Drivers of climate variability and increasing water salinity impacts on the farmer's income risk with future outlook mitigation

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Abstract

Purpose – The main aim of this study is to investigate the impact of climate change and water salinity on farmer's income risk with future outlook mitigation. Salinity and climate change are a threat to agricultural productivity worldwide. However, the combined effects of climate change and salinity impacts on farmers' income are not well understood, particularly in developing countries.

Design/methodology/approach – The response-yield function and general maximum entropy methods were used to predict the impact of temperature, precipitation and salinity on crop yield. The target minimization of total absolute deviations (MOTAD)-positive mathematical programming model was used to simulate the impact of climate change and salinity on socioeconomic and environmental indicators. In the end, a multicriteria decision-making model was used, aiming at the selection of suitable climate scenarios.

Findings – The results revealed that precipitation shows a significantly decreasing trend, while temperature and groundwater salinity (EC) illustrate a significantly increasing trend. Climate change and EC negatively impact the farmer's income and water shadow prices. Maximum reduction in income and water shadow prices was observed for A2 scenario (-12.4% and 19.4%) during 2050. The environmental index was the most important, with priority of 43.4% compared to socioeconomic indicators. Subindex amount of water used was also significant in study area, with 28.1% priority. The technique for order preference by similarity to ideal solution ranking system found that B1 was the best climatic scenario for adopting climate change adaptation in the research region.

Originality/value – In this study, farmers' income threats were assessed with the aspects of different climate scenario (A1, A1B and B1) over the horizons of 2030, 2040 and 2050 and three different indicators

(economic, social and environmental) in Northwestern region of Pakistan. Only in arid and semiarid regions has climate change raised temperature and reduced rainfall, which are preliminary symptoms of growing salinity.

1. Introduction

Climate change is a significant threat for developing country's agricultural sectors both physically and economically because of increases in temperature and reduction in precipitation (Chong *et al.*, 2014; Pandey, 2019). Generally, climate change effects are prevailing globally and causing substantial disorders that may have unavoidable influences on economic guidelines and policies (Jamal *et al.*, 2018; Pahore *et al.*, 2015; Pandey, 2019). Climate change has a significant effect on crop yields, surface water and groundwater quality and quantity (Nong and Simshauser, 2020; Jiapaer *et al.*, 2015). Several studies (Whitehead *et al.*, 2009; Dad *et al.*, 2021; Taylor *et al.*, 2013) were conducted to evaluate the climate change effects on surface water and groundwater, and this wonder will finally be a clue to a drop in the quality and quantity of surface and groundwater. As a result, it is vital for the environment protection domains to prepare for the preservation of water resource and the control of their pollution (Yang *et al.*, 2020; Shortle and Horan, 2017).

The term "water contamination" refers to a decrease in the morphological, molecular and biological quality of water (Jing *et al.*, 2020; Shortle and Horan, 2017; Deng, 2019). Globally, pollution is critically problematic (Jing *et al.*, 2020; Luo *et al.*, 2018). The agricultural, urban land use and economic activities caused saline water with increased pH could cause the reduction in its quality. Agricultural fertilizers (phosphorus, nitrogen) and pesticides used for farming area known as nonpoint sources of pollution that play a vital role in environmental quality and water quality (Khan *et al.*, 2019; Jahandari, 2020; Javed *et al.*, 2019). Another global challenge is irrigation from saline water, which significantly reduced the water quality and crop yield, particularly in arid and semiarid regions (Jamal *et al.*, 2018; Chong *et al.*, 2014; Liu *et al.*, 2016). Thus, salinity is a crucial environmental problem that decreases agricultural production, destroys soil physical texture, vicissitudes climatic situations, decreases biodiversity and develops human health problems (Fichez *et al.*, 2017; Rajagopalan *et al.*, 2018; Jing *et al.*, 2020). Previous studies (Döll *et al.*, 2020; Shortle and Horan, 2017; Han *et al.*, 2011; Fordyce *et al.*, 2000; Fichez *et al.*, 2017) also indicated that precipitation and temperature variations and increase of groundwater salinity (EC), significantly affected the crops yield. Therefore, it is essential to assess the income risk from the perspective of climatic change and EC (Jing *et al.*, 2020).

Changing climate and water saltiness have a significant influence on agricultural productivity and farmer income (Qiao *et al.*, 2017; Rajagopalan *et al.*, 2018). Therefore, climate variables, along with EC, are taken into account in this study. Our main goals are to assess the concurrent impacts of climatic change and EC on the shadow price of water and farmer's income risk, to examine "stakeholders" views in ranking the socioeconomic and environmental indicators and to choose the most appropriate climate scenario in the study area. The novelty feature of the current study is the concurrent impacts of climatic change and EC on "farmers" decisions. Examine the sustainability of agricultural activities is the most crucial fact in the impacts of climatic change on the economy (Marcis *et al.*, 2019; Ragkos *et al.*, 2017; Wang *et al.*, 2019). Therefore, socioeconomic and environmental indicators should be carefully taken into account (Gurler *et al.*, 2006). These indicators are

widely used on farm, regional and global scales (Adam *et al.*, 2000; Jamal *et al.*, 2018). For the sustainable agricultural policies design, these indicators are suitable (Marcis *et al.*, 2019). Therefore, in our study, the current indicators are assessed at a regional scale.

Generally, for complex decision-making issues, the two widely used approaches are technique for order preference by similarity to ideal solution (TOPSIS) and analytical hierarchy process (AHP) (Sun, 2010; Chen, 2020). Several research have used these methods (Chen, 2020; Li *et al.*, 2021; Zaree *et al.*, 2019). The rank of indicators is varied using the AHP and TOPSIS techniques. In comparison to other techniques, AHP is used more frequently to highlight and pick the alternatives (Sezhian *et al.*, 2011; Mohammadi Ghaleni and Ebrahimi, 2015). In this technique, the decision-making personnel decides the criteria for selection (Ding *et al.*, 2016). This technique's basis is paired comparison, which allows policymakers to observe different scenarios (Gurler *et al.*, 2006; Javed *et al.*, 2020; Deng, 2019). Therefore, these indicators and models can regulate suitable scenarios for acclimatizing to the wonder of climatic change in the region (Jiapaer *et al.*, 2015).

