

Earth's Future

RESEARCH ARTICLE

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Key Points:

- Trends in Iran's agricultural production and area did not follow natural water availability changes due to meteorological variability
- Iran's agricultural production continuously increased despite water availability reduction during 1981–2013
- The unsustainable growth of Iran's agriculture has important water, food, environmental, economic, and human security implications

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(continued)

Iran's Agriculture in the Anthropocene

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Abstract The anthropogenic impacts of development and frequent droughts have limited Iran's water availability. This has major implications for Iran's agricultural sector which is responsible for about 90% of water consumption at the national scale. This study investigates if declining water availability impacted agriculture in Iran. Using the Mann-Kendall and Sen's slope estimator methods, we explored the changes in Iran's agricultural production and area during the 1981–2013 period. Despite decreasing water availability during this period, irrigated agricultural production and area continuously increased. This unsustainable agricultural development, which would have been impossible without the overabstraction of surface and ground water resources, has major long-term water, food, environmental, and human security implications for Iran.

Plain Language Summary Given the heavy reliance of the agricultural sector on water availability, it is important to examine if Iran's agriculture has been impacted by water availability changes in recent decades. The investigation of the long-term impacts of natural water availability changes on agricultural activities in the country during the 1981–2013 period revealed that the agricultural sector in Iran continued to expand regardless of decreasing water availability in the country. This expansion was facilitated by the excessive use of nonrenewable water resources which has significant environmental and socioeconomic implications.

1. Introduction

Iran is currently experiencing water bankruptcy, with its water consumption exceeding the country's renewable freshwater budget (Madani et al., 2016). This has been mainly attributed to the country's unsustainable economic development plans, inefficient agriculture, and water overconsumption (Madani, 2014; Madani Larjani, 2005). Additionally, climate change and frequent droughts have potentially exacerbated Iran's water problems by limiting its renewable water supply and altering the spatiotemporal characteristics of temperature and precipitation in Iran (Abbaspour et al., 2009; Golian et al., 2015; Karandish et al., 2017; Karimi et al., 2018; Morid et al., 2006).

For a long time, the country had the ambitious target of becoming fully self-sufficient in food production (Amid, 2007; Bakhshoodeh & Thomson, 2001; Emami et al., 2018; Madani, 2014; Mesgaran et al., 2017) to satisfy its growing population that is now over 80 million people. Although this target has not been fully realized, food security has remained as top national priority in Iran given that fact that for decades the country has been under major international economic sanctions (Danaei et al., 2019; Madani, 2014) with the potential to jeopardize the country's ability to import food. Iran's increasing water shortage (Ashraf et al., 2019)

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and state of “water bankruptcy” (Madani et al., 2016) can limit its agricultural productivity and is a serious threat to the country's food security. The rising temperature that increases evapotranspiration and agricultural water demand (Bannayan & Rezaei, 2014; Eyshi Rezaie & Bannayan, 2012; Gohari, Eslamian, Abedi-Koupaei, et al., 2013; Lashkari et al., 2012; Sayari et al., 2014) can further restrain agronomic productivity in the country with limited water resources, where about 90% of water is consumed by the agricultural sector. Agriculture has a pivotal role in providing food and welfare in Iran. The sector satisfies 90% of the food demand, provides about 20% of employment, and contributes to about 10% of gross domestic product (GDP) (Mesgaran et al., 2016).

Iran is located mostly in arid and semiarid region that is characterized by low rainfall and high potential of evapotranspiration (Amiri & Eslamian, 2010). The country has varying climates from north to south and east to west. While the northern and western parts of the country are humid and the mountainous regions, relatively, have good water availability due to snow accumulation and melt, the southern, eastern, and central parts of Iran are dry, have limited surface water, and rely more on groundwater resources (Abbaspour et al., 2009; Ashraf et al., 2017; Mirzaei et al., 2019). The long-term annual precipitation over Iran is under 250 mm/year, one third of mean global precipitation. Precipitation of over 500 mm is only occurring over 8% of Iran's area (Figure 1a). As the result of climatic variability and change in soil characteristics across the country, only parts of Iran, mainly in north and west, are arable (Figure 1b).

Despite the importance and major role of the agricultural sector in Iran's political economy, food security, and environmental resilience, the studies of Iran's agricultural sector at the national level (e.g., Karandish et al., 2017; Karimi et al., 2018; Mesgaran et al., 2017; Mirzaei et al., 2019) are limited. Given the heavy reliance of the agricultural sector on water availability, it is important to examine if Iran's agriculture has been impacted by water availability changes in the country. This study addresses this knowledge gap and complements the previous national level studies of Iran's agriculture by investigating the long-term impacts of variability of natural water availability on this sector.

2. Materials and Methods

Figure 2 provides the graphical illustration of the analysis process in this study. First, the annual average standard precipitation index (SPI) (McKee et al., 1993) value was calculated using the spatial distribution of calculated SPI values that were obtained using the kriging method across Iran. SPI values help determine changes in natural water availability by quantifying abnormal dryness and wetness during the study period. Kriging method was used considering its better performance than other relevant interpolation approaches such as inverse distance weighting method (Drignei, 2009; Hudson & Wackernagel, 1994; Vajda & Venäläinen, 2003). Then, the relationship between agricultural area/production and SPI was investigated. Finally, the Mann-Kendall (MK) (Kendall, 1975; Mann, 1945) and Sen's slope estimator (SSE) (Sen, 1968) methods were used to evaluate the changes in agricultural production and area in response to natural water availability changes (SPI values).

The MK and SSE methods statistically assess the monotonic upward or downward trends in the variables of interest. The MK test determines the statistical significance and SSE measures the rate of change in variables of interest, i.e., the slope between data points (Q) in the time series. We first applied the MK method to determine the statistical significance of trends, i.e., to find if the changes are significant. When the MK test results showed a statistically significant trend for a variable (p -value ≤ 0.05), we used the SSE test to determine the rate of change in that trend. To compare some variables with different units and ranges of variability (e.g., SPI, agricultural production, and agricultural area), feature scaling based on the normalized method was used using the Student's t test (Hogg & Craig, 1995).

Considering data availability restrictions, we chose 1981–2013 as the study period for which historical records on average annual precipitation were complete at 85 synoptic stations across Iran. Figure 3 shows the locations of stations. The required data for the study were obtained from the Iran's Ministry of Agriculture Jihad, Ministry of Energy, and Ministry of Roads and Urban Development. The study data consisted of the average monthly precipitation at the selected synoptic stations, annual rain-fed and irrigated agricultural areas, and annual rain-fed and irrigated agricultural production. The agricultural data cover a variety of products, namely, cereal (e.g., wheat, rice, and barley), legume, industrial crops (e.g., oilseeds, sugar beets, and

