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REVIEW PAPER

# Groundwater quality in the Harran plain: hydrogeological characteristics, salinity, nitrate and drainage problems

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## Abstract

Agricultural irrigation activities in the Harran Plain of Şanlıurfa, Türkiye with the Southeastern Anatolia Project (GAP) from the 1990s onwards, have affected groundwater quality. This review examines the hydrogeological characteristics of the Harran Plain, the effects of intensive agricultural practices on groundwater quality, particularly the problems of salinity and nitrate pollution, and the extent of problems arising from inadequate drainage. With the start of irrigation, a rapid increase in the groundwater level and the salinization problems on the large soils occurred as a result of excessive irrigation practices combined with inadequate drainage infrastructure. In addition, used intensive fertilizer increased the nitrate accumulation in shallow aquifers, reaching concentrations that are risky for human consumption. Current measurements conducted until 2025 show partial improvements in groundwater quality thanks to drainage improvements and more efficient irrigation management: Electrical conductivity (EC) and nitrate concentrations are trending downwards in many areas compared to the mid-2000s. However, specific parameters of many wells still do not meet drinking water standards; nitrate concentrations and EC, in particular, remain at alarming levels in the central part of the plain. In light of these findings, recommendations based on existing legal regulations are presented for sustainable groundwater management in the Harran Plain. Establishing continuous monitoring stations, ensuring inter-agency data and authority coordination, disseminating water-saving modern irrigation techniques, completing the drainage network, and updating the 1960 Groundwater Law with a comprehensive Water Law to meet current needs are proposed as critical steps.

## Introduction

Located in southeastern Turkey, the Harran Plain is one of the country's most fertile agricultural lands and has been opened to large-scale irrigation since the 1990s as part of the Southeastern Anatolia Project (GAP). Before irrigation, dry farming was practiced in the plain for many years (Ozdogan et al., 2006). With the commencement of gravity irrigation from the Atatürk Dam in 1995, significant increases in agricultural production were achieved. However, unconscious and excessive water use and inadequate infrastructure conditions quickly brought about significant environmental problems. It was reported in various research results that nitrogen, phosphorus and heavy metals flow into the drainage channels due to uncontrolled irrigation and excessive fertilization (Yetim and Kara, 2011, Kara et al., 2022). According to the State Hydraulic Works (DSI) reports from 2003 (DSİ, 2003), a few years after the start of irrigation, the groundwater level rose significantly in some parts of the Harran Plain, and salinity problems arose due to insufficient drainage. Since a large part of the plain soils are alluvial, deep-profile clay soils, the groundwater level rose rapidly and approached the surface as a result of infiltration/percolation caused by excessive irrigation. This situation has led to salt accumulation and salinization in the soil profile in areas throughout the entire plain (Bilgili et al., 2011).

Groundwater resources are not only the main source used to provide drinking water but also an important factor for the life cycle in arid or semi-arid regions. With the increase in agricultural activities in arid and semi-arid regions, ecological and environmental concerns also increase (Singh et al., 2010). The rapid changes experienced in the Harran Plain with the start of irrigation have negatively affected not only the hydrogeological balance but also the water quality. Particularly after 1995, significant increases in nitrate concentrations were recorded in shallow aquifers as a result of intensive irrigation and fertilization. Studies by Yeşilnacar et al. (2007) revealed that nitrate concentrations in groundwater followed a steady upward trend from the first years of irrigation in the plain until the early 2000s. The highest levels of nitrate pollution were found particularly in the central part of the plain; this was reported as an indicator of intensive fertilizer use and agricultural activities. On the other hand, EC levels in groundwater initially increased as a result of uncontrolled irrigation water use and inadequate drainage. The widespread application of flood irrigation in the first years of irrigation in the plain, combined with the lack of drainage channels, caused salts in the soil to be transported to the groundwater over time; Thus, electrical conductivity (EC) values increased rapidly (Çullu et al., 2002, Kendirli et al., 2005). These problems caused early alarm bells to ring regarding the sustainable use of water resources in the region and prompted relevant institutions to seek preventive measures.

The aim of this article is to summarize the changes in groundwater quality in the Harran Plain from the beginning of irrigation practices to the present day and the factors affecting quality parameters. The article will first summarize the hydrogeological structure of the plain and then discuss the effects of agricultural activities (excessive irrigation, fertilizer use, etc.) on groundwater in light of literature findings. Scientific researches conducted in the plain (Kara et al., 2022; Kara et al., 2023; Karabulut et al., 2023; Yenigun, 2009; Yesilnacar and Gulluoglu, 2007, 2008; Yesilnacar and Uyanık, 2005; Yesilnacar et al., 2007; Yesilnacar et al., 2008) will be evaluated, particularly regarding salinity and nitrate pollution; the current state of water quality (including data for 2025) will be presented; and finally, measures and management strategies will be proposed to address the identified problems within the framework of existing legal regulations. This study was written with the idea that research conducted specifically on the Harran Plain can shed light on water management policies in similar semi-arid agricultural regions.

