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Managing Risks of Climate Change on Irrigation Water in Arid Regions

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Abstract
Abnormal changes in temperature, precipitation, atmospheric carbon dioxide, or solar radiation are examples of climate change that may affect irrigation water demand. Studies show an increasing trend in the earth's surface temperature, with decreasing trends in rainfall. With most studies focused on predicting the extent of climate change, fewer studies focused on developing appropriate response strategies. This paper aims to propose a systematic approach to identify, analyze, and respond to the risks of climate change on irrigation water in arid regions using the Risk Management process. The compound effect of these risks was analysed using Monte Carlo Simulation, which indicated a 69% loss in crop production due to climate change at a 90% confidence level. The proposed responses to the risks of climate change include strategies to avoid, transfer, mitigate, and/or accept these risks. The study has made three contributions to the state of the art. First, to adopt a well-recognized risk management methodology in climate change studies. Second, to quantify the compound effect of climate change risks on irrigation water in arid regions. Third, to recommend a set of response strategies to help policymakers mitigate the inevitable harmful effect of climate change on irrigation water.

Keywords Risk management · Climate change · Arid regions · Mitigation · Strategies · Monte Carlo Simulation · PMI

1 Introduction

Reduced river runoff and aquifer recharge in the Mediterranean basin are likely to exacerbate water scarcity in existing arid environments. As the temperature rises, the need for irrigation water increases and agricultural productivity decreases. Because of the warming climate, peak streamflow is expected to increase by 50–400% in the next decades, and to arrive 2–4 months earlier each year (Liu et al. 2021).

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FAO summarized the challenges facing agriculture and water with and without climate change. One of the main challenges is a 4 °C increase in global atmospheric temperature by 2080, which is equivalent to the effect of a 200% increase in the concentration of atmospheric CO_2. The average temperature is expected to rise at a slower rate in equatorial regions and at a faster rate in the upper latitudes. Precipitation is expected to increase at high latitudes and in tropical regions but will decrease in the existing dry semi-arid to arid mid-latitude regions and within continents (FAO 2015). Climate models estimate that by 2100, global temperatures will have risen by 4 °C and yearly precipitation will have decreased by 20% (Bradley et al. 2006; Mostafa et al. 2021a, b).

An increase in the temperature can raise the potential evapo-transpiration rate. Due to an anticipated increase in the evapo-transpiration rate in 2100, the influence of climate change would increase the potential irrigation needs in Egypt by around 6–16% (Attaher et al. 2006). Studies in Egypt's North Nile showed that yearly water requirements for maize and wheat in 2040 would rise by 2–15%, respectively, due to an increase of 8% in the potential evapo-transpiration (Attaher et al. 2006).

The demand for water from the local agricultural industry is predicted to rise in tandem with the expected temperature increase. In Portugal, seasonal irrigation demands for existing crops and new crops are predicted to grow by 7–13% and 13–70%, respectively (Rolim et al. 2017). Another study in 2021 predicted that irrigation water demands in 2050 for winter crops and summer crops would grow by 7.3% and 13.2%, respectively (Mostafa et al. 2021a, b). A global study in 2007, supported by another study in 2015, predicted that the effect of climate change on irrigation water requirements might result in a 20% rise in world irrigation water demand and a 10% decrease in agricultural productivity by 2080 (Fischer et al. 2007; Esteve et al. 2015).

For the period 1980–2100, the hydrologic simulator in the United States showed a 3–5 °C increase in annual average temperature, a 1.3% decrease in annual precipitation, an 8.5% decrease in stream discharge, a 2–5% decrease in groundwater storage, and an 11% decrease in crop productivity in the basin (Aliyari et al. 2021). Researchers in Iran predicted that the effect of climate change on the variability of potato yield would range between 6 and 29% (Shayanmehr et al. 2020). Another study on Egypt predicted that the water requirements for wheat would increase by 6.2% with a crop production decrease of 8.6% in 2050 (Mostafa et al. 2021a, b).

Due to the extreme weather and climatic events in recent years, there is an urgent imperative to minimize Greenhouse Gas emissions and improve the sustainability of the health system (Ebi 2022). The world's effort to face climate change further motivated the global research on finding new agricultural systems that can withstand the pressure of cold, heat, and humidity (Singh 2016).

Analysis of climate change risks across European regions showed the need to adopt measures to reduce the vulnerability of the irrigation and other agricultural sectors to climate change (Riediger et al. 2014; Iglesias and Garrote 2015). The Asian Development Bank (ADB) recommends climate change adaptation strategies such as increasing water efficiency by growing higher-value crops, assisting poor farmers by providing access to water and modern agricultural technology, and providing those farmers with social protection from extreme harsh events (Asian Development Bank 2020). Even though climate change has many potential impacts on the sustainability of agriculture, technological adaptation can partially alleviate these impacts (Hopmans and Maurer 2008). Direct seeded rice is one of India's adaptation measures that alleviated climate change impacts such as decreasing used water, increasing yield, and providing higher returns to farmers (Kakumanu et al. 2019).

