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Post-irrigation degradation of land and environmental resources in the Harran plain, southeastern Turkey

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Abstract Irrigation is a key factor in plant production systems. However, excessive and inappropriate water and soil management systems can cause significant environmental problems. The GAP (the Southeastern Anatolia Project, SEAP) is a multisectoral integrated regional development project. It aims to improve the economical and social welfare of the region as best as possible. The two main objectives of the GAP project include irrigation and energy production. Irrigation was introduced to the Harran plain in 1995, and it led to significant changes in the land use patterns. The use of high-yielding crop varieties and chemical inputs (fertilizers and pesticide usage) resulted in important increases in plant production. Conversely, there was also an increase in land mismanagement. This included practices such as excessive irrigation, intensive soil tillage, insufficient carbon, and soil nutrient cycling. These mismanagement practices lead to soil degradation, which in turn causes increased salinity in soil and groundwater, sediment and nutrient transportation with runoffs, soil erosion, contamination of surfaces and subsurface water sources with nitrates and pesticides, and greenhouse gas emissions. In order to balance yield losses due to the decreasing soil quality, fertilizers and other chemicals were used extensively. This considerably contributed to the environmental problems. Additionally, increasing welfare and population propagated urbanization on arable lands, i.e., the construction of houses, factories, and other agricultural facilities. This further degraded the land and the environment. In conclusion, land irrigation led to production increases, but at the expense of degradation in the environment and soil quality. Moreover, land degradation occurred and further degraded the environment. It is extremely important to improve soil and water management in order to minimize these impacts. The forementioned problems could be solved by improving irrigation efficiencies, good soil and water management strategies, formation of modern well-managed irrigation districts, and educating farmers. Agricultural subsidy-based sanctions could enable these solutions. This study used archived data

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and evaluations of earlier studies to examine important agroenvironmental influences of introducing irrigation in the Harran plain.

Keywords Harran plain · Irrigation · Environmental pollution · Land degradation

Introduction

Irrigation is necessary to meet the food and fiber needs of the growing population. However, inefficient and uncontrolled irrigation may cause environmental concerns, especially in arid and semi-arid areas. The GAP development project has several aspects including the provision of irrigation, the production of energy, and increasing the social and economical welfare of the region. The irrigation project in the GAP project aims to raise the economical and social welfare level of the region to the highest point and to help national and regional development by using soil and water resources in a functional manner (GAP 1996).

The completion of the irrigation project will result in the irrigation of an area of approximately 1.8 million ha within the GAP region. To date, approximately 424,710 ha of the targeted area was irrigated and this corresponded to 23.5% of the total area.

As part of the irrigation planning, the Harran plain was the first and the largest area considered for irrigation. An area of approximately 150,000 ha is under irrigation in the Harran plain. Following the irrigation of the Harran plain, irrigation facilities will be introduced to other plains located in the GAP region. These facilities are currently under construction. The Harran plain is located in the southern part of Şanlıurfa. It is 30 km wide in the west-to-east direction and 50 km in length in the north-south direction (Fig. 1). It shares a border with Syria.

The Harran plain was opened to irrigation in 1995. Irrigation was provided by the water carried by two 50-km-long tunnels to the plain. After the water reaches the plain, it is distributed via open canals and subcanals within the plain. The distribution of the irrigation water is managed by 22 irrigation associations that are bordered by subwatershed basins located within the plain. Irrigation is currently performed by classical flow irrigation (70%). Modern irrigation methods (pressurized systems) constitute the remaining 30%. Given that a high rate of flood irrigation techniques was mostly used, the irrigation efficiency was low with an average irriga-

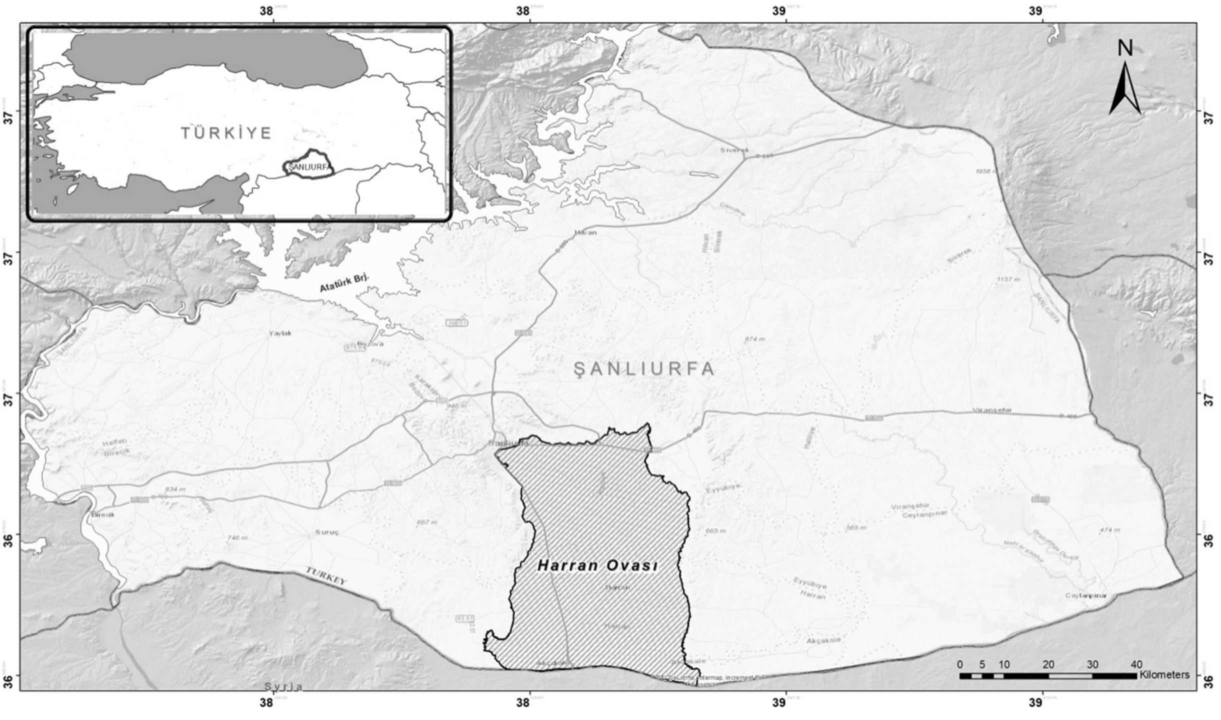


Fig. 1 The location of the Harran plain on GAP region, southeastern Turkey

tion efficiency of 45% for flow irrigation. This is lower than in the western countries (60–70%).

