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Major Drivers of Water Stress: An Empirical Analysis of Iran

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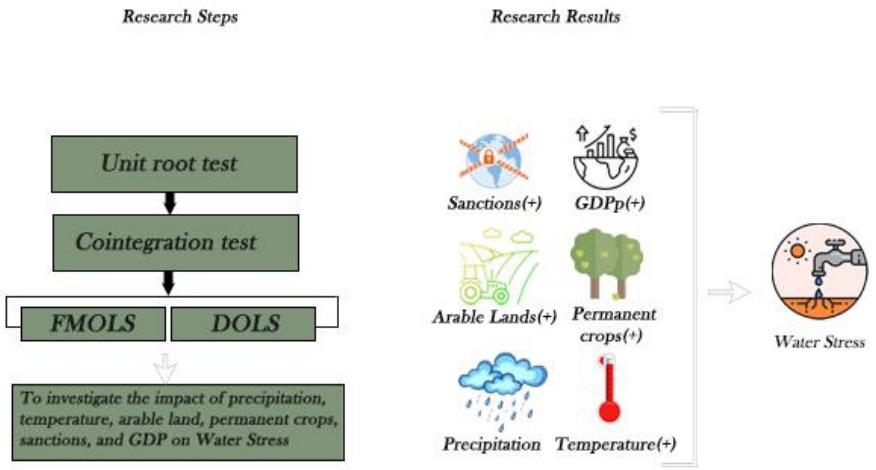
ABSTRACT

Water is fundamental to life and essential for sustainable development and social welfare. Iran is currently facing a severe water crisis, which has been intensified by climate change and regional water scarcity. This study examines the factors contributing to water stress in Iran from 1975 to 2019. Cointegration tests reveal long-term relationships among key variables. Results from DOLS and FMOLS estimates indicate that while precipitation has no significant effect on water stress, temperature, arable land, permanent crops, GDP per capita, and sanctions significantly exacerbate it. The primary drivers of water stress in Iran are rising temperatures, agricultural activities, and economic sanctions. While economic analyses often prioritize air pollution and carbon emissions as environmental metrics, this narrow focus overlooks broader challenges. In Iran, dust storms and water scarcity pose significant threats, requiring urgent action to prevent a worsening crisis. Policymakers should reconsider agricultural self-sufficiency goals, strengthen diplomatic efforts to

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mitigate sanctions, and implement robust water management strategies. Addressing water stress in Iran aligns with key Sustainable Development Goals (SDGs), including clean water and sanitation (SDG 6), zero hunger (SDG 2), good health and well-being (SDG 3), responsible consumption and production (SDG 12), and the impact of climate change on food production (SDG 13).

Graphical summary



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1. Introduction

From the dawn of humanity, civilizations have thrived along riverbanks, highlighting the crucial role of water in sustaining life. Conversely, the absence of water can spell disaster for these societies (Macklin & Lewin, 2015). Today, many regions that once nurtured early civilizations face a severe water crisis, notably in the Middle East and North Africa (MENA).According to (Kuzma, Saccoccia, & Chertock, 2023), 12 out of 17 MENA countries, including Iran, are experiencing intense water stress due to arid conditions, increasing water demands, and the projected impacts of climate change. **Figure 1** illustrates the water stress levels across various Asian countries, with red indicating the most severe stress and lighter shades of orange and yellow reflecting less severe conditions.

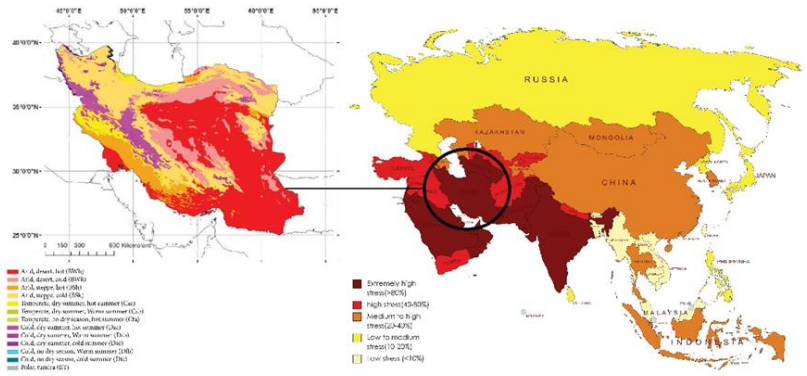


Figure 1. Geographical Distribution of Climate Types in Iran According to the Köppen Geiger Climate Classification map

Iran, spanning approximately 1,645,000 square kilometers, is situated between 25 and 40 degrees north latitude and 44 to 64 degrees east longitude. Rainfall varies drastically: the Lut Desert receives virtually no precipitation, while Bandar Anzali on the northern coast

experiences over 1,500 millimeters annually. Most rainfall occurs in the colder months, often falling as snow in the Alborz and Zagros mountain ranges. (Azarakhshi, 2005)

