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Risk Managing of Wheat Sustainable Production in Iran: A Portfolio Theory

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ABSTRACT

The challenge of water scarcity poses a significant environmental challenge for the agricultural sector, jeopardizing the sustainable production of vital crops like wheat. Iranian provinces that produce wheat have varying water resources and climatic conditions. These differences have resulted in distinct economic benefits and environmental risks in wheat production among the provinces. In this study, the water footprint of wheat in each province was calculated from 2000 to 2020, and its environmental costs were deducted from the gross margin. Consequently, the social benefit was considered as the return of the wheat production portfolio in each province to manage the risk of sustainable production. Subsequently, the portfolio theory was employed through quadratic mathematical programming to minimize the social benefit-risk and determine the proportion of wheat cultivation in each province for optimal portfolio and sustainable production. The results showed that the provinces of Khuzestan (21.6%), Fars (17.1%), Hamedan (16.1%), Kurdestan (13.2%), Khorasan Razavi (11.4%), Golestan (11.3%), Qazvin (5%), and Kermanshah (4.3%) are in the optimal portfolio. In the optimal portfolio, a significant share of wheat production was related to the provinces with low risk in production (Khuzestan and Fars). The findings suggest that it is necessary to consider economic risks along with environmental risks to achieve sustainable production in the long run. As a result, the eastern and central provinces (Sistan and Baluchestan, South Khorasan, Semnan, Isfahan, Yazd) with the highest water footprint were removed from the optimal portfolio, and the western provinces with higher gross margin and lower water footprint were replaced with a larger share (Kermanshah, Hamedan, and Kurdestan).

Keywords: Portfolio theory, Social benefit, Risk, Sustainable, Wheat.

INTRODUCTION

About 60% of the total world area harvested is devoted to grains. In 2020, global grain production reached 2.79 billion tons, with 649.759 million tons related to wheat. Iran produced 23.81 million tons, 70% of which was wheat,, accounting for 50% of arable land cultivation,

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highlighting its significant agricultural role (FAO, 2021). Agricultural production, especially grains, plays a vital role in food security and gross domestic product (GDP) in Iran. Iran is located in an arid and semi-arid region with a climate range of hot to humid Caspian coasts, temperate central plateau, hot and dry southern areas, and cold mountainous regions (FAO, 2020). Over two million hectares of irrigated and four million non-irrigated lands are used for wheat production (Agricultural Statistics[1], 2020). There are two main types: dryland and irrigated. The largest dryland wheat areas are in Kurdistan, East Azerbaijan, Hamedan, Kermanshah, and Zanjan, while the largest irrigated areas are in Khuzestan, Fars, Khorasan Razavi, and Golestan (Agricultural Statistics, 2020). Fig. (1) shows the harvested wheat area and production trend during the period 2000-2020. Throughout this period, wheat production has increased because permaculture in wheat production has been one of the Iranian agricultural economic priorities in recent years (MAJ, 2020). To meet the needs of the country, which is about 12 million tons per year, the government purchases this product at a guaranteed price to ensure the producer's income and reduce dependency on agricultural production imports (MAJ, 2020). Although a guaranteed price could lead to a higher level of wheat production, there is no guarantee that it also leads to sustainable production in the long run.

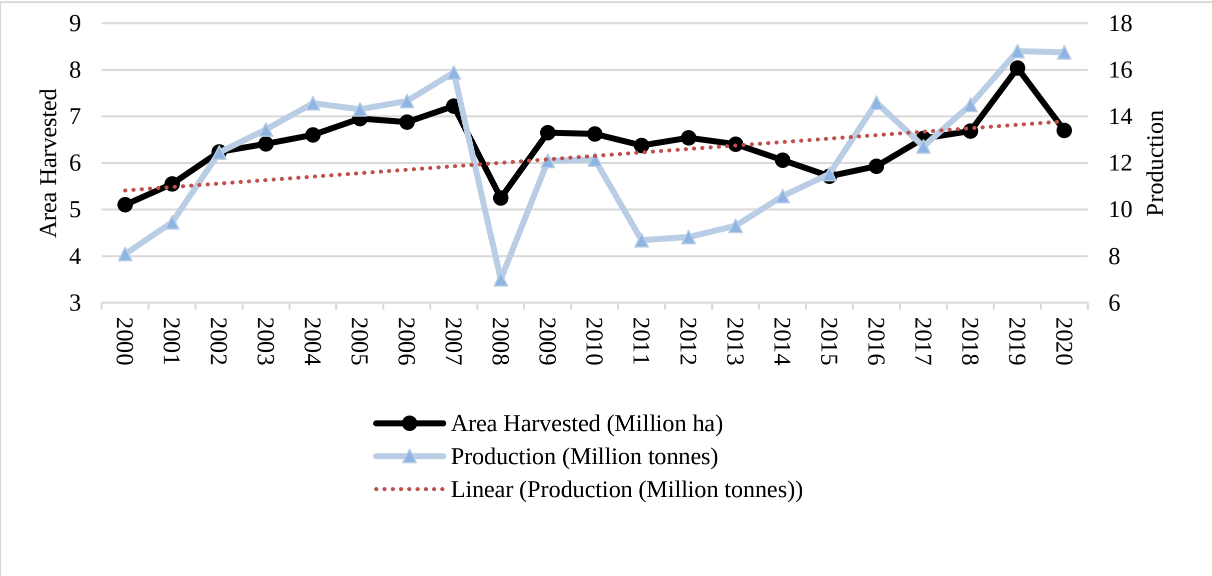


Figure 1. Area harvested and production of wheat in Iran (FAO[2], 2020).

