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 Kurdistan).

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

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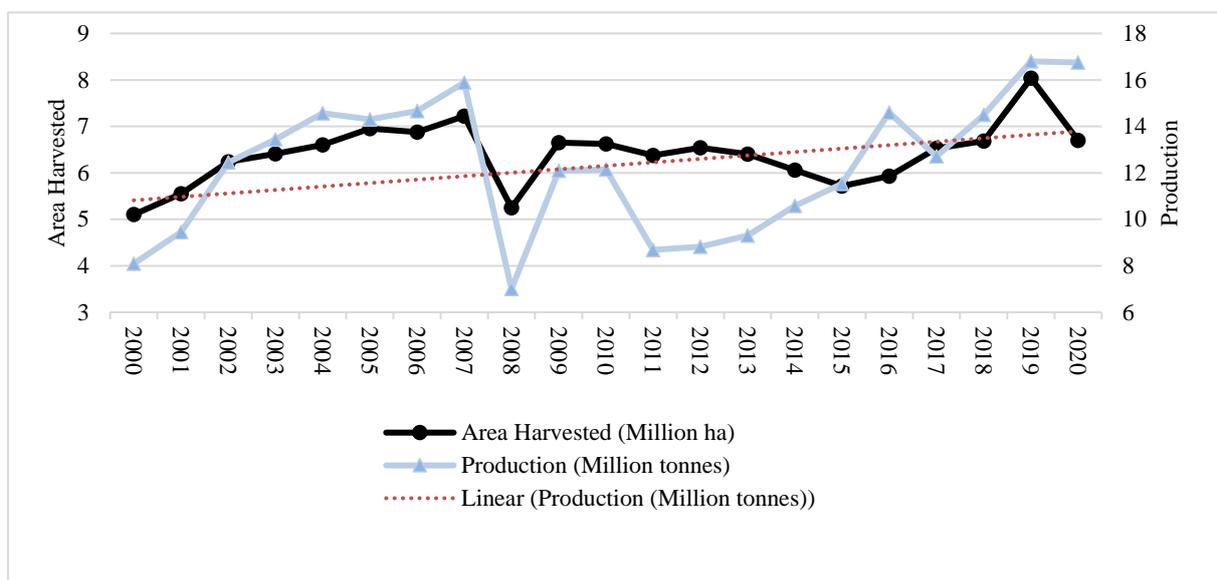
Figure 1. Area harvested and production of wheat in Iran (FAO[2], 2020).

49
50 Water scarcity is considered one of the long-term issues in agricultural production in Iran
51 (Zhang et al., 2016). Demand for water consumption has significantly increased in recent years
52 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

53 has been a decrease in average annual rainfall over the last few decades as a result of climate

54 change, leading to a reduction in water resources and unreliable access (Chouchane et al., 2018;

55 Fathi et al., 2020). Thus, the concept of water footprint has been introduced to measure the

56 extent of unsustainable and precarious access to water. The water footprint takes into account

57 the quantity and quality of water (Hoeksta and Chapagain, 2007, 2008; Mekonnen and

58 Hoekstra, 2011; Hoekstra and Mekonnen, 2012). Water footprint refers to the amount of

59 freshwater used to produce the products (Yang et al., 2006), which is a multidimensional

60 indicator including the quantity of water (amount of water consumed, known as blue and green

61 water), and the quality of water (amount of contaminated water, known as grey water) (Hoeksta

62 and Chapagain, 2007, 2008; Mekonnen and Hoekstra, 2011; Hoekstra and Mekonnen, 2012;

63 Tom et al., 2016; D'Ambrosio et al., 2018). Water footprint is influenced by climatic variables

64 like temperature, wind speed, precipitation, humidity, solar radiation, and chemical fertilizer

65 application, posing risks and uncertainties for crop yield and sustainable production

66 (Monjardino et al., 2015; Herold et al., 2018; Fathi et al., 2020). Climate change may cause a

67 decrease in Iran's non-irrigation land and irrigated grain yield over the next 50 years. Risks in

68 sustainable production are influenced by price and market factors (Fathi et al., 2020; Sewando,

69 2021). To reduce risks and sustain sustainable production, a combination of economic and

70 environmental criteria, considering the environmental side effects of agricultural activities, is

71 needed. Therefore, gross margin and water footprint can be suitable criteria for economic

72 evaluation and environmental costs, respectively.