2. Review of literature

Groundwater accounts for a significant portion of the world's renewable freshwater supply (Döll, 2009). Groundwater is vital for delivering agricultural, industrial and household water across many countries of the world (Nayak *et al.*, 2006). In Pakistan, the groundwater resources are mainly used for irrigation purposes, while its proper availability is crucial for the country's food security. A significant amount of water has been drained from groundwater basins in recent decades, resulting in a significant drop in the water table in several areas (Javed *et al.*, 2019; Tizro and Voudouris, 2008). Decreasing aquifer storage can lead to saline water intrusion, resulting in degradation of groundwater quality, crop production loss, salinization of irrigated lands and even social and economic problems in long run.

The appropriateness of groundwater for irrigation is determined by the hydro chemical factors observed in the groundwater (Jang *et al.*, 2008). The sodicity, salinity and toxicity concerns of irrigation water are quantified using these observed values. Aquifer groundwater quality is often evaluated via a network of monitoring wells that collect water samples. As a result, groundwater quality variable values are only known at a few distinct points inside aquifers, necessitating the use of an interpolation procedure to determine values at unsampled intermediary sites.

Salinity has become an increasing water security concern as a result of pressure induced by human activities and climate change, and the tendency in freshwater salinity is growing across the globe (Thorslund and van Vliet, 2020). In some areas, water salinity will affect the ability to accomplish water-related Sustainable Development Goals (Flörke *et al.*, 2019).

According to MacDonald *et al.* (2012), the groundwater resources in Africa have the ability to alter rural development if managed properly. But the salinity, according to Edmunds (2012), is one key characteristic that limits the consumption of groundwater for residential and food production usage, particularly in arid and semiarid regions. Groundwater quality is becoming more prominent in debates of long-term groundwater utilization (Gleeson *et al.*, 2020). Water with a high salinity inhibits the growth of plants, making it unsuitable for agriculture's irrigation. In arid areas, irrigation can cause the accumulation of soil salinity, making regions difficult for agriculture unless they are flushed. At the same time, drinking water is similarly affected, and at total dissolved solids (salinity) levels of more than 1,000 mg/L, it becomes highly unpleasant (Gurmessa *et al.*, 2022).

3. Study area and methodology

3.1 Study area

Climate change and salinity have a huge impact on Pakistan (Pahore *et al.*, 2015). Although the research area is critical for agricultural production, climate change and EC have a substantial impact on crop productivity (Javed *et al.*, 2019). As a result, District Kohat was chosen to anticipate the financial risk associated with climate change and EC. The study area is located between the $34°$ and $35°$ N and $71°$ and $72°$ E and elevation ranged between the 202 and 2,073 m (Figure 1). The study area has a long history of vegetables and cereals production (Haseeb, 2015). The main cereals are winter wheat, barley and summer maize, while the key vegetables are okra and winter turnip in summer.

3.2 Material and methods

The three future climate scenarios (A1B, A2 and B1) were used to forecast future precipitation, temperature and EC during 2030, 2040 and 2050. The A1B scenario represents business as usual, A2 represents the most extreme climate change and the B1 scenario represents the least extreme climate change. Several methods (as given below) were used to achieve the research objectives.

- Modified Mann–Kendall (MMK) test was used to compute the trend, significance and slopes of temperature, precipitation and EC.
- The climate model long Ashton research station weather generator (LARS-WG) was used to forecast future precipitation, temperature and EC.
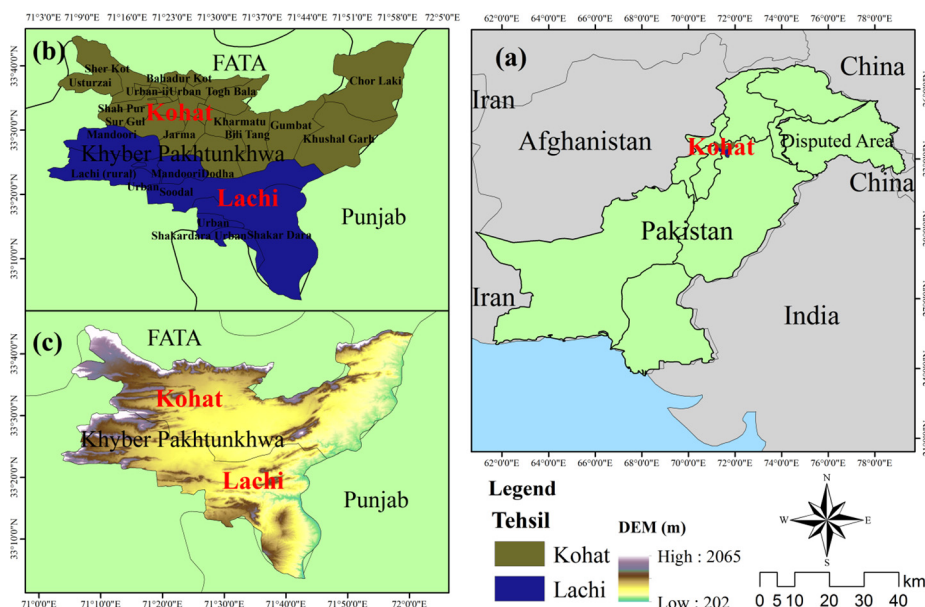- The generalized maximum entropy (GME) approach is adopted for the sensitivity analysis.

Figure 1.
Maps showing (a) Pakistan, (b) study area and (c) elevation (m)

- Target-minimization of total absolute deviations (MOTAD) model combined with positive mathematical programming (TM-PMP) was used for income risk assessment.
- AHP and TOPSIS methods were used to rank the economic, social and environmental indicators.

3.2.1 Modified Mann–Kendall test. The MMK was used to test the significance trends (Mann, 1945; Kendall, 1976; Yue and Wang, 2002). The statistic (Z) has a standard normal distribution with a mean value of 0 and a variance value of 1 under the no trend null hypothesis. After presenting a correcting factor n_1^s in Z, the MMK statistic ZM is obtained:

$$Z^* = Z/\sqrt{n_1^s}, where\ n_1^s = \begin{cases} 1 + \dfrac{2}{n_1}\displaystyle\sum_{jj=1}^{n_1-1}(n_1-1)r_{jj} & for\ jj > 1 \\ 1 + 2\dfrac{r_1^{n_1+1} - n_1 r_1^2 + (n_1-1)r_1}{n_1(r_1-1)^2} & for\ jj = 1 \end{cases} \quad (1)$$

where r_{jj} is a sample's self-correlation coefficient, and jj is lag. If Z or Z^* is positive (negative), the studied time series has an upward (downward) trend. The null hypothesis is denied if $|Z| > Z_{1-\beta/2}$ (or $|Z^*| > Z^*_{1-\beta/2}$) at a confidence level, where $Z_{1-\beta/2}$ is $(1-\beta/2)$ – quantile. At a confidence level of 0.05, if $|Z|$ or $|Z^*| \geq 1.96$, the trend is significant.

