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REVIEW

Soil degradation and agricultural sustainability: an overview from Iran

Iraj Emadodin · Daiju Narita · Hans Rudolf Bork

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Abstract During the past six decades, agriculture as a main sector in Iran's economy has been affected by economic development, land-use policies, and population growth and its pressures. From the 1940s until 2010, the percentage of the total urban population of Iran increased from about 21 % to around 72 %. Urbanization, industrialization, and intensive cultivation have dramatically affected soil and water resources. The exploitation of groundwater has been increased around fourfold from the 1970s to the mid-2000s. Total water resources per capita reduced around 23 % from 1956 to 2008. The average annual decrease in the groundwater table in Iran during the last two decades is 0.51 m. In 2008, the groundwater table fell around −1.14 m in average in Iran. The average use of chemical fertilizers increased from around 2.1 million tons in 1990s to about 3.7 million tons in 2009. During that period, fertilizer use efficiency decreased from around 28 % to around 21 %. Approximately 77 % of the agricultural land under irrigation suffers from different levels of salinity. According to the quantification of four indices, such as soil erosion, fall in groundwater levels, salinity, and use of chemical fertilizer, that are directly related to agricultural land use, the results show that agricultural management in Iran needs special attention to reach sustainable conditions. The total cost of soil and water degradation and use of fertilizers in agriculture are estimated around than US $12.8 billion (about 157,000 billion IRRials)—approximately 4 % of the total gross domestic product (GDP) and approximately 35 % of the GDP of the agricultural sector in Iran.

Keywords Human-induced soil degradation · Desertification · Population growth · Environmental changes · Sustainability · Agricultural land · Iran

I. Emadodin (✉) · H. R. Bork
Institute for Ecosystem Research, Christian-Albrechts-University, Kiel, Germany
e-mail: iemadodin@ecology.uni-kiel.de

D. Narita
Institute for the World Economy, Kiel, Germany

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1 Introduction

An increase in agricultural yield over the past several decades has not already come without several costs (Gliessman 2004). It caused some environmental, economic, and social problems (e.g., Kimbrell 2002; Gliessman 2004). A study of soil degradation and agricultural sustainability needs combined socioeconomic and environmental approaches. During around the last five decades, agricultural activities have been directly affected by population growth and the spatial distribution of the people. Land-use changes and intensive farming activities have negative effects on the value of the output and capacity of the agricultural land (e.g., Zinck et al. 2004; Emadodin et al. 2009; Emadodin and Bork 2011). Population growth increases the demand of food and agricultural activities. Productivity usually increases by an acceleration of the use of machinery and chemical fertilizers. An important factor for a successful strategy to maintain the level of agricultural production is a sustained increase in productivity. During the past six deceases, intensive agricultural practices have had significant effects on agricultural sustainability and productivity. Industrialization, population growth, and urbanization caused an intensification of land use and have created several problems for the natural and the human environment (e.g., Emadodin and Bork 2011). Agricultural sustainability is a multidimensional issue. Herdt and Steiner (1995) described three aspects of sustainability of a system, including space (the scale and level of assessment), time (long-term dynamics), and namely biophysical, economic, and social drivers. Sydorovych and Wossink (2008) developed a set of sustainability attributes. They indicated the main attributes of agricultural sustainability including economic, social, and ecological components in detail.

According to Altieri et al. (1983), American Society of Agronomy (1989), and Farshad and Zinck (2001), a sustainable agricultural system is a system that over long time:

- provides human food demand,
- uses land and other resources most efficiently,
- increases environmental quality through adoption of agricultural practices,
- is socially and politically acceptable, and
- improves the social and economic conditions of local people.

Land-use intensification has the most significant effect on soil productivity and its economical and ecological functions. As a technical approach, sustainable agricultural management needs:

- soil erosion control,
- good soil structure,
- good soil fertility conditions, and
- good water balance.

In order to study ecological and economical aspects of soil degradation in agricultural land, it is necessary to consider the trend of sustainability of agriculture practices with regard to output and input namely of energy, water, and matter.