**Literature Review**

Various studies have been conducted on changes in water quality before and after irrigation in the Harran Plain. From the very beginning of the plain's irrigation, researchers began documenting the rapidly rising groundwater level and the problems it created. For example, Ağca and Ergezer (1995) emphasized that drainage, salinity, and alkalinity problems became more pronounced in the plain's soils after irrigation and that urgent measures were needed. Early reports prepared by the State Hydraulic Works (DSI, 2003 and 2008) also drew attention to the rapidly increasing salinization problem in the field. According to observations by the DSI 15th Regional Directorate (Şanlıurfa), it was reported that a few years after irrigation, the groundwater level in some wells in the plain approached the surface very closely, and the groundwater reached a critical level in hectares of area. This finding was considered an indicator of how inadequate the drainage infrastructure was at that time and how widespread the problem was.

Regarding the environmental impacts of irrigation, Yeşilnacar and Güllüoğlu (2007) conducted an important study on the groundwater quality in the Harran Plain, the largest irrigation project within the scope of the GAP (Southeastern Anatolia Project). This study detected significant increases in some parameters such as nitrate, sulfate, electrical conductivity and salinity in the groundwater at the end of the first ten years (1995–2006) of intensive irrigation practices in the region, and revealed that nitrate pollution, in particular, had reached serious levels. The authors stated that excessive chemical fertilizer and inadequate drainage accelerated the infiltration of nitrate into the aquifer system. They reported that nitrate concentrations in some observation wells far exceeded the drinking water limit of 50 mg/L. Indeed, the occurrence of extreme nitrate values such as 720 mg/L in measurements taken in the following years confirms these initial findings. In the same study, it was stated that the electrical conductivity (EC) values in the plain also increased compared to the situation before the irrigation; and that many wells fell into the medium-high salinity class. In the following period, projects were carried out to monitor water quality in the Harran Plain. In a comprehensive report prepared by Yeşilnacar et al., (2016) and supported by the State Hydraulic Works (DSİ), changes in water quality were evaluated by taking regular measurements in 10 observation wells in the plain between 2006 and 2016. As a result of this study, it was reported that there was no significant increase or decrease in nitrate concentrations in groundwater during the ten-year period, and the values remained relatively stable. The authors stated that although the use of nitrogen fertilizers continued in the plain, nitrate may have been diluted due to the rise in groundwater levels, and therefore the concentrations did not change much over the years. In contrast, a noticeable improvement in conductivity values was detected from 2006 to 2016. It was stated that the EC values, which were quite high in the first years of irrigation, tended to decrease over time thanks to partial improvements in drainage infrastructure and the dilution of the water by rising groundwater levels. The report shows that when comparing the autumn (post-irrigation) measurements of 2006 and 2016, EC decreased significantly in many wells. These findings reflect the positive effects of drainage channels and field improvements.

Another important study on water quality in the Harran Plain was conducted by Yetiş et al. (2021). In this study, groundwater quality parameters in the plain between 2005 and 2015 were evaluated using geographic information systems (GIS) and pollution indices; spatial changes in water quality over the ten years were revealed. The results showed that approximately 70% of the samples examined in 2005 did not meet the relevant standards for at least one parameter. Partial improvements in water quality were observed in 2015. However, it was reported that the nitrate parameter, in particular, remained at critical levels in 2015, with the majority of samples exceeding the 50 mg/L limit. The risk maps prepared within the scope of this study clearly show that the central part of the plain is the region with the highest risk in terms of nitrate pollution.

Regarding the long-term effects of irrigation practices on soil and water systems, Bilgili et al. (2018) conducted a noteworthy study. The authors examined land degradation and environmental changes in the Harran Plain after irrigation; they particularly highlighted the increase in soil salinity and groundwater pollution. The study emphasized that even approximately 15-20 years after the start of irrigation, the drainage problem was not fully resolved, making it difficult to control salinity (Figure 1). Karabulut et al. (2023) examined the impact of socioeconomic factors on land use and they quantitatively demonstrated that the transition from dry to irrigated farming disrupted the hydrogeological balance in the Harran Plain, raising the groundwater level.