Water scarcity is considered one of the long-term issues in agricultural production in Iran (Zhang et al., 2016). Demand for water consumption has significantly increased in recent years due to the expanding agricultural activities and the improper use of water. Additionally, there

[1] https://biamar.maj.ir/ManagementReport/powerbi/DataBank/AgriBiReport?rs:embed=true
[2] FAO, https://www.fao.org/faostat/en/#data/QCL

has been a decrease in average annual rainfall over the last few decades as a result of climate change, leading to a reduction in water resources and unreliable access (Chouchane et al., 2018; Fathi et al., 2020). Thus, the concept of water footprint has been introduced to measure the extent of unsustainable and precarious access to water. The water footprint takes into account the quantity and quality of water (Hoeksta and Chapagain, 2007, 2008; Mekonnen and Hoekstra, 2011; Hoekstra and Mekonnen, 2012). Water footprint refers to the amount of freshwater used to produce the products (Yang et al., 2006), which is a multidimensional indicator including the quantity of water (amount of water consumed, known as blue and green water), and the quality of water (amount of contaminated water, known as grey water) (Hoeksta and Chapagain, 2007, 2008; Mekonnen and Hoekstra, 2011; Hoekstra and Mekonnen, 2012; Tom et al., 2016; D'Ambrosio et al., 2018). Water footprint is influenced by climatic variables like temperature, wind speed, precipitation, humidity, solar radiation, and chemical fertilizer application, posing risks and uncertainties for crop yield and sustainable production (Monjardino et al., 2015; Herold et al., 2018; Fathi et al., 2020). Climate change may cause a decrease in Iran's non-irrigation land and irrigated grain yield over the next 50 years. Risks in sustainable production are influenced by price and market factors (Fathi et al., 2020; Sewando, 2021). To reduce risks and sustain sustainable production, a combination of economic and environmental criteria, considering the environmental side effects of agricultural activities, is needed. Therefore, gross margin and water footprint can be suitable criteria for economic evaluation and environmental costs, respectively.

Agricultural risk management has been a focus in various studies (Marko et al., 2016; Sewando, 2021; Nguyen-Huy et al., 2018; Fathi et al., 2020), with a particular emphasis on capital risk management (Kim, 2021; Kim and Choi, 2019; Paquin et al., 2016; Atmaca, 2022). Portfolio theory, which aims to determine a set of assets that can achieve minimum risk with the highest return, has been used to maximize profits and minimize risk in agriculture (Markowitz, 1991;Viganò and Castellani, 2020; Bai et al., 2021; Atmaca, 2022; Ziakas, 2021). Studies have shown that implementing a crop portfolio can increase yields, reduce financial effects, and enhance profitability (Barkley et al., 2010; Goodwin and Hungerford, 2014; Mrkoa et al., 2016; Nguyen-Huy et al., 2018; Nguyen-Huy et al., 2018; Paut et al., 2019; Sewando, 2021). Geographical diversity has also been explored as a potential tool for farmer compliance and decision support. Paut et al. (2019) found that selecting appropriate varieties can reduce expected yield fluctuations by over 77%. Sewando (2021) evaluated the effectiveness of risk reduction strategies in portfolio diversity among agro-pastoralists, finding that integrated portfolios with good returns and moderate risk could be created through strategic choices between high-return, high-risk or low-return, low-risk crop, and livestock activities. The relationship between the agricultural sector and natural resources, as well as the environment, is significant. As a result, effective management of natural assets is vital for this sector. Nevertheless, there is a scarcity of research focusing on the risk management associated with this form of capital (Alvarez et al., 2017). Water is a critical natural resource whose conservation is essential for enhancing social welfare. In light of this perspective, the current research seeks to address the challenges associated with managing sustainable production risks. This study distinguishes itself from others by focusing on sustainable production while simultaneously minimizing the risks to social benefits across various provinces. Such an approach can provide insights into the optimal integration of diverse wheat-producing regions within the country. Therefore, the outcomes of this study could inform the government in crafting targeted policies to support wheat production in these areas. To achieve this objective, portfolio theory was employed. The optimal portfolio identifies the contribution of each province to wheat production in Iran, taking into account social (economic-environmental) benefits. The criterion for social benefit was defined in terms of returns, ensuring that sustainable wheat production is maintained by minimizing long-term risks, thereby guiding the government in making informed decisions regarding this agricultural product.

The present article is organized as follows: Initially, the water footprint of wheat production in different provinces of Iran was calculated for the period 2000-2020, and the results were analyzed during this period. Then, by calculating the cost of water footprint (environmental costs) and subtracting it from the gross margin, the social benefit of wheat production was calculated for different provinces during 2000-2020. Finally, using portfolio theory, the optimal efficient frontier and consequently the optimal portfolio were determined for wheat-producing provinces in Iran and compared with the current conditions of the country.

2. MATERIALS AND METHODS

As the basis of modern portfolio theory (Moss, 2010), Harry Markowitz's mean-variance portfolio model was used to determine the optimal portfolio to minimize the risk of social benefit subject to the given level of social benefit. In this model, the minimum variance[1] (δ_p^2) is determined for a certain level of return (R^*) in the portfolio. The quadratic mathematical programming model (Eq. 1) was used for this purpose.

[1] - Risk of social benefit

$$\begin{aligned} &\text{Min } Z=\delta_p^2 \\ &St:\ \overline{Y}_p=\sum_{i=1}^{n} W_i\overline{Y}_i=R^* \qquad i=1,\ldots\ldots,30 \\ &\qquad \sum_{i=1}^{n} W_i=1 \\ &\qquad W_i\geq 0 \end{aligned} \tag{1}$$

In Eq. (1) $\overline{Y}_i$ reperesents the average social benefit derived from wheat in the ith province. This average social benefit is determined for the period 2000-2020. In section 2.1, a method is provided for calculating social benefits, W_i is the decision variable and represents the share of each province in the total area under cultivation for wheat in the country. In the optimal portfolio, the average expected return of the portfolio ($\overline{Y}_p$) is equal to the return (R*). The calculation of portfolio return variance, as outlined by Prol and Kim (2022), is presented in Equation 2. Here, σ_i^2 represents the variance associated with the social benefit of the ith province.

$$\delta_p^2=\sum_{i=1}^{n} W_i^2\,\sigma_i^2+\sum_{i=1}^{n}\sum_{j\neq i}^{n} W_i\ W_j.Cov(\overline{Y}_i.\overline{Y}_j) \tag{2}$$

Social Benefit

Social benefits were used as portfolio returns to determine sustainable wheat production (Eq. 3).

$$\begin{aligned} &\boldsymbol{\gamma_{it}}=P_{it}Y_{it}-TVC_{it}-P_{wit}WF_{it} \\ &\forall i=Proviance: 1.2\ldots.30 \\ &\forall t=2000.\ldots.2020 \end{aligned} \tag{3}$$

where P_{it} is the real price[1] of wheat (10^3 Toman per hectare), Y_{it} represents yield (tonnes per hectare), TVC_{it} is total variable cost (10^3 Toman per hectare), P_{wit} is the real price of water, and WF_{it} represents the water footprint of wheat in province i in time t.

