*International Journal of Agricultural Management and Development*
*Available online on: www.ijamad.iaurasht.ac.ir*
*ISSN: 2159-5852 (Print)*
*ISSN:2159-5860 (Online)*

# The Effects of Climate Change on Iran's Sugarcane Production (Case study: Khuzestan sugarcane)

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*Received: 02 February 2022,*
*Accepted: 29 July 2023*

Abstract

Climate change, stemming from global warming, poses a significant threat that necessitates comprehensive and concerted global action. The agricultural sector, crucial for Iran's production cycle and food security, is particularly vulnerable to climate change, given the country's hot and arid climate. Iran faces a heightened risk of climate change impacts, exacerbating its existing vulnerabilities. Notably, Khuzestan province hosts major sugarcane industries, where significant and escalating changes in climatic variables have been observed. This article explores the repercussions of climate change on the sugarcane industry in Khuzestan province over the period of 1971-2020. Utilizing the Dynamic Ordinary Least Squares (DOLS) econometric model, the study examines the impact of climate factors, such as temperature and precipitation, on sugarcane production. The findings unveil a nonlinear relationship between climatic factors and production, particularly temperature and precipitation. The observed nonlinear relationship, depicted as an inverted U-shape in the graph, underscores the significance of climate change for agricultural production. While government ownership and exclusive rights over sugarcane cultivation in Khuzestan were expected to foster prosperity and maximize productivity, the sugarcane system has gradually evolved to prioritize sustainable self-sufficiency as the ultimate goal. However, climate change has posed significant challenges to achieving this goal. In conclusion, the negative ramifications of climate change on sugarcane production underscore the urgency of action. Recommendations include minimizing human intervention in nature, diversifying crop varieties to ones more resilient to climate change, altering cultivation patterns, and implementing supportive policies to mitigate the effects of climate change on the sugarcane industry.

***Keywords:***
***Climate change, dynamic ordinary least squares, precipitation, sugarcane production in Khuzestan, temperature***

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## INTRODUCTION

Climate change stands as one of the paramount global challenges necessitating comprehensive cooperation. The incidence of natural disasters and accidents worldwide has surged fivefold. Presently, climate change impacts all regions differently, manifesting in warmer, colder, and shorter seasons, with projections indicating further intensification in the coming decades (WMO, 2021). Climate change significantly alters the risk of flooding, particularly in regions with high regional and temporal temperatures, amplifying the risk through shifts in rainfall patterns, a crucial hallmark of climate change (Guo et al., 2020). According to a recent UN report on climate change, the daily lives of at least 3.3 billion people are "extremely susceptible" to its effects, with individuals now 15 times more likely to experience extreme weather conditions than in previous years (IPCC Report, 2022). Moreover, climate-related disasters such as floods and droughts have the potential to displace large populations, exacerbating existing geopolitical tensions (UN Report, 2022).

Agriculture, as one of the most critical economic sectors globally, faces profound impacts from climate change. The agricultural ecosystem, encompassing food security, human health, and environmental protection, is particularly vulnerable to the effects of climate change. Climate change significantly alters agricultural ecosystems and poses serious threats to food security, human health, and environmental sustainability. Among all economic sectors, agriculture is the most dependent on climate conditions (Sivakumar, 2021). Climate change affects agricultural productivity through various mechanisms, including changes in precipitation patterns, shifts in planting and harvesting dates, and rising temperatures and evapotranspiration rates (Amirnejad and Asadpour, 2017). Global warming is predicted to have significant impacts on the agricultural economy by altering temperature, carbon dioxide levels, runoff, frost occurrences, precipitation patterns, and their interactions (Wani et al., 2020). The economic repercussions of climate change are evident in changes in crop yields, production, and supply, impacting food security, as well as long-term alterations in climate parameters affecting farmers' profitability and income (Amirnejad and Asadpour, 2017). Consequently, the agricultural sector is vulnerable both economically and physically to changes in weather factors such as temperature and precipitation (Benhin, 2008). Changes in weather patterns can reduce crop yields during crucial harvest periods (Ben Zaied, 2013). By 2050, the demand for food is expected to increase by 70 percent. Overexploitation of existing resources, soil and water pollution, and excessive use of pesticides and chemical fertilizers will exacerbate instability (Vahdati et al., 2020).