The slope of the trend (*b*) is robustly estimated by (Sen, 1968):

$$b = \text{Median}\left(\frac{x_k - x_m}{k - m}\right) \quad \text{for all of } m < k \quad (2)$$

where x_m and x_k are values in the *m*th and *k*th years, respectively.

3.2.2 Forecasting of climate and groundwater salinity scenarios. The LARS-WG model was used to forecast the future climatic parameters of precipitation and temperature. In the first step, the model was calibrated from 1980 to 2019. The precipitation, the minimum temperature and maximum temperature variables were compared to the observed data in the monthly scale; at significance level 0.05, there were no significant difference between the predicted and the actual values. The Pearson correlation finding shows that at the significance level of 0.01, the model's credibility was significant. After the calibration model, the future projecting of precipitation and temperature with A1B, A2 and B1 scenarios during the years 2030, 2040 and 2050 was inaugurated and compared with 2018. As stated in the third annual report of international panel on climate change (2007), this model was used in the hadley centre coupled model version 3 general circulation model to calculate differences in weather elements (including precipitation and temperature) using the A1B, A2 and B1 scenarios. The world is deemed convergent in A1B scenario, with a population of 9 billion people by 2050, then progressively decreasing. In addition, economic growth will accelerate and new technology will spread over globally. This scenario promotes the utilization of several energy kinds in a balanced manner. The world is not homogeneous under the A2 scenario, economic progress is regional and population is continuously rising. Countries in scenario B1 are deemed convergent and ecologically sound, and the population continues to expand progressively, though at a slower rate than scenario A2. The climatic scenarios considered were pessimistic, moderate and optimistic, i.e. scenarios A2, A1B and

B1, respectively. These scenarios, which are also the foundations for the LARS-WG model, generally contain the areas' climate features, cooperation of the countries and the process of population change through time (Akbari *et al.*, 2020).

The following equation was used:

$$F_{fut} = F_{obs} + \left(F_{GCM}^{fut} - F_{GCM}^{base} \right) \tag{3}$$

where F_{fut}, forecasting variable, F_{obs}, observed variable, F_{GCM}^{fut} and F_{GCM}^{base} are the forecasting variables on the model grid and generated on the model grid in the benchmark year.

Moreover, the EC was forecasted in the study area with an aspect of climatic scenarios. First, the influence of population, precipitation and regional gross domestic product (GDP) on the EC was measured by using the following equation (Javed *et al.*, 2019; Khan *et al.*, 2019):

$$In(EC)_t = \alpha + \beta_1 In(pop)_t + \beta_2 In\left(\text{Precip}\right)_t + \beta_3 In(GDP)_t + u_t \tag{4}$$

where t is time (1980–2019), precipitation, GDP and population values of district Kohat. After predicting equation (4), β_1 shows the EC sensitivity to an increase in population.

3.2.3 Generalized maximum entropy model estimation. The GME model was used to estimate the crop yield's sensitivity against precipitation, temperature and EC. The sensitivity was estimated by using the following equation:

$$Y = F(T, \text{Precip, EC, Trend}) \tag{5}$$

In equation (5), Y stands for yield, T for average temperature throughout the crop planting period, Precip for average precipitation in the research region, EC for EC and time variable, i.e. trend, for production technology.

Furthermore, the general algebraic modeling system software package CONOPT3 algorithm and the accuracy of estimated coefficients were assessed using the normal entropy criteria. Additionally, regression coefficients are measured as separate stochastic variables with a supportive range (Golan *et al.*, 1996). These supported values are known as a probable number in these intervals. In contrast, the regression coefficients are the sum of multiplication of the probabilities of the intervals in each number. In the present study, five supportive measures were selected for each of the coefficients and error judgments. The 3σ (three-sigma) rule has been used to calculate supportive values. The normal entropy criteria compute the following:

$$S\left(\hat{p}\right) = \left[\left(-\sum_j P_k^j \ln P_c^j \right) - \sum_j \left(P_c^j \ln p_c^j \right) - \sum_j \left(P_k^j \ln p_k^j \right) - \sum_j \left(P_{ei}^j \ln P_{ei}^j \right) \right] \Big/ K \ln M \tag{6}$$

In equation (6), M is the number of supportive points for the coefficients, ρ denotes the discount rate, P_{it} is crop price, K is the total number of estimated coefficients, $1 - S(\hat{P})$ also indicates the goodness of fit. Be aware that the GME technique necessitates the presumption that the values produced for the production function's parameters are anticipated values that rely on a set of selected support values. Therefore, even when a moment restriction is applied, differing support values that were predetermined may result in various parameter assessments. Hence, a major restriction is that policy implications are susceptible to the

selection of these values. The last restriction connected to the utilization of general climate models is uncertainty from model biases because of the model's construction and climatic susceptibility.

3.2.4 Computing of target MOTAD model. The TM-PMP was used to find the variations and impact of climatic change and EC on income risk and water shadow price (Arribas *et al.,* 2017). The predictable value of the objective function of the TM-PMP model is given as:

$$MaximizeEV = (1 + \rho)^{-t} \bigg/ T \left[\sum_{i}^{n} \sum_{t}^{T} \left(P_{it} Y_{it} - \left[\alpha_{it} X_{it} + 0.5 \beta_{it} X_{it}^2 \right] \right) \right] \qquad (7)$$

The equation (7), i denotes the various types of crops, including irrigated maize, barley, turnip, okra, Alfalfa and wheat and t denotes time ($t = 1,2,\ldots,8$). The average expected value is required for numerous years for risk programming models. The ρ denotes the discount rate, P_{it} is crop price and X_i is cropping area. The α_{it} and β_{it} denote the linear and quadratic coefficients of the cost function, respectively. The constraints of this model are as follows:

$$\sum_{i} \varphi_i X_i \leq R \qquad (8)$$

In equation (8), R denotes the total available resources, such as chemical pesticides, land, fertilizers, water, machinery and labor. The φ_j denote the technical coefficient of inputs used in crop production.

$$\sum_{i} \theta_{it} X_i + \overline{Z}_t \geq TI \qquad (9)$$

In equation (9), θ_{it} gross profit of the crops, Z_t = average income and TI = target income.