There were significant changes in land use due to irrigation (Fig. 2). Irrigation in conjunction with increasing mechanization led to the expansion of arable areas and changes in crop design. As a result, there were increases in crop production and the welfare of farmers (producers) in the plain. There was an increase of approximately 59.77% in the rate of irrigable areas in the plain. Prior to widespread irrigation in 1984, the total area with irrigation amounted to 15,120 ha. It increased to 58,400 ha in 1992 and 184,500 ha in 2011 (Çelik and Gülersoy 2013).

Following irrigation, the main cropping pattern revealed that cotton was the most commonly grown crop. It was followed by wheat–corn cultivation. The crop design also included crops such as soybean and sesame, which were not grown prior to irrigation. The highest increase in the rate of crop production was observed with respect to cotton (Figs. 3 and 4). There were significant increases in cotton production areas. These increases were because of the existence of suitable areas for cotton growing. To meet the textile industry's need for raw material, agricultural subsidies were given to farmers to encourage cotton production. This also increased cotton production. As a result, Şanlıurfa within the GAP region became the largest cotton producer in Turkey. As per the 2013 statistics, approximately 45% of the cotton produced in the country was in Şanlıurfa (Turkish Statistical Institute (TUIK) 2013). Infrastructural development such as land consolidation, irrigation, and roads and farm roads played an important role in this increase. Conversely, increases in cotton production areas also augmented problems such as soil quality degradation and soil erosion. According to DSI, a daily average of 670 ton soil sediments was lost due to runoffs and drainage water (Darama et al. 2007). Soils where cotton is produced are generally vulnerable to soil erosion due to the insufficient retention of soil residues (Reeves 1997). Decreases in soil organic matter and aggregate stability are typical in cotton production and result in soil erosion. Primary soil tillage, planting, hoeing for weed control, and intensive cultivation aerate soils. This speeds up the mineralization of soil organic matter and thereby decreases soil organic matter contents (Moulin et al. 2011).

The use of irrigation, especially that of high-yielding varieties and chemicals (fertilizer and pesticide use), led to significant crop yield increases. Unfortunately, the increases could not be maintained. The decreases in the efficiency of production inputs caused by the soil quality degradation resulted in problems in maintaining the same yield. Decreased productivity increased the use of chemicals (i.e., more fertilizers and pesticides). In addition to these incorrect applications, intensive soil tillage, insufficient carbon and nutrient circulation, and damages in the soil biological structure caused compaction, erosion, salinity, sodicity, and organic matter losses. This in turn decreased production and caused the degradation of soil and water resources.

Excessive and uncontrolled irrigation led to the following environmental problems: salinity; high water

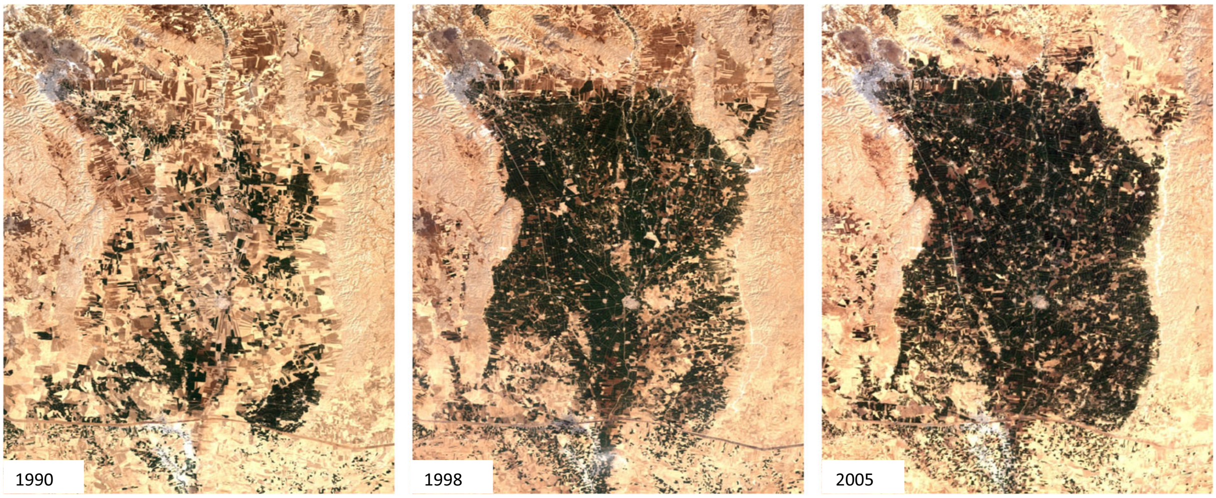


Fig. 2 Land use changes in the Harran plain, 5 years before irrigation (1990); 3 years after irrigation (1998); and 10 years after irrigation (2005)

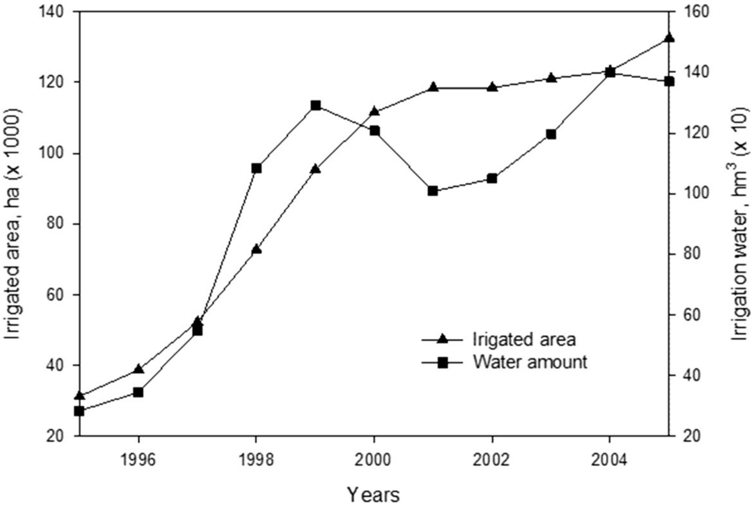


Fig. 3 Changes in the amount of irrigated area (ha) and amount of water released to the plain for irrigation (hm^3) among years after irrigation started

levels; runoffs and soil erosion; contamination of surface and subsurface waters with nitrates, pesticides, and other chemicals; phosphorous contamination due to runoffs; increased greenhouse gas emissions; and the urbanization of arable lands (Kendirli et al. 2005; Yesilnacar and Gulluoglu 2008; Atasoy and Yesilnacar 2010; Cullu et al. 2010a; Bilgili et al. 2013). There were several studies focused on examining basic environmental problems that resulted from irrigation. However, at this point, studies to find solutions for the existing environmental problems are required.