73 Agricultural risk management has been a focus in various studies (Marko et al., 2016; Sewando,

74 2021; Nguyen-Huy et al., 2018; Fathi et al., 2020), with a particular emphasis on capital risk

75 management (Kim, 2021; Kim and Choi, 2019; Paquin et al., 2016; Atmaca, 2022). Portfolio

76 theory, which aims to determine a set of assets that can achieve minimum risk with the highest

77 return, has been used to maximize profits and minimize risk in agriculture (Markowitz,

78 1991;Viganò and Castellani, 2020; Bai et al., 2021; Atmaca, 2022; Ziakas, 2021). Studies have

79 shown that implementing a crop portfolio can increase yields, reduce financial effects, and

80 enhance profitability (Barkley et al., 2010; Goodwin and Hungerford, 2014; Mrkoa et al., 2016;

81 Nguyen-Huy et al., 2018; Nguyen-Huy et al., 2018; Paut et al., 2019; Sewando, 2021).

82 Geographical diversity has also been explored as a potential tool for farmer compliance and

83 decision support. Paut et al. (2019) found that selecting appropriate varieties can reduce

84 expected yield fluctuations by over 77%. Sewando (2021) evaluated the effectiveness of risk

85 reduction strategies in portfolio diversity among agro-pastoralists, finding that integrated

86 portfolios with good returns and moderate risk could be created through strategic choices
87 between high-return, high-risk or low-return, low-risk crop, and livestock activities. The
88 relationship between the agricultural sector and natural resources, as well as the environment,
89 is significant. As a result, effective management of natural assets is vital for this sector.
90 Nevertheless, there is a scarcity of research focusing on the risk management associated with
91 this form of capital (Alvarez et al., 2017). Water is a critical natural resource whose
92 conservation is essential for enhancing social welfare. In light of this perspective, the current
93 research seeks to address the challenges associated with managing sustainable production risks.
94 This study distinguishes itself from others by focusing on sustainable production while
95 simultaneously minimizing the risks to social benefits across various provinces. Such an
96 approach can provide insights into the optimal integration of diverse wheat-producing regions
97 within the country. Therefore, the outcomes of this study could inform the government in
98 crafting targeted policies to support wheat production in these areas. To achieve this objective,
99 portfolio theory was employed. The optimal portfolio identifies the contribution of each
100 province to wheat production in Iran, taking into account social (economic-environmental)
101 benefits. The criterion for social benefit was defined in terms of returns, ensuring that
102 sustainable wheat production is maintained by minimizing long-term risks, thereby guiding the
103 government in making informed decisions regarding this agricultural product.

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

111
112 **2. MATERIALS AND METHODS**

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

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[1] - Risk of social benefit

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

(1)

118 In Eq. (1) $\overline{Y}_i$ reperesents the average social benefit derived from wheat in the ith province. This

119 average social benefit is determined for the period 2000-2020. In section 2.1, a method is

120 provided for calculating social benefits, W_i is the decision variable and represents the share of

121 each province in the total area under cultivation for wheat in the country. In the optimal

122 portfolio, the average expected return of the portfolio $(\overline{Y}_p)$ is equal to the return (R*). The

123 calculation of portfolio return variance, as outlined by Prol and Kim (2022), is presented in

124 Equation 2. Here, σ_i^2 represents the variance associated with the social benefit of the ith

125 province.

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

(2)

126

127 **Social Benefit**

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

129 3).

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

(3)

130 where P_{it} is the real price[1] of wheat (10^3 Toman per hectare), Y_{it} represents yield (tonnes per

131 hectare), TVC_{it} is total variable cost (10^3 Toman per hectare), P_{wit} is the real price of water,

132 and WF_{it} represents the water footprint of wheat in province i in time t.

133 It should be noted that to calculate the social benefit after the water footprint of wheat (blue,

134 green, and grey water) was calculated (section 2.2), it was multiplied by the price per cubic

135 meter of water to obtain the environmental costs $(P_{wit} WF_{it})$ of wheat production. This value

136 was then subtracted from the gross margin to obtain the social benefit (γ_{it}).

137

138 **WF calculation**

139 WF is used as an environmental criterion in this research. The total WF during the crop growth

140 season is derived from the total components of blue, green, and grey WF (Hoekstra and

141 Chapagain, 2007, 2008; Hoekstra et al., 2011):

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

(4)

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

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

142 In Eq. [4], i and t represent different provinces (1, 2, .., 30) and time (1 to 21) respectively.

143 $WF_{it.green}$ is green, $WF_{it.blue}$ is blue and $WF_{it.grey}$ is grey WF for the ith province and tth year

144 in terms of (m^3/ton). To calculate the green WF, effective rainfall was calculated by the US

145 Department of Agriculture method (USDA, 1993). Therefore, effective rainfall during the crop

146 growing season is calculated according to Eq. [5], and the green WF is calculated by Eq. [6].

$$If: P < 250 \ mm. \ P_{eff} = \left(P/125\right) \times (125 - 0 \cdot 2P) \tag{5}$$

$$If: P > 250 \ mm. \ P_{eff} = 125 + 0 \cdot 1P$$

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

147 In the above equations, P_{eff} represents the effective precipitation during the growing season

148 (mm), P indicates precipitation during the growing season(mm), Y_{it} is regarded as the yield of

149 wheat in province i during the period t (ton/ha), and 10 shows the conversion factor of mm into

150 m^3.ha. Green WF is related to the proportion of water obtained from effective rainfall.

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

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

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

152 where CWU reperesents crop water use in m^3/ha, which is calculated by summing up the daily

153 crop evapotranspiration (ET) during the growing season in mm (Eq. 7) (Hoekstra and

154 Chapagain, 2007, 2008; Hoekstra, et al., 2011). In this equation, $ET_{it.blue}$ reperesents ET of

155 blue water (mm) pertaining to province i in time period t. 10 serves as the conversion factor

156 from mm unit to m^3/ha.