It should be noted that to calculate the social benefit after the water footprint of wheat (blue, green, and grey water) was calculated (section 2.2), it was multiplied by the price per cubic meter of water to obtain the environmental costs ($P_{wit}WF_{it}$) of wheat production. This value was then subtracted from the gross margin to obtain the social benefit (γ_{it}).

WF calculation

WF is used as an environmental criterion in this research. The total WF during the crop growth season is derived from the total components of blue, green, and grey WF (Hoekstra and Chapagain, 2007, 2008; Hoekstra et al., 2011):

$$WF:\quad WF_{it}=WF_{it.green}+WF_{it.blue}+WF_{it.grey}. \tag{4}$$

[1] Real price is the nominal price divided by the consumer price index (CPI)

$\forall i = Proviance: 1.2 \ldots..30$, t=2000, ….,2020

In Eq. [4], i and t represent different provinces (1, 2, .., 30) and time (1 to 21) respectively. $WF_{it.green}$ is green, $WF_{it.blue}$is blue and $WF_{it.grey}$ is grey WF for the i^th^ province and t^th^ year in terms of (m^3/ton). To calculate the green WF, effective rainfall was calculated by the US Department of Agriculture method (USDA, 1993). Therefore, effective rainfall during the crop growing season is calculated according to Eq. [5], and the green WF is calculated by Eq. [6].

$$\begin{aligned} &If: P < 250\, mm.\ P_{eff} = \left({}^{P}/_{125}\right) \times (125 - 0 \cdot 2P) \\ &If: P > 250\, mm.\ P_{eff} = 125 + 0 \cdot 1P \end{aligned} \tag{5}$$

$$WF_{it.green} = \frac{P_{eff} \times 10}{Y_{it}} \tag{6}$$

In the above equations, P_{eff} represents the effective precipitation during the growing season (mm), P indicates precipitation during the growing season(mm), Y_{it} is regarded as the yield of wheat in province i during the period t (ton/ha), and 10 shows the conversion factor of mm into m^3.ha. Green WF is related to the proportion of water obtained from effective rainfall.

The calculation of Blue WF is conducted using equations [7] and [8].

$$CWU_{it.blue} = 10 \times \sum_{d=1}^{n} ET_{it,blue} \tag{7}$$

$$WF_{it.blue} = \frac{CWU_{it.blue}}{Y_{it}} \tag{8}$$

where CWU reperesents crop water use in m^3/ha, which is calculated by summing up the daily crop evapotranspiration (ET) during the growing season in mm (Eq. 7) (Hoekstra and Chapagain, 2007, 2008; Hoekstra, et al., 2011). In this equation, $ET_{it.blue}$ reperesents ET of blue water (mm) pertaining to province i in time period t. 10 serves as the conversion factor from mm unit to m^3/ha.

Crop evapotranspiration (ET) was determined as follows (Allen et al., 1998):

$$ET = K_c \times ET_0 \tag{9}$$

where K_c is the crop coefficient (between 0.4-1.3 during the growth period) and ET_0 is the reference evapotranspiration (mm d^{-1}). The reference evapotranspiration was calculated by the Penman-Monteith equation (Allen et al., 1998), which was calibrated by Razzaghi and Sepaskhah (2012) for semi-arid environments in the study area as follows:

$$ET_0 = \frac{\Delta \times (R_n - G) + K_{time} \times \rho_a \times C_p \times \left(\frac{(e_s - e_a)}{r_a}\right)}{\left(\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)\right) \times \lambda} \qquad (10)$$

where ET_0 is the reference evapotranspiration (mm d^{-1}), R_n is the net radiation (MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), Δ is the slope of the saturation vapor pressure-temperature relationship (kPa $^{o}C^{-1}$), γ is the psychrometric constant (kPa $^{o}C^{-1}$), λ is the latent heat (MJ kg^{-1}), C_p is the specific heat of the air (kJ kg^{-1} $^{o}C^{-1}$), ρ_a is the mean air density at constant pressure (kg m^{-3}), r_a is the aerodynamic resistance (s m^{-1}), r_c is the canopy resistance (s m^{-1}), e_s is the saturated vapor pressure (kPa), e_a is the actual vapor pressure (kPa) and K_{time} is a time determination conversion coefficient. K_{time} is 86400 (s d^{-1}) if ET_0 is determined in mm d^{-1}. (e.g., see Razzaghi and Sepaskhah (2012) and Allen et al., (1998) for more details).

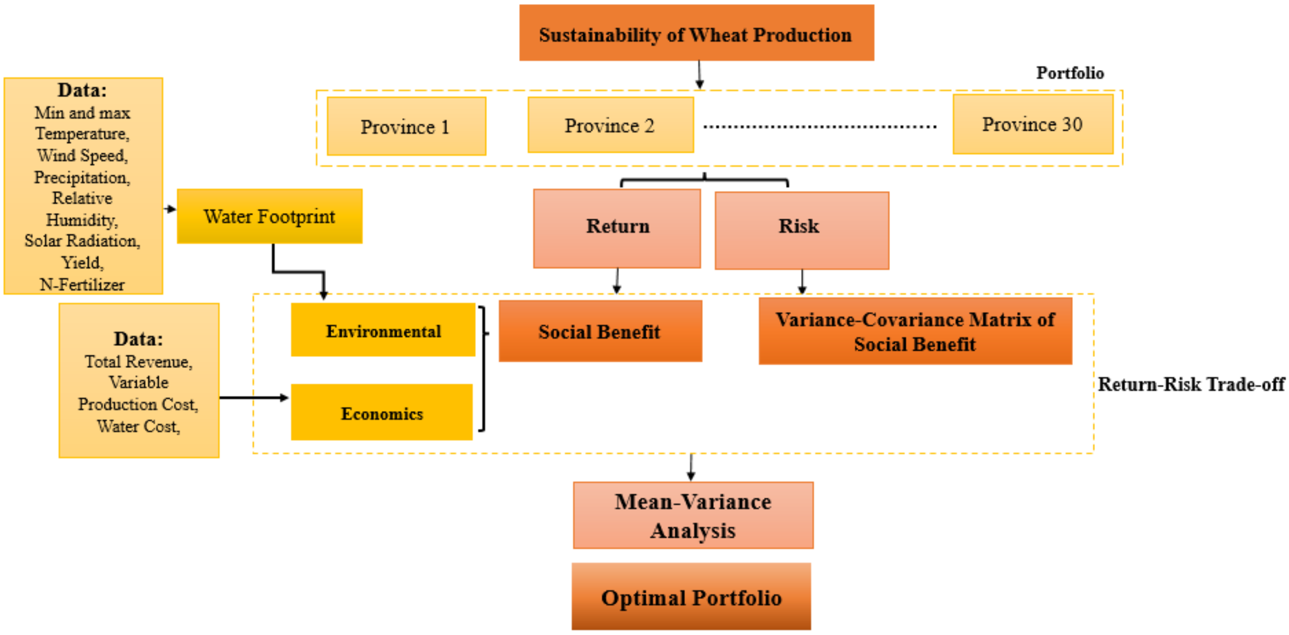
The Grey WF component is calculated using Eq. [11]:

$$WF_{it.grey} = \frac{(\alpha \times ar_{it})/(c_{max} - c_{nat})}{Y_{it}} \qquad (11)$$

where ar_{it} represents the application rate of fertilizer in the province i at period t (kg.ha^{-1}), α indicates the percentage of leached nitrogen (%), which is regarded as the maximum acceptable concentration (kg.m^{-3}), and describes the natural concentration for the pollutant examined (kg.m^{-3}) (Hoekstra and Chapagain, 2007,2008; Hoekstra, et al. 2011).

WF components are a function of random variables of climatic conditions (i.e., minimum and maximum air temperatures, wind speed, precipitation, relative humidity, solar radiation) in ET estimation. Therefore, the WF of wheat production is a random variable and is affected by climate parameters and water availability.

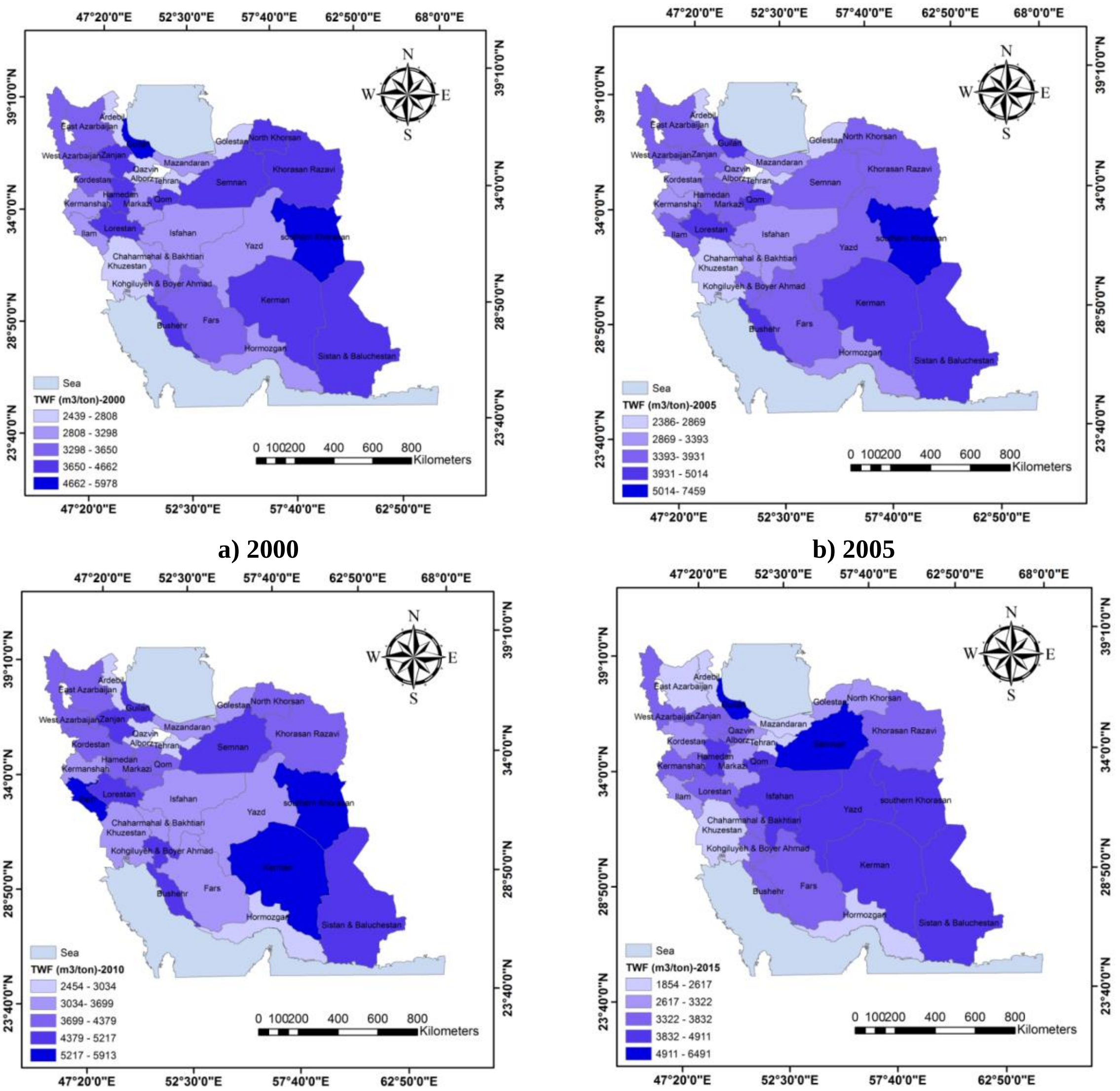
This study aims to answer the question of which wheat-producing provinces in Iran have had lower social benefit risk over time. It will examine the hypothesis that provinces leading in wheat production experience lower social benefit risk. In Fig. 2, the flow chart of the methodology is shown. Almost all provinces in Iran are wheat producers, and there is a variety of climates and water footprints for wheat production. Therefore, all provinces were chosen for the study. Subsequently, an optimal portfolio for wheat production provinces with minimal risk in social benefit was selected. In the present study, the necessary data used to determine WF were collected from the meteorological stations in the wheat-producing provinces by the Meteorological Services of Iran (2020). Additionally, in order to calculate the economic criterion, the necessary data (price, cost, and yield) were obtained from the Ministry of Agriculture- Jihad (MAJ) (2020) from 2000 to 2020.



