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Climate change risks related to agriculture and food production: An evaluation of current risk assessments

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Preface

Climate change has consequences on humans and nature worldwide. In recent years, human activities have increased CO2 concentrations. Increasing emissions of greenhouse gases affects changes in temperature, rainfall and other climatic parameters, which is predicted to have negative consequences on the agricultural system. In other words, climate is one of the most fundamental natural factors and its change is one of the most important challenges of this century. Due to the socio-economic importance of agriculture for food security, it seems necessary to assess risks of climate change on the agricultural system and provide adaptation strategies. In this thesis, I will try to compare current practice of climate risk assessment in different study samples with contemporary risk science based on inter alia the (A,C,U) scheme. Finally, I thoroughly evaluate a case study and determine the effect of changing climate parameters, i.e. temperature and rainfall, on crop yields and the amount of risk created.

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Chapter 1: Introduction

1-1 Background

In accordance with the latest Intergovernmental Panel on Climate Change report (IPCC, 2021), climate change is bringing multiple different changes in different regions e.g:

- Climate change is intensifying the water cycle. This brings more intense rainfall and associated flooding, as well as more intense drought in many regions.
- Coastal areas will see continued sea level rise throughout the 21st century.
- Further warming will amplify permafrost thawing, and the loss of seasonal snow cover, melting of glaciers and ice sheets, and loss of summer Arctic sea ice.
- Changes to the ocean, including warming, more frequent marine heatwaves, ocean acidification, and reduced oxygen levels.
- Altering the Earth's radiative balance and air pollutants with adverse effects on human health and ecosystems

What are the effects of climate change on food production? Food production could be disrupted as drought conditions, extreme temperatures, or floods affect land and crops.

About 60 percent of global grain production today occurs in just five regional breadbaskets, and four grains make up almost half of the calories in the average global diet. Food production centers around the world have been experiencing climate change from the Americas to Europe, Asia to Australia (McKinsey Global Institute, 2020).

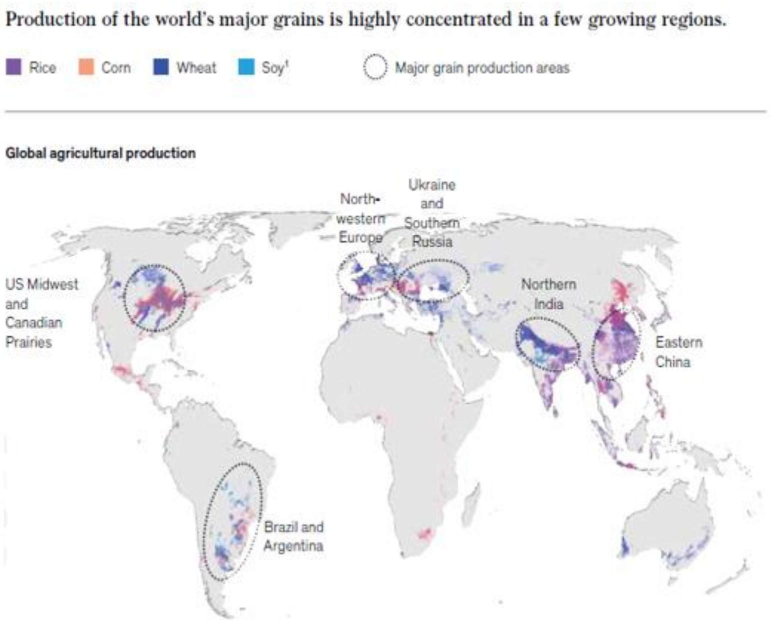

Figure 1- 1: Global agricultural production

According to IPCC, Earth has warmed by roughly 1.1 degrees Celsius since 1850-1900 and finds that averaged over the next 20 years, global temperature is expected to reach or exceed 1.5°C of warming (IPCC, 2021).

Increasing temperature and changing climate affects production and distribution of agricultural products and the associated revenues and livelihoods. By 2030, heat stress can cause significant reductions in rice production quantity in south and southeast Asia. Incidents of warmer night temperatures have a greater negative effect on rice yield. +1°C above critical temperature (> 24°C) may lead to 10 per cent reduction in both grain yield. Rising global temperature will affect wheat production in all producing countries as wheat has a relatively low optimum temperature. Water stress, triggered by increasing temperatures, reduction in number of rainy days and increasing length of dry spells will likely impact rice and wheat production in Asia, the United States and Australia. Cost of livestock production, which is heavily dependent on water, will likely increase due to higher water prices. Higher summer temperatures can lead to increase in livestock mortality, especially during transportation, and yield reductions if cooling measures are not implemented. Water-stress is a major challenge for vegetable yield as vegetables consist of 90 per cent water. On the other hand, high precipitation and flooding can result in submergence and soil erosion that destroys vegetable plots, resulting in yield reduction. Profitability of livestock business will decline at most sites due to increases in water price, energy price, carbon price and feed price (Teng, Caballero-Anthony, Tian, & Lassa, 2015).

However, under globalized and interconnected food production, no country will be free from future climate impacts.

At the present several studies for risk assessment of agriculture and food production due to climate change have been done, mostly depends on the magnitude, likelihood (frequency), and as well as the vulnerability.

The International Strategy for Disaster Reduction (ISDR) of the United Nations defined risk associated with natural disasters as the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Conventionally risk is expressed by the notation Risk = Hazards x Vulnerability.

According to the fifth report of the IPCC (IPCC, 2014), risk of climate change contains two factors, namely the degree of loss or adverse impacts and its probability of occurrence. Based on the definition of the IPCC, the risk of climate change can be expressed by Risk = Hazard x Probability which includes the degree of agricultural loss from climate change (hazard) and its probability of occurrence. Since estimation of the probability of occurrence is difficult, CCEAF concept (climate change effect accumulated frequency) has been developed to calculate the probability of occurrence (Dong et al, 2016).

Building the assessment model based on the kinds of climatic factors causing agricultural production risks and mathematical statistics method are some of the quantitative methods for risk assessment of agriculture and food production due to climate change.

Risk science has raised concerns about current practices on how to assess and describe risk based on perspectives of the type ‘Risk = Hazards x Vulnerability’ (JONES & BOER, 2004). Suggestions for improved approaches and methods have been presented. This thesis will look closer at this challenge.

1-2 Purpose

The purpose of the thesis is to improve the knowledge about how climate change risk assessments are conducted in relation to agriculture and food production, by comparing current practice with contemporary risk science.

1-3 Approach /methodology

The study is built on contemporary risk science such as (Aven & Thekdi, Risk science : an introduction, 2022) etc. The analysis is mainly a conceptual analysis. (Aven , 2015)

The comparisons with risk science will be based on inter alia the (A,C,U) scheme, where A is e.g. a temperature rise, and C the consequences given the occurrence of A e.g. increase in food prices due to rising production cost, shifting food production centers, or quality life of human being, and associated uncertainties U.

1-4 Content

This thesis has been compiled in the form of four chapters. In the first chapter, the background, goals and methods were examined. In the second chapter, the definition of risk are discussed and examples of risk assessment are presented. At the end of this chapter, each of the presented case studies will be examined in terms of the Risk description (A,C,U). In the third chapter, by examining a case study in Iran, problem solving steps are presented in order to assess the risk based on the impact of temperature and rainfall changes on agricultural production in the region. At the end, and in the fourth chapter, the conclusion of the research is presented.

Chapter 2: Descriptions of example cases

2-1 Climate changes

Climate change means any specific change in the patterns of the average climate, which occurs over a long period of time in a specific region or for the entire global climate. Climate change reflects abnormal changes in the climate within the Earth's atmosphere and its consequences in different parts of the globe. Investigating the effects of climate change in order to assess the vulnerability of different sectors caused by this phenomenon and determine appropriate adaptation measures is of particular importance in climate change studies in catchments. In this regard, modeling as one of the tools to simulate and examine the perspective of the effects of climate change, which has been considered in various studies. In this regard, the use of comprehensive catchment simulation models due to their ability to simulate the interaction of climatic and hydrological components is of particular interest. In order to compare the SWAT model with other models at the Farmanbar et al (2017) conducted a study. After comparing 11 hydrological models, they introduced the SWAT model as one of the most useful models for long-term simulation of agricultural basins. A study in a basin in eastern Pennsylvania showed that the SWAT model is more accurate in estimating seasonal flow and that this model is more suitable for applying different scenarios (Srinivasan et al., 2005). In order to identify nutrient critical areas in Zaribar Lake, Imani (2017) used the SWAT model to simulate the catchment area and after identifying these areas, examined the best management measures to reduce the pollution load in the basin using this model.

2-1-1 Farming and climate changes

Climate change as an environmental issue affects all aspects of human life (Varela Ortega et al., 2013). The process of climate change, especially changes in temperature and precipitation, is very important because of its far-reaching environmental, economic and social effects. The effects of climate change and climate change directly affect natural factors and directly and indirectly affect human and social factors. Climate indicators that can be considered in the context of climate change are: temperature, precipitation, humidity, and wind direction and intensity (Dowsett et al., 2007).