In recent years, new problem areas regarding water quality have also been identified in the region. In particular, a study by Kara (2025) showed that intensive agricultural activity in the Harran Plain led to heavy metal accumulation in the soils around drainage canals. Soil samples taken between May and October 2020 revealed high levels of elements such as Al, Fe, and Mn, as well as heavy metals such as Cu and Zn associated with agricultural activities.

**Figure 1.** Long-term effects of excessive irrigation: Saline soils in the region

A significant source of these pollutants has been shown to be the reuse of recycled water for irrigation by farmers in the downstream section of the water-scarce plain, which is discharged into drainage canals. Indeed, Kara's findings revealed that during the summer months, approximately 60 m³ of water per second is returned to the plain through the Arıcan drainage bridge and that this water brings back salt, nitrate, and various pollutants to the agricultural areas. This situation leads to the accumulation of toxic substances in the soil over time and indirectly affects groundwater. Mentioned study is important in demonstrating how interconnected water and soil quality are under intensive agriculture in the Harran Plain.

## Hydrogeological Characteristics and Groundwater Level

The Harran Plain is a wide graben structure extending in a north-south direction. The plain is filled with Miocene and younger alluvial and Neogene sediments within the Akçakale graben in the west. Eocene limestone formations (Germuş and Tektek mountains) are exposed on the edges of the plain, and these limestones play a role in groundwater recharge in places (Figure 2).

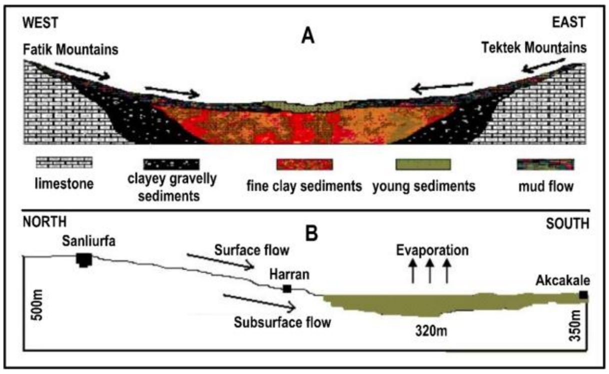


**Figure 2.** Physiographic sections of the Harran plain (Sönmez et al. 2011)

The aquifer system within the plain mostly consists of an alluvium-tershale mixture geological environment; the shallow aquifer is located within sandy-clay alluvium, while the deep aquifer includes fractured limestone units in some sections. In terms of soil structure, the profiles in the Harran Plain are generally clayey, but also sandy layers are found in well-drained areas.

The dramatic rise in groundwater levels (Figure 3) has varied particularly depending on the micro-topography of the plain. Due to the accumulation of water in the low-lying central and southern parts of the plain, the groundwater has almost risen to the surface, and signs of marsh formation have been observed over time. According to a report prepared by the Ministry of Forestry and Water Affairs in 2017, it was determined that the groundwater level was at a critical level (very close to the surface) in an area of approximately 8,000 hectares in the Harran Plain. These areas are generally low-lying points far from drainage channels, where water tends to accumulate through natural flow. The proximity of groundwater to the surface reduces the root depth of plants, leading to yield losses, and accelerates the accumulation of salt on the soil surface through evaporation, creating barren areas known as "white soil."

