



Impact assessment of vegetation loss on the ecosystem functions in a semiarid watershed in Iran

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Abstract

The main purpose of this study is to investigate the effects of land cover changes and vegetation loss under conditions of change in climatic parameters (temperature and precipitation) and determining their impacts on different ecological functions in the eastern watershed of Lake Urmia and its four sub-watersheds in northwestern Iran. The method used has been a quantitative assessment of selected ecosystem functions using a self-parameterizing, physically based model called Water World Policy Support System as well as applying satellite images to detect land-use/cover changes. Modeling of important ecological and hydrological parameters including vegetation density, water balance, surface runoff, and soil erosion was performed and for each of them, the quantity of changes was calculated and mapped. Then, by standardizing the maps for each parameter and overlapping them, cumulative impact levels across the watershed were classified. The result showed that with decrease in rainfall and increase in temperature, the average vegetation density decreased by 32% in the watershed and from 79 to 47%. Decreased vegetation, followed by increased runoff by about 2.5% and equivalent to 19,656.95 cubic meters per year. Consequently, the average net soil erosion has been changed from -0.012 to 0.20 mm per year per square meter. Hence, the average soil erosion in the watershed has increased by more than 3 tons per hectare. Based on the final results, more than 40% of the watershed area is under severe and very severe ecological impact.

Keywords Land use/cover · Ecosystem function · Environmental impact · Self-parameterizing model · Lake Urmia

Introduction

Vegetation acts as a critical factor in improving the ecological capacities, functions, and stabilizing the natural conditions of each region. It also creates a balance between the key elements of the environment including water, soil, and air. Grassland ecosystems play a vital role in providing a variety of ecosystem goods and services over time (De Groot et al. 2010). For example, large vegetation patches provide benefits such local climate regulation, habitat for indigenous species, and improved biodiversity as an important part of the landscape structure. Also, riparian corridors with good vegetation control sediment and erosion, maintain the quality of aquatic habitats, and the soil protected in the infiltration areas of water branches (McGarigal and Marks 1995; TT 1995; Dramstad et al. 1996). Therefore, in ecosystem assessments, large patches of natural vegetation are considered a vital landscape pattern. Although the vegetation pattern of each landscape and its structural components is the result of the interaction between physiographic conditions, climate (temperature and precipitation), natural disruption

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regime, and human use of the landscape, there is ample evidence that vegetation in different parts of the world has been severely affected by both climate and land-use changes in recent decades (Dirnböck et al. 2003; Galbraith et al. 2010; Hanewinkel et al. 2013; Riordan and Rundel 2014; Song et al. 2018).

Lake Urmia in a semiarid watershed in northwestern Iran is one of the international wetlands under the Ramsar Convention (<https://www.ramsar.org>), with significant economic, social, tourism, and environmental importance. However, the declining trend of the lake water level and its gradual drying up over the last two decades has raised many concerns (Khazaei et al. 2019). Due to the settlement of more than 3 million people around the lake, the existence of gardens, agricultural lands, and a variety of animal and plant species, if the problem worsens and dries up completely in the coming years, it could lead to a national crisis for environmental health and destroy the habitability and livelihood of the people of that area. In previous studies, various reasons have been identified for this problem, the most important of them is unprincipled conversion and land-use change, including the development of agricultural lands and gardens (Fathian et al. 2013; Mohammad et al. 2015); hydrological changes due to more withdrawals from the downstream river (Fathian et al. 2015, 2016b; Ahmadaali et al. 2018); as well as climate change (increase in average temperature and decrease in precipitation) (Delju et al. 2013; Alizadeh-Choobari et al. 2016; Shadkam et al. 2016; Khazaei et al. 2019; Tahroudi et al. 2019). Especially as this problem intensifies, a considerable vegetation loss in the lake watershed gradually impacts the plant index species of the region. (Talebi et al. 2016; Sobhani et al. 2019; Balkanlou et al. 2020; Ghorbanalizadeh et al. 2020). Therefore, the importance of conducting this study in the watershed of Lake Urmia is to introduce a suitable method for measuring the cumulative impacts of land-use and vegetation cover changes. This method is even useable in other watersheds that experience similar conditions.

In recent years, several studies in different parts of the world have emphasized the use of the concept and tools of the spatiotemporal modeling of the ecosystem functions as an appropriate method for assessing environmental impacts and consequences (Galic et al. 2012; Munns Jr et al. 2016; Dong et al. 2018; Kang et al. 2018; Faber et al. 2019; Xing et al. 2020). The most important advantages of using such models in environmental impact assessment are the possibility of handling large quantities of data, establishing links between changes in various components of the environment and the impact of human actions on them nonlinearly, enabling the measurement of environmental changes over time dynamically and not statically, and the possibility of mapping spatial distribution impacts in the watershed. However, many environmental impact

assessment studies in developing countries still use traditional descriptive methods using matrices and checklists based on qualitative expert judgments. These qualitative methods are generally subjective and based on simple linear relationships between natural components and environmental impacts. Therefore, they cannot show clearly the complex relationships between ecosystem components and environmental impacts and cannot be mapped. In Iran, only a few studies in the last few years have applied spatially explicit models to quantify alterations in ecosystems under the influence of various drivers of change, including land-use and climatic parameters (Zarandian et al. 2016, 2017, 2018; Sadat et al. 2019; Daneshi et al. 2020; Mirsanjari et al. 2020; Nematollahi et al. 2020). However, this study focuses on ecosystem function modeling to assess cumulative eco-hydrological impacts caused by the loss of vegetation at the watershed scale. Then, the result outputs of the modeling approach used for spatial zoning of areas have been most impacted by ecological consequences.

For this purpose, the main stages of the research are briefly: (a) determining the baseline (past/the year 2000) status of the selected physio-ecological parameters including land cover/land use (LULC), climatic parameters (temperature and precipitation), vegetation, hydrological parameters (runoff, water balance, and soil erosion) of the Lake Urmia watershed; (b) assessing the existing (after 15 years/the year 2015) status of the selected physio-ecological parameters and their changes, based on simulations with the model used; (c) analysis of ecosystem impacts due to vegetation loss using the results of the previous two steps; and (d) zoning of cumulative ecological impact levels in the watershed.

A novel approach in this research is to use a self-parameterizing physically based model which can provide detailed spatial datasets at various ecological scales such as watersheds for rapid quantitative environmental assessments. Its key innovations include the fact that it comes with all data required for application, is very high spatial resolution (1 km or 1 hectare) and yet global in extent, and is particularly well suited to heterogeneous environments with little or no available data.

The produced maps and suggestions of this study are applicable in quantitative environmental assessments to increase the awareness of policy and decision makers. Also, such investigative outcomes can help to determine workable strategies to reduce/prevent existing and future adverse environmental consequences, adapt to current conditions, and in general, improve the state of water and land management in the Lake Urmia watershed. The method used in this research can also be used to assess and map the environmental status of other areas and to conduct quantitative environmental assessments instead of purely descriptive methods.

Materials and methods

Study area and data collection

The Urmia Lake watershed in northwestern Iran is an inland area in which all rainwater runoff flows to the central saline lake. This large watershed includes several sub-watersheds with an area of 52,000 square kilometers. However, in this study, only a part of the eastern boundary of the watershed located in the province of East Azerbaijan (Fig. 1a), consisting of four sub-watersheds: Aji Chai, Qala Chai, Sufi Chai, and Marduq Chai (Fig. 1b), was studied, with an area of 15,783 square kilometers and under the title of Eastern watershed of Lake Urmia.

The watershed of Lake Urmia is generally a mountainous area that includes two famous volcanic peaks of Iran, namely Sahand (3707 m) and Sabalan (4810 m), and large areas of fertile land in the valleys and around the lake. Most parts of the watershed are located at an elevation of more than 1280 m above sea level. The main characteristic of geology, especially in the eastern part of the basin, is the high erodibility of geological formations (Alkhayer et al. 2019), which has a major role in the concentration of sediment load of river flows, especially in flood seasons. In such circumstances, the role of watershed vegetation in neutralizing the erosive potential of its geological formations is crucial. Climatically, the study area has cold winters and relatively temperate summers. The average annual rainfall in the Urmia Lake watershed in the long run has been 352 mm but, since the mid-1991s, a long period of drought has severely affected the hydrological condition of the watershed (Farajzadeh et al. 2014). The average annual air temperature recorded in the watershed varies between 6.4 and 13.2 °C (Fathian et al. 2016a). The four sub-basins that make up our study area (Fig. 1b) provide a total of about 14% of the water of Lake Urmia. In the study area, the frequency and richness of floristics increase from salt marshes and lowlands to higher elevations (Ghorbanalizadeh et al. 2020). Examination of existing reports shows that there are about 564 plant species from 299 genera and 64 families in the ecological area of Lake Urmia.

There are 26 urban areas and more than a thousand rural points in the study area. The main human activities are agriculture and animal husbandry; however, during the last three decades, with a significant increase in population, urban areas have been developed and several industrial factories have been built in the region. However, the agricultural sector is the main consumer of water resources. In recent decades, 17 dams were constructed or are under construction within the study area to control river flow and act as irrigation networks for water distribution.

Methods

The main methods used in this study include reviewing available information and data from previous research, climatic and hydrological analysis, modeling of vegetation and structural changes in land cover/land use (LULC) in the watershed using satellite images and their analysis in GIS, modeling of various ecosystem functions and their changes due to vegetation loss and then the mapping of areas with the most cumulative impacts due to changes in ecosystem functions (Fig. 2).