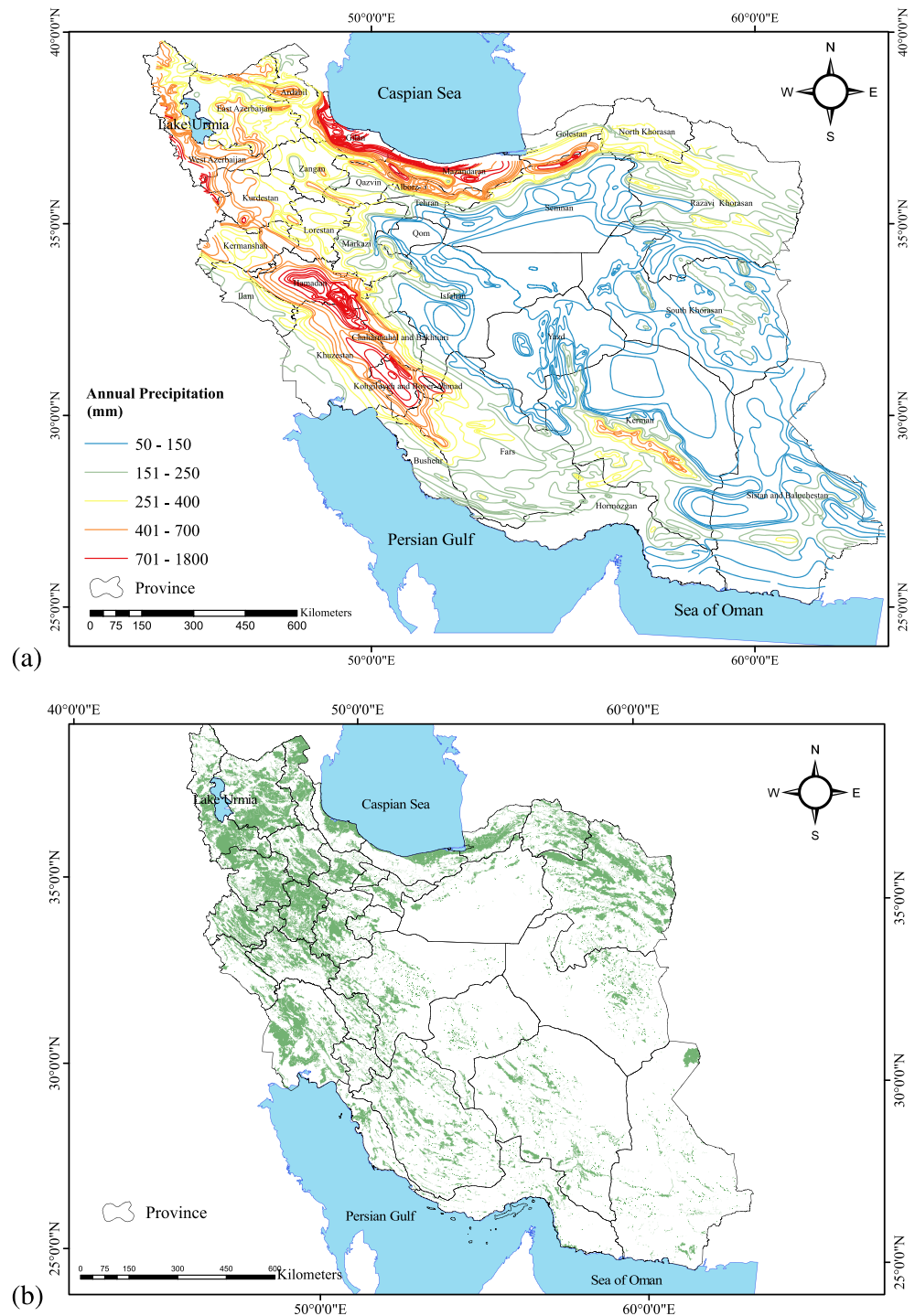


Figure 1. (a) Average annual precipitation, (b) agriculture land distribution (green colors) across Iran.

cotton), special vegetation (e.g., medicinal plants, potato, onion, and tomato), cucurbits, and forage. Table 1 shows the statistical overview of the agricultural area and production in Iran during the study period.

3. Results

3.1. Temporal Variation in Agricultural Production and Area

On average, about 7.2% of Iran's total land area was cultivated during the study period, with 4.9% being irrigated and 2.3% under rain-fed farming. Cereal products dominated Iran's agriculture production using 45.6%

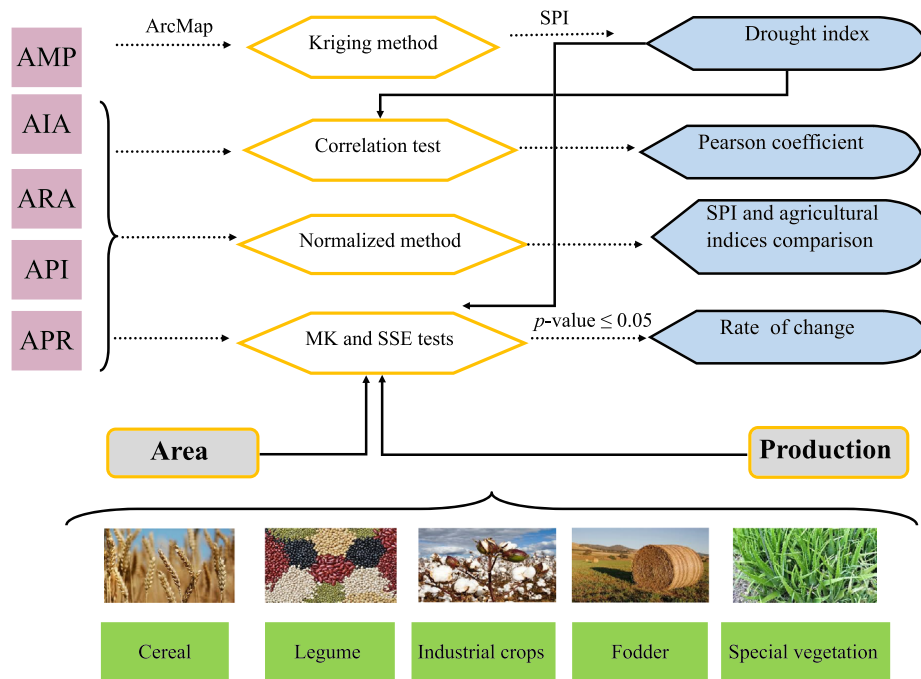


Figure 2. The analysis procedure and components. The green rectangles represent the input data, the orange hexagons represent the test elements, and the blue polygons represent the test outputs. AMP = average monthly precipitation; AIA = annual irrigated area; ARA = annual rain-fed area; API = annual agriculture production in irrigated land; APR = annual agriculture production in rain-fed land.