In recent years, numerous studies have delved into investigating the ramifications of climate change on the agricultural sector. Significant contributions have been made by researchers such as Rajabalinejad et al. (2023), Kemerodi and Bostanabad (2019), Amirnejad and Asadpour Kurdi (2017), Soleimaninejad et al. (2016), Khaleghi et al. (2015), and Hosseini et al. (2013). Each of these studies explored the impact of climate change on the agricultural sector, with findings highlighting the influence of climatic variables, particularly temperature and precipitation, on value added within this sector. Rajabalinejad et al. (2023) employed the "safety cube theory" (Rajabalinejad, 2019) to conduct a comprehensive assessment of climate change's impact on Iran’s agricultural economy spanning 50 years. The study offers practical solutions to mitigate climate change damages through dynamic and targeted diplomacy. It recommends that Iran’s climate policy adopt a comprehensive approach, considering the entire climate change system, and implement a balanced and intelligent strategy to mitigate its effects at the national level, while also fostering regional and international cooperation.Furthermore, Asadpour Kordi et al. (2023) recommended, based on their study, that governments develop industrial development plans grounded in medium and long-term strategies, emphasizing advanced industries and workforce innovation support. This approach is envisaged to catalyze transformation in the agricultural industry and foster its development.

The Islamic Republic of Iran, characterized by a hot and dry climate, faces significant challenges in its agricultural sector, with many regions experiencing water scarcity and stress. Agriculture contributes more than 8 percent to Iran's Gross Domestic Product (GDP). Owing to its unique ecological structure, Iran is particularly sensitive to environmental changes, rendering it more vulnerable compared to other countries. Consequently, climate changes in these regions can have substantial effects on agricultural production systems (Amirnejad and Asadpour, 2017). Climate change is recognized as the most significant threat to sustainable development, inflicting severe damage on natural resources, the environment, human health, food security, and economic activities (Rahimi et al., 2019). Additionally, alongside the potential impact of climate change, sanctions can also affect various economic sectors, including agriculture (Madani, 2021).

Sugarcane, a tropical crop, thrives in hot, humid conditions unless halted by flowering. Its normal life cycle spans approximately 15 to 18 months, requiring temperatures ranging from 27 to 38°C throughout its growth phases. Optimal temperatures of 32 to 38°C are essential for germination, while temperatures exceeding 38°C can inhibit photosynthesis rates. Adequate water supply is equally vital for crop development (Kelkar, Kulkarni et al., 2020).

In recent years, Iran has experienced climate change-induced abnormal rains leading to severe weather events, floods, and droughts. Numerous studies conducted in Iran have documented a significant increase in annual temperatures (Hemadi et al., 2011). In dry regions like Khuzestan province, nearly 100 percent of agricultural production relies on irrigated farming (Shahbazi, 2019). Given the significance and urgency of the issue, along with limited research in this area, understanding the local and regional effects of climate fluctuations on crop evapotranspiration is crucial. These changes are particularly pertinent in fertile agricultural areas such as Khuzestan (Shahbazi, 2019).

Studies conducted in Iran, mirroring global trends, have observed an escalating annual temperature. A study in the Khuzestan Plain aimed to examine the impact of rising temperatures on sugarcane water consumption. This investigation involved analyzing annual temperature time series alongside theoretical principles of evaporation, transpiration, and crop water demand. Results from the annual time series analysis revealed a temperature increase of 3.7°C over a 100-year period.

Through sensitivity analysis of the water demand model, the study demonstrated varying responses in potential evaporation and transpiration to changes in temperature, wind speed, sunshine hours, and relative humidity. Specifically, for every 1 percent change in these factors, potential evaporation and transpiration exhibited respective alterations of 14, 8, 4, and 2.7 percent. The increase in potential evaporation and transpiration rates attributed to temperature rise was recorded as 2.04, 2.01, 1.52, and 2.23 mm per year in the Behbahan, Ahvaz, Dezful, and Karkheh regions, respectively (Hemadi et al., 2011).

Furthermore, a study on precipitation statistics over the past 50 years in the southwest basin, encompassing the Karun and Karkheh basins in Khuzestan province, highlighted significant changes in precipitation patterns, including the emergence of rain waves and floods (Special Committee of the National Flood Report, 2019).

The industrial production of sugarcane holds significant economic importance in Iran, contributing significantly to GDP and job creation. Sugarcane is considered a strategic crop with the potential to facilitate sugar self-sufficiency in the country. Understanding the impact of climate change on the sugarcane economy necessitates assessing its effects on production volume, cultivated area, supply quantity, and price index of the crop. The economic repercussions of climate change, including those on the sugarcane economy, will influence agricultural and sugarcane production practices, environmental policies, and international measures. Additionally, its feedback will play a crucial role in either exacerbating or mitigating global warming, thereby affecting potential strategies for climate change control.

Given its strategic importance in Iran's agriculture, sugarcane production has the potential to bolster the country's self-sufficiency in sugar production. Khuzestan province, responsible for approximately 70 percent of Iran's sugarcane production, holds the primary production rank (Amili, 2013), hence its selection as the focal point for studying the effects of climate change on sugarcane.

Given the global and national significance of sugarcane production, particularly in the context of climate change, this study aims to address the following questions:

Does the total production of sugarcane in Iran correlate with average annual temperature changes?How does precipitation variability impact sugarcane yield or production in Khuzestan province?

