Agricultural Water Management 295 (2024) 108774

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

# Assessing the impacts of climate change on water resource management and crop patterns in Eastern Iran

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ARTICLE INFO

Handling Editor: J.E. Fernández

*Keywords:*
Land uses
Agricultural production
Resource stability
Hydro-economic model
Irrigation systems
Water consumption

ABSTRACT

Rapid population growth and climate change are poised to significantly impact water resources and agriculture. Consequently, it becomes imperative to delve into the repercussions of climate change on agriculture and natural resources in developing nations. In this research, an economic–hydrological model was employed to assess the influence of climate change on water management and cropping patterns in the Eastern border catchment of Iran. The climatic data used in this study, spanning the years 1997–2022, encompassed daily rainfall and temperature records from the Khorasan and Sistan & Balouchestan meteorological organization, as well as the Iranian Statistical Center. Monthly water discharge data were obtained from the Khorasan and Sistan & Balouchestan regional water authority, while information on crop levels and agricultural inputs was collected from the Khorasan and Sistan & Balouchestan agricultural jihad organization. The findings reveal that areas dedicated to cultivating high-yield crops experienced a decrease when associated with high water consumption, whereas the cultivation areas of high-yield crops expanded when water consumption was reduced. The implementation of modern irrigation methods, such as pressurized irrigation, not only conserves valuable water resources but also enhances efficiency, ultimately resulting in decreased water consumption and increased production. Consequently, the provision of enhanced training programs aimed at educating farmers about these practices and facilitating their adoption can play a pivotal role in adapting to and mitigating the challenges posed by climate change.

## 1. Introduction

Climate change refers to deviations in the climate of a region from the long-term historical data and expectations. Over the past half-century, our global climate and environment have experienced significant alterations. The proliferation of industries and the widespread use of fossil fuels for energy generation have resulted in heightened concentrations of greenhouse gases, notably including CFC, $CH_4$, $N_2O$, and, especially, $CO_2$. It is evident that an increase in heat-trapping gases in the atmosphere inevitably leads to a rise in the Earth's temperature (Mirzaei et al., 2023a; Skodienė et al., 2022).

Climate change stands as a pivotal factor impacting ecosystem services (Fu et al., 2017, Hoyer and Chang, 2014, Tolessa et al., 2017, Wang et al., 2020). Globally, there are forecasts or already observable instances of more frequent and severe droughts, rainfalls, and heatwaves, all serving as unmistakable indications of climate change (Ozerola, 2020; Smaniotto Costa et al., 2015; Guerreiro et al., 2018). Madani (2014) highlights Iran's water crises including depleting groundwater levels, drying lakes, water supply, and extreme events. With nearly 85% of the country being in semi-arid and arid climates, the country faces both prolonged droughts, as well as floods. In the past two decades, floods have affected 11 million people in Iran and caused over 2600 fatal casualties (Madani 2014). Explicitly, climate change has posed several threats to the sector and has the potential to significantly impact food security, food inequality, farmer income, labour employment opportunities, poverty alleviation, and regional development across countries

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https://doi.org/10.1016/j.agwat.2024.108774
Received 24 January 2024; Received in revised form 7 March 2024; Accepted 9 March 2024
Available online 13 March 2024
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(Pakroh and Abdolkamal, 2023).

The management of water resources confronts an array of challenges, often stemming from the confluence of climate change, socio-economic stressors, and competing demands from diverse stakeholders across many regions. Alterations in precipitation patterns, rising temperature, and sea level elevation, in tandem with socio-economic pressures, are recognized as principal drivers of water scarcity. These factors increasingly strain water resource managers' ability to meet the escalating water needs of various users (Jódar et al., 2019; Phan et al., 2019; Barnett et al., 2020; Rasool et al., 2023).

The agricultural sector holds a pivotal position in the national economy of Iran, providing employment opportunities and ensuring food security for diverse communities. As such, it is imperative to optimize the utilization of production resources and tools to minimize resource consumption while concurrently enhancing the profitability and well-being of farmers. However, the agricultural industry faces a dual challenge: a scarcity of resources and the need to bolster crop production to meet the escalating demands driven by population growth (Loizou et al., 2019; Rodrigo-Comino et al., 2022; Mirzaei et al., 2023b).

Numerous studies have delved into the water management approach, including notable contributions by Cai et al., (2003); Medellín-Azuara et al., (2009); Harou et al., (2009); Asadzadeh et al., (2014); Ward, (2014); Esteve et al., (2015); Nguyen et al., (2016); Basheer et al., (2018); Mirchi et al., (2018); Amjath-Babua et al., 2019; García et al., (2019); Geressu and Harou, (2019); Do et al., (2020). Additionally, the economy-based approach has been a cornerstone in water resource studies, exemplified by Duarte et al., (2002); Velázquez, (2006); Brouwer et al., (2008); Calzadilla et al., (2010); Antonelli et al., (2012); Cazcarro et al., (2013); White et al., (2015); Lutter et al., (2016); Almazán-Gómez et al., (2019); Teotónio et al., (2020).

Beyond these established approaches, certain studies adopt a more holistic perspective, integrating water and economic systems to form an 'integrated hydro-economic model,' as demonstrated by Jonkman et al., (2008); Dellink et al., (2011); Kahsay et al., (2019); Knowling et al., (2020); Eamen et al., (2022).

Turning attention to climate change studies, noteworthy contributions include those by Guo et al. (2021), Yang (2020), Reshmidevi et al. (2017), Xing-Guo et al. (2017), and Tolessa Leta et al. (2016). These investigations explore the impact of future climate changes and diverse management scenarios on water-related ecosystem services within the ecological and economic region, as well as water resources in the agricultural sector.

Predictions by the World Geographic Group suggest that rising water demand due to global warming could lead to a reduction in water reserves by 4–24% by 2050, significantly escalating irrigation water demand during the product growth season (Xing-Guo et al., 2017). Furthermore, the studies reveal that climate change surpasses Land Use and Land Cover (LULC) changes in impacting water yield, with LULC changes more significantly influencing water purification (Guo et al., 2021). The anticipated increase in temperature, evaporation, and transpiration is poised to intensify irrigation demands until the end of the century, potentially leading to a decline in river runoff and groundwater, and creating tensions in the region's irrigation demand (Reshmidevi et al., 2017). Predictive climate change scenarios also highlight the main factors, such as changes in rainfall during wet and dry seasons, contributing to a decline in the overall water balance, with a continuous 15% decline in groundwater flow anticipated until 2100 (Tolessa Leta et al., 2016).

Some studies also focus on the impact of climate change on catchment areas, as evidenced by Reshmidevi et al. (2017), Reder et al. (2016), Shrestha and Lohpaisankrit (2017), Michalak (2019), Stańczuk-Gałwiaczek (2018)). These studies indicate a decline in the average water volume in the shallow part of the soil, with projections showing a potential decrease in the ratio of river runoff and underground water feeding by the end of the century. An increase in temperature and evapotranspiration is expected by the end of the century, accompanied by a slight rise in average annual precipitation. However, too much attention to climate change may pose a noticeable problem in economic activities, emphasizing the need for equal attention from stakeholders to address political and community barriers to climate change adaptation (Biswas et al., 2022).