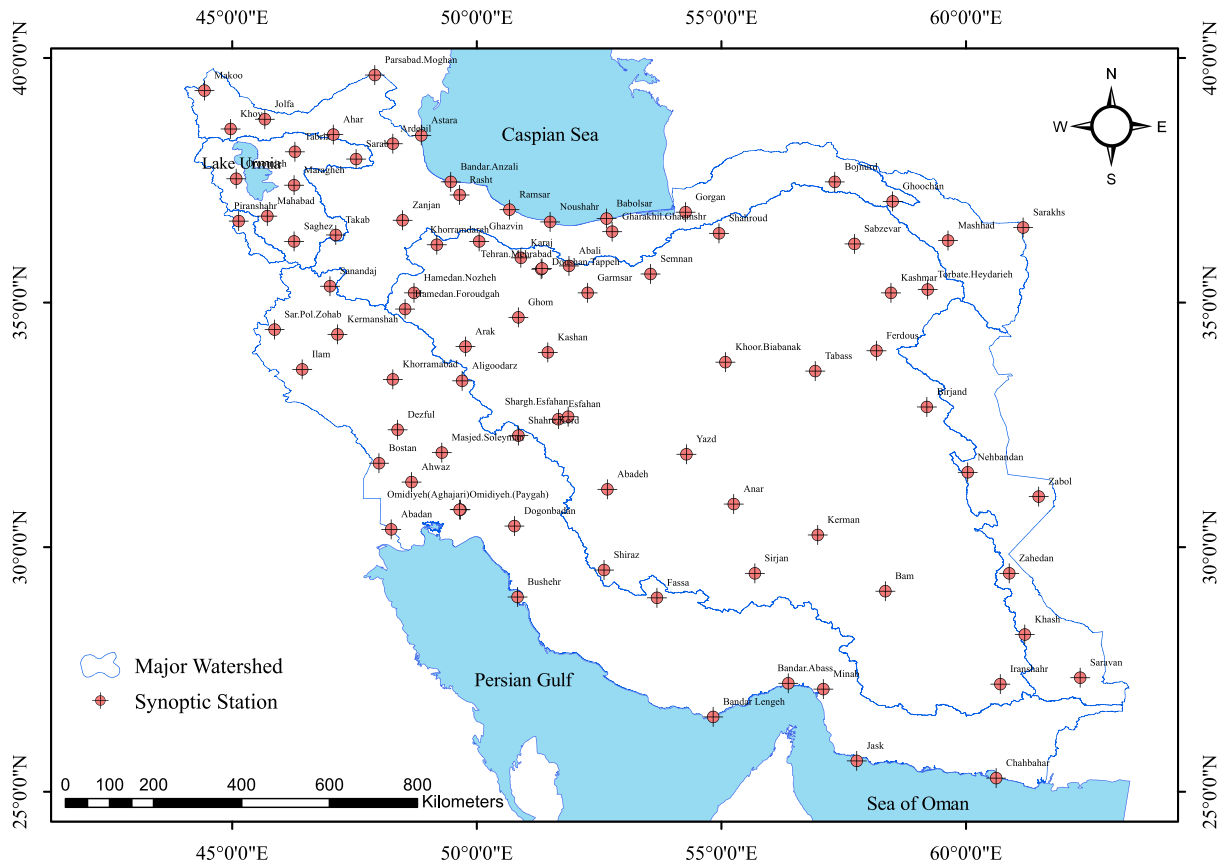


Figure 3. Location of 85 selected synoptic stations used in this study. Annual SPI values at each station were calculated and then the annual SPI across Iran was determined using the kriging method.

Table 1
Statistical Overview of Agricultural Area and Production in Iran (1981–2013)

Variable	Mean	Maximum	Minimum	SD	CV
Irrigated production (ton)	42,727	65,265	17,954	14,163	0.33
Rain-fed production (ton)	6,010	8,353	2,980	1,241	0.21
Total production (ton)	48,737	73,618	22,490	14,899	0.31
Irrigated area (hectare)	5,787	6,740	4,254	571	0.10
Rain-fed area (hectare)	6,138	7,118	4,423	673	0.11
Total area (hectare)	11,925	13,418	10,268	853	0.07
Cereal area (hectare)	8,810	9,787	6,916	711	0.08
Legume area (hectare)	810	1,363	344	263	0.32
Industrial product area (hectare)	607	722	461	79	0.13
Special vegetation area (hectare)	410	555	271	91	0.22
Cucurbits area (hectare)	325	498	232	64	0.20
Fodder area (hectare)	845	1,024	520	123	0.15
Other product area (hectare)	118	254	0	71	0.60
Cereal production (ton)	15,497	24,016	8,602	4,118	0.27
Legume production (ton)	496	711	178	155	0.31
Industrial production (ton)	8,093	12,583	4,180	2,396	0.30
Special vegetation production (ton)	9,487	16,288	2,793	4,278	0.45
Cucurbits production (ton)	5,468	8,872	3,144	1,568	0.29
Fodder production (ton)	9,569	16,163	1,857	4,294	0.45
Other product production (ton)	126	453	0	119	0.95

Note. SD = standard deviation; CV = coefficient of variation.

of Iran's cultivated area during 1981–2013. The average production of cereal, legume, industrial crops, special vegetation, cucurbit, and fodder was 1.76, 0.61, 1.00, 23.14, 16.82, and 11.32 ton per hectare (t/ha), respectively (Figure 4). About 41.8%, 20.2%, 98.6%, 93.9%, 83.4%, and 85.9% of the total area that was, respectively, used for cereal, legume, industrial products, special vegetation, cucurbit, and fodder was irrigated. The average irrigated and rain-fed productions were, respectively, about 3.07 and 0.82 t/ha for cereal, 1.38 and 0.42 t/ha for legume, 1.16 and 1.00 t/ha for industrial crops, 23.88 and 5.76 t/ha for special vegetation, 18.84 and 6.02 t/ha for cucurbit, and 12.11 and 6.50 t/ha for fodder during the study period (Figure 4).

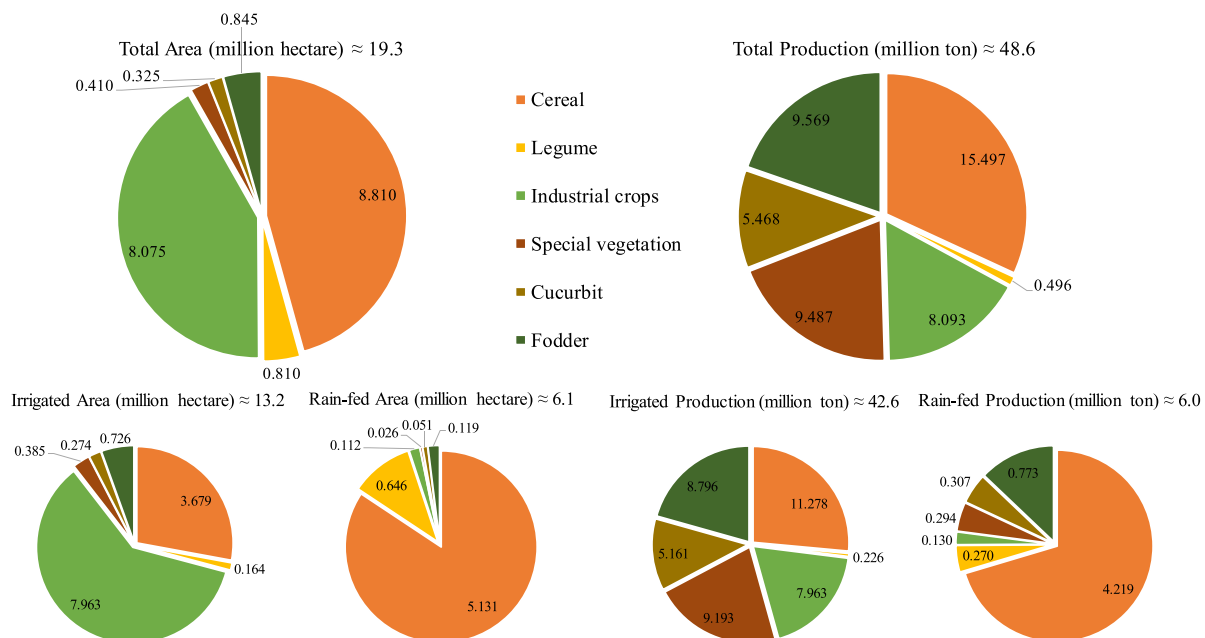


Figure 4. Average irrigated and rain-fed area/production for cereal, legume, industrial crops, special vegetation, cucurbit, and fodder in Iran during the 1981–2013 period.

