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Abstract

Arid and semi-arid regions are particularly vulnerable to global environmental change because of their fragile climatic conditions. The rapid development of land use is expected to affect aquatic ecosystems in these regions. In this study, we focused on how land use change affects the stream flow and inflow to Urmia Lake in the Mordagh Chay basin, Iran. This case-study exemplifies dynamics found across a much larger region. We mapped changes in land use between 1993–2015 using satellite imagery and modeled future changes using the Dyna-CLUE model. We projected future land use change until 2030 under four scenarios: continuing of the current trend of water use, 40% water withdrawal reduction, and two other scenarios with 40% water withdrawal reduction and improvements of irrigation efficiency up to 50% and 85%. Between 1993–2015, 21% of the study area changed to orchard and arable land mostly at the cost of rangeland. However, upon reduction of water withdrawal our analyses showed that garden must decrease between 27% and 40%. Rainfed cropland is projected to experience a major increase in all scenarios, especially in the case of reduced water withdrawal, where it will increase by 217%. In order to achieve sustainable water resources management land use plays a major role and leads to different land use futures in this type of semi-arid regions.

Keywords

Land use change, Scenario Development, Irrigation efficiency improvement, Urmia Lake, Iran

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1. Introduction

The rapid development of land use and climate change are expected to affect aquatic ecosystems in arid and semi-arid regions. In recent years, hydrological processes and components of river basins were severely affected by land use changes and climate variability (Juckem et al., 2008). Land use change, which is characterized by the complex interaction of structural and behavioral factors (Verburg et al., 2004), has become an important process of the global environmental change. Changes in land use altered landscape patterns and affected the functioning of ecosystems (Lambin and Meyfroidt, 2011), including their ability to regulate hydrological processes (Gebremicael et al., 2013; Gwate et al., 2015). Understanding how land use change affects the hydrological processes and watershed water yield, especially stream flow, is essential to sustainable water resources management (Narsimlu et al., 2013). Land use change also affects streamflow in other ways: it decreases streamflow when water withdrawal is increased to meet the irrigation requirements of expanded agricultural area or as result of urban consumption (Bian et al., 2017). Numerous studies investigated the effect of land use change on the hydrology worldwide. Yan et al. (2018) observed reduced surface runoff by about 22 mm over 20 years in the Loess Plateau of China due to upstream land use change (increase in the rate of forest and grassland). The effects of land-use/land-cover (LULC) changes on hydrological ecosystem functions in southern Italy were investigated by Nasta et al. (2017). Their results revealed that afforestation reduced Alento River Catchment (UARC) water yield and increased its actual evapotranspiration.

In other areas, increases in surface runoff have been observed as result of land use changes. Mohammady et al. (2017), through a study in the Baghsalian watershed of Iran, found that the conversion of forest and rangeland to agriculture and residential area led to an increase in surface and subsurface runoff. In two Indian watersheds, deforestation resulted in up to 20% increases in surface runoff (Sajikumar and Remya, 2015). Gao et al. (2016) found unequal contributions of land surface alteration and reduction in precipitation on stream flow in a Chinese Loess Plateau catchment. Their findings revealed that land

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surface change contributed more to the hydrological changes than the reduction in precipitation. There are several cases reported where changes in runoff by climate change or human (land use) activities drastically affected ecosystems (Clarke, 1993; Boomer et al., 2000; Zhuang et al., 2011; Ginoux et al., 2012; D'Odorico et al., 2013; Cretaux et al., 2013; Magesh and Chandrasekar, 2017). Unsustainable development and expansion of irrigated agricultural area led to drying up of the two tributary rivers of the Aral Sea (Cretaux et al., 2013). The Aral Sea shrinking, which started in 1960, had very severe negative outcomes and the Amu and Syr rivers rich ecosystems suffered significant harm and water shortage (Clarke, 1993; Boomer et al., 2000).

In this study, we focus on the Urmia lake region, which experiences similar problems as the Aral Sea (Golabian, 2010; Zarghami, 2011; AghaKouchak et al., 2015). Therefore, our study region is exemplary of a much larger change process that causes a severe environmental crisis on regional and international scales. The drying of Urmia Lake occurs as a consequence of regional water resource plans such as low irrigation efficiency and intensive agriculture activities, construction of several dams and a crossway and upstream competition in the use of water (Masih et al., 2011; Hassanzadeh et al., 2012; Alipour and Ghasemi Tangal Olya, 2014; Madani, 2014; AghaKouchak et al., 2015; Fazel et al., 2017). The shrinking of the lake shows that the natural ecosystem services in delivering and supplying water resources in the Lake basin are not enough to compensate the continuous increasing water demand. The lives of many people depend on the Lake Urmia, so drying of this lake can be a serious threat to the millions of inhabitants living in surrounding areas and neighboring countries and may lead to salty dust storms. Studying the land use changes in the lake basin is important to understand and, possibly, prevent further deterioration of the environment in this region. Previous studies on the Urmia Lake were mainly focused on the driving forces (Hasanzadeh et al, 2012; Madani, 2014), the consequences of the drying of the lake (UNEP, 2012; AghaKouchak et al., 2015) and the contribution of the driving forces in shrinking (Hasanzadeh et al., 2012; Fazel et al., 2017) of the lake at the basin scale. The role of land use change is of specific interest in the Urmia Lake basin as it is supposed to be a major driver (Faramarzi, 2012; Khazaei et al., 2019), while at the same time provides an option for wiser management in the future. Integrated water resources management needs, in this context, sustainable land use that will consider the quantity and quality of water resources in the region. Historical land use change detection and the simulation of future scenarios is a means to study different future pathways. Scenario analyses are useful to examine future effects of socio-economic development on the provisioning of ecosystem services (Bennett et al., 2009; Geneletti, 2013) which is receive increasing attention worldwide (Liu et al., 2017; Malek and Verburg, 2017).