Despite its rich 7,000-year-old civilization, much of Iran is situated in a hot and arid region. Ironically, the country is renowned for its three World Food Organization-recognized agricultural heritages, showcasing sophisticated water management practices and qanat **sys**tem**s** that facilitated agricultural expansion and water conservation in desert areas. Neverthele**ss**, Iran is now grappling with a severe water scarcity crisis. (FAO, 2014, 2020; Madani, 2014)

The combined effects of drought, rising water demand, resource degradation, and mismanagement have placed immense pressure on Iranian society, leading to increasing discontent and political unrest. Future water security concerns are compounded by climate change and transboundary water issues with neighboring countries. (Climate Diplomacy, 2020)

Data from 1986 to 2016 reveals trends of warming, declining precipitation, and reduced runoff, highlighting unsustainable water use, particularly from groundwater sources, to support irrigated agriculture. These trends emphasize the urgent need to understand and address changes in water resources to mitigate and adapt to regional challenges (Moshir Panahi, Kalantari, Ghajarnia, Seifollahi-Aghmiuni, & Destouni, 2020) groundwater extraction in Iran has also led to land subsidence, causing significant infrastructure damage. (Haghshenas Haghighi & Motagh, 2021)

While economic studies often focus on air pollution and carbon dioxide emissions as indicators of environmental quality (Biswas, Farzanegan, & Thum, 2012; Cole, 2007), this approach overlooks a broader range of environmental challenges. In Iran, carbon dioxide emissions are not the primary environmental concern. Dust storms and water stress pose more significant threats, and neglecting these issues could exacerbate the crisis. This highlights the need for a more comprehensive exploration of various factors that contribute to environmental degradation and sustainability, especially considering that 24% of global deaths are linked to environmental hazards. (WHO, 2016).

The level of water stress indicates a country's water resource utilization to meet its demand, reflecting the sustainability and progress challenges in addressing water scarcity (World Bank, 2022).

Studying water stress in Iran aligns with Sustainable Development Goals, including clean water and sanitation (SDG 6), zero hunger (SDG 2), good health and well-being (SDG 3), responsible consumption and production (SDG 12), and the impact of climate change on food production (SDG 13). This research aims to comprehensively identify the primary drivers of water stress in Iran during the period between 1975 and 2019. Departing from the conventional focus on CO2 emissions prevalent in many environmental studies, we introduce a novel approach that integrates both environmental factors (like rising temperatures and agricultural practices) and socioeconomic dimensions (particularly the impact of economic sanctions). This multi-faceted analysis aims to provide a more nuanced understanding of the complex factors contributing to water stress in Iran.

The article is structured as follows: the theoretical framework and research background are presented in the next section. The research methodology and data review are the subject of section four. Empirical findings and discussion are allocated to section five, while the conclusion and policy recommendations are presented in section six.

2. Literature Review

This section will provide an overview of water stress, followed by an analysis of the mechanisms that contribute to this phenomenon, including agriculture, climate change, economic growth, and economic sanctions.

2-1- Water Stress

Water stress is measured by the ratio of freshwater withdrawn from all sectors to the total available freshwater resources, considering environmental needs. This indicator, also known as water withdrawal

intensity, considers sectors like agriculture, industry, and services. (World Bank, 2022)

Notably, many companies and others use the terms "water scarcity," "water stress," and "water risk" (often to indicate geographic areas where water challenges are more pronounced) in various ways and often interchangeably. These terms are useful insofar as they help the community and organizations understand the degree and nature of water-related challenges for a geographic area and make informed decisions about how to manage them. (Schulte, 2014)

Studying and managing groundwater is difficult because it is hidden. Assessing its global status is challenging due to limited spatial data, so we rely on mixed observations and models, often from well-documented areas. Areas facing greater depletion receive more attention with existing data and models, but still show few details. Despite the challenges, efforts to improve global and regional groundwater assessments continue. (Lall, Josset, & Russo, 2020)

Climate change has begun to have an adverse impact on water resources, and energy production has become more water-dependent in the 21st century. Electricity generation, excluding wind power plants, is dependent on water resources to varying degrees (Fecht, 2019; Novruzova, 2021).

Water and energy are essential for development. Water resource development projects provide opportunities for development in a wide range of sectors, from agriculture to tourism, energy to health. It should therefore be borne in mind that water is not only essential for meeting the vital needs of all living beings but also for the dissemination and continuation of sustainable development and social welfare. Since no other natural economic and renewable resource has yet been discovered to perform similar tasks in the development process. It seems that no resource can replace natural renewable water for a long time. (Yildiz, 2017)

2-2- Agriculture and Water Stress

Agriculture is a vital sector in Iran, heavily reliant on natural resources like land and water. In dry and semi-arid regions, such as Iran, the expansion of agricultural activities exacerbates water scarcity. Unsustainable water consumption for irrigation has led to critical issues, including groundwater depletion, land subsidence, and reduced agricultural productivity. These problems have been intensified by

climate change, poor water management, and a lack of policy foresight. As a result, Iran is facing a significant threat to its water security and national stability. Given that agriculture accounts for a large portion of the country's water usage and employs a significant part of the workforce, understanding the drivers behind unsustainable water consumption is crucial for developing solutions to Iran's growing water crisis.