This overview follows the DPSIR (Driving forces, Pressure, State, Impacts and Response, assessment framework of soil degradation, Fig. 1) that is adapted by EEA (European Environment Agency 2001). DPSIR model was applied by Görlach et al. (2004) to assess the economic impacts of soil degradation. The results of this study may be useful to increase the awareness of policymakers in order to a better management of agricultural land. Also, we recommend an ecological economics approach for decisions related to land use in the future.

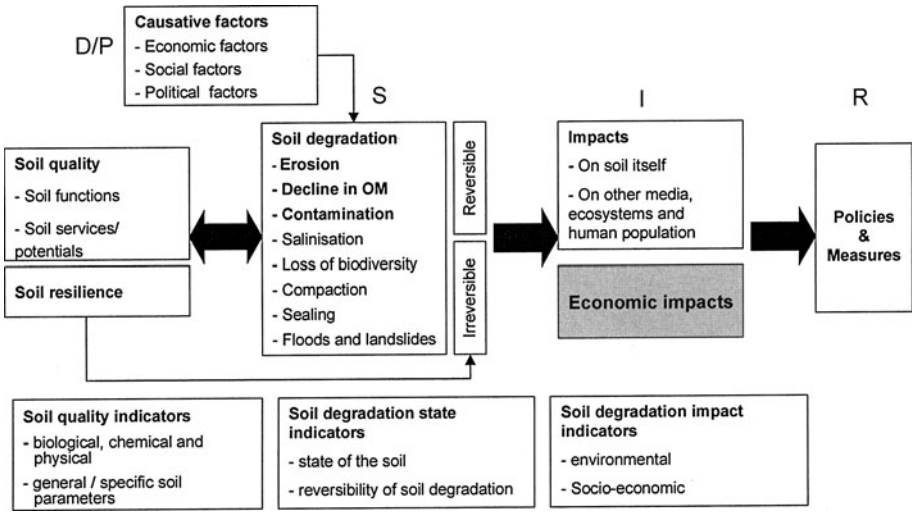

Fig. 1 The DPSIR soil degradation assessment framework (extract from Görlach et al. 2004)

1.1 Share of agriculture in Iran's economy

Gross domestic product (GDP) is considered as a measurement of the size of an economy. Agriculture is an important economic sector in Iran and provides 11 % of Iran's gross domestic product (GDP) today, while industry and services provide 45 and 44 %, respectively. Since 1965, the share of GDP of the agricultural sector has decreased by 16 % points (Table 1). This change shows a dramatic decrease in the contribution of agriculture in the economy of Iran. The share of agricultural labor force in Iran decreased from 56 % in 1956 to around 21 % in 2010 (Table 2). The machinery use in agricultural activities increased from around 5,000 tractors in 1960s to 330,000 tractors in 2008 (Rezaei-Moghaddam et al. 2005; Iranian Ministry of Jihad-e-Agriculture 2009). The annual use of chemical fertilizers increased from around 0.1 million tons in the mid-1960s (Mahdavi 1969) to around 3.78 million tons in 2009. Total agricultural production

Table 1 Change in value added of GDP from different sectors (1965–2009)

Year	Agriculture (%)	Industry (%)	Services (%)
1965	27	30	43
1970	20	38	42
1975	10	55	35
1980	16	31	53
1985	19	27	54
1990	19	29	52
1995	18	34	48
2000	14	37	50
2005	10	45	45
2009	11	45	44

Source: World Bank (2012), Iranian Central Bank (2010)

Table 2 Labor forces in Iran (1956–2010)

Sector	1956 (%)	2010 (%)
Agriculture	56	21
Industry	20	31
Services	24	48

Source: Lieberman (1979), Statistical Centre of Iran (2010)

Table 3 Main farming systems in Iran (2009)

Farming system	Area (1,000 ha)	% Of total arable land	Production (10,000 tons)	% Of total
Irrigated	6,218	41.34	5,605	72
Rain fed	6,222	41.36	838	11
Horticulture	2,600	17.30	1,340	17
Total	15,040	100	7,783	100

Source: Iranian Ministry of Jihad-e-Agriculture (2009)

increased from around 57 million tons in the 1990s to around 97 million tons in 2009 (FAO 2005; Iranian Ministry of Jihad-e-Agriculture 2009).