The aim of this study was to assess historical land use change and develop plausible future scenarios for one of the catchments draining into Urmia Lake as one of the environmental hotspots in the region. Special emphasis was given to the required land use changes for achieving more sustainable water management and improvements to irrigation efficiency on land use.

2. Materials and methods

2.1. Case study

Mordagh Chay basin is located in East Azerbaijan province, Iran (Fig. 1), and extends between 46° 19′ 49″ to 46° 30′ 22″ E longitude and 37° 19′ 08″ to 37° 44′ 04″ N latitude. The area covers approximately 360 km^2 and is surrounded by Sahand Mountains in the north and the slightly flat area in the south. Mordagh Chay River originates in Sahand Mountain and provides surface water for the region. This basin, which is one of the Urmia Lake sub-basins, has been affected by intense agricultural area expansion representative of entire Urmia lake basin.

Most of the residents of Mordagh Chay river basin are employed in the agricultural sector and the economy is mainly dependent on agricultural products. Unlimited withdrawal of ground and surface water is free to everybody and provides an incentive to the local population to change from more extensive rainfed arable land and rangelands to more intensive irrigated gardens (Alipour and Ghasemi Tangal Olya, 2014). Technological progress helped local people to overcome biophysical limitations and provided access to deep underground water resources. The local population has made large investments in the agricultural sector.

The Iranian government is trying to manage water resources in the Urmia Lake basin more sustainably, both by limiting water withdrawals from the agricultural sector and improving irrigation efficiency to increase inflows into the lake. Specifically, in the "Integrated Management Plan for Lake Urmia Basin, 2010" the Iranian government committed to restoring the water resources of the lake. This plan includes two main projects that are currently being implemented by Ministry of Energy and Agriculture who are responsible for the water supply (Integrated Management Plan for Lake Urmia Basin, 2010). First, water withdrawals for agriculture need to be reduced by 40%, and the irrigation efficiency in the area needs to be improved (Integrated Management Plan for Lake Urmia Basin, 2010; Morid, 2012). Secondly, dam construction is temporarily suspended, with an inter-basin water transfer proposed by the Ministry of Energy in the Lake basin.

2.2. Data, preprocessing, and classification

To analyze past land use change, we classified multi-spectral high resolution (30 m) satellite imagery spanning over 23 years (1993–2015) including Landsat 5 (TM), Landsat 7 (ETM+) and Operational Land Imager (OLI) for the years of 1993, 2004 and 2015, respectively. The images were downloaded from earthexplorer.usgs.gov and glovis.usgs.gov. We selected images when the date coincided with the growing season and vegetation is vigorous, for easy distinction among various land use types (Shi and Li, 2012). Therefore, we acquired images for the summer months June and July.

First, the images were corrected using radiometric enhancement and extraction, and afterwards calibrated atmospherically (Gounaridis et al., 2014). We applied the Dark Object Subtraction (DOS) algorithm in ENVI 5.3 (Chavez, 1988) to eliminate atmospheric scattering effects (Vanonckelen et al., 2013; Bernardo et al., 2017). Maximum Likelihood was used to classify land use types in the study area (Sun et al., 2013; Jia et al., 2014; Iounousse et al., 2015; Movia et al., 2016; Magesh and Chandrasekar, 2017). Land use was classified into five types: residential area, arable land, rangeland, bare soil, and orchard (Table 1). Orchards represent irrigated cropland and are mostly used for apple cultivation, but also for walnuts, apricots, plums, and peaches.

2.3. Dyna-CLUE model

We applied Dyna-CLUE, a spatially explicit land use model (Verburg and Overmars, 2009), to study the spatial patterns of land use change and explore possible future land use developments. The model allocates future land use change, defined by scenario-based demands for different land use types, to the most suitable locations. The suitability of the locations was derived by estimating relations between observed (current) land use and location factors using logistic regression (Verburg and Veldkamp 2004). Probabilities of occurrence of the land use types resulting from the estimated logistic regression models were interpreted as location suitability in the model. In the logistic regressions the presence/absence of land use types was used as a dependent variable while biophysical, climatic and socioeconomic spatial factors were used as location factors, the independent variables in the model. Biophysical and climatic factors were represented by precipitation, temperature, evapotranspiration, elevation, slope, aspect, and soil depth, hydrological group, texture and pH. To represent socioeconomic factors, we used distances from main roads, rivers and settlements. The period