Preparation of LULC maps

LULC has two separate terminologies that are often used interchangeably. Land cover refers to the natural assets such as forests, grasslands, water bodies, and so on, while land use refers to a variety of human-made assets such as agricultural farms, human settlements, and urban and industrial infrastructures (Rawat and Kumar 2015). Changes in grassland cover were considered as an indicator of changes in watershed vegetation. Thus, the LULC map was prepared as the first step of this research to determine the rate of vegetation change over time. To produce a LULC map of the study area in the past (baseline) and present (current) time conditions, the 2009 *Landsat images of the Enhanced Thematic Mapper Plus (ETM+)* sensor and the 2015 *Landsat 8* satellite images of the OLI sensor were, respectively, used, with a resolution from 15 to 30 m. Images were downloaded from the Global Land Cover Facility (GLCF) site (<http://glcf.umd.edu/>) and US Geological Survey (USGS) (<http://www.usgs.gov/>). After making radiometric corrections of the images to reduce the reflective effects of the atmosphere, they were processed and classified using eCognition Developer software (Baatz et al. 2005) and by object-oriented classification method (Yan 2003; Benz et al. 2004; Cleve et al. 2008; Blaschke 2010). Normalized Water Difference Index (NWDI) (McFeeters 1996, 2013) and Normalized Vegetation Difference Index (NDVI) (Pettoirelli et al. 2011) were used to extract water cover, agricultural use, rangelands, and scattered vegetation. Finally, the accuracy of the satellite image processing was examined. To form a testing dataset for accuracy assessment, a sample of 450 randomly chosen points (50 points per each LULC class) was utilized (Hay 1979). To assess the classification accuracy, the quality of the class allocation was summarized using a confusion matrix. Table 1 shows the confusion matrix for the 2015 LULC map. Based on the calculations using Table 1, the overall accuracy and Kappa coefficient were, respectively, 90% and 0.88 (for the LULC map of 2015), and 89% and 0.87 (for the LULC map of 2009).

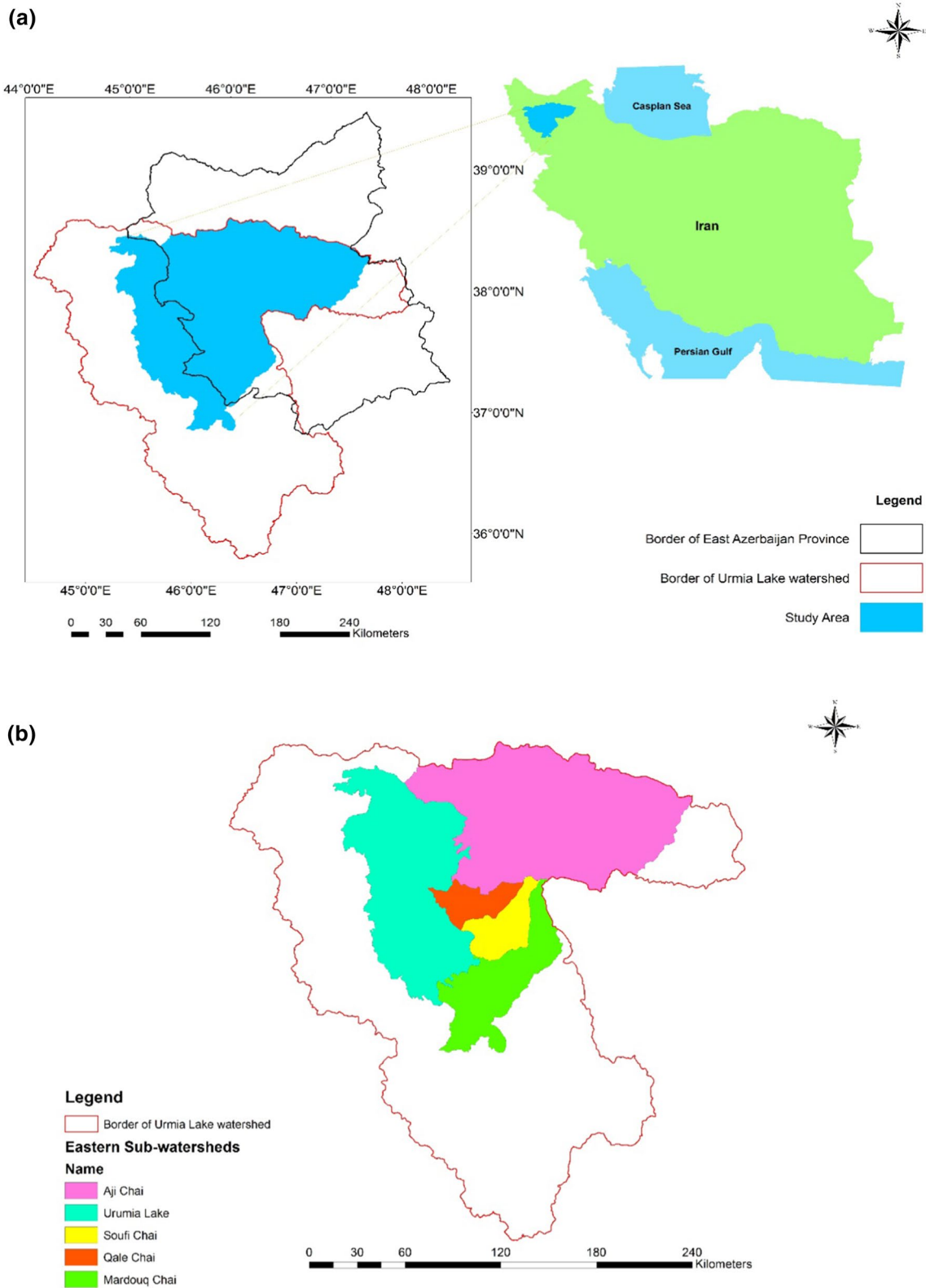


Fig. 1 The geographical location of the study watershed in the West Northern Iran (a); and four sub-watersheds of the Eastern Urmia Lake Watershed (b)

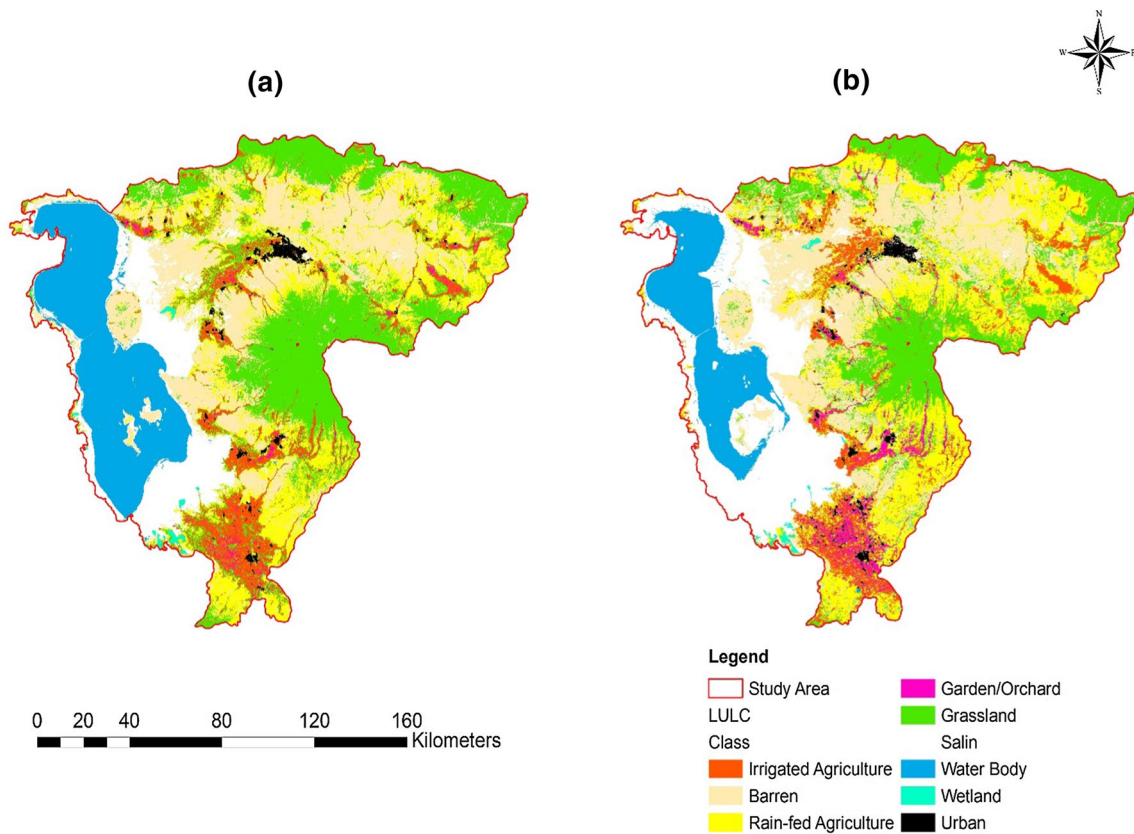


Fig. 2 Comparison between the LULC maps produced for the years 2009 (a) and 2015 (b)

Table 1 The confusion matrix for classification accuracy assessment (LULC 2015), using 450 sample points

Reference data											Row total
		Irrigated agriculture	Barren	Rain-fed agriculture	Garden/orchard	Grassland	Saline	Water body	Wetland	Urban	
Classified data	Irrigated agriculture	26	1	0	3	0	0	0	0	1	31
	Barren	2	105	2	0	3	1	0	0	0	113
	Rain-fed agriculture	3	1	86	0	3	1	1	0	1	96
	Garden/orchard	2	0	2	8	0	0	0	1	0	13
	Grassland	2	1	0	0	65	0	0	0	1	69
	Saline	0	3	0	0	2	73	0	0	0	78
	Water body	0	1	0	1	1	0	35	0	0	38
	Wetland	0	0	1	0	0	0	0	4	0	5
	Urban	0	1	0	0	0	1	0	0	5	7
Column total		35	113	91	12	74	76	36	5	8	450

Time series analysis of climatic parameters (precipitation and temperature)

Based on data availability and location of meteorological stations in the Urmia watershed, data analysis of 7 synoptic stations (including Tabriz, Urmia, Maragheh, Sarab,

Mahabad, Takab, and Saqez stations) was performed to test climatic trends. To determine the boundaries of each meteorological station in the watershed, the Thiessen network (Thiessen 1911) was outlined. Monthly rainfall data and average monthly temperature of 30 years (from 1985 to 2015) of these stations were entered into R software for

time series analysis and a time series diagram was plotted for rainfall and temperature data from each synoptic station. Then, using the area coefficient of Thiessen polygons, the average weight of 7-time series related to rainfall and the monthly temperature was used as the time series of rainfall and monthly temperature of the whole watershed of Urmia Lake. To evaluate the significance of rainfall and temperature trends in synoptic stations and also in the whole Urmia watershed, the Mann–Kendall sequence test (Mann 1945; Kendall 1948) was used.