Materials and methods

This study involved evaluation of published manuscripts, project reports, and university theses and analyses of existing archive data in the pre- and post-irrigation periods of the Harran plain which underwent significant environmental, agricultural, and socio-economic changes after irrigation started.

Study site

The study site covers the Harran plain which is located in Şanlıurfa, southeastern Turkey (37° 9.7′ and 36° 42′ N Lat, 38° 49.6′ and 39° 7.9′ E Long), upper Mesopotamia, between the Euphrates and Tigres Rivers (Fig. 1). The plain extends 30 km across north–south and 50 km in the east–west direction covering a total area of 225,000 ha, 150,000 ha of which is currently under flow irrigation. The furrow irrigation began in the plain in 1995. The irrigation water is carried by two tunnels from Ataturk Dam, which is

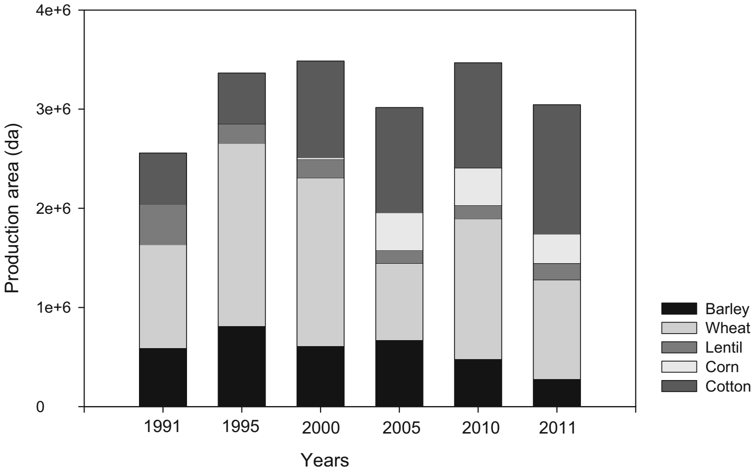


Fig. 4 The crop diversity in the Harran plain and changes in amount of production areas before and after irrigation (Turkish Statistical Institute, TUIK)

part of multibillion dollar regional GAP development project (Southeastern Anatolia Project, SEAP) launched by the Turkish government in the early 1990s with aims to irrigate 1.5 million ha land in southeastern Turkey covering 10% of total arable area of the country once completed. The plain is mainly under cotton and wheat–corn crop management and has a semi-arid climate with mean annual temperature, rainfall, and evaporation rates of 17.2 °C, 365.2 mm, and 1848 mm, respectively. Most precipitation is received during fall season (December to February). Elevation of the plain ranges from 358 in south to 530 m in north with a general slope of 0–2%. The concavely shaped plain is surrounded by mountains in the north, east, and west directions and groundwater generally moves toward the south, where the more salt-affected soils are located. The soils of the Harran plain have been formed on calcareous materials and are classified as entisol, vertisol, and aridisol according to the Soil Taxonomy and as fluvisol, xeresol, lithosol, and vertisol in FAO/UNESCO system (Dinç et al. 1988). Soils are mostly finely textured (clay loam and clay) and high in $CaCO_3$, pH, and CEC but low in soil organic matter contents (0.5 to 1.5%).

Erosion data

Erosion data including flow rates and suspended sediment load transported with main drainage canal was collected by General Directorate of Hydraulic Works (DSI in Turkish acronym) from the flow gauge station located in Akçakale town in Şanlıurfa.

Urbanization analysis

For the analyses of urbanization, two Landsat images, Landsat 5 TM (acquired at Path173 Row34 on July 12, 2005) and Landsat 8 OLI (acquired at Path173 Row34 on July 19, 2015), provided by United State of Geological Survey (USGS), were used. Both images have a spatial resolution of 30 m. After converting irradiance to reflectance, atmospheric corrections were made using Quick Atmospheric Correction (QUAC) algorithm of ENVI (Exelis). The Normalized Difference Built-up Index (NDBI) which is the ratio between the near-infrared band (NIR) with low reflectance on the built surfaces and the shortwave infrared band (SWIR) with a high reflectance (Zha et al. 2003) was derived by the following equation:

$$\mathrm{NDBI} = (\mathrm{SWIR} - \mathrm{NIR})/(\mathrm{SWIR} + \mathrm{NIR}) \quad (1)$$

Finally, in order to extract the built-up areas, a supervised classification method was applied to NDBI images with combination with multispectral bands 1,2,3,7 in Landsat 5 TM and 2,3,4,7 in Landsat 8 OLI. Training data was collected by a visual inspection of the true color images of the same scene used in this study.

Results

Salinity in groundwater and soil

Salinization is inevitable in arid and semi-arid areas where irrigation is conducted. In these areas, the main reasons for salinity and sodicity include insufficient precipitation, high evaporation, insufficient drainage systems, and high ground water levels (Kendirli et al. 2005). Typically, due to excessive irrigation and lack of drainage, salt-affected soils are located in the low-lying parts of the Harran plain. This results in shallow groundwater (Kendirli et al. 2005; Bilgili 2013). Following the insufficiency of irrigation, salinity problems increased the level of groundwater to critical levels. Drainage problems combined with salinity and sodicity issues were the result of factors including uncontrolled and excessive irrigation applications, drainage systems faults, and significant amounts of water losses. The lack of irrigation programs, the application of water exceeding plant needs, traditional and low efficiency irrigation systems, and clogged and unfunctioning drainage canals are among the main reasons for increase in groundwater levels and salinity of the groundwater and soil surfaces. Irrigation water quality is normally better than acceptable. However, the salinity of surface runoffs results in water salinity that exceeds the initial irrigation water salinity. Moroever, as the water moves through the soil profile, deep percolation occurs and dissolves natural salts, thereby adding salts to groundwater. Additionally, in the lower reaches of irrigated areas where irrigation water is not sufficiently fresh, fresh and saline drainage waters are mixed together. However, certain practices may contaminate drainage water and increase its salt content. The quality of irrigation water reaching the plain from the dam is 0.38 dS m^{-1}, while groundwater quality ranges between 1 and 3 dS m^{-1} (Çullu et al. 2010a).