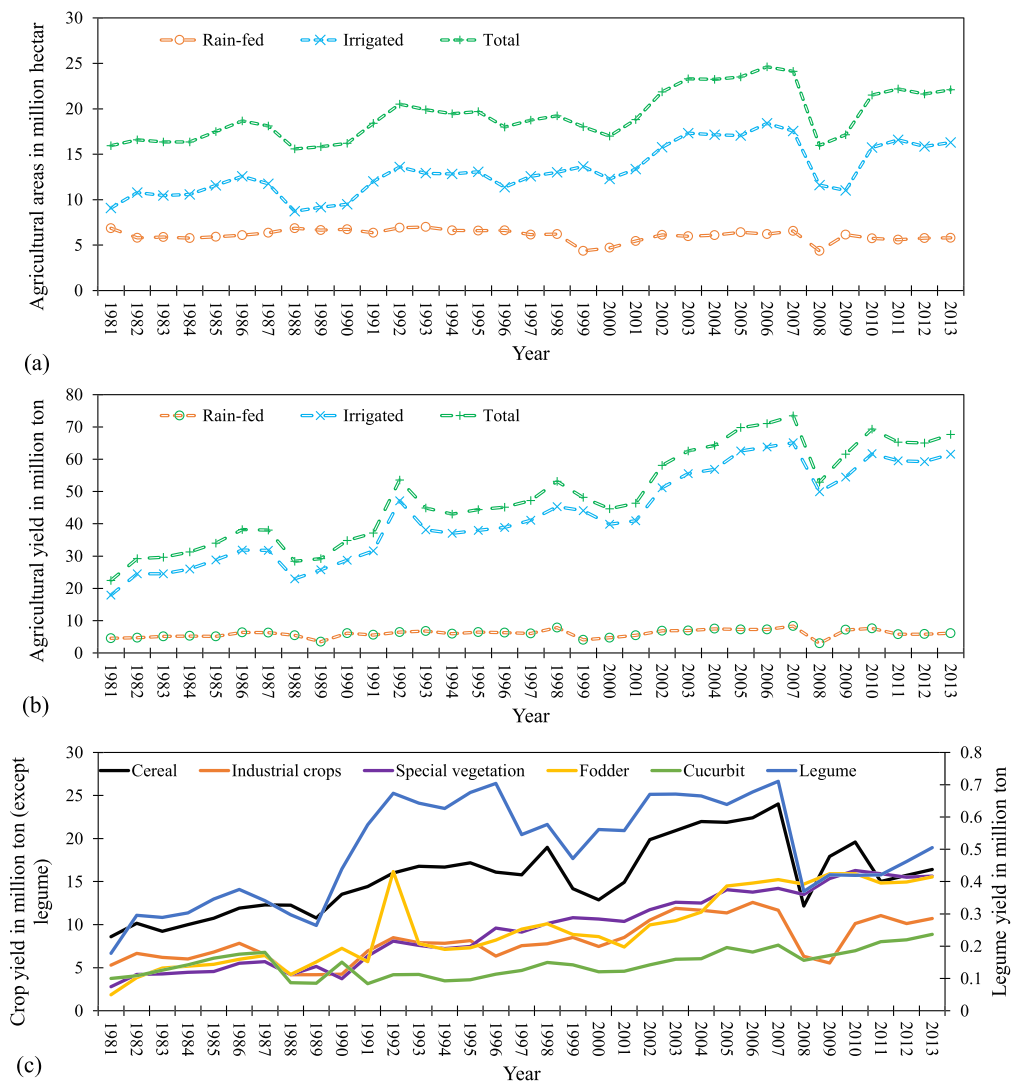


Figure 5. Iran's irrigated and rain-fed agricultural (a) area, (b) production, and (c) production by crop type (1981–2013).

The temporal variations of Iran's agricultural production and area are illustrated in Figures 5a and 5b, respectively. Irrigated and rain-fed agriculture production, respectively, increased by 137% and 59% during the study period. Total production and agricultural area reached their maximum values in 2007 (74 million tones and 13 million hectares, respectively). Irrigated production was a major part of total production and while the irrigated production had a clear increasing pattern, the rain-fed production only showed a weak increasing trend as discussed in section 3.3. The maximum and minimum shares of rain-fed farming in the total agricultural production were about 20% (in 1981) and 5.5% (in 2008), respectively. The maximum and minimum shares of rain-fed agriculture in total production area were about 62% (in 1981) and 42.3% (in 2008), respectively.

Most of Iran's agricultural land area was used for cereal production. Most of the irrigated and rain-fed areas were used for industrial crop and cereal production while cereal was the main product of both areas in terms of weight. Although Iran's total cultivated area has not significantly changed (Figure 5a), total agricultural production in Iran has increased during the 1981–2013 period (Figure 5b). To an extent, this can be attributed to improvements in farming practices and increased access to water through infrastructure and economic development. Nevertheless, for proper interpretation of this observation, one must also note the changes in land use patterns and crop types across the country.