Modeling vegetation changes concerning key hydrological parameters (runoff, water balance, and soil erosion)

The Water World Policy Support System model (<http://www.policysupport.org/waterworld>) was used (from now on referred to as the WWPSS model) for simultaneous modeling of changes in vegetation and hydrological parameters in the eastern watershed of Lake Urmia. This tool is a self-parameterizing, physically based model developed by the Department of Geography of the King's College London and AmbioTEK a not-for-profit environmental research consultancy specializing in environmental and geospatial monitoring and simulation modeling. The model can produce a hydrological baseline representing the mean water balance for 1950–2000 and allows users to apply ensemble scenarios

for climate change or examine the impact of policy options for land cover change or land management interventions.

Many international studies have used WWPSS to model vegetation change and its relationship with hydrological and drought conditions as well as climate change (Null et al. 2010; Mulligan 2012, 2013; Pandeya 2013; Van Soesbergen 2013; Birch et al. 2014; Velasco Arguello 2014; Mulligan 2016; Peh et al. 2016). Ground cover in this model shows the fraction of tree, vegetation, and barren lands (bare without vegetation) in mosaics with a resolution of 1 square kilometer or 1 hectare, depending on the user's choice obtained from the MODIS VCF satellite sensor. In these satellite images, each cell of the raster network is distinguished into three types of tree cover, vegetation (non-wood cover) and no vegetation (bare lands) (Carroll et al. 2010). In this study, grass, tree vegetation, and barren land cover maps for 2000 are three of the key baseline data that were prepared by connecting to the global Modis satellite database with the initial running of the model and in the data preparation process. Then, the current vegetation status map was produced using the scenario-generating tool of this model. In the modeling process, the rate of changes of grassland vegetation was adapted from the LULC maps. Figure 3 shows the trend of vegetation changes from baseline (3a) to current (3b) and the extent of its changes from the past to present time.

The water remaining after evapotranspiration is called the water balance which is available for various hydrological functions. The water balance in this model is computed by

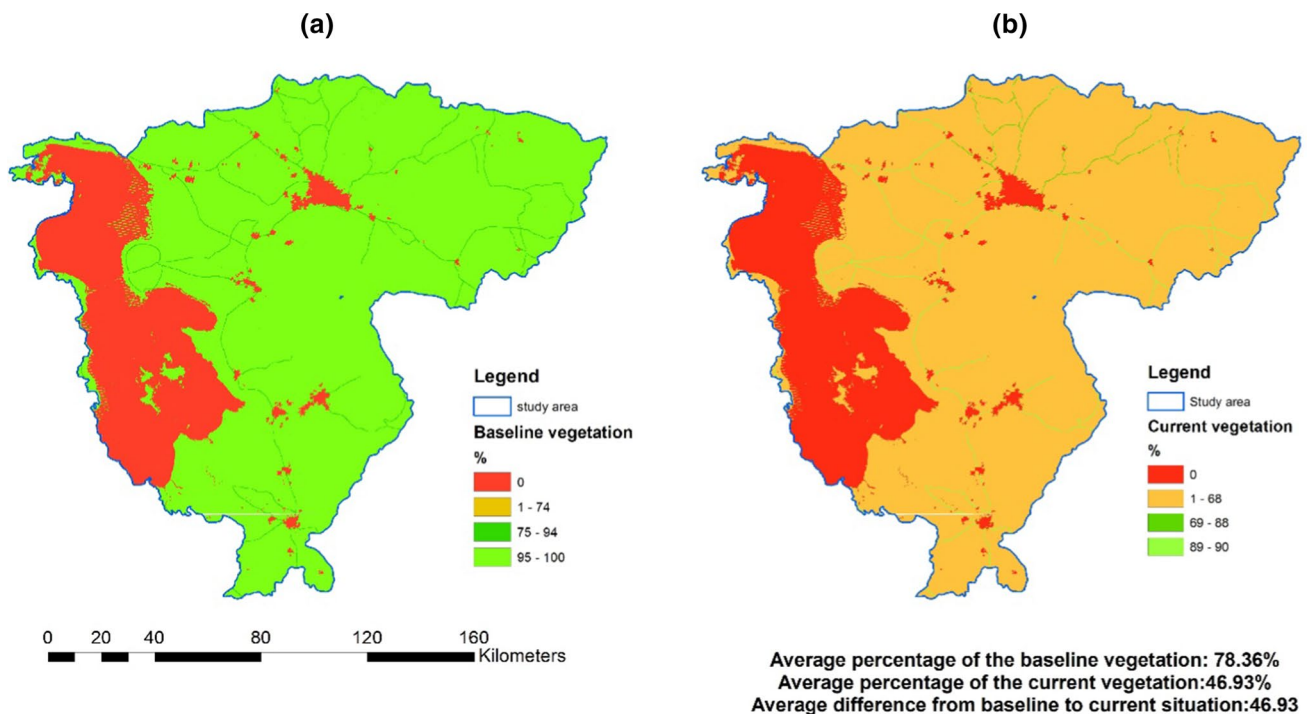


Fig. 3 The trend of vegetation changes from baseline (a) to current (b) and the extent of its changes from the past to present time

calculating the amount of wind-driven precipitation and its aggregation with fog and then subtracting the actual amount of evapotranspiration from them and based on climatic information and vegetation data obtained from remote sensing data. The evapotranspiration of arid and semiarid regions including our study area is greater than the average precipitation received. The difference between precipitation and wind-driven precipitation indicates the effect of wind speed on the distribution of precipitation in an area, because the areas exposed to wind receive more precipitation. Also, the effect of snow and ice on rainfall and temperature and its share in the amount of water obtained from melting snow and ice in this model is simulated.

Water balance and runoff calculation (surface water flow) is one of the main methods for estimating water production in the ecosystem. In this model, cumulative downstream outflow is calculated as total runoff available after deducting actual evapotranspiration from the total precipitation amount. Hence, runoff is calculated as the water balance accumulated in the downstream. Negative water balance (actual evapotranspiration > precipitation) in a cell means upstream runoff consumption. In this study, the WWPSS model was implemented to estimate baseline runoff before vegetation loss using a vegetation baseline map. Then, for the second time, the model was implemented based on the current vegetation status map after its reduction/loss. Then, the results of the outputs of the two stages of model implementation were compared to determine the extent of changes in runoff production.

The details of the equations and processes related to this model and the method of calculations related to various types of climatic, physical, and ecological variables and the validation of the model described in previous studies (Bruijnzeel et al. 2011; Mulligan 2013; Van Soesbergen 2013; van Soesbergen and Mulligan 2014).

Moreover, the WWPSS model can evaluate water quality/regulatory functions such as net soil erosion and sedimentation (Mulligan 2012). In this model, soil erosion is calculated based on the Thornes equation (Thornes 1990). The model presents two key types of outputs for soil erosion calculations, entitled hill-slope erosion and net soil erosion (erosion minus deposition). Erosion refers to degraded soil and sedimentation refers to the amount of soil that accumulates in each of the cells of the raster network. Net erosion is the volume of soil that eventually enters as sediment in waterways and rivers. To run the model, first by adapting the boundary of the eastern watershed of Lake Urmia, on nine 1-degree mosaics (100 km) with a resolution of 1 hectare, the geographical scope of the model run was defined in the software. Then, through the steps of data preparation and simulation, which are the first two steps in the model running process, key maps for water balance (budget), runoff, and net soil erosion generated for the baseline watershed

(before vegetation loss with an average percentage of 78%). The desired hydrological maps for the current state (after the loss of vegetation with an average percentage of 46%) also generated using the software simulation process. Figures 4, 5, and 6 show the status of the water budget, runoff, and net soil erosion for both baseline (past and before vegetation loss) and current (present and after vegetation loss) states, respectively.

Preparing a zoning map of the cumulative physio-ecological impacts due to changes in ecosystem functions

As mentioned earlier, the generation of four maps related to important physio-ecological parameters of vegetation density, water budget, runoff, and net soil erosion was carried out during the modeling process and their changes determined based on metric units. To make it possible to overlay and combine these maps in the form of a single map, which can show the zones with the most changes in all four parameters in aggregate and as cumulative impacts of changes in all four selected ecosystem functions, maps needed to be standardized. For this purpose, the levels of impacts of each parameter were defined in a numerical range of 1–10 using the measured metric units of each parameter acquired by modeling outputs, where the number one means the lowest and the number ten means the highest level of impacts. Appendix 1 shows how these impact rating levels are performed in the 1–10 range and based on the metric quantities obtained from the modeling. Then using the classification and raster calculator tools in Arc Map software, standard maps for each of the four parameters were produced on a scale of 1–10. Finally, by overlaying them together, the map of the cumulative impact levels produced for the watershed of Lake Urmia.