The dangerous phenomenon of climate change is caused by rising greenhouse gases and changes that occur in atmospheric processes, resulting in global warming (Easterling et al., 2004: 11). Among greenhouse gases, atmospheric carbon dioxide emissions rose to 289 ppm from 379 ppm in 2005 before industrialization, and will continue to exceed 600 ppm by the end of the 21st century. (Intergovernmental Panel on Climate Change (IPCC), 2013: 118). Climate change is associated with the threat of agriculture. Among the threats of climate change in the agricultural sector, increasing soil erosion potential, reducing soil quality, reducing agricultural production and the negative impact on food security and global sustainability, which has made this phenomenon one of the most acute challenges in the 21st century. Will face it (Lal et al., 2011: 280; Zobeidi et al., 2016: 521; Yazdanpanah et al., 2013 a, b). Interestingly, agriculture plays a dual role in climate change. First, agriculture is a huge source of greenhouse gas emissions, and second, agriculture creates significant opportunities to reduce climate change, for example through carbon sequestration. Estimates show that the share of agriculture in greenhouse gas emissions is approximately 10 to 14% of total emissions. Agriculture is the largest source of CO2 emissions, and also produces 52% and 84% of the total emissions of methane and nitrous oxide, respectively (De Pinto et al., 2018: 49).

Therefore, controlling and reducing greenhouse gas emissions is a fundamental, necessary and one of the most important mechanisms to prevent the adverse effects of climate change (Anita et al., 2010: 33). Reduction refers to measures that reduce greenhouse gas emissions and increase so-called carbon sequestration to limit long-term climate change (Sánchez et al., 2016: 4). Since most scientists consider the phenomenon of global warming to be characterized by human activities, they want people to participate in measures to reduce the emission of heat trapping gases and thus reduce the negative effects of global warming. People's response to climate change may be largely determined by their perceptions of the problem itself (rather than their attitudes toward specific behaviors) (Hu et al., 2016: 3). As Spence et al.(2011) said, one of the reasons people are insensitive or indifferent to climate change is the perception that climate change has nothing to do with regional scales or individuals. Thus, it seems that changing people's perceptions of climate change and increasing their participation is essential for a successful transition to a low-carbon economy (Capstick et al., 2015: 41; Wibeck , 2014: 388).

Climate change can have several effects on agriculture, mainly through changes in average rainfall and temperature, as well as by causing severe events such as floods and prolonged droughts (Maia et al., 2018). Agriculture as a major sustainable food source is highly dependent on climate events and changes (Vij et al, 2021). In recent decades, climate change has been one of the main factors in changing agricultural production in important agricultural areas (Reidsma et al., 2009). Studies have shown that less developed areas, especially farmers in these areas, can be severely affected by climate change. Because they do not have the necessary social and economic capital for adaptive strategies such as access to modern irrigation methods and cultivation of drought-resistant crops (Malhi et al, 2021). Climate change has reduced crop production and reduced farmers' incomes by reducing access to water (Gohar & Kashman, 2016). These adverse effects of climate change on agricultural production can lead to severe poverty and widespread food insecurity in the world (Connoly-Boutin & Smit, 2016).

In the agricultural sector, although small changes in agricultural activities can greatly reduce greenhouse gas emissions, the implementation of such activities at the local level is usually influenced by various factors (Sánchez et al., 2016). Hence, in today's developed world and in past scientific research and political debates, the reduction of climate change (for example, the reduction of greenhouse gas emissions has received much attention in public debate and academic research (Sejian et al., 2015).

In particular, significant efforts have been made over the past 20 years to change people's perceptions of climate change. However, most of this research is in Europe and North America, and a small part of it is about the general understanding of climate change in developing countries (Vignola et al., 2013: 305). On the other hand, the issue of people's willingness to participate in measures to reduce climate change has not been considered as much as the level of belief in global warming (Broomell et al., 2015). However, studies such as Broomell et al. (2015,) Xie et al., (2019), Sinatra et al., (2017), Ambusaidi et al., (2012), Boyes et al., (2019), Spence et al., (2011) and Hu and Chen (2015) are found worldwide in this field.

Understanding the views of agricultural stakeholders on the existence of climate change and its causes is at the heart of the development of interventions to support mitigation and adaptation to climate change. Agricultural stakeholders can be product producers, agricultural consultants, climatologists, extension educators, etc. (Prokopy et al., 2015).

In addition, the role of extension information in climate change and its effects on agriculture is very important, and extension systems can help farmers cope with climate change by providing information related to the causes and effects of climate change and through this, the agricultural extension sector plays an important role in sensitizing and educating farmers on how to reduce climate change (Onyeme et al, 2013).

2-2 Methods of expressing risks

There are several approaches to describing and measuring risks. According to ISO 31000, risk arises from the effect of uncertainty on objective and an effect is a positive or negative deviation from what is expected. Objective is what must happen and uncertainty is what might happen.

The SRA glossary provides several similar definitions of the risk concept. One definition which accepted by many of Norwegian entities is "Risk is the consequences of the activity and associated uncertainties". R = (A, C, U), where C is the future consequences and U is the uncertainties related to these consequences. The consequences are seen in relation to a reference value, for example the normal state, some plans or objectives (Aven, 2014).

In line with risk concept, we describe Risk (R)= (C', Q, K). C' is some specified consequences considered in future, for example the number of fatalities, costs, or the occurrence of particular events. Q is an uncertainty measure, for example probability, and K is a description of the background knowledge that supports C' and Q. The knowledge K often formulated as assumptions, information, theories, models, and argumentation. An assessment of the strength of this knowledge (SoK) can be considered as a part of Q, for example in probabilities (Bjørnsen & Aven, 2019).

When we apply probability as a measure for uncertainty in risk context, we shall explain what the probability means because interpretation could strongly affect the decision making process. Many interpretations of a probability exist, but only a few are meaningful in practice. There are two kind of probabilities (interpretation) exist in broad categories:

a. Objective probabilities (including classical probabilities, frequentist probabilities)
b. Subjective probability (including the Bayesian framework)

Objective probabilities (interpretation) are constructed based on repeatable experiments and subjective probability (interpretation) is judgmental, knowledge based probability. Professor Dennis Lindley compares subjective probabilities to an uncertainty standard typically an urn: if a person assigns a probability of 0.1 for an event A, he or she compares his/her uncertainty (degree of belief) of A occurring with drawing a specific ball from an urn containing 10 balls (D. V. Lindley, 2006).

In general, we show these three elements C, Q, and K, respectively, leading to the description or characterization of risk (C, Q, K). When events are focused, we are directed to (A ', C', Q, K). Table 2-1 illustrates it (Aven, T., & Thekdi, 2022*).*

Table 2- 1: General elements of a full risk description or characterization (A',C',Q,K) for a risk (A,C,U) related to an activity

A'	Specified events
C'	Specified consequences
(C',Q)	A description of the risk (C,U): The uncertainties U expressed by Q: Probability (imprecise probability) and Strength of knowledge (SoK) judgments
K	The knowledge that Q (and A' and C') are based on

2-3 Example cases analysis

Based on previous studies, personal or direct experience is predicted to be one of the factors that influence the tendency to perform reducing behaviors. In fact, personal experiences affect the perception of climate change in the region (Capstick et al., 2015). Personal experiences with local climate and extreme climate events may turn climate change from an abstract concept to a familiar, real, and immediate one. It seems that those who have personal experiences of global warming are more likely than those without personal experience to participate in issues related to shrinkage (Akerlof et al., 2013). In this regard, the study of Broomell et al. (2015: 70) has shown that having personal experience with climate change affects people's general intentions to reduce climate change and also their intentions to perform a specific behavior to reduce climate change.

Also, the study of Spence et al. (2011) shows that people who experienced floods were more inclined to save energy to reduce climate change. Demonstrating the relationship between climate change in the region and climate change seems to be an important strategy to increase concern and action to reduce climate change. In addition, having experience is one of the important factors influencing the perception of risk (Spence et al., 2011). Perception of risk refers to people's beliefs about adverse consequences for important matters (Hyland et al, 2016). In general, risk perception means assessing the environmental, health, and economic consequences of climate change at the local, regional, and universal (Clements et al., 2021).

Research shows that one of the factors that makes people perceive climate threats as a distant danger is that climate change is difficult to understand directly (Brulle, 2020). A study by Bradley et al., (2020) shows that people who had personal experience of the effects of global warming had a higher level of risk perception. In addition, experience also affects people's self-efficacy. Self-efficacy perceived by Bandura (1994) is defined as "judging an individual's ability to produce a certain level of performance. Self-efficacy beliefs determine how people feel and think, as well as motivate them, and leads to behavior in them. This concept has been cited and used in theories of behavioral intention. Also, Bandura's conceptual self-efficacy with behavioral control perceived in the theory of planned behavior is related.