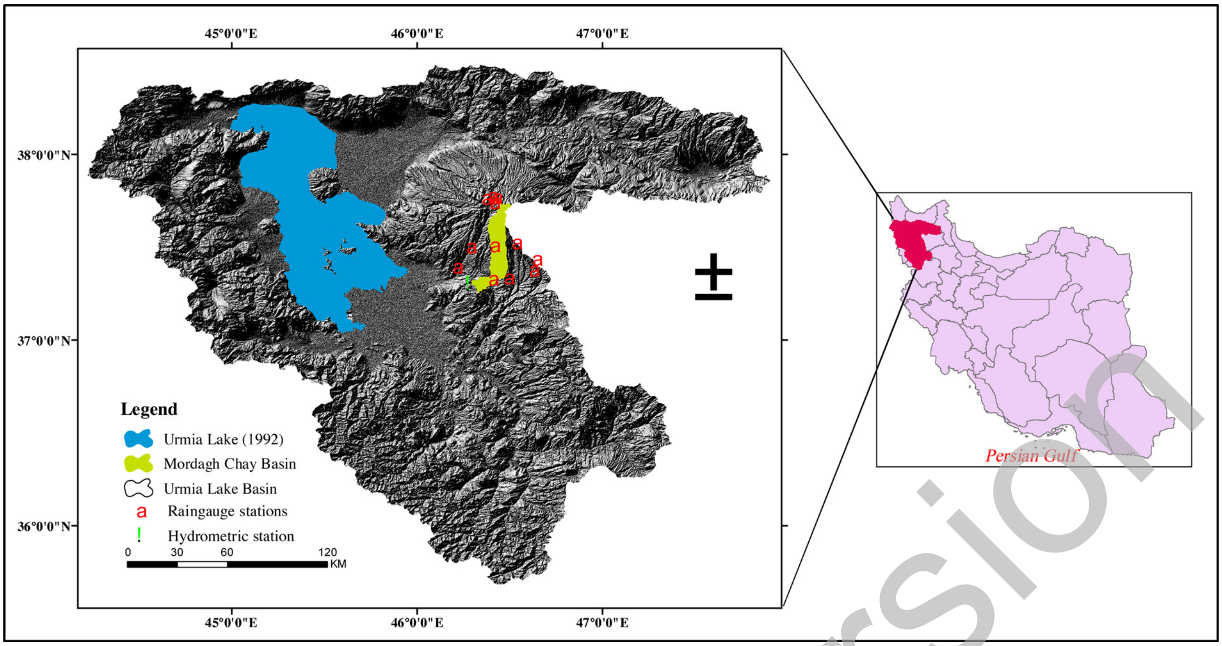

Fig. 1. Location of the study area in the Urmia Lake basin.

1993–2015 was used for model calibration and assessing to what extent the parameterization is able to represent observed land use changes. The land use map of 2015 was used as a starting point to simulate future land use change until 2030.

2.4. Future land use change scenarios

We developed a set of future land use change scenarios that are based on observed trends in land use change and also considered possible reductions in irrigation water withdrawal and improvements to irrigation efficiency as potential measures to halt the drying up of Urmia Lake. A first scenario ("trends" scenario) was based on a continuation of the historic trends in land use without reduction in water withdrawal and efficiency improvement. Then, we developed three additional scenarios where land use demands were adapted to reduce water withdrawal for irrigation by 40%. The "no-efficiency improvement" scenario presents a future, where water withdrawal will be reduced, without improving the efficiency of irrigation systems in the area. To achieve this, demands of the water-intensive orchard land use were decreased by 40% as this land use is the only irrigated land use. The remaining two scenarios present two different levels of improvements to irrigation efficiency, allowing smaller reductions in orchard area. Reducing water withdrawal in all scenarios however meant that, in spite of efficiency gains, we had to decrease the future demand for irrigated cropland (orchards) as compared to the reference scenario.

There is no general definition of irrigation efficiency, but it could be defined as the fraction of the water which reaches the fields to benefit crops (Malek and Verburg, 2017). Only about 4% of Iran's irrigated agriculture is characterized by high irrigation efficiency (Faramarzi, 2012) while larger regions face considerable water losses due to low efficiencies (Ardakanian, 2005). In this study, we focused on overall irrigation efficiency because our case study only uses water withdrawn in the area, and does not depend on water transported from other sources. Overall irrigation efficiency represents the share of water that is lost in the region in irrigation practices due to inefficiencies (FAO, 2008).

The current irrigation efficiency of the study area is about 35% (FAO, 2016; Ardakanian, 2005), which we considered as the reference irrigation efficiency for the trend and no-efficiency scenarios. For these two scenarios, the land use change was simulated following the historical trend for the demand of agricultural land, however with and without reduction in water withdrawal. We also reduced water withdrawal by 40% for our other two scenarios while at the same time increasing the irrigation efficiencies. In the "low efficiency improvement" scenario, we increased the irrigation efficiency to 50%. This presents a low-cost improvement scenario, where the existing irrigation systems with flooding the fields is still used, but with reduced water losses in the water conveyance systems (such as improvement in irrigation canal maintenance). The "high efficiency improvement" scenario presents a situation, where the irrigation systems are upgraded to highly efficient sprinkler, but mostly drip irrigation systems. The irrigation efficiency in this scenario is increased to 85%. Our irrigation efficiency improvements are based on plausible technological improvements for the climatic conditions (Fader et al., 2016). The scenarios are summarized in

Table 1
Land use classes description.

Land use	Description
Bare soil	Includes areas with no or sparse vegetation cover, mostly in the high elevation of the mountain area in the study area. Bare soil areas in the higher altitudes are covered by snow most of the year. In the basin upstream, it is usually rocky and with approaching to the downstream a little thick of soil is included.
Arable land	Areas planted with annual crops (also vegetables), mostly wheat, barley, and peas. A rotation system is applied, where crops are kept fallow for a year. After harvesting it is also used for livestock grazing. The local agricultural activities mainly depend on arable land.
Orchard	Area that are irrigated and covered mostly by tree crops, mostly apples but also grapes, prunes, peach and apricots. They are situated in close to rivers and local residential areas. The regional agricultural activities significantly depend on irrigation and therefore this land use type.
Rangeland	Areas covered by herbaceous vegetation used for livestock grazing and fodder, which cover a major part of the study area. The two species of *Astragalus adscendens* and *Thymus kotschyanus* are the dominant species which covered more than 90% of this type of land use.
Residential area	Villages, defined by low density of built-up areas due to the rural nature of the study area.

