

Article

Assessment of Agricultural Water Resources Sustainability in Arid Regions Using **Virtual Water-Footprint** Concept: Case of South Khorasan Province, Iran

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Abstract: Cropping pattern plays an important role in providing food and agricultural water resources sustainability, especially in arid regions in which the concomitant socioeconomic dangers of water shortage would be inevitable. In this research, six indices are applied to classify 37 cultivated crops according to Central Product Classification (CPC). The respective 10-year data (2005-2014) were obtained from Agricultural Organization of South Khorasan (AOSKh) province. The water footprint concept along with some economic indicators are used to assess the water use efficiency. Results show that blue **virtual water-footprint** contributes to almost 99 percent of Total Virtual Water (TVW). In this occasion that an increasing pressure is exerted on groundwater resources, improper pattern of planting crops has to be beyond reproach. The improper cropping pattern in **this region has the study area** led to the overuse of $346 \times 10^6 \text{ m}^3$ of water annually. **More specifically, Cereals account cultivation was neither environmentally nor economically sustainable and since they accounted** for the largest **proportion share** of water **use in usage at the province level and its cultivation is not socioeconomically sustainable and therefore, importing them are of high importance in comparison with other categories should be considered as an urgent priority.** Vegetable cultivation **can could** be further increased, **instead of other water-intensive crops such as fruits,** at the province level not only due to their **low** TVW, but also **due to their** higher financial **advantages output.**

Keywords: Water Footprint; Water Use Efficiency; Virtual Water Trade; Water Self-Sufficiency; Sustainability; Arid regions.

1. Introduction

Population boom along with climate change and economic miracle has posed serious dangers to water supply deprivation. In this situation, the uneven temporal and spatial distribution of water resources in (semi-)arid regions exacerbate the environmental problems originated from overexploitation of groundwater aquifers. Declining groundwater levels, dried lakes and land subsidence show clear signs of water scarcity (WS) [1,2]. Inexorable linkage between the water and food nexus has consequently attracted considerable attention from researchers of different disciplines in recent years [3,4]. Agriculture is the major user of water and therefore, have a significant effect on water resources around the world, especially in arid and semi-arid regions [5,6]. Human actions exert a lasting influence not only on water-cycle and in turn, in providing food security, but also on the

natural ecosystems, social well-being, and the economy of an area. What is more, we should be able to feed more than 9 billion global population which is likely to live in the next 40 years [7].

The solution lies in changing the production practices and modifying the cultivation patterns. In order to do so, Hoekstra and Hung (2002) [8] developed a new concept named virtual water as an indicator measures the both two rainfall and groundwater resources used in the production chain (namely green and blue water footprint, respectively). Using this concept is now globally recognized as an effective strategy in order to saving water regarding sustainability of the water resources. For example, the UK, Brazil, China and the United States have applied this strategy to improve their water resources sustainability [9–12].

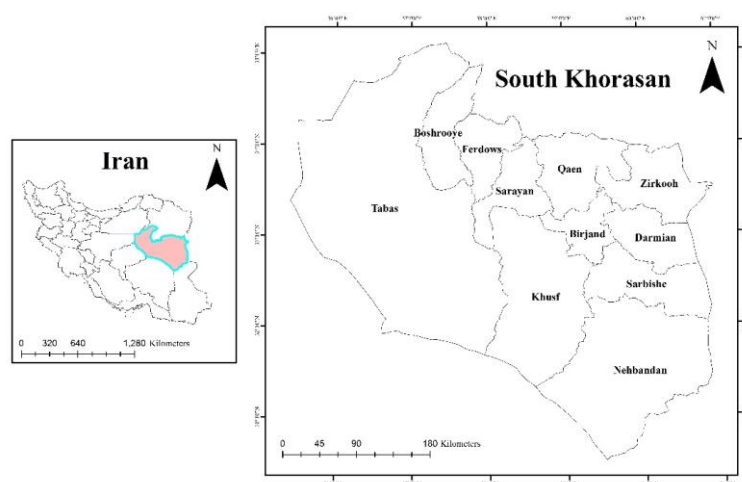


Figure 1. Map of the study area, South Khorasan and its 11 counties

The aim of this study is to evaluate the sustainability of water resources in the South Khorasan province. Prolonged drought granted permission to the farmers to exploit groundwater supplies during the drought. According to the Regional Water Company of South Khorasan (RWC SKh), more than 90% of the available water in the province has been used in traditional agriculture, therefore, regarding this high consumption, the role of proper water allocation in cultivation patterns in this region should be considered. Different crops are harvested in the province and recent droughts during 2005 now have not reduced the water withdrawals, although the harvested area decreased by 23% [13]. This is mainly due to the improper reallocations of cultivation lands planned by the authorities. In this paper, the sustainability of the crop production in the period of 2005–2014 is investigated applying the water footprint concept and measuring the virtual water flows in the province. Some indicators, including Water Self-sufficiency (WS) and average revenue per hectare, are applied in this study to evaluate the province situation regarding the above-mentioned issues. Different sets of meteorological and agricultural data have been analyzed and applied to quantify the water footprint of different crops using the CROPWAT model [14]. The contribution of rainfall (green) and irrigation (blue) parts in total water consumption is distinguished in this study, and therefore, calculating the net virtual water flows, water self-sufficiency and WS would be possible for each share.

Merely a few comprehensive assessments are carried out in Iran regarding the evaluation of water resource management and sustainability using the water footprint concept as well as other indices like Water Self-sufficiency [13,14]. This is while other studies often focused their attention to

calculating different components of water footprint in some particular agricultural products not the sustainability assessment of the water resource allocation to agricultural practices [1,15].

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2. Materials and Methods

2.1. Study Area

South Khorasan province is located in east of Iran and lies between 30°15' N to 34°03' N latitudes and 57°43' E to 61°04' E longitudes with almost 151,193 square km area and 768,898 inhabitants. Birjand, Boshrooye, Darmian, Ferdows, Khusf, Nehbandan, Qaen, Sarayan, Sarbishe, Tabas, and Zirkooh are the 11 counties of the province as shown in Figure 1. This province accounts for almost 9 percent of Iran's territory and is the third biggest province in the whole country. Temperature is ranging from -13.57 °C to 46.83 °C with a dry and hot summer. Spatial pattern of precipitation in this region varies between 89 mm in Tabas to 186 mm in Qaen. Temporal distribution of precipitation is even more uneven. Most of the annual rainfall occurs from January to April. As the province is located near the one of the hottest deserts in the world (Dasht-e Lut), low relative humidity is a common feature of this region with 10 to 58 percent. The east (Tabas) and south (Nehbandan) part of the province are the driest parts, respectively and the north part (Qaen) has the highest humidity. The dominant wind direction is north to south with speed of up to 6.5 m/s. Due to the high temperature values during the year alongside the moderate wind speed values, the evapotranspiration amount is high ranging from 964 mm to 1552 mm per year in the study region. The evapotranspiration rate in each county is depicted in Figure 3.