$$\sum_{t} \varphi_t \overline{Z}_t = \delta \qquad (10)$$

In equation (10), φ_t = probability of occurrence of the event and δ = parameter can be projected by changing the different cropping patterns.

$$\sum_{i} ROT_i X_i \leq 0 \qquad (11)$$

In equation (11), ROT_i represents the crop rotation.

$$\overline{Z}_t \, and \, X_i \geq 0 \qquad (12)$$

Equation (12) indicates the positivity of the decision variables. During the 2018–2019 academic year, stats and information were gathered from 250 farmers in district Kohat through face-to-face interviews and questionnaire. Target MOTAD's outcomes are sensitive to the target income level defined, which could be a disadvantage. Given a value of λ, a target income occurs indicated via $T_L (\lambda)$ like a model having target income lower than T_L (λ) will be equivalent to deterministic linear programming. Another target income value is

indicated by the symbol $T_U (\lambda)$, and a model with a target income higher than $T_U (\lambda)$ is impractical. Both $T_L (\lambda)$ and $T_U (\lambda)$ are anticipated to be growing functions of λ. The variation in the target income has been identified as a potential disadvantage.

3.2.5 Selection and ranking of indicators. The present research has adopted three major factors (economic, social and environmental). These factors are further broken down into subfactors like the economic index (profit to water consumption ratio and gross margin). Subindicators of laborers per hectare are shown in the social indicator. A subindictor of the environmental index is the amount of water consumption, phosphate and nitrogen fertilizer efficiency.

The AHP method is a well-known approach for the ranking and prioritization process (Cueva *et al.*, 2012; Ploeg *et al.*, 2020; Ying *et al.*, 2019). The AHP method includes three stages constructing a hierarchy of hierarchies, pairwise comparisons and normalization or prioritizing (Shi and Zhao, 2008). The following steps were used in this study:

- Hierarchy of decision-making
- Evaluation of decision-making criteria and their scores are calculated in relation to one another. Further paired comparison between the numbers 1 and 9, where 1 represents the average or same important and 9 represent most important.
- At the end, for getting priorities, normalization and weighted average are employed.

The 56 agriculture's expert's questionnaires (including agricultural extension research center employees of district Kohat and agricultural nongovernment organizations) during 2018–2019 were analyzed to weigh and pairwise comparison of indices subindicators. The main indicators and then the subindicators are compared pairwise, economic vs social index, environmental vs economic index and environmental vs social index. From the respondent's views, the importance of these indicators has been obtained. Using expert choice software, the pairwise comparison matrix method was applied to obtain the indicators and subindicators weighted rendering the respondents. Additionally, the TOPSIS was used to select the best scenario. The ranking of alternatives is obtained using the following equation.

$$C_i^* = S_i^- \big/ {(S_i^- + S_i^*)} \tag{13}$$

In equation (13), C_i^* between zero and one, S_i^- represents an alternative and S_i^* represents the ideal alternative. During the application, it is important to pay close attention to the rank reversal fact. It outlines the modifications to the judgment options' order when the issue is expanded to include a fresh judgment option. The validation of rank reversal in literature is still a topic of discussion. A limitation of AHP is the subjective nature of the modeling procedure. This indicates that the approach cannot assure that the conclusions are unquestionably true. The number of paired comparisons grows as the hierarchy's levels rise, making the AHP model's construction significantly more time and work intensive.

4. Results
Applying population forecasting in scenarios A1B, A2 and B1, are considering the EC elasticity (β_1 coefficient). The correlation between other variables and EC is presented in Table 1. The population has a significant effect on EC. For example, 1% increase in population will increase the EC up to 1.673%. The EC was predicted during 2030, 2040 and 2050 concerning the results estimated in Table 1. For predicting changes in precipitation, temperature and EC, the climate scenarios forecasting results were compared with 2019 (benchmark).

4.1 Temporal variations of precipitation temperature and groundwater salinity
The temporal analysis was performed between the annual average precipitation, temperature and EC over 1980–2019 (Appendix Figure A1). Precipitation, temperature and salinity curves all varied on a regular basis. Precipitation, on the other hand, exhibited a declining trend during the years 1980–1998 years, while temperature and EC increased. Generally, the EC curve followed the precipitation curve; for example, from 2000–2004 to 2006–2012, the precipitation decreased and the salinity increased. However, there were few points where both precipitation and EC illustrated decreasing patterns, such as years 1984, 2005 and 1985–1987. The EC and temperature curves also showed an almost similar pattern; for example, from 1989 to 1994, the temperature curves showed a decreasing pattern and similarly, EC curves also illustrated decreasing patterns.

The trend of significance and slope of EC, precipitation and temperature were also computed using the MMK, and Sen's slope tests (Sen, 1968) designed a nonparametric approach for determining the slope of a trend in a sample of N data pairs. The temperature and EC illustrated a significantly increasing trend with the Z values of 2.15 and 5.82. While the precipitation illustrated a significantly decreasing trend with the Z value of -3.37. The highest Sens slope (b) score, -3.21, is found for precipitation, indicating a declining pattern, while the smallest value, 0.04, is recorded for temperature (Table 1).

4.2 Spatial pattern of land cover, precipitation, temperature and groundwater salinity
Figure 2 depicts the spatial pattern of ground water salinity, rainfalls and temperatures in 2019 across various land covers. The majority of the land cover consists of croplands, which cover almost 43%, followed by sparse vegetation, forest and urban areas (Figure 2). The salinity, precipitation and temperature range from 1 to >3 deci Siemens per meter (dS/m), 80 to 260 mm and 14 to 28°C, respectively. A remarkable point has been observed from the maps that land cover has a significant role in climate change. For example, North and Northwestern areas of forest land cover received maximum precipitation (i.e. 212–260 mm), while the lowest temperature and salinity values have been observed, i.e. 14°C to 19°C and 1.0–2 dS/m, respectively. Precipitation and temperature also play a significant role in salinity control; for example, the Northeastern region has received the lowest precipitation, highest temperature and lowest salinity (1 dS/m). While the Northwestern region has received higher precipitation, lowest temperature and highest salinity (>2.5 dS/m).

The spatio-temporal analysis of precipitation, temperature and salinity depicted that these parameters are interconnected and show significantly increase or decrease trends. Therefore, these parameters were selected for the "farmers" income threats assessment with different climate scenarios.