Table 2
Summary of the developed scenarios.

Scenario	Description	Land use processes
Trend (A)	Scenario based on observed trends between 1993–2015.	Land use trends for gardens and arable land follow observed trends.
Water reduction scenarios		
Water withdrawal for irrigation reduced by 40%		
No efficiency improvement (B)	Existing irrigation efficiency of 35%.	Garden area reduced by 40%, and are replaced by rainfed arable land.
Low efficiency improvement (C)	Improvements to overall irrigation efficiency to 50%. This will be achieved by improving the maintenance of existing irrigation systems and reducing the losses in water conveyance systems (irrigation canals).	Garden area reduced by 27% and replaced by rainfed arable land
High efficiency improvement (D)	Overall irrigation efficiency in the area is improved to 85%. This presents a high investment scenario, where existing irrigation systems are replaced by highly efficient sprinkler and mostly dripping systems. The overall efficiency is based on Fader et al. (2016).	Irrigation efficiency improvements allow 45% expansion of garden areas.

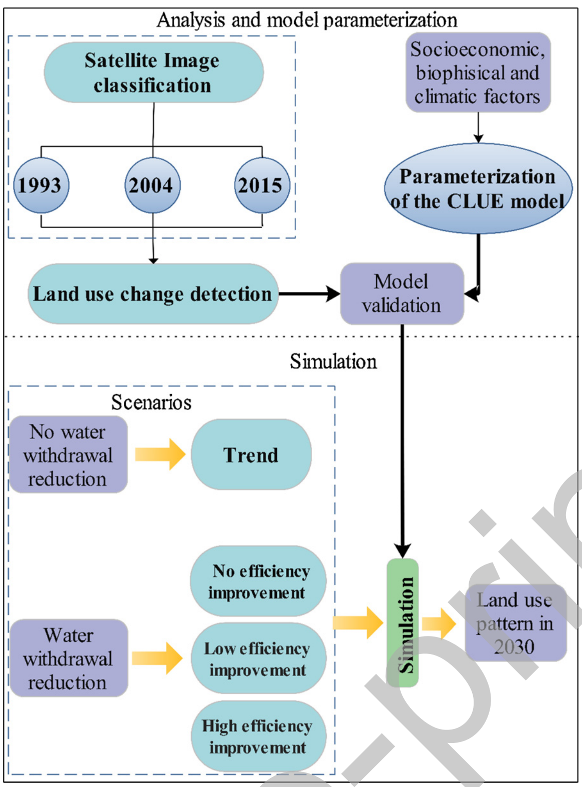

Fig. 2. An overview the methodology.

Table 2. Fig. 2 provides an overview of the key elements of the methodology.

3. Results

3.1. Classification and land use change detection

Classified land use maps for the years of 1993, 2004 and 2015 are shown in Fig. 3. The Kappa values of the supervised classification were calculated as 0.9, 0.84, and 0.82 for 2015, 2004, and 1993, respectively. Although Kappa statistics are not a complete measure for assessing the accuracy of classified land cover maps and have to be considered with care (Olofsson et al., 2014), all values of our classified maps are considered as reasonable when put in comparison with other studies using Landsat satellite imagery. Over 23 years, significant changes were found in the irrigated agriculture and rangeland areas.

Fig. 4 also shows the areas covered by the various land use classes for the years 1993, 2004 and 2015. The land use has significantly changed over the analyzed time period, particularly in the period between 2004 and 2015 (Figs. 3 and 4). The area covered by gardens has increased from 2091 ha in 1993 to 7859 ha in 2015 which accounts for approximately 22% of the whole study area. At the same time, the rangeland area has decreased from 24,381 ha (68% of the area) in 1993 to 16,773 ha (47%) in 2015.

Land displacement drastically changed the area in the second period (2004–2015): expansion of orchards on arable land has caused arable land to compensate for losses by expanding on rangeland (Table 3). This means that not only the area of arable increased at the cost of rangeland, but also that a net loss of arable land happened due to the fast conversion to gardens. The land transition matrix reveals that during 1993–2015, 20.7% of the whole study area has changed to gardens and arable land, mostly at the cost of rangeland.

3.2. Land use model calibration

The logistic regression models revealed how local socioeconomic and biophysical location factors explain the land use pattern of the study area (Table 4). For example, the probability for the occurrence of orchards decreased with increasing slope, elevation, and distance from the villages as well as for specific soil hydrological groups and slope aspect. The probability for the occurrence of rangeland decreased by increasing the distance from road and river, elevation, evaporation, soil depth and pH. High evaporation significantly affected the suitability of arable land.

The results of the regression models (ROC value) showed good relationship between the observed land use pattern and the location factors: most of the ROC values were above 0.9 and all were above 0.8 (Table 4). The overall Kappa coefficient was 0.8 for the calibration through comparison of the observed and predicted land use map in 2015. Sometimes, good model fit for location factors result is not a guarantee for good land use model results because changes in the land use and its location factors evolve over the time (Overmars and Verburg, 2005) together with other model parameters and structural assumptions in the land use model representation. Therefore, we also conducted a model run during the observed period of historic land use change to see how well the model could capture the spatial patterns of the observed land use changes.