Agriculture can consume large portions of land, even in dry and semi-arid regions where extensive agriculture is difficult (Ritchie & Roser, 2020). Recent studies highlight the severity of Iran's water scarcity, primarily driven by agricultural practices. (Behling et al., 2022) report widespread agricultural expansion, overexploitation of groundwater, and reduced vegetation growth in dry areas, causing a sharp decrease in total water storage.

(Ashraf, Nazemi, & AghaKouchak, 2021)focus on the critical role of human-induced drought in groundwater depletion across Iran. Their study, which uses groundwater data from 478 sub-basins and 30 basins in Iran, estimates a nationwide decline of approximately 74 cubic kilometers between 2002 and 2015. The study attributes the groundwater crisis to excessive water withdrawals for irrigation, leading to increased soil salinity, land subsidence, and threats to socio-economic security.

(Haghighi et al., 2020)provide a regional perspective by examining water sustainability in Fars Province, southern Iran. They define three stages of water sustainability—sustainable, transitional, and unsustainable—and conclude that the province has shifted to unsustainable water use after 2006. The expansion of irrigated agriculture, combined with climate change, reduced river flows, and declining groundwater levels, has led to instability in agricultural production and reduced agricultural areas.

(Mirzaei, Saghafian, Mirchi, & Madani, 2019) explore the groundwater-energy-food nexus in Iran's agricultural sector, revealing that agricultural policies supported by subsidized water and energy have resulted in unsustainable water consumption. The study

emphasizes that such practices threaten national security by driving Iran toward water bankruptcy.

(Madani, 2021) identifies farmers as one of the most vulnerable groups affected by water scarcity. The study points to decades of poor management, weak environmental governance, and a failure to consider water as a key constraint in Iran's development plans. With around 90% of the country's water allocated to agriculture, this sector continues to exert immense pressure on water resources, particularly in the context of economic sanctions that limit the government's ability to create alternative livelihoods for farmers.

Studies outside of Iran also highlight similar challenges. For instance, (Barrios, Ouattara, & Strobl, 2008) investigated the impact of climate change on agricultural production in sub-Saharan Africa, finding that climate-related factors have been a major driver of agricultural performance (Eklund, Mohr, & Dinc, 2024) examined land abandonment in Northeast Syria due to agricultural drought, revealing long-term water mismanagement as a key contributor to land degradation and migration.

2-3- Climate Change and Water Stress

Climate and weather changes disrupt the water cycle and directly impact water resources. Global warming and rising temperatures increase evaporation and affect precipitation levels, exacerbating water shortages. These changes not only affect access to water but also increase water demand across various sectors. Given the importance of water as a vital resource for life and economic development, particularly in regions facing water scarcity, it is essential to examine the impacts of climate change on water stress. This study focuses on these impacts, with a particular emphasis on Iran, where water scarcity presents significant challenges. The aim is to investigate how climate change exacerbates water stress and what implications this has for water management and policy.

Water and climate change are inextricably linked. Extreme weather events increasingly make water scarcer, more unpredictable, more polluted, or all three. These impacts threaten the entire water cycle, sustainable development, biodiversity, and people's access to water and sanitation (Chen & Lai, 2023).

The impacts of climate change on water availability are expected to be particularly adverse in drier climatic regions such as the

Mediterranean. Increasing water scarcity will intensify competition for water resources not only between sectors but also between countries sharing transboundary river basins. Additionally, the interdependence of the energy sector on water resources and the water supply sector on energy inputs makes the "water-energy nexus" a major challenge for the near future (Teot, Rodr, & Roebeling, 2019).

In the Zayandeh Rud basin, for instance, climate and socioeconomic changes will likely increase pressure on water resources by mid-century, potentially leading to a water crisis. Despite a 9% reduction in agriculture, irrigation demand is expected to rise from 17% to 19%. This, along with increasing demand for drinking and industrial water, will put further strain on both water resources and the agricultural sector as climate change reduces overall water availability (Aghapour, Nazari, & Araghinejad, 2020).

(Haghighi et al., 2020) examined the distribution of meteorological droughts from 1977 to 2016 and found no significant negative trend in annual rainfall during that period. However, the occurrence of hydrological droughts increased significantly between 1997 and 2016. The expansion of irrigated agriculture, with over 60% of rain-fed farming being replaced by irrigated agriculture, especially between 1997 and 2006, placed considerable pressure on both surface and groundwater resources.