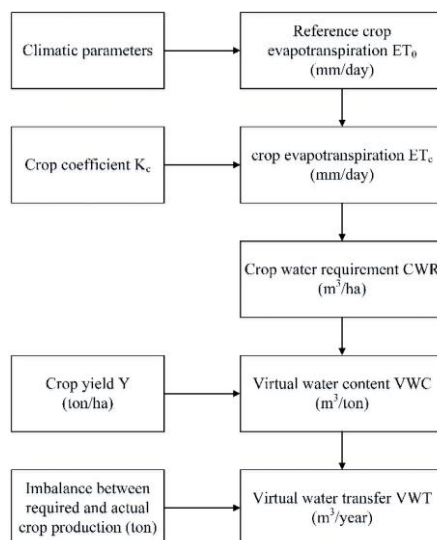


Figure 2. Procedures in calculating the virtual water flows (adopted from Liu *et al.* (2015) [4521])

10-year climate data (2005–2014) was obtained from South Khorasan Province Metrological Organization (SKhMet) [46] [22]. The collected data includes monthly average maximum and minimum temperature, wind speed, sunshine hours, precipitation, and relative humidity measured in one station in each county. Agricultural data consists of harvesting area, crop production, crop yield and planting and harvesting dates obtained from AOSKh [4316].

In this section, the virtual water content of main 37 cultivated crops in the South Khorasan province is investigated. The water footprint of ~~crop production~~ is the volume of water used in ~~the~~ production chain, which is a composition of precipitation (green WF) ~~and~~ irrigation resources (blue WF), ~~and the amount of water is needed to assimilate the pollution in order to maintain the existing ambient water quality within the standard levels.~~ In addition, considering the concept of virtual water footprint, the virtual water trade in the province ~~was~~ analyzed. To analyze the ~~WF~~ water resource management of the province, an annual temporal scale, county spatial level, and two sources of water (i.e., rainfall and irrigation) ~~were~~ applied. ~~It should be added that this study considers only the amount of water is used in land to produce unprocessed crop, the total amount of water used in their production and consumption chain. As a result, the virtual water content term is used to assess the agricultural sustainability of the water consumption of the province instead of water footprint term. By using the CROPWAT model, it is possible to distinguish between the rainfall (green) and the irrigation (blue) sources of water used to produce one mass unit of a crop, and therefore, calculating the net virtual water flows, water self-sufficiency and WS would be possible for each share. In this study, the VWC of a crop is estimated as the sum of the green and blue VWC only.~~

Considering exporting water in the virtual form and its concomitant dangers according to the limited water resources in some regions is undeniable. In arid regions, when the available water resources are limited such as South Khorasan province, this challenge is more critical and therefore, assessment of virtual water concept should be considered in more details. If this concept applied correctly, the water shortage can be alleviated in the study region.

In this study, initially, the procedures of figuring out the virtual water content of unprocessed agricultural crops are described, and then the water footprints of these crops are calculated. Regarding the calculated water footprints, it is analyzed how the water footprint of unprocessed crops cultivated in the region pose the main threat to sustainable development of the province. To reach this aim, a variety of practical indices including water self-sufficiency (WSS) and water scarcity

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(WS) indices are defined to show how overexploitation of water resources can endanger not only the environmental but also the socioeconomic sustainability.

2.2.1. Virtual water content estimates

A crop's Virtual Water Content (VWC) is the ratio of total crop evapotranspiration (ET, in m³/ha) to the crop yield (Y, in ton/ha) as described by Hoekstra *et al.* [17]:

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$$VWC = \frac{ET}{Y} \quad (1)$$

The selected 37 crops in this research, as described in Table 2, account for almost 80 percent of cultivated crops in South Khorasan [13,16]. For these cultivated crops in the region, the contribution of different types of water resource (i.e., green and blue) to the total crop evapotranspiration are distinguished in order to measure the participation of all sources in the province. Comparing of these contribution percentages will guide the local authorities through the dominant water resources in the region to make more practical decisions to control them.

2.2.2. Crop Evapotranspiration

Evapotranspiration from the two sources of available water in the region (i.e., rainfall and irrigation) is calculated as follows:

$$ET = K_c \times ET_0 \quad (2)$$

where ET refers to evapotranspiration (mm). To calculate ET from both the green and blue water resources the CROPWAT model is used in this study [18,23]. The CROPWAT model is a decision support tool developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) to help water authorities and decision makers determine crop water requirements [44,20]. This model calculate the reference crop evapotranspiration using the soil moisture balance with the Penman-Monteith method. Meteorological data such as maximum and minimum air temperature, precipitation, relative humidity, wind speed, and sunshine hours are considered as input variables in this model. The reference crop evapotranspiration is solely affected by climatic parameters and is defined as the evapotranspiration from a reference surface and is quantified as follows [17,24]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900(e_a - e_d)}{T + 273}}{\Delta + \gamma(1 + 0.34U_2)} \quad (3)$$

in which R_n is the net radiation at the grass surface (MJ/m².h), G is the soil heat flux density (MJ/m².h), Δ is the slope of the saturated vapor pressure curve at temperature T (kPa/°C), γ is psychrometric constant (kPa/°C), T is mean hourly air temperature (°C), U_2 is averaged hourly wind speed at height of 2 m above the ground surface (m/s), and e_a and e_d are the saturation and actual vapor pressure, respectively (kPa).

The crop coefficient (K_c) are computed in a daily basis during the growing period of crops. Following the proposed approach by Allen *et al.* [19,25], the total crop evapotranspiration is determined by summation the results of multiplying daily K_c by reference evapotranspiration (ET_0) as shown in Equation (2). One of the capabilities of the CROPWAT model is distinguishing between evapotranspiration from green and blue water resources.