Given the compelling evidence and modelling data, the significance of climate change and its implications for water management, particularly in agriculture, cannot be overstated. In this study, dedicated efforts were made to mitigate and alleviate the adverse consequences of global climate change on the agricultural sector. The investigation into the influence of climate change on water management and cultivation patterns within the Eastern border catchment employed an economic-hydrological model. This section provides an overview of some of the conducted studies on the economic-hydrological ramifications of climate change.

Based on the available evidence and modelling, the importance of understanding the effects of climate change on water management, especially in the agricultural sector, is underscored. This study aims to reduce and minimize the severity of global climate change and its harmful effects. The investigation into the effects of climate change on water management and the cultivation pattern of the catchment area of eastern Iran in the agricultural sector, utilizing an economic-hydrological model from 1997 to 2022, is undertaken. The study's goals encompass examining the effect of climate change on water resources and the area under cultivation for agricultural products.

## 2. Materials and methods

### 2.1. Study area

The eastern border catchment of Iran holds a paramount position as the principal watershed within Iran's geographical divisions. Encompassing an expansive area of 103,169 $km^2$, this catchment stretches from Jam Mountains in Khorasan to the Bampesht and Hamant Mountains in Sistan and Baluchistan, situated along the eastern border of Iran. This catchment encompasses regions spanning Khorasan and Sistan & Baluchistan provinces. In the middle of the basin, the Hamon Hirmand, situated at an elevation of 460 m.a.s.l. near Zabol city, stands the largest freshwater lake with Iran's central plateau. Its primary source of water is the Hirmand River, the majority of which flows through Afghanistan (Fig. 1).

In the Eastern border catchment area, staple crops such as wheat, barley, cotton, sugar beet, and fodder plants play a crucial role in meeting both nutritional needs and driving economic activity. Among these, wheat stands out as a fundamental component of global food security, serving as a staple for billions of people worldwide. However, the irrigation method predominantly utilized in the region, namely surface irrigation, presents challenges in terms of water efficiency. With an irrigation efficiency of 35%, a significant portion of water is lost within the delivery network and head ditches before reaching the fields (Mirzaei et al., 2024). While surface irrigation has historical significance dating back thousands of years, its inefficiencies highlight the need for modernization and improvement in water delivery systems.

Addressing these inefficiencies is essential for enhancing agricultural productivity and sustainability in the catchment area. By implementing more efficient irrigation methods and optimizing water delivery systems, such as transitioning to pressurized irrigation systems, it is possible to reduce water losses and improve overall water use efficiency. This not only ensures better utilization of water resources but also contributes to the resilience of agricultural systems in the face of climate change and growing water scarcity concerns.

### 2.2. Methodology

A nonlinear optimization economic model based on farm management was implemented in this study. This model, using a random


**Fig. 1.** Eastern Iran border catchment.

approach, determines the farmer's behaviour towards risk and creates an optimal combination of land allocation $x_c$ to different products (c) considering technical, structural, and political constraints provided by the following equations.

The objective function (Eq. (1)) shows the maximisation of farmers' expected utility, U, calculated as the expected farm income, Z, minus a risk component that represents utility losses driven by the risk inherent to crop production, following Hazell and Norton's (1986) approach. This risk component is composed of a farmer's risk aversion coefficient, φ, and the standard deviation of farm income, σ(Z), according to market and nature variability that will affect crop prices and yields.

$$\text{Max } U = Z - \varphi.\ \sigma\ (Z) \tag{1}$$

Eq. (2) shows farm income estimation, where: gmc: gross margin per crop (c); Xc: production area per crop (c); sbc: subsidies per crop (c); fco: family labour opportunity cost; flabp: family labour use per period of the year (summer or winter) (p); hlw: hired labour wage (Rial/h); hlabp: hired labour per period (p); wpm3: volumetric water price; WC: farm water consumption; wpha: irrigation water fee paid per hectare; sirrg: irrigated area in the farm.

$$Z = \sum_c gm_c.x_c + \sum_c sb_c.x_c - fco\cdot\sum_p flab_p - hlw.\sum_p \mathrm{hlab}_p - wmp^3\cdot WC - wpha\cdot sirrg \tag{2}$$

This maximisation is subjected to different constraints, including land (Eq. (3)), labour (Eqs. (4 and 5)) and water (Eq. (6)) limitations: where, surf: farm size area; labreqc¸p: labour requirements per crop (c), and period (p); flab_avp: maximum family labour available per period (p); wreqc: crop net water requirement; hri: technical efficiency of the irrigation technique (ri); wavail: farm water endowment per hectare; H: efficiency of the water conveyance system.

$$\sum_c X_c \leq surf \tag{3}$$

$$\sum_c labreq_{c,p} \cdot X_c \leq flab_p + hlab_p \tag{4}$$

$$flab_p \leq flab - av_p \tag{5}$$

$$\sum_c (wreq_c / h_{ri}) \cdot X_{c,ri} \leq sirrg \cdot wavail \cdot H \tag{6}$$

Model calibration was done using the risk aversion coefficient (φ). For this, it is assumed that the difference between actual cropping patterns and those that maximise income is due to different farmers' perceptions of risk. Therefore, model calibration was done finding the risk aversion coefficient (φ) that matches simulated cropping patterns to real cropping patterns in the selected farm types. Model validation was done using comparative data for land and labour parameters in the study area. Fig. 2

The existing inputs are used as input variables. After the economic model estimates the cultivation pattern, it is regarded as an input variable for WEAP (Water Evaluation and Planning) software. This software calculates the total water needed for irrigation (water required for crop production as output). In the next step, the economic model considers the WEAP results on the level of water released for irrigation (limited water available for farms), the level of production (to estimate the gross profit of each product), and the water requirement of products (wreqc). wreqc is under the climate scenario simulated to modify the farmers' initial product pattern to a new optimal allocation. The new cultivation pattern is then utilized to calculate the water reallocation, supply the required irrigation demand, and calculate crop production under a new scenario in the WEAP model. Climate scenarios include a climate change scenario and a severe climate change scenario in which the average temperature changes, precipitation, relative humidity, and wind speed will be used.

Climate scenarios include a scenario of lack of climate change and a severe climate change scenario. This scenario includes changes in temperature, precipitation, relative humidity, and wind in the basin. Climate scenarios are mainly simulated through a hydrological model showing the product's physical specifications and the water system through climate variables changes. The scenarios include the following:

A) Basic scenario: It uses base year cultivation patterns and current irrigation water allocation for the planning process.

B) Environmental scenario: It considers the basin's ecological flow and complete adaptation to the current irrigation water rate.

C) Economic scenario: It includes the actual water price to provide the basin and irrigation systems' total water services costs.

D) Independent adaptation scenario: It investigates changes in cultivation patterns because of climate change and the level of water available.

Generally speaking, the environmental flow will be implemented by the WEAP model, while water allocation is simulated in the economic model (Esteve et al., 2015).

The data required for the study were classified by completing a questionnaire via a stratified random sampling method from farmers in the region. Statistics from agricultural jihad in Khorasan and Sistan & Balouchestan provinces were collected. The number of questionnaires was calculated by Cochran's method.