Other adaptation strategies to support farmers and farming practices include the assessment of farmers' awareness of climate change; implementation of proper public climate policies; and diversification of farm management practices such as new technologies, improved seeds, financial access, and professional learning (Nkurunziza et al. 2022; Sohail et al. 2022).

Although most researchers focus on the prediction of climate change parameters such as CO_2 and temperature in future years, there is no quantification of the predicted impact of climate change on crop yield production in case all the climate change risks occur simultaneously. Moreover, suggestions to deal with climate change lack the utilisation of a systematic approach to manage the identified climate change risks, at the time they are expected to occur.

2 Study Objective

The main goal of this study is to adopt the systematic Risk Management Process developed by PMI 2008 in climate change studies. Through using the systematic PMI Risk Management Process, the following objectives would be achieved.

- Propose a systematic approach to manage the risks of climate change.
- Identify the risks of climate change on irrigation water and crop yield.
- Quantify the compound effect of climate change risks on crop yield; in case all risks occur simultaneously.
- Propose response strategies to minimise the adverse impact of climate change on irrigation water and crop yield.

The systematic PMI Risk Management process has not been adopted by any other previous climate change study. All previous studies concentrated on identifying climate change risks and developing mitigation strategies as a one-time event. The motivation to adopt the systematic PMI Risk Management process in this study is to promote the use of a cyclic process as the challenges of climate change dynamically evolve over time. The PMI's risk management process is a cyclic process with a never-ending implementation loop, which would require policymakers to continuously review the climate change risks and update their response strategies. The way this study uses the cyclic PMI Risk Management process to deal with the risks of climate change is novel.

3 Factors Affecting Crop Yield

The main cause of climate change is the increased concentration of Green House Gasses (GHG) in the atmosphere, which results from the rapid growth of the population and industrial activities. GHGs include carbon dioxide (CO_2), nitrogen oxide (N_2O), and methane (CH_4). Increasing atmospheric CO_2 emissions could be linked to the expansion of the burning of biomass and the consumption of fossil fuels. It is predicted that atmospheric CO_2 will increase from 388 ppm to about 520 ppm in the year 2050. Methane (CH_4) has a global warming potential equal to 72 times that of CO2 (Mostafa et al. 2021a, b). GHGs have an adverse effect on crop production. During the period from 1998 to 2011, rice and corn production decreased by 40%, and CO_2, N_2O, and CH4 emissions increased by 5% (Kumar et al. 2018).

Temperature rise is heavily influenced by climate change. For example, Egypt's temperature is expected to rise by 1.4 °C in 2050 and 2.5 °C in 2100 (Agrawala et al. 2004). The temperature increase during the growing season of crops will increase crop water demand. Crop water demand is expected to increase by 10–30% in 2100, compared to the current condition (Hopmans and Maurer 2008). There is a non-linear relationship between yield and temperature, and heat waves have a strong negative impact on crop yields. Yields around the turn of the millennium are predicted to decrease by 31–43% under the scenario of slow-warming and by 67–79% under the scenario of fast-warming (Fisher et al. 2008).

As the temperature rises, the rate of evaporation from the earth and sea will rise as well. It is predicted that precipitation will increase in high latitudes and tropical regions but decrease in semi-arid and arid mid-latitudes (Walsh et al. 2014). It is expected that precipitation will increase by 2.1% and 3.7% in years 2050 and 2100, respectively (Agrawala et al. 2004). Since rainfall has a great influence on fish production and crop yield, yield is not always proportional to rainfall, because exceeding the optimal value will reduce yield (Milosevic et al. 2015). The expected increase in temperature may force fish to try to migrate to colder areas; or move to deeper places or upstream (Singh 2016).

If the rate of precipitation becomes lower than the rate of evaporation, the water level and volume in rivers and lakes would drop, and the soil would become drier. These changes will result in the emergence of pests such as blue-green algae, which lower the level of dissolved oxygen, leading to a negative impact on fish production (Singh 2016). Further effects of pests include: a 10–12% maize yield loss due to the African maize stalk borer pest, a 19–30% loss in stored grain due to the large grain borer pest, and a 15% loss in many crops due to the cotton bollworm pest (Boa and Chernoh 2015).

There is a strong correlation between changes in temperature and changes in surface ozone (O_3). It is expected that the change in yearly average O_3 may reach 20% due to climate change when compared to recent records (Doherty et al. 2013). There is strong evidence that O_3 pollution is strongly affecting crop productivity. Due to O_3 pollution, crop yield would decrease by 4.3% for maize, 10.6% for wheat, and 12.1% for soybeans in the year 2030 (Lienhard et al. 2018).