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

158 $$ET = K_c \times ET_0 \tag{9}$$

159 where K_c is the crop coefficient (between 0.4-1.3 during the growth period) and ET_0 is the

160 reference evapotranspiration (mm d^{-1}). The reference evapotranspiration was calculated by the

161 Penman-Monteith equation (Allen et al., 1998), which was calibrated by Razzaghi and

162 Sepaskhah (2012) for semi-arid environments in the study area as follows:

163
$$ET_0 = \frac{\Delta \times (R_n - G) + K_{time} \times \rho_a \times C_p \times \left(\dfrac{(e_s - e_a)}{r_a} \right)}{\left(\Delta + \gamma \left(1 + \dfrac{r_c}{r_a} \right) \right) \times \lambda}$$
(10)

164 where ET_0 is the reference evapotranspiration (mm d^{-1}), R_n is the net radiation (MJ m^{-2} d^{-1}), G

165 is the soil heat flux (MJ m^{-2} d^{-1}), Δ is the slope of the saturation vapor pressure-temperature

166 relationship (kPa ºC^{-1}), γ is the psychrometric constant (kPa ºC^{-1}), λ is the latent heat (MJ kg^{-1}

167 ^{1}), C_p is the specific heat of the air (kJ kg^{-1} ºC^{-1}), ρ_a is the mean air density at constant pressure

168 (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

169 saturated vapor pressure (kPa), e_a is the actual vapor pressure (kPa) and K_{time} is a time

170 determination conversion coefficient. K_{time} is 86400 (s d^{-1}) if ET_0 is determined in mm d^{-1}. (e.g.,

171 see Razzaghi and Sepaskhah (2012) and Allen et al., (1998) for more details).

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

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

173 where ar_{it} represents the application rate of fertilizer in the province i at period t (kg.ha^{-1}), α

174 indicates the percentage of leached nitrogen (%), which is regarded as the maximum acceptable

175 concentration (kg.m^{-3}), and describes the natural concentration for the pollutant examined

176 (kg.m^{-3}) (Hoekstra and Chapagain, 2007,2008; Hoekstra, et al. 2011).

177 WF components are a function of random variables of climatic conditions (i.e., minimum and

178 maximum air temperatures, wind speed, precipitation, relative humidity, solar radiation) in ET

179 estimation. Therefore, the WF of wheat production is a random variable and is affected by

180 climate parameters and water availability.

181 This study aims to answer the question of which wheat-producing provinces in Iran have had

182 lower social benefit risk over time. It will examine the hypothesis that provinces leading in

183 wheat production experience lower social benefit risk. In Fig. 2, the flow chart of the

184 methodology is shown. Almost all provinces in Iran are wheat producers, and there is a variety

185 of climates and water footprints for wheat production. Therefore, all provinces were chosen for

186 the study. Subsequently, an optimal portfolio for wheat production provinces with minimal risk

187 in social benefit was selected. In the present study, the necessary data used to determine WF

188 were collected from the meteorological stations in the wheat-producing provinces by the

189 Meteorological Services of Iran (2020). Additionally, in order to calculate the economic

190   criterion, the necessary data (price, cost, and yield) were obtained from the Ministry of

191   Agriculture- Jihad (MAJ) (2020) from 2000 to 2020.
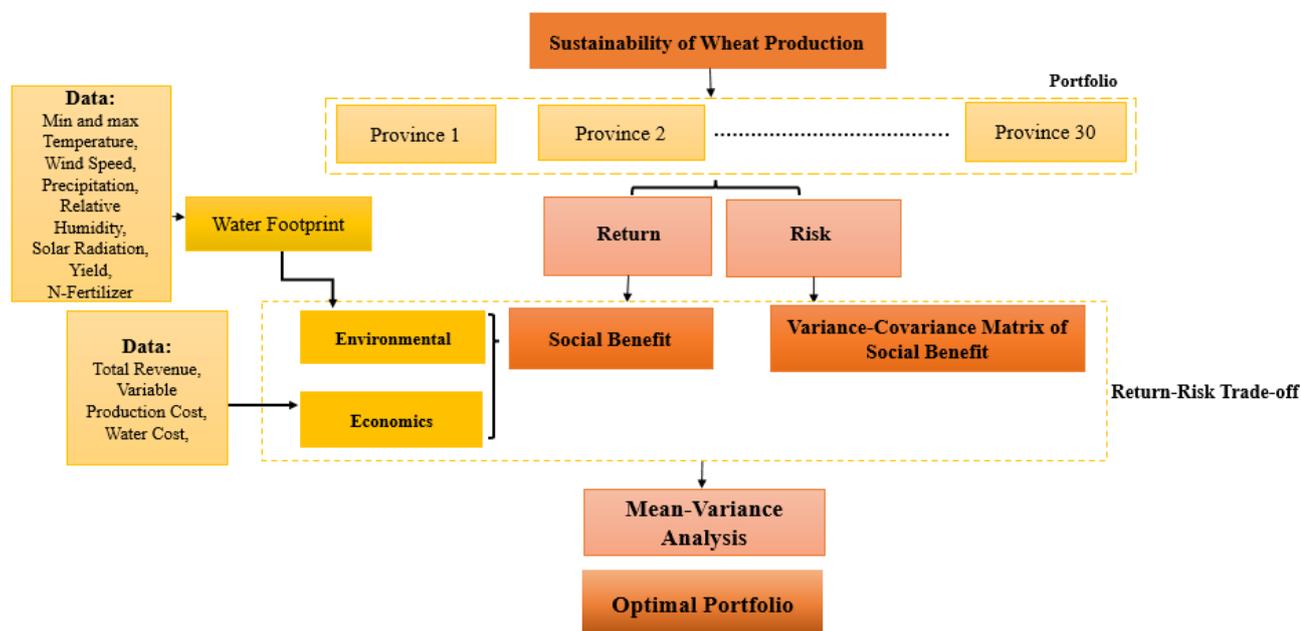
193   **Figuew 2.** Flow chart of methodology.

