 12). Over the entire period (1985–2020), it is found that the mean monthly stream flow was decreased by 7.04% during dry months and increased by 20.66% in wet months for Meki river. Similar trend was also observed for Katar river during the dry and wet periods (Table 8). It showed a continuous decrement by 2.14 (from 1985 to 1995), 0.72 (from 1995 to 2005), 1.05 (%) (from 2005- to 2020) during the dry season. During wet period, it showed an increment by 6.14% (1985–1995), 3.89% (1995–2005) and 4.62% (2005–2020).

Over the entire study period (1985–2020), as presented in Table 8, the mean monthly stream flow declined by 3.86% and rose by 15.36% for Katar river during dry months and wet months, respectively.

The increment of stream flow during wet seasons in both sub-watersheds (Meki and Katar) is mainly associated with the expansion of agricultural land at the expense of other LULC types particularly Woodland. During wet season, the incoming rainfall was converted into SURQ more quickly in the agricultural land than Woodland due to low infiltration and canopy interception (Gebremicael et al. 2018). On the contrary, this phenomena also results in the reduction of water infiltrating in to the ground which drops groundwater storage in aquifer and flow towards streams during the dry period. The finding of this study is consistent with other studies carried out in Ethiopian Rift and elsewhere in other Ethiopian regions (Kebrom and Hedlund 2000; Gete and Hurni 2001; Solomon et al. 2010; Abate 2011; Rientjes et al. 2011; Gebremicael et al. 2013; Temesgen et al. 2014) in which the average monthly stream flow rises and declines during wet and dry seasons, respectively, due to LULC change.

Based on the results of this research, it can be concluded that ZLW had experienced a substantial LULC change over the past 35 years. Deforestation and an increase in agricultural land triggered by the rapid population growth have modified the LULC in the entire watershed in general and Meki sub-watershed in particular. Alteration of LULCs (rain-fed to small-scale irrigations) are also anticipated in the near future as farmers in the down streams (rift floor) have already in a good progress of using both groundwater and surface water to cultivate market-oriented cash crops such as onion, tomato and others. The evaluation of the historical LULC changes and its subsequent impacts' analysis on stream flow and water balance components revealed the urgent need to devise effective watershed management strategies prior to the occurrence of extreme events in the area.

Hypothetical LULC change scenarios

Even though obvious changes in water balance components and stream flow have been observed with historical LULC change, the impacts of some hypothetical LULC change scenarios is required to further understand the sensitivity of ZLW hydrology. For this purpose, two (Bad and Good) land management scenarios were tested based on past and possible future LULC condition of the region. The first scenario, the Bad management scenario (Case-I) reflect the possible LULC changes such as the expansion of Cultivated land, the replacement of Woodland with rain-fed agriculture, which is a widespread phenomenon in ZLW. To reproduce this trend, a gradual change from Woodland to Cultivated land was considered by assigning 0 (no change), 20, 40, 60, 80 and

100% changes, where 100% represents complete removal of the Woodland. In each phase, the area under Cultivated land increases by 20% to compensate the decline of Woodland area while the other LULC classes remained unchanged. On the contrary, the Good management scenario (Case-II) is considered in relation with the watershed rehabilitation activities started in 2019 by the Government of Ethiopia in a bid to combat climate change and environmental degradation. Therefore, a gradual Woodland recovery at the expense of Cultivated land was applied in a similar fashion with Case-I to explore the impacts on water resources of ZLW.

Figures 13 and 14 provide the impacts of gradual LULC change scenarios on ET, SURQ, PERC and WYLD. This hypothetical scenario (Case I) suggests that intensification of Cultivated land at the expense of Woodland would have a significant impact on the water balance components of the study area. For example, the complete replacement of Woodland by Cultivated land increases the simulated ET by 0.31% and SURQ by 6.53%. On the contrary, this change triggered the decline of PERC and WYLD by 7.18% and 0.91%, respectively. However, locally at sub-watershed scale

(e.g., sub-watershed-6; see Fig. 3) where the Woodland is the dominant LULC type, the impact is more prominent than the watershed scale. This change resulted in a decrease of 0.36% and 22.06% in PERC and WYLD, respectively, whereas this change also triggered an increase of 0.21% in ET and 20.18% in SURQ. In general, this gradual LULC change scenario showed closer to the linear response of the water balance to Woodland removal. The finding of this hypothetical scenario further justified that the change in the water balance components in the watershed since 1985 were mainly attributed to the conversion of Woodland to Cultivated land.