It is worth mentioning that, crop coefficients for each crop have undergone some changes in their quantity in each county as some county's relative humidity and wind speed do not observe the minimum conditions (RH=45%, $K_c=2$ m/s) using the methodology described in Allen *et al.* [19,25].

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The Virtual Water Content (VWC) ~~and Water Footprint (WF)~~ of a crop ~~are equivalent and determined~~ determines how much water ~~are~~ embodied in an unprocessed crop during the growing period. The green and blue VWC of the crops in each county are determined as:

$$\text{WF}_{\text{blue}} \text{VWC}_{\text{blue}} = \frac{\text{CWR}_{\text{blue}}}{Y} \quad (4)$$

$$\text{WF}_{\text{green}} \text{VWC}_{\text{green}} = \frac{\text{CWR}_{\text{green}}}{Y} \quad (5)$$

where CWR is crop water requirements (in m^3/ha) defined as the crop water evapotranspiration and Y refers to the crop yield (ton/ha).

Using 10-year, county-level data of crop production, the average yield of each crop are calculated. The temporal scale of the applied data set provided by AOSKh [13][16] of the South Khorasan province is annually and therefore, the assessment of the annual virtual water trade in agricultural production will be possible. Due to the low precipitation in the study region (139 mm annually), the rainfed productions amount is very small (ranging from zero to just 8 percent of total production) and therefore, the major component of total agricultural productions come from irrigated cultivated lands. Regarding the small share of rainfed agriculture, in this study only the irrigated productions are considered.

2.2.3. Virtual water trade in crops

One of the big challenges in quantifying the virtual water trade in the study region is the lack of data. In most cases either the imported/exported productions dataset is not available or the access of the researchers to these data sets is limited. In this study, the annual trade in agricultural crops at a county-level scale in the period of 2005 to 2014 has been investigated. Applying the approach proposed in Liu *et al.* [15][21], the required amount (tonnage) of each crop for domestic uses is calculated using the per capita consumption of each crop in the region multiplying by the population of each county in the study province. Comparing the required crop amounts in order to provide food security of the inhabitants with the actual (total) crop produced in each county of the region, determine either a particular county will export the surplus productions or must import the crops due to its food shortage.

Due to the lack of the required information of traded water in processed crops in the study region, this amount is not included in the traded virtual water. In addition, it is not possible to trace final destination of crops consumption in province level. The main reason for this limitation is the lack of information of transported tonnage of agricultural products alongside the limited access to the available information.

2.2.4. Water Self-sufficiency and Water Scarcity

~~The assumption that a water scarce region should rely heavily on importing to reap the benefits of water imported in order to alleviate the pressure have exerted to their water resources, would be reasonable enough. Regions with copious amount of water resources, though, have this opportunity to take financial advantage of exporting water in the virtual form [20]. To quantify the water scarcity, Water scarcity (WS) index is defined as the ratio of the water consumption in a region to the total water available in that region [21]:~~

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$$\text{WS} = \frac{\text{WU}}{\text{WA}} \times 100 \quad (6)$$

in which WU refers to the total ~~consumption~~usage of ~~water includes the both~~ rainfall (green) and irrigation (blue) sources of water ~~used to produce the crops, in crop production~~ and WA is the total available water ~~where in a specific region~~. In this study, the ~~value~~amount of WU is computed by multiplying the ~~calculated virtual water footprint~~content of each crop (m^3/ton) ~~in (in m^3/ton) to the total production of that crop (ton) in any year in the study period. As a result, the in ton). The WU in this equation~~Equation (2) refers ~~to only to~~ the amount of water consumed ~~through agriculture and does by agricultural practices~~ not ~~include~~ other usages of water (i.e., household, industry, mining, services ~~and~~, etc.). ~~With identifying the characteristics of each meteorological station (such as geographical location and the amount of annual rainfall) within each county and using the concept of isohyet lines, WA is computed from by using the averaged renewable water resources fallen annually. ArcGis software. The required information for calculating data to calculate these parameters is provided by Regional Water Company of South Khorasan province. As shown in Table 1, in the case of overexploitation WS value exceeds 100 percent. Determining the situation~~Different situations of a region regarding WS values is shown in Table 1. ~~As shown in this table, in the case of overexploitation, WS value exceeds 100 percent.~~

Table 1. ~~Categorization of water scarcity [22]~~

~~. Categorization of water scarcity [27]~~

Water Scarcity (WS) (%)	Situation
WS > 100	Overexploited
60 ≤ WS < 100	Heavily exploited
30 ≤ WS < 60	Moderate exploited
WS < 30	Slightly exploited

To indicate the region's dependency to outside (imported) water resources index of Water Dependency (WD) is defined as the ratio of imported water to the total water consumed in a region [8]:

$$WD = \begin{cases} \frac{NVWI}{WU + NVWI} & \text{if } NVWI \geq 0 \\ 0 & \text{if } NVWI < 0 \end{cases} \quad (7)$$

where NVWI is the net virtual water imported to the region. This index changes in range of 0 to 100 percent in which 0 means the region is fully self-sufficient in providing its food requirements and 100 percent refers to a region which ~~import~~imports all its required foods. Therefore, water self-sufficiency (WSS) is inversely related to the water dependency as follows:

$$WSS = 100 - WD \quad (8)$$

3. Results

In this study, the crops harvested in the province are categorized in six categories as shown in Table 2. The ~~virtual~~ water ~~footprint~~ contents of crops are calculated in all counties in the province.