The intensification in agricultural activities over the past five decades took place alongside the changes of unsustainable land use/land cover. From the 1950s until 2008, around 5 million hectares of forest was converted to farmland, pasture, and urban areas (Emadodin and Bork 2011). The main farming systems are presented in Table 3. According to Mclachlan (1988) in the early 1960s, approximately 4 % of the country were under the plow or covered with fruit trees. In the mid-1950s, the development of oil industry and oil export caused the development of multipurpose dams and agricultural equipment that improved farming practices. Land reforms, which involve regulations of farmland ownership, have been started in 1962 and continued until 1971. The release of 6–7 million hectares of state land resulted in a high number of new landowners (Mclachlan 1988). According to Amid (1990), those land reforms improved welfare for only a small group of rural people and poverty remained as main problem, but the general agreement is that land reform changed the agricultural system. More land was brought under cultivation, and the use of fertilizers significantly increased along with diversification of crops and particularly cash cropping (Rezaei-Moghaddam et al. 2005).

Over the last 50 years, irrigated areas have increased rapidly from approximately 2.5 million hectares in the mid-1950s to around 8 million hectares in the mid-2000s (UN 1961; Iranian Ministry of Jihad-e-Agriculture 2009). The production of wheat (the most important cereal in Iran, 35 % of the food grain production) increased from around 8 million tons in 1990 to 13.5 million tons in 2009 (from around 6.6 million hectares of which 37 % are irrigated). According to the Iranian Water Resource Management Company (2008), the exploitation of groundwater increased from around 16 billion cubic meter in 1973 to about 70 billion cubic meter in 2004. Qanat as a traditional water management system for irrigation in arid and semiarid climates has played a significant role in the agricultural development of Iran in the past (Fig. 2). According to Amid (1990), approximately 75 % of water for irrigation was supplied by qanats in 1960. The number of useable qanats decreased from around 50,000 in the mid-1970s (Mclachlan 1988; Kheirabadi 1991) to around 34,300 in the mid-2000s (Iranian Water Resource Management Company 2004). Drilling wells surrounding qanat's canals, long-term drought, collapse of the roofs of qanats, sedimentation, and earthquakes decreased the quantity of water, and

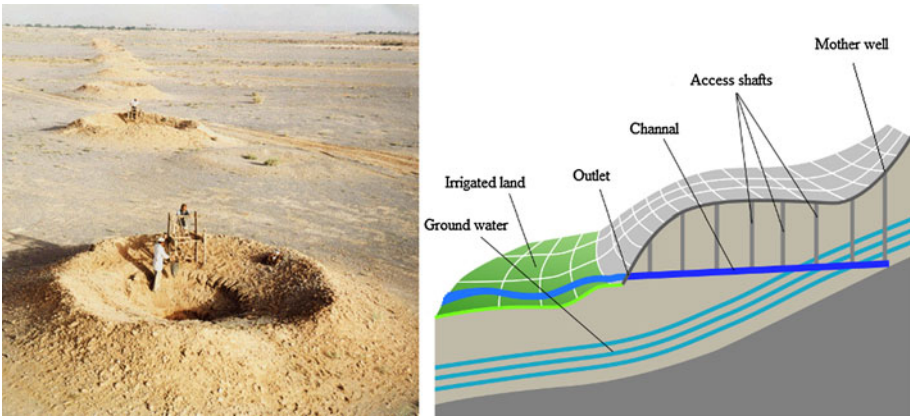

Fig. 2 A section of qanat (*Source*: http://www.wetech-institut.de and http://en.wikipedia.org/wiki/File:Qanat-3.svg)