Table 1.
Result of forecasted groundwater salinity model and trends of temperature, precipitation and EC over 1980–2019 using MMK test (at 0.05 level of significance)

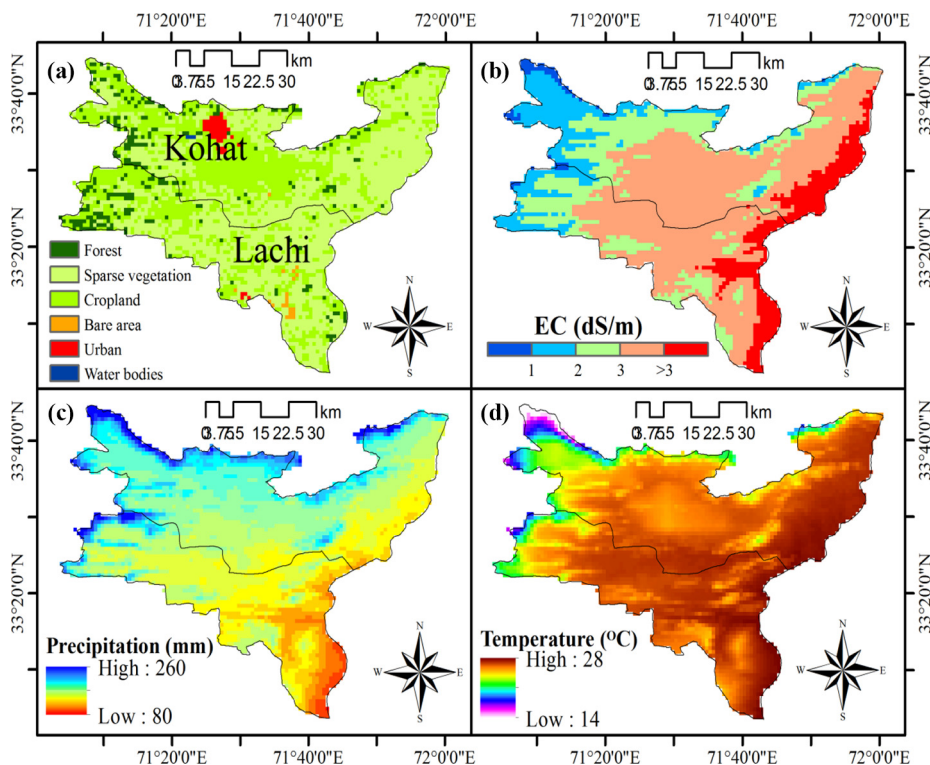| Variables	Coefficient	*t*-statistics	Significance level
Constant	−0.6	−1.3	0.3
Population	1.7	3.8	0.0
Precipitation	0.1	3.6	0.0
GDP	0.5	3.4	0.0
Fertilizer	0.0	0.2	0.9
Trends of temperature, precipitation and EC			
Variables	Z	Trend and significance	Sen's slope (*b*)
Temperature	2.2	Significant increase	0.1
Precipitation	−3.4	Significant decrease	−3.2
EC	5.8	Significant increase	0.1

Figure 2.
Showing the spatial
pattern of (a) land
cover, (b) groundwater
salinity, (c) precipitation
and (d) temperature in
year 2019

4.3 Spatial distributions of future changes in precipitation, temperature and groundwater salinity

The LARS-WS model was used to predict spatial distributions of future changes in precipitation, temperature and salinity. Figures 3–5 illustrated the changes in precipitation, temperature and salinity according to the future scenarios regarding the benchmark year 2019. The changes were predicted in the study area, by the moderate (A1B), high climate change (A2) and conservative climate change model (B1) scenarios. Generally, under all the considered future climate scenarios, temperature and EC increase and precipitation decreases overall horizons (2030, 2040 and 2050). Precipitation is projected to increase or decrease depending on the location and the scenario; for example, A2 scenario largely showed the highest changes in precipitation (Figure 3). Overall, among the scenarios with decreasing precipitation, the projected change is from −1.8 to −3.2 mm (larger reductions were observed in South region). The pattern of decreasing precipitation was more certain in the South and increased in northwest small area. Similarly, the maximum increase in temperature and salinity was observed in the A2 scenario across Northeast region (greater than 2°C and greater than 0.8 dS/m, respectively).