## 3. Results and discussion

This section presents the outcomes of the cultivation patterns within the Eastern border catchment, analyzed under various scenarios spanning 26-year intervals. The analysis employed a straightforward linear mathematical programming approach, with the hydrological model being assessed using WEAP software.

Initially, to simulate and ascertain the optimal cultivation pattern, and to draw comparisons with the existing conditions in the study area, all pertinent equations were encoded and integrated into the model. Subsequently, as simulation conditions were introduced for each

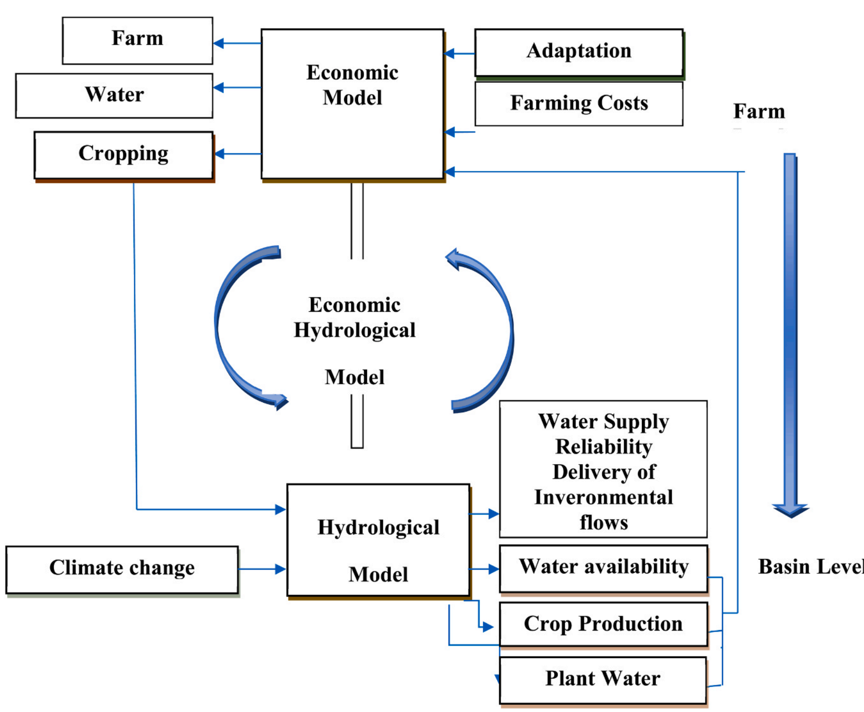


**Fig. 2.** Flowchart of the used mode.

scenario, the results derived from model implementation were documented and subjected to comparative analysis.

### 3.1. Results of linear planning in the basic scenario

Table 1 provides a breakdown of the percentage of land under cultivation, water consumption (measured in cubic meters per hectare), and farm income (in 10 Rials, approximately 2 USD $ per hectare). The findings suggest that in the early years of this study period, rainfed wheat cultivation witnessed significant growth (85.9%) compared to other crops. This surge was attributed to its lower water consumption and increased income, mainly because traditional farming methods were prevalent during this period, with limited technological advancements in agriculture. Consequently, most farmers preferred crops that demanded fewer resources and incurred lower costs. Table 1

From 1997–2001, water consumption per hectare increased from 1422 $m^3$ $ha^{-1}$ to 8222 $m^3$ $ha^{-1}$. This escalation was primarily due to the expansion of crops like potatoes, sugar beets, buckwheat, barley, and cotton, which require higher water consumption. Income per hectare also saw an uptick in recent years, driven by increased crop values, expanded cultivation areas, and heightened production.

However, from 2001 to 2003, both the area under cultivation and water consumption declined, being very variable since then. During this period, reduced rainfall led to lower water availability, prompting farmers to opt for less water-intensive crops. According to Table 1, sugar beet accounted for the smallest cultivation area due to its high water consumption and labour-intensive nature, resulting in lower farm income. In contrast, rainfed wheat dominated the cultivation landscape because it relied solely on rainwater, involved minimal labour in planting and harvesting, and yielded the highest income.

The lowest water consumption per hectare was recorded in 1997, while the highest occurred in 2014. Income was at its lowest in 1996 but peaked in 2014. Comparing water consumption in 1997 and 2015 reveals a threefold increase in water use per hectare. However, farm income surged more than 48 times, driven by improved water efficiency, the adoption of new irrigation techniques, and rising agricultural product prices.

Analyzing the cultivation patterns of 2011 and 2012, a decrease in water consumption per hectare from 7229 $m^3$ $ha^{-1}$ to 2823 $m^3$ $ha^{-1}$ is observed. Simultaneously, farms increased from 5 100 083 (10 Rials) per hectare to 9 586 860 (10 Rials) in 2012. Regarding crop cultivation areas, water-intensive crops, like sugar beets and cotton, saw reduced cultivation, while rainfed crops, particularly rainfed wheat, nearly doubled in cultivation area. Irrigated wheat and barley also decreased in area as they require higher water inputs. This shift resulted in a reduction of water consumption, with the increase in potato cultivation area, a high-yield crop that consumes substantial water, offsetting the income and achieving a balance in water consumption. The subsequent year saw a rise in water consumption per hectare due to increased cultivation of high-water-consumption crops, causing income per hectare to decline. This research underscores the importance of water-efficient crops in maintaining income levels.

In summary, Table 1 highlights that increased cultivation areas for high-water-consumption crops like potatoes, sugar beets, and cotton correlate with higher incomes. However, these crops entail significant water usage and elevated production costs. The increased yield of these crops incentivizes farmers to select them for cultivation when water availability is not constrained.

### 3.2. Bio-environmental scenario

In the bio-environmental scenario, an additional constraint has been introduced to the model. This limitation involves separating the amount of runoff required by the environment from the agricultural activities cycle.

The formula for calculating environmental runoff is as follows:

$$E_t = EV_t.\ 10^{-3}.\ [((-3).\ 10^{-5}.\ S_t) + (0.023.\ S_t + 0.4098)] \quad (7)$$

Volumes are measured in cubic meters, and the variables are defined as follows: *Et* represents the volume of runoff required by the environment in period t, $EV_t$ is the rate of evaporation from the dam reservoir in period *t* per millimetres and *St* is the volume of dam reservoir in period *t* (Mohammad Reza Portabari et al., 2008).