As surface irrigation systems are low in efficiency, there is a significant loss of irrigation water from the plains during the irrigation period. Poor water management results in the discharge of most of the irrigation water to drainage canals. This decreases the salinity of drainage water, which is then reused in irrigating the fields (Bahçeci 2008).

In the plain, the groundwater level is regularly monitored, groundwater depths are recorded monthly, and the salinity level of groundwater is monitored by DSI (General Directorate of State Hydrulic Works) once every 3 months. The poor drainage conditions in an area of approximately 5000 ha area resulted in increases in the ground water levels (DSI 2004). Especially, in the low-lying areas of the plain located in the Turkey–Syria border, the groundwater level increased after irrigation. In 45% of the opened monitoring wells, the levels were determined in the 0–2-m range, which is an acceptable critical level (Kendirli et al. 2005). Bahçeci and Nacar (2009) observed that the water level table fluctuates between 0.40 and 1.20 m during the irrigation season and between 1.40 and 1.60 m otherwise (in the nonirrigation season). The combination of high evaporation rates (1800 mm/year) and clay soils results in the capillary upward movement of the shallow groundwater. This allows the groundwater table to increase, prevents salts from being washed away, and causes salt accumulation in the rooting zone. These salts remain in the root zone and increase the salinity (Steenhuis et al. 2006; Bilgili et al. 2011, 2013).

In pre-irrigation periods of the plain, when groundwater was used for irrigation, there were salinity problems in an area of approximately 3000 ha. The main reasons for this include faults in drainage conditions and low irrigation water quality (groundwater quality). The combined effects of climate, topography, soil properties, and poor management strategies such as uncontrolled and excessive irrigation led to increases in salinity and sodicity problems over the years (Kendirli et al. 2005).

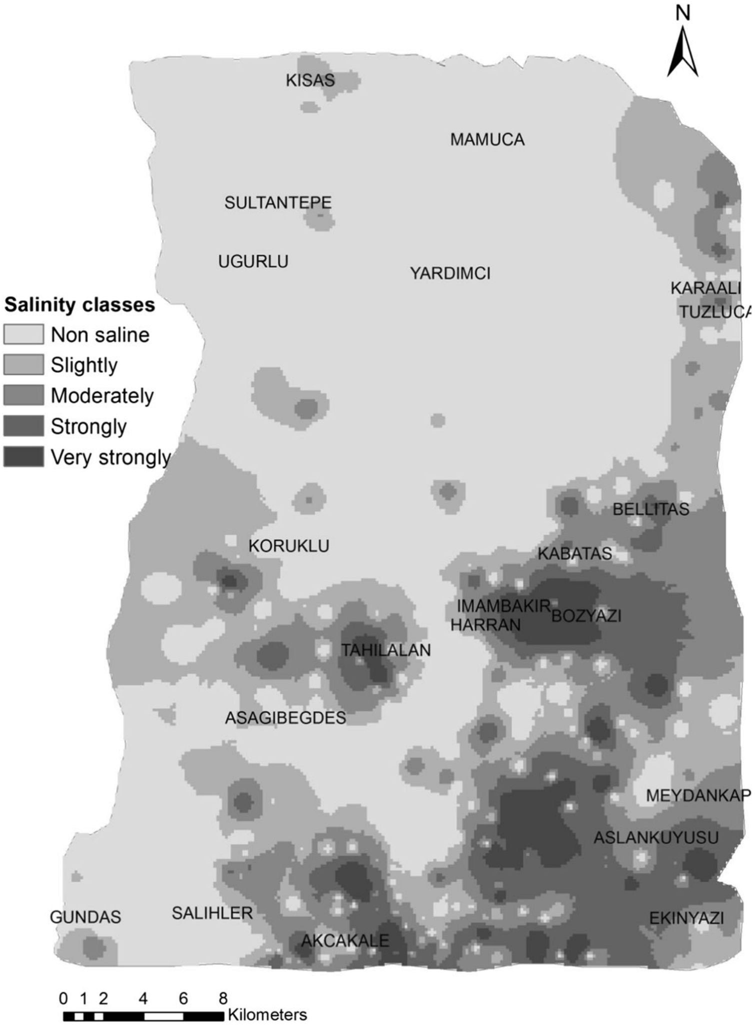
The salinity levels and changes in soil salinity in the period 1987 to 1997 were compared and mapped with those in the year 2000 (Çullu et al. 2002). According to this study, an area of approximately 11,403 ha area was affected by salinity. Soil salinity was highly impacted by groundwater level and salinity. The variations in groundwater levels and soil salinity in four soil profiles in the saline areas were observed during the irrigation season from May to August. Groundwater levels were higher than the critical level of 2 m for crops, and it could increase up to 80 cm. The salinity levels could increase to 30 dS m^{-1} (Çullu et al. 2010a).

According to Çullu et al. (2010b), in the Harran plain, an area of approximately 18,000 ha, which corresponded to 10% of the plain, was affected by various salinity levels. The distribution of saline areas indicated 12,630 ha as saline areas and 5094 ha area as saline–alkaline areas. These areas are generally located in low-lying areas of the plain with elevations between 350 and 400 m (Cullu et al. 2010b). According to the data, salinity rates in 2000 were approximately 11,000 ha. It displayed an increment of approximately 55% in 2009. Thus, it exceeded area of 17,000 ha within a decade. Saline areas were mainly distributed in the low-lying areas in the southeastern part of the plain. They were also distributed through the eastern parts as well as some areas in the upper northern parts of the plain (Fig. 5).