On a global scale, (Gosling & Arnell, 2016)conducted an assessment of the impacts of climate change on water scarcity. Using climate change data from 21 global climate models (GCMs), they estimated water resources in 1,339 river basins worldwide. They applied the Water Crowded Index and Water Stress Index to assess the exposure of different regions to water scarcity as a result of climate change. Their findings indicate that by 2050, between 0.5 and 3.1 billion people will be exposed to increased water scarcity due to climate change, although the severity of impacts will vary depending on regional climate patterns.

2-4- Economic Growth and Water Stress

Economic activities can harm the environment, as the environmental Kuznets curve theory suggests (Bo, 2011). Most studies focus on carbon dioxide emissions as an indicator of environmental degradation (as mentioned earlier) and show how economic growth leads to higher emissions. However, economic activities also rely on water and can negatively impact water stress. Water and economic growth have a two-way relationship.

By 2050, economic growth and population increases alone could result in an additional 1.8 billion people facing at least moderate water stress. Eighty percent of these people would be in developing countries (Schlosser et al., 2014).

(Desbureaux, Damania, Rodella, Russ, & Zaveri, 2019) studied the relationship between economic activity and water quality using data from 19 countries between 1990 and 2014. They found that heavily polluted rivers led to reduced economic growth in downstream areas (water pollution harms agriculture, industry, health, etc.). These areas lost between 0.8% and 2.0% of potential economic growth. These losses suggest that the true costs of environmental degradation are significantly underestimated in many places and are much higher than sustainable levels.

Water scarcity is already a serious threat to food security and economic prosperity in many countries. Future population growth is expected to further strain existing water resources, both regionally and globally (Schewe et al., 2014).

2-5- Sanctions and Water Stress

There haven't been many studies on the environmental effects of sanctions. Sanctions can disrupt a country's economy, putting pressure on natural resources. This happens because the sanctioned country is forced to rely on its own resources, often natural resources, to meet its needs. In this way, sanctions can act as a catalyst for environmental problems (Madani, 2020).

Economic sanctions are political tools used to isolate and damage the economies of target countries. They aim to force these countries to change their policies or make political changes. The number of sanctions imposed by international organizations like the European Union and the United States has increased since the 1990s. However, there's still debate about whether these punishments are justified. Even

worse, the unintended consequences of sanctions can build up and make it harder to achieve global climate goals. This is because sanctions can speed up negative environmental impacts (Rustler, 2019). A sanctioned country might be forced to create industries that cause serious environmental damage (Frauhiger, 2018).

Sanctions that limit access to international funding or foreign investment can stop investment in targeted sectors. This can ultimately hurt the country's overall economic output (GNP) (Brooks, 2002). For example, economic sanctions have made the recession in Iran deeper and longer (Iranmanesh, Salehi, & Jalaee, 2021).

(Fu, Chen, Jang, & Chang, 2020) studied the impact of international sanctions on environmental performance. They used data from 22 sanctioned countries between 2000 and 2016. Their findings showed that sanctions (of various types) lowered the Environmental Performance Index score of the sanctioned countries. The decrease ranged from 4.5 to 14.0 points depending on the type of sanction.

3. Methodology

To avoid spurious regression, it is essential to determine the time series properties of the variables before selecting the estimation method. This ensures that the model produces reliable forecasts by avoiding misleading results. One key aspect is checking for a cointegration relationship between non-stationary variables, which can significantly affect the accuracy of the model's predictions (Engle & Granger, 1987).

In cases of spurious regression, the results may appear misleadingly accurate, with high t-values and R2R^2R2 values close to one, while the Durbin-Watson (DW) statistic is low, increasing the risk of type 1 errors (Newbold & Granger, 1974). Therefore, tests like the Augmented Dickey-Fuller (ADF) unit root test are applied to assess whether the series are stationary or contain random trends (Dickey & Fuller, 1979).

Once the time series properties are established, long-run relationships are estimated using methods like Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS). DOLS provides reliable estimates by including lagged

terms and capturing the dynamic effects of the variables (Stock & Watson, 1993), while FMOLS addresses endogeneity issues by using instrumental variables (Phillips, PC, Hansen, 1990). Both methods are useful in estimating the relationships between variables while accounting for non-stationarity and endogeneity.

The models for this study are structured as follows:

$$L(WS_t)=\beta_0+\beta_1 L(P_t)+\beta_2 L(T_t)+\beta_3 L(GDPp_t)+\beta_4 L(AR_t)+ \beta_5 L(PC_t)+\beta_6 (ES_t)+\gamma_1 L(WS_{t-1})+\varepsilon_t \quad \textbf{(1)}$$

$$\Delta L(WS_t)=\beta_0+\beta_1 \Delta L(P_t)+\beta_2 \Delta L(T_t)+\beta_3 \Delta L(GDPp_t)+\beta_4 \Delta L(AR_t) +\beta_5 \Delta L(PC_t)+\beta_6 \Delta (ES_t)+\gamma_1 \Delta L(WS_{t-1})+\varepsilon_t \quad \textbf{(1)}$$

So that: $L(WS_t),L(P_t),L(T_t),L(GDPp_t),L(AR_t),L(PC_t),(ES_t)$ respectively denote the natural logarithms of water stress, precipitation, temperature, per capita GDP, agricultural land, perennial crop land, and economic sanctions. Lagged values of $L(WS_t)$ are included to capture dynamic effects and autocorrelation.