Given that 77 percent of crop production in Iran occurs in semi-arid regions susceptible to the impacts of climate change, it is imperative to prioritize research in these areas. Despite numerous studies investigating the effects of climate change on the agricultural sector in recent years, research specifically focused on sugarcane has been notably limited.

While various studies have explored how climate change affects sugarcane production and evaluated its consequences on the sugarcane industry, few have considered the broader industry-wide impacts and economic repercussions across the sugarcane value chain (Linnenluecke et al., 2018). Enhancing productivity, a crucial driver of economic growth, entails utilizing efficient production methods across all resources, including labor, capital, and energy (Eskandari et al., 2022).

A review of 90 studies, including articles, proceedings, and book chapters, revealed that 61 of them evaluated the observed or predicted effects of climate change on sugarcane production. These studies often yielded differing conclusions regarding how sugarcane production is influenced by increases in air temperature or atmospheric carbon dioxide levels. Furthermore, only 17 adaptation studies have focused on observed or predicted impacts of climate change, exploring management or agricultural practices as potential adaptations. However, there is limited evidence regarding successful adaptation outcomes. Additionally, another stream of articles has discussed reducing energy use and greenhouse gas emissions in the sugarcane production process, primarily aiming to mitigate environmental impacts (Linnenluecke et al., 2018).

Azizi et al. (2022) conducted a study using panel data and the dynamic ordinary least squares (DOLS) method to assess the threshold levels of temperature and rainfall and their impact on irrigated barley yield. Their findings confirmed an inverted U-shaped relationship between climate change variables and irrigated barley yield in Iran. The estimated threshold levels were determined to be 15.48ºC for temperature and 239 mm for rainfall. Beyond these thresholds, increases in temperature and rainfall were found to have a negative impact on barley yield in the country. The study also revealed that the long-term elasticity of temperature indicates a decrease in yield with rising temperatures, a pattern that also holds true for precipitation and barley yield.

Climate change is anticipated to have significant implications for sugarcane production globally, particularly in developing countries.

These nations often possess relatively low adaptive capacity, high vulnerability to natural hazards, and limited forecasting systems and mitigation strategies. Sugarcane production has already been negatively impacted by, and is expected to continue facing considerable challenges due to, increases in the frequency and intensity of extreme environmental conditions caused by climate change. However, the extent of this impact varies depending on geographical location and the adaptive capacity of the region (Zhao and Li, 2015).

Ghafari et al. (2019) conducted a study to examine the impact of climate change on Iran's sugarcane sector's economic growth. They utilized a dynamic calculable general equilibrium model based on the social accounting matrix of 2019. Their findings indicated that considering the projected decrease in rainfall over a twenty-year period leading up to 2030, the production, consumption, investment, and export levels in the sugarcane sector were projected to decline by 4.469, 5.025, 4.462, and 13.770 percent, respectively. Conversely, imports in this sector were anticipated to increase by 504.5 percent. Given the adverse effects of climate change on macroeconomic variables in the sugarcane sector, the government was urged to implement appropriate measures to support the sector in adverse climatic conditions.

In a study by Linnenluecke et al. (2018), the impact of climate change on Australian sugarcane production was investigated. Utilizing climatic data from Australia, including maximum and minimum temperatures and precipitation spanning from 1964 to 2012, the study revealed that annual CO2 emissions, along with maximum temperature, had a negative effect on Australian sugarcane production, while minimum temperature showed a significant positive effect during the study period.

Kelkar et al. (2020) conducted research to assess the potential effects of climate change on the production of three major crops: sugarcane, cotton, and rice in India. Their analysis demonstrated a significant decrease in the production of these crops as a result of climate change.

Tokunaga et al. (2015) conducted a study to examine the impact of climate change on agricultural production in Japan. Utilizing dynamic panel analysis and reviewing data from 1995 to 2006 across eight regions in Japan, the researchers analyzed the effects of three climatic variables: temperature, solar radiation, and precipitation—on crop production using the production function. Their findings revealed that a 1°C increase in the average annual temperature led to a 5.8 percent reduction in rice production in the short run and a 3.9 percent reduction in the long run.

These studies serve as examples of recent research exploring the effects of climate change on sugarcane production. Consistently, studies conducted in Iran and other countries have highlighted temperature and precipitation as crucial climatic variables influencing sugarcane production. The current research aims to investigate these key climatic factors' impact on sugarcane production using the production function. Data were compiled as a time series and analyzed using the Dynamic Least Squares (DOLS) method, incorporating climatic data such as average temperature and total precipitation from the Khuzestan Synoptic Station over a consecutive 50-year period (1971-2020).