According to the theory of planned behavior, beliefs about the effectiveness or effectiveness of a behavior in mitigating climate change affect the intention to do that behavior. In other words, if a person believes that a behavior is effective in reducing climate change, his belief will indirectly increase his desire to do that behavior (Brosch et al, 2021). Also based on a study by Smith and Mayer (2019), the "effectiveness of responses" in general (called collaboration self-efficacy) or people's belief that their efforts to reduce global warming are not ineffective will make a difference. Is a strong predictor of behavioral intentions. Brommel et al. (2015) in their study concluded that effectiveness predicts the intentions of individuals to reduce climate change. Research in various fields shows that experience is one of the factors that affect attitudes. According to Fownes et al (2019), experiences such as losing a job, being a victim of a crime, or changing one's financial status are associated with one's invisible characteristics and determine one's attitude. Attitude is defined as value judgment (Crano and Prislin, 2006) or as a constant positive or negative feeling about a person, thing, or issue. Mo et al. (2017) in a study entitled "The Impact of Climate Change on North China's Agricultural Water Resources" found the effects of climate change on China's agricultural water resources worrying. Citing the World Geographic Group's forecast, they acknowledged that by 2050, as global warming intensifies and water demand for crops increases, water resources will shrink by about 4 to 24 percent and water demand will increase.

Malek et al. (2018) also studied the effect of climate change on reducing farmers' access to water in Washington and predicted changes in the two periods of 2030-2060 and 2060-2090, taking into account the period 1980-2010. The results of this study showed that in the watershed, a 9% increase in water evaporation losses can be compensated by reducing non-evaporative water losses. Therefore, general changes can be reduced in the future. However, evaporation losses will continue to exist and will have a negative impact on groundwater. In the end, the results of this study show that the impact of climate change on water resources and the damage to this sector depends on the type of irrigation and climatic conditions. Zhuang et al. (2018) have studied and analyzed the effects of climate change on China's water resources. The results of climate forecasts of this study show that there is a trend of increasing temperature and decreasing rainfall, and as a result, water shortages formed from 2016 and 2017 will continue and water inflows will decrease.

Pholkern et al. (2018) in their study of the potential impact of climate change on groundwater resources in northeastern Thailand showed that over the next 30 years (2045) the average annual temperature in the two scenarios under study is 1.3 degrees and 2.2 degrees- C will increase while in these two scenarios, precipitation is expected to increase by 20.85% in the first scenario and 18.35% in the second scenario. Therefore, under the first scenario, the groundwater charge decreases and in the second scenario, it increases. The results of this study also showed that climate change will increase water salinity in deep water by 8.08% and semi-deep water by 56.92%. Kisakye and Van der Bruggen (2018) have examined the effect of climate change on water resources and water security in Ogandar. The results of this study show that water supply and water security will be drastically reduced due to climate change, and this will be to the extent that water security will be reduced by more than 50% in the 2070s.

Iyalomhe et al. (2015) using regional risk assessment method in spatial and comprehensive analysis of the effects of climate change on groundwater resources and related systems (wells, rivers, agricultural areas, valves, etc.) in the Esino River Basin have been paid in Italy. The results also indicate the capability of the method in multilateral analysis of the effects of climate change on groundwater resources. This study shows that the decrease of groundwater level in the context of climate change has limited effects on agricultural areas, forests and natural environments, which covers only 5% of the total area under study. Also, the study of the progress of saline water shows that the progress is limited to only a few hundred meters, which has no special consequences for human activities. Studies on the application of regional risk assessment framework in the field of water resources are limited to the application of this framework in analyzing the status of groundwater resources and the consequences of quantitative and qualitative changes in these resources.

Feng (2014) investigated climate change using 12 atmospheric circulation models from the fifth IPCC report. According to the scenario RCP8.5 models predict temperatures of 3 to 10 degrees Celsius by the end of the 21st century. Also, an increase in precipitation is predicted for the upper latitudes of the earth.

Sharmila et al (2015), examined the effects of climate change in India. The predictions of the 20 selected models show that significant changes in summer monsoon rains in India will occur by the end of the 21st century, proving the extreme sensitivity of these rains to global warming.

Shrestha et al (2016) studied the effects of climate change on the groundwater of the Mekong Delta. In this study, two scenarios, RCP4.5 and RCP8.5, have been used to predict the future condition of groundwater resources. Groundwater recharge forecasts indicate a reduction in the short, medium and long term. As a result, groundwater levels and storage are projected to decline in the future.

Khaleghi (2015) concluded that climate change affects the economic sectors of the country (production, factors of production income and revenues of inputs, and this effect on the sectors that are related). They have more interaction with the agricultural sector, so climate change in the future could pose serious risks to the value added of the agricultural sector and reduce production incentives, which in turn can have indirect effects on the pattern of trade, development and Have food security.

Alibakhshi et al (2020) showed that there is a significant relationship between CO_2 emissions and wheat production and an increase in the production of this gas, which means an increase in temperature and global warming, reduces the production of heat-sensitive crops. Expanding CO_2 production, declining wheat production and, as a result, income and welfare, are hampered. A study of the economic effects of climate change in Austria shows that climate change can quadruple macroeconomic damage. Climate change rates will increase significantly by the middle of this century, and net costs will double or quadruple, which will weaken economic power and reduce social and economic well-being.

Dowla et al (2018) while emphasizing the negative effects of climate change on agriculture showed that these changes have a significant impact on crop yield, water needs, income and household welfare. Finally, in order to adapt farmers to these climate changes, productivity improvements, development of irrigation based on new technologies and reform of agricultural policies are proposed. The study of the consequences of climate change in the agricultural sector of northwestern Vietnam and the issue of farmers' adaptation showed that the relationship between household income and climate variables is unchangeable and inflexible, and net income due to rising temperatures and declining rainfall in 2050 and 2100, without compatibility model 178% and 21/28%, and in the compatibility model, respectively will decrease by 37.0% and 0.2%.

Tadesse et al. (2021) evaluated the impact of climate-based smart agriculture on soil fertility, crop yield and soil carbon in southern Ethiopia. This study was conducted to investigate the effects of the integration of different CSA methods on crop production, soil fertility and carbon sequestration after continuous up to 10 years. CSA practices include the use of soil and water conservation structures (SWCs) in conjunction with biological measures, hedge planting, crop residue management, grazing management, crop rotation, and perennial crop-based crop systems. Scenes with CSA interventions were compared to the usual farming (ie control) business practices. Wheat yield (Triticum sp.) was measured from 245 households. The results showed that the yield was 30-45% higher under CSA methods than the control ($p < 0.05$). The total carbon stored at 1 m soil depth in CSA landscapes was three to seven times higher than the control. CSA interventions slightly increased soil pH and showed 2.2-2.6 and 1.7-2.7 times more total nitrogen and phosphorus in the plant than the control, respectively. The normal water difference index (NDWI) time series showed higher soil moisture under CSA. The findings show a significant opportunity to integrate CSA practices to create resilience to climate change for poor farmers by improving crop yields, reducing nutrient depletion, and reducing greenhouse gas emissions through soil carbon sequestration.

Based on various models that predict environmental behavior, such as the rational action model (Ajzan et al, 2002) and the Hines model (1987), attitude predicts the tendency to perform a particular behavior. O'Connor et al. State that individuals with pro-environmental attitudes are more likely to support efforts to reduce greenhouse gas emissions. According to the theory of level of interpretation, psychological distance is related to geographical, social and temporal distance in a person's (mind). This theory establishes a relationship between perceived psychological distance and subjective interpretation of events. Whereas the general intention to perform a behavior such as "I intend to take action to stop global warming" reflects a higher level of abstraction and is more psychological to the individual; When thinking about global warming on an abstract level, people focus on the bigger picture and the main features of this phenomenon that provide an overview of the situation. But against the intentions of special measures such as (I try to use less air conditioners in summer and air heaters in winter) leads people to focus on the details of global warming, so that personal experiences Becomes more prominent (Brommel et al., 2015). Hence, personal experience is expected to influence psychological distance as well as psychological distance of individuals' desire or intention to take specific measures to reduce climate change.

In the following, according to the risk assessment relationship, i.e. *Risk = (A, C, U)*, the samples examined in this section will be examined. The results are presented in Table 2-1.