Figuew 2. Flow chart of methodology.

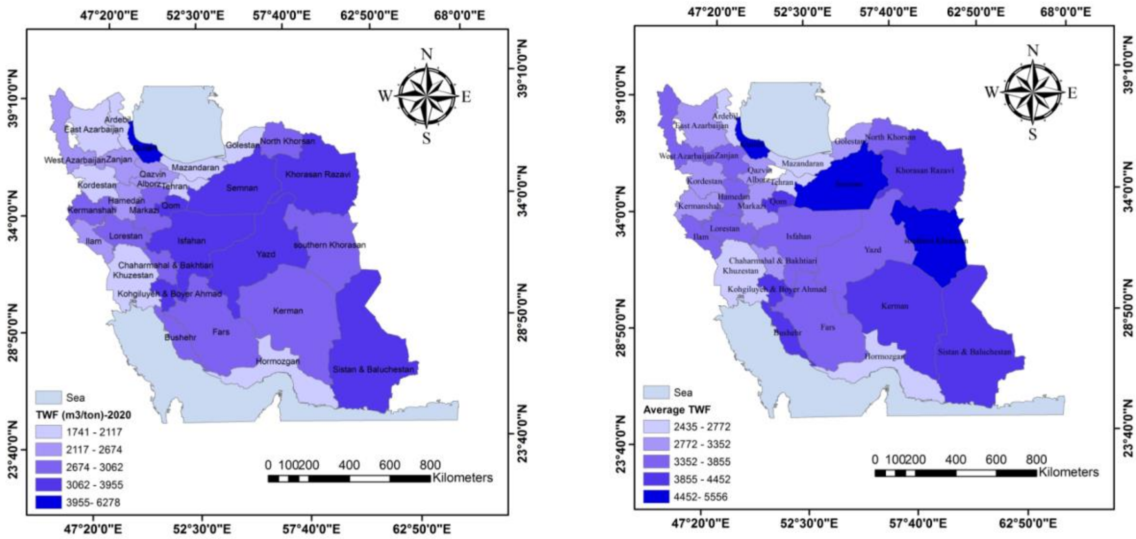
RESULTS AND DISCUSSION

The analysis of the water footprint associated with wheat production across 30 Iranian provinces from 2000 to 2020 showed significant differences. The highest WF was found in Guilan, Southern Khorasan, Semnan, and Sistan and Baluchestan, while the lowest was in Ardabil, Tehran, Khuzestan, and Mazandaran. Northeastern, eastern, and southeastern provinces had the highest water footprint in 2000, 2005, 2010, and 2020. The results of this study corroborate earlier research. Specifically, they are in agreement with the findings reported by Ababaei and Etedali (2017) as well as Aliqliania et al. (2017). By calculating the components of wheat WF for the whole country, it is observed that the average WF of blue, green, and grey during the study period is equal to 2625.76, 428.10, and 594.13 m^3/ton, respectively (Appendix 1). In contrast, the global average for these components in wheat production are significantly lower, at 1279, 343, and 208 m^3/ton (Mekonnen and Hoekstra, 2010). This comparison indicates that the average blue and grey water footprints in Iran exceed the global averages by more than a factor of two. Furthermore, the distribution of each component within the total water footprint is characterized by contributions of 72% from blue WF, 12% from green WF, and 16% from grey WF. Therefore, the blue water footprint has the largest share in the total water footprint of wheat, which is due to the country's semi-arid climatic situation. This situation leads to the high water requirement of a certain plant. On average, the highest amount of green water footprint was related to ‘Kohgiluyeh and Boyer Ahmad’ and ‘Guilan’ provinces during the study period with 762 and 687 m^3/ton, respectively, and the lowest was related to Yazd province with 119 m^3/ton (Appendix 1). Guilan province has the highest annual precipitation rate and the highest blue water footprint (4184.5 m3/ton), while Khuzestan has the lowest (1480.7 m3/ton). The high blue water footprint is due to high humidity and wheat yield, consistent with Aliqliania et al.'s (2017) findings. The study shows low precipitation and stable arid and semi-arid climates in most provinces of Azerbaijan, leading to increased use of chemical fertilizers to boost crop yield and mitigate climate effects. The grey water footprint is highest in southern provinces due to the usage of chemical fertilizers.



a) 2000 **b) 2005**

c) 2010 **d) 2015**



e) 2020 **f) Average of Total WF (2000-2020)**

Figure 3. Total Water footprint of Wheat (m^3 tone).

Fig. (4) shows the wheat harvested area (million ha) and the calculated total water footprint of wheat (billion cubic meters). The annual total water footprint of wheat production in the country was calculated using the weighted average. For this purpose, the share of each province in the total wheat harvested area was taken as the weight. The highest and lowest harvested areas are 2.47 (in 2007) and 1.88 (in 2019) million hectares, respectively. Moreover, the annual average water footprint of wheat production is 26.2 billion cubic meters during the study period. However, in 2019, due to the reduction of wheat cultivation, the total water footprint decreased to about 19.4 billion cubic meters. In 2000, with an area of 2.67 million hectares, the total water footprint was at its maximum and equivalent to 31.1 billion cubic meters. Therefore, the total wheat harvested area and its distribution among different provinces play a significant role in the overall wheat water footprint. During the period under review, the harvested area of wheat decreased due to climate change in the country. Climate change has led to decreased harvested areas, increased yield risks, and reduced farmers' incomes in Iran. The government has implemented a guaranteed price protection policy to prevent production reduction. Water footprint calculations reveal an increase in environmental damage, highlighting the need for risk management in order to achieve sustainable production.