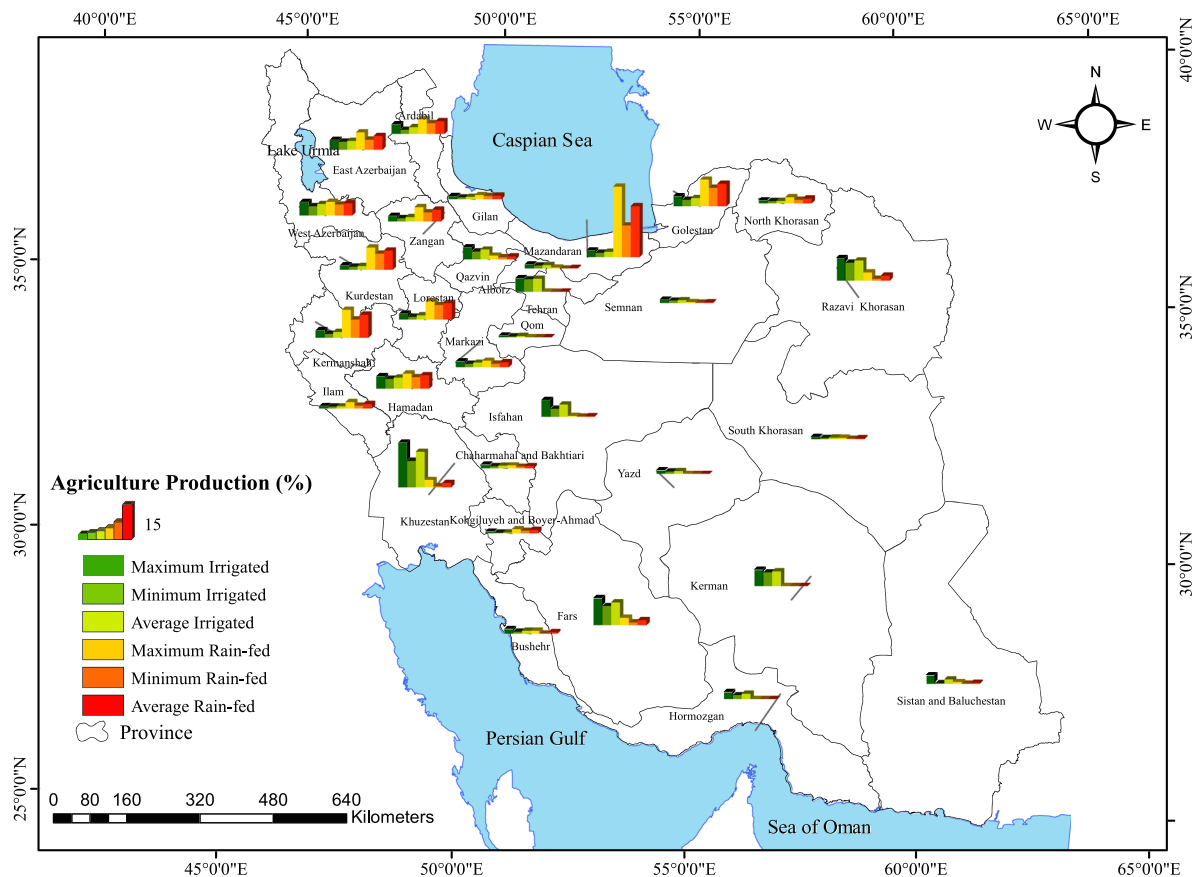


Figure 6. Spatial distribution of agricultural production (minimum, maximum, and average) in Iran from 2004 to 2013. The highest agriculture production occurred in the western and northern parts of Iran. Although the southern, eastern, and central parts of Iran do not generally benefit from high surface water availability, the irrigated farming production in some of these areas was comparable with provinces that have better surface water availability and land suitability.

Despite the growth in agricultural yield (Figures 5b and 5c), the food self-sufficiency goal was not realized in Iran during the study period (Amid, 2007; Mesgaran et al., 2017). Increased food production was not sufficient to keep up with the increasing food demand as the result of rapid population growth, forcing Iran to continue importing portions of its strategic foods. Iran was the ninth-largest wheat importer and the third-largest rice importer in the world in 1999 (Alizadeh & Keshavarz, 2005). Due to a severe drought at the end of the past millennium, Iran rose to the position of a fifth-largest wheat importer in the world in 2001 (Alizadeh & Keshavarz, 2005).

3.2. Spatial Distribution of Agricultural Production and Area

Figures 6 and 7, respectively, indicate the provincial shares of the agricultural production and area across Iran. Minimum, average, and maximum values of agricultural production and area for both rain-fed and irrigated lands over the study period are also shown in these figures. Given the changes in provincial boundaries during the study period and lack of complete time series, these figures have been produced based on the available data from 2004 to 2013.

The Khuzestan and Mazandaran provinces had the highest irrigated (about 18.4%) and rain-fed (29.5%) production in Iran, respectively, from 2004 to 2013 (Figure 6). The Khuzestan province with a relatively high surface water availability had the highest irrigated farming area (14.7%). The Kermanshah and Kurdistan provinces that generally have a relatively high potential for rain-fed agriculture (Mesgaran et al., 2017) had the highest rain-fed farming area (11% each) in the country (Figure 7).

The western and northern provinces have the highest contribution to rain-fed agriculture. This is consistent with higher precipitation (Figure 1a) and better land suitability for rain-fed agriculture in these provinces

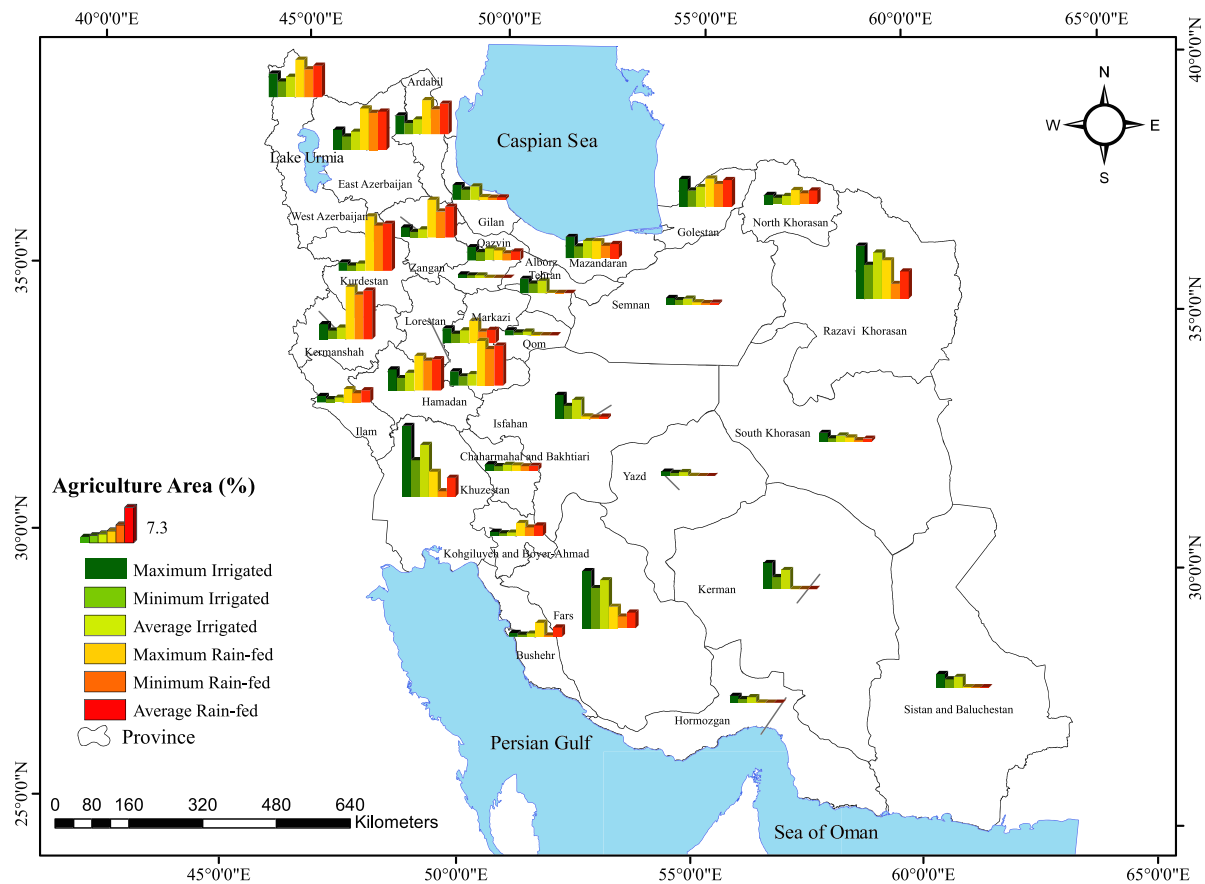


Figure 7. Spatial distribution of agricultural area (minimum, maximum, and average) in Iran from 2004 to 2013. Most of Iran's rain-fed areas are located in western and northern parts of Iran. Although the southern, eastern, and central parts of Iran do not generally benefit from high surface water availability, the area of irrigated lands in some of these regions are comparable with provinces that have better surface water availability and land suitability.

(Mesgaran et al., 2017). In the case of irrigated farming, however, agricultural production and area are inconsistent with climatic and land suitability conditions in some parts of Iran. The southern, eastern, and central parts of Iran do not generally benefit from high surface water availability. Nevertheless, the irrigated farming production and area in some of these provinces are comparable with provinces with better surface water availability and land suitability. A general increasing trend for the irrigated area was observed almost in all provinces. The highest increase in the irrigated area during 2004–2013 was about 135% and occurred in South Khorasan, one of Iran's driest provinces (Figure 1a).