194

195   **RESULTS AND DISCUSSION**

196   The analysis of the water footprint associated with wheat production across 30 Iranian

197   provinces from 2000 to 2020 showed significant differences. The highest WF was found in

198   Guilan, Southern Khorasan, Semnan, and Sistan and Baluchestan, while the lowest was in

199   Ardabil, Tehran, Khuzestan, and Mazandaran. Northeastern, eastern, and southeastern

200   provinces had the highest water footprint in 2000, 2005, 2010, and 2020. The results of this

201   study corroborate earlier research. Specifically, they are in agreement with the findings

202   reported by Ababaei and Etedali (2017) as well as Aliqliania et al. (2017). By calculating the

203   components of wheat WF for the whole country, it is observed that the average WF of blue,

204   green, and grey during the study period is equal to 2625.76, 428.10, and 594.13 m^3/ton,

205   respectively (Appendix 1). In contrast, the global average for these components in wheat

206   production are significantly lower, at 1279, 343, and 208 m^3/ton (Mekonnen and Hoekstra,

207   2010). This comparison indicates that the average blue and grey water footprints in Iran exceed

208   the global averages by more than a factor of two. Furthermore, the distribution of each

209   component within the total water footprint is characterized by contributions of 72% from blue

210   WF, 12% from green WF, and 16% from grey WF. Therefore, the blue water footprint has the

211   largest share in the total water footprint of wheat, which is due to the country's semi-arid

212   climatic situation. This situation leads to the high water requirement of a certain plant. On

213   average, the highest amount of green water footprint was related to 'Kohgiluyeh and Boyer

214   Ahmad' and 'Guilan' provinces during the study period with 762 and 687 m^3/ton, respectively,

215   and the lowest was related to Yazd province with 119 m^3/ton (Appendix 1). Guilan province

216   has the highest annual precipitation rate and the highest blue water footprint (4184.5 m3/ton),

217   while Khuzestan has the lowest (1480.7 m3/ton). The high blue water footprint is due to high

218   humidity and wheat yield, consistent with Aliqliania et al.'s (2017) findings. The study shows

219   low precipitation and stable arid and semi-arid climates in most provinces of Azerbaijan,

220   leading to increased use of chemical fertilizers to boost crop yield and mitigate climate effects.

221   The grey water footprint is highest in southern provinces due to the usage of chemical

222   fertilizers.