γ_1 represents the coefficient of the lagged dependent variable $L(WS_{t-1})$, indicating the dynamic effect of the dependent variable. $\beta_{6,\ldots},\beta_2,\beta_1,\beta_0$ are coefficients representing the effects of lagged independent variables, and ε_t is the disturbance term.

4. Empirical Findings

4-1- Data Overview

The country under study is Iran. The study period is 2019-1975. **Table 1** provides a report of the model variables and the source of data collection for each variable.

Table 1.Variables and Data Sources

Variable	Unit	Definition	Source
WS	Freshwater withdrawal as a proportion of available freshwater resources	The level of water stress	World Bank
PR	Millimeters	Annual Precipitation	Trading Economics

TE	Celsius	Annual average temperature	Trading Economics
GDP	Per capita Gross Domestic Product (constant 2015 US dollars)	Gross Domestic Product	World Bank
AL	1000 hectares	Land used for cultivating crops in rotation with fallow periods.	FAO
PC	1000 hectares	Land cultivated with long-term crops that do not require replanting for several years.	FAO
ES	International sanctions imposed by US, EU, UN.	Economic sanction	Global Sanctions Database

Freshwater Withdrawal as a Proportion of Available Freshwater Resources (WS): This indicator, measured by the World Bank, represents the level of water stress in a country. It is the ratio between the total amount of freshwater withdrawn by all sectors and the total amount of renewable freshwater resources available, after accounting for environmental water requirements. A higher value indicates greater stress on freshwater resources.

Annual Precipitation (PR): Measured in millimeters by Trading Economics, this refers to the average amount of rainfall a country receives in a year.

Annual Average Temperature (TE): This metric, also measured by Trading Economics, indicates the average temperature a country experiences throughout a year.

Gross Domestic Product Per Capita (GDP): This indicator, measured by the World Bank in constant 2015 US dollars, represents the average economic output per person in a country.

Arable Land (AL): This metric, measured by the Food and Agriculture Organization (FAO) in hectares. Land used for cultivation of crops in rotation with fallow, meadows and pastures within cycles of up to five years. The total of areas under "Temporary crops," "Temporary meadows and pastures," and "Temporary fallow." Arable land does not include land that is potentially cultivable but is not cultivated.

Permanent Crops (PC): Measured by the FAO in hectares. Land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee), land under trees and shrubs producing flowers (such as roses and jasmine), and nurseries (except those for forest trees, which should be classified under "Forestry"). Permanent meadows and pastures are excluded from Permanent crops.

International Sanctions (ES): The sanction variable in this study is extracted from the Global Sanctions Database (GSDB). The data provides detailed information on various types of sanctions imposed during the period of 1950-2020. This allows for the categorization of sanctions into military, arms, trade, financial, and travel sectors. Additionally, sanctions can be classified based on the imposing countries. Since economic sanctions have the most significant impact on a country's economy and deterrence level due to their ability to block and restrict trade and financial channels, this study focuses on economic sanctions, specifically financial and trade sanctions. To examine the effects of economic sanctions, dummy variables are created to represent the sanctions imposed on Iran by the sending countries (the United States, the European Union, and the United Nations).

Table 2 provides a summary of the descriptive statistics of the variables.

Table 2: Summary Statistics of the Data

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum

Water STRESS	45	66.92132	15.27784	39.35458	81.28908
PRECIPITATION	45	231.7353	39.29846	148.6	345.41
TEMPERATURE	45	17.99133	0.685773	16.53	19.32
GDPP	45	4541.814	1054.051	2986.998	7622.345
ARABLELAND	45	15570.5	1021.466	12981	17388
PERMANENTCROPS	45	1318.667	388.6583	590	1891
ECONOMIC SANCTION	45	0.911111	0.287799	0	1

Water Stress: The average water stress level is 45, with a standard deviation of 66.92. This indicates a **wide range** of water stress levels across the dataset.

Precipitation: The average annual precipitation is 231.74 millimeters, with a standard deviation of 39.29 millimeters.

Temperature: The average annual temperature is 17.99 degrees Celsius, with a very low standard deviation of 0.69 degrees Celsius.

GDPP: The average GDP per capita is 4541.81 US dollars, with a standard deviation of 1054.05 US dollars. This indicates moderate variation in income levels across the different areas. The minimum (around $2987) and maximum (around $7622) GDP per capita values highlight this disparity

Arable Land: The average amount of arable land is 15570.50 square kilometers, with a standard deviation of 1021.47 square kilometers.

Permanent Crops Land: The average amount of permanent crops is 1318.67 square kilometers, with a standard deviation of 388.66 square kilometers.