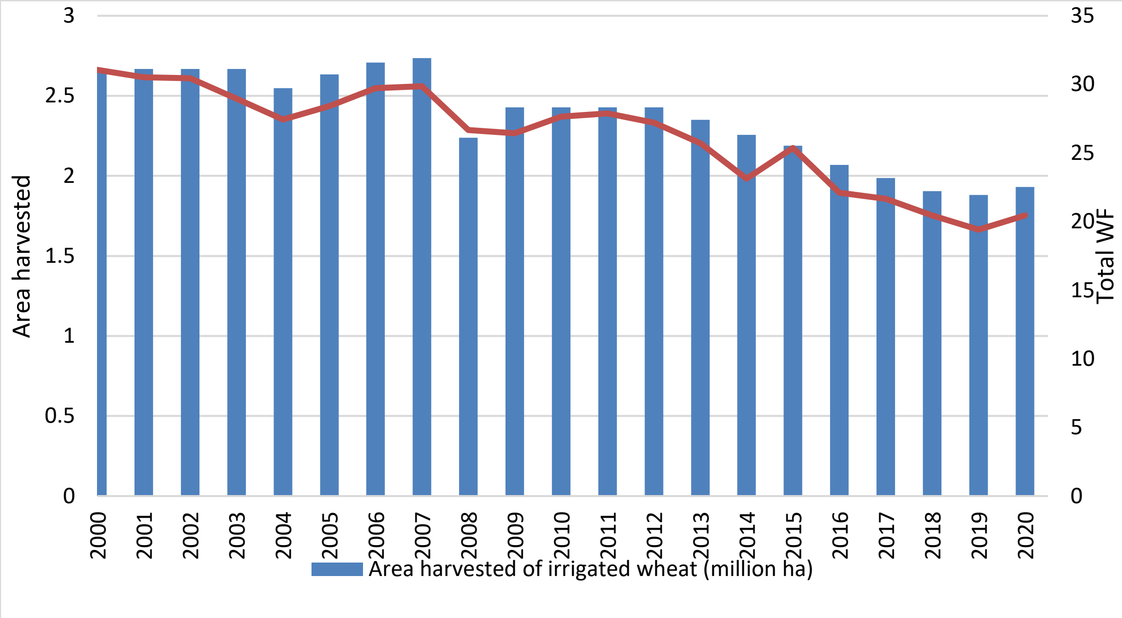


Figure 4. Area harvested and Total water footprint of irrigated wheat [MAJ (2020) and research findings].

Fig. (5) shows the share of different provinces in the total wheat harvested area during the period 2000-2020 using the column chart. Also, the risk of social benefits due to wheat production during the studied years is shown using a line chart. The risk is expressed by deviations from the criteria of social benefit. The share of different provinces in the total cultivated area is expressed as a percentage. The last column of the chart shows the share of provinces in the optimal portfolio and the resulting risk. According to the results, Khuzestan (21.6%), Fars (17.1%), Hamedan (16.1%), Kordestan (13.2%), Khorasan Razavi (11.4%), Golestan (11.3%), Qazvin (5%) and Kermanshah (4.3%) are in the optimal portfolio. Despite having a low cultivation share in the provinces of Kurdistan, Golestan, and Hamedan in the current situation of the country, these provinces have a significant share in the optimal portfolio. This can be attributed to the prevailing climate of these provinces, which are located in the west of the country (Fig. 3). Low evapotranspiration in Fars and Khuzestan provinces can reduce water footprint, environmental cost, yield risk, and social benefit-risk in wheat production. These provinces are crucial centers of wheat production in Iran, aligning with the country's annual pattern. According to Figs. 5, between 2004 and 2006, the share of these two provinces decreased significantly, which led to an increase in the standard deviation of social benefits of wheat harvested area compared to other years in this period. This confirms the major role of these provinces in the optimal portfolio in reducing the risk of social benefits of wheat production throughout the country.

The trend line of risk in Fig. 5 shows that the social benefit-risk decreases over time, except in 2008 and from 2011 to 2013. From 2014 onwards, this downward trend has continued due to the relative stability of the share of major wheat-producing provinces in the total harvested area. The increased risk in 2008 can be explained by the significant decrease in the harvested area compared to other years (Fig.1). The country's precipitation reduction of 143.3 mm this year has led to a decrease in harvested area and fluctuating social benefits. Despite high cultivation area, wheat production has decreased due to reduced yield per hectare.