## METHODOLOGY

Mathematical modeling serves as a valuable tool for studying farm-level adaptations, offering various techniques to explore different aspects of agricultural adaptations. Examples of these modeling techniques include decision models like agent-based models (ABM) and decision support models (DSM), as well as optimization models such as linear programming (LP), non-linear programming (NLP), and mixed integer programming models (MIP). ABM and DSM, in particular, are effective for assessing adaptation measures on farms (Shrestha et al., 2016). In this study, the investigation focused on climatic factors impacting sugarcane production utilizing the production function. The production function illustrates the relationship between input utilization and output production across varying levels of input consumption. The general form of the production function is represented as Eq. (1) (Amirnjad and Asadpour, 2016, 2017):

$$Y= f(x_1, x_2, ..., x_n) \qquad (1)$$

In which Y represents the amount of production and X represents the production factors (labor, capital, and materials). If both manageable production factors and unmanageable production factors are considered in the production of a crop, then the production function will be as Eq. (2):

$$Y= f(x_1, x_2, ..., x_n) \qquad (2)$$

In which X1 is the vector of production inputs, X2 is the climatic factors of temperature and precipitation, and X3 is the level of technology that has been used. This study used Eq. (2) according to Linnenluecke et al. (2018) and Kelkar et al. (2020) that both used the important climatic variables of temperature and precipitation.

$$Ly_t=F(Lrain_t.Lrain^2{}_t\ .Ltem_{it}\ .Ltem^2{}_t) \quad (3)$$

In which $Ly_t$ is the natural logarithm of Iran's total sugarcane production, Lraint is the natural logarithm of total annual precipitation, $(rain^2)_t$ is the natural logarithm of the second power of the total annual precipitation, $Ltemp_t$ is the natural logarithm of the average annual temperature, $(Ltemp^2)_t$ is the natural logarithm of the second power of the average annual temperature.

It should be noted that the relationship between the climatic variables of temperature and precipitation and the total production of sugarcane is represented by the square power of these variables in Eq. (3), so the relationship is not estimated only linearly but a more accurate estimate is obtained in the long run.

The DOLS method was used to achieve this goal because this is a common method to examine long-term relationships between dependent and explanatory variables of the model and the change in weather conditions is considered over a period of time according to the definition of climate change. The DOLS method can be beneficial in examining this phenomenon (Ben Zaied, 2013).

The Dynamic Ordinary Least Squares (DOLS) method, proposed by Stock and Watson (1993), is a dynamic composite data model estimation technique. This method examines how a dependent variable responds to variations in independent variables by adjusting the ordinary least squares (OLS) method. One of the significant advantages of the DOLS method, compared to other cointegration vector estimators, is its applicability in small sample sizes, its ability to mitigate simultaneous bias, and its adherence to a normal asymptotic distribution. Additionally, Kao Weiqiang (2000) has demonstrated that this method is more efficient and allows for reliable statistical inferences. In this method, Eq. (4) is employed to estimate the long-term coefficients:

In which P represents past and future trends (precedence or delay), ΔX (i,t-j) represents the difference of explanatory variable with interval, ΔX(i,t+j) represents the difference of explanatory variable with future trends, γj represents the coefficients of breaks or past trends, δj represents the coefficients of future trends, uit represents the error of estimating the long-term dynamic relationship, and Yit represents the dependent variable.

The study area was located in the west of Khuzestan Province (32°11'01"-31°06'89" N and 47°72'16"-48°26'.37" E) in the southwest of Iran. The data of this study were in the form of time series for 1971-2020. Data were derived from the information provided by the Central Bank of the Islamic Republic of Iran, the Ministry of Agricultural Jihad, the Sugar Organization, and the Meteorological Organization of Iran. Due to the lack of access to provincial production data, national data were used. Also, Eviews9 software was employed to estimate the model.

## RESULTS

To comprehend the variables utilized in the study, their statistical attributes are delineated in Table 1, summarizing their minimum, maximum, average, and standard deviations.

*Table 1*

*Descriptive Information of the Respostatistical characteristics of the variables used in the study for the sugarcane productndents.*

| Variable Name | Variable Description | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|---|
| Y | Sugarcane production (tons) | 578 | 7800 | 3151/652 | 2169/264 |
| TEMP | Annual average temperature (Celsius) | 23/72 | 26/89 | 25/33 | 0.61 |
| RAIN | Total annual precipitation (mm) | 93/96 | 470/23 | 254/1 | 80/29 |

Table 1 displays the minimum and maximum production of sugarcane in Khuzestan during the investigated period of 1971 to 2020, which were 578 and 7800 tons in 1971 and 2017, respectively. Additionally, the maximum average annual temperature recorded in this province was 26.89°C in 2010, while the minimum temperature was 23.72°C in 1977. As for the rainfall variable, the highest total annual rainfall was 470.23 mm observed in 1997, whereas the lowest rainfall occurred in 2010, measuring 93.96 mm.