qanats were abandoned during that period. According to the Iranian Water Resource Management Company (2008), still active qanats provide approximately 10 % of the water for agricultural purposes in Iran. They supply approximately 8.2 billion cubic meter of water annually. Meanwhile, the number of wells increased from around 40,000 in 1973 to approximately 410,000 in 2008. Agriculture uses approximately 89.5 billion cubic meter of water annually. During the past 40 years as a result of economic development and urbanization, water demand had increased in different sectors rapidly. With an incessant population growth and an increasing demand of water, the situation of Iran's water resources will deteriorate in the future. Total annual water resources per capita have reduced from around 7,000 cubic meters in 1956 to about 1,590 cubic meters in 2008. Water management in Iran needs to improve in order to increase the efficiency of water use in agriculture. According to the Iranian Water Resource Management Company (2008), the number of traditional, semi-modern, and modern drainage and irrigation networks are 4,805, 568, and 85, respectively. Water efficiency in agriculture is estimated to be approximately 35 %. This indicates that Iran needs more investment in water recourse management to increase the efficiency of water use in the future. Drought has direct effects on agricultural production and the price of agricultural products in Iran. According to Iranian Ministry of Jihad-e-Agriculture (2009), the area under cultivation decreased from around 14 million hectares in 2007 (with an average annual precipitation of 278 mm) to around 12.7 million hectares in 2008 (with an average annual precipitation of 138 mm). Total agricultural production of Iran decreased from around 90 million tons in 2007 to around 67 million tons in 2008 (Table 3).

Desertification is a serious environmental threat in Iran and creates unfavorable conditions for farmland. Around 42 million km^2 (about 33 %) of the global land surface is affected by desertification (Eswaran et al. 2001). According to Iranian Forests, Range and Watershed management organization (2008), the desert covers around 20 % of total land of Iran (about 0.33 million km^2). Around 1 million km^2 of land in Iran is at risk of desertification (Ahmadi 2004a; Abdinejad 2007). Anti-desertification activities have been started in 1958 by Soil and Water Conservation Committee that it became as a part of the Ministry of Agriculture (Abdinejad and Nategi 2010; Amiraslani and Dragovich 2011). From 1965 until 2006, around 2,300 km^2 of the sand dune areas was stabilized by oil mulch and about

Fig. 3 Anti-desertification activities through the plantation of *Haloxylon* sp. near the city of Shahriar in Tehran Province, north central Iran (Photo: Emadodin)

21,000 km^2 through afforestation and sowing programs (Amiraslani and Dragovich 2011; Fig. 3). Although many activities and projects have been done to mitigate the effects of desertification, it is still a major problem and costs more than US $1 billion annually (Ekhtesasi 2004; Emadodin and Bork 2011).

2 Identification and estimate of the key indicters

In order to assess the trend of sustainability in agriculture in Iran, three main attributes of agricultural sustainability will be considered below. As an environmental aspect, soil erosion, fall of groundwater level, salinity, and the use of fertilizers will be estimated in detail. The demographic dynamics as main social aspect and the total costs of soil and water degradation as an important economic aspect are considered.

3 Main attributes of agricultural sustainability in agricultural land in Iran

3.1 Environmental aspects

3.1.1 Soil erosion

Around 17 billion cubic meters of water is annually used for different sectors (agriculture, industry, etc.) in Iran. About 76.6 % of this water is used for irrigation. According to Iranian Ministry of Jihad-e-Agriculture, dam sedimentation reduces storage capacity around 0.2 billion cubic meters per year. Every year, 0.5 % of the potential dam capacity is lost due to sedimentation. The annual costs of damages from dam sedimentation are approximately US $0.6 billion in Iran (modified after World Bank 2005).

Fig. 4 Sand deposition on agricultural land (Photo: Ekhtesasi)

Approximately 1.2 million km^2 of the land area of Iran is affected by different types of soil erosion (Ahmadi 2004b). Wind erosion as a main effect of land degradation in arid and semiarid areas of Iran affects about 200,000 km^2 of land in 19 from 31 provinces. In critical areas, its impact affects more than 150,000 residential units and 6,300 km^2 of farmland (FRWO 2004; Abdinejad and Nategi 2010; Emadodin and Bork 2011; Fig. 4).