4-2- Unit Root and Cointegration Test

In time series econometrics, stationarity should be examined before model estimation. Verifying the stationarity of a random process allows for statistical assumptions and should be checked as the first test

for time series. In time series variables, stationarity is one of the important features considered in regression modeling. Stationarity means the stability and reliability of the time series. When a time series is stationary, patterns, trends, and statistical properties change little over time, and regression results can be trusted. The results of the unit root test are reported in Table 3.

Table 3. Dickey-Fuller Unit Root Test

Variable	Level Statistic	First Difference Statistic	Result
LOG_WS	-2.280060	-2.782142*	I(1)
LOG_PERCCIPITATION	-1.450207	-11.77380***	I(1)
LOG_TEMP	-1.023184	-9.770610***	I(1)
LOG_GDPP	-1.882563	-4.154292***	I(1)
LOG_ARABLELAND	-2.123217	-3.576618***	I(1)
LOG_PERMANENTCROPS	-1.247954	-3.909172***	I(1)

*, **, *** represent 10%, 5%, and 1% respectively

According to Table 3, all variables are non-stationary based on the Augmented Dickey-Fuller test at the level but become stationary (integrated) with one or more differencing. In other words, all model variables are integrated of order (1). Additionally, according to the Johansen cointegration test, a long-run relationship between the model variables is confirmed. The results of the cointegration test are reported in Table 4.

Table 4. Johansen Cointegration Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.756588	166.7138	125.6154	0.0000
At most 1 *	0.508874	105.9548	95.75366	0.0083
At most 2 *	0.448569	75.37950	69.81889	0.0168
At most 3 *	0.373448	49.78426	47.85613	0.0326
At most 4	0.284462	29.68075	29.79707	0.0516
At most 5	0.195049	15.28778	15.49471	0.0537
At most 6 *	0.129386	5.957911	3.841465	0.0146
None *	0.756588	166.7138	125.6154	0.0000

4-3- Model Estimation

The results of estimating equations **(1)** and (2) are reported in **Table 5**.

Table 5. Research Model Estimation

Variable	DOLS		FMOLS	
	Coefficient	p-value	Coefficient	p-value
LOG_PERCCIPITATION	0.055677	0.7638	-0.013442	0.8868
LOG_TEMP	2.559395	0.0014	1.959757	0.0010
LOG_GDPP	0.254303	0.0242	0.177757	0.0652
LOG_ARABLELAND	1.043819	0.0019	0.762237	0.0037
LOG_PERMANENTCROPS	0.240751	0.0669	0.357874	0.0000
ECONOMIC SANCTION	0.347469	0.0546	0.253128	0.0062
C	-17.76455	0.0001	-13.04640	0.0001

According to the model estimation results in **Table 5**, geographical factors such as precipitation do not have a significant impact on water stress, while temperature significantly increases water stress. Gross domestic product, arable land, and permanent crops have a significant role in increasing water stress. In addition, sanctions have a positive and significant impact on water stress.

5. Discussion

Table 5 indicates that precipitation does not significantly impact water stress.

Figure *2* shows that Iran, with an average annual precipitation of about 240 millimeters, is in a warm, dry region and often experiences below-average rainfall. Therefore, low precipitation is not an unusual phenomenon in the country, and people have lived with this amount of precipitation for many years. The results of this study confirm the study of Haghighi et al. (2020), which showed that meteorological drought did not show a significant negative trend in annual precipitation during the years 1977-2016, but the occurrence of hydrological droughts increased significantly during the period 1997-2016. The expansion of irrigated areas and the replacement of more than 60% of rainfed agriculture with irrigated agriculture (especially between 1997 and 2006) put significant pressure on surface and groundwater resources.

This means that a low-precipitation country like Iran has exacerbated the trend of increasing water stress by changing the type of agriculture from rainfed to irrigated.

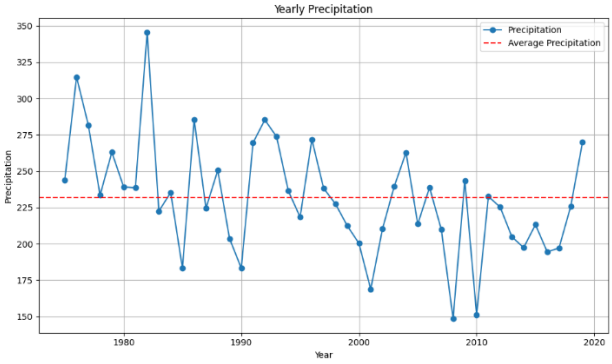


Figure 2. Time Series of Annual Precipitation in Iran (mm)

Temperature has a significant positive impact on water stress, as indicated by our results. **Figure 3** illustrates an increasing trend in Iran's mean temperature. Global warming has exacerbated this rise, placing the Middle East, including Iran, in a particularly vulnerable position(Wisevoter, 2023).

Higher temperatures can increase evaporation rates and lead to more evaporation of water from lakes, rivers, and soil.