a) 2000   b) 2005

c) 2010   d) 2015
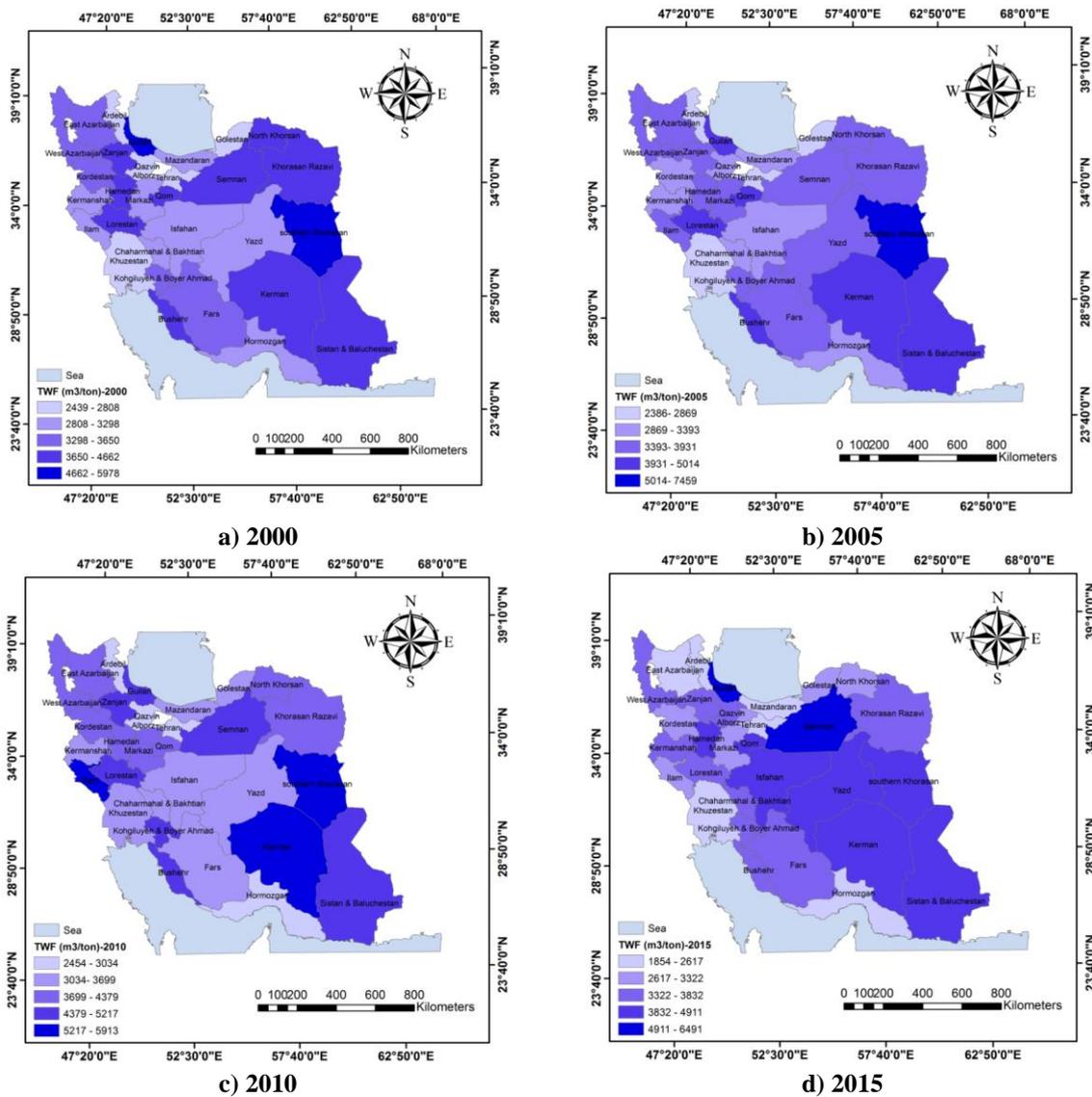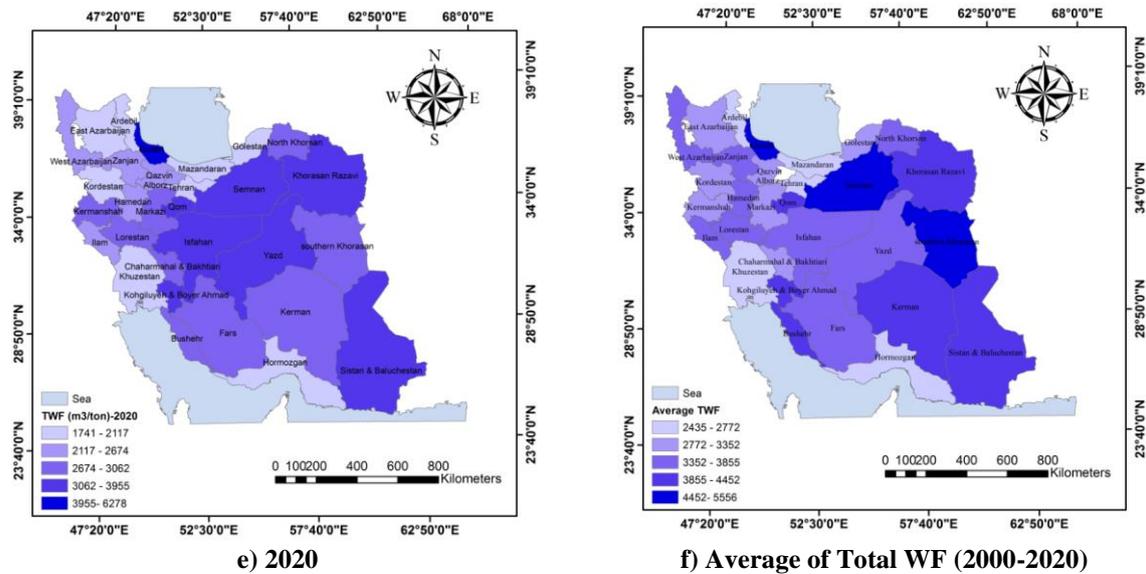
e) 2020   **f) Average of Total WF (2000-2020)**