Water erosion removes a maximum of 500 million tons soil from about 15 million ha of agricultural land each year (Samani et al. 2009). According to Pimentel et al. (1995), soil formation takes between 200 and 1,000 years to form 2.5 cm of topsoil. In Iran, soil is lost due to erosion approximately 19 times faster than it forms. Therefore, the present and future potential for soil degradation is very great.

In the United States and China, an estimated 4 and 7 billion tons of soil is lost from the 260 and 108 million ha of agricultural land each year, respectively (Pimentel et al. 1995; Berry 2003; Bennett et al. 2008). Pimentel et al. (1995) also indicated that the total cost of on-site effects of the water erosion in United States is US $20 billion for replacing lost nutrients. The economic cost of soil erosion in China is estimated to be US $6 billion for replacement of nutrients.

The area of arable land under cultivation in Iran is estimated to be approximately 16 million hectares. A maximum of 32 tons ha^{-1} y^1 of soil is lost from farmland in Iran due to water erosion. One ton of soil contains approximately 28 kg of N, P, and K; therefore, around 896 kg of nutrients is lost per hectare (Bybordi 2003). According to the average price of chemical fertilizer, the annual costs of the loss of nutrients due to soil erosion on arable land—with regard to the loss of soil fertility—are estimated to be approximately US $2.7 billion per year.

3.1.2 Groundwater

The long-term average of Iran's annual precipitation is 247 mm (1968–2008). About 70 % of the total precipitation is falling in only 40 % of the area of the country. A long-term analysis of annual rainfall in Iran shows a significant variability in spatial and temporal distributions as well as in frequency and intensity (Ahmadi-Givi and Parhizkar 2008). The average annual potential evaporation varies from approximately 700 mm near the Caspian Sea to more than 4,000 mm in central part of Iran (Qadir et al. 2008). According to Iranian Ministry of Energy, in 2009, the country received around 352 billion cubic meters of water through precipitation, which is approximately 13 % less than the long-term average. In average, approximately 280 billion cubic meters per year is lost via evapotranspiration. Approximately 130 billion cubic meters charges surface and groundwater water annually. Around 89.5 billion cubic meters of water is used in average per year in Iran; around 93 % of this amount is used by agriculture (Hojjati and Boustani 2010). Around 8 million hectares is under irrigation in Iran. And irrigation in iran,and approximately 45 % of water is supplied through surface water and 55 % with groundwater. Groundwater plays an important role in Iran's agricultural activities; 362,784 wells (including deep and semi-deep) supply in average 43.8 billion cubic meters of water for agriculture per year (Table 4). Approximately 30 billion cubic meters of water is supplied through springs and qanats annually. The average decrease in the groundwater table is 0.51 m with a reduction of approximately 4.7 billion cubic meters. In 2008, the groundwater table fell around 1.14 m with about 9.1 billion cubic meter of reduction in groundwater resources (Iranian Water Resource Management Company 2008; Iranian Ministry of Jihad-e-Agriculture 2009). The main cause of water table fall in Iran is over-pumping. According to Iranian Water Resource Management Company, around 85 % of average annual replacements of wells in Iran are the result of falling groundwater levels and drying the wells. Around 28,000 wells have been replaced from 1996 to 2003 (3,500 wells annually). On average, 62 wells were abandoned per year because of groundwater pollution (World Bank 2005).