3.3. Future land use change scenarios

We simulated four spatially explicit land use change scenarios (Fig. 5). The scenarios with no and low irrigation efficiency improvement differed substantially from the observed trends and high irrigation efficiency improvement (Fig. 5B and C). Based on observed trends and our scenario definitions, the region might experience respectively 40% and 26% of orchard abandonment (Fig. 5B and C) in case water withdrawal is reduced considerably. We show that no or low improvements

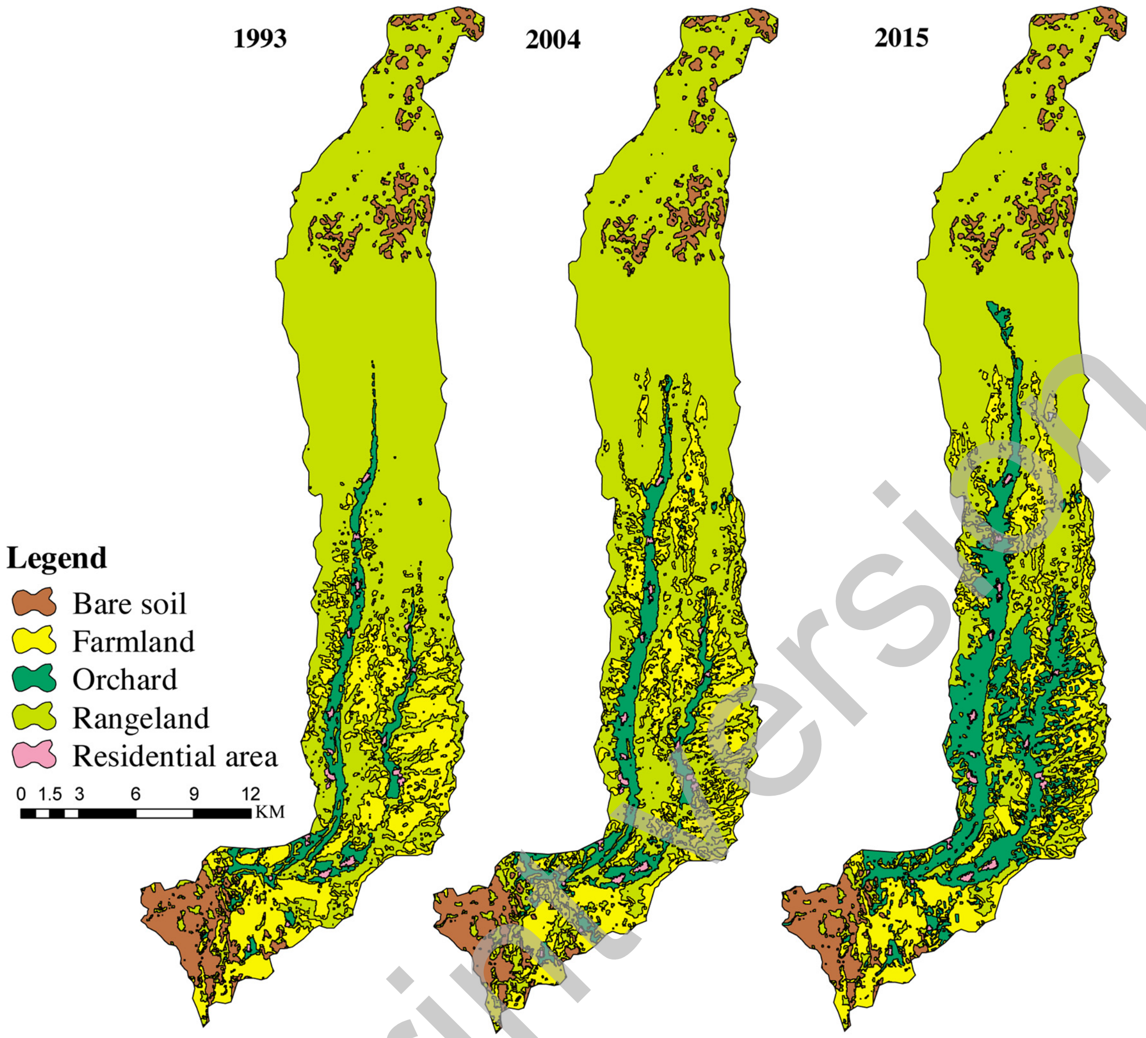

Fig. 3. Supervised classification results for the years of 1993, 2004 and 2015.

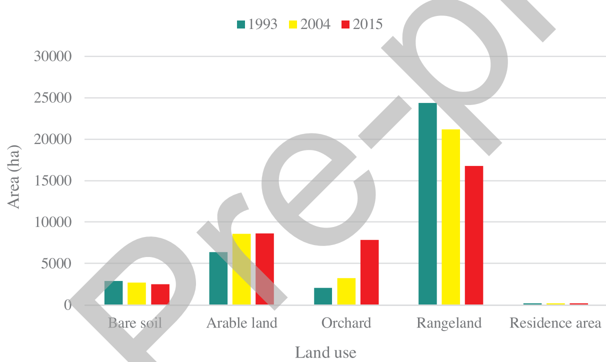

Fig. 4. Area covered by each land use class over 1993–2015.

to irrigation efficiency will lead to widespread conversion of irrigated orchards to rainfed arable land. This increase is particularly high in the no efficiency scenario, where we project a 217% increase in arable area (Figs. 5B and 6). Moreover, gardens will not be able to contribute to increasing demands for cropland based on observed trends. Only orchards close to settlements and rivers will remain (Fig. 5B and C). This means that crops that can provide a higher income to farmers (fruit) will need to be replaced by annual crops. The high efficiency improvement scenario (Fig. 5D) showed that considerable improvements to irrigation systems in the area need to be implemented in order to maintain the cultivation of irrigated crops in the area. Only this way orchards can also contribute to an increase of crop production in the area.