As a direct consequence of climate change, the sea level is expected to rise. This would adversely affect low farmland through flooding and salinization, which is projected to cause crop yields to decrease by 12–24% (Agrawala et al. 2004). The salinity of estuaries and coastal wetlands is predicted to increase as river flow declines and the amount of sediment and nutrients delivered to the coast decreases. Soil salinity reduced the yield of sensitive crops by 14–33%, while salt-moderate crops were affected by salinity less than salt-tolerant crops, for which the yield was reduced by 4–20% (Amer et al. 2020).

4 Methodology

The methodology followed the formal Risk Management Process discussed in the next section. First, a list of climate change risks is identified. Second, qualitative and quantitative analyses of the identified risks are performed. The qualitative risk analysis classifies the risk relative to their severity to identify the importance of each risk. The quantitative risk analysis is performed on highly important risks to quantify their overall impact on irrigation water and crop yield. Third, responses to the risks that have been identified are suggested to help policymakers lessen the adverse effects of these risks.

5 Risk Management

Risk management is an important aspect of management to achieve noble project outcomes and is one of the knowledge areas identified in the Project Management Body of Knowledge (PMI 2008). Risk management is a process well-known for managing manufacturing processes and construction projects. It is a systematic process to plan for actions needed to deal with uncertain events, either threats or opportunities, that may happen to a specific system. Uncertain events are future events that may or may not occur but, if they do, have a considerable impact, either positive or negative, on one or more objectives of the system. These uncertain events or conditions are referred to as Risks (PMI 2008). Risk is defined as the combination of the likelihood of an event occurring and the magnitude of its consequences (ISO 2018). The goal of risk management is to increase the likelihood and impact of favourable events while decreasing the likelihood and impact of unfavourable events (PMI 2008). Risk Management Process includes the following five phases: (1) Risk Identification; (2) Qualitative Risk Analysis; (3) Quantitative Risk Analysis; (4) Risk Response; and (5) Risk Monitoring and Control.

5.1 Risk Identification Phase

Risk identification is a critical phase for specifying the risks affecting the system and documenting their characteristics. Techniques such as Brainstorming, or Delphi are usually used to extract risks from a panel of experts. The climate change risks are categorised as: a) ecological risks; b) irrigation project risks; c) environmental risks; d) social risks; e) health risks; f) safety risks; and g) economic risks.

With the help of the cause-effect diagram, the relationship between the causes and effects of climate change risks was linked. One of the main effects of climate change is food shortages, which has two sub-effects: the decrease in crop production and the increase in crop prices. Climate change causes may be direct or indirect. Direct climate change causes include a change in runoff timing; a change in precipitation type, volume, and timing; an increase in evaporation; the emergence of pests and crop diseases; and the use of unsuitable crop patterns. Indirect climate change causes include greenhouse gas emissions, which could lead to an increase in temperature and a rise in sea water, which in turn leads to an increase in soil salinity and a change in crop evapotranspiration, which in turn leads to an increase in water demand. Figure 1 shows the cause-effect diagram for climate change risks. A list of risks based on the cause-effect diagram is shown in Table 1.

5.2 Qualitative Risk Analysis Phase

After identifying and categorising all climate change risks, the second step was to qualitatively analyse these risks. During the qualitative risk analysis, the severity of risks is subjectively identified based on two factors: the likelihood of risk occurrence and its impact if it occurs. In this study, the Delphi technique has been utilised to assess the likelihood and

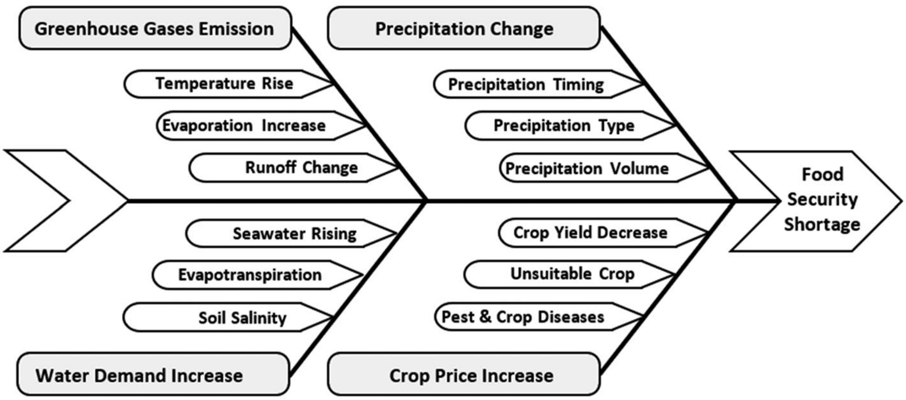

Fig. 1 Cause-Effect diagram for the climate change Risks

impact of climate change risks. This was done with the help of the opinions of 48 experts who were asked to rate the likelihood and impact of each climate change risk in an online survey.

