Impacts of future climate and land use change on water yield in a semiarid basin in Iran

Shirmohammadi Chelan, Bagher; Malekian, Arash; Salajegh, Ali; Taheri, Bahram; Azarnivand, Hossein; Malek, Ziga; Verburg, Peter H.

published in
Land Degradation & Development
2020

DOI (link to publisher)
10.1002/ldr.3554

document version
Version created as part of publication process; publisher's layout; not normally made publicly available

document license
Other

citation for published version (APA)
Shirmohammadi Chelan, B., Malekian, A., Salajegh, A., Taheri, B., Azarnivand, H., Malek, Z., & Verburg, P. H. (2020). Impacts of future climate and land use change on water yield in a semiarid basin in Iran. *Land Degradation & Development*, *31*(10), 1252-1264. https://doi.org/10.1002/ldr.3554

Impacts of future climate and land use change on water yield in a semi-arid basin in Iran

Bagher Shirmohammadi[a], Arash Malekian[*a], Ali Salajegheh[a], Bahram Taheri[b],
Hossein Azarnivand[a], Ziga Malek[c], Peter H Verburg[c,d]

[a]Faculty of Natural Resources, University of Tehran, Karaj, Iran, Telefax: +982632249313, E-mail:malekian@ut.ac.ir

[b] Amirkabir University Foundation's Nexus and HSE Center, Tehran, Iran

[c] Environmental Geography Group, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam, the Netherlands

[d]Swiss Federal Institute for Forest Snow and Landscape Research, WSL Zürcherstrasse 111, CH-8903, Birmensdorf, Switzerland

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/ldr.3554

Impacts of future climate and land use change on water yield in a semi-arid basin in Iran

Abstract

Studying the interaction between hydrology, land use and climate change is necessary to support sustainable water resources management. It is unknown how land management interventions in dry climate conditions can benefit water yield in the context of climate and land use change interactions. In this study, we assessed the effects of both land use and climate change on the Mordagh Chay basin water yield using the Integrated Valuation Ecosystem Service and Tradeoffs model (InVEST). First, we modelled the current water yield, followed by developing six combined climate-land use scenarios until 2030 based on the CCSM4 climate model for the RCP4.5 and RCP8.5 scenarios. We used three future land use scenarios simulated by the Dyna-CLUE model. The trend scenario of land use change, which does not include any improvements in irrigation efficiency, significantly affected basin water yield under both climate scenarios. Water yield decreases by 19.8% and 31.8% for the RCP4.5 and RCP8.5, respectively. Under all land use scenarios that included improvements in irrigation efficiency the water yield responded positively. For the RCP4.5 scenario, the water yield was projected to increase between 16.6 and 18% depending on the land use scenario. The increase in water yield under the RCP8.5 climate scenario was much lower than for the RCP4.5 scenario (about one third). Overall, the results showed that by adopting appropriate irrigation efficiency, it is possible to achieve a better balance between environmental needs, regional economic and agricultural development. The results provide insight into possible sustainable development options and also provide guidance for managing the other Urmia Lake sub-basins while the approach of integrated assessment of climate, land use change and land management options is also applicable in other conditions to help inform sustainable management.

Keywords: InVEST, Irrigation efficiency improvement, Ecosystem Services, RCP scenarios, Urmia Lake basin,

1. Introduction

The recent changes in climate have significantly affected natural systems globally (IPCC, 2014). Increasing temperature and change in precipitation patterns affect the hydrological characteristics in basins, leading to floods and long-term drought (Singh et al., 2016; Upgupta et al., 2015). Meanwhile, socioeconomic development and population growth resulted in land use change, leading to additional pressures on the environment (Millennium Ecosystem Assessment, 2005). Human-induced activities have significantly increased evapotranspiration because of large expansion of water-intensive and irrigated agriculture (Kundu et al., 2017), changes in vegetation cover (Feng et al., 2012; Khazaei et al., 2019) and expansion of (plantation) forest (Tange et al., 2018; Yan et al., 2018). Integrated land-climate changes resulted in a substantial change from basins' natural water supply-demand balance, particularly in the arid and semi-arid regions. As a result, several water bodies and wetlands dried due to lower water provisioning of the upstream ecosystems (Sajikumar and Remya, 2015). The most notable example is the Aral Sea, where its two tributaries have dried over the last 58 years as a result of unsustainable socioeconomic development (Cretaux et al., 2013; Clarke et al., 1993; Boomer et al., 2000). Currently, the Urmia Lake located in northwest Iran is being exposed to similar pressures as the Aral Sea (Shadkam et al, 2016). Recent surveys suggested that the supply of water resources in the Lake region are not adequate to sustain the lake's ecological needs because of economic development of the region (Hassanzadeh et al., 2012; AghaKouchak et al., 2015; Fazel et al., 2017). Even with a stagnating socioeconomic development, the lake's situation could degrade further due to future climate change (López-Moreno et al., 2014). Increases in the temperature would lead to higher water demands and could reduce its availability (IPCC, 2013; Jiménez Cisneros et al., 2014). In such a situation, it is the supply-side water resources management approach which should guarantee a sustainable use of the region's water resources in the future. To achieve this, future responses of the basin need to be assessed by jointly assessing the effects of land use and climate change. Moreover, it is necessary to understand the historic change in land use and climate for a proper evaluation of their effects (Lambin et al., 2011).

The combined effects of future climate and land use changes on hydrological components, particularly water yield and surface runoff, have been studied using different hydrological models. A study in South Australia revealed that change in climate has impacted water yields significantly more than land use change (Shrestha et al., 2017). Trange et al. (2017) investigated the effects of both land use and climate changes on the Sekong, Sesan, and Srepok River Basins in Southeast Asia and found that the annual discharge is projected to increase by the twenty-first century which would make these regions prone to land use and climate change. A study on how the Urmia Lake is affected by human activates (land use) and climate change, indicated a high contribution of land use change as compared to climate change in the lake shrinking and drying (Khazaei et al., 2019). This study revealed that the human-driven vegetation cover and associated irrigated agriculture expansion were the dominant drivers of the drying lake and resulted in high total evapotranspiration and associated consumptive use of water which has decreased the inflows to the lake.

Kundu et al. (2017) reported that the Narmada basin water yield in India experienced an increase by 3.4% between 1990-2011 and could additionally increase by 17.5% until 2050. Another example from southwest China shows the combined effect of climate and land use changes on surface runoff (Wu et al., 2017), where they noted the high contribution of climate changes on runoff as compared to a low contribution of human-induced land use change across the basin.

This paper aims to study the effects on the Mordagh Chay basin water yield as one of the sub-basins of the Urmia Lake region through considering both land use and climate changes. We used the Integrated Valuation of Ecosystem Services and Tradeoffs model (InVEST) to simulate water yield. The main objective of the paper is to analyze plausible pathways for sustainable water resource management considering future climate and land use changes. We aimed to asses possible future trajectories that aim to better achieve a balance between socioeconomic development and environmental sustainability.

2. Materials and Methods

2.1 Study area

Mordagh Chay basin is one of the Urmia Lake region sub-basins which is located on the southern site of the Sahand Mountains, where the Mordagh Chay River originates, in East Azerbaijan province, Iran (Figure 1). Annual mean temperature and precipitation are 11.3℃ and 429.2 mm, while the maximum and minimum temperature of the Mordagh Chay basin are -18℃ and 39.2℃, respectively. The mean annual evaporation and mean annual runoff are 1318.41 mm and 83 mm/m2, respectively. According to field surveys and morphological examination, the Mordagh Chay basin soils are grouped as Antisol (East Azerbaijan Natural Resources Research Center, 2014) and its parent material and major units are respectively formed from the Andesite and Dacite rocks (East Azerbaijan Natural Resources Research Center, 2014). The area is covered by various vegetation including annual rainfed crops, irrigated orchards and natural vegetation. Rainfed crops mostly include wheat, barley, and peas planted through a rotation system. Orchards are the most water-intensive land use and covered by tree crops, mostly apples but also grapes, prunes, peach and apricots. Mordagh Chay basin is one of the main pillars of apple production in the region and the local economy heavily relies on it. Natural vegetation, which covers a major part of the study area is used for livestock grazing and fodder. Herbaceous vegetation including Astragalus adscendens and Thymus kotschyanus are the dominant species which cover more than 90% of the natural vegetation (East Azerbaijan Natural Resources Research Center, 2014).