Table 2- 2: Risk assessment of case analysis

References	Objective	A	C	U
Broomell et al, (2015)	Personal experience with climate change predicts intentions to act	(a) belief in Global Warming (GW), (b) environmental worldview, (c) self-efficacy, (d) personal experience with GW, (e) belief in the free-market system, and (f) knowledge about causes of GW.	Increased negative environmental impacts	Human Behaviors in Relation to Climate Change
Spence et al, (2011)	Perceptions of climate change and willingness to save energy related to flood experience	Relationship between flooding experience and preparedness to reduce energy use	Rising food prices due to declining production	Occurrence of abnormal events such as floods
Fownes et al, (2019)	Testing the influence of recent weather on perceptions of personal experience with climate change and extreme weather	Increasing the temperature and reducing precipitation	Impact on daily life and thermal comfort	Uncertain conditions of climate change
Mo et al, (2017)	Impacts of climate change on agricultural water resources	Potential evapotranspiration (ET)	Increasing the demand for irrigation water, Reducing the available water resources for agriculture, Reducing the production of agricultural products such as wheat	Flexibility of agricultural systems against climate change
Malek et al, (2018)	Climate change reduces water availability for agriculture by decreasing non-evaporative irrigation losses	Water evaporation losses	Groundwater level reduction	Deep percolation (DP) of water

References	Objective	A	C	U
Pholkern et al. (2018)	Potential impact of climate change on groundwater resources	Increasing the average annual temperature	Increasing water salinity in groundwater, Increasing water security risks	Quantity and quality of climate scenarios
Iyalomhe et al. (2015)	Spatial and comprehensive analysis of the effects of climate change on groundwater resources and related systems	Increasing temperature, geomorphological features of the area	Decreasing groundwater level, Increasing the water salinity, Limited effects on agricultural areas, forests and natural environments	Predicting climate variables, radiative forcing and emissions scenarios and to the choice of climate, hydrological and hydrogeological models and their parameterization (inter- and intra-model variability).
Feng (2014)	Predicted climate change under future global warming and its effect on labor productivity	Increasing the temperature and rainfall	Decreased productivity due to climate change in various labor sections (eg agricultural, industrial, service).	Uncertainties in external forcings
Sharmila et al (2015)	Indian summer monsoon variability under climate change	Enhanced anthropogenic greenhouse gas emissions	Reducing the monsoon rainfall	Wind strength under future emission scenario, daily humidity
Shrestha et al (2016)	Climate change impacts on groundwater resources	Increase in average annual temperature, Changing the rainfall in dry and wet seasons	Reducing the levels and store groundwater, Reducing the production of agricultural products such as rice	Changing rainfall pattern and groundwater quality
Khaleghi (2015)	Assess impact of climate change on agriculture sector, production	Farm production function considering climate factors (temperature and precipitation)	Reduction of agricultural production, Negative impact on the income of a	Climate change and global warming

References	Objective	A	C	U
			large segment of society	
Alibakhshi et al (2020)	Effects of Climate Change on the Agricultural Market	Increasing the greenhouse gas emissions	Reducing wheat production, Reducing the income and welfare of the people	Climate change
Dowla et al (2018)	Developing wheat for improved yield and adaptation under a changing climate	Increase in temperature and decrease in rainfall	Significant impact on crop yield, water needs, income and household welfare	Soil properties, precipitation pattern, drought severity
Zytynska (2021)	Impact of climate-based smart agriculture on soil fertility, crop yield and soil carbon	Climate-Smart Agriculture	Food security, Soil fertility, crop yield and soil carbon	Biological measures, hedge planting, crop residue management, grazing management, crop rotation and crop systems

Chapter 3: Analysis, discussion

3-1 Introduction

In this chapter, according to the risk relationship, i.e. *Risk=(A,C,U)*, first the case study used is introduced and then the solving steps using the proposed approach are presented.

3-2 Case Study

The present study evaluates the risk of climate change and its impact on agriculture in a large-scale river basin located in the plain of Mashhad, Iran. This region, as shown in Figure 3-1, in northeastern Iran between 35 degrees and 59 minutes north to 37 degrees and 03 minutes north latitude and 60 degrees and 06 to 58 degrees and 22 minutes east longitude with an area of 9762 (km Square) is located. This area is surrounded by Binalood mountain range from the south, Hezar Masjed heights from the north, Jamroud river basin from the southeast and Atrak river basin from the northwest. Its climate is semi-arid to dry, with an average monthly temperature ranging from 11.6 ° C to 26.7 ° C. The average slope of the land is about 16.2% and its height varies from 856 to 3247 with an average of 1487 (meters). The average annual rainfall reported by local authorities from 1991 to 2015 is 262 mm, which varies from 178 to 381 (mm). The average annual evapotranspiration in this area is reported to be between 236 and 310 mm *(Toosi et al, 2020)*

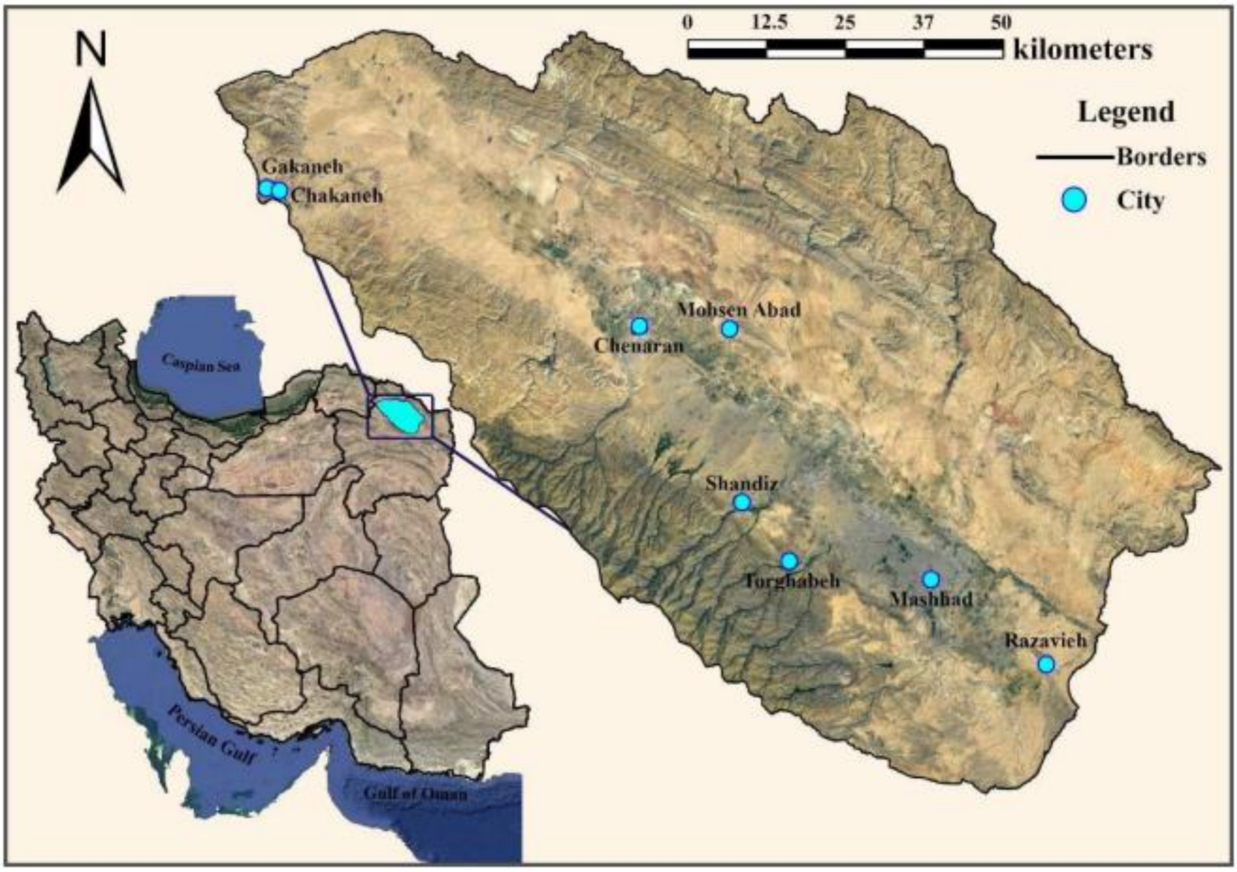

Figure 3- 1:Map Showing Mashhad Plain Basin located in Khorasan Razavi province, North-East of Iran (Toosi et al, 2020)

3-3 Conceptual framework

Based on *Aven & Thekdi (2022)* formula to risk assessment, the risk of climate change can be presented as *Risk=(A,C,U)* , where A is e.g. a temperature rise, and C the consequences given the occurrence of A e.g. increase in food prices due to rising production cost, shifting food production centers, or quality life of human being, and associated uncertainties U.

The amount of agricultural loss (risk) can be expressed directly by the fluctuation of unit performance and it can be quantitatively analyzed with the percentage of performance abnormalities of the product unit. Estimating the probability of occurrence is difficult for risk research. Climate change mainly affects agriculture through adverse trends and severe events. Severe events can be considered as severe conditions of unfavorable trends. These factors are known as risk factors. Therefore, problem solving steps are defined as follows:

Step 1:

- Determining the characteristics of climate change based on climate data such as temperature or precipitation change.

Step 2:

Determining the degree of abnormality of crop unit performance and degree of loss in agriculture based on historical data.

Step 3:

- Dividing the product unit performance anomaly into several different groups

Step 4:

- Classifying the anomaly percentage data based on different groups.

Step 5:

- Analyzing between the percentage of anomalies of different climatic factors and the performance of the product unit according to the characteristics of climate change using the regression equation

Step 6:

- Evaluation the multiple regression equation between the percentage of anomalies of multiclimatic factors and the performance of the product unit

Step 7:

- Determining the relevant risk by the equation *Risk=(A,C,U)*

Figure 3-2 provides a conceptual flowchart of the proposed problem-solving steps.