For each year, the environmental water requirements were

**Table 1**
Optimal planting pattern in the current conditions (baseline scenario).

| Cultivation pattern (percentage) | | | | | | | Consuming water ($m^3$ $ha^{-1}$) | Income (10 Rial –2$- $ha^{-1}$) | Year |
|---|---|---|---|---|---|---|---|---|---|
| Potato | Cotton | Sugar beet | R Barley | Irr Barley | R Wheat | Irr Wheat | | | |
| 1.08 | 0.46 | 0.56 | 1.95 | 1.88 | 85.90 | 3.30 | 1422 | 234248 | 1997 |
| 1.46 | 1.43 | 1.19 | 5.84 | 7.72 | 68.85 | 8.33 | 3028 | 526489 | 1998 |
| 7.07 | 1.90 | 1.80 | 6.05 | 6.06 | 58.96 | 12.99 | 5238 | 1058432 | 1999 |
| 4.73 | 6.01 | 3.72 | 36.05 | 12.22 | 4.48 | 27.62 | 8222 | 2074881 | 2000 |
| 4.74 | 6.98 | 3.72 | 36.04 | 12.23 | 4.50 | 27.62 | 8222 | 1766708 | 2001 |
| 5.68 | 1.91 | 1.20 | 3.23 | 8.42 | 59.54 | 14.85 | 5076 | 2340418 | 2002 |
| 1.34 | 0.78 | 0.85 | 4.95 | 3.17 | 77.67 | 6.03 | 2095 | 1201714 | 2003 |
| 2.45 | 1.97 | 1.48 | 4.93 | 5.56 | 66.00 | 12.44 | 3756 | 2330690 | 2004 |
| 5.18 | 1.50 | 1.28 | 4.20 | 5.51 | 64.76 | 12.40 | 4347 | 3664863 | 2005 |
| 4.69 | 1.85 | 2.41 | 1.40 | 7.95 | 57.13 | 17.40 | 5929 | 4510770 | 2006 |
| 5.91 | 1.24 | 2.05 | 3.60 | 6.03 | 61.95 | 14.40 | 4938 | 3241919 | 2007 |
| 0.52 | 3.12 | 1.09 | 1.69 | 9.28 | 33.30 | 45.80 | 7214 | 3204381 | 2008 |
| 4.49 | 0.66 | 0.07 | 3.75 | 3.83 | 75.69 | 6.34 | 2808 | 3327831 | 2009 |
| 3.73 | 1.46 | 0.52 | 3.96 | 7.47 | 60.53 | 11.17 | 4379 | 4261402 | 2010 |
| 7.62 | 2.29 | 0.67 | 1.33 | 8.61 | 53.83 | 20.47 | 6167 | 5100083 | 2011 |
| 0.39 | 1.92 | 0.75 | 4.85 | 9.69 | 41.83 | 35.40 | 5731 | 9586861 | 2012 |
| 9.58 | 2.28 | 1.07 | 6.04 | 13.06 | 35.06 | 27.74 | 7989 | 10840968 | 2013 |
| 9.46 | 2.35 | 1.40 | 9.33 | 17.03 | 25.62 | 29.64 | 8622 | 12920498 | 2014 |
| 4.13 | 0.85 | 0.36 | 52.55 | 8.05 | 15.74 | 13.15 | 3927 | 11341638 | 2015 |
| 5.28 | 0.73 | 0.75 | 55.95 | 7.53 | 11.68 | 12.19 | 4403 | 11044374 | 2016 |
| 4.78 | 0.74 | 0.43 | 57.32 | 6.38 | 11.58 | 11.58 | 4616 | 11228352 | 2017 |
| 4.63 | 0.85 | 0.50 | 59.22 | 6.07 | 11.42 | 11.85 | 4751 | 10235573 | 2018 |
| 4.30 | 0.72 | 0.75 | 61.1 | 5.97 | 11.12 | 11.35 | 4797 | 9408753 | 2019 |
| 3.26 | 1.05 | 0.53 | 62.25 | 5.80 | 10.91 | 10.58 | 5120 | 9571616 | 2020 |
| 3.08 | 1.15 | 0.67 | 64.25 | 5.14 | 10.74 | 10.13 | 5221 | 9617892 | 2021 |
| 2.84 | 1.12 | 0.48 | 63.28 | 4.95 | 11.25 | 10.15 | 4825 | 9851231 | 2022 |

calculated based on data from the Jihad Agricultural Organization. The total available water was then reduced each year by this environmental runoff requirement. The remaining water was allocated to agricultural use on the right side of the water limit. The model was implemented to generate a new cultivation pattern, referred to as the bio-environmental cultivation pattern, summarized in Table 2.

The results are derived from the implementation of two scenarios: the first scenario assumes no environmental runoff limitations, while the second scenario accounts for these limitations. Table 2 provides information on the net income and crop cultivation patterns in the studied areas, with the proposed cultivation pattern being the outcome of implementing the second scenario.

In this bio-environmental scenario, the area under cultivation of Irr and R wheat is 16.85 and 42.91 ha, and the area under cultivation of Irr and R barley is 7.26 and 26.35 ha, respectively. The results show that in these four cases, the percentage of changes compared to the base scenario is less than 10%. The area under sugar beet cultivation is 1.47 ha, which has increased by 26% compared to the base scenario. The area under cultivation of potato and cotton is 2.45 and 1.76 ha, which has decreased by 43% and 3%, respectively, compared to the base state.

Certain crops like cotton, sugar beet, and potatoes accounted for less cultivation area because of their high water consumption and production costs. Notably, the water consumption in this scenario was lower than in the basic scenario across all studied years, resulting in reduced farmer incomes compared to the case without environmental runoff limitations.

Rainfed crops, which require zero irrigation based on available water sources, dominated the cultivation area in this model. Different crops, such as irrigated and rainfed barley and wheat, took higher priority with increased inputs, leading to a relatively larger area under cultivation. Conversely, crops like potatoes, sugar beets, and cotton had a smaller cultivation area compared to barley and wheat.

In conclusion, it was determined that to ensure sustainable use of the currently available water, farmers should maintain wheat cultivation at its current level. However, if the current water level is considered a threat to sustainability, reducing the area under wheat cultivation becomes necessary, taking environmental concerns into account. Comparing this model with the basic and economic model, it is evident that the area under cultivation of irrigated crops (potatoes, sugar beets, and cotton) decreased due to increased water demand, as these crops consume twice as much water. Each year, as water consumption increased, income per hectare also increased, except for 2008, when income decreased and water consumption increased due to changes in the crop cultivation area. Crops with high yields but higher production costs, such as potatoes, sugar beet, and cotton, were reduced, while rainfed wheat and barley, with lower production costs and increased income, gained prominence. In the last years of the study period, income per hectare increased even as water consumption decreased, attributed to technological advancements in agriculture and a shift from traditional to industrial irrigation methods.

### 3.3. Economic scenario

The economic value of water impacts crop cultivation patterns and represents the gross profit for farmers in the area per unit of water allocated. This value depends on the availability of water resources and their utilization in production activities. When an area faces water scarcity, increasing water resources can enhance profits, indicating a positive economic value for water. Conversely, if an area does not fully utilize its water resources, adding more water does not increase profits, suggesting any economic value.

In this context, the value of water for farmers is equivalent to the economic value of the last unit of water consumed. This section delves into the monetary value of each water consumption unit (cubic meters). The economic value of water for each cubic meter was calculated for various years, reflecting a variable value. This calculation demonstrates that an additional unit of water input can increase farmers' gross profits. However, when water prices rise, and consumption decreases with constant conditions, farmers may shift towards cultivating low-yield rainfed crops in response. Conversely, they opt for irrigated crops, which yield higher economic returns (Vaziri et al., 2006).