The altitude in the mountain area reaches up to 3681 m while the lowest part of the valley is at 1480 m. The Mordagh Chay basin has an area of about 360 km2 and a total population of 17196 which live in 20 local communities (Statistical

Center for Iran, 2016). The Mordagh Chay River is a tributary to the Urmia Lake and provides surface water for the agricultural activities in the region. The location in the mountains leads to four distinct seasons which determine its suitability for agriculture. The climate varies over the seasons: summer is hot with occasional short-time heavy precipitation, whereas winter is cold and its precipitation is mostly in the form of snow. Autumn and spring are the main rainfall seasons. The monthly and seasonal precipitation distribution of the Mordagh Chay basin are presented in Table 1.

Table 1.

The basin has been affected by rapid expansion and intensification of agricultural areas in the last decades, similar to other areas in the Urmia lake basin (Shirmohammadi et al, 2019). Over a 23 year period (1993-2015), 20.7% of the study area has changed to irrigated agriculture and rainfed cropland, mostly at the cost of natural vegetation (Shirmohammadi et al, 2019). During this period, the orchard area has increased more than three times during the period 1993 to 2015. While the area covered by natural vegetation decreased from 68% in 1993 to 47% in 2015 (Shirmohammadi et al, 2019).

Fig.1.

Unsustainable governance related to land planning and management as well as water resources management has led to untapped use of ground and surface water resources in the study area and in the whole lake basin. A plan entitled "Integrated Management Plan for Lake Urmia Basin" has been presented in 2010 (Integrated Management Plan for Lake Urmia Basin, 2010). The main objectives of this plan are increasing inflows to the lake by saving more water from the agriculture sector as well as halting dam construction in the lake region (ULRP, 2016). Saving 40% water from the agriculture sector is a currently implemented policy objective by the government to sustain the lake above the ecological level through sustainable water resources management. To save 40% water in agriculture, increasing the irrigation efficiency is seen as the main measure.

2.2 Data

This study is divided in three parts: land use change detection and simulation, collection of climate change data, and hydrological modelling using the InVest model. For the land use change detection and modeling we used the data from Shirmohammadi et al. (2019) that used LANDSAT satellite images (USGS, 2018) and the Dyna-CLUE land use change model (Verburg and Overmars, 2009) to detect land use changes and modeling future scenarios, respectively. The climate data used in this study were obtained from the East Azerbaijan Water Authority and Natural Resources Research Center and also Iranian Climatological Institutions. Most of the meteorological and hydrological data were obtained directly from the ground stations while a few of them, including plant available water content, depth to root-restricting layer, Z parameter and reference evapotranspiration, were calculated based on measured data. Future climate projections were obtained from the Worldclim.com website for the CCSM4 model (Hijmans et al., 2005). We used the CCSM4 model, as it has been identified as most representative for our study area (Pal and Eltahir, 2015). The model output is available at different spatial resolutions under four RCP scenarios. In this study, we used the most detailed spatial resolution of the model which is approximately 1 km.

2.3. Mordagh Chay water yield model

To assess future land use and climate change effects on the Mordagh Chay basin hydrology, we used the InVEST model (Sharp et al., 2015). This open-source ecosystem service model, has been used widely worldwide (Redhead et al., 2016; Boithias et al., 2014; Terrado et al., 2014; Pessacg et al., 2015; Hamel and Guswa, 2014; Xiao, et al., 2015). The model was developed to support decision makers by suggesting multiple approaches and pathways on how to deal with the emerging environmental challenges, such as changes in land use, land management and climate change (Sharp et al., 2015). The model calculates the annual or seasonal average water yield of a basin by considering the relative contribution of each part of the catchment on water production (Sharp et al., 2015).

The model uses the Budyko Curve (Budyko, 1974), which is established based on the available water and energy balance, to estimate the basin water yield. This approach assumes that the rate of evapotranspiration directly depends on the available water resources (precipitation) and atmospheric demand (evapotranspiration) (Yang et al., 2011). The Budyko curve is used to divide the precipitation into runoff and evapotranspiration components (Mendoza et al, 2011; Sharp et al, 2015). By subtracting various uses of water in a given area, the mean annual water yield is calculated using Equation 1 for each pixel, watershed and sub-watersheds scale (Sharp et al., 2015):

$$y = \left[1 - \left(\frac{AET}{P}\right)\right] * P \qquad \text{Equation (1)}$$

Where *y*, *AET*, and *P*, are the annual water yield, annual actual evapotranspiration and annual precipitation at the corresponding scales, respectively.

Due to the difficulty to measure basin-scale annual actual evapotranspiration (Redhead et al., 2016) and the need for highly specialized equipment in plot scale measurement (Evans et al., 2012), Budyko (1974) established a methodology to deal with those issues. That methodology, which was later modified by Fu (1981) and Zhang et al. (2004), relates actual evapotranspiration to the potential evapotranspiration (Eq. 2).

$$\frac{AET}{P} = 1 + \frac{PET}{P} - (1 - (\frac{PET}{P})^{w})^{\frac{1}{w}} \qquad \text{Equation (2)}$$

Where *w* is the empirical parameter used to determine the shape of the Budyko curve that relates the potential evapotranspiration to the actual evapotranspiration. w is determined by precipitation, plant available water content and the constant Z parameters through the Equation 3 (Sharp et al., 2015).

$$w = Z\frac{PET}{P} + 1.25 \qquad \text{Equation (3)}$$

Donohue et al. (2012) developed a methodology for calculation of the Z constant which represents the local precipitation pattern (Eq. 4).

$$Z = 0.2 * N \qquad \text{Equation (4)}$$

Where *N* is the number of precipitation events higher than 1 mm per year over the given period.

2.4. Model sensitivity analysis and calibration

The empirical parameter *Z*, which captures the seasonal climate variability and catchment topography characteristics, was first estimated based on the average annual number of rainy days above 1 mm/day (Donohue et al., 2012) and refined by calibration to observed streamflow data (Hamel and Guswa, 2014). We analyzed water yield model sensitivity to the Z, Kc (for the irrigated agriculture and rangeland as dominant and extensive land uses, respectively) and climate parameters (Hamel and Guswa, 2014).

The average number of rainy days (with more than 1 mm of the observed rainfall) in the area is 35. Using Equation 4 (Donohue et al., 2012), we obtained the value 7 for the Z factor, which we considered as a baseline run of the model. The value was varied between 1 and 22 for the sensitivity analysis. According to Sharp et al (2015), its value is allowed to change between 1-30 where in this study we changed its value between 1-22 during calibration process, where the higher values had more impact on the results. Since there were no local references for the value of Kc for our region, we used the international value based on a FAO report by Allen et al (1998).

Irrigated agriculture, which accounts for more than 92% of basin water resources withdrawals (Ardakaninan, 2005), and rangeland, which covers the major part of the study area, were selected for assessing the model sensitivity for the Kc parameter. As baseline value for Kc, the values 0.75 and 0.8 were used for orchard and rangeland respectively (Allen et al., 1998). We examined the model using the aforementioned values and compared the model output to the baseline run. Then, we examined the effect of ±10% variation of the Kc value for the orchard and rangeland land use types.

In order to assess the sensitivity of the water yield model outputs to the climate parameters, we examined 10 percent variations for both precipitation and reference evaporation as compared to the baseline while model calibration was implemented by comparing the model output with the observed data from the Geshlagh Amir hydrometric station located at the outlet of the basin (Hamel and Guswa, 2014). The model performance in the estimation of basin water yield was assessed by analyzing the differences between observed and predicted water yields.

2.5. Climate and land use change scenarios

We assessed the combined effects of land use and climate changes on the Mordagh Chay hydrological behavior under future RPCs 4.5 and 8.5 scenarios. The new climate changes scenarios, published in the Fifth Assessment Report (AR5) 2014 called Representative Concentration Pathways (RCPs), were designed to assess future climate change impact. These scenarios are based on specific future greenhouse gas concentrations and emission pathways (Riahi et al., 2011; van Vuuren. et al. 2011).