Results

Comparison of changes in LULC during the period 2009–2015

Area changes of LULC types in the period 2009–2015 are presented in Table 2. In general, based on changes over time, the area of lands covered by irrigated agriculture, water bodies, wetlands, and grasslands has decreased by about 10, 40, 15, and 32%, respectively. In contrast, the area covered by rain-fed, saline, gardens, and urban lands has increased by about 27, 63, 226, and 31%, respectively. Given that all declining LULCs are directly dependent on the availability of sufficient water, such changes are an indication of water scarcity in the study area. Part of irrigated agricultural lands has been converted to rain fed to compensate for

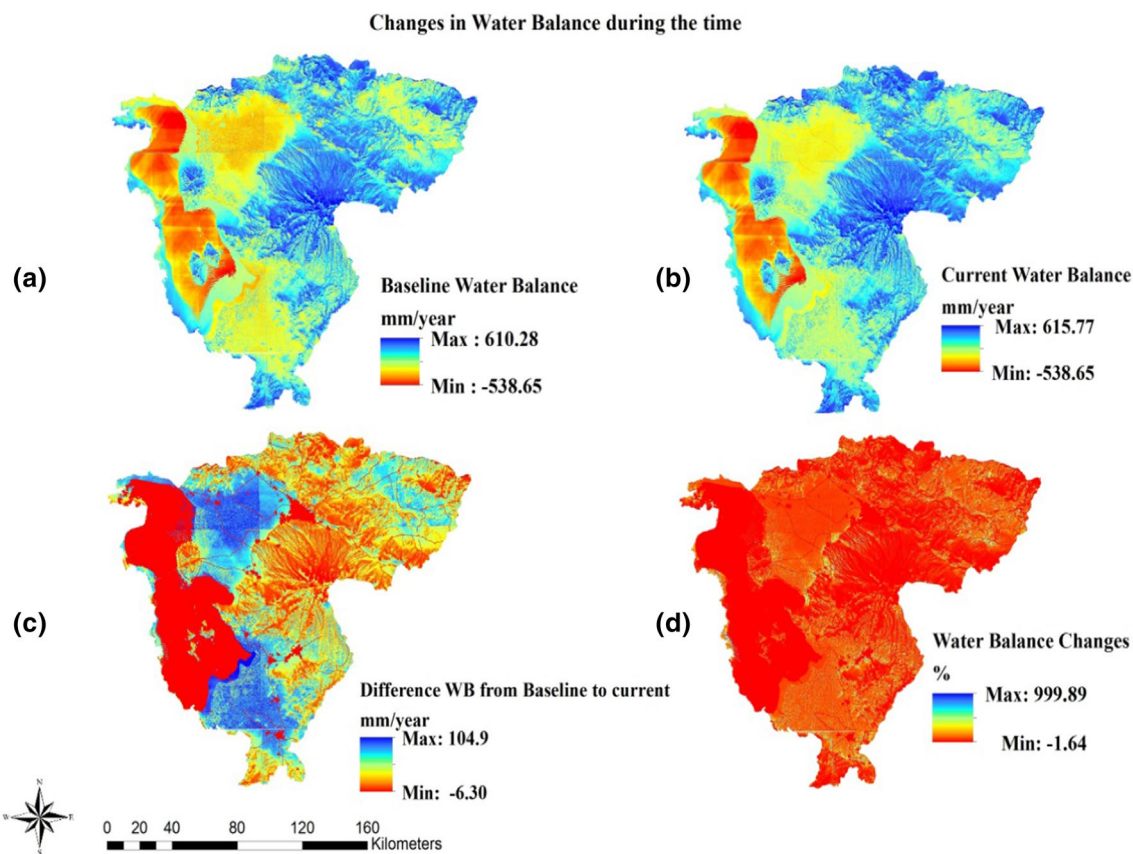


Fig. 4 The status of the water balance for baseline (a) and current (b) conditions; difference from baseline to current (c); and percentage of water budget change (d)

water shortages. However, the uncontrolled development of gardens as a land use that needs more irrigation is due to incorrect land conversion decisions, despite the declining trend of available water resources, with the economic motivation of farmers to generate more income. Consequences of water shortages and unprincipled decisions of gardens and the growing trend of urban development, in general, have led to the replacement of different natural cover (wetlands, grasslands, and other water areas) with human-made cover and useless cover (saline and barren). The continuation of this process of change can cause significant damage to the ecological structure and functions of the watershed. As a key result of the LULC study, the rate of reduction/loss of grassland vegetation as an important natural land cover was determined to be -32% .

Results of analysis of climatic parameters

Precipitation

Based on the results of the Mann–Kendall test for precipitation data of the seven stations (Table 3), the null

hypothesis was rejected because the p value for Maragheh station, which is located approximately in the center of the eastern watershed of Lake Urmia, is less than 0.05 (significant level $\alpha = 0.05$). It means that the precipitation parameter in this station has had a significant decreasing trend in the case period. However, for other stations and the entire watershed, because the p values were greater than 0.05, a significant decrease in precipitation was not confirmed.

The graphs of forwarding and backward series for the total precipitation were prepared using the Mann–Kendall test for the watershed (Fig. 7). According to this graph, the rainfall decreases from 1989 to 1991. After 1991, the downward trend reversed, the precipitation entered an upward trend in 1994. Then, this upward trend gradually decreased again. From 1999, the downward trend resumed. Then, the declining trend of precipitation is statistically significant from 2000 to 2003, and can be called a period of severe drought. In 2004, 2006, 2007, 2011 to 2014, this trend is still decreasing, with the difference that it is not statistically significant in these years. However, in the years 2005, 2008 to 2010, the rainfall has a significant decreasing trend.

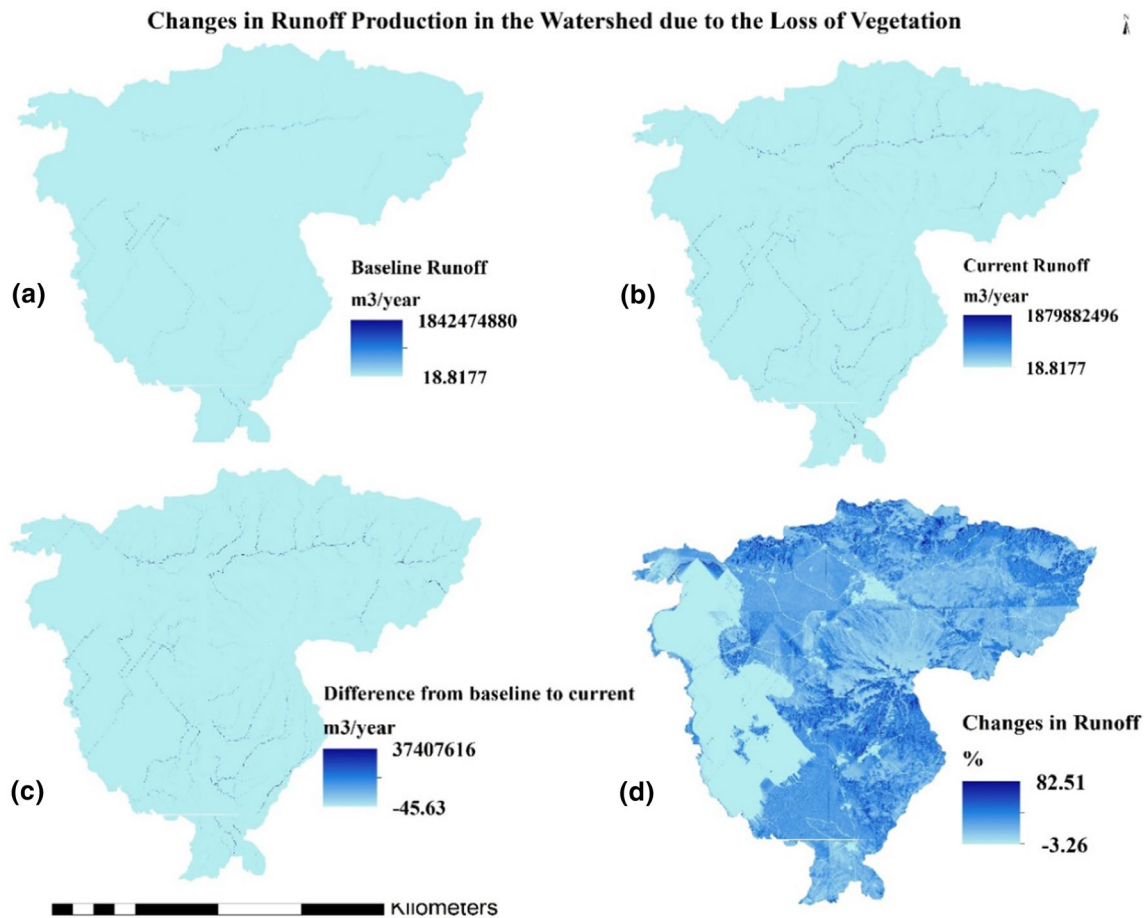


Fig. 5 The status of runoff production for baseline (a) and current (b) conditions; difference from baseline to current (c); and percentage of runoff change (d)

Temperature

The Mann–Kendall test was performed for the temperature data of the seven stations as described in the previous section. According to the results of the Mann–Kendall test, the air temperature trend in Tabriz, Urmia, Maragheh, and Mahabad stations is an increasing trend and is statistically significant. In the other three stations (Sarab, Takab, and Saqez), the temperature trend decreases but is not statistically significant.