In 2040, the decreased precipitation is almost double compared to 2030; for example, changes in precipitation range is greater than 5 and less than −10 mm during the 2040, while in 2030, range is between >3 and <−5 mm. Similarly, the changes in temperature range are between 1°C and >4°C and salinity 0.3 and >1.2 dS/m (Figure 5).
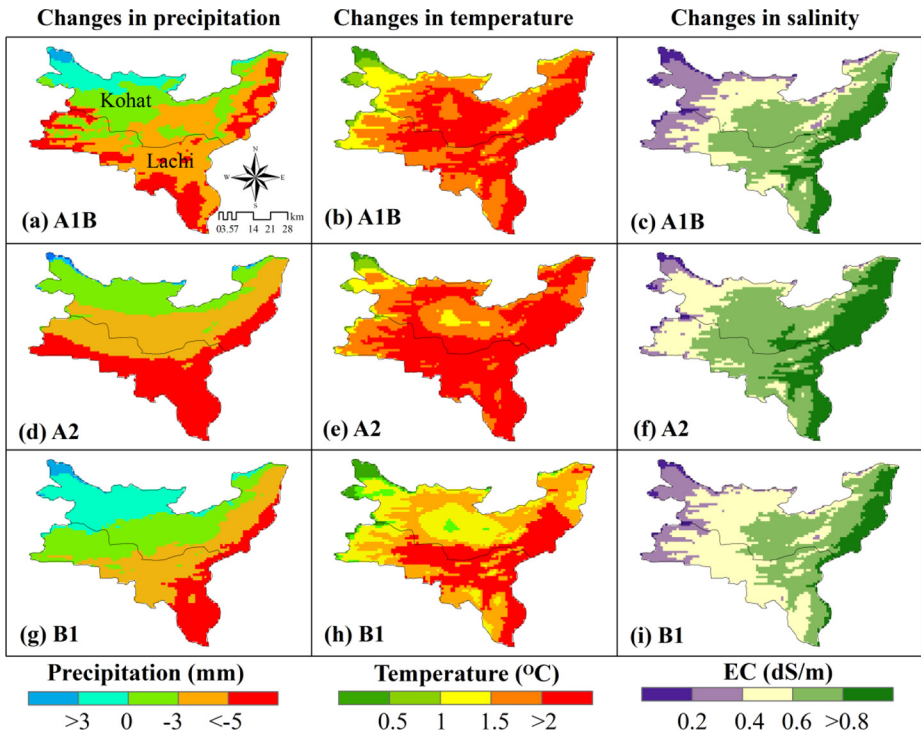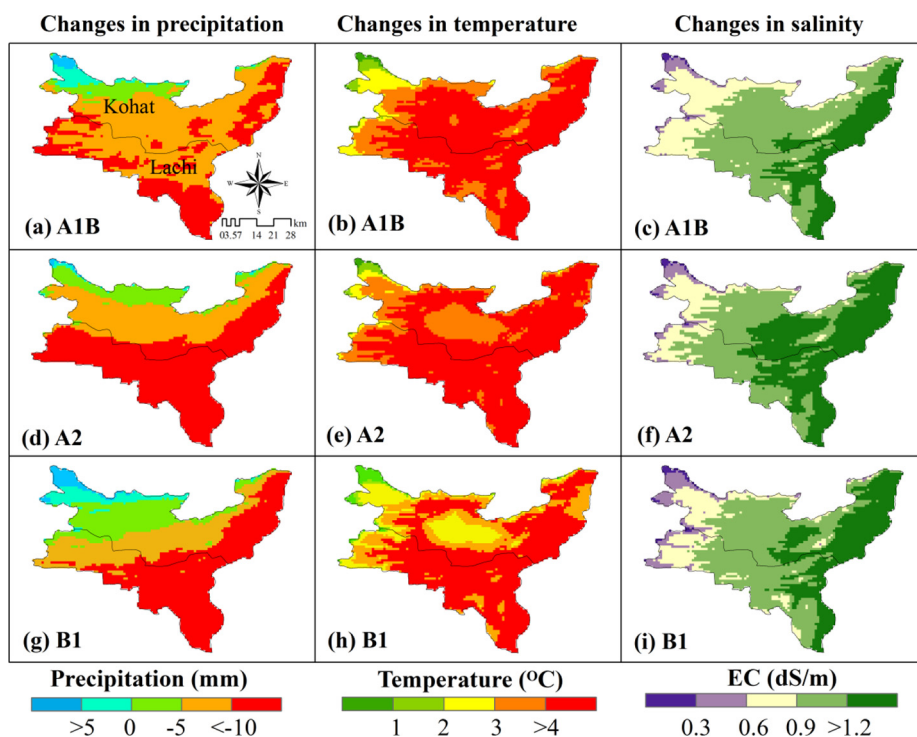
Figure 4.
Precipitation,
temperature and
groundwater salinity
changes in district
Kohat under low (B1),
moderate (A1B) and
high (A2) emission
scenarios for 2040
relative to the 2019
reference period

Appendix Figure A2 depicts a fall in the water's shadow price in 2030, 2040 and 2050, based on climate scenarios and groundwater salinity. Overall, an increase in EC and climate change reduced the water shadow price. Nevertheless, in A2, the largest reduction in shadow price of water in the 2050 forecast was 19.4% and the smallest variances in water shadow price are associated with the B1 scenario, which has decreased by 6.7%, 10.3% and 12.4%, correspondingly.

4.6 Evaluating the impact of climate and groundwater salinity scenarios on different indicators
Table 3 shows the assessment of the impacts of indicators on climate scenarios and salinity, socioeconomic and environmental indices. The economic indexes, such as the ratio of profit to consumed water and gross margin, diminished in all scenarios. The maximum reductions in profit of consumed water and gross margin were observed for A2 scenario during 2050. The cultivation areas in the region reduced in the prospect of climate change. However, there were no significant changes in farm employment prospect of climatic change and EC. The environmental indicators, fertilizer (nitrate and phosphorus) quantity intensify in all the scenarios. The most significant environmental indicator, water consumption, diminished with the prospect of climate change and EC. The maximum reduction is related to the B1 scenario in 2030.

4.7 Determining the importance of indicators and subindicators
The AHP model was used to calculate the difference of economic, social and environmental indicators and subindicators weights (Table 3). First, the main indexes were pairwise
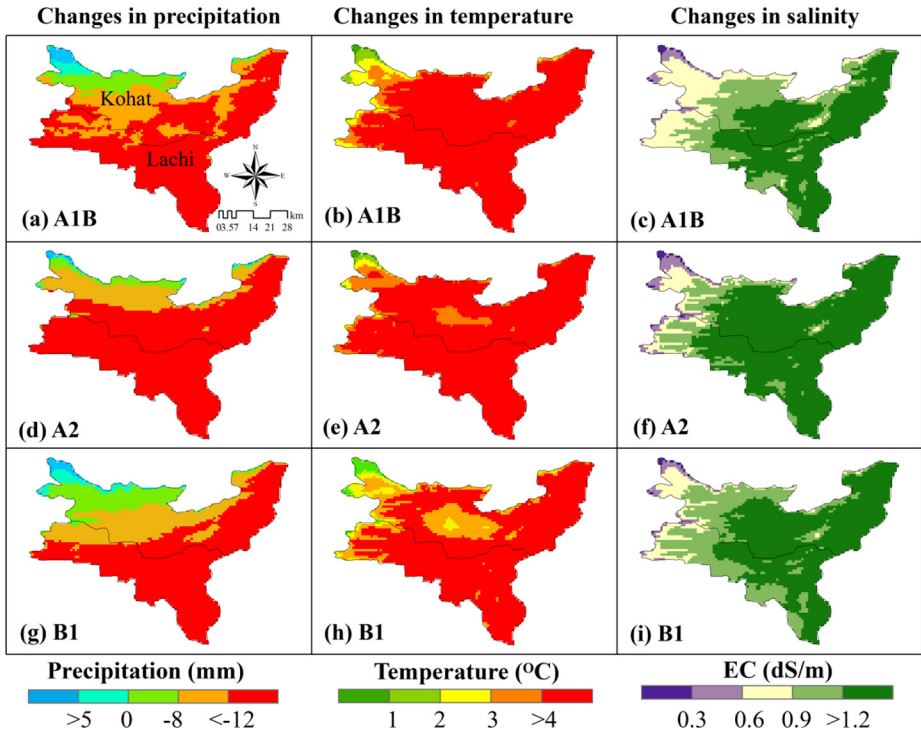
Figure 5.
Precipitation, temperature and groundwater salinity changes in district Kohat under low (B1), moderate (A1B) and high (A2) emission scenarios for 2050 relative to the 2019 reference period

Table 2.
Estimation of crop yield sensitivity to temperature, precipitation and salinity