~~Figure 8 illustrates the evapotranspiration amounts of crop categories in the province. It can be seen that fruits have the biggest evapotranspiration (1,562 mm per year), followed by fiber crops (1,464 mm per year). Legumes and vegetables have the minimum values of evapotranspiration with 981 and 1,026 mm per year, respectively. Although the crop water requirement of legumes and oil seeds are much lower than the other categories, but their low yields lead to the high virtual water contents with 11,990 m^3/ton and 12,171 m^3/ton , respectively. Vegetables with 927 m^3/ton are ranked the latest place in respect with TVW.~~

Table 2. Classifying the different crops used in this research (*“hereafter only “fiber crops” is used*)

Group (number of crops)	Included Crops
Cereals (5)	wheat, barley, maize, alfalfa, millet
Legumes (4)	chickpea, mung bean, bean, lentil
Fiber Roots and fiber crops [*] (4)	potato, sugar beet, turnip, cotton
Vegetables (9)	tomato, onion, cucumber, eggplant, zucchini, sweet melon, water melon, garlic, cantaloupe
Fruits (13)	apple, pear, quince, sour cherry, cherry, plum, peach, apricot, table grape, pistachio, almond, walnut, carrot
Oil seeds (2)	sesame, sunflower

Due to the arid ~~climatic conditions, as described earlier,~~climate and ~~very~~the low annual precipitation (~~as described in Section 2.1~~), green virtual water (GVW) is a mere fraction of TVW in the study region. The largest proportion of GVW ~~among the six categories~~ belongs to the cereals with only 1.42%. This small contribution of GVW within the province have exerted enormous pressure on the South Khorasan aquifers. ~~The contributions of~~Table 3 ~~compares different~~ crop categories regarding ~~the their~~ green and blue VWC ~~are presented in Table 3~~. As shown in Table 4, the same crops have different VWC in different counties and therefore, ~~it can be concluded that~~ each county ~~can~~would be ~~considered suitable~~ for cultivation of particular ~~typetypes~~ of crops. Regarding this issue, during the period of 2005–2014, it ~~was~~could be possible to save more than ~~346 × 10⁶~~ $346 \times 10^6 \text{ m}^3$ water annually without any reduction in the harvested lands, ~~only~~ by applying the proper cropping pattern. ~~That is, in the region. This huge volume of water could be saved annually~~ if spatial prioritization of crops based on TVW (as shown in Table 3) ~~was observed, just by moving had been applied and~~ the cultivation of some type of crops ~~was moved~~ to the counties with the minimum water footprint (VWC or ~~equally with the~~ maximum water productivity), ~~it was viable to save this huge amount of water annually~~. Table 4 ~~shows depicts~~ that there ~~was~~ ~~aware~~ remarkable ~~difference~~differences in water productivity ~~through throughout~~ the province ~~which~~. Using these ~~results in agricultural practice~~ could ~~have been considered by the authorities but ignored and with the led to producing the same volume of water, a very small amount of crops produced by using by far less water, and consequently, the considerable pressure exerted on the groundwater could be substantially relieved~~ (column 4 in Table 4). ~~Unfortunately, this great opportunity for saving a huge amount of water in such an arid region with limited water resources was lost due to ignoring the concept of virtual water by the local authorities.~~

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Table 3. 10-year mean of virtual water content and other components in the entire province (ETc: Crop Evapotranspiration, GVW: Green Virtual Water, BVW: Blue Virtual Water, TVW: Total Virtual Water)

Crops	ETc (mm)	GVW (m ³ /ton)	BVW (m ³ /ton)	TVW (m ³ /ton)	GVW proportion (%)	Water productivity (Kg/m ³)
Cereals	1213	49	3454	3502	1.42	0.286
Legumes	981	77	11922	11999	0.69	0.083
Fiber crops	1464	26	3293	3319	0.83	0.301
Vegetables	1026	13	923	937	1.36	1.068

Fruits	1563	59	4994	5052	1.21	0.198
Oil seeds	1059	60	13110	13171	0.50	0.076

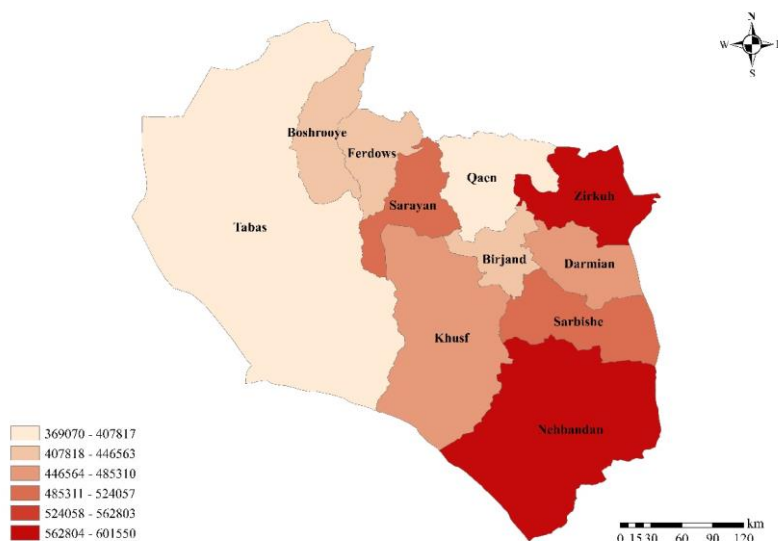


Figure 3. Evapotranspiration rate in South Khorasan province (m^3 per hectare)

The main reasons for high amounts of water footprints in the study region can be as follows: the semi-aridity and climatic situation, the wrong policies of the local authorities for achieving self-sufficiency in providing food-security, low yields of crops due to the inefficient agriculture, and subsequently, the low values of water used to produce crops.

The proportion of each type of crops based on their cultivation area and areas along with the amount of production of each type of crops are depicted in Figure 4. As shown in this figure, with a contribution share of just 7% in cultivated lands, vegetables account for 27% of crop production. At the province-level, cereals are the main part major type in both cultivated lands (61%) and crop production (45%). This amount of production has led to export around the surplus of 24,117 tonnage of cereals annually, which in turn attributed to 68.31×10^6 . It means that 68.31×10^6 m^3 water transferred out annually outside the boundaries of the province. This is while at the province level. However, the South Khorasan imports province is a net virtual water in collaborate importer with regard to the other five categories crop types. Based on the results of this study, these five crop types are responsible for importing 936.87×10^6 m^3 water from outside the province. As shown in Figure 7, fruits have the largest share of the imported virtual water imported to the province with around 423×10^6 m^3 annually.