The trend scenario visualizes the pattern of land use in the case of continuing increase of gardens (Figs. 5A and 6). While this scenario is unlikely due to limited water resources and climate change, our high efficiency scenario demonstrated, that increases in orchards are possible with limited impacts on water resources if high irrigation efficiency is achieved (Fig. 5D and 6).

4. Discussion

The water resources of a river basin primarily depend on precipitation. However, human activities can affect these resources through the modification of the catchment's physical characteristics. Our case study is illustrative of the large impacts that land use change can have on water resources and how land use patterns would strongly differ if more sustainable land use practices for integrated management of land and water resources were implemented. Land use clearly plays an important role in the sustainability of water resources in a river basin and can have both direct and indirect impacts that are beyond the boundaries of the region (Alipour and Ghasemi Tangal Olya, 2014; Faramarzi et al., 2012). Our study indicates that while rainfed agriculture is likely to have higher water use than rangeland, its water use cannot be compared with that of intensive orchards that need to be irrigated (Alipour and Ghasemi Tangal Olya, 2014). However, we also indicate that by adoption of adequate technology, orchard expansion

Table 3
Transition matrix of land use change over 1993–2015.

1993–2004	Bare soil	Arable land	Orchard	Rangeland	Residential area
Bare soil	91.66	1.94	0.08	6.32	0.00
Arable land	0.23	92.25	6.35	1.17	0.00
Orchard	0.00	1.03	97.88	1.09	0.00
Rangeland	0.01	10.63	3.24	86.12	0.00
Residential area	0.00	0.00	0.00	0.00	100
2004–2015					
	Bare soil	Arable land	Orchard	Rangeland	Residential area
Bare soil	92.08	7.07	0.85	0.00	0.00
Arable land	0.30	71.30	27.34	1.06	0.00
Orchard	0.00	1.26	97.30	1.44	0.00
Rangeland	0.01	10.72	10.90	78.37	0.00
Residential area	0.00	0.00	0.00	0.00	100

could continue with only slightly increased impacts on the hydrology.

The large expansion of orchard land use in the past decades has been stimulated by apple marketing, while economic reasons have also stimulated more urban investors in this sector. To facilitate this development, increased withdrawal of both ground and surface water was needed to meet the irrigation requirements of the expanded agriculture area (Hassanzadeh et al., 2012; Alipour and Ghasemi Tangal Olya, 2014; Fazel et al., 2017). Those changes led to a sharp and substantial decrease in the basin water resources, not only in the study area but also in other Urmia Lake sub-basins, and causes threat of drought to the surrounding plains of the lake.

Expansion of cropland (both rainfed and irrigated) in the region started at least two decades ago when the Iranian government applied a new policy for agricultural products (Madani, 2014). The government promoted economic development with increased agricultural production. More production not only requires more land but also, in this case, more water withdrawal. Meanwhile, ensuring food security led to expansion of arable area mostly at the cost of rangeland.

Spatial policies can directly affect land use or indirectly through affecting other driving forces. In the absence of legal considerations, economic forces were fundamental factors influencing the anthropogenic change of land (Wang et al., 2008). Demographic development has also led to increased growth in agricultural products to meet the increased demand (Dehghan, 2011). Implementation of development projects without considering the principals of sustainable development as well as socioeconomic issues caused local people to be free in converting rangeland to rainfed cropland and orchards (irrigated agriculture), especially between 1993–2004 (Alipour and Ghasemi Tangal Olya, 2014). Orchards and rainfed cropland area intensification were promoted by a lack of land and water governance, land ownership issues, availability of land and water due to the adoption of new technologies for pumping water in the second period as well as demographic growth were the accelerator components in this period. These changes resulted in unsustainable water withdrawal due to expanded irrigated cropland on the account pof arable land which was traditionally characterised as dryland farming (Alipour and Ghasemi Tangal Olya, 2014). Our results confirm the findings of Khazaei et al (2019), where tit was found that expanded irrigated agriculture as major driving force of the region is responsible for lake level decline through affecting its inflows.

Streamflow and precipitation trends showed that rainfall decreased slightly in the studied period, while the observed streamflow trends indicated a remarkable decrease (Fig. 7). These data were collected from the Maragheh Synoptic station and Gheshlagh Amir hydrometric station. Before 2003 (1992–2003), the streamflow and precipitation followed similar trends (Fig. 7). After 2003, however, the precipitation and stream flow demonstrate different trends and behavior.

During last three decades, the short-term annual average of precipitation (257.6 mm) decreased by 12.2% (Hassanzadeh et al., 2011 reported a 10% reduction for the whole Urmia Lake basin) in comparison with long-term value (293.5 mm). In the same period the stream flow has drastically decreased: its short-term annual average

Table 4
Most important socioeconomic and biophysical location factors identified from the logistic regression.

Variables	Bare soil	Arable land	Orchard	Rangeland	Residential area
Aspect	0.0043	*	−0.0014	−0.0006	*
Distance to river	*	−0.0001	0.0003	−0.0001	*
Distance to road	0.0024	−0.0002	0.0003	−0.0002	*
Distance to main road	−0.002	−0.0002	0.0004	0.0002	0.0006
Distance to village	−0.00042	*	−0.0002	0.0002	−0.1167
Elevation	0.0030	0.0120	−0.0212	−0.0023	−0.0348
Evaporation	−1.416	−2.4103	0.0793	−0.3829	*
Precipitation	0.5758	0.2856	0.3705	0.0050	*
Temperature	167.7140	281.935	*	43.4688	*
Slope	0.0178	−0.0098	−0.0155		*
Soil depth	*	−0.0104	0.0193	−0.0077	*
Soil hydrological group	*	1.0657	−1.16172		*
Soil pH	−3.2078	*	0.5714	−0.1938	*
Soil Texture	−1.4032	*	0.4277	0.2138	*
Constant	134.3668	451.5965	−204.7267	105.1975	62.6135
ROC	0.96	0.83	0.91	0.84	0.99

* The factor has not been implemented in the regression model.