3.1.3 Salinity

Salinity as one aspect of soil degradation is a main problem in sustainable agricultural management. Agricultural land in Iran suffers from two main processes of salinization, resulting from natural processes (as a result of the geological conditions, climatic factors, the intrusion of saline bodies of water into the coastal aquifers, etc.) and human activities (Fig. 5). The salt-affected area in Iran is about 34 million ha. The highly salt-affected soils and slightly to moderately salt-affected soils are 8.5 and 25.5 million ha, respectively (FAO 2000; Qadir et al. 2008). Over-pumping of the groundwater through exploitation of saline aquifers and lack of drainage facilities are considered as important anthropogenic driving forces of salinity. Around 50 % of the irrigated areas are affected by different

Table 4 Number of wells and the amount of water supply for different sectors in 2008

Area of use	Agriculture	Industry	Urban area	Rural area	Total
Number of well	362,784	27,390	10,515	13,570	414,259
Water supply (billion cubic meter)	43.8	1.7	2.7	1.9	50.1

Source: Iranian Water Resource Management Company (2008)

Fig. 5 Salinity and soil degradation, near the city of Shahriar in Tehran Province, north central Iran (Photo: Emadodin)

Table 5 Soil salinity in irrigated lands in Iran

Salinity level	dS/m	Irrigated land (million ha)	(%)
Slight salinity	4–8	0.9	19
Moderate salinity	8–16	1.2	26
Strong salinity	16–32	1.5	32
Very strong salinity	>32	1.1	23
Total		4.7	100

Source: Moameni (2004), World Bank (2005)

levels of salinity in Iran (Cheraghi 2004). The main result of salinization in agricultural lands is the loss of productivity. Table 5 shows irrigated lands and their salinity levels. According to Qadir et al. (2008), soils with severe to extreme salinity are located in the Central Plateau, Khuzestan and Southern Coastal Plains and the Caspian Coastal Plain of Iran. In these areas, salinity is one of the main factors effecting on crop production.

3.1.4 Use of fertilizer

Fertilizers are used to increase plant growth and productivity. They are divided into two groups: macronutrients (e.g., nitrogen, phosphorus, potassium) and micronutrients (e.g., chlorine, manganese, iron, zinc). The use of fertilizers and pesticides may be useful for increasing the production, but it has several negative environmental effects on eutrophication and human health. Around 19 billion cubic meters of waste water from agriculture, industry, and urban areas recharges to surface water and about 10 billion cubic meters to groundwater (Iranian Water Resource Management Company 2004). According to Iranian Ministry of Jihad-e-Agriculture in 2008, around 4,700 tons of micronutrient fertilizers has

Table 6 Relationship between rainfall, fertilizer use, and agricultural production (1990–2009)

Year	Average amount of fertilizer (×1,000 tons)	Mean annual precipitation (mm)	Production (million tons)	*P*/*F* (%)
1990–1995	1,959	267	54.9	28.02
1996–2000	2,402	239	59.3	24.69
2001–2005	3,173	237	71.7	22.59
2006–2009	3,786	236	81.6	21.55

Source: Iranian Ministry of Jihad-e-Agriculture

P production, *F* average amount of fertilizer

been applied in arable land. The macronutrient fertilizers such as nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) have been used, 2.3, 0.8, and 0.2 million tons, respectively. Also, around 8,000 tons of pesticides have been used in cultivated areas in 2008. Approximately 70 % of chemical fertilizers were produced in Iran, and about 30 % were imported from other countries. According to Table 6, the average use of fertilizers increased around two times from 1990 to 2009. Fertilizer use efficiency has been decreased from 28.02 to 21.55 during the last three decades.

3.2 Demographic dynamics

Iran has a total land area of 1.65 million km^2 and a total population of around 74 million. Population growth and urbanization in Iran during the last five decades as major aspects of demographic transition are the result of economic development during this period. According to Iranian Statistic Centre, the number of cities in Iran increased 20-fold from 1956 to 2008 (Hesari 2008). From 1936 to 2010, the percentage of rural population in Iran decreased from 79 to 28 %, although the absolute size of rural population exhibited an increase during that period (Fig. 6). Urban manufacturing, construction, and services absorbed a large amount of labor force. Figure 7 illustrates the distribution of the population in Iran today. According to this map, the north, north-center, and the west of Iran have a high population density of more than 500 persons per sq km, while the density is less than 2 persons per sq km in the center and the desert area. Around 22 million people