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Table 4. Difference in water productivity and the water saving potential

Crop type	min water productivity (kg/m^3)	max water productivity (kg/m^3)	Difference in production (%)	Annual water saving potential (Mm^3)
Cereals	0.196	0.383	95.03	119
Legumes	0.049	0.152	213.32	2
Fiber crops	0.107	0.860	706.28	131

Vegetables	0.655	2.237	241.63	49
Fruits	0.161	0.269	67.34	38
Oil seeds	0.049	0.467	853.16	8

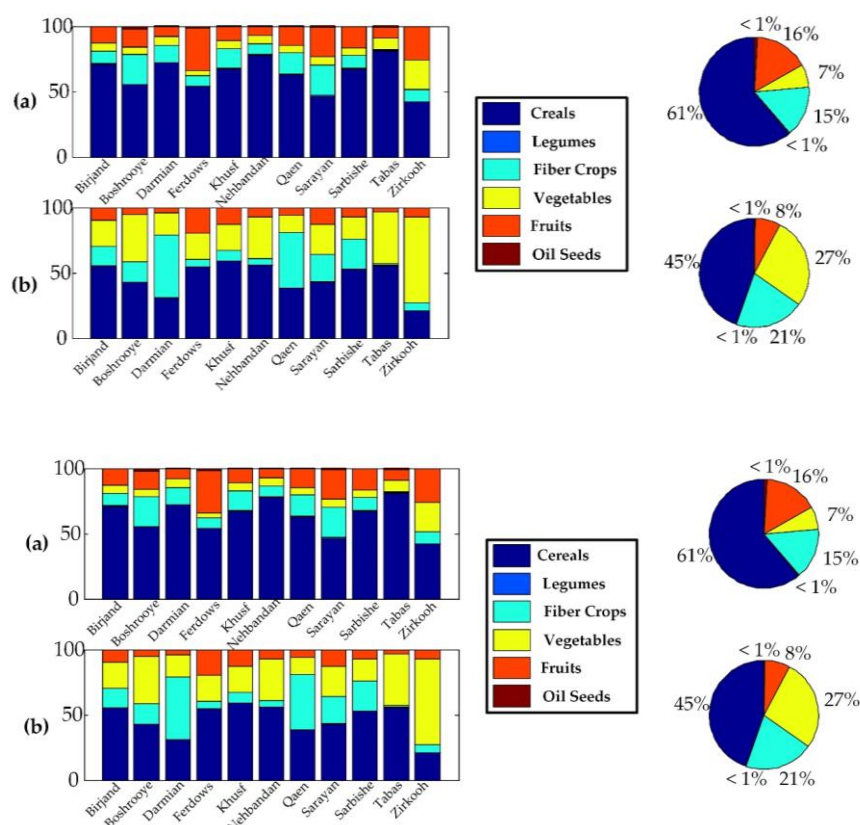


Figure 4. (a) The state of cultivation area, and (b) the crop production in each county

Analyzing the results of the study shows that the province not only ~~is~~ self-sufficient in producing all types of cereals, but also ~~it provides~~ fulfilled the cereal ~~needs~~ requirements of some other regions. This situation ~~is~~ was neither economically sustainable (Figure 8) nor environmentally sustainable as ~~its~~ cereal's virtual water ~~amount is~~ content was relatively high (Table 3).

During the study period, ~~the decade~~ from 2005 to 2014, there was an ~~increasing~~ inclination with ~~52% to increase towards increasing~~ the cultivation area of the fruits ~~by 52%~~ [16]. The water and agricultural authorities of the province ~~have~~ encouraged the farmers to harvest cereals more due to the high economic value of them in comparison with other types of crops (Figure 8), as well as their high strategic importance. On the other hand, ~~the~~ production of other crop types ~~was~~ reduced significantly due to ~~the~~ severe droughts ~~which~~ that the whole province confronted with. In spite of these reductions, the pressure on the water resources, mainly includes aquifers, ~~has been increased~~ did not decreased (Figure 5). The main reason for this issue is that water and agricultural authorities of the province had no clear idea and understanding from the virtual water concept. Due

to this misunderstanding, the production of fruits, as a water-intensive type of crops, increased by 52%. In the period of 2005 to 2014 the remains of crop types, i.e. cereals, legumes, fiber crops, vegetables, and oil seeds, experienced a decline in their harvested area by 24, 75, 47, 28, and 28 percent, respectively. This shift to produce more water-intensive crops ~~has~~ increased the groundwater consumption from $794800.24 \times 10^6 \text{ m}^3$ in 2005 to $1376.351392.62 \times 10^6 \text{ m}^3$ in 2014 (around 73.95% increase).

Although Boshrooye and Sarayan ~~are~~ were almost self-sufficient, this self-sufficiency has been achieved by putting an enormous pressure on their limited water resources and therefore, their WSs ~~are~~ were far beyond the bounds of sustainability (Figure 9). Other counties such as Ferdows, Qaen, Sarbisheh, and Zirkuh ~~produce~~ produced crops unsustainably by a WS of 366, 283, 175, and 171 percent while experienced just 35, 30, 31, and 55 percent of dependency, respectively (Figure 9). Tabas ~~are~~ was slightly exploited due to its small agricultural practices. Khusf, by 49% of WS, ~~utilizes~~ utilized its water resources moderately (Table 1). Birjand, Darmian, and Nehbandan relied heavily on their groundwater resources to achieve the WS of 89, 86, and 71 percent, respectively. Other counties, though, in order to achieve their desired self-sufficiency in agricultural productions ~~overexploit~~ overexploited their limited groundwater resources.

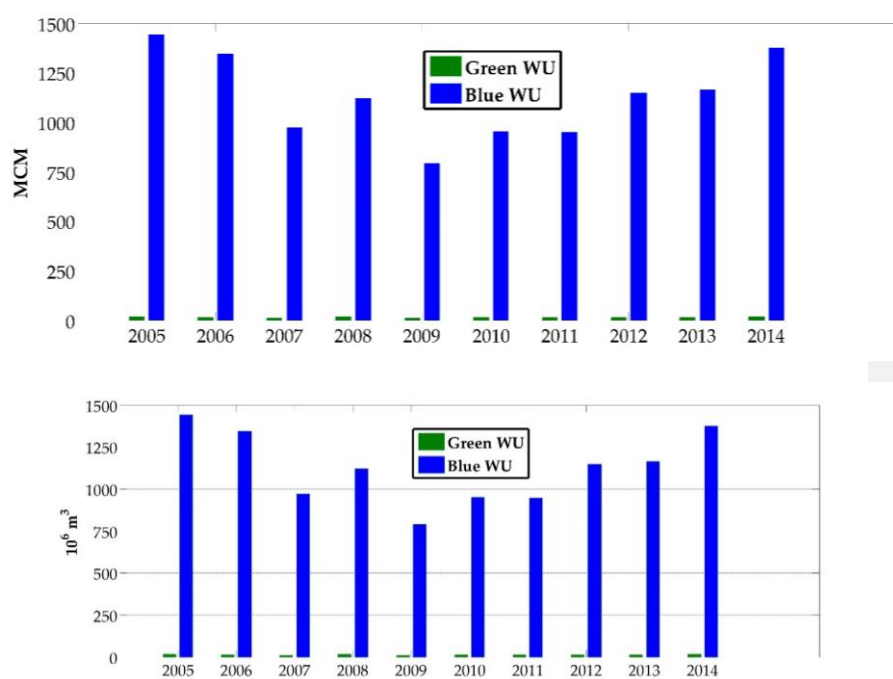


Figure 5. The variation of green and blue water use (WU) in the province from 2005 to 2014