In this economic scenario, the area under cultivation of Irr and R wheat is 18.77 and 44.15 ha, and the area under cultivation of Irr and R barley is 8.08 and 8.11 ha, respectively. The results show that in these three cases, the percentage of changes compared to the base scenario is less than 15%. But in the case of rainfed barley, the rate of reduction is

**Table 2**
Planting pattern with bio-environmental scenario.

| Year cotton | Income (10 Rial −2$- ha$^{-1}$) | Consuming water (m$^3$ ha$^{-1}$) | Cultivation pattern (percentage) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Irr Wheat | R Wheat | Irr Barley | R Barley | Sugar beet | Cotton | Potato |
| 1997 | 229563 | 1432.55 | 4.99 | 87.76 | 2.18 | 2.03 | 0.79 | 0.58 | 1.07 |
| 1998 | 500165 | 3039.55 | 10.30 | 70.75 | 8.05 | 5.98 | 1.38 | 1.58 | 1.48 |
| 1999 | 1037263 | 5248.55 | 15.00 | 60.83 | 6.35 | 6.12 | 2.03 | 2.04 | 7.05 |
| 2000 | 1971137 | 8228.55 | 29.61 | 6.33 | 12.55 | 36.08 | 3.98 | 6.12 | 4.71 |
| 2001 | 1678373 | 8228.55 | 29.61 | 6.33 | 12.54 | 36.15 | 3.96 | 6.12 | 4.71 |
| 2002 | 2223397 | 8086.55 | 16.86 | 61.41 | 8.71 | 3.32 | 1.44 | 2.04 | 5.64 |
| 2003 | 1177680 | 2106.55 | 8.04 | 79.53 | 3.48 | 5.04 | 1.08 | 0.92 | 1.33 |
| 2004 | 2214156 | 3765.55 | 14.45 | 67.86 | 5.87 | 5.72 | 1.70 | 2.09 | 2.43 |
| 2005 | 3591566 | 3637.55 | 14.40 | 69.17 | 5.85 | 4.27 | 1.51 | 1.62 | 2.6 |
| 2006 | 4285232 | 4913.55 | 19.42 | 62.65 | 8.25 | 1.47 | 2.63 | 1.98 | 3.02 |
| 2007 | 3177081 | 4168.55 | 16.06 | 66.60 | 6.29 | 3.67 | 2.30 | 1.38 | 3.12 |
| 2008 | 3044162 | 5626.55 | 32.54 | 50.45 | 9.55 | 1.78 | 1.31 | 3.28 | 0.51 |
| 2009 | 3094883 | 2128.55 | 8.35 | 80.01 | 4.12 | 3.82 | 0.30 | 0.79 | 2.03 |
| 2010 | 4048332 | 3543.55 | 19.17 | 65.41 | 7.76 | 4.04 | 0.75 | 1.59 | 0.70 |
| 2011 | 4998081 | 4884.55 | 22.47 | 60.29 | 8.95 | 1.39 | 0.89 | 2.43 | 3.00 |
| 2012 | 9107518 | 3719.55 | 21.01 | 63.21 | 8.28 | 4.11 | 0.81 | 1.70 | 0.30 |
| 2013 | 10624149 | 7517.55 | 28.56 | 39.98 | 12.85 | 8.87 | 1.25 | 2.32 | 8.59 |
| 2014 | 12274473 | 4337.55 | 20.17 | 17.45 | 11.01 | 46.32 | 1.03 | 1.58 | 1.84 |
| 2015 | 10887972 | 3268.55 | 15.14 | 17.59 | 8.35 | 55.03 | 0.58 | 1.00 | 1.73 |
| 2016 | 10492155 | 3215.55 | 14.17 | 13.54 | 7.82 | 60.31 | 1.73 | 0.86 | 0.99 |
| 2017 | 11003785 | 3210.55 | 13.91 | 12.58 | 6.44 | 62.30 | 1.23 | 0.76 | 0.98 |
| 2018 | 9416727 | 3182.55 | 13.68 | 11.86 | 6.39 | 64.30 | 0.78 | 0.73 | 0.96 |
| 2019 | 9220578 | 3114.55 | 13.22 | 11.80 | 5.53 | 64.85 | 1.26 | 0.66 | 0.84 |
| 2020 | 9093035 | 3101.55 | 12.92 | 10.83 | 4.87 | 65.30 | 0.88 | 0.50 | 1.79 |
| 2021 | 9425534 | 3082.55 | 12.73 | 10.76 | 3.87 | 65.93 | 1.30 | 0.48 | 1.30 |
| 2022 | 9358669 | 3048.20 | 11.48 | 10.83 | 2.95 | 67.13 | 1.50 | 0.81 | 1.20 |

65%. The area under sugarbeet cultivation is 1.4736 ha, which has increased by 2617% compared to the base scenario. The area under cultivation of potato and cotton is 2.451.49 and 4.31 ha, which has decreased by 4365% and increased 31.36%, respectively, compared to the base state.

The results of changes in cultivation patterns (Table 3) resulting from this scenario reveal that as water prices increase, the area dedicated to barley cultivation experiences the sharpest decline despite its low water requirements. This can be attributed to increased costs, further reducing the gross profit of this product due to its lower economic efficiency. In contrast, potatoes exhibit minimal changes under this policy. Potatoes' substantial economic benefits lead to relatively fewer fluctuations in their production efficiency compared to other crops. Farmers in this region prefer potatoes due to their consistent profitability and export potential. Wheat, with its low water requirement and practical economic advantages, is least affected by this policy.

One of the most influential policies affecting water consumption in agriculture is water pricing. The primary objective of agricultural activities, as economic endeavours, is profitability. Consequently, agricultural production units react to changes in economic variables (Balali, 2010), such as water prices hike. As water prices increase, the overall cost of water input rises, prompting farmers to select water consumption combinations that maximize benefits per unit of water. Thus, increased water input costs through pricing can lead to reduced water consumption, assuming other factors remain constant (Vaziri et al., 2006).

The model calculation involves two scenarios: the economic scenario aimed to maximize program efficiency and minimize labour utilization, while the bio-environmental scenario aimed to minimize water usage. In the bio-environmental scenario, the cultivation of cotton, sugar beet, and potatoes decreased due to high water consumption. Conversely, in the economic scenario, sugar beet and cotton cultivation declined due to rising labour costs. Potatoes, despite their significant water and labour requirements, remained a focus due to government pricing policies emphasizing their economic value. The continuous increase in the guaranteed price of wheat compared to market-driven crops like potatoes contributed to a steady expansion of wheat cultivation.

In this research, the primary objectives are economic in nature, focusing on maximizing income and minimizing water consumption. Given these goals, aimed at reducing wheat production, the use of policies as a strategic tool, considering macroeconomic goals and policies, appears reasonable (Hatef et al., 2006).

Analyzing the cultivation pattern reveals that in the early years, rainfed crops occupied the largest area under cultivation. However, as agriculture modernized and industrialized, considering costs and agricultural profitability, the area under rainfed crops decreased, while high-yield irrigated crops expanded.

Comparing the basic and economical cultivation models, it is evident that the percentage of crop cultivation and water consumption remained relatively stable over the study period. The price of water in the region did not significantly influence crop selection. However, despite the absence of changes in crop types and cultivation areas, farmers' incomes experienced a significant decline. Comparing the basic scenario with the environmental scenario, there was little change in the cultivation model, but farmers' income per hectare dropped by nearly 10 per cent. In summary, in all years, farmers' incomes, both in the environmental and economic scenarios, decreased compared to the baseline scenario, which witnessed economic growth.