Figure 3. Total Water footprint of Wheat (m³ 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.
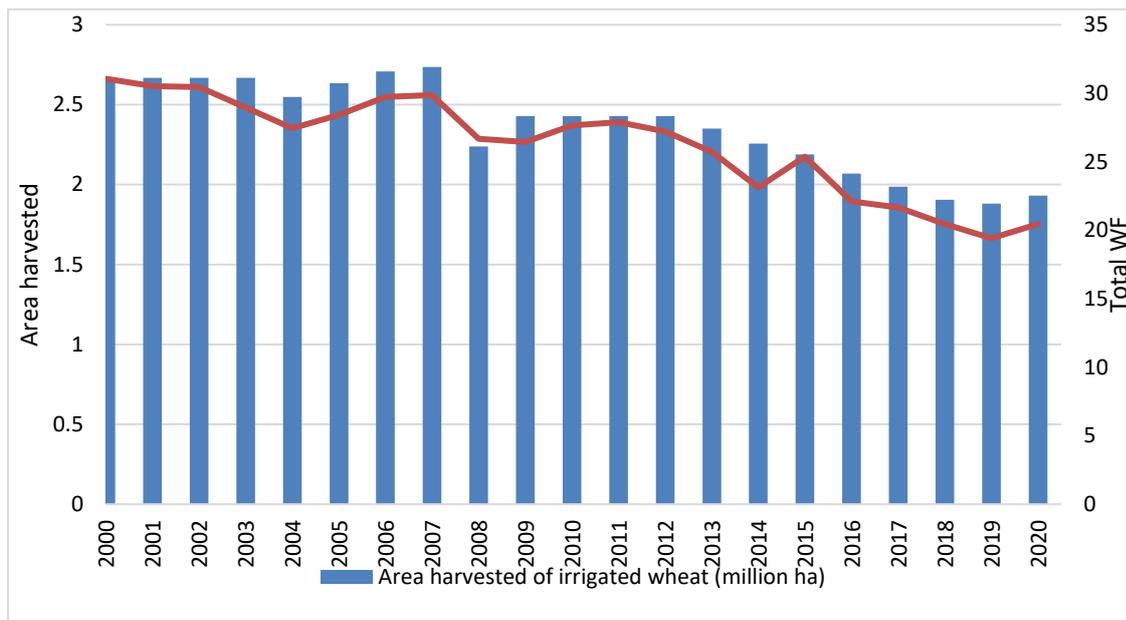
Figure 4. Area harvested and Total water footprint of irrigated wheat [MAJ (2020) and research findings].

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.

264 The trend line of risk in Fig. 5 shows that the social benefit-risk decreases over time, except in
265 2008 and from 2011 to 2013. From 2014 onwards, this downward trend has continued due to
266 the relative stability of the share of major wheat-producing provinces in the total harvested
267 area. The increased risk in 2008 can be explained by the significant decrease in the harvested
268 area compared to other years (Fig.1). The country's precipitation reduction of 143.3 mm this
269 year has led to a decrease in harvested area and fluctuating social benefits. Despite high
270 cultivation area, wheat production has decreased due to reduced yield per hectare.
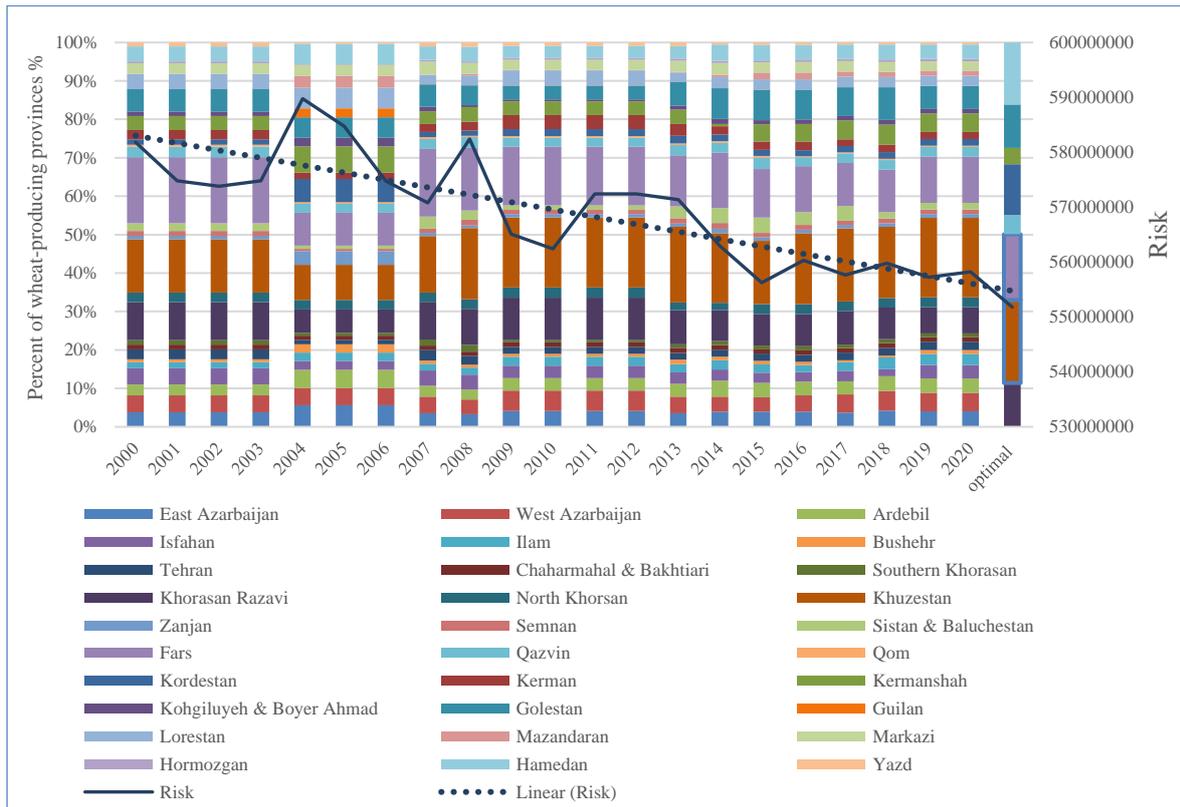
271