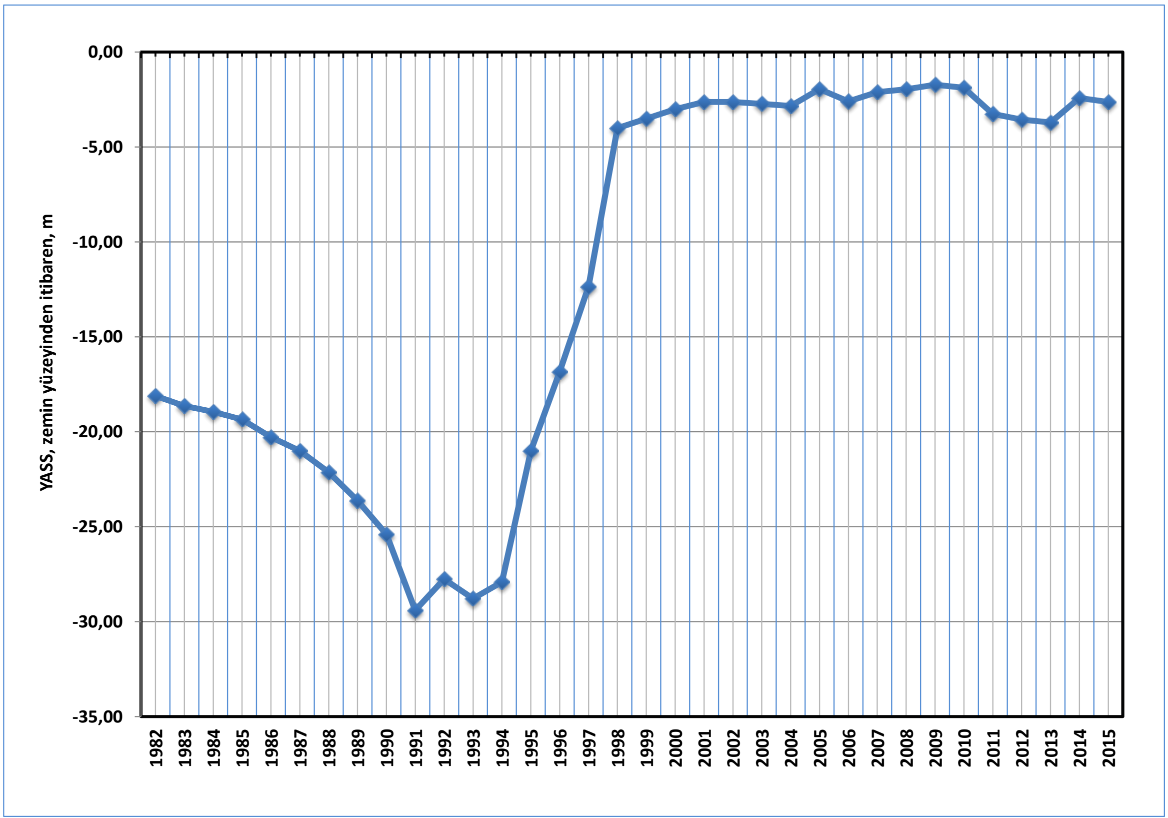


**Figure 3.** Changes in groundwater level in observation wells over the years (DSI, 2015)

The main reasons for the rise in groundwater levels are excessive and uncontrolled irrigation practices and inadequate drainage infrastructure. In the Harran Plain, the classic flood irrigation method was widely used for many years, with farmers irrigating their fields with abundant water using the "furrow" and "basin" method. However, due to the insufficient drainage ditches and control structures within the fields, a significant portion of the water applied accumulated in the land or seeped deep, feeding the groundwater. Furthermore, because the horizontal movement of water is slow in the low-lying plain area, even irrigation water that became surface runoff largely accumulated in the immediate vicinity and infiltrated underground. As a result, in this semi-arid region with irregular rainfall, irrigation water acted almost like artificial rainfall, feeding the aquifers. As Karabulut et al. (2023) stated, in the Harran Plain, between 1990 and 2020, dry farming areas decreased from 37% to 7%, while the irrigated land ratio increased from 21% to 54%; this radical transformation disrupted the natural recharge-consumption balance in the groundwater regime and made groundwater level rise inevitable.

To combat groundwater, rise in the plain from the mid-2000s onwards, the State Hydraulic Works (DSI) began implementing some measures such as the construction and the rehabilitation of drainage channels. Particularly during the 2009–2012 period, underground drainage (tile drainage) systems were installed in certain areas of the plain, and new lines were constructed to collect surface water. The effect of these works was seen in the slowing of the rate of rise in the water table and a drop of several meters in the level in some areas. Indeed, the report by Yeşilnacar and Atasoy (2018) stated the significant decreases in groundwater level in areas where drainage improvements were made during the 2006–2016 period. However, the drainage infrastructure is still far from covering all irrigated areas in the plain. The problem of water accumulation continues in the downstream sections, and in these regions, farmers find a solution to meet their water needs during the irrigation season by returning the runoff water discharged into the drainage channels back to their fields. Although this practice is understandable in terms of water reuse, it creates a serious vicious cycle considering that drainage water generally contains high levels of salt and pollutants: Salt and nitrate accumulation increases even more in fields re-irrigated with drainage water, which both reduces soil fertility and adds a pollutant load to the groundwater again. Therefore, a holistic drainage management and water reuse strategy needs to be implemented in the Harran Plain to control the groundwater level.