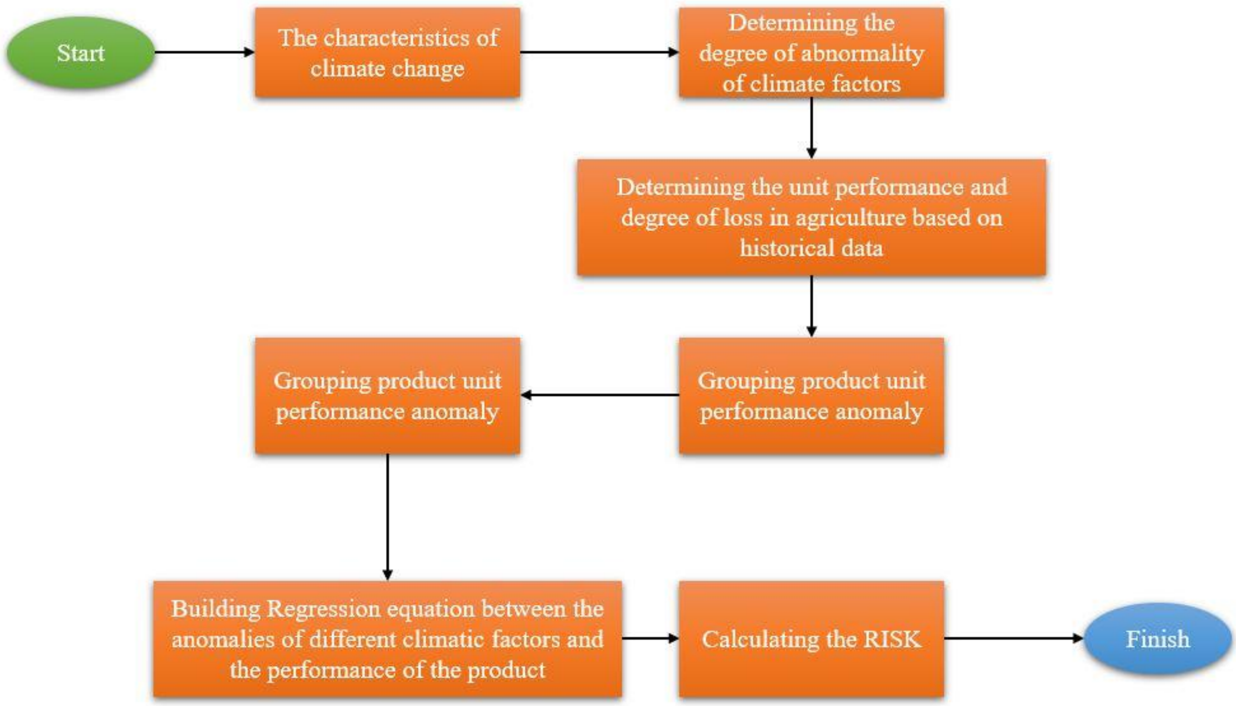

Figure 3- 2: The conceptual framework of present study

3-4 Results

In this section, we will evaluate the risk and present the results, based on the case study data and based on the steps taken to solve the problem. In the first step, the average annual temperature changes in the last 50 years and the last 20 years are analyzed. This is presented in Figures 3-3 and 3-4, respectively. As can be seen in these figures, the trend of changes in the average annual temperature in both the last 50 and 20 years has been downward. The rate of temperature decrease in the recent 50 and 20 years are by an average of 0.53 °C and 2.5 °C per decade, respectively.

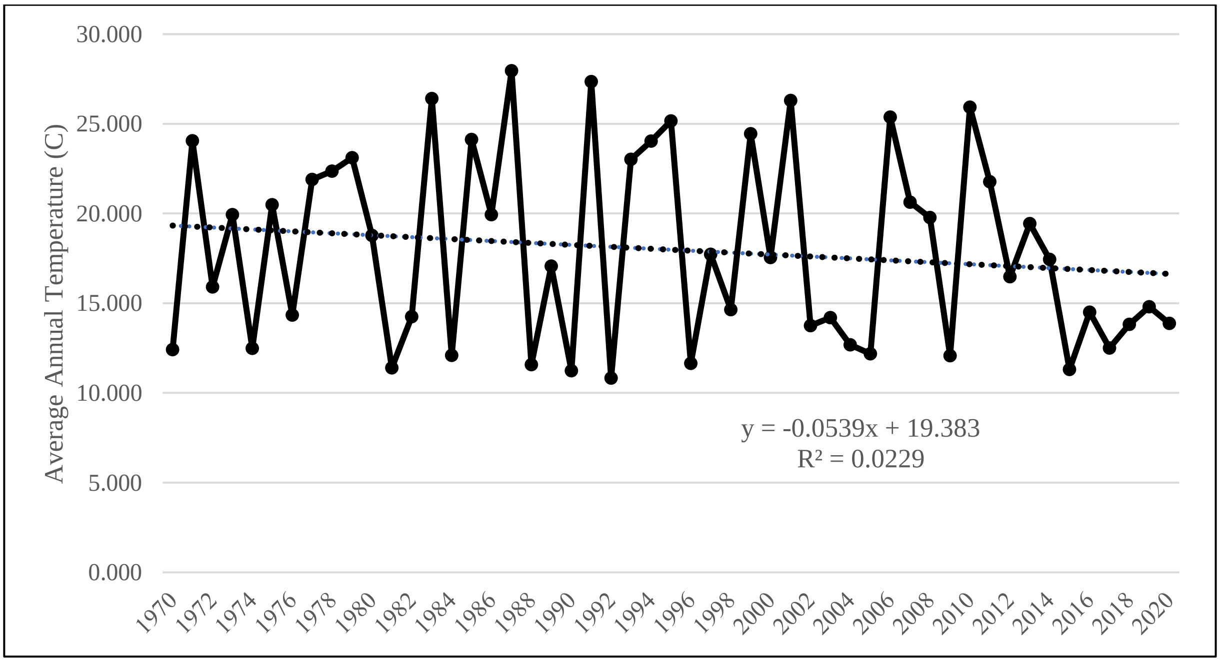

Figure 3- 3:Trends in average annual temperature from 1970-2020 (Recent 50 years)

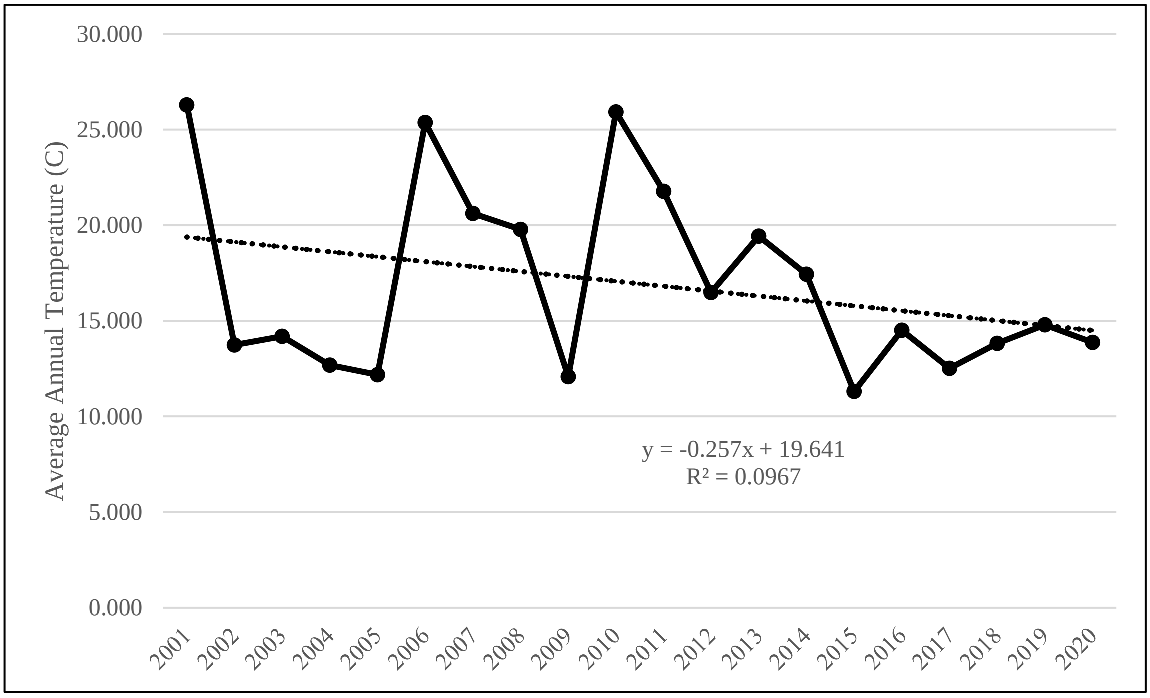

Figure 3- 4: Trends in average annual temperature from 2001-2020 (Recent 20 years)

Also in Figures 3-5 and 3-6, the average annual rainfall changes in the study area are presented for 50-year and 20-year intervals, respectively.