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

274

275 The return and risk associated with the wheat cultivation portfolio across various provinces in
276 Iran from 2000 to 2020 are illustrated by blue points in Figure 6. The optimal points of this
277 portfolio delineate an efficient frontier curve, represented in light red on the graph. This frontier
278 signifies the optimal combinations that yield the highest return for a given level of risk, or
279 conversely, the lowest risk for achieving a specified return. The optimal portfolio, characterized
280 by returns of 14,420.3 (10^3 Toman per hectare) and a risk level of 24,120.5, is situated at the
281 midpoint of this curve. Moving along the efficient frontier curve, we should take on higher
282 risks to achieve greater social benefits. In order to attain a specific social benefit, we must be
283 willing to accept a higher level of risk. However, embracing the risk for social benefits results

284 in increased fluctuations in environmental costs (water footprint) or economic benefits (gross
285 margin). Therefore, to achieve higher social benefits and thus accept more risk, we have to
286 accept the risk of provinces entering the optimal portfolio that have more environmental cost
287 fluctuations in wheat production or create fewer gross margin due to low yields. However, due
288 to the Iranian water resources conditions, it is impossible to include provinces with higher
289 social benefit fluctuations in the optimal portfolio. So, selecting the optimal portfolio (red dot)
290 for a certain social benefit creates a lower risk.
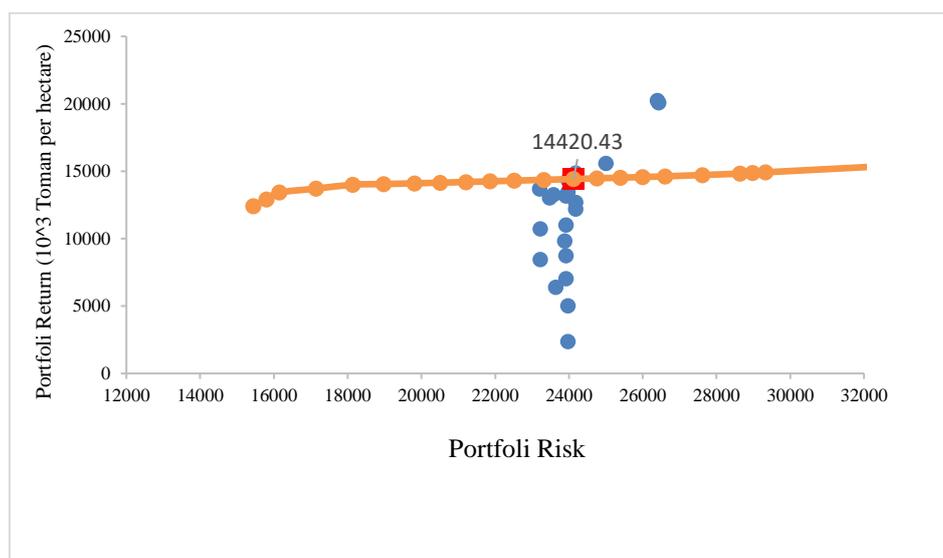
291

292 **Figure 6.** Efficient Frontier of Iran Wheat Production Basket 2000–2020. Note: Efficient
293 frontier is the set of feasible portfolios where the portfolio risk as different target returns is
294 minimized. Portfolio risk and Portfolio return are defined as standard deviation and social
295 benefit, respectively. Blue dots in the figure are defined as actual portfolio performance plots
296 of wheat for each year between 2000 and 2020. The red dot in the figure is the optimal portfolio.
297

CONCLUSIONS

299 The conclusions of this study, indicated that taking into account the environmental costs along
300 with the gross margin will lead to sustainable production in the long run while conserving more
301 water resources. Furthermore, the results showed that the provinces with a lower risk during
302 the period 2000 to 2020, such as Fars and Khuzestan, are in the optimal portfolio. It is
303 recommended that the current conditions of wheat cultivation be maintained and improved over
304 time in the mentioned provinces. On the other hand, some provinces were removed from the
305 optimal portfolio due to high fluctuations in water footprint or gross margin. These provinces
306 include the provinces in the east and center of the country, namely Sistan and Baluchestan,
307 South Khorasan, Semnan, Isfahan and Yazd. These provinces exhibit high fluctuations in both
308 water footprint and gross margin, and therefore, they should be carefully managed. To mitigate