**Groundwater Quality: Salinity And Nitrate Pollution**

Intensive agricultural activities have significantly altered the chemical composition of groundwater in the Harran Plain. While the dominant hydrogeochemical water type in the plain before irrigation was Ca-$HCO_3$ (calcium bicarbonate), especially in shallow aquifers after irrigation, Ca-$NO_3$ (calcium nitrate) and Ca-$SO_4$ (calcium sulfate) water types have become prominent because of the mixing of agricultural nitrate and sulfate compounds (fertilizers and soluble salts in the soil) into the groundwater. Nitrogen fertilizers commonly used in the plain (e.g., urea, ammonium sulfate) are converted into nitrate in the soil and transported to the lower layers by rainwater and irrigation water, leading to nitrate accumulation in aquifers over time. Shallow aquifers have been directly affected by this diffuse pollution load. Measurements taken in the early 2000s revealed that nitrate concentrations in shallow wells exceeded 100 mg/L. The aforementioned study by Yeşilnacar and Güllüoğlu (2007) reported that as of 2005, nitrate exceeded the 50 mg/L limit in 55% of the groundwater samples, and subsequent studies showed that this rate had risen even further, reaching 70% by the mid-2010s (Yetiş et al., 2021). Extremely high nitrate values, such as 720 mg/L, were detected in some wells.

Salinity (generally assessed via electrical conductivity, EC) is critically important for the suitability of groundwater in the Harran Plain for agricultural use. According to the classification of the State Hydraulic Works (DSI), waters with an EC value between 750 and 2250 µS/cm are considered "medium salinity," while those exceeding 2250 µS/cm have a "high salinity" risk. In the early years after the plain was opened to irrigation, a large portion of groundwater samples fell into this high salinity category, with EC values reaching very high levels such as 8000 µS/cm (means 8 dS/m) in some wells (Bilgili et al., 2011). This phenomenon clearly shows that salts washed from fields with inadequate drainage directly entered the aquifer system. However, thanks to the drainage channels commissioned in the second half of the 2000s and improvements in irrigation management, the salinity problem has shown a relative tendency to decrease. Spatial distribution of average annual EC in groundwater of Harran Plain for the years of 2005 and 2015 is presented in Figure 4. Data from 10 observation wells examined during the 2006–2016 period revealed that EC values, initially in the 4000–8000 µS/cm range, decreased to the 2000–3000 µS/cm range in 2016. This improvement has two main causes: firstly, the partial removal of excess salt from the soil surface over the

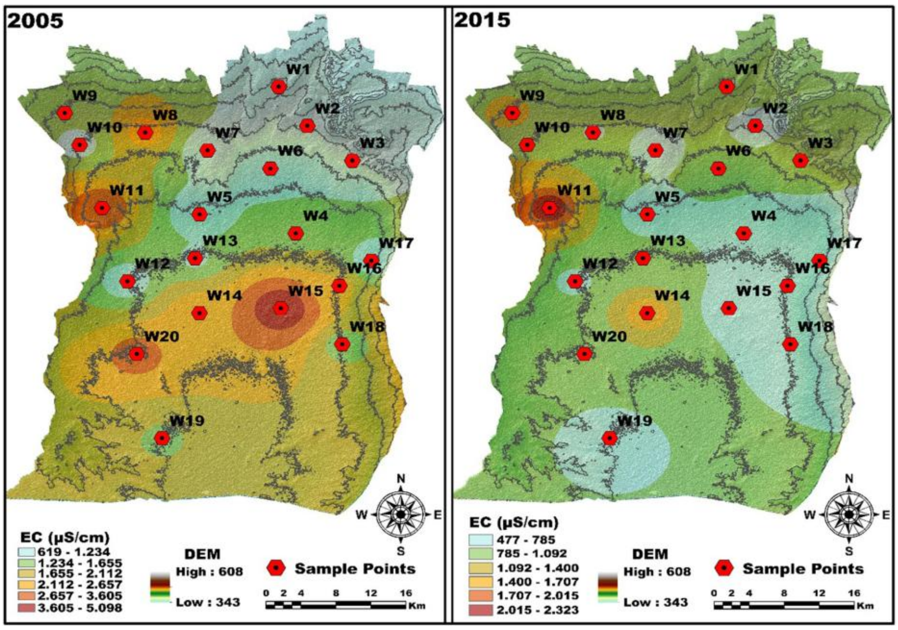


**Figure 4.** Spatial distribution of average annual EC in groundwater of Harran Plain (Yetis et al., 2021)

years through leaching (flowing away via drainage channels); and secondly, the dilution effect caused by rising groundwater levels. Rising groundwater, in a sense, reduced the salt concentration in the aquifer, thereby lowering conductivity values. Indeed, Yeşilnacar and Atasoy (2018) emphasized that a significant decrease in the average groundwater EC in the plain was recorded from 2006 to 2016, and that this positive development coincided with improvements in the drainage system.