Table 2
Trends of Cultivated Area (Million Hectares/Year) and Production (Million Tons/Year) in Iran (1981–2013)

	Q*	Q _{min95} **	Q _{max95} ***
Irrigated crop production	1.368	1.187	1.595
Rain-fed crop production	0.071	0.028	0.104
Total production	1.414	1.215	1.687
Irrigated crop area	0.048	0.034	0.063
Rain-fed area	−0.022	−0.043	0.003
Total area	0.028	−0.003	0.062

Note. Q* is the mean slope between the start (1981) and end (2013) points of the study period. Q_{min95}** is the minimum slope between start and end points at the 95% confidence interval. Q_{max95}*** is the maximum slope between start and end points at the 95% confidence interval.

3.3. Trend Analysis Results

Table 2 shows the statistical trend analysis results for agricultural area and production from 1981 to 2013 based on the MK and SSE methods. The MK test results revealed that trends for both agricultural area and production under irrigated and rain-fed farming were significant (p -value ≤ 0.05). The SSE test results showed a decreasing trend for rain-fed agricultural area (−22,000 ha/year) and an increasing trend for irrigated crop production (1,368,000 t/year), rain-fed production (71,000 t/year), total production (1,414,000 t/year), irrigated crop area (48,000 ha/year), and total area (28,000 ha/year) during the study period.

Table 3 summarizes the observed trends of changes in agriculture products based on the MK and SSE tests. The MK and SSE results indicate that total production for all crops, total areas for forage, special

Table 3
Trends of Agriculture Production in Iran (1981–2013)

Agronomic Product Type	Yield (million ton/year)			Area (million hectare/year)		
	Irrigated	Rain-fed	Total	Irrigated	Rain-fed	Total
Forage	NT	NT	0.397	NT	NT	0.007
Cucurbits	0.145	0.012	0.132	0.003	−0.002	NT
Special vegetation	0.429	0.008	0.427	0.009	NT	0.008
Industrial production	NT	NT	0.169	0.004	NT	0.004
Legume	0.003	0.005	0.008	NT	0.16	NT
Cereal	0.368	NT	0.411	0.025	−0.072	NT

Note. NT = No Trend observed (p -value ≤ 0.05).

vegetation, and industrial production had significant increasing trends; while total agriculture areas for cucurbits, legume, and cereal did not have notable trends during the study period. The total special vegetation area had the highest increasing trend with the rate of 8,000 ha/year. The total production for special vegetation and legume had the highest (0.427 million t/year) and lowest (0.008 million t/year) increasing rates, respectively. An increasing rate of total production for all types of crops and especially for cucurbits (0.132 million t/year) is also important as it reflects increased water consumption. This is of significant importance when considering the fact that some of these crops are mostly cultivated in the south and central parts of Iran with limited surface water availability.

The MK and SSE tests for major cereal products indicated that except for barley, which showed no significant trend, all cereal products in Iran had increasing trends in both area and production (Table 4). One must also note that although the area under rain-fed cultivation of some crops such as cereal and cucurbits has decreased, no negative trends were observed in their rain-fed yields (Table 3). This reflects increased production efficiency due to using more drought tolerant varieties of crop seeds, consuming fertilizers, and improved agricultural practices.

3.4. Drought Impacts on Agricultural Production and Area

The results of Pearson correlation analysis showed that the agricultural area and production in both rain-fed and irrigated lands of Iran are not correlated with the SPI except for rain-fed cereal area/production and rain-fed industrial production that had a weak correlation (coefficient R smaller than 0.5) with SPI (Table 5). The highest positive correlation between SPI and cereal rain-fed area/production showed that rain-fed cereal has the highest sensitivity to meteorological variability among all types of crops. Iran's rain-fed cereal production is vulnerable to droughts. In general, Table 5 suggests that Iran's agriculture has expanded even in dry years due to the desire for agricultural production growth and/or lack of ability to limit water withdrawal by farmers during dry years. While this unsustainable agricultural expansion can reduce the food security concerns of Iran in the short run, the long-term impacts of this practice on surface and ground water resources that have led the country into the state of water bankruptcy are dramatic and can be irreversible.

Table 4
Trends of Agriculture Area (Million Hectares) and Yield (Million Tons) for Major Cereal Crops in Iran (1981–2013)

Time series	Q*	Q _{min95} **	Q _{max95} ***
Wheat area	0.010	−0.001	0.021
Rice area	0.004	0.002	0.006
Wheat production	0.244	0.125	0.342
Rice production	0.036	0.018	0.050

Note. Q* is the mean slope between the start (1981) and end (2013) points of the study period. Q_{min95}** is the minimum slope between start and end points at the 95% confidence interval. Q_{max95}*** is the maximum slope between start and end points at the 95% confidence interval.

In 1983, maximum rain-fed cucurbits area coincided with the maximum SPI (Figure 8a). Rain-fed cereal area/production had almost a similar trend to the SPI index during the investigation period (Figures 8a and 8b), i.e., the Pearson correlation coefficient had its highest values for the relationship between SPI and rain-fed cereal area and production (0.49 and 0.43, respectively) (Table 5).

Overall, the rain-fed area has been reduced as the tendency for irrigated agriculture that is less vulnerable to drought and meteorological variability has increased. Negative values were obtained for rain-fed area of most crops in the last 4 years of the study period although the SPI values were positive in three of these years (Figure 8a).

The irrigated area and production for all agriculture crops (except for irrigated legume area) increased during the study period as shown in

Table 5
Pearson Correlation Coefficient Between SPI and Irrigated and Rain-Fed Agricultural Area/Production in Iran (1981–2013)

Irrigated				Rain-fed			
Cereal area	0.14	Cereal production	0.08	Cereal area	0.49	Cereal production	0.43
Legume area	0.12	Legume production	0.14	Legume area	0.14	Legume production	0.22
Industrial area	0.28	Industrial production	0.23	Industrial area	0.19	Industrial production	0.41
Special vegetation area	−0.18	Special vegetation production	−0.13	Special vegetation area	−0.22	Special vegetation production	−0.08
Cucurbits area	−0.11	Cucurbits production	0.09	Cucurbits area	0.13	Cucurbits production	0.11
Forage area	−0.18	Forage production	0.13	Forage area	0.08	Forage production	−0.21

Figures 8c and 8d, respectively. Despite experiencing several severe droughts, some highly water consumptive crops such as cucurbits, special vegetation, and forage had high production values during the dry years (Figure 8d).

4. Discussion

Rapid urbanization in Iran involved turning some existing farmlands into urban and industrial lands. The resulting loss of agricultural land area was balanced by agricultural expansion in other areas of the country, including forests. As shown in Figure 5a, while the total farmed area has not changed much, the rain-fed and irrigated areas have decreased and increased, respectively. In some areas of the country, rain-fed farms were turned into irrigated farms through access to new sources of water and technologies. The extreme droughts of the late 1990s and 2008 (Alborzi et al., 2018; Khazaei et al., 2019; Tabari et al., 2013; USDA, 2008), which affected most of the country, incentivized this transformation. Total production under conventional farming dramatically decreased during these droughts, especially for cereal production (Figure 5c). On the other hand, the biggest increase in irrigated production took place during 1990–1993 (Figure 5b). This can be attributed to the increase in water availability for agriculture due to higher than average precipitation (Madani et al., 2016) as well as the construction of a number of large dams during this period (Alizadeh & Keshavarz, 2005) that increased surface water availability for agriculture.