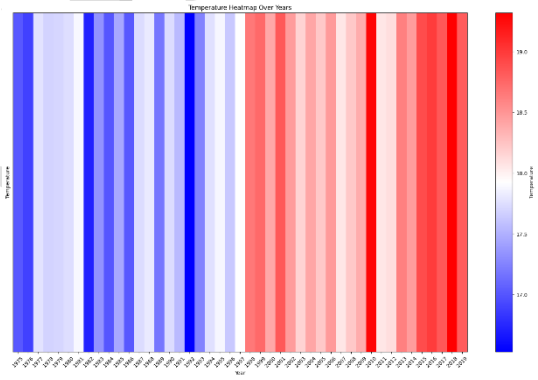


Figure 3. Time Series of Annual Mean Temperature in Iran

This increased evaporation can exacerbate drought and water scarcity conditions and impact ecosystems and human activities. These findings are also in line with the studies of (Alizadeh Choobari & Najafi, 2018), which showed that from 1951 to 2013, Iran warmed by nearly 1.3 degrees Celsius (+0.2 degrees Celsius per decade), with the minimum temperature increasing twice as much as the maximum. As a result , there has been an increase in the frequency of heat extremes and a decrease in severe cold occurrences. Similarly, the results of (Soltani et al., 2016) confirm that temperatures are rising, with a significant increase in the number of hot days and warm nights, and a decrease in the number of cold days and cold nights. The mean maximum and minimum temperatures have also increased.

Gross domestic product (GDP) has a positive and significant impact on water stress. **Figure 4** shows the time series of GDP per capita. Economic activities and agricultural and industrial processes associated with GDP often require significant water use. This can lead to increased demand for water resources and potentially put pressure on local water resources. Although agriculture accounts for about 10% of GDP and consumes about 90-80% of water resources, It can be agreed with Madani (2021) that Iran has made little progress in diversifying its economy. However, it is still largely dependent on its natural resources, especially oil and water.

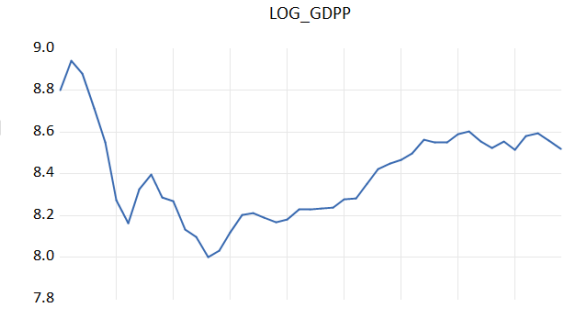


Figure 4. Time Series of GDP per Capita

Arable land has a positive and significant impact on water stress. As you can see in **Figure 5**, arable land and crops account for a large share of agricultural products. Slogans such as self-sufficiency in agricultural production, especially in grains such as wheat and barley, have brought large areas of arable land under cultivation in the country, which itself consumes more than 80% of the water in this sector. Studies such as those by (Ashraf et al., 2021), (Behling et al., 2022), and (Moridi, 2017)confirm that water abstraction for agriculture has significant negative impacts on water resources. However, it remains to be seen how long the potential for cultivation will exist given the country's water resource constraints.

Despite the fact that the Middle East is the largest importer of grains, and this is due to water resource problems, Iran produces most of its own needs domestically (Zolfaghari & Jariani, 2021). This ensures food security for the country, but on the other hand puts additional pressure on water resources, which in the long term is a crisis-generating situation, as it puts the country in a position where it not only does not have water for agricultural production but also food security is at risk.

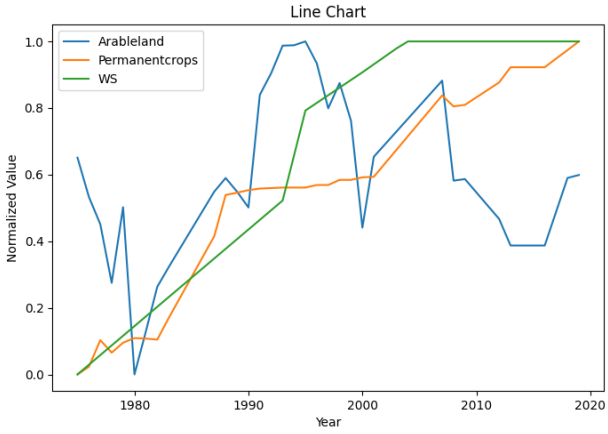


Figure 5. Time Series of Comparison of Water Stress, Arable Land, and Permanent Crops (Data Normalized)

permanent crops have a positive and significant impact on water stress. As you can see in **Figure 5**, there is an increasing trend in permanent crop areas. Permanent crops typically require more water than arable land. Permanent crops include orchards and vineyards where plants are planted once and continue to produce for several

years. These crops have a constant need for water throughout their lifespan, especially during critical periods such as flowering and fruit growth. In contrast, arable land is used for annual crops that are planted and harvested in the same growing season. While annual crops also require water, their water needs are generally lower than those of permanent crops.