Crops	Salinity	Temperature	Precipitation
Maize	−0.02	0.88	0.25
Wheat	−0.12	−1.10	0.87
Barley	−0.46	−1.55	0.35
Turnip	0.25	−0.15	1.47
Okra	0.53	0.46	0.32
Alfalfa	−0.05	−0.07	−0.03
Estimate the farmer's income risk with respect of climate scenarios			
Scenario	2030	2040	2050
A1B	−6.7	−8.4	−9.8
A2	−7.8	−9.3	−12.5
B1	−5.8	−7.3	−9.2

compared to determine the degree of importance of each indicator and subindicators. The results revealed that the environmental indicators are 43.4%, which have the highest importance, followed by economic (31.5%) and social indicators (25.1%). The economic index is essential in this region because of the lower income and profits of the farmers. The subindicators of economic indicators, i.e. gross margin, is 19.3% importance, while the water consumed benefit ratio is 12.2% importance. The social indicator of farm employment

| Scenario | Time horizon | Economic indicators | | Social indicator | Environmental indicators | | |
		The ratio of profit to consumed water (10^{16} tomans/000 m^3)	Gross margin (10^{16} tomans)	Farm employment (Person/Ha)	Amount of water used 1,000 m^3	Nitrogen fertilizer (Kg/Ha)	Phosphate fertilizer (Kg/Ha)
Benchmark	2018	9.5	2,434.3	18.4	353,467.426	175.1	93.2
A1B	2030	9.2	2,376.6	18.5	353,467.122	175.2	93.2
	2040	9.1	2,367.7	18.4	353,467.134	175.5	93.5
	2050	9.0	2,364.2	18.4	353,467.138	175.6	93.4
A2	2030	8.9	2,366.5	18.4	353,467.215	175.4	93.4
	2040	8.6	2344.6	18.4	353,467.227	175.7	93.6
	2050	8.2	2,329.1	18.4	353,467.232	175.3	93.6
B1	2030	9.4	2,393.3	18.4	353,467.244	175.5	93.4
	2040	9.2	2,385.9	18.4	353,467.248	175.8	93.5
	2050	9.1	2,371.4	18.4	353,467.252	175.9	93.6

The analytical hierarchy process (AHP) weight of each indicator and subindices

Subindicators	Unit of measurement	Normalized weight subindicators (%)		Unit of measurement	Normalized weight subindicators (%)
Economic	31.5	Ratio of profit to consumed water		Billion tomans/thousand cubic meters	12.2
		Farm profit		Billion tomans	19.3
Social	25.1	Farm employment		Person/hectare	25.1
Environmental	43.4	amount of water used		1,000 m^3	28.1
		Nitrogen fertilizer		Kilograms/hectare	8.2
		Phosphate fertilizer		Kilograms/hectare	7.1

Notes: Kg denotes kilogram, 000 denotes thousand, Ha denotes hectare, 10^{16} denotes one billion and m^3 denotes cubic meter

Table 3.
Economic, social and
environmental
indices assessment
respect of climatic
and groundwater
salinity scenarios

importance is equal to 25.1%. The importance of environmental subindicators (water used, nitrogen and phosphate fertilizer) were 28.1%, 8.2% and 7.1%, respectively.

4.8 Ranking of climate scenarios
Finally, the TOPSIS model was used to investigate the ranking of climatic scenarios according to each time horizon. The comparative proximity rate and the outcome of the climatic scenarios ranking proportional to the socioeconomic and environmental indicators and their subindicators importance rate is displayed in Table 4. B1 scenario obtained rank 1, followed by A1B and A2. In the study area, B1 scenario is presented as an attractive scenario. Thus, B1 plays a significant role in policymaking; this scenario enhances the gross margin and profit. Furthermore, the B1 scenario reduced the EC compared to A1B and A2 scenarios, which improved the environmental indicators. Therefore, the B1 scenario is an environmentally friendly scenario for the agriculturist benefit and income.

5. Discussion
The present study showed that during 1980–1998, temperature and soil salinity showed an increasing trend while the precipitation depicted a decreasing trend. From 1980–1998, industrialization and climate change increased carbon emissions, significantly increasing the temperature and decreased precipitation (Vila-Traver *et al.*, 2021; Qureshi and Jamil, 2021). Our findings demonstrated that the rainfall and salinity of soil curves followed a nearly identical pattern. The result is plausible, as rainfall reduces groundwater uses for irrigation and minimized the saltwater intrusion risk in freshwater aquifers (Naderi and Saatsaz, 2020; Fichez *et al.*, 2017).

Further, in the present study, we evaluated the water shadow price and income risk with the perspective of climatic change and EC. In this view, the socioeconomic and environmental indicators have been assessed. For this reason, precipitation, temperature and EC have been predicted, and exposure of these variables on crop yield (i.e. maize, barley, turnip, okra, alfalfa and wheat) have been assessed in the study area. Additionally, the integrated TM-PMP application used for the socioeconomic and environmental indicators in the A1B, A2 and B1 scenarios are determined over 2030, 2040 and 2050 prospects. Our results revealed that harmful precipitation impact on some crops might be because of an increase in humidity or the disease outbreak and pests attack, which is an ultimate reason for the decrease in the crops yield (Fichez *et al.*, 2017; Pahore *et al.*, 2015).

Our finding revealed that the climate changes and increased EC significantly reduced the income risk and shadow price of water in the area. Generally, the shadow price of water reduced in the climatic scenarios in a ranking as A2 < A1B and <B1, and the highest

Time horizon	Scenario	Ci	Si⁻	Si⁺	Ranking
2030	B1	0.623	0.001	0.001	1
	A1B	0.593	0.001	0.001	2
	A2	0.454	0.001	0.002	3
2040	B1	556.000	0.003	0.001	1
	A1B	0.423	0.001	0.001	2
	A2	0.213	0.001	0.002	3
2050	B1	0.534	0.004	0.001	1
	A1B	0.325	0.004	0.001	2
	A2	0.156	0.002	0.004	3

Table 4.
Selected and ranking of suitable climate scenario for study area

reduction was observed in the A2 scenario. In the future, policies should be conducted in a larger perspective; all nations must focus on economic growth through efficient energy resource usage; otherwise, a surpluses would result in a fall in the water shadow price (Wolfram *et al.*, 2011). In the A2 climatic scenario, the farmer's income was significantly reduced, whereas the B1 climatic scenario saw the least change. As a result of the divergence and the expanding population, the income risk will increase (Rattsø and Stokke, 2013).