Some remedial practices for nitrate have been implemented in the Harran Plain since the 2020s. Recently, research has focused on alternative crops that can be grown in the area instead of cotton and corn, which consume more water and fertilizer than others. For example, plants like peanuts, which are becoming widespread in the region, and soybeans, planted as a second crop instead of corn, are expected to require less water and contribute to the soil's nitrogen balance. Furthermore, nitrate leaching can be reduced by using techniques that allow for more controlled application of water and fertilizer, such as drip irrigation. While such sustainable agricultural practices are not yet widespread throughout the plain, positive results have been reported in pilot areas. Spatial distribution of nitrate concentration in groundwater of Harran Plain for 2005 and 2015 is shown in Fig.5. A recent assessment by Yazıcı Karabulut and Karabulut (2025) indicates that nitrate levels in some parts of the Harran Plain decreased by more than 50% between 2005 and 2025 due to the improvement achieved through more effective fertilizer management and water use. The same study indicated that wells in the southern part of the plain, which initially contained the most polluted water have shown significant quality improvements over the past 20 years. For example, reductions of over 80% in EC values and sharp decreases in nitrate and sulfate levels have been recorded. These findings are important because they indicate that water quality can improve over time if the right measures are implemented.

However, as of 2025, nitrate concentrations in many wells, particularly in the central part of the plain are above the 50 mg/L threshold and in some places exceed 100 mg/L. Sulfate ($SO_4^{2-}$) has also been detected above limit values in certain areas. This indicates that despite the measures taken in the plain, the effects of agricultural pollution sources have not been completely eliminated. Furthermore, in terms of salinity, an increasing trend in sodium, chloride, and electrical conductivity values has been detected in some stations in 2025 compared to 2015. This negative development can be attributed to insufficient drainage due to climatic fluctuations (periodic droughts) and the renewed acceleration of salt accumulation. All these results reveal that the groundwater quality in the Harran Plain has a fragile balance, and that the measures taken for the continuity of improvement must be implemented in a long-term and disciplined manner.

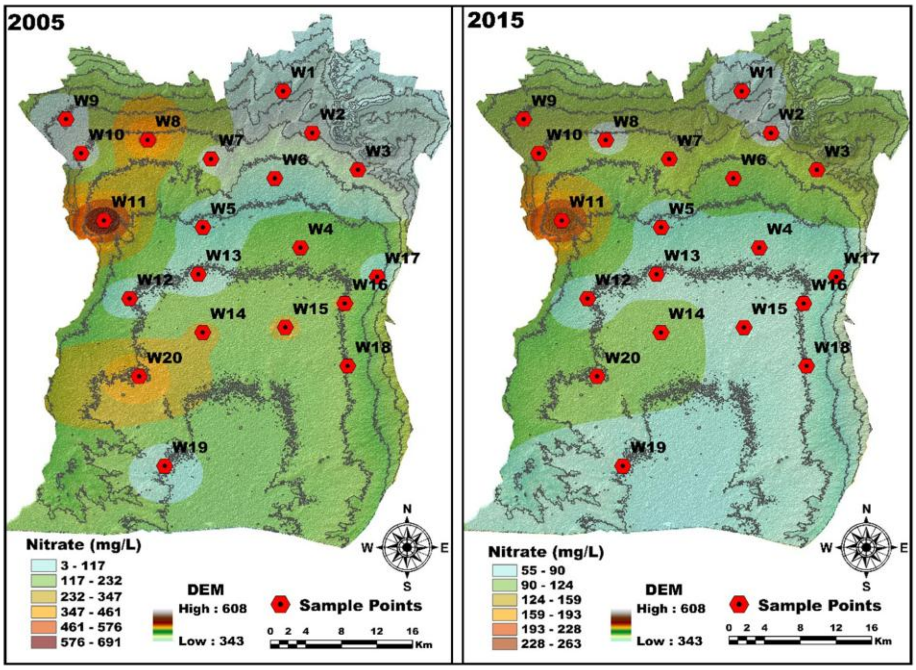


**Figure 5**. Spatial distribution of average annual concentration of nitrates in groundwater of Harran Plain (Yetiş et al., 2021)

**Impacts Of Agricultural Activities and Drainage Problems**

In the case of the Harran Plain, it is understood that the deterioration in groundwater quality is largely human induced (anthropogenic). The irrigation revolution in the plain over the last thirty years has brought with it intensive agricultural inputs and land-use changes (Bilgili et al., 2018). Land use change in the Harran plain in 15 years is shown in Figure 6. While traditional dry farming provided the soil with only as much water as the rainfall and limited fertilizer annually, irrigated farming has allowed farmers to harvest more than one crop per year; thus, the water and fertilizer load on the soil has increased exponentially (Kahraman et al., 2016). This increase in production brought about by modern irrigation leads to various problems if it is not supported by effective planning and education. Another important factor is the use of fertilizers and chemical inputs. Nitrogen fertilizers (urea, ammonium nitrate, etc.), phosphorus fertilizers, and pesticides/herbicides are used intensively in the region to increase yield. The portion of nitrogen fertilizers that cannot be used by plants is converted into nitrate in the soil and is carried into the groundwater by precipitation or irrigation water.