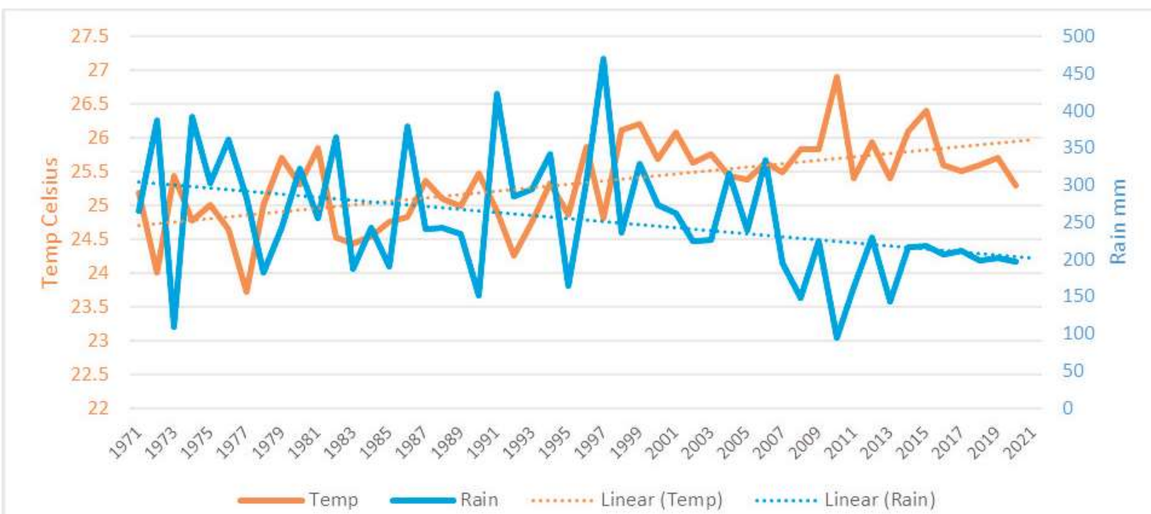


*Figure 1.* Annual average precipitation and temperature of the studied period.

According to Figure 1, the average annual precipitation and temperature over the studied period indicate a notable trend. Since 1997, there has been a consistent increase in temperature, depicted by the upward movement of the graph. Concurrently, there has been a declining trend in average annual rainfall. This decrease in rainfall could exacerbate the intensification of temperature, resulting in adverse effects on the environment and agriculture. A rise in average seasonal temperature has the potential to shorten the growing period of many crops, subsequently reducing their yield. In the long term, climate change can impact agriculture in various ways, influencing the quantity and quality of crops in terms of productivity, growth rate, photosynthesis, transpiration rate, moisture availability, and more. In the subsequent analysis, before estimating the model, the stationarity of the variables was initially assessed using the widely employed augmented Dickey-Fuller (ADF) test. A summary of the results is presented in Table 2, which includes the logarithm of the examined variables at their original level and subsequent to the first differentiation.

*Table 2*
*Stationary results for variables at level and first order difference.*

| Variable | Variable in level | | First order difference | |
|---|---|---|---|---|
| | Generalized Dickey-Fuller test | | Generalized Dickey-Fuller test | |
| | t statistic | Possibility | t statistic | Possibility |
| **LY** | -1.51 | 0.52 | -7.09*** | 0 |
| **Lrain** | 06.88- | 0 | -9.59*** | 0 |
| **Lrain2** | -6.89 | 0 | -6.69*** | 0 |
| **LtempP** | -6.89 | 0.06 | -12.80*** | 0 |
| **Ltemp2** | -2.88 | 0.06 | -12.82*** | 0 |

According to the results of the unit root tests presented in Table 2, it is observed that, except for the precipitation variable, which exhibits stationarity at the 1% significance level, the remaining variables display nonstationarity at the 1% level and possess a unit root. Consequently, their first-order differences are stationary or I(0) at the 1% significance level across all instances. The estimation of the model with nonstationary variables may lead to spurious regression results. To mitigate reliance on spurious regression, various differencing methods and cointegration tests are employed. Additionally, the KPSS test yielded similar outcomes. Hence, if cointegration exists among the variables in the model, the results of the model estimation are deemed reliable. In this study, the Johansen method was utilized to conduct the cointegration test within the model. The null hypothesis of this test posits the absence of cointegration or a long-term relationship. The results are presented in Table 3.