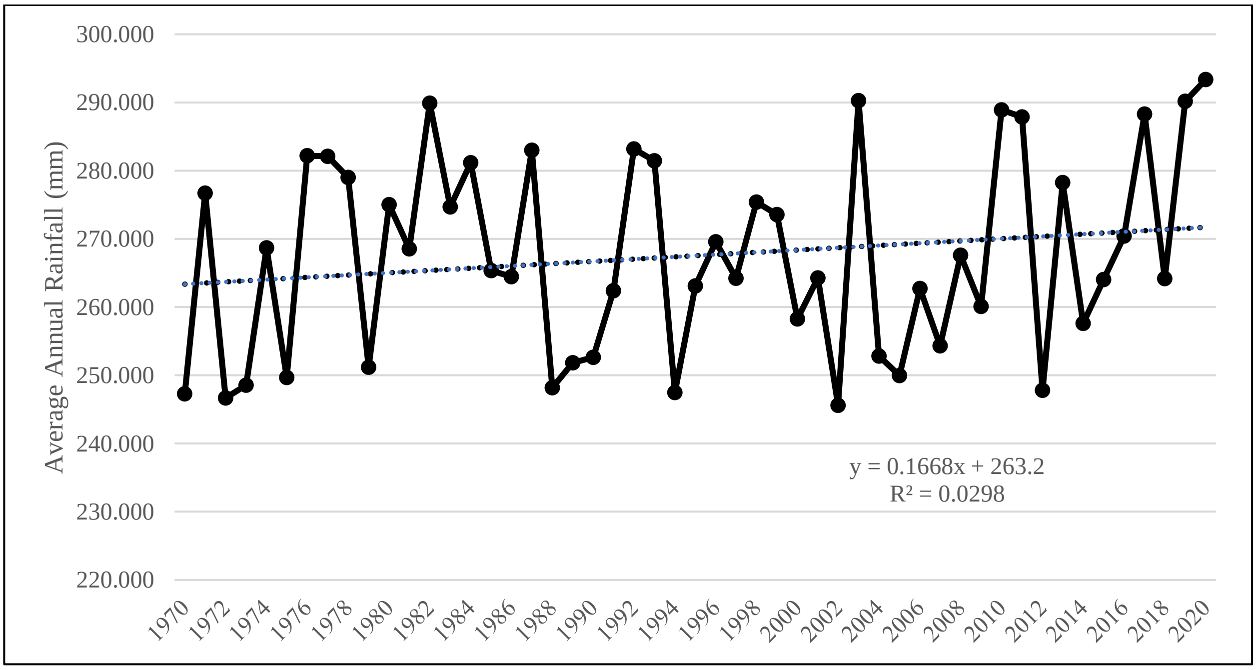

Figure 3- 5: Trends in average annual rainfall from 1970-2020 (Recent 50 years)

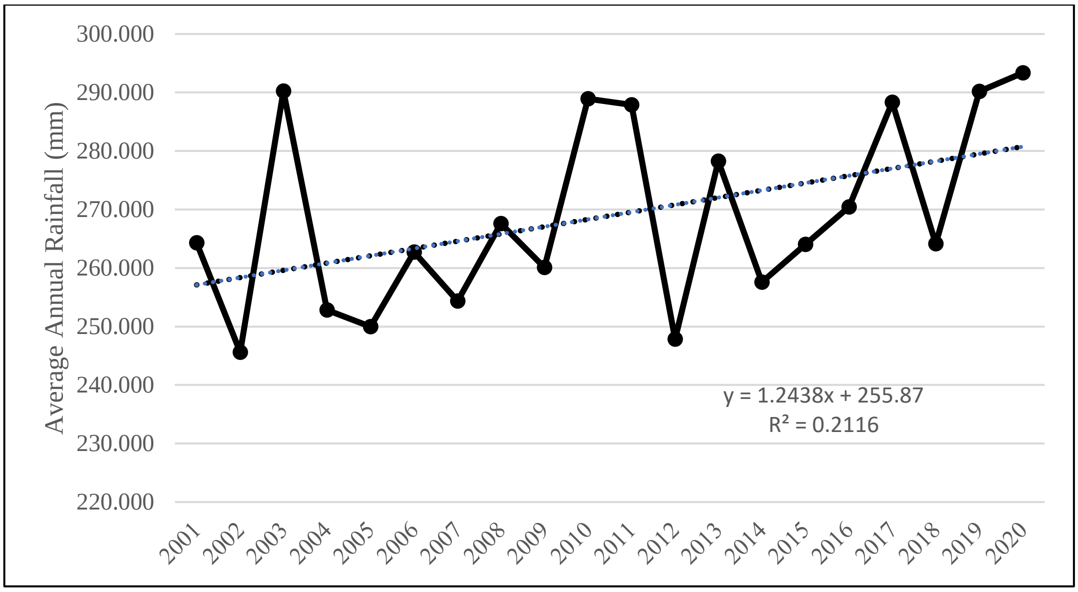

Figure 3- 6: Trends in average annual rainfall from 2001-2020 (Recent 20 years)

According to the results of evaluating the trend of annual rainfall changes, which are presented in Figures 3-5 and 3-6, it is observed that the trend of rainfall changes is upward. In particular, it can be seen that the upward trend of rainfall has increased by 1.6 mm per decade in the last 50 years and by 12.4 mm per decade in the last 20 years.

The results of Figures 3-3 to 3-6 show that the local climate of the region has experienced a gradual decrease in temperature and a relative increase in rainfall, especially in the last 20 years.

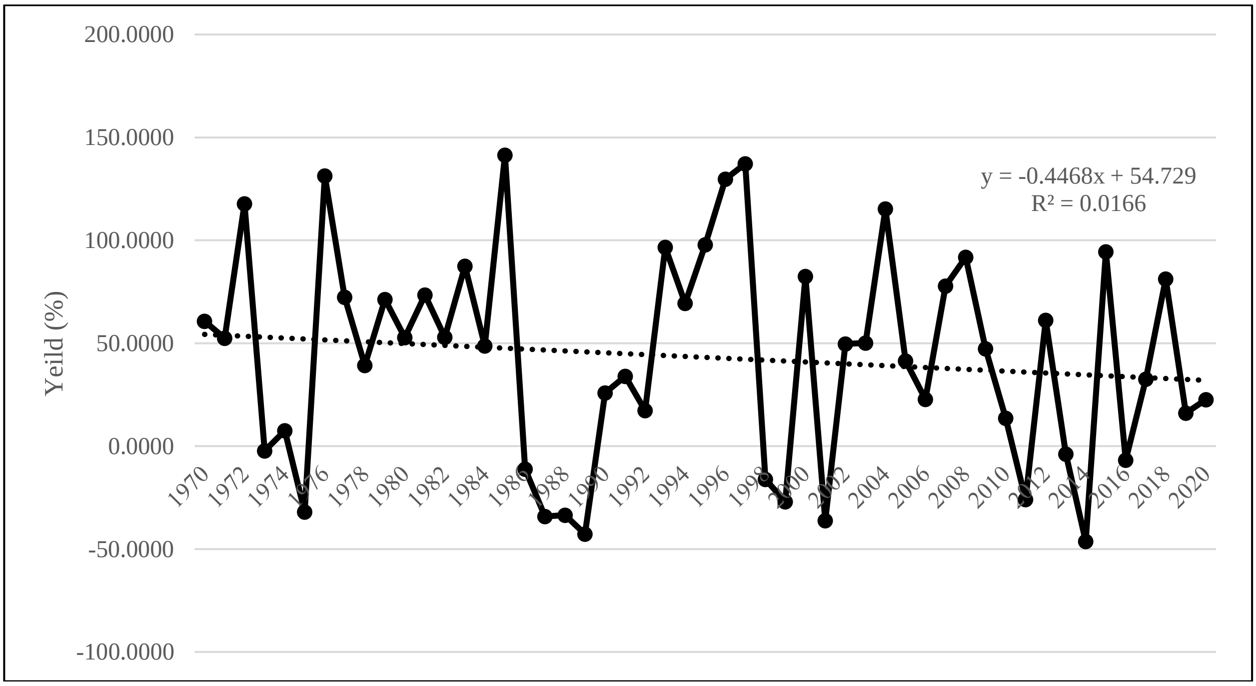

Figure 3- 7: Graph of changes in agricultural production yields; Positive values indicate an upward trend in production and negative values indicate negative performance

In the next step, we will segment the abnormal performance of agricultural production. Since the number of years studied is 50, as a result, 10 groups were used to classify them. The results show that the highest percentage of anomalies in production efficiency is equal to 141.39% and the minimum is -46.32%. As a result, a distance of about 19% is desirable for grouping. Therefore, it can be said that the selected groups are ±19%, ±38%, ±57%, ±76% and ±95%.
In the next step, by classifying the anomaly percentage data and determining the frequency of anomaly percentage, the amount of increase or decrease in crop yield per hectare was determined, which indicates the possibility of changing the increase or decrease in crop yield, which is known as U in the risk equation. Fig 3-8, shows the probabilities obtained in terms of increasing or decreasing the productivity of the product.