The results of weighting indexes proposed that the social index (25.1%) is least esteemed in the region followed by the economic index (31.5%), while the environmental index is most important (43.4%). The findings are consistent with Jahandari (2020), which assessed weighting indexes in Iran and reported that the environmental index is most important than the social index, while different from Cueva *et al.* (2012); they conducted the study in Spain and stated that gross income and water consumption subindicators are most prominent among the indicators. The lowest important indicator is phosphorus fertilizer among the environmental subindicators (Jahandari, 2020). Finally, the TOPSIS technique was used to categorize the climate scenarios to demonstrate the most suitable climatic scenario. The B1 scenario innovative forecasts, which globally performed divergence and environment friendly, and the organizing and programming to this scenario should have more advantages in the study area. The slightest advantages would occur once it is universally performed independently and divergently (Döll *et al.*, 2020).

The development of soluble salts in waters and soils, known as salinization, is a worldwide problem that is occurring at a massive scale. Salinization is an anthropogenic (e.g. unsustainable groundwater extraction) and natural (e.g. tidal overflow) process (Herbert *et al.*, 2015; Rengasamy, 2006) that can irrevocably pollute rivers, soils and aquifers (Chong *et al.*, 2014; MacDonald *et al.*, 2016; Dasgupta *et al.*, 2015), posing a direct threat to millions of people's water and food security (Clarke *et al.*, 2015; Szabo *et al.*, 2016). The widespread character of salinization has become intensely obvious (Wong *et al.*, 2014), with a large body of research describing the problem in both arid and semiarid areas inland waters and groundwater sources (Ketabchi *et al.*, 2016; Jolly *et al.*, 2008). The problem is becoming a significant ecological and social challenge in worldwide river deltas, which are gateway to over 500 million individuals and have a population density that is more than seven times that of the rest of the world (Giosan *et al.*, 2014; Ericson *et al.*, 2006).

6. Conclusion

According to the findings of the current study, climate changes and growing EC have significantly lowered both the income risk and the water's shadow price in the research region. The water's shadow price was often lowered in climatic scenarios with the rankings of A1B, <B1 and <A2, well with highest drop seen in the B1 scenario. The salinity and temperature showed a significant increasing trend, while precipitation depicted a significantly decreasing trend. The environmental indicators were revealed to be relatively important indicator than economic and social indicators. The subindicators of environmental indicator's importance are ranked as water consumption > nitrogen > phosphate fertilizers. The B1 climate scenario is most suitable as compared to the A1B and A2 scenarios. Compared to the other indicators, the environmental indicator is the most critical in the farming sector and must be reflected for future policy planning. This study suggested that forest reduces the negative impact of the environment on farmer's income. Therefore, for adaptation of policy regarding climate change, forestation should be taken into account to reduce the income risk. The study conclusions revealed that the preceding suggestions for agro-sustainability with changing climate should be emphasized in subsequent studies. Effective treatments must be integrated in coordinated policies and

approaches to be much more successful. Gender-sensitive policies should be multiscale, multisector and multistakeholder in nature. Learning through knowledge and per formance should be observed, reviewed and updated regularly. The current study used the data from 1980–2019; the current study encourages the researchers to use the updated data, and some of the variables' data were unable to execute in our study because of time and financial limitation. Thus, in future study, these matters should be taken into account for more reliable results.

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Appendix

Figure A1.
Temporal variation of
precipitation,
temperature and
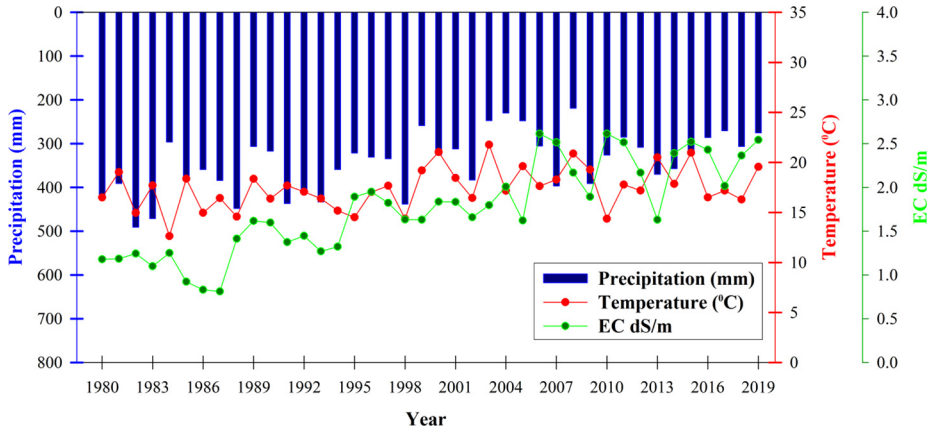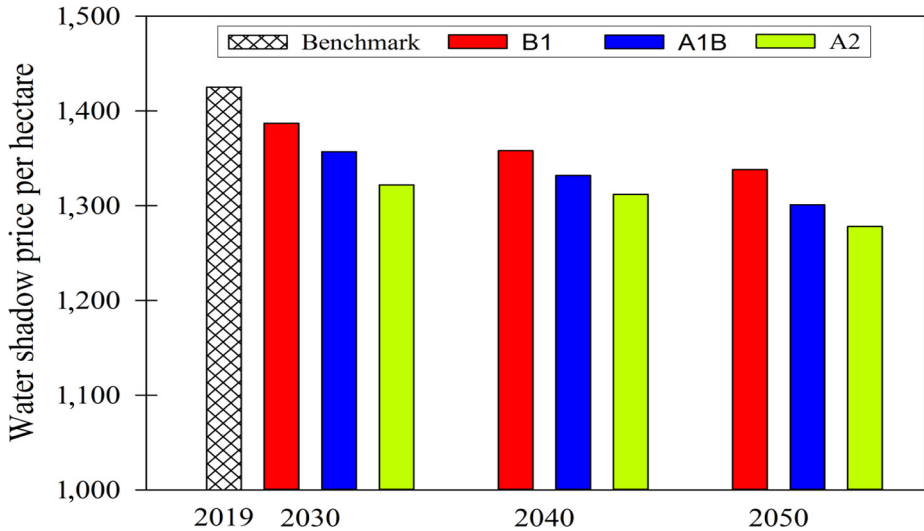groundwater salinity
during1980–2019

Figure A2.
Change in shadow
prices of water in
climate and
groundwater salinity
under emission
scenarios relative to
the 2019 reference
period

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