An interesting point in the time series analysis of air temperature based on the Mann–Kendall test (from 1984 to 2014) is that air temperature in four stations closer to the lake (Tabriz, Urmia, Maragheh, and Mahabad) has an increasing trend and is statistically significant and in the other three stations that are far from the lake (Saqez, Takab, and Sarab) has a downward trend and is not statistically significant. Based on the analysis performed and considering the downward trend of the lake surface, it can be concluded that the decrease in the lake cover has led to an increase in temperature in the vicinity of the lake.

Results of modeling eco-hydrological parameters

Vegetation

The quantity of change in vegetation density varies between -41% and zero, with a negative sign indicating a decrease (loss) of vegetation in the modified parts (Fig. 3). Table 4 compares the minimum, maximum, and average percentage of herbaceous vegetation in both baseline and current conditions and the difference between them.

Therefore, the percentage of grassland vegetation decreased on average 31.69% in the study area. This output of the WWPSS vegetation model was consistent with the results of a comparison of LULC maps from 2009 and 2015, which showed a reduced rate of rangeland vegetation of -32% . Also, according to the model output, the increase in barren lands or lands with poor vegetation is about 32% . It is interpreted as changes caused by drought and the gradual conversion of grasslands to bare lands in the study area. In the case of tree cover, it must be said that, apart from

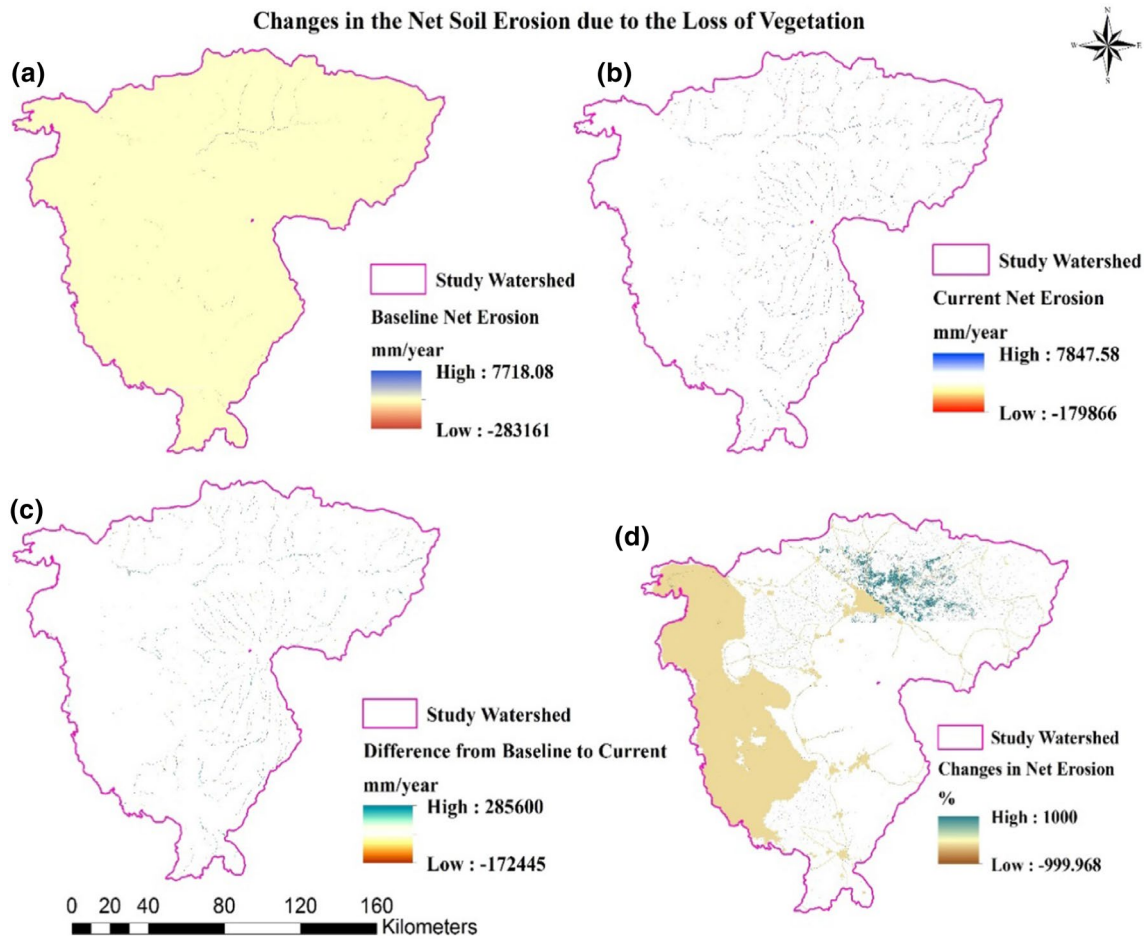


Fig. 6 The status of net soil erosion for baseline (a) and current (b) conditions; difference from baseline to current (c); and percentage of erosion change (d)

Table 2 Changes in the area of LULC in the watershed under study during the period 2009–2015

LULC Code	LULC Class	Area (km ²)		Changes (km ²)		Changes (%)	Trend
		Baseline (2009)	Current (2015)	Increase	Decrease		
1	Irrigated agriculture	1815.40	1647.49		167.91	−9.24	↓
2	Barren	5241.96	5440.41	198.45		3.78	↑
3	Rain-fed agriculture	4006.16	5106.57	1100.41		27.46	↑
4	Garden/orchard	180.41	587.45	407.04		225.61	↑
5	Grassland	5456.71	3703.33		1753.38	−32.13	↓
6	Saline	2541.42	4139.84	1598.42		62.89	↑
7	Water body	3622.48	2183.56		1438.92	−39.72	↓
8	Wetland	76.55	65.02		11.53	−15.06	↓
9	Urban	218.88	286.30	67.42		30.80	↑

Table 3 Mann-Kendall test results of rainfall time series. *Source* Research Findings

Station name	Average annual precipitation (mm) 1984–2014	Mann–Kendal test				Test result
		S	Var(S)	tau	2-sided <i>P</i> value	
Tabriz	241	–21	3461	–0.0452	0.7339	H0 not be rejected
Sarab	242	84	3460	0.181	0.1582	H0 not be rejected
Urmia	313	–23	3461	–0.495	0.7084	H0 not be rejected
Maragheh	302	–191	3461	–0.411	0.0012**	H0 was rejected
Mahabad	402	–43	3461	–0.0925	0.4753	H0 not be rejected
Saqez	460	–115	3461	–0.247	0.0526	H0 not be rejected
Takab	350	–118	3460	–0.254	0.0511	H0 not be rejected
Entire Urmia Watershed	238	–97	3461	–0.209	0.1027	H0 not be rejected

Bold values indicate that the decreasing trend of the precipitation is significant in the Maragheh station

Fig. 7 Graphic representation of the forward, $u(t)$, and the backward, $u'(t)$ series of the Mann-Kendall for annual rainfall in the Urmia watershed

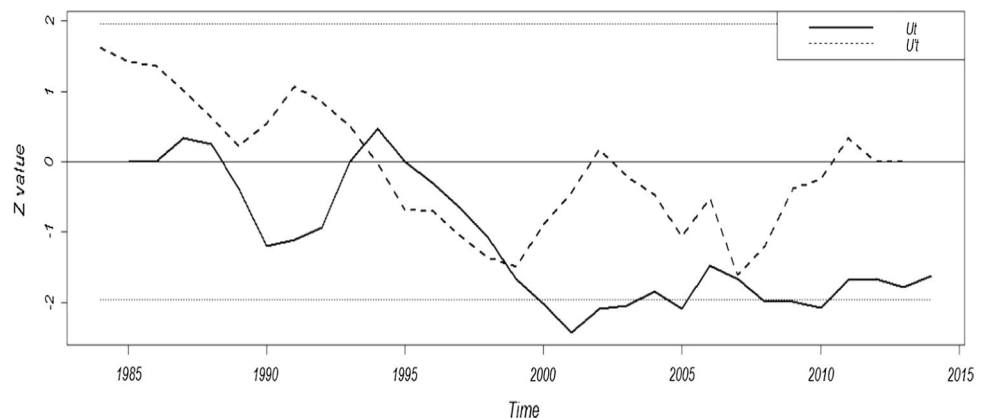


Table 4 Changes in the average, minimum, and maximum percentage of herbaceous vegetation in the study area from the past to the present. *Source* Research Findings

Herbaceous vegetation (%)						
Baseline vegetation (2000)			Existing vegetation (2015)			Average difference from baseline to current status
Minimum	Maximum	Mean	Minimum	Maximum	Mean	
0	100	78.26	0	90	46.93	–31.69

human-made gardens, the study area generally has very poor tree cover, which can almost be ignored.