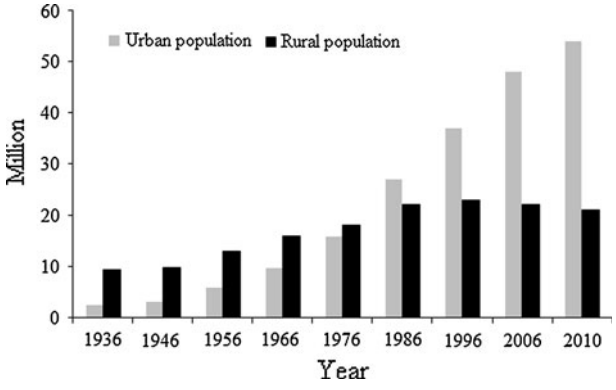

Fig. 6 Population growth in rural and urban areas (1936–2010) (*Source*: Hesari 2008; Statistical Centre of Iran 2010)

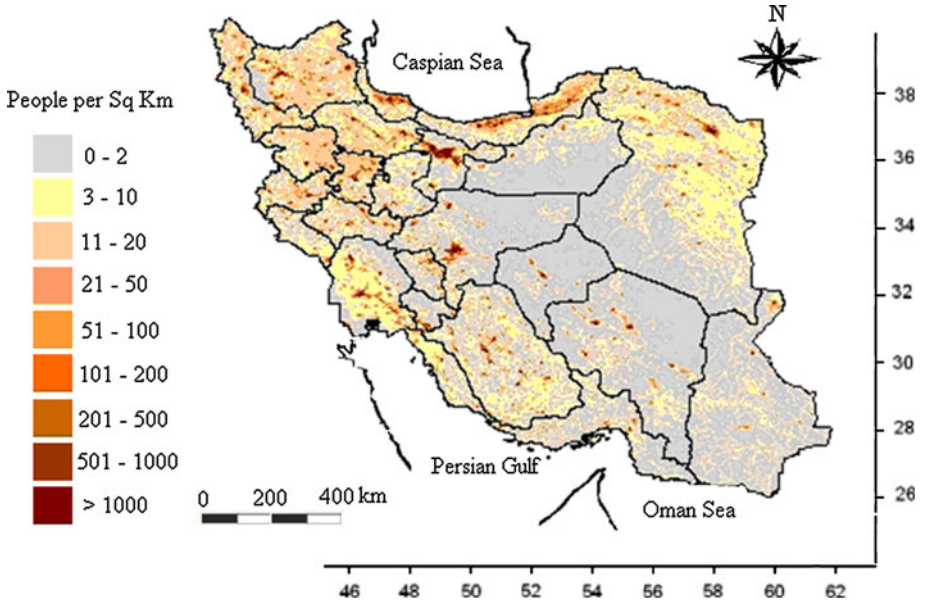

Fig. 7 Density and distribution of the population (modified after FAO 2002) (c) FAO 2011 (*Source*: FAO Country Profiles http://www.fao.org/countryprofiles)

are living in rural areas; 23 % of them engage in agriculture, and 77 % are working in the industry and service sectors. Around 30 % of the total active people in the agricultural sector are women today. As a social development index, the literacy rate has increased from around 15 % in 1956 to approximately 82 % in 2010 (Lieberman 1979; UNDP 2010). Literacy differentiation between urban and rural areas changed from 35 % in 1976 to 13 % in 2006. According to the Literacy Movement Organization of Iran, around 4.5 million illiterate people are still working in industry or agricultural sectors today. The mortality rate for children in an age less than 5 years per 1000 people has been decreased from 190 in 1970 to 31 in 2009 (World Bank 2009).

According to World Bank (2005), total health costs related to inadequate water supply, water pollution, sanitation, and hygiene are estimated to be around US $3.9 billion in 2002.

Energy use (kilogram of oil equivalent per capita) increased from 569 in 1970 to around 2,600 in 2007. CO_2 emission per capita has been increased from around 2 metric tons in 1960 to 7 metric tons per capita in 2007(World Bank 2009). According to Iranian Ministry of Energy, the share of the agricultural sector in total CO_2 emission is around 2.5 %.