*Table 3*
*Johanson Test Results.*

| The number of cointegration equations | Eigenvalue | Statistics Trace | Critical limit 0.05 | Probe |
|---|---|---|---|---|
| **Zero*** | 0.51 | 91.6 | 69.82 | 0 |
| **One** | 0.3 | 32.32 | 29.79 | 0.087 |
| **Two** | 0.22 | 15.06 | 15.49 | 0.197 |
| **Three** | 0.05 | 2.54 | 75843 | 0.11 |

According to Table (3), a cointegrating vector is observed at the 1% significance level, confirming the existence of a long-term relationship. Following the confirmation of cointegration in the model, various methods can be employed to estimate the long-term pattern. As mentioned earlier, this study utilizes the fully modified ordinary least squares (DOLS) method. The results of estimating the DOLS model are presented in Table (4).

*Table 4*
*DOLS Model Results.*

| Probability value | t statistic | Standard deviation | Coefficient value | Variable |
|---|---|---|---|---|
| 0 | 4.259 | 1155.56 | 4922.278** | Ltemp |
| 0 | -4.241 | 178.932 | -758.855** | Ltemp2 |
| -0.086 | 1.786 | 9.147 | 16.344* | Lrain |
| -0.06 | -1.964 | 0.845 | -1.660* | Lrain2 |
| 0 | -4.323 | 1853.368 | -8013.186** | C |
| | | $R^2$= 81 | | |

According to Table (4), the estimated coefficient of determination is 0.81, indicating that 81 percent of the variance in the dependent variable is explained by the explanatory variables of the model. Furthermore, the results suggest a non-linear relationship between both climatic variables, rainfall, and average annual temperature, and production. The coefficients of the first and second powers of these variables indicate an inverted U-shaped relationship. Specifically, there exists a threshold point where an increase in temperature and precipitation leads to a rise in production before reaching the maximum point. However, after surpassing this threshold, further increases in temperature and precipitation result in a decline in production. This threshold point in the logarithmic model is determined by Eq. (5) (Hosseininasab and Paykari, 2012):

$$X = exp\left(\frac{-\alpha}{2\alpha}\right) \qquad (5)$$

in which X is the maximum temperature or precipitation (return threshold), α1 is the coefficient of the variable's first power, and α2 is the coefficient of the variable's second power.Therefore, according to Eq. (5), the maximum annual temperature for sugarcane is 25.62°C. This indicates that the increase in the average annual temperature will enhance sugarcane production up to 25.8°C, beyond which further increases will result in a reduction in production. Similarly, Eq. (5) was utilized to estimate the maximum point of precipitation for sugarcane, with the threshold being calculated at 137.40 mm. This suggests that an increase in precipitation up to this threshold will boost sugarcane production, but any further increase will have an adverse effect on its production.

Climate change, historically present, has garnered significant international attention in recent decades due to its exacerbation resulting from human activities, significantly impacting agricultural production worldwide. Indeed, climate change has become one of the most pressing environmental challenges globally, particularly affecting the agricultural sector. Iran's agricultural production system, characterized by limited flexibility in adapting to technological and capital changes, renders it increasingly susceptible to climate change. Hence, this study aimed to investigate the impacts of climatic variables, specifically average annual temperature and total annual precipitation, in Khuzestan. To achieve this objective, the dynamic ordinary least squares (DOLS) method was employed, given its suitability for examining long-term relationships between dependent and explanatory variables, aligning well with the concept of climate change, which denotes weather condition alterations over time.

The findings reveal a non-linear relationship between both precipitation and average annual temperature with production. The sign of the first- and second-power coefficients of these variables indicates an inverted U-shaped relationship, signifying a threshold beyond which further increases lead to decreased production. Similar significant relationships between temperature and other crops in Iran have been reported in studies by Zarkani et al. (2014), Momeni and Zibaei (2013), Alijani et al. (2011), Sultana et al. (2009), and Linnenluecke et al. (2018).

## CONCLUSIONS

According to the findings, it is imperative to prioritize measures aimed at mitigating temperature increases, as the non-linear relationship between temperature and sugarcane production suggests that temperatures exceeding the maximum threshold are detrimental to sugarcane yields. To achieve this, strategies such as reforestation, environmental conservation, and the adoption of clean energy sources like solar and wind power should be pursued to counteract the upward trend in temperatures.

Policy initiatives aimed at reducing the adverse impacts of climate change on the agricultural sector should be revisited and implemented through sustainable development programs. These programs should focus on fostering a societal culture of responsible consumption management and the adoption of environmentally compatible technologies. Given the interdependent relationship between climate change and human well-being, such measures are essential for promoting sustainable development.

Furthermore, the research underscores the significant impact of climate variables, namely temperature and precipitation, on sugarcane production. As such, the study's findings can inform strategic planning for policymakers in addressing climate change. For instance, policymakers may consider initiatives such as the development of resilient seed varieties capable of withstanding extreme weather conditions, the promotion of temperature-resistant cultivars, and exploring alternative cultivation methods. Additionally, government support for the agricultural sector during unfavorable climatic conditions is essential to safeguarding agricultural productivity and ensuring food security.