A significant amount of yield losses occurred because of the salinity and high groundwater levels. The results of a remote sensing study indicated that increasing EC values up to 13.4 dS m^{-1} caused decreases in cotton and wheat yields of approximately 29.6% and 35.4%, respectively (Çullu 2003). In another study conducted in the plains, the estimated cotton crop yield losses due to salinity reached up to 15% (Aydoğdu et al. 2014).

To decrease the high groundwater levels and remediate soil salinity, drainage studies were initiated by the Ministry of Food Agriculture and Lifestock, General Directorate of Agricultural Reform, in 2012 in an area of over 50,000 ha, which included areas that were affected by salinity or had the potential to be affected by salinity. Currently, drainage studies were conducted in an area of 40,000 ha. Early observations suggest that the results are positive and that there were decreases in the level of groundwater and soil salinity (Çullu et al. 2015). Another drainage study by Bahçeci and Nacar (2009) under controlled conditions also suggested positive changes. They reported that the level of drainage significantly decreased. Salts were washed quickly, and EC levels decreased from 10.3 to 2 dS m^{-1}. The success of drainage studies can be attributed to soil properties including the presence of common clay minerals (e.g., polygorskit) and high permeability. Additionally, naturally existing high gypsum content in some areas prevents soil sodicity, and hence the current salinity

Fig. 5 Kriging map of soil salinity in the Harran plain



problem can be solved with drainage (Aydemir and Sönmez 2008). As a result of drainage infrastructure, the salinity level decreased. Various approaches other than drainage, such as trials using forage crops that accumulate salt and the use of remediation materials, were also used for the remediation of salinity and groundwater level problems (Aydemir et al. 2009).

Contamination of water sources and NO_3 pollution

After the Harran plain was opened to irrigation, the contamination of surface and groundwater sources occurred due to intensive agricultural activities, excessive and uncontrolled irrigation, and excessive fertilizer and chemical usages. Increased agricultural production led to the increased use of fertilizers and chemicals and caused increased contamination of water sources. The decreased soil quality resulted in yield losses. To balance the yield losses, farmers used more fertilizers and chemicals, which further degraded the quality of the environment. According to extant research and surveys, pollution existed and contaminant levels were mostly higher than critical limits. The Harran plain was declared as polluted by high nitrate concentrations according to the National Nitrate Directive Project conducted by the government throughout the country. The goal of the project was to determine and control agricultural origin of nitrogen and nitrogen compounds and to prevent contamination.

High nitrate concentrations exceeding threshold values for drinking water (50 mg NO_3^- L^{-1}; WHO 1985) have been observed in surface and subsurface water samples taken from the Harran plain. During the irrigation season, water from 10 different drainage canals was sampled and analyzed for chemicals. According to the obtained results, the average NO_3 levels were higher than the critical limits (50 mg/L) (Yetim and Kara 2011). The researchers attributed the high nitrate concentrations to increased fertilizer applications as demanded by crops and to uncontrolled and excessive irrigation that caused the nitrates to be easily washed into drainage canals.

Bilgiç (2014) collected water samples from 10 collector drain pipes and five open drainage channels and measured parameters such as pH, nitrate, total dissolved solids, and EC of the water samples. Findings indicated that nitrate values in open drainage canals ranged from 34.58 to 59.42 mg/L, and nitrate values in collector pipes ranged from 3.03 to 77.31 mg/L. The values were found to be high at the beginning of the irrigation season, and they decreased toward the end of the irrigation season. The results showed that phosphorus and potassium did not present any problems. The average nitrogen losses with drainage water per day was calculated to be approximately 3 kg.

Similar to surface water contaminations, high nitrate concentrations were also observed in groundwater. Yeşilnacar et al. (2008) performed monthly observations during 1 year in 24 observation wells in the Harran plain. They found that nitrate levels in nearly all the wells were higher than the maximum allowable limit of 50 mg L^{-1}. The observed nitrate levels ranged from 1.3 to 806 mg L^{-1}, with an average of 153 mg L^{-1} (Fig. 6). This was atrributed to intensive agricultural applications and excessive amounts of chemical fertilizers. The situation was worsened by excessive and uncontrolled irrigation. Contaminations were considered to be agricultural in origin. However, in addition to increases in agricultural activities in the plains, industrial and commercial developments were observed. Hence, possible contaminants also included domestic wastes, animal manure, fertilizers, and contaminants originating from industrial activities (Yesilnacar et al. 2008; Yesilnacar and Gulluoglu 2008). In addition to nitrates, the same researchers observed other quality parameters in groundwater. EC values ranged from 1317 to 2935 µS/cm, which increased the average limit of 650 µS/cm (Yesilnacar and Gulluoglu 2007). Overall, the quality of irrigation water used in the plain was 380 µS/cm, and it was classified as C2-S1. The groundwater quality was found to be within the class of C3-S1 or C4-S1.

Mismanagement and poor planning of irrigation systems are among the main causes of groundwater contamination. Fertilizer application also affects spatiotemporal variations of contamination. Additionally, the obtained results are related to the method of fertilizer application. For example, irrigation performed immediately after fertilizer application together with seeding causes more nitrates to be washed away as compared