An overview of the three cultivation models reveals that they favoured crops with lower water consumption. In an economic structure prioritizing economic goals over environmental concerns, wheat consistently occupied the largest cultivation area each year. Cotton and sugar beet areas decreased from their existing patterns. Comparing farm incomes in different models from 1997 to 2022, it is evident that farm income is higher in the economic structure and linear planning patterns than in the environment scenario. Water consumption in the economic structure indicates an increase compared to current conditions.

### 3.4. Adaptation scenario

Following the estimation of the cultivation model within the economic framework, the obtained data was subsequently input into the WEAP software as a variable. WEAP performs intricate calculations, determining the total water necessary for irrigation, the water requirements of various crops, and the resultant crop production levels. It furnishes us with crucial insights and values. Subsequently, utilizing the economic model, the results from WEAP software are incorporated to

**Table 3**
Planting pattern with economic scenario.

| Year cotton | Income (10 Rial −2$- ha$^{-1}$) | Consuming water (m$^3$ ha$^{-1}$) | Cultivation pattern (percentage) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Irr Wheat | R Wheat | Irr Barley | R Barley | Sugar beet | Cotton | Potato |
| 1997 | 210823.2 | 1436.55 | 8.99 | 87.74 | 4.18 | 2.04 | 0.80 | 0.59 | 1.08 |
| 1998 | 473840.1 | 3042.55 | 12.33 | 70.71 | 8.03 | 5.91 | 1.01 | 1.57 | 1.06 |
| 1999 | 952588.8 | 5252.55 | 24.99 | 60.81 | 6.36 | 6.13 | 1.03 | 2.03 | 7.07 |
| 2000 | 1867393 | 8229.55 | 32.62 | 6.33 | 12.52 | 36.13 | 1.95 | 2.11 | 4.73 |
| 2001 | 1554703 | 8236.55 | 31.6 | 6.33 | 12.54 | 36.16 | 1.96 | 0.12 | 4.73 |
| 2002 | 2106376 | 5090.55 | 18.85 | 61.39 | 8.72 | 3.31 | 1.43 | 2.04 | 5.68 |
| 2003 | 1081543 | 2109.55 | 8.04 | 79.52 | 3.47 | 5.04 | 1.08 | 0.93 | 1.34 |
| 2004 | 2097621 | 3770.55 | 14.45 | 67.85 | 5.86 | 5.01 | 1.70 | 2.09 | 2.46 |
| 2005 | 3335025 | 4361.55 | 14.41 | 66.61 | 5.80 | 4.28 | 1.51 | 1.63 | 5.18 |
| 2006 | 4059693 | 5943.55 | 24.3 | 54.08 | 10.35 | 1.84 | 3.31 | 2.46 | 3.08 |
| 2007 | 2917727 | 4951.55 | 16.06 | 63.85 | 6.25 | 3.68 | 2.29 | 1.38 | 5.91 |
| 2008 | 2883943 | 7227.55 | 47.81 | 35.19 | 9.55 | 1.77 | 1.32 | 3.25 | 0.53 |
| 2009 | 2995048 | 2822.55 | 8.35 | 77.55 | 4.13 | 3.83 | 0.30 | 0.78 | 4.48 |
| 2010 | 3835262 | 4393.55 | 13.17 | 62.38 | 7.77 | 4.04 | 0.75 | 1.59 | 2.73 |
| 2011 | 4590075 | 6181.55 | 22.48 | 55.68 | 8.91 | 1.41 | 0.90 | 2.42 | 7.62 |
| 2012 | 8628175 | 5745.55 | 37.39 | 43.68 | 10.00 | 4.93 | 0.98 | 2.05 | 0.39 |
| 2013 | 9540052 | 8003.55 | 29.73 | 36.91 | 13.37 | 6.12 | 1.30 | 2.41 | 9.58 |
| 2014 | 11628448 | 8636.55 | 37.64 | 27.47 | 17.33 | 9.41 | 1.63 | 2.48 | 9.46 |
| 2015 | 10207474 | 3941.55 | 1.15 | 17.59 | 8.35 | 52.63 | 0.59 | 0.98 | 4.13 |
| 2016 | 10050380 | 4417.55 | 14.18 | 66.51 | 7.82 | 3.06 | 1.72 | 0.86 | 5.27 |
| 2017 | 10105517 | 3820.55 | 12.58 | 18.27 | 7.60 | 3.16 | 0.96 | 0.93 | 5.12 |
| 2018 | 9109660 | 3921.55 | 12.01 | 17.98 | 6.60 | 2.93 | 0.50 | 0.98 | 4.87 |
| 2019 | 8467878 | 3740.55 | 11.75 | 17.23 | 6.37 | 2.04 | 1.54 | 0.86 | 4.30 |
| 2020 | 8614454 | 3621.55 | 11.22 | 16.89 | 5.96 | 2.09 | 1.23 | 0.83 | 3.87 |
| 2021 | 8559924 | 3547.55 | 10.85 | 14.98 | 5.83 | 2.06 | 1.93 | 0.73 | 3.76 |
| 2022 | 8866108 | 3541.22 | 11.23 | 14.48 | 6.53 | 2.05 | 1.83 | 0.76 | 3.82 |

gauge the quantity of water allocated for irrigation (values exceeding the available water limit for farms), crop production (for calculating the gross profit per crop), and water requirement of crops ($wreq_c$). These values are instrumental in modifying the initial cultivation model of farmers to a new and optimal allocation.

In this process, to calculate the reallocation of water, the revised cultivation model considers the fulfilment of irrigation demands and the estimation of crop production under various climate scenarios. These scenarios rely on statistical data on temperature, precipitation, relative humidity, and wind speed.

### 3.4.1. Climate low-change scenario

In the scenario of minimal climate change, the lowest statistics reflecting alterations in temperature, precipitation, relative humidity, and wind speed were used. The outcomes derived from the adaptation scenario's cultivation model in the absence of significant climate change are presented below.

Based on the statistics provided in Table 4, water consumption is projected to rise until 2001. The upward trend is primarily due to a decline in rainfall, resulting in drought conditions that necessitate farmers to supplement water for their crops. Consequently, they will be compelled to tap into surface and groundwater sources more extensively. This heightened utilization of water resources has the potential to bolster production levels. Accordingly, as indicated in Table 4, farmer income also experiences a significant increase.

In this climate low-change scenario, the area under cultivation of Irr and R wheat is 19.33 and 50 ha, and the area under cultivation of Irr and R barley is 7.30 and 8.30 ha, respectively. The results show that in these three cases, the percentage of changes compared to the base scenario is less than 25%. Nevertheless, in the case of rainfed barley, the rate of reduction is 649%. The area under sugar beet cultivation is 1.62 ha, which has increased by 39% compared to the base scenario. The area under cultivation of potato and cotton is 1.86 and 3.46 ha, which has decreased by 56% and increased 9%, respectively, compared to the base state.

In the 2014–2015 crop year, data from the Meteorological Organization of Iran reveals that an average of 138 mm of rainfall was recorded, signifying a 43% decrease in rainfall compared to long-term averages. This decrease coincided with the highest water use in 2014. In contrast, in 1997, the data showed higher precipitation levels than in other years, prompting farmers to rely more on rain-fed crops. Consequently, they achieved lower production levels than with irrigated crops, leading to higher irrigation utilization of rainwater. This resulted in reduced production and annual income compared to the preceding year.