Water balance

According to the model calculations, in the baseline condition, the watershed water balance (precipitation minus evapotranspiration, which can also be called water budget) was 19.29 on average, –53.55 minimum, and 610.28 mm maximum per year (Fig. 4a). In the existing conditions and after the loss of vegetation with an average rate of –32%, the average and maximum water balance has changed to 36 and 615.77 (mm/year), respectively, and its minimum has remained unchanged. Although the average water balance has increased by about 50%, and given the region's water

shortage conditions, this may be thought to be a good result; but this is because, in the baseline conditions, more vegetation would consume more water. As vegetation declines (in the current condition), some of the water previously stored in this cover is released now into the watershed. Figure 4b shows that the water balance in the eastern lands of the immediate vicinity of Lake Urmia after the loss of vegetation has increased slightly and in other lands in the far east of the lake has decreased. Figures 4c and 4d also show the amount of changes in water budget based on metric unit (mm per year) and percentage (%), respectively. To show the results of the water balance analysis more accurately, we also compared the changes in water balance at the level of each four sub-watersheds (Fig. 1. b). Accordingly, the baseline average water balance of four sub-watersheds of Qale Chai,

Aji Chai, Sufi Chai, and Marduq Chai was 129.92, 104.56, 83.17, 54.04 mm per year, respectively. The highest and lowest baseline water balances were in the sub-watersheds of Qale Chai and Marduq Chai, respectively. With the loss of vegetation, the total amount of current water balance in all four sub-watersheds has increased, as shown in Fig. 8 the average and percentage of these changes. Accordingly, the highest increase in water balance with more than 52 mm per year (78%) occurred in Marduq Chai, and the lowest increase with 37 mm per year (51% compared to baseline) occurred in Aji Chai.

Runoff

The amount of water production was estimated based on the runoff production as the accumulated water balance downstream. Accordingly, the minimum, average, and maximum runoff production in the eastern watershed of Lake Urmia in baseline conditions was estimated to be 18.81, 833998.33, and 1842474880 cubic meters per year, respectively (Fig. 5a). Also, the lowest and highest average runoff production was in the sub-watersheds of Qale Chai (239516.2) and Marduq Chai (1,245,909.59) cubic meters per year, respectively. In the current situation with the loss of vegetation and the consequent changes that have occurred in the water balance of the watershed, the average production runoff in the watershed compared to the baseline has increased by about 2.5% and equivalent to 19,656.95 cubic meters per year (Fig. 5b). Figures 5c and 5d also show the amount of changes in runoff production based on metric unit (m^3 per year) and percentage (%), respectively. Accordingly, with decrease in vegetation density and increase in water balance in all four sub-watersheds, the average runoff production has also increased; the changes in the sub-watersheds are

shown in Fig. 9. The calculations show that the least and most changes in runoff production occurred in Aji Chai and Sufi Chai sub-watersheds, respectively.

Net soil erosion

In the WWPSS model, the net soil erosion is calculated based on the total amount of eroded soil minus the soil that deposits on the slopes of hills and water canals. Therefore, the amount of net soil erosion includes degraded soil and sediments that are transferred from upstream to downstream through water streams and rivers, which can lead to major ecological and economic impacts. Based on the results of the model, in the baseline condition of the watershed and before the loss of its vegetation, the minimum, maximum, and average net erosion caused by the slope of the hills were equal to -283160.87 , 7718.08 , and -0.012 mm/ m^2 per year, (Fig. 6a). Negative numbers in the interpretation of the model results indicate the deposition of soil in a given area and their non-transfer from upstream to downstream in the form of sedimentation due to erosion (negative values mean deposition is higher than erosion). Hence, the negative numbers of the baseline soil erosion indicate that soil erosion was not considered an ecological problem in the past due to suitable vegetation. In other words, the watershed's ecological state was such that it also stabilized the soil. In general, the rate of soil stabilization was higher than its erosion in the whole watershed. In the current situation and after the loss of grassland vegetation due to the changes in precipitation and temperature and land use, the minimum, maximum, and average net erosion due to the slope of the hills in the study area are, respectively, equal to $-179,856.73$, 7847.57 , and 0.20 millimeters per year per square meter (Fig. 6b). Taken together, these numbers indicate a significant reduction in

Fig. 8 Comparison of the average and percentage of changes in the water balance in four sub-watersheds of the Eastern Lake Urmia watershed due to loss of the vegetation

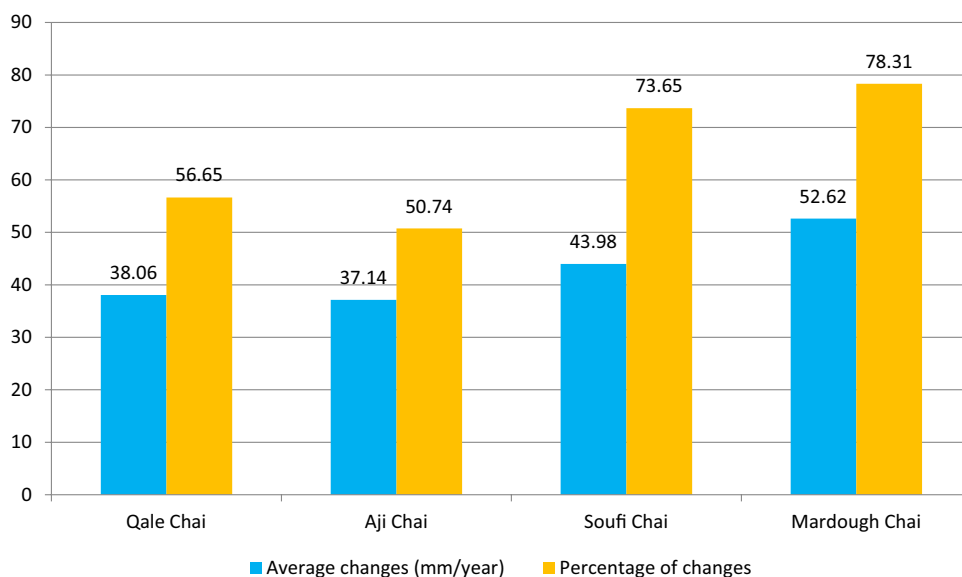
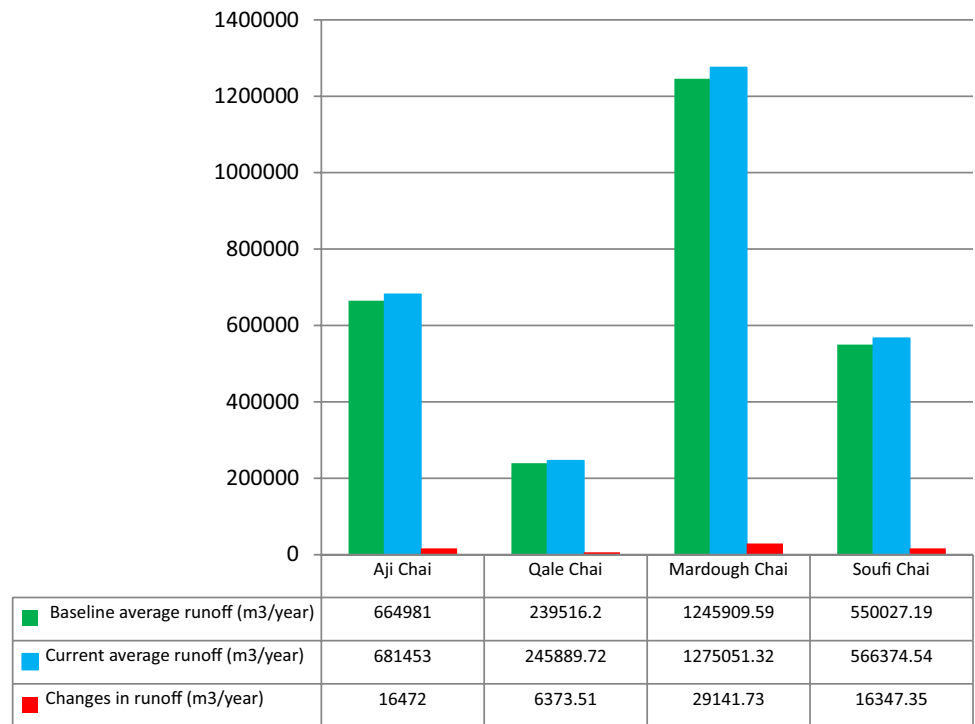


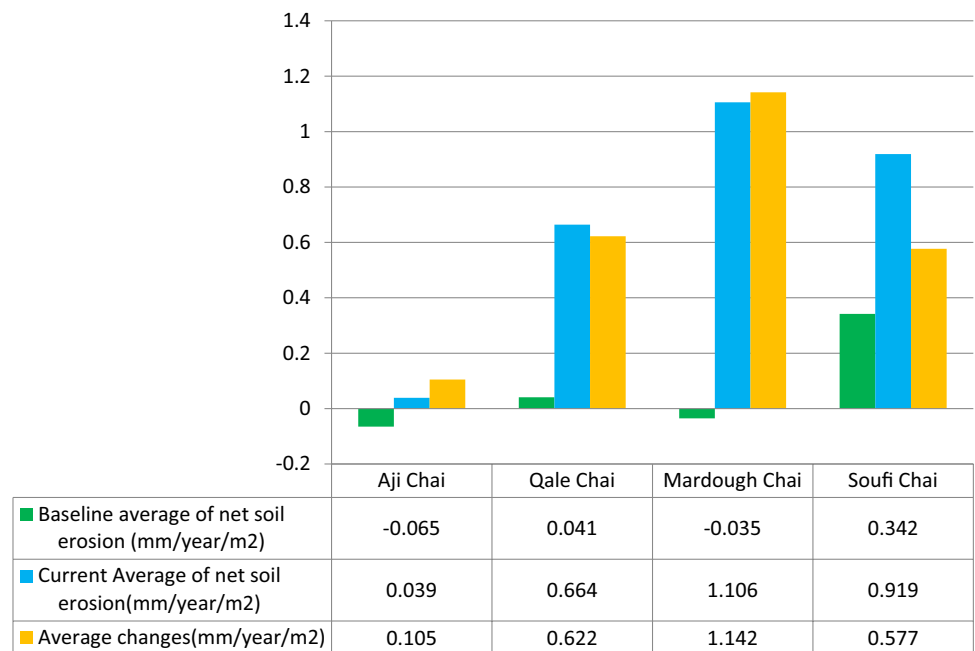
Fig. 9 Changes in average runoff production in four sub-watersheds of the Eastern Lake Urmia watershed due to loss of the vegetation and increasing of the water budget



soil stabilization capacity (approximately 36%) and a significant increase in soil erodibility (45% increase in average erosion) (Fig. 6c and d). However, since the type of soil and its erodibility are distinct in different sub-watersheds and due to the changing physiographic and topographic characteristics of the land, this erosion rate should be considered separately in the sub-watersheds. Figure 10 shows the

amount of change in the average net soil erosion in four sub-watersheds. In Aji Chai and Marduq Chai sub-watersheds, the average erosion has changed from a negative value in the baseline to a positive number in the current situation. It indicates a sharp increase in the erosion rate. At the same time, the increase in erosion in the Marduq Chai sub-watershed is very significant. To calculate the tonnage of eroded soil in

Fig. 10 Comparison of the average rate of the net soil erosion in the four sub-watersheds in baseline and current states and differences in average soil erosion during the time



the period between the base year (2000) and the current year (2015), by converting millimeters per square meter to cubic meters per square meter and multiplying it per hectare and specific gravity of soil, the annual tonnage of soil erosion per hectare was calculated for each of four sub-watershed. (Soil specific gravity coefficient for the study area based on previous soil studies was considered 1.5 g/cm³.) Then, according to the area of each sub-watershed, the total amount of eroded soil in the desired period was determined. Table 5 shows the results of the calculations.