We developed 6 scenarios by combining three land use scenarios and two RCPs. The future land use scenarios were developed using the Dyna-CLUE model, a spatially explicit allocation model (Verburg and Overmars, 2009). The scenarios are based on observed trends in land use change over the past 15 years and include possible reductions in irrigation water withdrawal and improvements to irrigation efficiency as potential measures to halt the drying up of Urmia Lake. We used past, current and simulated future land use maps as documented by Shirmohammadi et al. (2019). Three land use scenarios were considered: a reference scenario, following the observed land use trends between 1993s and 2015, and two scenarios with different improvements to irrigation efficiency (Table 2; details in Shirmohammadi et al. (2019)).

Table 2

While the reference scenario does not assume improvements in irrigation efficiency the other two are based on plausible improvements to irrigation efficiency for semi-arid regions (Fader et al., 2016). Scenario B assumes small irrigation efficiency improvements bringing the water use efficiency up to 50%. In the high irrigation efficiency scenario (scenario C) the highest theoretically possible irrigation efficiency improvement (85%) is assumed. Figure 2 shows the future land use map as simulated for each scenario.

Fig. 2

OrchardOrchardorchardorchardorchardorchardorchardorchardorchardThe water yield of the basin was projected under each of the scenarios separately for the period 2015-2030 and was compared with the baseline period (1993-2015). Figure 3 summarizes the different methodological steps of this study.

Fig. 3.

3. Results

3.1. Sensitivity analysis and calibration

The sensitivity of the water yield model for climate parameters (precipitation and evapotranspiration), Kc for two land uses including orchard and rangeland as well as the Z factor was tested. For a 10% increase and decrease in the orchard Kc, the model result was affected by a 2.5% decrease and 4% increase, respectively. For the same increase and decrease in the Kc of rangeland, the water yield showed a 16% decrease and 25% increase, respectively. There was a very low sensitivity to the Z values (Hamel and Guswa, 2014). The change in the Z value from 7 to 4 only slightly affected water yield (less than 1 mm).

The water yield was projected to respond by a 22% increase and a 21% decrease as results of a 10% increase and decrease in precipitation, respectively. For the same increase and decrease of evapotranspiration, basin water yield was projected to increase by 11% and decrease 12%, respectively. A summary of the sensitivity analysis results and relative changes in basin water yield are presented in Table3. Our results show that the predicted water yield is primarily sensitive to the precipitation and evapotranspiration.

Table.3.

The calibration results showed that the InVEST model is capable to capture the hydrological behavior of the basin in water production to a reasonable extent. The mean observed water yield in the Mordagh Chay river basin was about 86 mm and the model estimated 93 mm. Figure 4 depicts the Mordagh Chay basin water yield for the baseline year of 2015.

Fig. 4.

The maximum and minimum amount of water yield for the Mordagh Chay basin are 0 and 565 mm (Figure 4). This means that there are different contributions across the study area in water provision, where the values of 0 and 565 mm represent the area with high and low contribution in water yield which, respectively, covered by water intensive land use and the mountain area with a natural vegetation cover.

3.2. Impacts of future land use-climate change scenarios on the basin water yield

An increasing trend in both temperature and precipitation was found in the scenarios based on the climate projections of the CCSM4 for both RCP 4.5 and 8.5. The rate of increase in temperature for the RCP8.5 scenario is higher than in the RCP4.5 scenario with an increased up to 7% and 13% compared to the baseline for RCP4.5 and RCP8.5, respectively. Precipitation has increased up to 14% and 9%, respectively for RCP4.5 and RCP8.5.

The difference between the projected average temperatures is about 0.67 °C for the study area. However, the difference between the projected average water yield is about 18.55 mm/m2. The results indicate that the RCP8.5 will have much negative effects on the basin water provision features as compared to the RCP4.5 scenario. This conversion in scenario A was more intense than in scenario C. We observed an overall increase in water yield under the B and C scenarios. The water yield of the study area was projected to increase as compared to the baseline, however, there are some differences among the scenarios except for scenario A. The two RCP4.5 based land use scenarios resulted in considerable increases in water yield (Table 4). The basin water yield was projected to increase more than three times in RCP4.5 related scenarios as compared to the RCP8.5 based scenario.

The Trend scenario (scenario A) significantly affected basin water yield through both RCP4.5 and 8.5. Under these scenarios, the water yield would decrease by 19.8% and 31.8% in the case of RCP4.5 and RCP8.5, respectively (Table 4).

The increase in water production in the area was significant for the RCP4.5 scenario, and it can increase the Mordagh Chay water yield by 17.8% and 16.6% for land use change scenarios B and C, respectively. Whereas, only 5.4 and 4.5 percent increase in water yield is projected for the scenarios B and C based on RCP8.5.

Table 4

Implementation of scenario A under RCP4.5 suggests that the Mordagh Chay basin would face a decrease of water yield from 93 (mm/m2 per year) in 2015 to 75.5 in 2030 (Figure 5a). In the case of the other two scenarios an increasing trend in water yield can be seen, where the increase for scenario B is slightly higher than for scenario C. Since the expansion of irrigated agriculture for scenario C is higher than in scenario B, under this scenario more area would contribute to the higher water withdrawal levels. Furthermore, through this scenario, the region would be more exposed to water stress because of high evapotranspiration from expanded irrigated agriculture, which could expose the basin even more to climate change. For scenario B, water yield will increase from 93 (mm/m2 per year) in 2015 to 109 (mm/m2 per year) in 2030. Projected water yield for scenario C is approximately 1-3 (mm/m2 per year) lower than scenario B (Figure 5a).

Figure 5b depicts the projected water yield for developed land use change scenarios under RCP8.5. There were two distinct differences between these scenarios. First, the projected water yield for the basin under RCP4.5 is higher than that for the RCP8.5 scenario. Secondly, over the period 2015-2030, an increasing trend in water yield is seen for RCP4.5 whereas for RCP8.5 the yield remains constant.

Fig. 5

Figure 6 shows the projected water yield value for the different land use change scenarios under RCP8.5. A decrease in water yield, from 93 mm/m2 per year in 2015 to an average 64 mm/m2 per year in 2030, was projected for scenario A under RCP8.5. The similar increase in water yield has seen for both scenarios B and C under RCP8.5, where the water yield can increase from 93 mm/m2 per year in 2015 to 98 mm/m2 per year in 2030 (Figure 7)

Fig. 6

Fig.7

4. Discussion

Climate and land use change are major driving forces directly and indirectly affecting river basin hydrological behavior, particularly water yield. While there are studies that include both climate and land use change, this study goes beyond earlier studies by also testing forward looking scenarios aimed at improving the hydrological conditions through irrigation efficiency improvement and change in land use. Continuing the trend of conversion of both rangeland and farmland to orchards in our study area would significantly decrease the basin water yield. These land use changes affect water yield by a structural change in the basin due to an increase in infiltration and evapotranspiration rates (Stone, 2011; Khazaei et al., 2019). Since conversion to orchards can be controlled by land management and planning, the management strategies assumed in the scenarios can be used to manage the water yield in the region. The scenario C results are in accordance with Tang et al. (2018) and Fu et al. (2017) that found that the expansion of plantation forest area, which is comparable to our orchard land use in water use, led to a decrease in water yield. While our results do not suggest a considerable difference between the RCP4.5 based land use scenarios (B-RCP4.5 and C-RCP4.5) and the RCP8.5 based land use scenarios (B-RCP8.5 and C-RCP8.5) in terms of projected water yield, there was a distinct impact of the differences in land use between the scenarios. Expansion of orchards associated with the projected increase in temperature and precipitation will drastically affect the basin water yield (scenario A). In spite of the differences in context and climate conditions, these results are similar to Monprapussorn (2018) that identified that climate change associated with decrease in natural land cover would ultimately degrade ecosystem delivery service in Thailand.

Irrigated agriculture is responsible for a major part of the water consumption of the study area and is projected to expand under the two land use scenarios (A and C). However, the high efficiency scenarios (C-RCP4.5 and C-RCP8.5), can provide a considerable increase in inflow to the Urmia Lake (Table 4). While scenario B requires a tradeoff between the water balance and the development of agriculture in the region, the C scenarios for both RCP4.5 and RCP8.5 show a situation where the region is able to expand its irrigated agriculture, therefore promoting a growth in the local economy, while still improving the water inflow in Urmia Lake (Table 4). This will, however, demand considerable investments in improving the irrigation systems in the region.