Studies in the Harran Plain have shown that the amount of nitrogen applied, especially in cotton and corn cultivation, can be significantly above the plant's needs, creating a breeding ground for nitrate leaching and aquifer contamination. In addition to nitrate, traces of pesticide and herbicide residues have also been detected in the water. Although the levels of these chemicals have not yet created a critical pollution problem like nitrates, they pose a risk of persistent aquifer contamination in the long term. In terms of heavy metals, impurities in fertilizers (e.g., traces of cadmium in phosphorus fertilizers) or elements such as arsenic and mercury from pesticides can accumulate in the soil over time and leach into the water. Indeed, recent analyses have reported that arsenic (As) levels in some groundwater samples exceeded the drinking water standard of 10 µg/L, posing a health risk, especially for children (Yetim and Kara, 2011). Although arsenic is likely of geogenic origin (naturally occurring arsenic can be found in limestone and gypsumlitic layers in the region), anthropogenic activities may have increased its mobilization.

All these findings demonstrate the necessity of integrated water and agricultural management approaches in the Harran Plain. It is essential to prevent overuse during years of abundant water and to plan for its reuse without compromising quality during periods of scarcity. Furthermore, training and extension activities for farmers, and raising awareness about the efficient use of water and fertilizers, are of paramount importance (Aydogdu et al., 2015). In recent years, the Ministry of Agriculture and Forestry has begun implementing water efficiency and fertilizer recommendation programs based on soil analysis in the region. Expanding and continuing these efforts will be critical for both the preservation of groundwater quality and the long-term productivity in farmers' production.

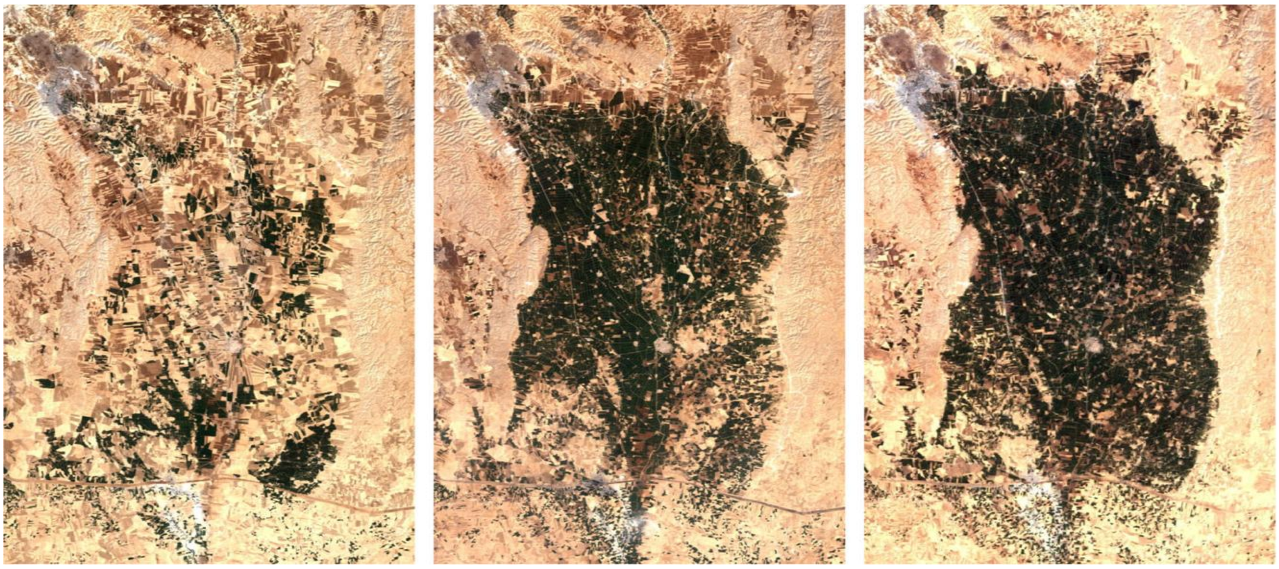

**Figure 6.** Land use changes in the Harran plain, 5 years before irrigation (1990); 3 years after irrigation (1998); and 10 years after irrigation (2005) (Bilgili et al., 2018)