## ACKNOWLEDGMENTS

The authors express their gratitude for the collaboration and guidance provided by Dr. Maryam Asadpour Kurdi, whose contributions significantly enhanced the quality and depth of the article.

## CONFLICT OF INTEREST

There are no relevant conflicts of interest for any of the authors' patents, whether planned, pending, or issued, or other relationships or activities that readers could perceive as having influenced, or that give the appearance of potentially influencing, any aspect of the work covered in this manuscript. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## AUTHORS’ CONTRIBUTIONS

Each of the authors contributed to the development of the paper.

## REFERENCES

Alijani, F., Karbasi, A., R. and Mozafari Masan, M. (2011). Investigating the effect of temperature and rainfall on the yield of water wheat in Iran. *Agricultural Economics and Development,* 76,143-166. (Persian)

Alizadeh, Mohammad and Golkhandan, Abulqasem (2013). Testing the Leviathan hypothesis for selected developing countries. Journals of Regional Economy and Development, 21. (Persian)

Amili, H., 2013. The interview is available at: www.isna.ir/news/khouzestan-23420

Amirnejad, H. and Asadpour Kurdi, M. (2017). Investigating the effects of climate change on Iran's wheat production. Agricultural Economics Research 9(35), 163-182. (Persian)

Asadpour Kordi, M., Rajabalinejad, A. and Kaviani Darani, M., 2023. The effect of knowledge-based economy indicators on employment in the agricultural sector, a case study of OPEC member countries. In: *National Conference of Knowledge-Based Agricultural Economy and Entrepreneur*. Iran: Sari University.

Azizi, J., N. Zarei and S. Ali (2022). "The short-and long-term impacts of climate change on the irrigated barley yield in Iran: an application of dynamic ordinary least squares approach." *Environmental Science and Pollution Research* 29(26): 40169-40177.

Ben Zaied, Y. (2013). Long Run Versus Short Run Analysis of Climate Change Impacts on Agriculture. Working Paper 808.

Benhin, J. K.A. (2008). South African crop farming and climate change: An economic assessment of impacts. *Global Environmental Change*, 18: 666-678.

Climate Change 2022: Impacts, Adaptation and Vulnerability (ipcc.ch)

Eskandari, S., Y. ZeraatKish, R. Moghaddasi and J. Azizi (2022). "Determinant factors energy efficiency and emission of pollutants Co2 & So2 in Iran's agricultural sector." *International Journal of Environmental Science and Technology* 19(3): 1717-1728.

Feqh Majidi, A, and Ebrahimi, S. (2013). Applied econometrics of panel data using Eveiws, Noor Alam. (Persian)

Food and Agriculture Organization (FAO) Annual Report 2014.

Fotros, M, Nemati, M, and Akbari Sh, A. (2010), "Iran's Human Development Index in 2010", *Political-Economic Magazine*, No. 284. (Persian)

Ghafari, I, Akbari, G, Ahmad and K. Kalai (2019). "The effect of climate change on the economic growth of Iran's agricultural sector (the dynamic calculable general equilibrium model approach)." *Agricultural Economics and Development* 32(4): 333-342. (Persian)

Guo, Y., Y. Wu, B. Wen, W. Huang, K. Ju, Y. Gao and S. J. T. L. P. H. Li (2020). "Floods in China, COVID-19, and climate change."

Hemadi, K., M. Jamei and F. Z. Houseini (2011). "Climate change and its effect on agriculture water requirement in Khuzestan plain, Iran." *Journal of Food, Agriculture & Environment* 9(1): 624-628. (Persian)

Hosseini, S., Nazari, M. and Iraqinejad, S.H., (2013). Investigating the effect of climate change on the agricultural sector with emphasis on the role of applying adaptation strategies in this sector. *Economic research and agricultural development of Iran,* vol. 44, no. 1, PP. 1-16. (Persian)

Hosseininesab, S.A. and Paikari, S., (2012). Investigating the effect of economic growth and trade liberalization on environmental pollution. Economic Magazine: *A Bimonthly Review of Economic Issues and Policies*, vol. 9-10, pp. 61-82. (Persian)

IMF: The International Monetary Fund Annual Report 2019.

KAO, C. and CHIANG, M.H., (2000). On the estimation and inference of a cointegrated regression in panel data. *Advances in Econometrics*, vol. 15, pp. 179-222. http://dx.doi.org/10.1016/ S0731-9053(00)15007-8.

Kao, C., Chiang, M.H. (2000). On the estimation and inference of a cointegrated regression in panel data. *Advances Econometrics*, 15: 179–222.

Kelkar, S. M., A. Kulkarni and K. K. Rao (2020). "Impact of climate variability and change on crop production in Maharashtra, India." Curr. Sci 118(8): 1235-1245.