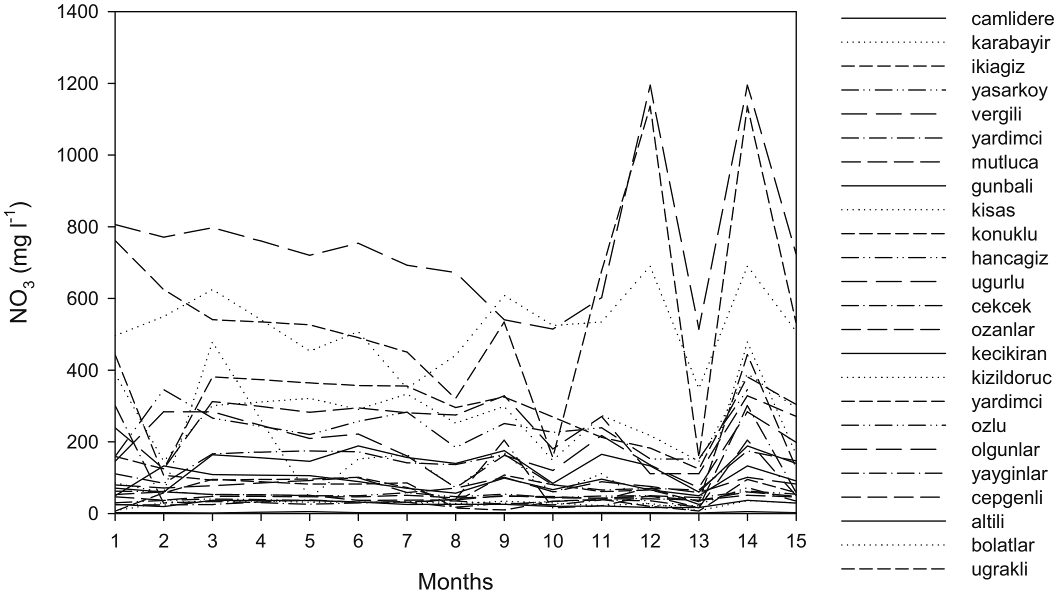


Fig. 6 Monthly distribution of nitrate concentrations in different wells across the Harran plain during October to December

to fertilizer application before seeding (Yesilnacar et al. 2008; Bilgiç 2014).

The amount of fertilizers applied in the plain is a very important factor that impacts the contamination of nutrient-rich water sources. This amont usually exceeds the plant requirements. In the plain, the amounts of fertilizer applied for winter wheat, cotton, and the second corn crop are 700, 1000, and 1000 kg ha^{-1} NPK, respectively. The fertilizer application rates prefered by farmers are approximately 25% higher than the actual fertilizer requirements of the plants.

Furthermore, residual nitrates in the soil can be effective in releasing nitrates from soil into the environment. For example, cotton fields are generally left unplanted until the next seeding season and no agricultural activity is performed. In this case, because of the precipitation during the fall season, the residual nitrates from the previous season may leave the soil and reach water resources in the following year when the cotton fields are not cropped.

The contamination of water sources with pesticides and other chemicals used for plant protection was also determined. Applied agricultural fighting agents caused the contamination of groundwater. Intensive agriculture led to an increase in the use of pesticides such as endosulfan and other chemicals. Groundwater contaminations were reported because of the intensive use of these chemicals. Morever, this contamination was due to macropores that caused endosulfan to be carried away throughout the soil profile and reach groundwater resources (Atasoy and Yesilnacar 2010; Atasoy et al. 2012).

The soil structure of the Harran plain is also an important factor in the accelerated pollution of the groundwater by contaminants. Vertisol soils are common in areas of cotton production. These soils have features such as shrink, swell, and deep cracks with high permeability. High permeability was attributed to the microagragates formed in these clay soils (Erşahin and Yeşilsoy 1993). Hence, the leaching of nitrates and the contamination of groundwater become easy due to the excessive amounts of nitrate applications.

Greenhouse gas emissions

In addition to nutrient losses through washing, excessive irrigation and fertilizer applications cause increases in greenhouse gas emissions (e.g., N_2O) from soils. The combination of excessive fertilizer and irrigation applications in intensive agriculture (especially in cotton cultivation) leads to denitrification in the form of nitrogen losses such as N_2O emissions to the atmosphere In a research study, emissions of three different greenhouse gases (CH_4, CO_2, and N_2O) under cotton cultivation were monitored for the experimental period of 2 years (Tonkaz et al. 2010). In the experiment, cotton parcels were exposed to different fertilizer doses and irrigation water applications. The effects of fertilizers, irrigation, and yields were investigated. The researchers observed that increasing fertilizer application doses led to increases in N_2O emissions. Therefore, they suggested that controlled application of fertilizer and irrigation was necessary to decrease the emission level. Furthermore, attention must be focused on the method and timing of fertilizer application in order to decrease the emission amounts.

Runoff and soil erosion

Soil erosion in the plains was accelerated due to excessive and uncontrolled irrigation. The soil eroded by irrigation reaches drainage ditches adjoining the agricultural fields. Moreover, the nutrients carried by the eroded sediments causes eutrophication. The nutrient-rich water in the ditches led to crop growth in the ditches and eventually clogged the ditches. Excessive and uncontrolled irrigation and heavy tillage caused a significant amount of sediments and phosphorus to be carried to the ditches. Drainage canals were clogged by reeds and mosses as a result of eutrophication.

During the irrigation season, the plain is irrigated and all the drainage waters are collected and flowed out of the plain at an outlet point (main discharge canal), as shown in Fig. 1. In the plains, the amounts of sediments discharged and carried are regularly monitored at the main outlet of the plain. The sediment content of the water sampled at eight points throughout the main drainage channel passing through the plain was analyzed. The results indicated that the main drainage canal has a flow rate of 24 m^3/s and carries approximately 670 tonnes of sediments with erosion (Darama et al. 2007). Over the years, the erosion continued and increased due to lack of controls (Fig. 7). The amount of sediments and discharge rates were highly correlated. The sediment content increased with an increase in the discharge rates.

Crop rotation is another important factor that causes high rates of erosion due to excessive irrigation. The

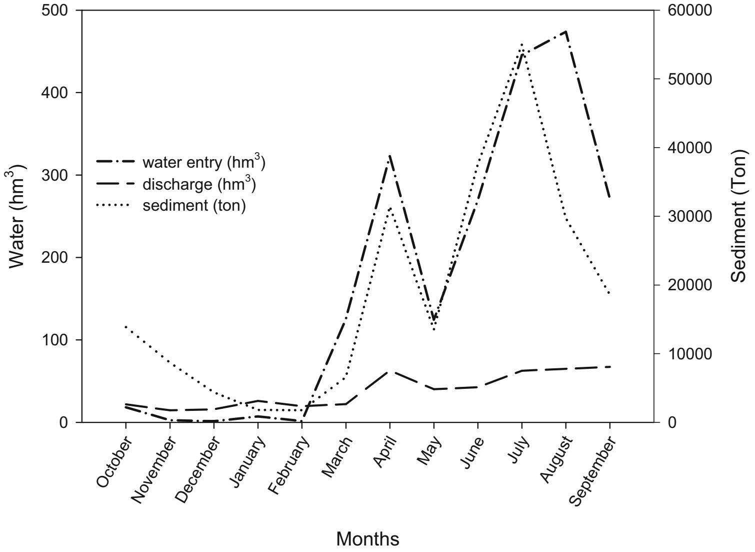


Fig. 7 3 years (2010–2011–2012) average data for water entry to the plain (hm^3) discharge rate from main drainage canals and sediment yield (ton)

cropping pattern impacts the amount of erosion. Common crop rotations preferred in the plain mostly consist of water-demanding crops. Both water-demanding crop rotations, namely, wheat–corn and cotton, require frequent irrigation. As cotton is the main part of the cropping design and requires frequent irrigation (in general, seven to eight times during the growing season), it causes soil degradation, resulting in an increasing amount of soils to be carried away. Figure 8 illustrates the amounts of erosion and the amount of cultivated areas over a time period. Over time, erosions increased with an increase in the plant growth area.