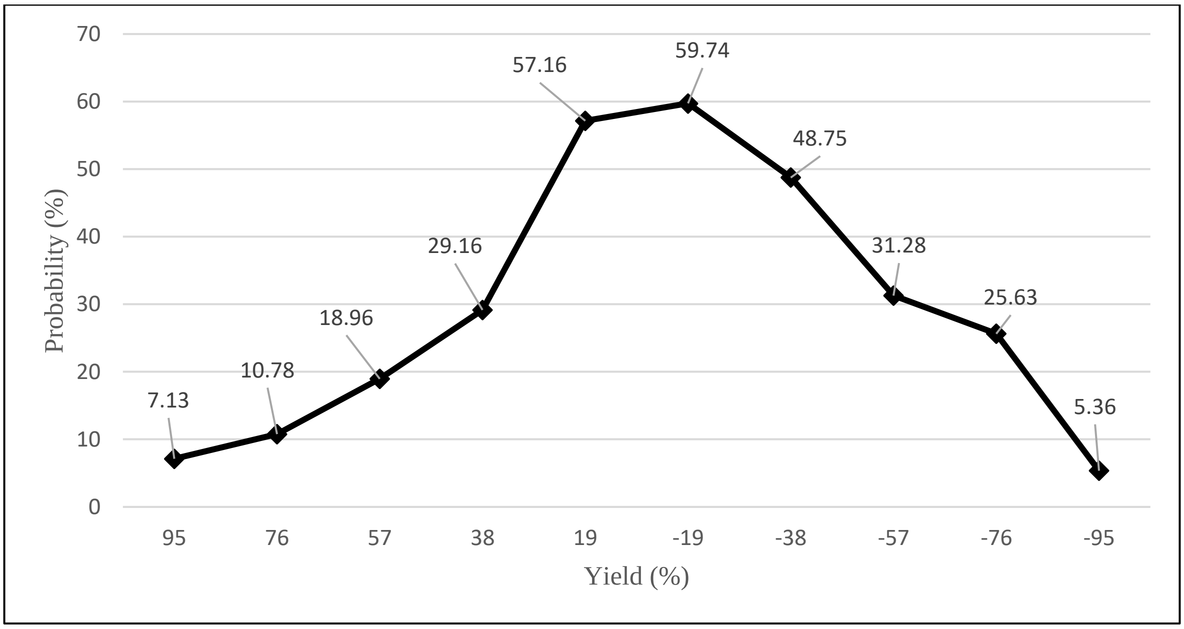

Figure 3- 8: Percentage of anomalies increase or decrease in yield and its probability

As shown in Figure 3-8, the probability of reducing yield from 19 to 95% is 59.74%, 48.75%, 31.28%, 25.63%, and 5.36%. On the other hand, the same figure shows that the probability of increasing production yield from 19 to 95 percent is equal to 57.16%, 29.16%, 18.96%, 10.78%, and 7.13%.
In the next step, the regression equation should be determined in terms of annual return changes based on changes in temperature and rainfall over the past 50 years. Hence, the following regression equations of yield are obtained for temperature and rainfall, respectively.

$$y = -0.0056x_1^2 + 0.2393x_1 + 16.793$$

$$y = 0.0088x_2^2 - 0.2912x_2 + 267.24$$

In the above equations, Y represents the percentage of performance anomalies and x_1 and x_2 represent the abnormal percentages of the average annual temperature and annual rainfall, respectively.

In the next step, the maximum reduction in risk (risk) must be calculated through the regression equations obtained in the previous step. For each of the temperature and precipitation indices, using the results of Figure 3-8, the probability of occurrence (probability) of the greatest decrease in return (risk) can be obtained. The results obtained from this section are presented in Table 3-1.

Table 3- 1:Risks of separate temperature and rainfall changes on yield

Temperature Changes		Rainfall Changes	
Yield decrease	-4.14	Yield decrease	-17.24
Probability	60.79	Probability	42.16
Risk	3.79	Risk	9.23

As can be seen in Table 3-1, in temperature changes, the maximum yield reduction and probability are 4.14 and 60.79%, respectively, and the risk is 3.79%. Also, in terms of rainfall, the maximum reduction in yield and its probability were 17.24 and 42.16%, respectively, and its risk was 9.23%.

Then, the multiple regression equations obtained the percentage of performance anomaly with the percentage of anomaly of average annual temperature and annual precipitation from 1970 to 2020, which ar.e presented below:

$$y = 0.16x_1 + 325x_2 + 0.0185x_1x_2 + 69.76$$

Finally, in order to determine the maximum amount of change in the percentage of anomaly of the average annual temperature and annual rainfall, and to calculate the maximum reduction in performance (risk) due to comprehensive effects, we use the above equation. In addition, Figure 3-8 can also be useful in determining the probability of reduced yield. The results are presented in Table 3-2.

Table 3- 2:The comprehensive impact risks of temperature and rainfall changes on production yield (%)

Parameter	Value (%)
Maximum temperature increase	75.96
Maximum rainfall increase	-29.15
Yield decrease	-21.28
Probability	39.86
Risk	13.28

As can be seen in Table 3-2, the assessment of the comprehensive effects of temperature and rainfall and the determination of the final risk by considering both factors simultaneously, led to a maximum yield reduction of 21.28 with a probability of 39.36%, the risk of which is increased by 13.28%.

Chapter 4: Conclusion

4-1 Conclusion

In recent years, human activities have increased CO_2 concentrations, which has led to global warming, reduced rainfall and the phenomenon of climate change. Climate change is predicted to have a negative effect on the agricultural system. On the one hand, increasing the temperature due to climate change reduces yield and on the other hand, increasing atmospheric CO_2 concentration increases yield. The outcome of these two, in addition to other factors such as pests and diseases, determines the potential for action in the face of climate change. Due to the socio-economic importance of agriculture for food security, it seems necessary to assess the effects of climate change on the agricultural system and provide solutions to adapt to it. The phenomenon of climate change and predicting its effects on the planet in order to reduce vulnerability and deal with it is very important. Among the important issues in climate change studies are the deep uncertainty of this phenomenon and the analysis of the future perspective of variables in these conditions.

In this study, using a quantitative method and using the risk definition Risk = (A,C,U), the agricultural risk caused by climate change was assessed. For this purpose, 7 steps of risk assessment were considered for the proposed method. The case study is the Mashhad basin in Khorasan province, Iran. The proposed method, based on a reliable theory, can quantitatively identify the risk of climate change on agriculture and achieve objective results. This method can be generalized to agricultural products in different regions. Compared to the Bayesian model method, this method has less input and comprehensive consideration of extreme climatic events.

The main uncertainty of this research is the choice of regression curve between climatic factors and crop yield, which will lead to different evaluation results. In this method, we used the quadratic quota to adapt the relationship between crop yield and individual climatic factors according to crop growth rules. That is, when a climatic factor gradually increases, performance increases. When the climatic factor reaches a certain value, the efficiency reaches the maximum value. And if the climate factor continues to rise, performance will begin to decline. Using other regression curves may reduce the accuracy and level of explanation.

The results showed that in the study area, instability due to climate change, especially in the last 20 years, has increased with the trend of further warming and drying. The maximum reduction in yield and its probability were 4.14 and 60.79%, respectively, for the maximum increase in temperature was 75.96% and the risk was 3.79%. The maximum reduction in yield and probability was 17.24 and 42.16%, respectively, the maximum reduction was 29.15% and the risk was 9.23%. For the comprehensive effects of temperature and precipitation, the maximum yield reduction and its probability were 21.28% and 39.86%, respectively, and the risk increased to 13.28%. If we do not adopt appropriate adaptation strategies, the number of casualties due to the negative effects of multiclimatic factors and the probability of their occurrence will increase accordingly, and the risk will clearly increase.

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Appendix 1

Risk management

Uncertainty about future events and their predictions always causes human actions to be done cautiously. Highly competitive environment, interdependence of events, complexity of tasks, new technologies and rising costs due to the adverse consequences of uncertainty have made the science of management and risk recognition important.

Risk management is the process of measuring or evaluating risk and then designing strategies for risk management, and in general, the goal of risk management can be to reduce the risks that prevent investors and key project owners from reaching pre-determined goals and increase the potential for using the opportunities (Kunreuther et al, 2013).

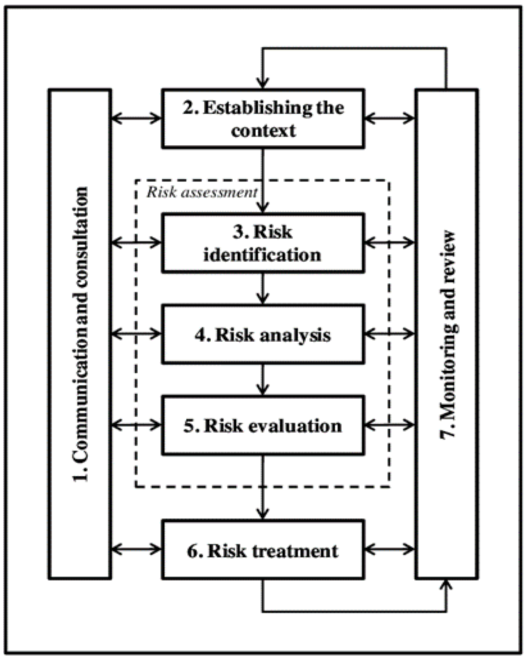

Figure 6- 1: The risk management Process

Risk identification

Risk identification is the process of identifying potential risks affecting predetermined goals and determining the characteristics of each of them and documenting them. The scope of implementation of this process varies according to the necessity of the steps of the intended goals and is proportional to the characteristics of the project or production of the product. Complete and timely knowledge of risk makes it easy to take corrective actions and also the effectiveness of these measures in controlling risk. A correct and complete understanding of the mission, scope of work, and expected results of stakeholders is essential for a comprehensive identification of project risk.