Clearly, the changes in irrigated agricultural area and production in Iran did not follow the patterns of natural water availability changes across time and space. The continued increase in irrigated agricultural area and production despite the reduction in precipitation have not been feasible without extensive reservoir building for surface water storage (Madani, 2014), implementing interbasin water transfer projects (Gohari, Eslamian, Mirchi, et al., 2013; Madani & Mariño, 2009; Mirchi & Madani, 2016) and overuse of groundwater (Mirzaei et al., 2019) that have created significant environmental and socioeconomic problems (Madani, 2014; Madani et al., 2016; Shahriar et al., 2018; Sharifikia, 2013).

The insensitivity of the irrigated production of most crops to natural water availability changes in areas with limited water availability reflects the lack of policies and ability at the national level to regulate crop choices and water withdrawal during dry years and make the national crop pattern compatible with water availability. The agricultural expansion in Iran was enabled by using nonrenewable water resources through building 127 dams (Figure 9a) with a total reservoir storage volume of about 35 km³ (Figure 9b) and drilling a high number of wells (about 540,000 wells) (Figure 9c) across that has led to declining groundwater levels (Figure 9c) in Iran during 1981–2013.

The dramatic pressure on surface and groundwater resources as well as recent droughts have resulted in drying rivers, lakes, wetlands, qanats and springs, declining groundwater level and well discharges, soil erosion, desertification and frequent dust storms, biodiversity losses, and increased pressure on rural livelihood (AghaKouchak et al., 2015; Ashraf et al., 2017; Jamshidzadeh & Mirbagheri, 2011; Jowkar et al., 2016; Madani, 2014; Mirchi & Madani, 2015; Mirnezami et al., 2018; Mirzaei et al., 2019; Nodefarahani et al., 2020; OCHA (Office for the Coordination of Humanitarian Affairs), 2000; OCHA (Office for the Coordination of Humanitarian Affairs, 2001).

The overuse of groundwater (Mirzaei et al., 2019; Nabavi, 2018) has resulted in declining groundwater tables, land subsidence (Haghighi & Motagh, 2019; Motagh et al., 2008, 2017; Mousavi et al., 2001), and sinkholes (Madani, 2014; Vajedian & Motagh, 2019). Saltwater intrusion due to groundwater table decline as

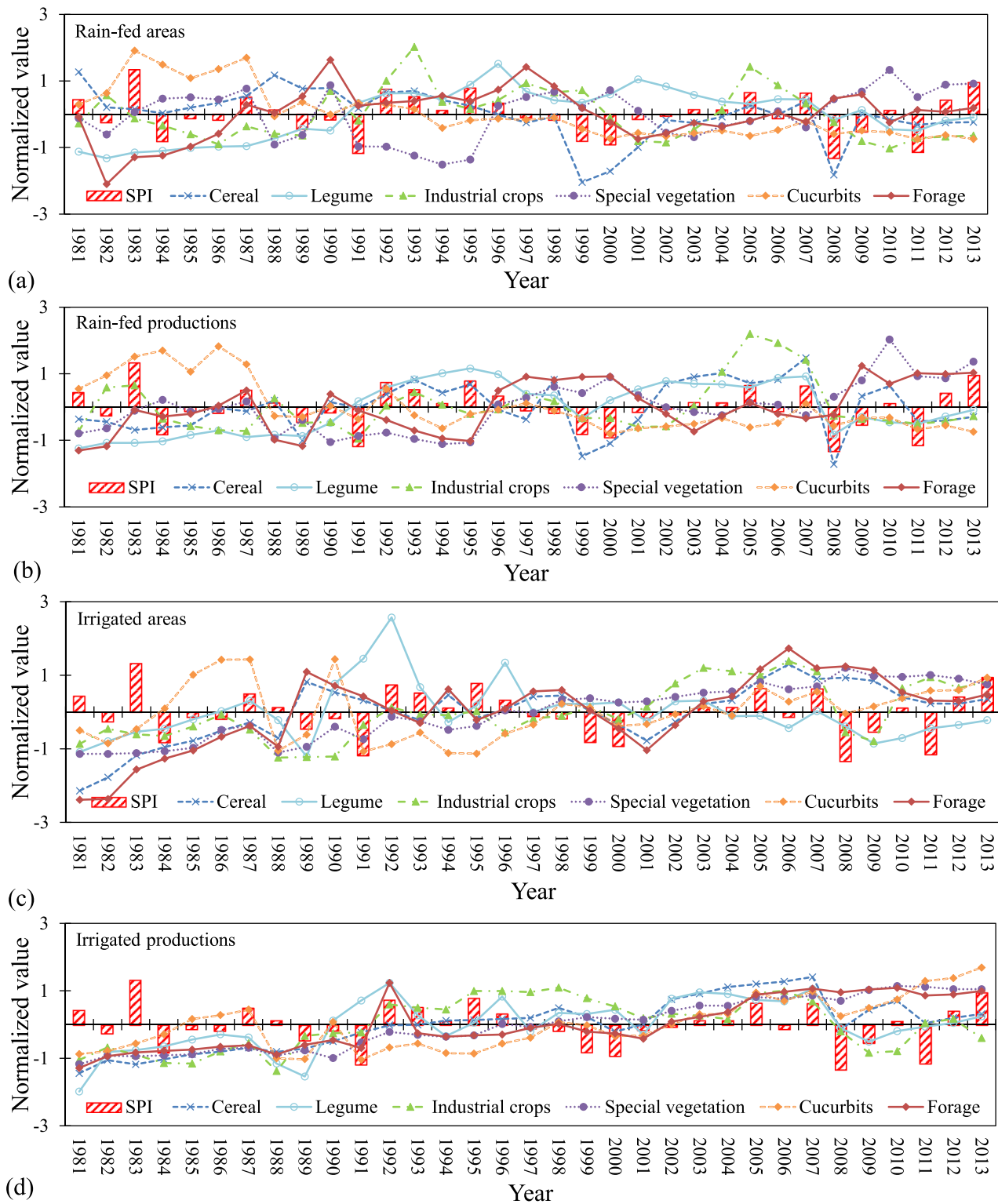


Figure 8. Trends of SPI and (a) rain-fed areas, (b) rain-fed productions, (c) irrigated areas, (d) irrigated productions.