A 5-point Likert scale has been used to determine the likelihood and impact of each risk. To assess the likelihood of climate change risks, each point of the 5-point Likert scale was associated with a numerical value; (1), (2), (3), (4), and (5) for Rare, Unlikely, Possible, Likely, and Almost Certain, respectively. The Expert Average Likelihood for all climate change is shown in Column 2-Table 2.

Similarly, to assess the impact of climate change risks, each point of the 5-point Likert scale was associated with a numerical value; (1), (2), (3), (4), and (5) for Insignificant Impact, Minor Impact, Moderate Impact, Major Impact, and Critical Impact, respectively. Column 3-Table 2 shows the Expert Average Impact for each climate change risk. Column 4-Table 2 reveals the severity for each risk, which results from multiplying the expert average likelihood by the expert average impact. Column 5-Table 2 reveals the classification of each risk relative to its severity.

The classification of climate change risks into 5 coloured zones was inspired by the concept introduced by PMI (2019), in which risks are classified into 5 coloured zones relative to their severity. Since the score of both likelihood and impact ranges from 1 to 5, the severity (the likelihood multiplies the impact) ranges between 1 and 25. The classification divided the severity scale into 5 equal zones: zone I (Blue) includes risks with a severity of 1 to 5, zone II (Green) includes risks with a severity of 6 to 10, zone III (Yellow) includes risks with a severity of 11 to 15, zone IV (Orange) includes risks with a severity of 16 to 20, and zone V (Red) includes risks with a severity of 21 to 25.

5.3 Quantitative Risk Analysis Phase

The quantitative risk analysis phase analyses risks of high importance as identified during the qualitative risk analysis phase. Quantitative risk analysis aims to quantify the simultaneous impact of high-important risks using Monte Carlo Simulation. As recommended by PMI (2019), risks of high severity should be further analysed to quantify their impact on

Table 1 List of identified climate change risks

Risk Category	Risk Code	Risk	Interpretation
Ecological risks	R_1	Greenhouse gases emission	Carbon dioxide results from burning fossil fuels, nitrous acid, fluorinated gases, sulphur hexafluoride, and nitrogen trifluoride
	R_2	Precipitation volume change	Changes in intensity, quantity, and trimming of precipitation
	R_3	Precipitation type	Precipitation as liquid (drizzle, mist, and rainfall) or frozen (snow, hail, and sleet)
	R_4	Temperature rising	Rapid increase in average temperatures throughout the country
	R_5	Evaporation increasing	Evaporation caused by raising the temperature or lowering the pressure
	R_6	Runoff change	The part of the precipitation that appears in surface streams and is affected by the amount and intensity of rainfall
	R_7	Soil salinity increasing	increase caused by salty irrigation water, irrigation method, or high-water table level
	R_8	Sediment, nutrient availability, and moisture regimes	The root system's environment controls nutrients, water availability, and crop growth
	R_9	Seawater rise risk on costal banks erosion	Coastal erosion caused by offshore dredging, river sediment reduction, and the degradation of seagrass meadows, marshes, and coastal sand dunes
Irrigation projects risks	R_{10}	Irrigation water demand increasing	Increased crop consumption because of climate or soil moisture content changes
	R_{11}	Selecting irrigation method	Selecting surface or modern irrigation methods suitable to crop and soil types
Environmental risks	R_{12}	Temperature rise risk on crop growth period decreasing	Increases in temperature, which increase the water demand of the crop and affect the period of growth
	R_{13}	Surface ozone pollution	Air pollution results from burning coal and other fuels, which produces ozone pollution as a byproduct
	R_{14}	CO_2 rise risk on increasing crop evapo-transpiration	Increased crop evapo-transpiration due to CO2 and temperature increases
	R_{15}	Temperature rise risk on crop evapo-transpiration increasing	Increased crop consumptive use caused by temperature increase
	R_{16}	Selecting crop pattern	Selecting a crop pattern that is suitable to the climate, soil type, and available water
Social risks	R_{17}	Sea water level rise	the rise in ocean levels as the consequence of global warming

Table 1 (continued)

Risk Category	Risk Code	Risk	Interpretation
Health risks	R_{18}	Emerging pests and crop diseases	The emergence of crop pests and diseases, which reduce average yields
	R_{19}	Emerging diseases	The emergence of diseases which may affect human health
Safety risks	R_{20}	River flow change	Change in river flow due to a change in precipitation and runoff
	R_{21}	Flooding increasing	Floods caused by a change in precipitation and runoff
Economic risks	R_{22}	Increasing of food price	increase in food prices due to a decrease in crop yield and overpopulation
	R_{23}	Food security	The accessibility to an adequate supply of safe and acceptable foods that are produced in a way that is both socially and environmentally responsible