Figure 8 provides a comparison between water evapotranspiration and average revenue per hectare of crop types. From 2005 to 2014, the total water consumption in cereals, legumes, fiber crops, vegetables, and oil seeds decreased by 25% or $217.06 \times 10^6 \text{ m}^3$. The irrigation water consumed in fruits, though, increased dramatically by 148% or $251.00 \times 10^6 \text{ m}^3$. This reallocation of limited water resources to water intensive crops like fruits resulted in increasing water consumption over this time

period (Figure 5). Regarding the depicted results in this figure, vegetables are the best option to reallocate lands due to their environmentally (low TVW) and economically (high revenue per hectare) sustainability.

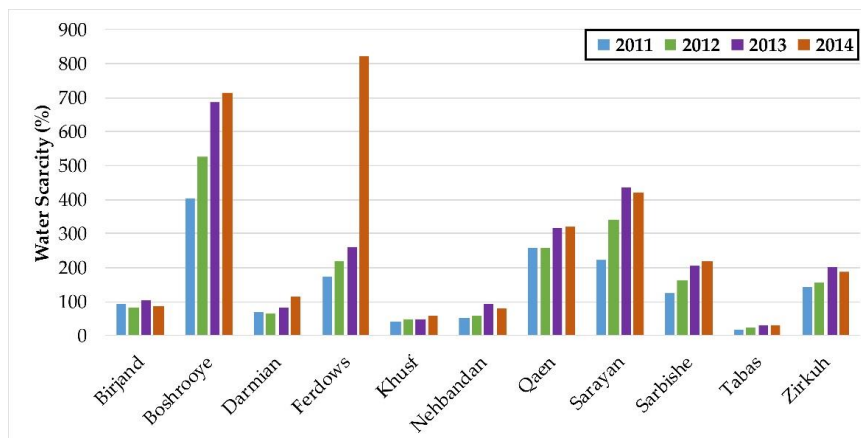


Figure 6. Temporal variability of the water scarcity (WS) in all counties from 2011 to 2014

The contribution of available renewable water resources ~~for~~ of each county is quantified using the isohyet lines from the long-term precipitation data. Unfortunately, the data of water availability for the period of 2005 to 2010 was not available in the Regional Water Company of South Khorasan province, and therefore, only the available data for the period of 2011 to 2014 was used in this study. The amount of water withdrawal and water along with the available for water of 11 counties of the province ~~are~~ presented in Table 5. According to this table, Boshrooye ~~has~~ had the largest water usage with the average of $221.43 \times 10^6 \text{ m}^3$ annually. Qaen and Sarayan ~~are~~ were the next largest water users with an average withdrawal of $195.51 \times 10^6 \text{ m}^3$ and $173.17 \times 10^6 \text{ m}^3$, respectively. On the other side, Khusf and Tabas used the least amount of water in crop productions with $28.72 \times 10^6 \text{ m}^3$ and $31.05 \times 10^6 \text{ m}^3$, respectively.

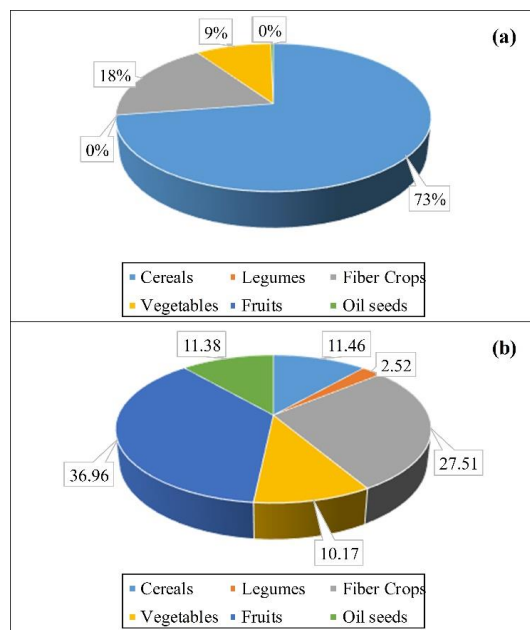


Figure 7. (a) The fractional contribution of exports, and (b) imports of the province during 2005-2014 (1142.53 Mm³ is imported and 274.97 Mm³ is exported at the province level)

A similar trend of ~~WSWSs~~ in each county within the province ~~is found~~ was identified. As illustrated in Figure 6, an increasing trend in WS ~~can be~~ found for all the counties, excluding Birjand where its WS fluctuated from year to year. Ferdows, though, experienced an abrupt change in ~~its~~ WS in 2014 as its cultivation area dramatically increased from 4329 hectare in 2013 to 19637 hectare in 2014. This increasing trend is mainly due to misunderstanding of the food security concept by the policy makers. They ~~translate~~ translated the "food security" as producing all the food ~~needs~~ requirements within Iran's territory to reduce dependency to foreign countries or even achieving absolute self-sufficiency, regardless ~~to~~ of long-term consequences of unsustainability. With this incorrect definition of food security, the consequent water resources problems in the region would be expectable.

The proportion of crops transferred within the province are depicted in Figure 7 either the crops imported ~~to~~ or exported from the counties. Cereals ~~are~~ were the largest type of crops which either exported from or imported to the counties. Birjand, Darmian, and Zirkuh imported around 65.7% of the cereal productions of other counties annually and the remains ~~are~~ were exported outside the province, including about 24,117 tonnage of cereals which is equivalent to $68.31 \times 10^6 \text{ m}^3$ of water. According to the values of WS of the counties, as shown in Figure 6, this situation ~~is~~ was not environmentally sustainable. In other types of crops the province ~~is~~ was net virtual water importer and all the virtual water exports in them ~~are~~ were interregional. This amount of imported water ~~is~~ was not enough to alleviate the enormous pressure exerted on the groundwater aquifers as the average WS in the South Khorasan province ~~is~~ was 206%.