The obvious difference between the scenarios is indicative for the large impacts of land use change on the basin water yield in comparison with the impacts of climate change. The increased water yield in scenarios B and C is because of water savings due to efficiency improvement, and most importantly, by reducing water withdrawals by 40% which counteract some of the negative impacts of climate change in the area. By implementation of these two scenarios (B and C), the basin would be able to yield more water while at the same time facilitate the development of the regional agricultural sector. This demonstrates the higher sensitivity of the basin water yield to land use change as compared to climate change under these scenarios, particularly the two considered scenarios A-RCPs4.5 and 8.5 (Stone, 2015; Khazaei et al., 2019). However, expansion of orchards can increase the exposure of the basin to climate change because of the high potential for evapotranspiration leading to a significant decrease in water yield. These findings are in contrast with Tu (2009), Kim et al. (2013), Sananda et al. (2017) and Wu et al. (2017). Their results suggested a high contribution of climate change on runoff as compared to a low human land use induced contribution. In contrast, our results are in the line with Stone, (2015), Gao et al. (2016), Alborzi et al. (2018) and Khazaei et al. (2019) that found that land surface change has contributed more to the hydrological changes than the reduction in precipitation. The differences in importance of the land use and climate components are context dependent: in our study area land use impacts are very large and changes from (semi-) natural vegetation to intensively cultivated area have large hydrological impacts. In other areas land use changes are less pronounced and climate impacts may exceed these easily.

There are other uncertainties that can affect our results that were not addressed in this study. Due to inaccessible and incomplete data, we were unable to include other future climate change effects beyond changes to temperature, precipitation and evapotranspiration, such as changes to yields, periodic droughts, pests, and other hazards. Also, in spite of the availability of multiple different climate model outputs we have chosen to focus on the output of one single model. We have chosen for the CCSM4 model output over the output of other climate models. The Community Climate System Model version 4 is a GCM with the lowest total sum of root mean square errors for our region (Pal and Eltahir, 2015). While accounting for other climate models would increase the assessment of uncertainty, the larger uncertainty of those model predictions for our region would bias such an analysis. Finally, there is uncertainty in the scenario conditions. Scenario C assumes a very high level of irrigation efficiency. The ability of farmers to achieve such a high level of irrigation efficiency is not the same for all farmers in the region, as some farmers might be more (or less) able to adapt their irrigation systems (Harmanny and Malek, 2019).

We have shown, that in order to improve the sustainability of water resource management under future climate and anthropogenic activities, both improving the efficiency as well as reducing water withdrawals are necessary. Otherwise, more efficient use of water for irrigation could lead to an expansion of irrigated areas by local farmers, as was demonstrated in other scenario studies (see for example Malek et al., 2017). Moreover, financial mechanisms are necessary for irrigation improvement, as not all farmers can afford such investment into irrigation infrastructure.

5. Conclusion

The Mordagh Chay basin water resources are highly dependent on future land use and climate change. We found that the change in land use has a major role in sustainable water resources management of the Urmia Lake region. In the case of current management system, water supplies would not be able to meet the water requirement of expanded agricultural land without major impacts on the hydrology, unless the efficiency of irrigation systems is increased considerably. Such negative consequences would be exacerbated in the event of a projected warmer and drier climate that would lead to higher evapotranspiration and water consumption leading to more water shortages. The improvement of the efficiency of irrigation systems as a mitigation and adaptation strategy can increase agricultural production and improve the sustainability of using regional water resources. As the proposed high irrigation efficiency may affect return flow from agriculture, the area under cultivation must be precisely monitored and continuously controlled. In this way, limiting the expansion of agricultural activities in the future is a key element in maintaining the balance between water supply and demand in the region.

Conflict of Interest: There is no conflict of interest to declare.

References:

Aghakouchak, A., Norouzi, H., Madani, K., Mirchi, A., Azarderakhsh, M., Nazemi, A., Nasrollahi, N., Farahmand, A., Mehran, A & Hasanzadeh, E., 2015. Aral Sea syndrome desiccates Lake Urmia: Call for action. Journal of Great Lakes Research. 41, 307-311. https://doi.org/10.1016/j.jglr.2014.12.007.

Alborzi, A., Mirchi, A., Moftakhari, H., Mallakpour, I., Alian, S., Nazemi, A., Hassanzadeh, E., Mazdiyasni, O., Ashraf, S., Madani, K., Norouzi, H., Azarderakhsh, M., Mehran, A., Sadegh, M., Castelletti, A., AghaKouchak, A., 2018. Climate-informed environmental inflows to revive a drying lake facing meteorological and anthropogenic droughts. Environ. Res. Lett. 13, https://doi.org/10.1088/1748-9326/aad246.

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations, Rome, Italy.

Ardakanian, R., 2005. Overview of water management in Iran, The National Academies press. (Chapter 1).

Boithias, L., Acuña, V., Vergoñós, L., Ziv, G., Marcé, R., and Sabater, S., 2014. Assessment of the water supply: demand ratios in a Mediterranean basin under different global change scenarios and mitigation alternatives. Science of the Total Environment.470–471, 567– 77. https://doi.org/10.1016/j.scitotenv.2013.10.003.

Boomer, I., Aladin, N., Plotnikov, I & Whatley, R., 2000. The palaeolimnology of the Aral Sea: a review. Quaternary Science Reviews. 13, 1259-1278. https://doi.org/10.1016/S0277-3791(00)00002-0.

Budyko, M., 1974. Climate and Life. Translated from Russian by Miller D. H. Academic, San Diego, CA.

Clarke, R., 1993. Water: The International Crisis. MIT Press, Cambridge, MA, 193 pp.

Cretaux, J.F., Letolle, R & Bergo-Nguyen, M., 2013. History of Aral Sea level variability and current scientific debates. Global and Planetary Change. 110, 99-113. DOI:10.1016/j.gloplacha.2013.05.006.

Donohue, R.J., Roderick, M.L, McVicar, T.R., 2012. Roots, storms and soil pores: Incorporating key ecohydrological processes into Budykos hydrological model. Journal of Hydrology. 436-437, 35-50. DOI:10.1016/j.jhydrol.2012.02.033.

East Azerbaijan Natural Resources Research Center, 2014. Climatological and soils reports of the MordaghChay basin (in Persian).

East Azerbaijan Natural Resources Research Center, 2014. Physiographic and climatological studies of Mordagh Chay River basin (in Persian).

Evans, J., McNeil, D., Finch, J., Murray, T., Harding, R.,Ward, H., Verhoef, A., 2012. Determination of turbulent heat fluxes using a large aperture scintillometer over undulating mixed agricultural terrain. Agric. For. Meteorol. 166, 221–233. https://doi.org/10.1016/j.agrformet.2012.07.010.

Fader, M., Shi, S., Bloh, W., Bondeau, A & Cramer, W., 2016. Mediterranean irrigation under climate change: more efficient irrigation needed to compensate increases in irrigation water requirements. Hydrology earth system science. 20, 953–973. https://doi.org/10.5194/hess-20-953-2016.

FAO, 2016. AQUASTAT website. FAO's information system on water and agriculture. Food and Agriculture Organization of the United Nations.

Fazel, N., Haghighi T.A & Klove, B., 2017. Analysis of land use and climate change impacts by comparing river flow records for headwaters and lowland reaches. Global and Planetary Change. 158, 47-56. DOI: 10.1016/j.gloplacha.2017.09.014.

Feng, X.M., Sun, G., Fu, B.J., Su, C.H., Liu, Y., Lamparski, H. 2012. Regional effects of vegetation restoration on water yield across the Loess Plateau, China. Hydrology and Earth System Sciences. 16, 2617-2628.

Fu, B.P., 1981. On the calculation of the evaporation from land surface (in Chinese). Sci. Atmos. Sin. 5, 23–31.