Table 2 Severity and Classification of identified risks

Risk Code (1)	Expert Average Likelihood (2)	Expert Average Impact (3)	Risk Severity (4)	Risk Classification Zone (5)
R_1	2.52	3.60	9.07	III
R_2	2.77	4.32	12.00	III
R_3	1.18	2.90	3.42	II
R_4	1.73	4.44	7.68	II
R_5	1.88	4.00	7.50	II
R_6	1.02	2.40	2.45	II
R_7	2.38	3.10	7.36	III
R_8	1.60	2.30	3.68	I
R_9	1.67	2.66	4.44	II
R_{10}	2.56	4.56	11.67	III
R_{11}	2.69	4.43	11.90	III
R_{12}	1.08	2.90	3.13	II
R_{13}	1.83	4.88	8.93	II
R_{14}	1.00	2.90	2.90	I
R_{15}	1.00	1.63	1.63	I
R_{16}	1.06	2.22	2.35	IV
R_{17}	1.58	3.80	6.00	IV
R_{18}	1.00	1.66	1.66	I
R_{19}	1.77	3.59	6.35	IV
R_{20}	1.56	3.89	6.07	IV
R_{21}	1.56	4.10	6.40	IV
R_{22}	1.08	2.79	3.00	IV
R_{23}	1.94	4.65	9.02	IV

the system. Thirteen risks in zones II, III, and IV, having the highest severity, were further analysed using the Monte Carlo Simulation.

The probabilities of risk shown in Column 3-Table 3 are calculated by dividing the Expert Average Likelihood shown in Column 2-Table 2 by 5 which is the maximum possible likelihood according to the scale provided during the survey questionnaire. The impacts provided in Column 4-Table 3 are adopted from previous studies presented under the Factors Affecting Crop Yield header. The expected values in Column 5-Table 3 are calculated by multiplying the probability of the risk and its corresponding quantitative impact (Elnashar and Elyamany 2018).

5.4 Monte Carlo Simulation

The simultaneous impact of the thirteen quantitative climate change risks is performed using Monte Carlo Simulation with the help of @Risk software®. The simulation output is the crop production, while the simulation inputs are the impact of the climate change risks. The quantitative impacts of the thirteen risks were collected from the literature as follows:

Table 3 Expected Value for high-important risks

Risk Code	Zone	Probability (%)	Impact	Expected Value
R_1	III	50.4	388 – 520 ppm	196 – 262.08 ppm
R_2	III	55.4	1.5 – 3.7%	0.83 – 2.05%
R_4	II	34.6	1 °C – 2.5 °C	0.346 °C – 0.865 °C
R_5	II	37.5	20%	7.5%
R_7	III	47.5	-	-
R_{10}	III	51.2	10 – 30%	5.12 – 15.36%
R_{11}	III	53.8	-	-
R_{13}	IV	36.6	20%	7.32%
R_{17}	IV	31.6	3 – 5 mm/year	0.948 – 1.58 mm/year
R_{19}	IV	35.4	-	-
R_{20}	IV	31.2	-	-
R_{21}	IV	31.2	0.5 – 1%	0.156 – 0.312%
R_{23}	IV	38.8	-	-

- Greenhouse gasses emission risk (R_1) causes losses in crop yield by 40%.
- Temperature rising risk (R_4) causes losses in crop yield by 55%.
- Increasing of soil salinity risk (R_7) causes losses in crop yield by 18%.
- Surface ozone pollution risk (R_{13}) causes losses in crop yield by 9%.
- Emerging pests and disease (R_{19}) risk causes losses in crop yield by 15%.

The remaining 8 risks (R_2, R_5, R_{10}, R_{11}, R_{17}, R_{20}, R_{21}, R_{23}) have no direct impact on crop production. Therefore, their impact was ignored in the simulation model.

The percentage losses in crop yield were entered into the @Risk software® as the impact, where the probability of each risk is considered as a probability curve with the mean equal to the Expert Average Likelihood presented in Table 2. The percentage loss in crop yield (Y) is expressed in Eq. (1).

$$Y = 0.4^{*} * R_1 + 0.55 * R_4 + 0.18 * R_7 + 0.09 * R_{13} + 0.15 * R_{19} \quad (1)$$

where, Y = percentage losses in crop yield, $R_{1,4,7,13,19}$ = probability of the risk.

The @risk software® runs the simulation on Eq. (1) for 100 times (as a simulation for 100 years) to provide the probability distribution curve for the percentage loss in crop yield as shown in Fig. 2. In this figure, the percentage losses in crop yield at 90%, 50%, and 10% confidence levels equals 69%, 57%, and 45%, respectively. The descriptive statistics of the distribution curve indicate that the mean and standard deviation for the percentage losses in crop yield equal 0.57 and 0.09, respectively. The minimum and maximum values for percentage losses in crop yield are equal to 0.34 and 0.85, respectively. The sensitivity analysis shown in Fig. 3 indicates that the percentage loss in crop yield is very sensitive to the change in R_4 by 63.6%.