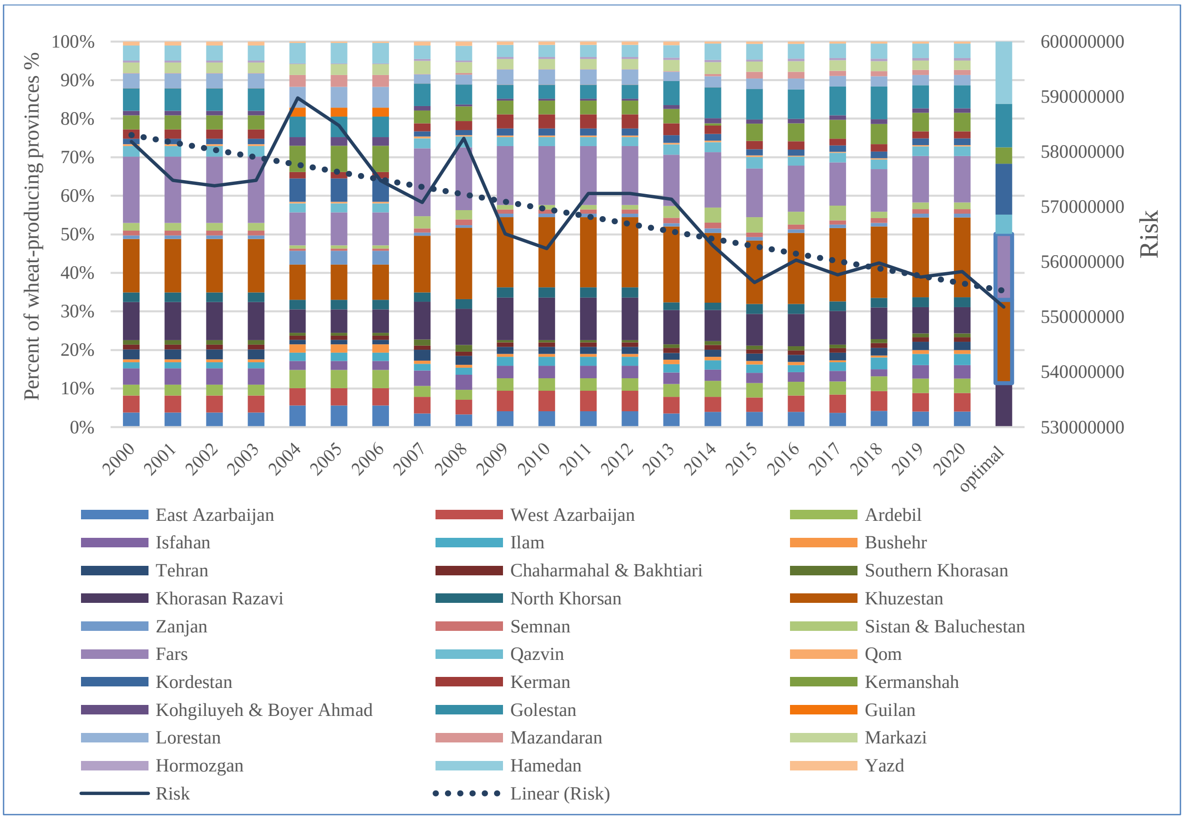


Figure 5. Comparison of share of cultivated area and social benefit-risk of wheat-producing provinces with optimal basket during the period 2020-2000.

The return and risk associated with the wheat cultivation portfolio across various provinces in Iran from 2000 to 2020 are illustrated by blue points in Figure 6. The optimal points of this portfolio delineate an efficient frontier curve, represented in light red on the graph. This frontier signifies the optimal combinations that yield the highest return for a given level of risk, or conversely, the lowest risk for achieving a specified return. The optimal portfolio, characterized by returns of 14,420.3 (10^3 Toman per hectare) and a risk level of 24,120.5, is situated at the midpoint of this curve. Moving along the efficient frontier curve, we should take on higher risks to achieve greater social benefits. In order to attain a specific social benefit, we must be willing to accept a higher level of risk. However, embracing the risk for social benefits results in increased fluctuations in environmental costs (water footprint) or economic benefits (gross margin). Therefore, to achieve higher social benefits and thus accept more risk, we have to accept the risk of provinces entering the optimal portfolio that have more environmental cost fluctuations in wheat production or create fewer gross margin due to low yields. However, due to the Iranian water resources conditions, it is impossible to include provinces with higher social benefit fluctuations in the optimal portfolio. So, selecting the optimal portfolio (red dot) for a certain social benefit creates a lower risk.

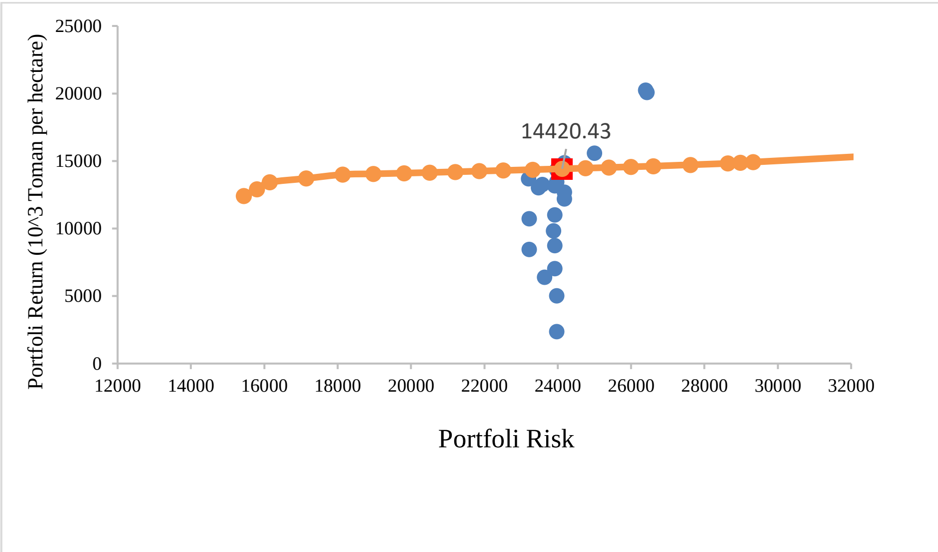


Figure 6. Efficient Frontier of Iran Wheat Production Basket 2000–2020. Note: Efficient frontier is the set of feasible portfolios where the portfolio risk as different target returns is minimized. Portfolio risk and Portfolio return are defined as standard deviation and social benefit, respectively. Blue dots in the figure are defined as actual portfolio performance plots of wheat for each year between 2000 and 2020. The red dot in the figure is the optimal portfolio.