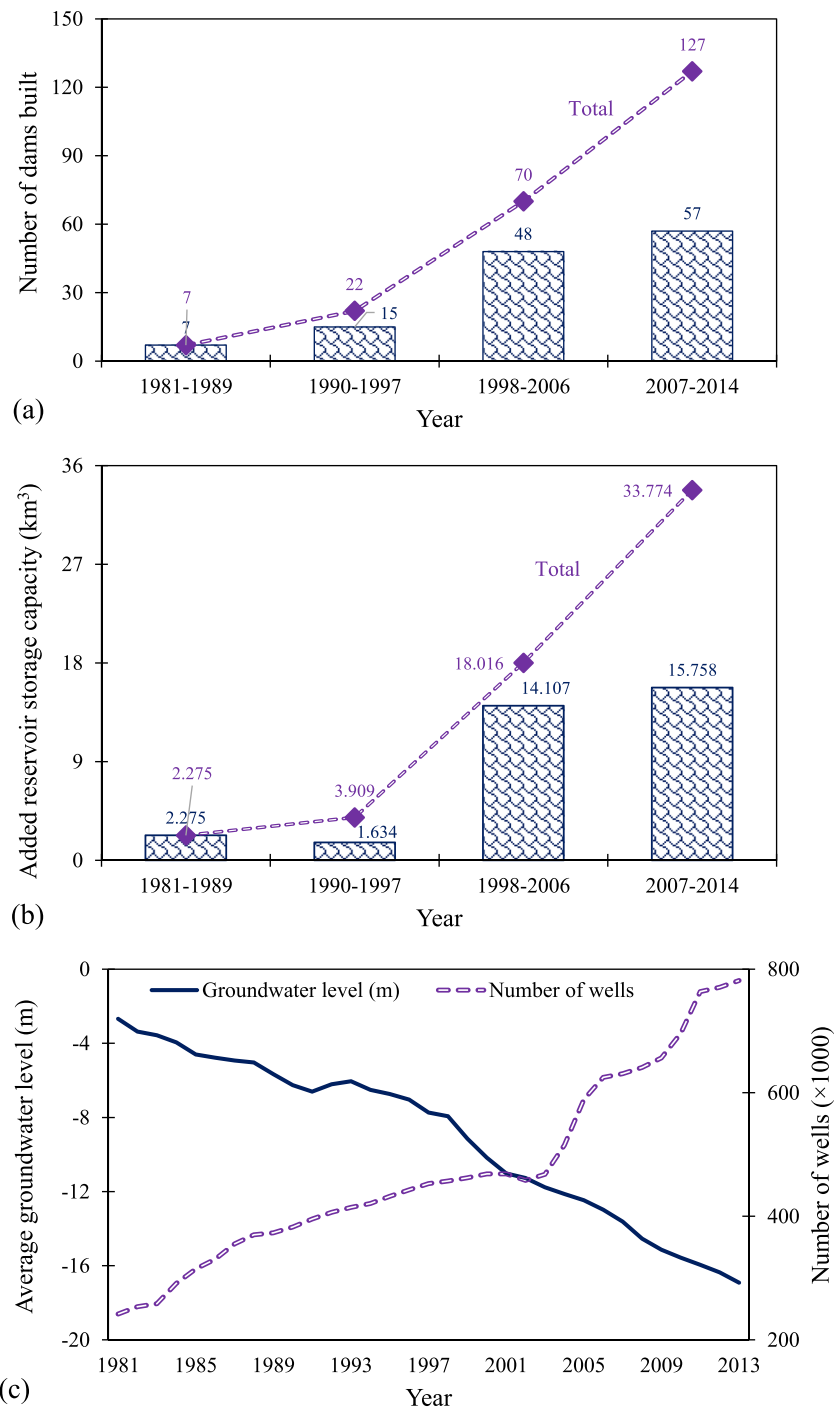


Figure 9. Changes in the (a) number of dams, (b) added reservoir storage capacity, and (c) number of wells and average groundwater level in Iran during the study period.

well as the lack of effective drainage systems have increased salinity in agricultural lands, limiting agricultural productivity and crop choices. Currently, 41 million ha (25%) of Iran has saline soils according to FAO standards (Mesgaran et al., 2017). Yet Iran's government remains determined to expand the irrigated agricultural areas to increase agricultural production and employment opportunities.

In the early 1990s, almost two million tons of chemical fertilizers were being used annually in Iran. Within three decades, the weight of consumed chemical fertilizers was doubled in pursuit of increased food

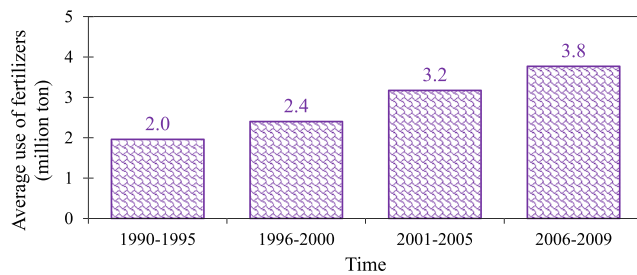


Figure 10. Chemical fertilizer consumption in agricultural lands across Iran (1999–2009).

production (Figure 9). This increasing trend in fertilizer use was motivated by national food self-sufficiency policies as well as the natural quality of lands. In most areas, Iran's soil is rich in CaCO_3 and categorized as calcareous (Khormali & Toomanian, 2018), a soil type that constrains the availability of nutrients (especially micronutrients) for plants (Bui et al., 1990). While increased fertilizer use and the accompanied consumption of nutritional elements in the agricultural sector improves agricultural production, they have long-term implications for safe water availability in the long run. Significant amounts of untreated wastewater, mainly originating from agricultural lands, are discharged into surface and ground water resources. Given the low value and decreasing trend of fertilizer use efficiency in Iran (decreased from about 28% to 21.6% during the 1990–2009 period) (Emadodin et al., 2012), the agricultural effluents are rich in nutrients and significantly deteriorate water resources quality. As a result, most lakes and reservoirs around the country are suffering from eutrophication (Akbarzadeh et al., 2008; Aradpour et al., 2020; Noori et al., 2019; Rezaei et al., 2012). In addition, groundwater pollution by nitrate, as a nutrient that mainly originates from agricultural lands, is considered as a serious problem for most aquifers around the country (Esmaeili et al., 2014; Ghahremanzadeh et al., 2018; Mahvi et al., 2005; Noori et al., 2020).

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5. Conclusions

Agriculture plays an essential role in providing food security and socioeconomic stability. Iran's agricultural production has increased in the last decades as a result of land and water resources development. However, the agricultural sector is vulnerable to water availability changes, meteorological variability, extreme climate events such as droughts, and climate change. Here we explored if the agricultural sector development is in a sustainable track and if it has been impacted by the anthropogenic water availability changes in recent decades.

Results indicate that the agricultural development in Iran is not consistent with natural water availability changes across time and space. Despite decreasing water availability, the agricultural production in Iran has increased over the 1981–2013 period. The rain-fed agriculture in Iran has had some correlation with natural water availability and has been vulnerable to droughts. The productivity of this sector has increased through improved farming practices while the total rain-fed farming area across the country has decreased. The latter is due to turning some rain-fed farms into irrigated farms and/or losing agricultural lands to urban development. Iran's irrigated agriculture has not been affected by declining water availability and has grown both in terms of production and area. The increase in the area of irrigated agriculture has compensated for the loss of rain-fed lands. So the total cultivated area of the country during the study period has remained almost unchanged. The outcome of this unsustainable, water-dependent growth is depleting groundwater resources and shrinking rivers and surface water bodies across the country.

The anthropogenic impacts of local decision-making and climate change pose a serious threat to Iran's agriculture, water/food security, and environmental resilience. Urgent policy reforms are needed to adapt the agriculture sector to natural water availability, ecologic carrying capacity, and the expected impacts of climate change in different parts of the country. Without such reforms, groundwater overdraft, surface water shortage, water quality deterioration, and environmental degradation would continue and increase the risk of food insecurity, job losses, migration, conflicts, and tension in Iran.

Conflict of Interest

The authors declare no conflict of interests.

Data Availability Statement

All data used in this study can be obtained from figures and tables. Data for agricultural production and area are available in Table 1 and Figures 4 to 8. SPI data are available in Figures 3 and 8. Data for number of dams built, added reservoir storage capacity, average groundwater level, and number of wells are available in Figure 9. Also, average use of fertilizer's data are available in Figure 10.

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