The interpretation of these results indicates that, in the long term and over the course of 100 years, crop production could be reduced to approximately half its current values. This blows the whistle on adopting several strategies to mitigate the effect of climate change and GHG released into the atmosphere during the upcoming years.

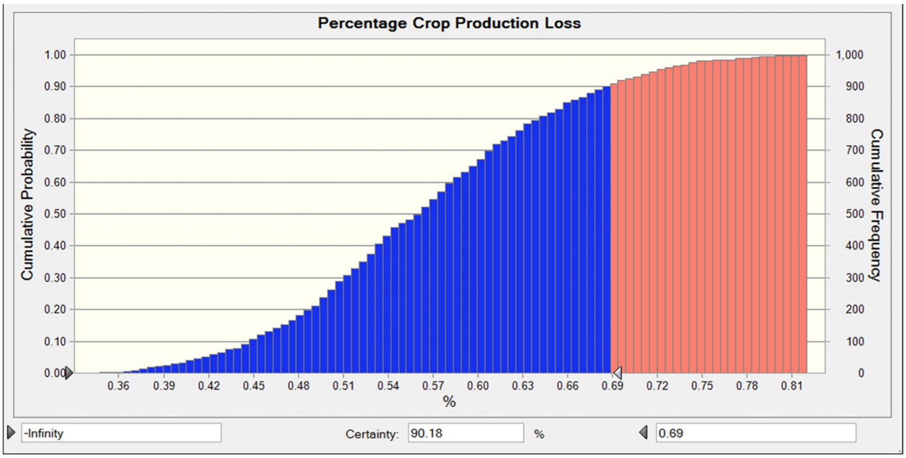

Fig. 2 Cumulative Probability of Crop Production Loss

5.5 Risk Response Phase

The process of creating choices and deciding actions to increase opportunities and reduce threats to the food security system is known as risk response strategy. The proper response to risks could be achieved through the adoption of strategies to reduce the main cause of

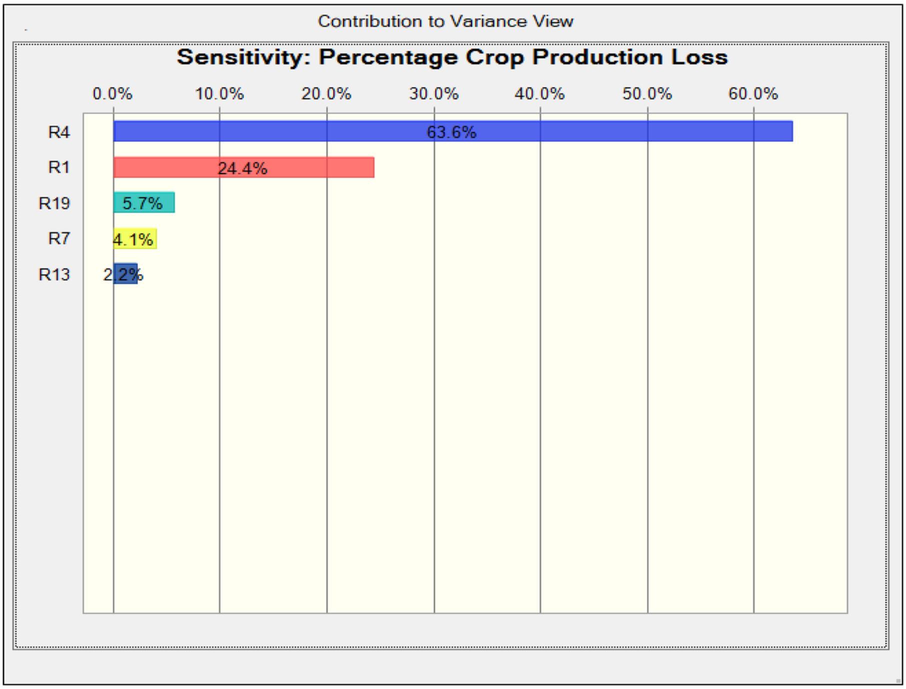

Fig. 3 Sensitivity analysis of Crop Production Loss

climate change, which is greenhouse gases, and developing contingency plans to mitigate its harmful impacts. The four main response strategies to the climate change threats are:

(a) Avoid the risk, which involves removing the cause of the risk.
(b) Transfer the risk, which entails finding a third party who is ready to take the responsibility for managing the risk.
(c) Mitigate the risk, which lowers the likelihood and/or the impact of the risk to an acceptable level.
(d) Accept the risk, which can be adopted when it is not possible or practical to respond to the risk by the three other strategies.