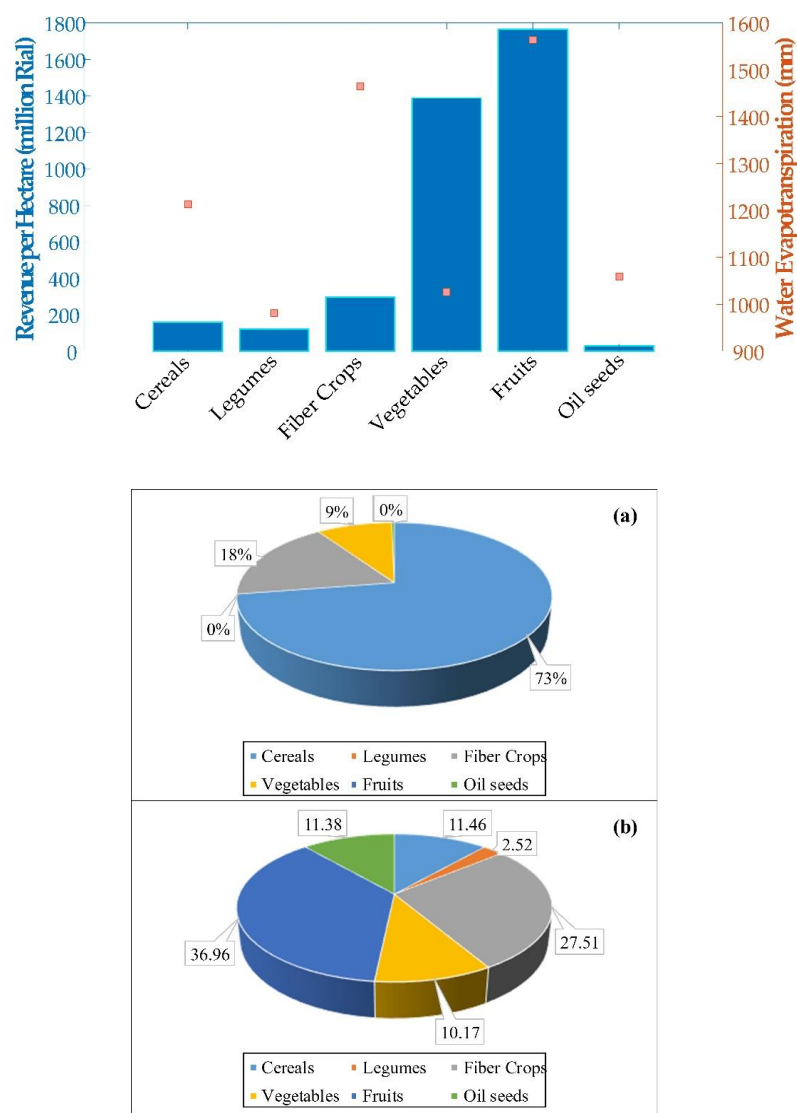


Figure 7. (a) The fractional contribution of exports, and (b) imports of the province during 2005-2014 (1143.53 Mm³ is imported and 274.97 Mm³ is exported at the province level)

Figure 8 provides a comparison between water evapotranspiration and average revenue per hectare of different crop types. From 2005 to 2014, the total water consumption in cereals, legumes, fiber crops, vegetables, and oil seeds decreased by 25% or $217.06 \times 10^6 \text{ m}^3$. The irrigation water consumed in fruits, though, increased dramatically by 148% or $251.00 \times 10^6 \text{ m}^3$. This reallocation of limited water resources to water-intensive crops like fruits resulted in increasing water consumption during this period (Figure 5). Regarding the depicted results in this figure along with the results shown in Table 3, vegetables are the most environmentally (low TVW) and second economically

(high revenue per hectare) sustainable category. Therefore, it is worth to increase the cultivation area of this crop type. By applying this crop pattern, farmers would gain more profit by using the same amount of water or even less.

As can be seen in Figure 8, fruits have the biggest evapotranspiration (1,563 mm per year), followed by fiber crops (1,464 mm per year). Legumes and vegetables have the minimum values of evapotranspiration with 981 and 1,026 mm per year, respectively. Although the crop water requirement of legumes and oil seeds are much lower than the other categories, but their low yields lead to the high virtual water contents with 11,999 m³/ton and 13,171 m³/ton, respectively. Vegetables with 937 m³/ton are ranked the latest place in respect with TVW.

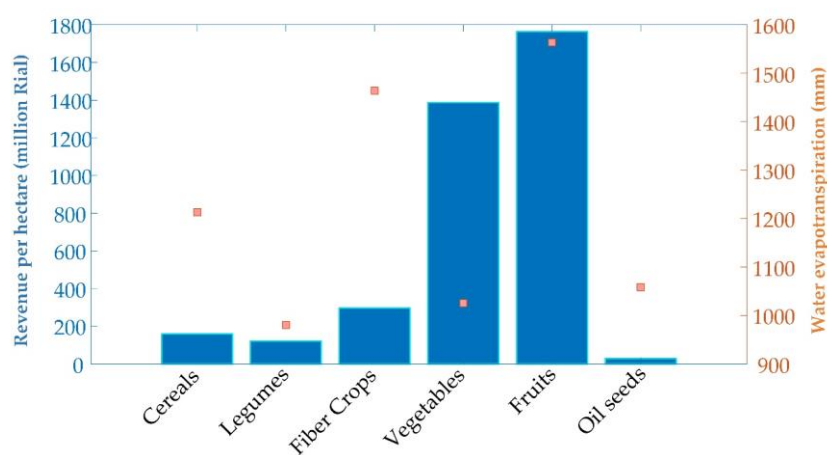


Figure 8. 10-year average of South Khorasan crop revenue per hectare and crop water requirement

Fruits, however, is the type that captured the greater amount of imports with 422.61×10^6 m³ annually. Fiber crops (265.33×10^6 m³), oil seeds (129.20×10^6 m³), vegetables (90.88×10^6 m³), and legumes (28.84×10^6 m³) held the next positions, respectively.