Accordingly, the average soil erosion rate in the entire eastern watershed of Lake Urmia has reached 3 tons per hectare per year. However, due to the physiographic and topographic differences of the sub-watersheds, various soil types, and vegetation density, this amount is very different in each sub-watershed. The worst conditions of soil erosion have occurred in the Marduq Chai sub-watershed. During this period, the rate of soil erosion has increased from less than 1 ton per hectare per year to more than 16 tons per year and has caused the loss of more than 5 million tons of soil in 15 years. These rates are 10 and 14 tons per hectare per year for Qale Chai and Sufi Chai sub-watersheds, respectively. In the Aji Chai sub-watershed, although from the past, due to less erodibility, the net erosion rate was negative, this rate has also changed to a positive number. It means that the process of soil formation and its deposition has changed to an erosive trend here. Overall, as expected, the 32% loss of vegetation in the study area has caused a destructive consequences collectively led to the degradation of more than 8 million tons of soil in just 15 years.

Summary of physio-ecological impacts of vegetation loss in the watershed

In this section, the baseline and existing situation of the watershed under the impacts of vegetation loss were compared. This comparison should be made using environmental indicators. In this study, vegetation and LULC status considered as a biological and morphological indicators. Also water balance, runoff, and soil erosion were considered as echo-hydrological indicators. We considered changes in the value of these indicators from baseline to current as environmental impacts. The quantities of changes in each of the indicators show that some ecological functions of the watershed ecosystem were negatively impacted. With a 32% reduction in vegetation density, the watershed habitability declined. In addition, the consequent release of water from the lost vegetative tissues, including the aerial and terrestrial organs of plants, increased the available water by 37%. This event jeopardizes the function of flood control in watersheds. This change has also led to a significant increase in runoff, which in turn, with the intensification of erosion on the slopes of hills and water canals, the average net soil erosion in both watersheds and sub-watersheds has increased significantly. Therefore, in addition to impairing the soil protection function in the watershed, it can also reduce the quality of running water due to the increased sediment load of rivers. Table 6 shows the quantitative changes of selected physio-ecological parameters in the two baseline and current periods.

Table 5 Calculation of soil tonnage lost due to vegetation loss over time

Name of Sub-watershed	The difference between the average net soil erosion rates over time (mm/year)	Overall rate of difference in soil erosion over time (tons/hectare)	Sub-watershed area (hectares)	Tonnage of soil lost over time (ton)
Aji Chai	0.105	1.575	1,063,942.99	1,063,942.99
Qale Chai	0.622	9.33	92,004.78	858,404.59
Marduq Chai	1.142	17.13	306,137.09	5,244,128.35
Sufi Chai	0.577	8.655	116,240.39	1,006,060.57
Total			1,578,325.25	8,172,536.5

Table 6 Comparison of baseline with the current situation of the eastern watershed of Lake Urmia based on the average of environmental indicators representing ecosystem functions and as the output of ecological modeling and quantification of changes in the current situation

Ecosystem function	Environmental indicators represent the situation	Unit of measurement	Average status index		
			Baseline	Current	Changes
Rangeland habitat	Vegetation density	%	79	47	-32
Hydrological balance	Water budget	mm/year	19	56	37
Flood control	Runoff	m ³ /year	833,998.33	853,655.29	19,657
Water quality	Erosion in hillslopes and water canals	mm/year	0,002	0.013	0,011
Soil conservation	Net soil erosion	mm/year	-0.012	0.20	0.188

Zoning map of the cumulative physio-ecological impacts

The eastern watershed of Lake Urmia is relatively large. Therefore, a map of the cumulative physio-ecological impacts produced as a useful output of this study can inform the preparation of an executive management plan for the future with the aim of environmental impact mitigation. It is important to note that the distribution of pressures, impacts, and consequences is not uniform throughout the watershed. Moreover, according to the different natural structures across the watershed, the significance of environmental impacts and consequences will be different. Therefore, the type and amount of managerial responses should be commensurate with the above conditions. Accordingly, Fig. 11 shows the standard maps for each of the modeled ecological parameters on a scale of 1–10. Figure 12 also shows the final cumulative impact levels map in the Lake Urmia watershed, which is the result of overlapping and combining standardized maps in Fig. 11. To increase the understanding of impact leveling, Fig. 13 has been reclassified into four categories of low, medium, high, and very high impacted areas.

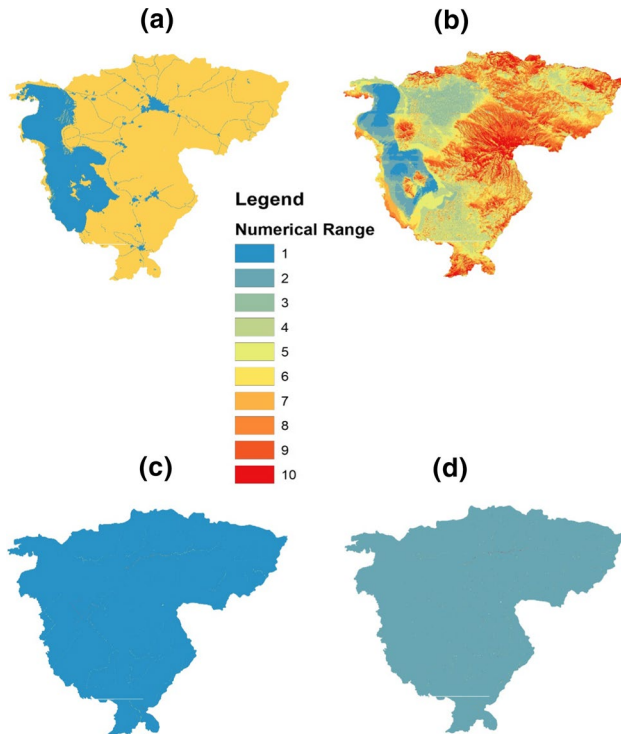


Fig. 11 The standard maps for each of the modeled ecological parameters on a scale of 1–1: **a** vegetation density, **b** water balance, **c** runoff, and **d** soil net erosion

cumulative impact level map in the Lake Urmia watershed

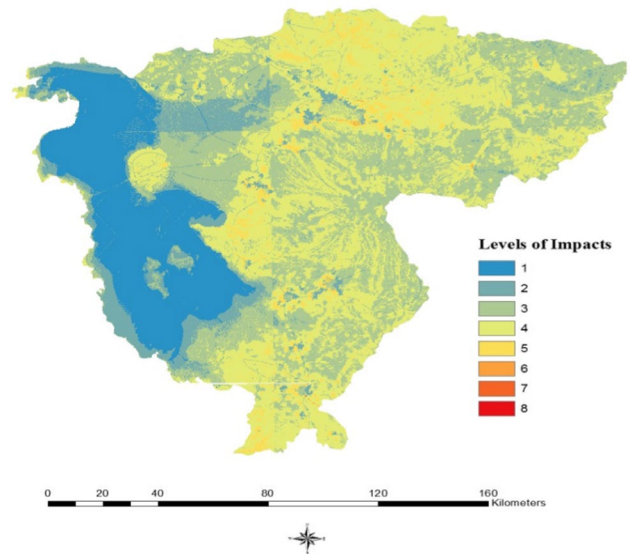


Fig. 12 Final cumulative impact level map in the Lake Urmia watershed, as a result of overlapping and combining standardized maps in Fig. 11

Discussion and conclusion

Performing ecosystem assessments has become increasingly important as the impact posed by human drivers and pressures on natural ecosystems increases (Reidsma et al. 2011;

ImPact Classification in the Lake Urumia Watershed

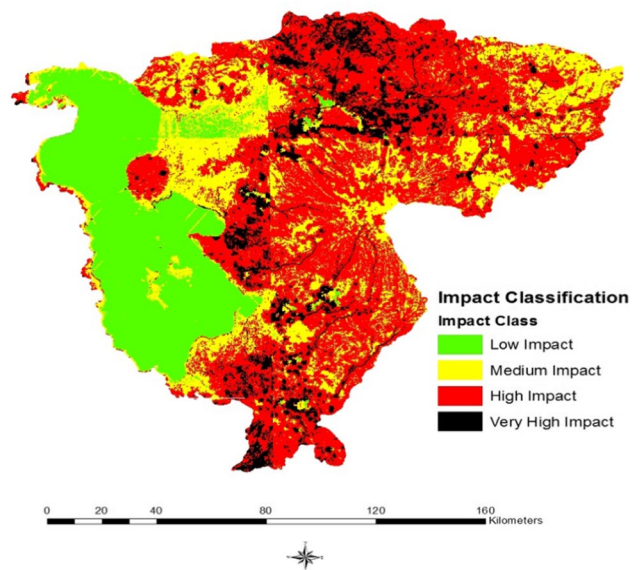


Fig. 13 Reclassified map of cumulative impact levels in the Lake Urmia watershed

Christie et al. 2012; Seppelt et al. 2012; Levin et al. 2014). In developing countries, including Iran, one of the primary problems in assessing environmental impacts is that data on eco-hydrological parameters for baseline ecosystem conditions and past times are not available for many watersheds. Therefore, there is a data gap to compare current trends with the past. In addition, due to the lack of appropriate methods for measuring changes in ecosystem functions (Patil et al. 2001; Costanza et al. 2017), more previous ecological assessments have been based on using mere descriptive and subjective methods.