Figures 11 and 12 show that the percent changes in the annual average water balance components for the Second scenario representing the gradual conversion of Cultivated land to Woodland area. It is evident that SURQ and PERC is the most sensitive followed by ET and WYLD. This suggested that Woodland could not only uptake water through leaves and roots but also facilitate the infiltration of rainwater into the aquifer. Therefore, more positive result might come from watershed rehabilitation initiatives. The hypothetical

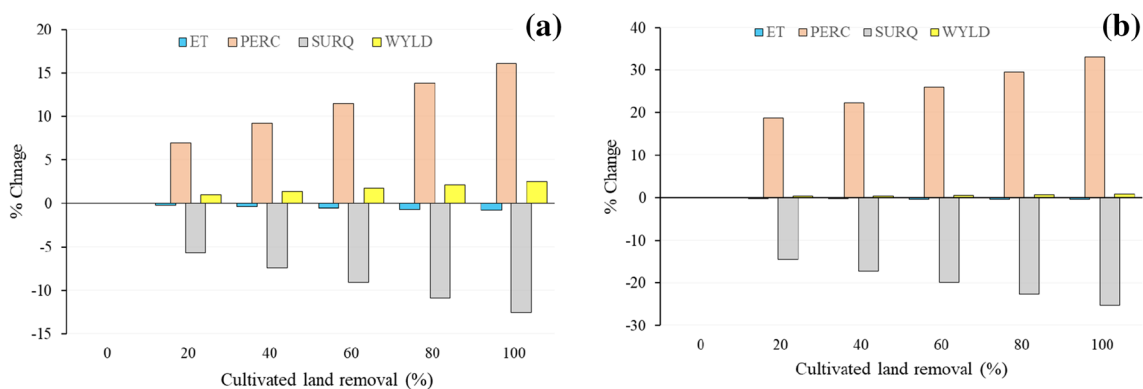


Fig. 13 Percentage change of ET, PERC, SURQ and WYLD plotted against percentage of Woodland removed from the entire watershed (a) and sub-watershed (b) based on the gradual LULC area change scenarios

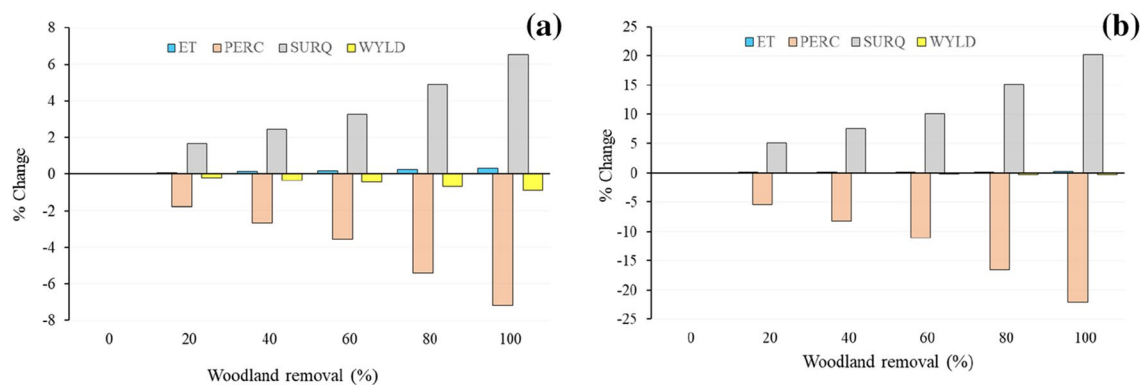


Fig. 14 Percentage change of ET, PERC, SURQ and WYLD plotted against percentage of Woodland removed from the entire watershed (a) and sub-watershed (b) based on the gradual LULC change

LULC change scenario applied in this research is the base to a comprehensive contribution of the Woodland and Cultivated land to the water balance components. Although the result from the scheme is not detailed, the significance of the aforementioned LULC types can be deduced from this paradigm.