Fu, Q., Li, B., Hou, Y., Bi, X., Zhang, X., 2017. Effects of land use and climate change on ecosystem services in Central Asias arid regions: A case study in Altay Prefecture, China. Science of the Total Environment. 607-608, 633-646. DOI: 10.1016/j.scitotenv.2017.06.241.

Gao, G., Fu, B., Wang, Sh., Liang, W & Jiang, X., 2017. Determining the hydrological responses to climate variability and land use/cover change in the Loess Plateau with the Budyko framework. Science of the Total Environment. 557-558, 331-342. doi: 10.1016/j.scitotenv.2016.03.019.

Hame, P., Guswa, A.J., 2014. Uncertainty analysis of a spatially-explicit annual water-balance model: case study of the Cape Fear catchment, NC. Hydrology and Earth System Sciences. 11. 11001-11036. https://doi.org/10.5194/hess-19-839-2015.

Harmanny, K.S & Malek, Ziga, 2019. Adaptations in irrigated agriculture in the Mediterranean region: an overview and spatial analysis of implemented strategies. Reginal Environmental Change. 19, 1401-1416. https://doi.org/10.1007/s10113-019-01494-8.

Hassanzadeh, E., Zarghami, M & Hassanzadeh, Y., 2012. Determining the main factors indeclining the Urmia Lake level by using system dynamics modeling. Water Resources Management. 26, 129–145. http://hdl.handle.net/10.1007/s11269-011-9909-8.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones P.G., Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Integrated Management Plan for Lake Urmia Basin, 2010. UNDP, GEF, Conservation of Iranian Wetlands Project, Department of Environment.

IPCC, Intergovernmental Panel on Climate Change, 2013. The Physical Science Basis. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, New York.

IPCC. Intergovernmental Panel on Climate Change., 2014. Climate Change: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, doi:10.1017/CBO9781107415324.004.

Jiménez Cisneros, B.E., Oki, T., Arnell, N.W., Benito, G., Cogley, J.G., Döll, P., Jiang, T., Mwakalila, S.S., 2014. Freshwater resources, in: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D.M., T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S.M., P.R. Mastrandrea, L.L.W. (Eds.)., 2014. Climate Change Impacts, Adaptation and Vulnerability – Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 229–269.

Khazaei, B., Khatami, S., Alemohammad, S.H., Rashidi, L., Wu, Changshan., Madani, K., Kalantari, Z., Destouni, G., Aghakouchak, A., 2019. Climatic or regionally induced by humans? Tracing hydro-climatic and landuse changes to better understand the Lake Urmia tragedy. Journal of Hydrology. 569, 203-217. DOI: 10.1016/j.jhydrol.2018.12.004.

Kundu, S., Khare, D., Mondal, A., 2017. Past, present and future land use changes and their impact on water balance. Journal of Environmental Management. 197, 582-596. DOI: 10.1016/j.jenvman.2017.04.018.

Lambin, E.F & Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming scarcity. Proceedings of the National Academy of Sciences of the United States of America. 108, 3465–3472. https://doi.org/10.1073/pnas.1100480108.

Lopez-Moreno, J.I., Zabalza, J., Vicente-Serrano, S.M., Revuelto, J., Gilaberte, M., Azorin-Molina, C., Moran-Tejeda, E., Garcia-Ruiz, J.M., Tague, C., 2014. Impact of climate and land use change on water availability and reservoir management: Scenarios in the Upper Aragón River, Spanish Pyrenees. Science of Total Environment. 493, 1222-1231. doi: 10.1016/j.scitotenv.2013.09.031.

Malek, Z., Verburg, P.H., Geijzendorffer, I.R., Bondeau, A., Cramer, W., 2017. Global change effects on land management in the Mediterranean region. Global Environment Change. 50, 238-254.

Mendoza, L., Pena, E., Ramırez, M., Prieto, J. and Galicia, L., 2006. Projecting land-use change processes in the Sierra Norte of Oaxaca, Mexico, Applied Geography. 26, 276-290.

Millennium Ecosystem Assessment (MEA)., 2005. Millennium Ecosystem Assessment Synthesis Report. Island Press, Washington, D.C.

Monprapussorn, S., 2018. Impacts of climate and land use change on ecosystem services: A case study of Sautsakorn province, Thailand. Ecological Informatics. 47, 45-49.

Pal, J.S and Eltahir, E.A.B. 2015. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. Nature Climate Change. DOI: 10.1038/NCLIMATE2833.

Pessacg, N., Flaherty, S., Brandizi, L., Solman, S., Pascual, M., 2015. Getting water right: a case study in water yield modeling based on precipitation data. Science of the Total Environment. 537, 225-234. DOI: 10.1016/j.scitotenv.2015.07.148

Redhead, J.W., Stratford, C., Sharps, K., Jones, L., Ziv, G., Clarke, D., Oliver, T.H., Bullock., 2016. Empirical validation of the InVEST water yield ecosystem service model at a national scale. Science of the Total Environment. 569-570. 1418-1426. http://centaur.reading.ac.uk/66324/.

Riahi, K., Rao, Sh., Krey, V., Cho, Ch., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., Rafaj, P., 2011. RCP8.5-A scenario of comparatively high greenhouse gas emission. Climate Change. 109: 33-57. DOI 10.1007/s10584-011-0149-y.

Sajikumar, N and Remya, R.S., 2015. Impacts of land cover and land use change on runoff characteristics. Journal of Environmental Management. 161, 460-468. doi: 10.1016/j.jenvman.2014.12.041.

Shadkam, S., Ludwing, F., van Vliet, M.T.H., Pastor, A., Kabat, P., 2016. Preserving the world second largest hypersaline lake under future irrigation and climate change. Science of the Total Environment. 559, 317-325. doi: 10.1016/j.scitotenv.2016.03.190.

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., 2015. InVEST 3.2.0 User's Guide. The Natural Capital Project, Stanford.

Shirmohammadi, B., Malekian, A., Salajegheh, A., Taheri, B., Azarnivand, H., Malek, Z., Verburg, P. 2019. Scenario analysis for integrated water resources management under future land use change in the Urmia Lake region, Iran. Land Use Policy. https://doi.org/10.1016/j.landusepol.2019.104299.

Shrestha, K.M., Recknagel, F., Frizenschaf, J., Meyer, W., 2017. Future climate and land uses effects on flow and nutrient loads of a Mediterranean catchment in South Australia. Science of the Total Environment. 590-591, 186-193. doi: 10.1016/j.scitotenv.2017.02.197.

Singh, s., Kumar, R.R., Bhardwaj, A., Sam, L., Shekhar, M., Singh, A., Kumar, R.R., Gupta, A., 2016. Changing climate and glacio-hydrology in Indian Himalayan Region: a review. WIREs Climate Change. doi:10.1002/wcc.393.

Statistical Center for Iran. www.amar.org.ir.

Stone, R., 2015. Saving iran’s great Salt Lake. Science (80). 349, 1044–1046.

Tang, Z., Sun, G., Zhang, N., He, J., Wu, N., 2018. Impacts of land-use and climate change on ecosystem service in eastern Tibetan Plateau, China. Sustainability. doi:10.3390/su10020467.

Tange, N.T.T., Shrestha, S., Shrestha, M., Datta, A., Kawasaki, A. 2018. Evaluating the impacts of climate and land-use change on the hydrology and nutrient yield in a transboundary river basin: A case study in the 3S River Basin (Sekong, Sesan, and Srepok). Science of the Total Environment. 576, 586-598.

Terrado, M., Acuña, V., Ennaanay, D., Tallis, H., and Sabater, S., 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. Ecol. Indicators. 37, 199–209. DOI: 10.1016/j.ecolind.2013.01.016.

Trang, N.T.T., Shrestha, S., Shrestha, M., Datta, A., Kawasaki, A., 2017. Evaluating the impacts of climate and land-use change on the hydrology and nutrient yield in a transboundary river basin: A case study in the 3S River Basin

(Sekong, Sesan, and Srepok). Science of the Total Environment. 576, 586-598. DOI: 10.1016/j.scitotenv.2016.10.138.

ULRP (Urmia Lake Restoration Program)., 2016. Approved Solutions, the Executive Status and progress of projects 2 (http://ulrp.sharif.ir/sites/default/files/field/files/02%20Urmia%20Lake%20Projects%20-%20%2094.09.02.pdf) (Accessed: 10 March 2016) (in Persian).