3.3 Economic costs of soil degradation

Soil degradation causes various negative effects on human activities and amenities, and some of those effects are quantifiable as economic costs through indirect estimation methods such as the replacement cost approach. GDP has grown during the last 35 years (Fig. 8). According to Iranian Statistic Centre, the price-adjusted household income has decreased from 2005 to 2009; the average reduction is greater for rural households (−17 and −5 %, respectively) than for urban households.

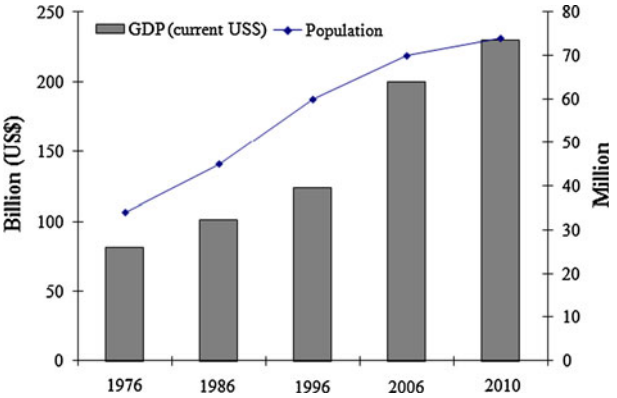

Fig. 8 Population growth and gross domestic production (GDP) (1976–2010) (*Source*: World Bank 2009, Iranian Central Bank 2010)

Soil degradation has direct and indirect economic cost. Loss of nutrients by soil erosion could be offset by application of chemical fertilizers. The total annual costs resulting from dam sedimentation and the reduction in soil fertility are estimated to be approximately US $3.3 billion (around 40,600 billion IRRials, based on 2012 US dollars). Considering the average price of the fertilizers, about US $7.5 billion (around 92,200 billion IRRials) is the annual costs of fertilizers in Iran. Meanwhile, the cost for one well with a depth of 100 m in Iran is US $38,400 (472 million IRRials), including mechanical drilling, piping, and pumping tests. Additionally, approximately US $4,800 or US $24,000 (59 or 295 million IRRials) is needed for diesel pumps and electric motor pumps, respectively. Accordingly, the total cost for drilling new wells (including equipment such as pipes and pumps) due to falling groundwater tables and pollution is estimated to be approximately US $170 million in Iran (about 2,100 billion IRRials). As for salinity, based on World Bank's data and estimation method (2005), the annual costs are estimated to be around US $1.8 billion (around 22,100 billion IRRials).

4 Conclusions

According to four main physical factors that were quantified for agricultural land in Iran, the results indicated that agricultural sustainability is not in suitable condition. Soil erosion is very active and causes several social, economic, and environmental problems. The cost of soil erosion from arable land—with regard to the loss of soil fertility—and dam sedimentation and average price of the fertilizers is estimated to approximately US $10.8 billion (about 132,800 billion IRRials). The decrease in groundwater level increased the economical costs around 0.17 billion US$ (around 2,090 billion IRRials).

Chemical fertilizer use increased approximately 38 times from the mid-1960s to the end-2000s with an average total price of the fertilizers of around US $7.5 billion in 2010. Salinity of soil in different levels as an important factor of soil degradation in agricultural land in Iran affects around 4.7 million hectares with average cost of yield loss around US $1.8 billion (about 22,100 billion IRRials). The total cost of soil and water degradation in agricultural area in Iran is estimated to be approximately US $12.8 billion (about 157,000 billion IRRials), which is around 4 % of the total Gross domestic product (GDP)

and around 35 % of the GDP in agricultural sectors annually. More specifically, sustainable agriculture in Iran needs:

- an increase in the efficiency of water use and an improvement of the drainage and irrigation network;
- an educational and technical development in the different agricultural sectors;
- a development of a regional suitable method to mitigate the effects of soil erosion and salinity;
- an ecological and economic approach in agricultural planning in the future;
- to provide suitable facilities to increase the investment in agricultural sectors; and
- an improvement of drought-resistant plants especially in horticulture;

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