In this research, a quantitative assessment method based on ecosystem modeling was used to relate the results of land-use change, and its effects on eco-hydrological parameters (vegetation, water budget, runoff, and soil erosion) with the aim of spatial zoning of environmental impacts and its application in principled and informed management of the watershed.

Quantification and mapping of changes in eco-hydrological parameters were performed by implementing the WWPSS model. This model allows environmental assessors who may have less technical capacity to perform hydrological calculations to make a cost-effective assessment in the shortest possible time, especially in case there are not sufficient data for assessments or no data on baseline ecosystem function conditions are available.

However, this model was previously used in other parts of the world, including assessing the effects of land-use change on water resources in Madagascar (Mulligan 2012), and measuring the effects multiple threats include climate change, deforestation, population growth, oil and mining on water security in the Amazon rainforest (van Soesbergen and Mulligan 2014) as well as some similar assessments by the World Bank and the US Environmental Protection Agency (US EPA) (Mulligan 2012), but it has not been previously used in Iran as a self-parameterizing physically based model that could be used in areas facing data and information poverty. In this study, due to the weakness of descriptive ecosystem assessments and the impossibility of measuring the aquatic ecosystem functions in many current research projects in Iran, it was found that the use of this model and other similar models can be very helpful in solving the existing methodological challenges.

In this study, based on studies of climatic parameters (temperature and precipitation), we found that except for a period during the years 1994–1999, during the last 30 years, the rainfall in the entire watershed of Lake Urmia has decreased and particularly, in the eastern part of the watershed, the decrease is significant. These results are consistent with a study conducted by Tahroudi et al. 2019 and confirmed the decreasing trend of precipitation during the period 1998–1992 in all rainfall stations of the watershed. On the other hand, the minimum temperature in the range

of 0.2–3.4 and the maximum temperature in the range of 0.9–2.9 °C have increased. This result is also consistent with the results of previous studies that have mainly confirmed the increasing trend of temperature in the watershed of Lake Urmia in recent decades (Delju et al. 2013; Alizadeh-Choobari et al. 2016), although different studies have different numerical estimations for the rate of temperature increase depending on the method used and the period of their research.

With decrease in rainfall and increase in temperature, the average vegetation density decreased by 32% in the watershed from 79 to 47%. Decreased vegetation density in the watershed has reduced evapotranspiration in the range between 7 and 13% and about 11% on average, followed by increased runoff; because with the loss of vegetation, water that is constantly collected and stored in the aerial and underground tissues and soil around the roots of plants is suddenly released into the watershed. This means increasing the overall runoff load, the potential for flood hazards, more sediments due to water erosion on the hillslopes and water canals, increasing net soil erosion and water turbidity, reducing water quality, and increasing sediment load in surface waters in the watershed. Fortunately, these were also confirmed by the results of the modeling. Accordingly, vegetation loss due to the changes in precipitation and temperature has caused the change in the average net soil erosion in the basin from -0.012 to 0.20 mm per year per square meter, in other words, the average soil erosion in the watershed has increased by more than 3 tons per hectare, and if such a trend continues, soil erosion will intensify. In this regard, it should be noted that the annual rate of soil erosion in Iran in different parts is estimated between 7 and 70 tons with the average rate of 16.5 tons per hectare (Sadeghi 2017; Mohammadi et al. 2021). Also, in another study, the average erosion rate was estimated at 12 tons per hectare per year using the RUSLE model for Asia (Yang et al. 2003). According to the results of this study, which has estimated the annual soil erosion rate of 10, 14, and 16 tons per hectare, respectively, for the sub-watersheds of Qale Chai, Sufi Chai, and Marduq Chai, comparing the results of other studies with this study shows that the estimated rates of spatial distribution of soil erosion are in good agreement with the results of previous studies.

One of the distinctive aspects of this research is the interpretation and summarization of the results of studies and modeling of changes in eco-hydrological parameters as a cumulative ecological impact map that can be used in environmental assessment and watershed management. Although, in previous studies (Alizadeh-Choobari et al. 2016), the synergy between the effects of changes in climatic parameters and changes in land use/cover and uncontrolled conversion of land into arable land has been mentioned, and agricultural activities have been identified as a major driver

of adverse changes in watershed hydrological conditions, but in our research, first of all, the results of climatic and hydrological studies have been analyzed using modeling and mapping approaches, which facilitates the application of research results in watershed management and makes the results more understandable and tangible for planners and decision makers of land allocation to different uses. Second, locating areas where the level of cumulative impacts is higher based on the combination of a set of echo-hydrological parameters, provides a clear picture of areas that require immediate implementation of vegetation restoration projects or where the process of human land-use development is more severely constrained. These findings can be used directly in the watershed management decision-making process. Declining of river water quality was one of the aspects of risks due to vegetation loss and increased water erosion, which was not examined in this study due to a lack of funding for sampling and testing. Therefore, it seems that future supplementary studies in this field can assess and evaluate more complete levels of potential and actual hazards related to the drought process of Lake Urmia and the loss of vegetation in the watershed. This issue is especially important due to the increasing trend of dam construction in this watershed and in terms of the serious consequences that soil erosion and increased sediment load of rivers can affect the useful life of dam reservoirs.

The results of this study showed that the application of WWPSS model with a reliance on various international databases can help solve the problems of data gap and the shortage of appropriate techniques for quantitative assessment. However, the use of this model also faces limitations. These constraints include times when there is a need for a very accurate prediction of the baseline and future values of the ecosystem functions at a particular point (e.g., the amount of flow or the volume of sediment due to erosion within dams). These limitations can lead to uncertainty in the results of estimates in cases where accurate measurements are required. In these cases, the results of the model must be confirmed by limited sampling and laboratory measurements.

In summary, in this study, the results of modeling of changes in echo-hydrological parameters with changes in climate parameters and structural changes in LULC were analyzed to be able to be the basis for local decision making in the control and prevention of environmental impacts and better watershed management. It seems that by further application of quantitative models of echo-hydrological functions in the future and various case studies and increasing the experiences and data produced by this type of evaluation, the capacities of the method used in this research can be improved and more innovative solutions could be found to address the ecological challenges in watershed management.

Appendix 1

The method of rating of cumulative impacts levels in the range 0 to 1 and based on metric quantities of 4 important parameters of vegetation density, water budget, runoff, and net soil erosion.

In the rating approach, the logical assumptions were that:

- By reducing the density of vegetation, the level of impact increases, because areas with lower vegetation densities are more vulnerable to changes in climatic parameters (reduced rainfall, increased temperature) and developmental pressures (land conversion and LULC change);
- With the reduction of the water budget, the level of impact increases, because a negative balance means more evapotranspiration from rainfall and consequently water stress (lack or lack of water budget);
- With increase in runoff, the level of impact increases, because larger quantities of runoff mean creating more risk in terms of floods, soil erosion, and reduced water quality (sediment pollution and turbidity, etc.);
- With increase in net soil erosion, the level of impact increases, because larger numbers of erosion, in addition to creating a risk to plant growth, also have subsequent socio-economic risks.

Impact level	Metric data acquired from modeling outputs			
	Veg- etation density (%)	Water budget (mm/year)	Runoff (m ³ /year)	Erosion (mm/ year)
1	84.62–90	348.66– 615.76	18.81– 14,744,195.10	–179,865.73 to –249.86
2	79.25– 84.62	276.23– 348.66	14,744,195.10– 73,720,900.27	–249.86– 486.27
3	73.88– 79.25	199.27– 276.23	73,720,900.27– 147,441,781.73	486.27– 1222.40
4	68.51– 73.88	117.78– 199.27	147,441,781.73– 228,534,751.33	1222.40– 1958.53
5	63.14– 68.51	36.29– 117.78	228,534,751.33– 324,371,897.23	1958.53– 2694.66
6	57.77– 63.14	–45.19– 36.29	324,371,897.23– 405,464,866.83	2694.66– 4166.92
7	52.40– 57.77	–135.74 to –45.19	405,464,866.83– 508,674,100.87	4166.92– 4903.05

Impact level	Metric data acquired from modeling outputs			
	Veg- etation density (%)	Water budget (mm/year)	Runoff (m3/year)	Erosion (mm/ year)
8	47.03– 52.40	–253.44 to –135.74	405,464,866.83– 508,674,100.87	4903.05– 6375.31
9	41.66– 47.03	–375.68 to –253.44	626,627,511.21– 737,208,833.39	6375.31– 7111.44
10	36.29– 41.66	–538.65 to –375.68	737,208,833.39– 1,879,882,496	7111.44– 7847.57

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Availability of data and material The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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