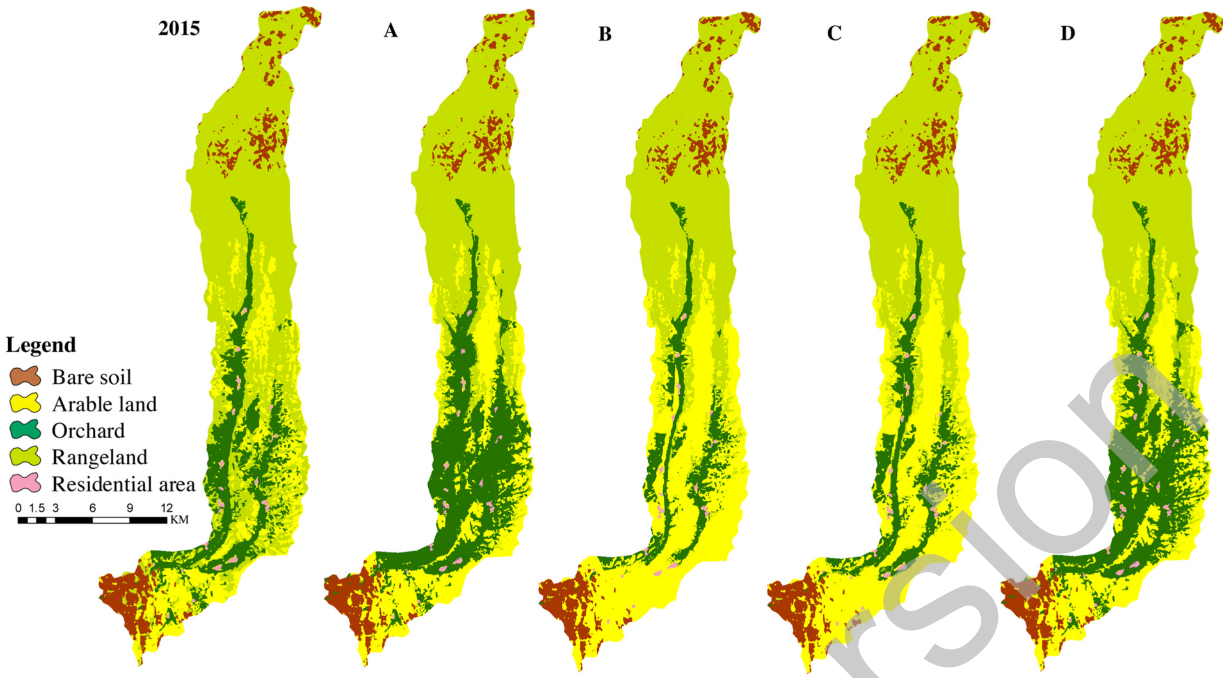

Fig. 5. Spatial changes in land use classes under various irrigation efficiency and water withdrawal scenarios.

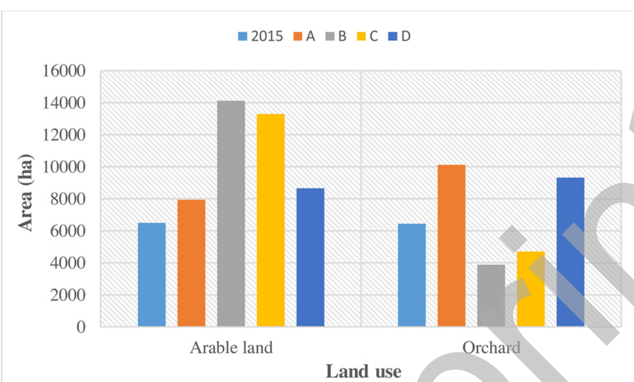

Fig. 6. Change in the land use area under various irrigation efficiency and water withdrawal scenarios.

(1.4 M^3/s) decreased by 35% compared to long-term stream flow (2.1 M^3/s) (Fig. 7). This means that streamflow decreased approximately three times more than the decrease in precipitation, which can be attributed to increased water withdrawal due to land use change, particularly agricultural activities. Land use change affected Mordagh Chay streamflow in two ways. First, a direct decrease was caused by withdrawals from ground and surface water to meet the irrigation requirements of expanded agriculture area. Second, by increasing the surface soil capacity to absorb water there was a decrease in surface runoff generation, combined with an increase in evapotranspiration (ET) as a result of vegetated area expansion (Gao et al., 2017). The findings from our study correspond with earlier works that indicated that groundwater depletion in the whole Urmia lake basin significantly influenced soil moisture and runoff (Wada et al., 2010; Zarghami, 2011; Khazaei et al., 2019). Most of the precipitation events were not sufficient to generate runoff unless a previous event occurred to meet the extra soil