Table 4 shows the recommended response strategy for each of the 23 identified climate change risks. Of the four response strategies mentioned above, the appropriate response to each climate change risk is assigned in this study based solely on the recommendation presented by past research studies. The optimum way to select the best response strategy involves outweighing the cost incurred by adopting each response, which would require a detailed cost analysis of the consequences of each risk response on the irrigation system, followed by the selection of the least costly response strategy. The detailed cost

Table 4 Risk response strategies for identified risks

Risk Code	Risk	Response Strategy			
		Avoid	Transfer	Mitigate	Accept
R_1	Greenhouse gases emission			√	
R_2	Precipitation volume change			√	
R_3	Precipitation type			√	
R_4	Temperature rising	√			
R_5	Evaporation increasing			√	
R_6	Runoff change			√	
R_7	Soil salinity increasing	√			
R_8	Sediment, nutrient availability, and moisture regimes			√	
R_9	Seawater rise risk on costal banks erosion			√	
R_{10}	Irrigation water demand increasing		√		
R_{11}	Selecting irrigation method			√	
R_{12}	Temperature rise risk on crop growth period decreasing	√			
R_{13}	Surface ozone pollution			√	
R_{14}	CO_2 rise risk on crop evapo-transpiration increasing			√	
R_{15}	Temperature rise risk on crop evapo-transpiration increasing	√			
R_{16}	Selecting crop pattern		√		
R_{17}	Sea water level rise	√			
R_{18}	Emerging pests and crop diseases	√			
R_{19}	Emerging pests and diseases			√	
R_{20}	River flow change			√	
R_{21}	Flooding increasing			√	
R_{22}	Increasing of food price			√	
R_{23}	Food security	√			

comparisons among the responses to each climate change risk are outside the scope of this study, but they need to be looked at by future research work.

The following sections discuss the detailed actions to be taken by policymakers to manage these risks as recommended by past research studies.

5.6 Avoided Risks

The strategy of avoiding the risk involves removing the cause of the risk. The following risks could be avoided by removing their causes.

5.6.1 R_{15}: Temperature Rise Risk on Crop Evapo-transpiration Increasing

This risk could be avoided using technological adaptation, such as the creation of new hybrid cultivars that have higher productivity and resistance to drought and diseases during harsh climates.

5.6.2 R_4: Temperature Rising

This risk could be avoided using technological adaptation, such as developing new crop patterns adapted to limited water, high temperatures, and salinity.

5.6.3 R_7: Soil Salinity Increasing and R_{17}: Sea Water Level Rise

These two risks could be avoided by:

(a) planting salt-tolerant crops and energy crops like Jojuba, Jatropha, Miscanthus, and Poplar which are suitable alternatives in saline soil (Amer et al. 2020).
(b) improving existing drainage systems to control the water table.
(c) soil leaching by identifying the types of salts affecting the soil and choosing the best method of reclamation (Amer et al. 2020).
(d) treating wastewater for industrial and health facilities before discharging it to the rivers.

5.6.4 R_{12}: Temperature Rise Risk on Crop Growth Period Decreasing, R_{18}: Emerging Pests and Crop Diseases, and R_{23}: Food Security

These three risks could be avoided by biodiversity and agricultural adaptation, such as:

(a) Choosing crops that are adapted to changes in the soil-climate environment
(b) Identifying the responses of plant species to different climate change conditions.
(c) Changing cultural practises or timing of planting.
(d) Physical and ecological adaptation by increasing carbon storage in soils through enhanced yields.

5.7 Transferred Risks

5.7.1 R_{10}: Irrigation Water Demand Increasing

This risk could be transferred by fostering multi-sector collaboration with the public water supply, energy, and environmental sectors to share risks and gains in water supply projects.

5.7.2 R_{16}: Selecting Crop Pattern

This risk could be transferred by increasing farmers' ability to use site-specific watering strategies, decision support systems, selecting drought tolerant cultivars, or lowering inputs such as nutrients or water to reduce vegetative vigor, and other sophisticated methodologies.

5.8 Mitigated Risks

5.8.1 R_1: Greenhouse Gases Emission

This risk could be mitigated by energy adaptation as:

(a) Use of bioenergy by cultivating commercial bio-energy crops.
(b) Request a change in demand from liquid fuel oil to natural gas.

5.8.2 R_{14}: CO_2 Rise Risk on Crop Evapo-transpiration Increasing

This risk could be mitigated by physical and ecological adaptation, such as preserving forest trees that remove CO_2 from the atmosphere through photosynthesis. A higher concentration of CO_2 in the atmosphere improves plant growth and increases water efficiency (Betts et al. 2007; Gedney et al. 2006; Long et al. 2006).

5.8.3 R_9: Seawater Rise Risk on Costal Banks Erosion

This risk could be mitigated by physical and ecological adaptations such as maintaining and restoring ecosystems and re-operating reservoirs.