Risk analysis

Analysis is divided into two categories: quantitative and qualitative analysis. In qualitative risk analysis, the process of identifying and assessing the probability of impact on known risks. In this process, potentially risky events are prioritized according to the potential impact of each on the goals. Then how to respond to them is determined. The quality and quantity of available information also play a crucial role in risk analysis. From the necessary inputs for risk analysis, the accuracy of the information is determined by determining the degree of their availability and also the degree of reliability of each of them. The nature and amount of information sources are also effective in determining the accuracy of information. The process of quantitative analysis is likely to have implications for project objectives. This process, using techniques such as Monte Carlo simulation and decision tree analysis, contains the following results:

- Determining the degree of probability of achieving any of the goals of the project or product production
- Calculating and determining the risk, time and related costs Determining priority risks
- Setting the cost, schedule or project scope goals in a realistic and achievable manner (Behzadi et al, 2018).

Risk evaluation and aggregation

ISO defines the concept of risk aggregation as: "Combination of a number of risks into one risk to develop a more complete understanding of the overall risk"(ISO/Guide , Risk Management -Vocabulary). In accordance with ISO, risk aggregation is an integral part of risk evaluation in risk management process and decision making.

Vulnerability

As shown in Figure 6-2, the concept of vulnerability is closely related to risk. Starting from the display of risk (A, C, U), we can divide the risk into two main parts (Aven, T., & Thekdi, 2022):

Risk = 'Event risk' (A,U) & Vulnerability (C,U|A)

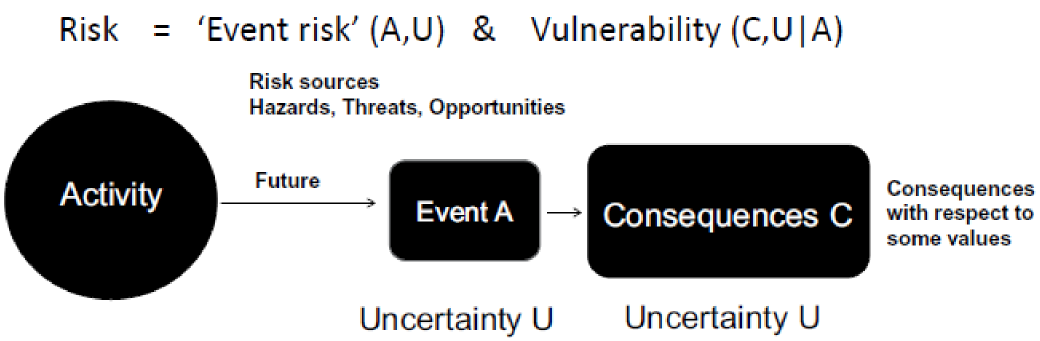

Figure 6- 2: The basic of risk concept consist of an event risk and vulnerability

To understand this, an example is given about a car accident. An accident is an example of a source of danger that we define as an element (action, ancillary activity, component, system, event) that alone or in combination with other elements has the potential to cause some adverse consequences. Here, event A refers to an accident and consequences C relate to the health effects of the driver and passengers resulting from the accident. The actual event A that occurs can also be "accident-free," which is reflected by the letter (A, U), which states that we do not know today before the activity occurs whether the accident will occur or not. We refer to (A, U) as "event contribution" or "event risk" expressing the risk of an accident or, more generally, the risk of event A. This risk is not the same as the probability of event A. Probability is a way of expressing U uncertainty, but the existence of the concept of risk is not dependent on a defined uncertainty (Aven, T., & Thekdi, 2022*)*.

In the case of a car, examples of sources of danger in addition to an accident include: distraction of the driver by the mobile device, health emergencies for the driver and /or passengers, high stress levels of the driver, high speed, intense discussions between passengers, active use of Carodio system, slippery roads, broken brakes and worn tires. Normally, sources of risk are important factors in the occurrence of event A, but formally we also refer to event A as the source of risk. What is identified as event A in the risk display (A, C, U) is not always clear. In the example of a car, we can refer to A as "brake failure", which is considered as the main source of danger for an accident.

The concept of vulnerability (C, U | A) is interpreted as a risk due to the occurrence of event A. Thus, vulnerability indicates the potential for adverse consequences with respect to an event (source of danger). Centralized values define what "undesirable" means. In the car example, the vulnerability is related to what happens to the driver and passengers due to an accident. In the case of risk, we can extend this definition by addressing the consequences and uncertainties that lead to vulnerabilities (C, U | A) and (D, U | A) (Aven, T., & Thekdi, 2022*)*.

Objective vs. subjective probabilities in risk context

As mentioned in former section, when we apply probability as a measure for uncertainty in risk context, we shall explain what the probability means because interpretation could strongly affect the decision making process. Many interpretations of a probability exist, but only a few are meaningful in practice. There are two kind of probabilities (interpretation) exist in broad categories:

a. Objective probabilities (including classical probabilities, frequentist probabilities)
b. Subjective probability (including the Bayesian framework)

Objective probabilities (interpretation) are constructed based on repeatable experiments and subjective probability (interpretation) is judgmental, knowledge based probability.

a.1- Classical probabilities

The classical interpretation applies only in situations with a finite number of outcomes which are equally likely to occur e.g. throwing a die. The probability of A is equal to the ratio between the number of outcomes resulting in A and the total number of out-comes.

P(A)= number of outcomes resulting in A/ total number of outcomes

The principle of indifference shall be meet over outcomes. The classical probability (interpretation) is not applicable in most real life situations because we do not have a finite number of outcomes which are equally likely to occur. As an example consider A = ‘‘the sea level will increase by one meter during the coming 30 years’’. To materialize a classical probability of the event A, we have to define a finite number of outcomes which are equally likely to occur, and the probability of A is equal to the ratio between the number of outcomes resulting in A and the total number of outcomes. We cannot meaningfully construct similar 30 years period and the classical probability has no proper interpretation for this event (Aven & Reniers, 2013).

a.2- Frequentist probabilities

Frequentist probability of an event A, $P_f(A)$, is defined as the fraction of times the event A occurs if the situation considered were repeated an infinite number of times. if an experiment is performed n times and the event A occurs n_A times, then:

$$P_f(A) = n_A / n$$

Frequentist probability p $= P_f(A)$ is a mind constructed quantity (model concept), established on the law of large numbers under certain conditions. It means that the probability of the event A exists and is the same in all experiments, and the experiments are independent. The concept of frequentist probabilities is applicable to only those situations for which we can figure out repeatable experiments in similar condition. Hence, this was not done in the actual case, it would be a serious weakness of the assessment if the frequentist probability framework used for interpretation of probability in risk analysis e.g. in previous example, an infinite population of similar 30 years period cannot be meaningfully defined.

b- Subjective probability

Subjective (knowledge-based) probability is a type of probability derived from an individual's personal judgment and it expresses a judgment (a degree of belief) of the assigner related to the occurrence of the event of interest. Subjective probabilities differ from person to person and is understood in relation to an uncertainty and measures a personal belief based on own experience and knowledge about whether a specific outcome is likely to occur. It contains no formal calculations and only reflects the subject's opinions.
There are two common interpretation of subjective probability:
b.1- Betting and related type of interpretation (Finetti’s representation theorem)
b.2- The reference to an uncertainty standard (Lindley’s uncertainty standard)

In line with de Finetti, the probability of the event A, P(A), equals the amount of money that the assigner would be willing to put on the table if he/she would receive a single unit of payment in the case that the event A were to occur, and nothing otherwise.
In line with de Lindley, a subjective probability is understood in relation to an uncertainty standard, typically an urn: if a person assigns a probability of 0.1 for an event A, he or she compares his/her uncertainty (degree of belief) of A occurring with drawing a specific ball from an urn containing 10 balls. The uncertainty (degree of belief) is the same.

Risk Policy:

Risk policy is statement of the extent and kinds of risks that a firm is willing to take in pursuant of its objectives. It varies from industry to industry and, within an industry, from firm to firm.

The purpose of risk policy is to set out the high level principles for management of key risks. The risks facing an organization could be Financial risks, Operational Risks, Market and Business risks, Environmental risks, Hazard risks, and etc. The aim of the Risk Policy is to ensure that risk assessment of a firm brings added value to the organization and its stakeholders through supporting the organization's objectives.