Upgupta, S., Sharma, J., Jayaraman, M., Kumar, V., Ravindranath, N.H., 2015. Climate change impact and vulnerability assessment of forests in the Indian Western Himalayan region: A case study of Himachal Pradesh, India. Clim. Risk Management. doi:10.1016/j.crm.2015.08.002

USGS., 2018. Earth explorer internet data portal. http://earthexplorer.usgs.gov Accessed in Month.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Karm, T., Krey, V., Lamarque, J.F., Masui, T., Menishausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K., 2011. The representative concentration pathways: an overview. Climate Change.109, 5-31. DOI 10.1007/s10584-011-0148-z.

Verburg, P.H., Overmars, K.P., 2009. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecology. 24, 1167-1181.

Wu, L., Wang, Sh., Bai, X., Luo, W., Tian, Y., Zeng, Ch., Luo, G., He, Sh., 2017. Quantitative assessment of the impacts of climate change and human activities on runoff change in a typical karst watershed, SW China. Science of the Total Environment. 601-602, 1449-1456. doi: 10.1016/j.scitotenv.2017.05.288.

Xiao, Y., Xiao, Q., Ouyang, Z. & Maomao, Q., 2015. Assessing changes in water flow regulation in Chongqing region, China. Environmental Monitoring and Assessment. 187, 1-13.

Yan, R., Zhang, X., Yan, Sh., Zhang, J., Chen, H. 2018. Spatial patterns of hydrological responses to land use/cover change in a catchment on the Loess Plateau, China. Ecological Indicators, 92, 151-160.

Yang, K., Ye, B., Zhou, D., Wu, B., Foken, T., Qin, J., Zhou, Z., 2011. Response of hydrological cycle to recent climate changes in the Tibetan Plateau. Climate Change. 109, 517–534. DOI 10.1007/s10584-011-0099-4.

Zhang, L., Hickel, K., Dawes, W.R., Chiew, F.H.S., Western, A.W., Briggs, P.R., 2004. A rational function approach for estimating mean annual evapotranspiration. Water Resource Research. 40, W02502. https://doi.org/10.1029/2003WR002710.

Table 1: The monthly and seasonally precipitation pattern of the Mordagh Chay basin

Seasonal rainfall distribution (%)		**Monthly rainfall distribution (%)**	
Summer	2.8	**September**	0.62
		August	0.71
		July	1.43
Spring	38.3	**June**	3.34
		May	16.69
		April	18.24
Winter	27.5	**March**	10.14
		February	8.98
		January	8.36
Autumn	31.5	**December**	10.95
		November	15.8
		October	4.74

Table 2: Summary of the land use change scenarios (Shirmohammadi et al, 2019). Each scenario is combined with both climate scenarios RCP4.5 and RCP8.5

Land use change scenarios	**description**	**Climate changes scenarios**	**Combined scenarios**
A	Scenario based on observed trends between 1993-2015.	RCP4.5	A-RCP4.5
		RCP8.5	A-RCP8.5
B	Reduce irrigation water withdrawals by 40% associated with irrigation efficiency improvement to 50%.	RCP4.5	B-RCP4.5
		RCP8.5	B-RCP8.5
C	Reduce irrigation water withdrawals by 40% associated with irrigation efficiency improvement to 85%.	RCP4.5	C-RCP4.5
		RCP8.5	C-RCP8.5

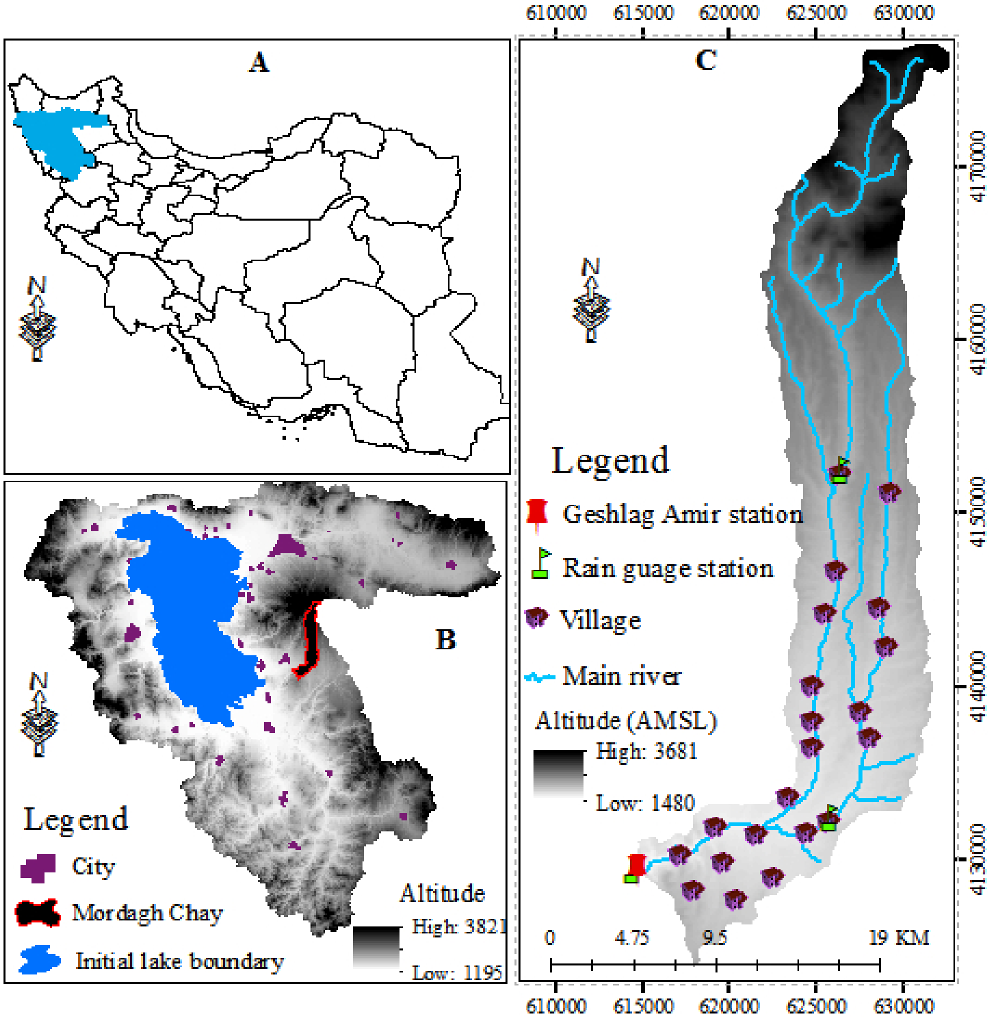
Table 3: Results of sensitivity analysis

Parameter	**Base line**	**Rate of changes (±10%)**	**Mean observed flow in baseline (mm)**	**Mean predicted flow (mm)**
Orchard Kc	0.75	0.825	93	91.25
		0.675	93	95.84
Rangeland Kc	0.8	0.88	93	81.4
		0.72	93	110.75
Precipitation (mm)	403	484	93	108.62
		396	93	78.09
Evapotranspiration (mm)	450	597	93	100.81
		729	93	84.48

Table 4: Impacts of future land use-climate change scenarios on basin water provisioning.