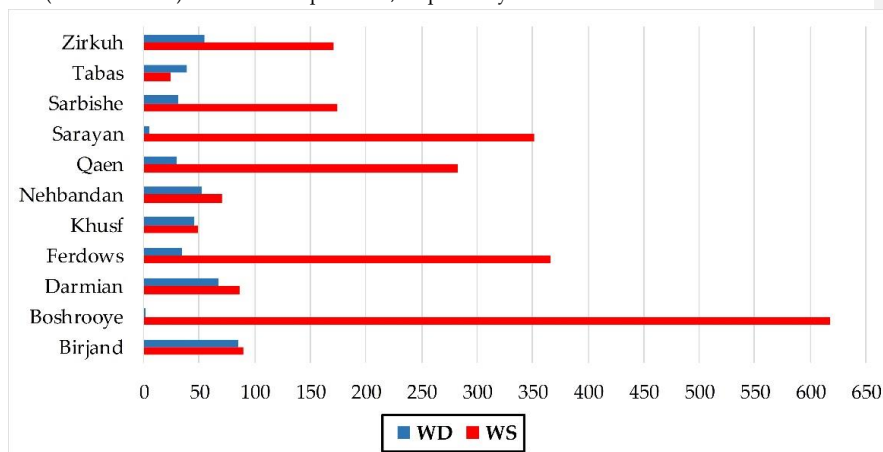


Figure 9. Water dependency against water scarcity in each county

Birjand and Darmian, although, ~~are~~ were net virtual water importers in all crop types, but their average WS of 92% and 83%, respectively implies that their crop production ~~are~~ were not sustainable. This ~~is~~ was also true for other counties as well, excluding Tabas with 25% and Khusf with 49% of WS. The low WS in Tabas ~~is~~ was mainly due to its large territory (accounted for 37% of entire province's area) in comparison with other counties and its low harvested area as a result of its harsh climatic condition. Other counties, though, ~~import~~ imported some type of crops while ~~export~~ exported the other ones. The contribution of each type of crops ~~are~~ is presented in Figure 7.

Table 5. Water withdrawals and availabilities for each county during 2011-2014

Counties	Water withdrawal (10 ⁶ m ³)				Water availability (10 ⁶ m ³)			
Year	2011	2012	2013	2014	2011	2012	2013	2014
Birjand	28.72	26.20	25.71	22.10	31.12	31.11	24.72	25.44
Boshrooye	160.29	208.46	216.39	232.17	39.71	39.69	31.55	32.47
Darmian	32.94	31.67	31.25	44.15	47.39	47.37	37.65	38.75
Ferdows	67.72	86.14	81.29	263.27	39.12	39.10	31.08	31.99
Khusf	56.43	64.92	51.72	63.66	134.12	134.07	106.56	109.66
Nehbandan	84.70	101.56	126.10	109.73	168.62	168.56	133.97	137.87
Qaen	181.09	180.53	176.13	183.98	69.92	69.89	55.55	57.17
Sarayan	102.78	158.40	160.94	159.52	46.39	46.37	36.86	37.93
Sarbishe	80.11	106.16	104.64	115.73	64.70	64.68	51.41	52.90
Tabas	57.84	83.03	83.47	86.12	355.02	354.89	282.06	290.29
Zirkuh	91.18	99.29	102.47	98.42	63.65	63.62	50.57	52.04

In terms of sustainability, nine counties ~~are putting~~ put their valuable and limited groundwater resources in grave danger of deprivation. Ferdows, Boshrooye, and Sarayan ~~have~~ continued to rely heavily on their groundwater aquifer systems as a result of self-sufficiency policies without considering the limited water resources (Figure 6). ~~In the study decade,~~ South Khorasan province has suffered the consequences of this mismanagement. Drying up lakes and wetlands, land subsidence and sinkholes, water quality degradation, desertification, coming down the groundwater levels, soil erosion, and dust storms as environmental consequences and losing lots of jobs, migration to towns, and suburban sprawl as social ones ~~are~~ were prompted as a result of the condition of insecurity [2].

5. Conclusion

In the study region (South Khorasan province, Iran) due to the low precipitation and high rates of evapotranspiration, green virtual water (GVW) accounts for a small fraction of total virtual water (TVW). Besides, in this occasion, the national policy to achieving full self-sufficiency in producing all the agricultural produce has exerted an enormous pressure to groundwater aquifers. In line with this policy, overexploitation have occurred in most counties of the South Khorasan province. The results of this study show that there are significant differences in the productivity of same crop categories in different counties throughout the province mainly due to different climatic parameters. It is shown that if the spatial prioritization for harvesting different crop categories had been established by the local authorities, more than 346×10^6 m³ water could be saved annually in the agricultural practices within the province without any reduction in cultivation area. Although there was a considerable decrease in the cultivation area of some crops during the period of 2005-2014, this reduction in cultivation areas did not contribute to water saving. This was largely caused by the expansion of the water-intensive crops cultivation, namely fruits.

In addition, the Water Scarcity of counties within the province has been quantified applying some indicators in this study. The results show that almost all the counties are heavily exploited or

even overexploited. In addition, there was an increasing trend in Water Scarcity of counties due to the growth of cultivation of water-intensive crops, such as fruits, which led to an increase in water exploitation.

Considering the water-related problems in South Khorasan province, there is a crucial need to change management strategies for limited available water resources. For example, importing water-intensive crops instead of producing them in the province can alleviate the situation. Furthermore, the region authorities should understand food self-sufficiency concept correctly and consequently the meaning of the “development”. Unfortunately, the current agricultural practices in the province is neither environmentally nor socioeconomically sustainable. Importing foods from outside the borders of the province, in the national scale, instead of producing them locally can save a huge amount of water annually. The results of the study indicate that, in the sustainability point of view, importing cereals and fruits are of high priority not only due to their high consumption in the province but also for their high TVW.

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5. Author Contributions

All authors contributed extensively to the work presented in this paper. As specific contributions, Ehsan Qasempour contributes in Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, and Writing – original draft. Ali Abbasi contributes in Conceptualization, Methodology, Project administration, Supervision, Validation, and Writing – review & editing.

6. Conflicts of Interest

The authors declare no conflict of interest.

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