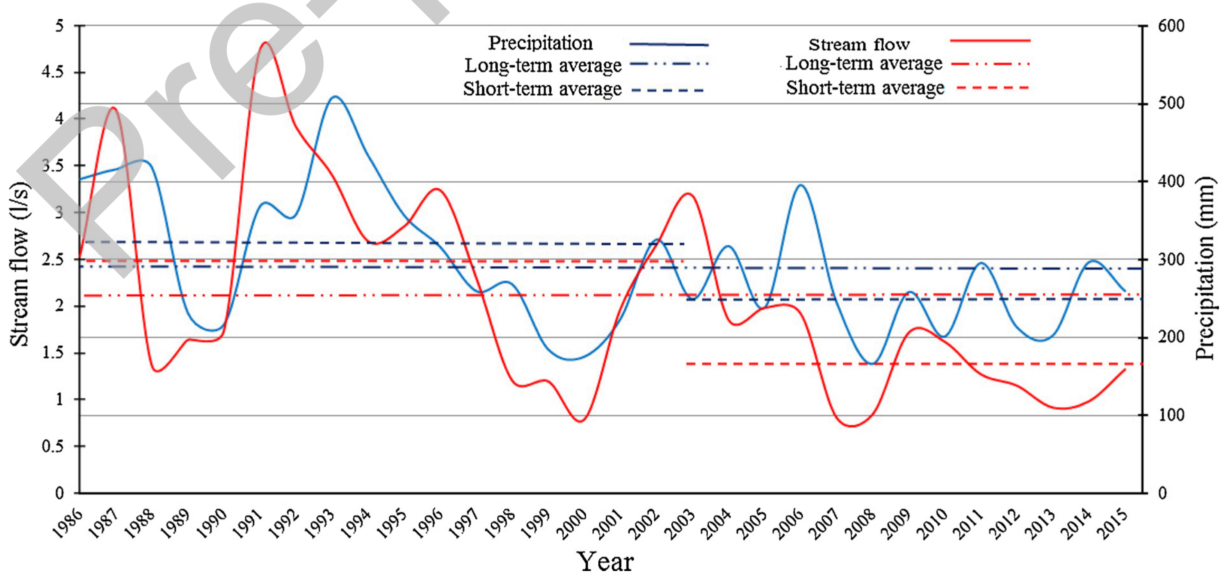

Fig. 7. The linkage of precipitation and water yield trends in the study area.

water storage (Wada et al., 2010; Zarghami, 2011).

Socioeconomic developments under water scarcity are becoming more challenging for societies worldwide (Loucks and Gladwell, 1999). In our study, we analyzed scenarios with reduced freshwater withdrawals and constrained the expansion of irrigated areas. In order to expand irrigated areas in the future to meet expected crop production increases, reducing water losses is inevitable. All the scenarios were designed based on current climate conditions and irrigated agriculture may in practice need to be restricted even more due to climate and precipitation variability as well as extreme weather events (Moriondo et al., 2011).

Our no and low efficiency improvement scenarios suggest substantial orchard abandonment in the area due to less available water resources. This perspective will negatively affect the local farmer's economic status, as they depend heavily on the production of irrigated crops. Besides investments in irrigation equipment, farmers may need to change crops or modify their agricultural activities. The results of the high efficiency scenario indicate that irrigation systems improvement enables production of more crops while overcoming the water shortage in Mordagh Chay and the wider Urmia Lake region. Irrigated agriculture is the highest water user not only in the whole Urmia Lake basin but also in the whole of Iran (FAO, 2008), as it is responsible for more than 90% of total water withdrawal. The results of the high efficiency scenario are similar to the historic trend scenario, suggesting that current trends of crop production can only be followed when improving the irrigation efficiency. The historic trend scenario presents a virtual scenario as it does not account for limited water resources and would, in reality, likely results in a collapse of the agricultural sector due to depletion of the water resources.

The scenarios presented in this paper should be interpreted as visualizations of alternative futures for the catchment. They are not meant as predictions, but rather as boundary objects to facilitate discussion and create awareness of the consequences of alternative land use choices. The scenarios are outcome oriented: except for the trend scenario they are driven by the target to reduce water withdrawals by 40%. It is unclear if this is sufficient for restoring some of the hydrologic situation of the catchment. Further climatic change and other changes in hydrology (like dams) are likely to have impacts that may negatively trade off on the reductions achieved in this catchment (Khazaei et al., 2019). At the same time, our study provides an entry point for including land use as part of the discussion on more sustainable and adapted water management in the region.

5. Conclusion

Unsustainable land use management strategies in the Urmia lake basin failed to recognize the emerging sign of the lake decline. There was no comprehensive policy that addresses the nexus between socioeconomic development and the sustained functioning of ecological systems. Currently, saving 40% water withdrawal in the agriculture sector through the improvement of irrigation systems efficiency is the key policy strategy to preserve the Urmia Lake. This study explored the plausible pathways to implement such a strategy through land use change scenarios in one of the Urmia Lake sub-basins. The results provide insights into what such more sustainable use of catchment water resources would mean for land use patterns. While dependent on local farmer activities, land use change in the region is driven by increased marketing opportunities for cash crops which can impact the lives of millions of people distant from the catchment through its impact on the destruction of the Urmia Lake basin. Local land use in this region, therefore, has national and international importance and should be considered when developing more integrated land and water resources management plans. We have shown the extent of land use change over the past decades and how structural changes in land use are needed to reach reductions in water withdrawal. The region will be unable to meet observed trends for the production of irrigated crops unless the irrigation efficiency is improved. Finally, we have shown that by improving the efficiency the dual aim to satisfy the increasing need for crops, and a limitation on water resource withdrawal is feasible and essential to avoid the need to strongly decrease the irrigated area. Sustainable planning of land use, particularly irrigated agriculture, is necessary to preserve water resources in the region, as well as maintain agricultural activities and people's livelihoods.

Declaration of Competing Interest

None.

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