A comparison between this cultivation model and the economic cultivation model reveals a 3% increase in the area dedicated to irrigated crop cultivation. Despite this expansion in irrigated crop cultivation, the water consumption per hectare decreases. The adaptation model's cultivation pattern exhibits a consistent reduction in water consumption, ranging from approximately 10 to 40 cubic meters across all years. This decrease is observed when the area dedicated to rainfed crop cultivation is less than in the economic scenario, with more emphasis on irrigated crops in this model.

Additionally, despite the increased cultivation area for high-value crops such as cotton and sugar beet, farmer income has declined. This suggests that the production of these crops has become more cost-intensive.

### 3.4.2. Severe climate change scenario

In the scenario of severe climate change, maximum values for temperature, precipitation, relative humidity, and wind speed were used. The outcomes from the adaptation scenario's cultivation model under the impact of severe climate change are detailed below:

In the challenging climate change scenario, there is a notable decrease in the area dedicated to crop cultivation, particularly affecting irrigated crops. Interestingly, in some years, the reduced water consumption has led to increased income for farmers in the rain-fed barley cultivation areas. This increase in production and revenue occurred despite lower water usage.

Comparing cultivated areas, it can be argued that, in certain years, both rain-fed crops and potato cultivation areas have decreased. However, areas dedicated to wheat, barley, cotton, and sugar beet have expanded, corresponding to an increase in water consumption. This increase in water usage has indeed led to higher production and income, especially for cotton and sugar beet. Nevertheless, these crops have

**Table 4**
Planting pattern in case of low climate change.

| Year cotton | Income (10 Rial −2$- $ha^{-1}$) | Consuming water ($m^3$ $ha^{-1}$) | Cultivation pattern (percentage) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Irr Wheat | R Wheat | Irr Barley | R Barley | Sugar beet | Cotton | Potato |
| 1997 | 252987.8 | 1307.261 | 9.30 | 83.15 | 1.94 | 4.10 | 1.02 | 0.61 | 0.97 |
| 1998 | 552813.5 | 2768.721 | 12.60 | 66.97 | 7.29 | 8.32 | 1.61 | 1.60 | 1.35 |
| 1999 | 1143106.6 | 4779.821 | 25.80 | 54.52 | 6.03 | 6.20 | 2.21 | 2.06 | 6.83 |
| 2000 | 2178625.1 | 7488.891 | 33.10 | 5.81 | 12.07 | 12.5 | 4.07 | 6.18 | 4.53 |
| 2001 | 1855043.4 | 7495.261 | 32.80 | 8.62 | 12.09 | 13.00 | 4.08 | 6.19 | 4.53 |
| 2002 | 2457438.9 | 4632.401 | 19.50 | 58.12 | 8.35 | 9.00 | 1.54 | 2.07 | 5.47 |
| 2003 | 1297851.1 | 1919.691 | 8.50 | 68.98 | 3.20 | 3.60 | 1.21 | 0.95 | 1.18 |
| 2004 | 2447224.5 | 3431.201 | 14.90 | 58.82 | 5.54 | 6.20 | 1.79 | 2.12 | 2.29 |
| 2005 | 3958052.0 | 3969.011 | 15.00 | 57.74 | 5.26 | 6.00 | 1.62 | 1.66 | 5.01 |
| 2006 | 4736308.5 | 5408.631 | 25.40 | 46.84 | 9.53 | 10.50 | 3.31 | 2.49 | 2.93 |
| 2007 | 3501272.5 | 4505.911 | 16.10 | 55.34 | 5.68 | 6.50 | 2.35 | 1.40 | 5.73 |
| 2008 | 3364600.1 | 6577.071 | 49.10 | 32.52 | 8.78 | 9.80 | 1.44 | 3.29 | 0.41 |
| 2009 | 3427665.9 | 2568.521 | 8.60 | 71.92 | 3.69 | 4.50 | 0.39 | 0.80 | 4.53 |
| 2010 | 4474472.1 | 3998.131 | 13.60 | 57.81 | 7.11 | 8.00 | 0.83 | 1.62 | 3.48 |
| 2011 | 5508089.6 | 5625.211 | 23.10 | 51.58 | 8.18 | 9.20 | 0.98 | 2.46 | 7.26 |
| 2012 | 10066204.1 | 5228.451 | 38.50 | 42.61 | 9.20 | 10.30 | 1.06 | 2.08 | 0.24 |
| 2013 | 11708245.4 | 7283.231 | 30.60 | 35.97 | 12.37 | 13.80 | 1.37 | 2.44 | 9.16 |
| 2014 | 13566522.9 | 7859.261 | 38.70 | 26.72 | 16.09 | 17.80 | 1.70 | 2.52 | 9.04 |
| 2015 | 12022136.3 | 3586.811 | 1.20 | 17.04 | 7.98 | 8.60 | 0.68 | 1.00 | 3.87 |
| 2016 | 11596592.7 | 4019.971 | 14.60 | 64.98 | 7.46 | 8.00 | 1.78 | 0.88 | 1.98 |
| 2017 | 12126620.2 | 3476.701 | 12.90 | 68.07 | 6.74 | 7.80 | 0.68 | 0.78 | 1.87 |
| 2018 | 10440284.5 | 3568.611 | 12.40 | 58.07 | 6.83 | 6.70 | 1.18 | 0.76 | 1.85 |
| 2019 | 10161453.2 | 3403.901 | 12.10 | 57.89 | 4.99 | 6.60 | 0.78 | 0.72 | 1.62 |
| 2020 | 10050196.8 | 3295.611 | 11.50 | 51.73 | 4.87 | 6.20 | 1.28 | 0.63 | 1.56 |
| 2021 | 10387323.4 | 3228.271 | 11.20 | 50.03 | 4.83 | 6.00 | 1.48 | 0.60 | 1.20 |
| 2022 | 10343792.6 | 3222.51 | 11.60 | 48.21 | 3.89 | 6.70 | 1.85 | 0.65 | 1.32 |

higher production costs, ultimately resulting in reduced income. This explains the decrease in revenue even as water consumption decreases in certain years.

The decrease in income observed in some years aligns with the argument from the preceding year, as it is justifiable due to increased water consumption in that year. However, for the remaining years under study, there is a consistent upward trend where production and income increase annually in tandem with water consumption on the farm.

In this model, which considers the maximum changes in temperature and precipitation, the reduction in the area under crop cultivation is primarily due to seasonal fluctuations. Increased rainfall during the rainy season leads to waterlogging and crop loss due to excessive water consumption. Conversely, higher temperatures and increased evaporation during hot seasons cause land dehydration, water scarcity during critical periods, and decreased crop cultivation.

Comparing this model with four basic models, namely environmental, economic, and no climate change, it becomes evident that the areas dedicated to irrigated wheat, dryland wheat, barley, and dryland barley cultivation are significantly lower than in the aforementioned models. However, the areas dedicated to sugar beet, cotton, and potato cultivation remain relatively stable. Concurrently, water consumption shows a decline due to increased rainfall. Nevertheless, income per hectare has decreased in all studied years, leading to reduced cultivation areas for crops such as wheat and barley.