Scenarios	**Mean water yield(mm)**	**Change in water yield by the year 2030 compared with the baseline**	
		(%)	**(m3 /year)**
A_RCP4.5	75.5	-19.8	-6670701.8

B_RCP4.5	110.07	17.8	6006674.8
C_RCP4.5	108.9	16.6	5603857.5
A_RCP8.5	64.2	-31.8	-10701476.2
B_RCP8.5	98.49	5.4	1831721.5
C_RCP8.5	97.6	4.5	1536420.6



A
B
C
Legend
City
Mordagh Chay
Initial lake boundary
Altitude
High: 3821
Low: 1195
Legend
Geshlag Amir station
Rain guage station
Village
Main river
Altitude (AMSL)
High: 3681
Low: 1480
0
4.75
9.5
19 KM
610000
615000
620000
625000
630000
4130000
4140000
4150000
4160000
4170000
N

Figure 1

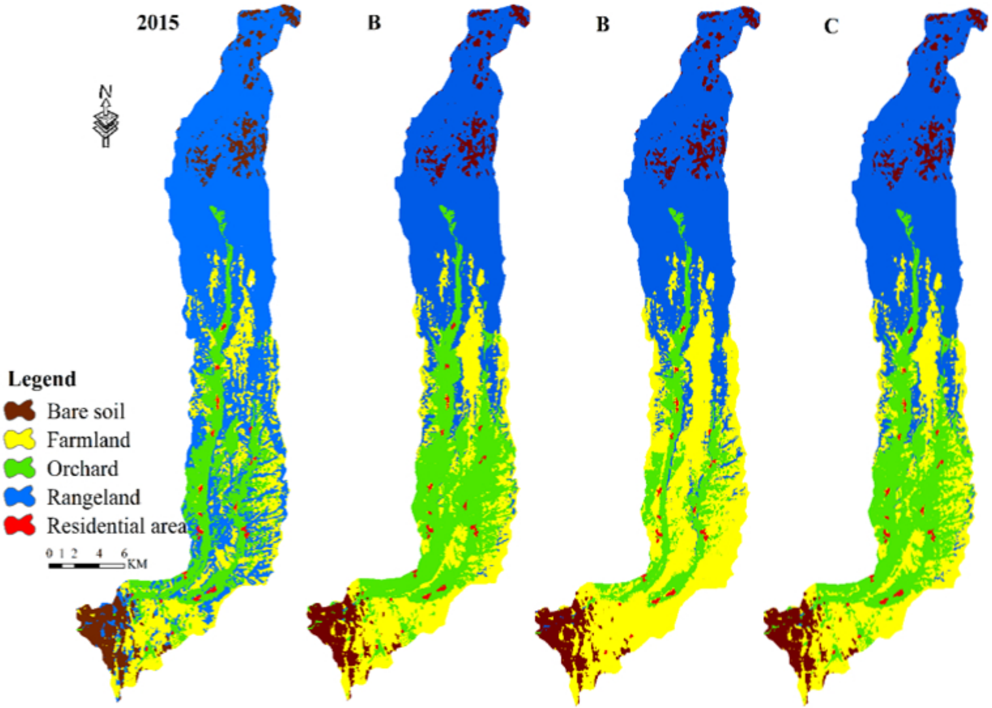

2015
B
B
C
N
Legend
Bare soil
Farmland
Orchard
Rangeland
Residential area
0 1 2 4 6
KM

Figure 2

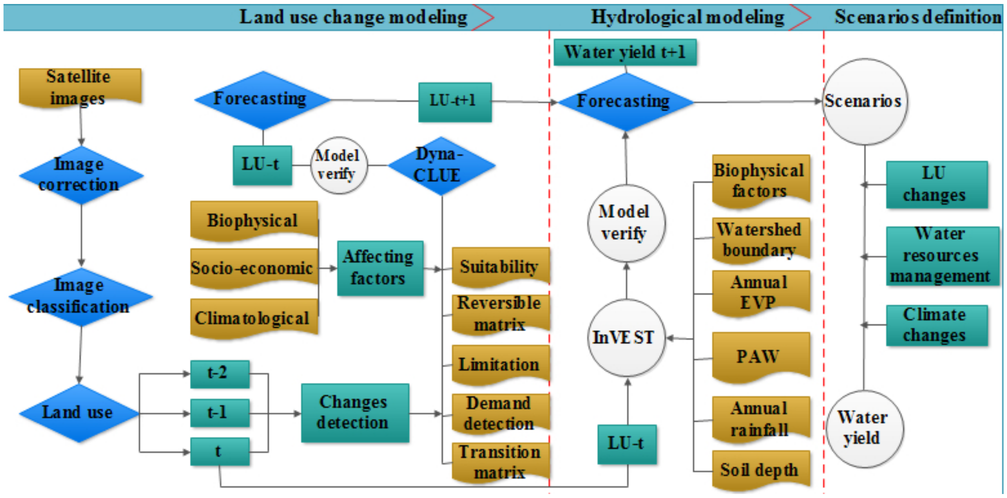

Land use change modeling
Hydrological modeling
Scenarios definition
Satellite images
Image correction
Image classification
Land use
Forecasting
LU-t+1
LU-t
Model verify
Dyna-CLUE
Biophysical
Socio-economic
Climatological
Affecting factors
Suitability
Reversible matrix
Limitation
Demand detection
Transition matrix
t-2
t-1
t
Changes detection
Water yield t+1
Forecasting
Model verify
InVEST
LU-t
Biophysical factors
Watershed boundary
Annual EVP
PAW
Annual rainfall
Soil depth
Scenarios
LU changes
Water resources management
Climate changes
Water yield

Figure 3

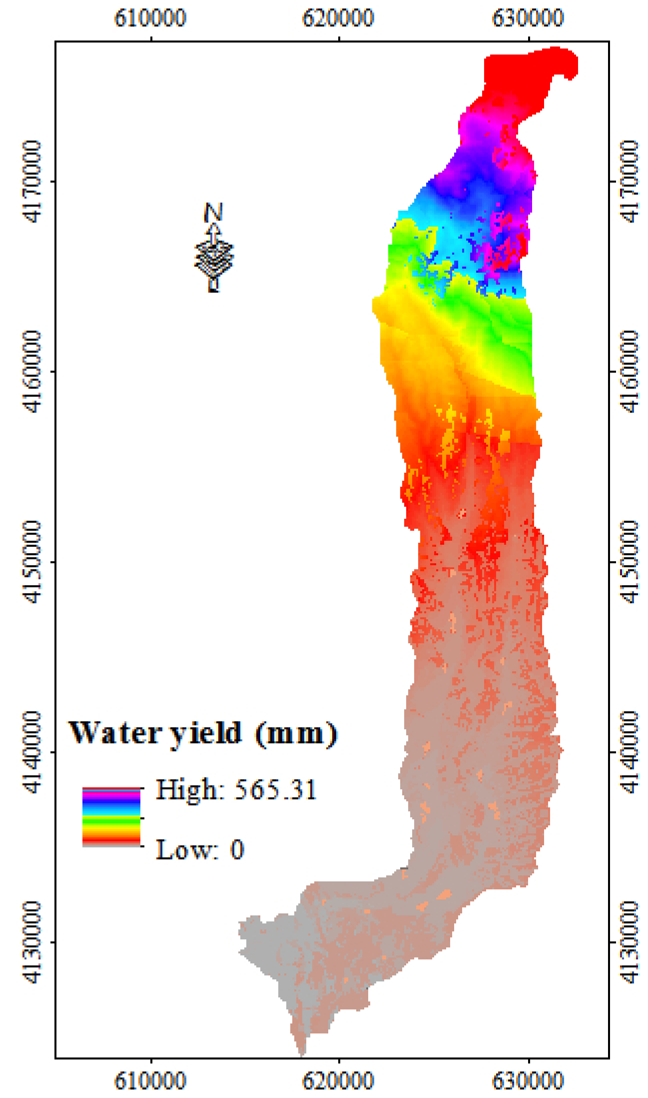
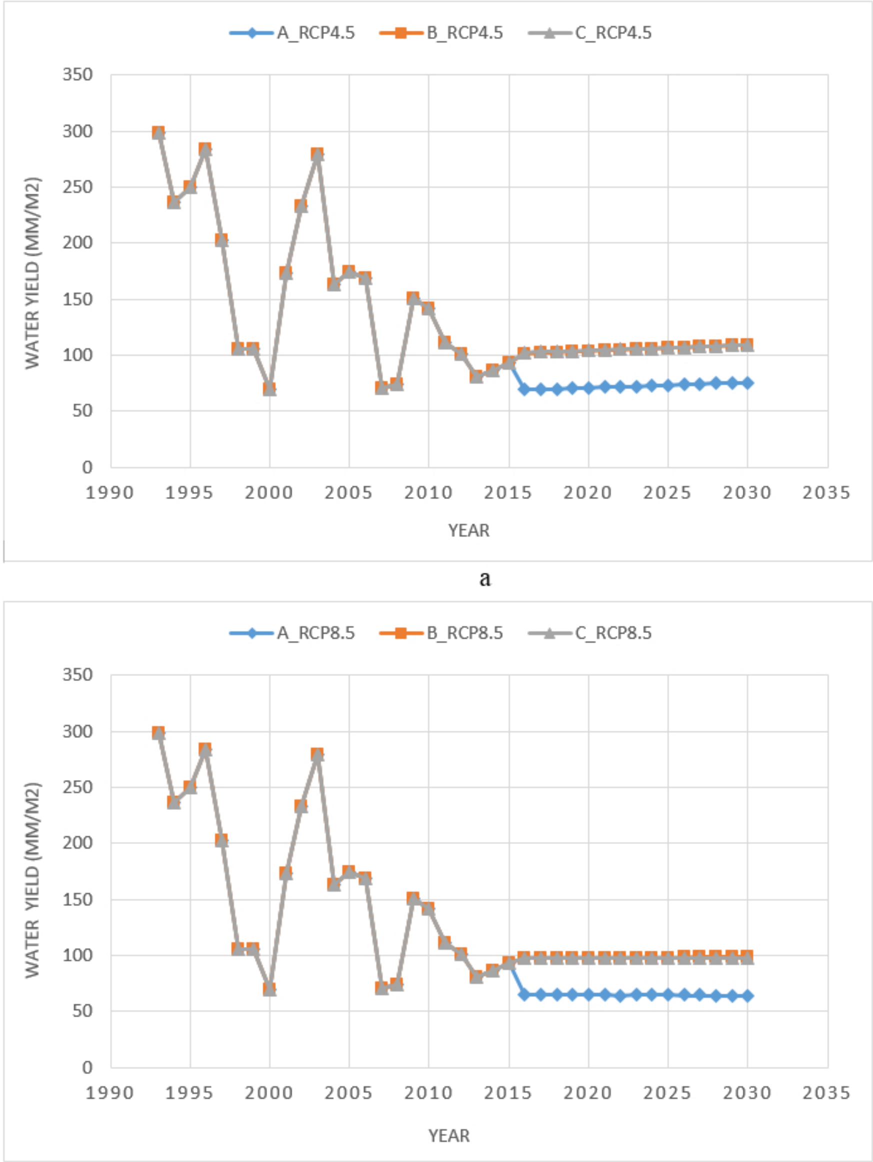