5.8.4 R_{19}: Emerging Pests and Diseases

This risk could be mitigated by biodiversity and agriculture adaptation, such as improving productivity in terms of quantity and quality to prevent the spread of weeds, pathogens, insects, and pests.

5.8.5 R_5: Evaporation Increasing, R_8: Sediment, Nutrient Availability, and Moisture Regimes, R_{11}: Selecting Irrigation Method

These three risks could be mitigated by technological adaptation, such as.

(a) Using modern irrigation systems to save water for agriculture.
(b) Improving irrigation efficiency to reduce water requirements (Hopmans and Maurer 2008).
(c) Improving water resources planning.
(d) constructing hydropower dams to achieve long-term irrigation demand control, water supply to urban areas, ecosystems, fisheries, and navigation.
(e) Using P.V.C. plastic pipes for canal lines.
(f) Integrate surface water and groundwater management to reduce vulnerability to climate fluctuations (Betts et al. 2007).
(g) Shift water to high value uses (MacAlister and Subramanyam 2018).
(h) Develop plans to improve sanitation and water quality to minimize industrial and sewage waste pollution and recycling.
(i) Investigate wind and solar desalination plants to compensate for anticipated water shortages.
(j) Carry out public awareness campaigns on water scarcity.

5.8.6 R_2: Precipitation Volume Change, R_3: Precipitation Type, R_6: Runoff Change, R_{21}: Flooding Increasing and R_{20}: River Flow Change

These five risks could be mitigated by technological adaptation, such as.

(a) Redesign of storm drainage, flood control, and levee work, including sizing of flood control reservoirs.
(b) Construction of hydropower dams to achieve long-term flood control and hydropower generation solutions.
(c) Using rainwater harvesting by collection and storage of rain.

5.8.7 R_{22}: Increasing of Food Price

This risk could be mitigated by biodiversity and agriculture adaptation by choosing crops that can provide lower income levels but can ensure long-term economic viability.

5.8.8 R_{13}: Surface Ozone Pollution

This risk could be mitigated by:

(a) Using refrigeration and air-conditioning products that do not contain ozone-depleting substances.
(b) Using vapour recovery nozzles at the gasoline pumps,
(c) Reformulating the cleaner burning gasoline to reduce the pollutants.
(d) Putting strict limitations on nitrogen oxide emissions from industrial combustion sources and power plants.
(e) Putting strict limitations on the amount of solvent usage in factories.

6 Risk Monitoring & Control Phase

Risk monitoring and control aims to track the identified risks, monitor the remaining risks, find new risks, ensure that the risk plan has been correctly executed, and assess its success in minimising risks. Also, in this phase, the risk strategy is implemented and monitored, and the risk plan is adjusted for new risks. Risk monitoring and control is a continuous process throughout the life cycle of the system.

7 Conclusion

As global warming escalates, it is expected that this warming could bring a negative change to irrigation water, which might affect the sufficiency of crop production. As the temperature increases, the evaporation rate of land and oceans also increases. Precipitation will increase in tropical and high latitude regions, but precipitation will decrease in arid and semi-arid mid-latitude regions, as well as within continents. Based on this analogy, many countries, especially those in the semi-arid to arid regions, would suffer more than the rest of the world. Although this issue has been heavily researched, previous research efforts overlooked the quantification of the predicted negative impact of climate change on crop yield in case all the risks occur simultaneously.

This paper proposed a systematic approach to manage the risks of climate change. The proposed approach identified the climate change risks, quantified their impact on crop yield in case all the variables occurred simultaneously, and finally recommended response strategies to manage these risks once they occur. The implementation of the risk management process passes through five phases: risk identification, qualitative risk analysis, quantitative risk analysis, risk response, and monitoring and control.

A Cause-Effect diagram was used during the identification phase to extract risks from experts. The result of the risk identification phase is a list of 23 climate change risks affecting crop production. Once all risks were identified and categorized, the second step was to qualitatively analyse these risks. The Delphi technique was used to assess the likelihood and impact of climate change risk. These risks were classified relative to their severity, the likelihood multiplies the impact, into 5 coloured zones to identify the relative importance of each risk. Next, quantitative risk analysis was utilised to numerically estimate the probability of meeting the objective, which is crop production losses. The quantitative risk analysis is based on the simultaneous assessment of the impact of all the risks identified through the Monte Carlo simulation. Thirteen risks in zones II and III were analysed during the quantitative risk analysis. The results of the quantitative risk analysis showed that the crop production losses due to climate change are estimated as 69%, 57%, and 45% at 90%, 50%, and 10% confidence levels, respectively.

The last phase of the risk management process is the risk response. The recommended response strategies to all the identified risks were stated and discussed at the end of the process. It is the duty of the decision-maker to enforce the implementation of these strategies to mitigate the harmful effect of climate change on crop production. It is worth noting that the proposed risk management should become a non-stop process to reap its full benefits.

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Declarations

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