Due to the retention of insufficient residues, soils where cotton is cultivated are generally vulnerable to soil erosion. In general, cotton production is characterized by decreases in soil organic matter and aggregate stability, which leads to soil erosion. Primary soil tillage, planting, hoeing for weed controlling, and intensive cultivation cause aeration of soils and decreases in the soil organic matter. This speeds up the mineralization of soil organic matter.

Bilgiç (2014) performed sediment measurements from five different open drainage channels and the values ranged from 113 to 207 mg L^{-1}. According to her calculations, in the plain, the rate of water leaving the plain is 24 m^3/s, and approximately 2.7–4.9 kg of sediments is lost with drainage water. This totals to 420 tonnes of sediment loss per day. Results of both studies (Darama et al. 2007; Bilgiç 2014) indicate that if each hectare field is at a depth of 0–20 cm and has an

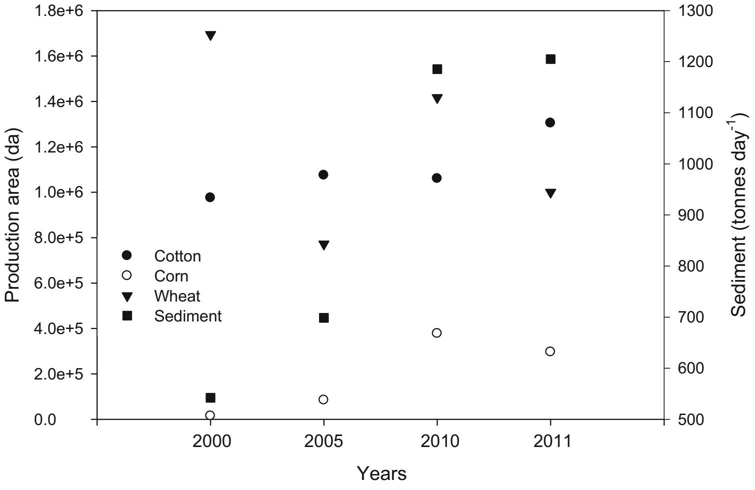


Fig. 8 Relationships between amount of planted area of different crops and average daily eroded sediment content in the Harran plain

average 2000–2500 tonnes of soil, then during the irrigation season, 0.2–0.3-ha areas are carried away by soil erosion.

Measurements of sediments and runoffs in the plain were also performed at the parcel level (Sönmez et al. 2011). The researchers measured runoff and discharge rates and amounts of phosphorous carried with sediments under different cropping designs. They reported that excessive irrigations caused significant amounts of runoffs and that substantial amounts of sediments along with phosphorous were carried by the runoff from agricultural areas. They performed runoff experiments under controlled conditions and determined high amounts of runoff from cotton parcels. Thus, they concluded that unless factors such as soil properties, topographical conditions, and crop varieties are considered and necessary precautions are taken, significant amounts of runoffs could occur in the plains as a result of uncontrolled irrigation. Thus, considerable amounts of sediments and phosphorous leave the agricultural areas and reach drainage channels causing eutrophication. To control eutrophication, the phosphorus carried from agricultural areas needs to be controlled (Sönmez et al. 2011). Both sediment losses and surface runoffs are increased by deep soil tillage and low efficiency irrigation. They also stated that the amount of total phosphorus concentrations was higher than the critical level. Their results showed that uncontrolled irrigation caused losses of sediments with runoffs from cotton fields. According to their findings, the highest amounts of sediments carried and runoffs were obtained as a result of deep tillage and low efficiency of irrigation techniques. Both tillage and irrigation efficiency were found to significantly impact the amount of sediments removed and surface runoffs.

Degradation in soil quality

Increased erosion and soil organic matter losses, monoculturing, and decreased soil biological activities led to soil degradation in the soils of the Harran plain. This further increased runoffs and erosion.

Similar problems also existed in the Harran plain in Southeastern Anatolia. Hence, soil and water resources were negatively impacted by these activities. The prevalent management system in the agricultural soil of the plains is not sustainable as it causes severe problems of soil degradation. Common symptoms of soil degradation include water erosion, salinization, waterlogging, decline in soil fertility, depletion of SOM, crusting, and compaction. The Harran soils are very poor in organic matter (1–2%) due to less crop residue additions and high temperature. Since the start of irrigation in the agricultural soils of the Harran plain, the soils were used intensively, and they were increasingly degraded due to unsustainable management methods and cropping designs. This resulted in the loss of production potential. Following the GAP development project (Southeastern Anatolia Project), the land use of the region changed, and increases in crop productivity were observed through the use of different crop varieties and chemical inputs (e.g., fertilizers and pesticides). However, these increases could not be maintained, and farmers faced difficulties in maintaining the same yield. This was because soil quality losses decreased the efficiency of crop inputs. Degradation of soil resources was further stimulated by political and socioeconomical conditions in the Harran plain. For example, higher subsidies are provided by the government for crops such as cotton, which requires frequent hoeing, further degrading the soil.

According to their research results, average soil quality indexes (SQI) obtained using linear and nonlinear scoring functions ranged from 32/100 to 48/100 (Bilgili et al. 2017). The soil quality of over 80% soils of the Harran plain was low or very low ($30 < \mathrm{SQI} < 70$; Moebius-Clune et al. 2016) due to intensive agricultural activities (i.e., irrigation, tillage) and cropping systems (cotton or wheat–cotton). Their findings also indicated that the soil quality was lower for soils under cotton rotation than those under wheat–corn rotation.