Table 5 illustrates that the majority of cultivated areas are dedicated to wheat and barley. This can be attributed to two main factors: first, many farmers in the study area opt for crops with lower production costs, and second, wheat and barley are widely favoured crops among farmers in most villages, covering a significant portion of the study area. Additionally, the guaranteed purchase price and purchase conditions for these two crops are more favourable compared to other crops, incentivizing farmers to cultivate them.

According to the severe climate change model, the highest water consumption occurred in the year 2014, totalling 8611 cubic meters per hectare. Consequently, rain-fed crops had the smallest area under cultivation, while irrigated crops saw the largest cultivation area. Comparing this to previous years, it is evident that this model results in increased crop cultivation and water consumption, leading to a higher income for farmers. Notably, in 2015, a comparison between water consumption and cultivation area revealed that less water usage can yield higher income. This highlights the potential benefits of implementing innovative agricultural practices that optimize water transfer methods and minimize waste in irrigation, ultimately reducing water costs and increasing farmers' profits and incomes.

## 4. Conclusions

In conclusion, this study underscores the profound impacts of climate change on water resource management and cultivation models in the Eastern border catchment of Iran. Through the integration of economic and hydrological models, the research aimed to optimize cultivation practices while considering both economic viability and environmental sustainability. The findings highlight the significance of enhancing cultivation efficiency to accommodate shifts in climate variables, thereby maximizing economic returns and minimizing water consumption. However, climate change poses substantial risks to agricultural production in the region, which could have far-reaching consequences for trade patterns, development, and food security. To address these challenges, proactive measures are imperative. Suggestions for future research and action include implementing demand management policies, conducting educational programs for farmers, tailoring cultivation models to local conditions, and developing comprehensive adaptation plans. By embracing these recommendations and fostering collaboration among stakeholders, including agricultural economists, meteorologists, and local leaders, it is possible to mitigate the adverse effects of climate change on water resources and agriculture while promoting sustainable practices for the future.

## Ethical Approval

Not applicable.

## Authors contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [FR], [AT],

**Table 5**
Planting pattern in case of severe climate changes.

| Year cotton | Income (10 Rial −2$- ha$^{-1}$) | Consuming water (m$^3$ ha$^{-1}$) | Cultivation pattern (percentage) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Irr Wheat | R Wheat | Irr Barley | R Barley | Sugar beet | Cotton | Potato |
| 1997 | 239119 | 1311.55 | 9.11 | 83.98 | 2.33 | 3.84 | 0.65 | 0.51 | 0.91 |
| 1998 | 537204.8 | 2917.55 | 12.35 | 67.64 | 8.75 | 7.60 | 0.85 | 1.45 | 1.20 |
| 1999 | 1079787 | 5127.55 | 25.28 | 55.07 | 7.24 | 5.60 | 1.65 | 1.85 | 6.64 |
| 2000 | 2116565 | 8092.55 | 32.44 | 5.87 | 14.48 | 11.41 | 2.93 | 5.80 | 3.97 |
| 2001 | 1802228 | 8047.55 | 32.14 | 8.71 | 14.51 | 11.90 | 2.90 | 5.81 | 3.97 |
| 2002 | 2387412 | 4965.55 | 19.11 | 58.70 | 10.02 | 8.19 | 0.72 | 1.92 | 5.28 |
| 2003 | 1225934 | 1984.55 | 8.33 | 69.67 | 3.84 | 3.24 | 0.88 | 0.84 | 1.09 |
| 2004 | 2377490 | 3656.55 | 14.60 | 59.41 | 6.65 | 5.64 | 1.23 | 1.95 | 2.10 |
| 2005 | 3738346 | 4236.55 | 14.70 | 58.32 | 6.31 | 5.47 | 1.07 | 1.51 | 4.86 |
| 2006 | 4601171 | 5851.55 | 24.89 | 47.31 | 11.44 | 9.60 | 2.36 | 2.18 | 2.70 |
| 2007 | 3306943 | 4826.55 | 15.78 | 55.89 | 6.82 | 5.93 | 1.76 | 1.18 | 5.60 |
| 2008 | 3268655 | 7096.55 | 48.12 | 32.85 | 10.54 | 8.98 | 0.55 | 3.15 | 0.11 |
| 2009 | 3394574 | 2737.55 | 8.43 | 72.64 | 4.43 | 4.10 | 0.21 | 0.76 | 4.46 |
| 2010 | 4346816 | 4308.55 | 13.33 | 58.39 | 8.53 | 7.30 | 0.10 | 1.54 | 3.33 |
| 2011 | 5202271 | 6096.55 | 22.64 | 52.10 | 9.82 | 8.41 | 0.14 | 2.36 | 7.04 |
| 2012 | 9778784 | 5620.55 | 37.73 | 43.04 | 11.04 | 9.43 | 0.12 | 1.97 | 0.05 |
| 2013 | 11057973 | 7958.55 | 29.99 | 36.33 | 14.84 | 12.65 | 0.12 | 2.30 | 8.94 |
| 2014 | 13179094 | 8611.55 | 37.93 | 26.99 | 19.31 | 16.33 | 0.08 | 2.35 | 8.81 |
| 2015 | 11568657 | 3916.55 | 1.18 | 17.21 | 9.58 | 7.86 | 0.12 | 0.93 | 3.78 |
| 2016 | 11265447 | 4392.55 | 14.31 | 65.63 | 8.95 | 7.26 | 1.05 | 0.71 | 1.90 |
| 2017 | 11453105 | 4851.55 | 12.64 | 68.75 | 8.09 | 7.13 | 0.25 | 0.71 | 1.80 |
| 2018 | 10440470 | 4980.55 | 12.15 | 58.65 | 8.20 | 6.03 | 0.57 | 0.65 | 1.78 |
| 2019 | 9597114 | 512311.60 | 11.86 | 58.47 | 5.99 | 6.09 | 0.18 | 0.64 | 1.55 |
| 2020 | 9763234 | 534231.60 | 11.27 | 52.25 | 5.84 | 5.71 | 0.72 | 0.51 | 1.50 |
| 2021 | 9810436 | 621822.60 | 10.98 | 50.53 | 5.80 | 5.52 | 0.94 | 0.46 | 1.14 |
| 2022 | 10048442 | 631542.20 | 11.37 | 48.69 | 4.67 | 6.30 | 1.24 | 0.48 | 1.26 |

and [MH]. Data curation and supervision were performed by [AC-C] and [JF-G]. The first draft of the manuscript was written by [FR], [AT], and [MH] and the writing-review and editing done by [AC-C] and [JF-G]. All authors commented on previous versions of the manuscript.

### Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

### Consent to Participate

Not applicable.

### Consent to Publish

All authors read and approved the final manuscript.

### Funding

Funding for open access charge: Universidad de Granada/CBUA.

### CRediT authorship contribution statement

**Mahdi Babaeian:** Writing – original draft, Software, Methodology, Investigation, Formal analysis. **Jesús Fernández-Gálvez:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Andrés Caballero-Calvo:** Writing – review & editing, Validation, Supervision, Methodology, Data curation, Conceptualization. **Fatemeh Rastegaripour:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Abolfazl Tavassoli:** Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

### Data Availability

Data will be made available on request.

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