Kemerodi, S. and Bostanabad, S., (2019). Investigating the impact of climate change on agricultural production and food security in East Azarbaijan province. *Environmental Science Studies*, vol. 4, no. 3, pp. 1801-1809.

Khaleghi, S., Bazazan, F. and Madani, S., (2015). The effect of climate change on the production of the agricultural sector and on Iran's economy (social accounting matrix approach). *Social Accounting Matrix Approach,* vol. 7, no. 25, pp. 113-135. (Persian)

Linnenluecke, M. K., N. Nucifora and Thompson, N., (2018). "Implications of climate change for the sugarcane industry." Wiley Interdisciplinary Reviews: *Climate Change* 9(1): e498.

Madani, K. (2021). "Have International Sanctions Impacted Iran's Environment?" *World* 2(2): 231-252. (Persian)

Momeni, S. and Zibaei, M., (2013). The potential impacts of climate change on the agricultural sector of Fars province. *Journal of Agricultural Economics and Development*, vol. 27, no. 3, pp. 169-179. (Persian)

Rahimi, J., A. Malekian and A. Khalili (2019). "Climate change impacts in Iran: assessing our current knowledge." *Theoretical and Applied Climatology* 135: 545-564. (Persian)

Rajabali Nejad, A., N. Nozari and B. Rahimi Badr (2023). "The effect of climatic variables and the role of sanctions on agricultural production in Iran." *Agricultural Economics and Development* 31(2).

Rajabalinejad, A., (2023). Environmental diplomacy and climate change (integral view for sustainable policymaker. *Foreign Policy Quarterly*, vol. 2, pp. 2023.

Rajabalinejad, M. (2019). *Safe integration for system of systems: The safety cube theory.* Paper presented at the 2019 14th Annual Conference System of Systems Engineering (SoSE).

Shahbazi, N. (2019). "Investigation of changes in precipitation and evaporation and transpiration of agricultural products in Khuzestan province under the influence of climate change*." Journal of Water and Soil Conservation Research* 25(6): 123-139. (Persian)

Shrestha, S., A. Barnes and B. V. Ahmadi (2016). Farm-level modelling: *Techniques, applications and policy*, CABI.

Sivakumar, M. (2021). Climate change, agriculture adaptation, and sustainability. Climate resilience and environmental sustainability approaches, Springer: 87-109.

Soleimaninejad, S., Durandish, A. and Nikokar, A. (2016). Identifying the economic and climatic factors affecting the added value of Iran's agricultural sector. In: The 10th Biennial Conference on Agricultural Economics of Iran. Kerman, Iran: Shahid Bahonar Universiy. (Persian)

Stock, J. H. and Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems, Econometrica, 61: 783-820.

Sultana, H., Ali, N., Iqbal, M. M. and Khan, A. m. (2009). Vulnerability and adaptability wheat production in different climatic zones of Pakistan under climate change. *J. of Climatic Change*, 94:123– 142.

The final reports of the "National Flood Report Special Committee" (2021), The report is available on the University of Tehran website at: https://news.ut.ac.ir/fa/news/15620

Tokunaga, S., Okiyama, M. and Ikegawa, M. (2015). Dynamic Panel Data Analysis of the Impacts of Climate Change on Agricultural Production in Japan. *Japan Agricultural Research Quarterly*, 49(2):149-157.

UN Climate Change Conference (unfccc) report. (2022) Availble at: https://unfccc.int/news/cop27-reaches-breakthrough-agreement-on-new-loss-and-damage-fund-for-vulnerable-countries

Vahdati, Koresh, Sarikhani and Saadat (2020). "A review of the sustainable development of the agricultural sector in Iran and the world." *Journal of Strategic Researches in Agricultural Sciences and Natural Resources* 5(1): 19-32. (Persian)

Wani, S., S. Mahdi, S. Samoon, G. Hassan and S. Dar (2020). "Climate Change-its Impact on Agriculture." 02: 82-86.

Wmo: World Meteorological Organization;

https://public.wmo.int/en/media/press-release/wmo-new-climate-report-clarion-call-urgent-action

Zarekani, F., Kamali, G.A. and Chizeri, A.H., (2014). The effect of climate change on the economy of rainfed wheat (a case study of North Khorasan). *Journal of Agricultural Economics*, vol. 2, pp. 301-310. (Persian)

Zhao, D. and Y.-R. Li (2015). "Climate change and sugarcane production: potential impact and mitigation strategies." *International Journal of Agronomy*, 2015.

**How to cite this article:**
Rajabalinejad, A., Nozari , N., & Rahimi Badr, B. (2023). The Effects of Climate Change on Iran's Sugarcane Production (Case study: Khuzestan sugarcane). *International Journal of Agricultural Management and Development, 13*(4), 211-755.