610000
620000
630000
4170000
4160000
4150000
4140000
4130000
N
Water yield (mm)
High: 565.31
Low: 0

Figure 4


A_RCP4.5
B_RCP4.5
C_RCP4.5
WATER YIELD (MM/M2)
350
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
YEAR
A_RCP8.5
B_RCP8.5
C_RCP8.5
WATER YIELD (MM/M2)
350
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
YEAR

a

b

Figure 5

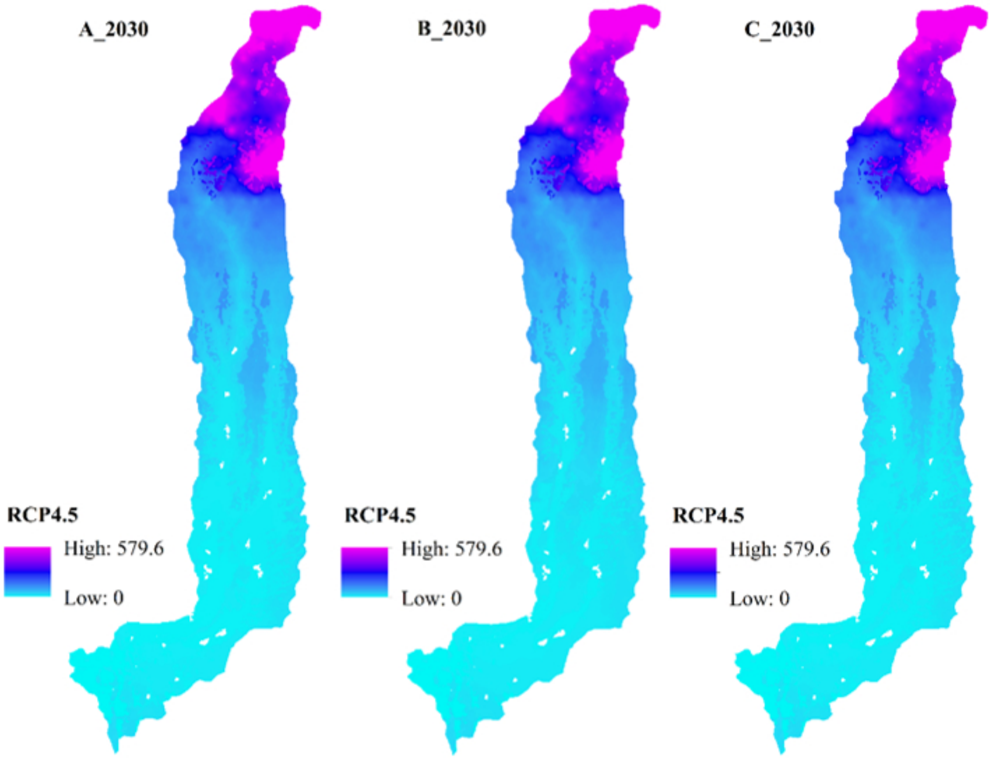

A_2030
B_2030
C_2030
RCP4.5
High: 579.6
Low: 0
RCP4.5
High: 579.6
Low: 0
RCP4.5
High: 579.6
Low: 0

Figure 6

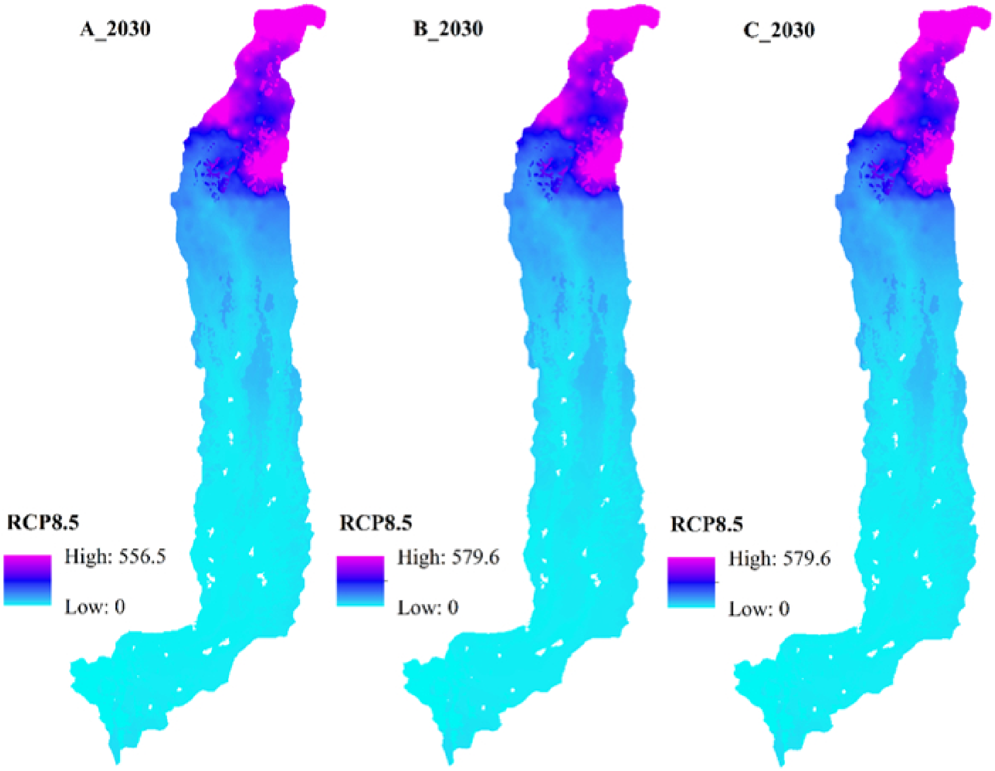

A_2030
B_2030
C_2030
RCP8.5
High: 556.5
Low: 0
RCP8.5
High: 579.6
Low: 0
RCP8.5
High: 579.6
Low: 0

Figure 7