CONCLUSIONS

The conclusions of this study, indicated that taking into account the environmental costs along with the gross margin will lead to sustainable production in the long run while conserving more water resources. Furthermore, the results showed that the provinces with a lower risk during the period 2000 to 2020, such as Fars and Khuzestan, are in the optimal portfolio. It is recommended that the current conditions of wheat cultivation be maintained and improved over time in the mentioned provinces. On the other hand, some provinces were removed from the optimal portfolio due to high fluctuations in water footprint or gross margin. These provinces include the provinces in the east and center of the country, namely Sistan and Baluchestan, South Khorasan, Semnan, Isfahan and Yazd. These provinces exhibit high fluctuations in both water footprint and gross margin, and therefore, they should be carefully managed. To mitigate the risks in these provinces and make them more sustainable for wheat cultivation, it is suggested to introduce more resilient agricultural practices, improve water management technologies, and encourage diversification in crop production. Study, like He et al. (2021), emphasizes that regional adaptation strategies, such as introducing more resilient crops, modifying irrigation techniques, or adjusting planting times, are often required in areas with higher environmental costs or lower economic returns. But at the same time, the provinces included in the optimal portfolio of the country have fewer water footprints during the study period, which is due to the prevailing climate in these provinces (Kermanshah, Hamedan, and Kurdistan provinces). With lower environmental costs, these provinces could have sustainable wheat production in the country in the long run. These provinces should be encouraged as part of the long-term strategy for sustainable wheat production. Sustainable farming practices, such as conservation tillage and water-efficient irrigation systems, could be promoted to maintain or improve these provinces' positive performance in terms of both economic and environmental aspects. Therefore, it is suggested to increase the share of these provinces in the current production of the country and encourage farmers to develop the harvested area in these provinces. For this, the government should pursue supportive policies other than the guaranteed price policy set throughout the country. The government can support farmers by subsidizing insurance based on the climate index of agricultural products to reduce income risk for farmers in these provinces and create an economic advantage for them to plant wheat. Moreover, the provinces with high environmental costs including the eastern and central ones, should be removed from the Iranian wheat cultivation portfolio over time, and alternative crops should be offered according to the prevailing climatic conditions in these provinces. Studies by González et al. (2019) argue that in regions where environmental conditions, like water availability, are less predictable, risk management strategies need to be considered carefully. Accepting more risk might make sense if the social benefits are crucial for economic development or food security. According to the results and their interpretation, the distribution of wheat among 8 provinces in Iran can create a lower risk with an inevitable expected return. Most of the previous studies conducted under the portfolio analysis framework in production, such as Nguyen-Huy et al. (2018), Holly Wang and Zhang (2003), and Barkley et al. (2010), found that optimal geographical diversity can be an agricultural risk management approach to achieving optimal expected returns. Similar to the previous studies, the results of this study also show that optimal geographical diversity in the long run is necessary to achieve sustainable production. Although the results of this study have beneficial implications for Iran, this approach applies to other agricultural areas and crops outside of the country. This is because the model developed in this study can analyze the risk of social benefits and may help governments and policymakers as part of an optimal geographical distribution strategy to achieve sustainable production. In future studies, different crops in the country's agricultural portfolio and the links between various provinces can be considered to maximize social benefits.

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APPENDIX:

Table (1a). A summary of the statistical results of the WF(m^3/ton) Iranian province calculation.

Table (1a). Average of wheat water footprint between 2000-2020.

	Water footprint (m^3.ton)			
Province	**Blue WF**	**Green WF**	**Grey WF**	**Total WF**
East Azarbaijan	2227.41	483.50	400.57	3111.47
West Azarbaijan	2581.95	519.43	368.23	3469.61
Ardebil	1594.46	389.49	451.67	2435.62
Isfahan	2625.69	269.58	662.45	3557.72
Ilam	2640.69	496.25	678.88	3815.83
Bushehr	2891.79	579.52	551.15	4022.45
Tehran	1625.34	338.25	481.00	2444.59
Chaharmahal & Bakhtiari	2171.25	519.96	529.16	3220.37
Southern Khorasan	3841.99	397.77	814.31	5054.08
Khorasan Razavi	3157.54	449.11	683.38	4290.04
North Khorsan	2472.87	496.99	672.58	3642.43
Khuzestan	1480.75	463.47	739.87	2684.09
Zanjan	2654.61	458.11	409.57	3522.29
Semnan	3888.68	233.60	624.92	4747.20
Sistan & Baluchestan	3625.81	188.26	637.30	4451.38
Fars	3598.41	509.25	952.04	5059.70
Qazvin	1938.32	387.81	575.82	2901.95
Qom	3097.32	257.86	754.74	4109.92
Kordestan	2210.72	450.05	395.69	3056.46
Kerman	3317.53	307.25	795.04	4419.82
Kermanshah	2412.59	390.55	457.28	3260.42
Kohgiluyeh & Boyer Ahmad	2696.84	762.00	587.24	4046.08
Golestan	1923.70	481.85	539.10	2944.65
Guilan	4184.54	687.41	704.28	5576.23
Lorestan	2859.72	550.31	445.29	3855.32
Mazandaran	1693.40	620.92	468.28	2782.60
Markazi	2432.53	420.97	498.22	3351.73
Hormozgan	1680.01	262.91	742.79	2685.71
Hamedan	2710.24	420.07	486.88	3617.20
Yazd	2617.68	119.06	780.74	3517.48
Mean	2625.76	428.10	594.13	3647.12
Min	1480.75	119.06	368.23	2435.62
Max	4184.54	762.00	952.04	5576.23

مدیریت ریسک تولید پایدار گندم در ایران: نظریه پورتفولیو

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چکیده

چالش کمبود آب یک چالش زیست محیطی مهم برای بخش کشاورزی است و تولید پایدار محصولات حیاتی مانند گندم را به خطر می اندازد. استان های ایران که گندم تولید می کنند، منابع آبی و شرایط آب و هوایی متفاوتی دارند. این تفاوت ها منجر به منافع اقتصادی متمایز و خطرات زیست محیطی در تولید گندم در بین استان ها شده است. در این تحقیق ردپای آب گندم در هر استان از سال 2000 تا 2020 محاسبه شد و هزینه های زیست محیطی آن از حاشیه ناخالص کسر شد. در نتیجه، منفعت اجتماعی به عنوان بازگشت سبد تولید گندم در هر استان برای مدیریت ریسک تولید پایدار در نظر گرفته شد. پس از آن، تئوری پورتفولیو از طریق برنامه ریزی ریاضی درجه دوم برای به حداقل رساندن سود اجتماعی و تعیین نسبت کشت گندم در هر استان برای سبد بهینه و تولید پایدار استفاده شد. نتایج نشان داد که استان های خوزستان (21.6%)، فارس (17.1%)، همدان (16.1%)، کردستان (13.2%)، خراسان رضوی (11.4%)، گلستان (11.3%)، قزوین (5%)، و کرمانشاه (4/3 درصد) در پرتفوی بهینه قرار دارند. در پرتفوی بهینه سهم قابل توجهی از تولید گندم مربوط به استان های کم ریسک در تولید (خوزستان و فارس) بود. یافته‌ها حاکی از آن است که برای دستیابی به تولید پایدار در بلندمدت، لازم است ریسک‌های اقتصادی در کنار ریسک‌های زیست‌محیطی در نظر گرفته شود. در نتیجه استان‌های شرقی و مرکزی (سیستان و بلوچستان، خراسان جنوبی، سمنان، اصفهان، یزد) با بیشترین میزان ردپای آب از سبد بهینه حذف شدند و استان‌های غربی (کرمانشاه، همدان و کردستان) با حاشیه ناخالص بالاتر و ردپای آب کمتر با سهم بیشتر جایگزین شدند.