Efficient water management is essential for sustainable agriculture. According to Fructidor (2023), citing the Food and Agriculture Organization (FAO), Iran was a top exporter of agricultural products in 2021, leading in figs (8,763 tons) and ranking second in pistachios (136,000 tons) and raisins. It was the fourth-largest exporter of dates (245,000 tons), fifth in cucumbers (166,000 tons), and sixth in kiwis (69,000 tons). In terms of production, Iran ranks third in dates, honey, pistachios, and dried fruits, and holds various other positions in almond, watermelon, kiwi, eggplant, onion, tomato, spinach, orange, grape, and pear production (Fructidor.com, 2023).

The diversity of products shows that all regions of Iran are involved in these productions. Although climatic diversity results in the production of different products, which can be a turning point for the country, on the other hand, attention should be paid to the amount of water used for these products and many regions experience higher water stress. The share of agricultural value added in GDP is about 10%. That is, 90% of the country's water resources are used for 10% of GDP! How long can these production and export ranks of agricultural products last given Iran's water situation? Does the country have the potential for such long-term production?

In addition, a high volume of agricultural products in Iran spoils before reaching the final consumer. This is a significant issue considering the large amount of water resources used in their production.

Sanctions have a positive and significant impact on water stress. The goal of sanctions is to weaken a country's economy in order to have a political deterrent effect**.** In a sanctioned and weakened economy, where financial and trade exchanges are limited and blocked, the

country's economy, due to insufficient access to technology and global markets, is forced to use natural resources such as oil and gas, forests and water to meet its domestic needs. Sanctions can indeed have an impact on water stress, especially if they affect the region's economy and access to resources. Sanctions put the country's economic pressure on natural resources, both in terms of employment and food security.

Perhaps, if Iran were not under sanctions, the volume of agriculture, consumption and employment in the agricultural sector would be lower. As can be seen in Figure 5, in the years leading up to the 2015-2016 JCPOA, despite the easing of sanctions but not the complete lifting of sanctions, the area of agricultural land has decreased, and with the possibility of withdrawing from the JCPOA, the area of this land has increased again. In mid-2018, the United States withdrew from the JCPOA. Of course, other factors should not be ignored in the reduction of agricultural land area, just as sanctions cannot be ignored and the level of hope for the process of lifting sanctions should be taken into account.

Economic sanctions can lead to a decrease in a country's financial capacity and limit its ability to invest in water infrastructure and management systems. This in turn can contribute to water stress by preventing the development of sustainable water supply and sanitation services. In some cases, sanctions can lead to a decline in overall living standards and make it difficult for individuals and communities to access safe water and sanitation facilities. Therefore, in a broader sense, the economic consequences of sanctions can have indirect effects on water stress in affected areas. Studies on the impact of sanctions on environmental quality are limited, and there has been no study on the impact of sanctions on water resources. For example, Fu et al. show that sanctions reduce Environmental Performance Index (EPI) (Fu et al., 2020).

6. Conclusion and Policy Recommendations

In conclusion, this study investigated the factors contributing to water stress in Iran from 1975 to 2019. While geographical factor like rainfall has little influence, temperature significantly increases water stress. Economic factors like GDP, arable land use, and agricultural production also play a major role. Interestingly, sanctions had a positive impact on water stress reduction.

Based on these findings, several policy recommendations are suggested. Since temperature has the biggest impact, prioritizing measures to adapt to climate change is crucial. Effective water resource management is also essential. This could involve better allocation of water resources, promoting water-saving technologies in agriculture and industry, and improving water governance.

Given agriculture's significant contribution to water stress, diversifying crops towards less water-intensive options and promoting sustainable practices are vital. Additionally, reviewing agricultural development policies that rely on subsidized water and energy is crucial, as these can lead to unsustainable consumption.

Furthermore, policies should be developed to lessen the negative effects of economic sanctions on water stress, or ideally, to remove them altogether. This could involve economic diversification and stronger diplomatic efforts.

By addressing these issues, policymakers can work towards reducing water stress in Iran and ensuring sustainable water management for the future. It's important to remember that water stress is a transboundary issue, not limited to Iran. Therefore, future studies should involve countries that share water borders. Increasing drought can lead to economic problems, water disputes, and economic pressure, not only affecting bordering farmers but also potentially causing tensions between countries over water security. Unfortunately, such conflicts are already a reality today.

Another concern is the phenomenon of migration, already on the rise due to war and drought, which creates significant problems, especially for European countries. If water stress intensifies, this migration is likely to accelerate, leading to even deeper problems.

Finally, it's important to acknowledge that this study did not address mismanagement and corruption due to insufficient data. However, considering the significant impact of corruption on environmental degradation, it's likely that corruption also plays a role in water stress. Hopefully, future research will explore this aspect in more detail.

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