Urbanization

The Harran plain has experienced rapid urban growth since the start of widespread irrigation. This has caused further environmental concerns. The population increases were accompanied by social welfare, urbanization in the plain through housing settlements, and industrialization. As a result, soils of the Harran plain are now being threatened by urbanization. In addition, gaps in the legal system contributed to the growth of built-up areas on good-quality first- and second-class fertile soils, and uncontrolled settlements took place on the plain. Nearby agricultural areas were the first to develop when cities expanded with immigration, from towns to city centers, as opening lands to urbanization appeared to be more profitable than agriculture.

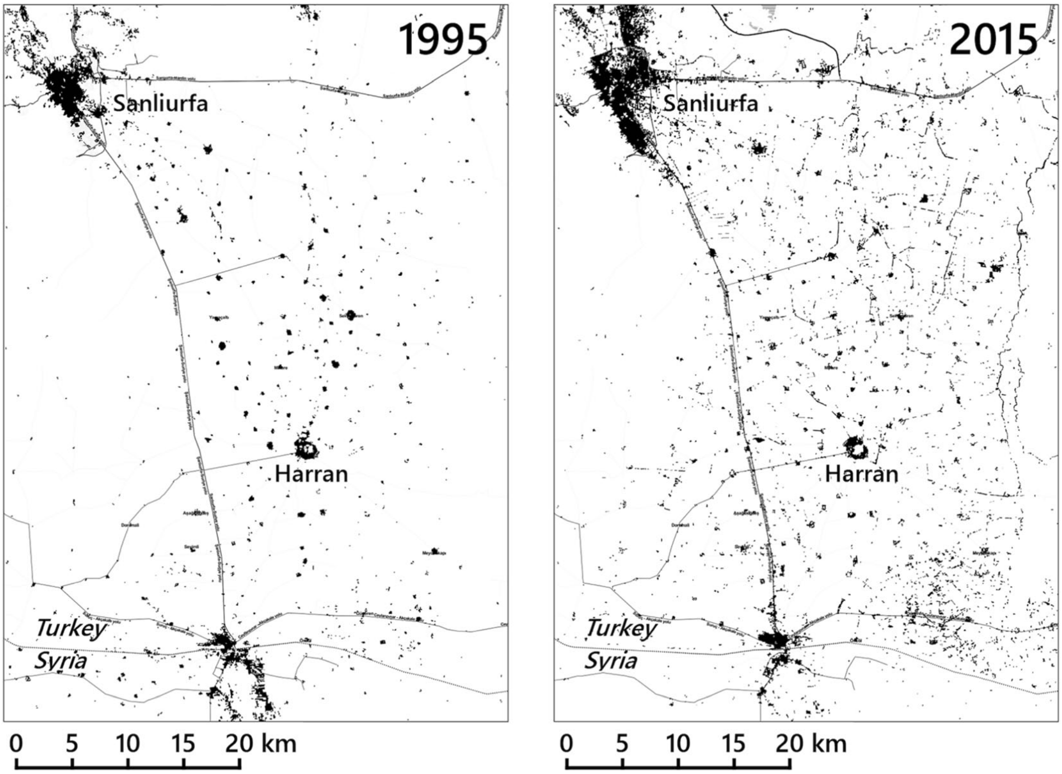


Fig. 9 Built-up areas extracted from Landsat imageries acquired in 2005 and 2015 showing changes in urbanization developments in the Harran plain between these years

The analysis of Landsat imageries acquired between July 12, 1995, and July 19, 2015, helped to identify the current situation with respect to built-up areas in the plain and at the beginning of irrigation. The automatic extraction of built-up areas was based on the spectral classification of the digital images. According to image analysis results, the rate of the built-up areas was 78 km^2 (7800 ha) in 1995, and it increased to 133 km^2 (13,300 ha) in 2015. This indicated an increase of over 70% within 20 years since the start of irrigation (Fig. 9). The constructions were mostly homes and industrial use facilities such as factories for products based on raw materials from primary crops including cotton and corn. In addition to the constructions determined, the arable lands disappeared because of the construction of open canals and roads.

The negative effects of urbanization are obvious given the uncontrolled occupation of fertile lands. Construction areas increased at the expense of agricultural areas. Crop productions decreased as a result of losses in the irrigated agricultural areas. Furthermore, urbanized areas were more vulnerable to pollution. Higher nitrate contaminations were reported in areas where intensive agriculture was combined with urbanization activities (Yesilnacar et al. 2008). Increases in urbanization also caused increased water consumption in the plains and decreased the infiltration of water, resulting in the formation of harder grounds.

Conclusion

With the introduction of irrigation into the plains in 1995 and with the start of irrigated farming, there was significant degradation in land and water sources. There were increases in environmental pollution, as shown in the contamination of surfaces and subsurface waters with NO_3 and other contaminants. Uncontrolled and excessive flood irrigations caused the level of groundwater to rise over critical levels and led to increased salinity. Uncontrolled and excessive irrigation combined with intensive soil tillage led to the occurrence of erosions with runoffs, sediment losses, and soil degradation with salinity and high groundwater levels. The loss of soil organic matter due to increasing erosion and intensive agriculture caused soil degradation. More fertilizers and chemicals were used in the degraded soil in order to balance the decreases in soil quality. This further contributed to the environmental pollution. Irrigation also led to an increase in urbanization and construction activities due to population growth and industrialization.

Farmers and other residents of the plain need to better manage soil and water resource systems for production activities. They must also minimize the input factors to mitigate soil erosion and environmental pollution. To achieve this, soil quality needs to be improved. This requires the application of reduced tillages and improvements in the amounts of organic soil matter. To date, studies focused on examining the environmental problems that exist in the plains since the onset of irrigation activities. However, studies are required to investigate the remediation of the problems and mitigate the problems in a sustainable manner. Farmer education is also important. Similar mistakes should not be repeated in other areas that will be opened up following the irrigation of the Harran plain. Applications of agricultural subsidy-based sanctions are alternatives to diminish the aforementioned negative impacts of irrigation and adopt controlled irrigation and sustainable agricultural activities.

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