309 the risks in these provinces and make them more sustainable for wheat cultivation, it is
310 suggested to introduce more resilient agricultural practices, improve water management
311 technologies, and encourage diversification in crop production. Study, like He et al. (2021),
312 emphasizes that regional adaptation strategies, such as introducing more resilient crops,
313 modifying irrigation techniques, or adjusting planting times, are often required in areas with
314 higher environmental costs or lower economic returns. But at the same time, the provinces
315 included in the optimal portfolio of the country have fewer water footprints during the study
316 period, which is due to the prevailing climate in these provinces (Kermanshah, Hamedan, and
317 Kurdistan provinces). With lower environmental costs, these provinces could have sustainable
318 wheat production in the country in the long run. These provinces should be encouraged as part
319 of the long-term strategy for sustainable wheat production. Sustainable farming practices, such
320 as conservation tillage and water-efficient irrigation systems, could be promoted to maintain
321 or improve these provinces' positive performance in terms of both economic and environmental
322 aspects. Therefore, it is suggested to increase the share of these provinces in the current
323 production of the country and encourage farmers to develop the harvested area in these
324 provinces. For this, the government should pursue supportive policies other than the guaranteed
325 price policy set throughout the country. The government can support farmers by subsidizing
326 insurance based on the climate index of agricultural products to reduce income risk for farmers
327 in these provinces and create an economic advantage for them to plant wheat. Moreover, the
328 provinces with high environmental costs including the eastern and central ones, should be
329 removed from the Iranian wheat cultivation portfolio over time, and alternative crops should
330 be offered according to the prevailing climatic conditions in these provinces. Studies by
331 González et al. (2019) argue that in regions where environmental conditions, like water
332 availability, are less predictable, risk management strategies need to be considered carefully.
333 Accepting more risk might make sense if the social benefits are crucial for economic
334 development or food security. According to the results and their interpretation, the distribution
335 of wheat among 8 provinces in Iran can create a lower risk with an inevitable expected return.
336 Most of the previous studies conducted under the portfolio analysis framework in production,
337 such as Nguyen-Huy et al. (2018), Holly Wang and Zhang (2003), and Barkley et al. (2010),
338 found that optimal geographical diversity can be an agricultural risk management approach to
339 achieving optimal expected returns. Similar to the previous studies, the results of this study
340 also show that optimal geographical diversity in the long run is necessary to achieve sustainable
341 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.

Province	Water footprint (m^3.ton)			
	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

472 **مدیریت ریسک تولید پایدار گندم در ایران: نظریه پورتفولیو**

473 **آذر شیخ زین الدین، فاطمه فتحی، و سید عباس سید صالحی**

474 **چکیده**

475 چالش کمبود آب یک چالش زیست محیطی مهم برای بخش کشاورزی است و تولید پایدار محصولات حیاتی مانند گندم را

476 به خطر می اندازد. استان های ایران که گندم تولید می کنند، منابع آبی و شرایط آب و هوایی متفاوتی دارند. این تفاوت

477 ها منجر به منافع اقتصادی متمایز و خطرات زیست محیطی در تولید گندم در بین استان ها شده است. در این تحقیق

478 ردپای آب گندم در هر استان از سال 2000 تا 2020 محاسبه شد و هزینه های زیست محیطی آن از حاشیه ناخالص کسر

479 شد. در نتیجه، منفعت اجتماعی به عنوان بازگشت سبد تولید گندم در هر استان برای مدیریت ریسک تولید پایدار در نظر

480 گرفته شد. پس از آن، تئوری پورتفولیو از طریق برنامه ریزی ریاضی درجه دوم برای به حداقل رساندن سود اجتماعی

481 و تعیین نسبت کشت گندم در هر استان برای سبد بهینه و تولید پایدار استفاده شد. نتایج نشان داد که استان های خوزستان

482 (21.6%)، فارس (17.1%)، همدان (16.1%)، کردستان (13.2%)، خراسان رضوی (11.4%)، گلستان (11.3%)،

483 قزوین (5%)، و کرمانشاه (4/3 درصد) در پرتفوی بهینه قرار دارند. در پرتفوی بهینه سهم قابل توجهی از تولید گندم

484 مربوط به استان های کم ریسک در تولید (خوزستان و فارس) بود. یافته‌ها حاکی از آن است که برای دستیابی به تولید

485 پایدار در بلندمدت، لازم است ریسک‌های اقتصادی در کنار ریسک‌های زیست‌محیطی در نظر گرفته شود. در نتیجه

486 استان‌های شرقی و مرکزی (سیستان و بلوچستان، خراسان جنوبی، سمنان، اصفهان، یزد) با بیشترین میزان ردپای آب

487 از سبد بهینه حذف شدند و استان‌های غربی (کرمانشاه، همدان و کردستان) با حاشیه ناخالص بالاتر و ردپای آب کمتر با

488 سهم بیشتر جایگزین شدند.

489