Conclusion

In this study, RS and GIS techniques were integrated with hydrological modelling in order to evaluate the impact of LULC changes on the hydrology of ZLW in the Ethiopian Rift. Remote sensing and GIS were utilized to produce LULC maps of 1985, 1995, 2005 and 2020 and to analyze the LULC dynamics in the study area. Calibrated and validated SWAT model was utilized for hydrological modeling to track the magnitude, trend and impact of LULC dynamics on the major water balance components including the stream flows of the watershed.

From the LULC change analysis results, it can be concluded that ZLW has experienced a significant LULC change over the past 35 years. The overall change from 1985 up to 2020 for Settlement, Cultivated land, Afro-alpine, Agroforest and Wetland was increased by 175.09%, 37.25%, 23.17%, 21.86% and 11.18%, respectively. In contrast, Plantation, Water body and Woodland were decreased by 1.2%, 0.1% and 87.34%, respectively. At the watershed scale, 58.3% of the watershed has remained unchanged while 41.7% of it has shown some degree of change. Among the identified eight LULC types, Settlement, Cultivated land and Woodland were found to be the most significantly modified LULC classes. These changes are primarily due to the increased demand of land for agricultural and Settlement purposes along with increased energy demand for fire-wood and charcoal in the watershed.

After successful SWAT model calibration and validation at Meki and Katar river gauging stations, the impacts of historic LULC changes on the hydrological balance of ZLW was assessed. LULC changes from 1985 up to 2020 showed major influences on the annual water balance components such as SURQ, PERC, WYLD and ET. At the watershed scale, the hydrological response due to LULC changes indicated that SURQ was increased by 87.07%; PERC was decreased by 63.22%; WYLD was raised by 31.86% and ET was raised by 4.91% between the years 1985 and 2020. However, the spatial change analysis of the water balance components due to LULC changes were found to be variable across the watershed. Both WYLD and SURQ were increased in the entire watershed. However, the most significant change in WYLD was exhibited in the Katar sub-watershed while high SURQ was observed in the Meki river sub-watershed. Generally, PERC showed a decrement in the

entire watershed but the pronounced changes of PERC was shown in the Meki sub-watershed. Similarly, the results from seasonal stream flow analysis indicated that the Katar flow is decreased by 3.86% and increased by 15.36% during the dry and wet seasons, respectively. On the other hand, Meki river flow showed a decrement (6.99%) during the dry seasons and an increment (20.67%) during the wet seasons. These changes in water balance components and stream flows were mainly associated with the expansion of agricultural and Settlement areas and reduction of Woodland. More importantly, an increased SURQ may have a wider implication for increasing soil erosion and lake bed sedimentation unless proper management is not implemented. Moreover, the continuous decline in PERC with the aforementioned change rate may highly affect the available groundwater resource of the watershed. Thus, appropriate LULC planning and management of ZLW towards averting the increasing trends of LULC changes before the occurrence of extreme scenarios with respect to a sustainable hydrological balance.

Acknowledgements The authors would like to acknowledge Addis Ababa Science and Technology University (AASTU) (EA-450/3-1/20), for financial support to carry out this research. The authors also acknowledge National Meteorological Services Agency (NMA) and Ministry of Water and Energy (MoWE) of Ethiopia for providing long term meteorological and hydrological data, respectively.

Funding This article was funded by Addis Ababa Science and Technology University, ANSD/02/1252/09, Abraham Mechal.

Declarations

Conflict of interest The authors declare no conflict of interest exists. Abraham Mechal, Tariku Takele, Matebie Meten, Gaddissa Deyassa, Yohannes Degu confirm that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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