## Conclusion and Recommendations

The potential impacts of large-scale irrigation projects on groundwater have been examined using the Harran Plain as an example. Irrigated agriculture, initiated to increase yields in semi-arid climatic conditions, has brought with it significant environmental problems such as rising groundwater levels, salinity, and nitrate pollution. The experiences gained from the plain have revealed the necessity and urgency of implementing sustainable management of water and soil resources, infrastructure investments, and correct agricultural practices. Based on current findings, the following key recommendations have been developed for the conservation and improvement of groundwater in the Harran Plain:

**Continuous Monitoring and Early Warning System:**

A long-term groundwater monitoring network should be established by identifying critical points in the plain. Water quality measurements should be carried out seasonally in observation wells selected based on the parameters (nitrate, ammonium, sulphate, pH, electrical conductivity, dissolved solids, etc.) in Annex 5 of the "Regulation on the Protection of Groundwater Against Pollution and Degradation" dated 2012. The 10 observation wells used in the study by Yeşilnacar and Atasoy (2018) should be regularly monitored by the State Hydraulic Works (DSİ). The monitoring results should be collected in a digital database and shared simultaneously with relevant institutions such as the DSİ, the Ministry of Agriculture and Forestry, and local governments.

**Inter-Institutional Coordination:**

Monitoring and protecting groundwater quality is a multi-stakeholder process in Türkiye. Currently, nitrate monitoring is carried out by the Ministry of Agriculture and Forestry (NIBIS database), while general groundwater monitoring is the responsibility of the State Hydraulic Works (DSI) and the Ministry of Environment, Urbanization and Climate Change. Data and authority discrepancies have been identified between these institutions. Therefore, it is recommended that a "Water Management Board" be established in the region to bring together all stakeholders (DSI, Provincial Directorate of Agriculture, irrigation associations, municipalities, universities) on a common platform. This board should be responsible for evaluating monitoring data, identifying pollution sources, and developing solution strategies.

**Improvement of Drainage Network:**

One of the most critical steps for a permanent solution in the Harran Plain is the establishment of a widespread drainage network. In accordance with the "Regulation on Monitoring Surface and Groundwater" dated 11.02.2014 and the "Regulation on Control of Water Use and Reduction of Water Losses in Irrigation Systems" dated 16.02.2017, the laying of underground drainage pipes and the regular maintenance of existing open drainage channels are necessary, especially in downstream areas. For situations where the reuse of drainage water is unavoidable, quality control is essential. Irrigation associations should have periodic analyses conducted on drainage water; if salinity or pollutant load is high, they should take measures to prevent the reuse of this water without dilution.

**Agricultural Input Management:**

Farmers should be trained on fertilizer use. Fertilization programs and soil analysis should be expanded to prevent excessive fertilizer use. Correct application of nitrogen fertilizers, especially in terms of timing and quantity, will significantly reduce nitrate leaching. The Ministry of Agriculture and Forestry's "Fertilizer Tracking System" and extension work should be supported specifically for the Harran Plain; demonstrations should be given to farmers on water and fertilizer conservation. Furthermore, the addition of legumes or deep-rooted plants to the crop rotation system should improve the soil's nutrient balance and contribute to groundwater reduction.

**Expansion of Modern Irrigation Techniques:**

To reduce water losses and control groundwater, the transition to pressurized irrigation (drip, sprinkler) systems should be encouraged. In this context, farmers should be offered incentives such as low-interest loans and grants to gradually move away from flood irrigation in the plain. Pressurized irrigation saves water by delivering it to the plant root zone in a controlled manner, and by avoiding excessive water consumption, it reduces the amount of water that leaches into the groundwater and carries pollutants. Practices which improve on-field water management, should also be encouraged.

**Legislation and Sanctions:**

Full implementation and updating of existing legislation on the protection of groundwater in Turkey is important. According to the regulation dated 07.04.2012, all groundwater bodies throughout Turkey should have been characterized and protection plans prepared by 2017. The level of completion of these studies in the Harran Plain should be reviewed. Similarly, the status of the achievement of the goal of establishing monitoring networks by 2019, as foreseen in the monitoring regulation dated 11.02.2014, should be examined. Any deficiencies should be addressed urgently. In addition, it is essential to update the Groundwater Law No. 167 of 1960, which does not meet today's needs. A comprehensive Water Law that will bring together the scattered legislation on water management under one roof will resolve the confusion of authority between different institutions and will bring clearer provisions for the protection of water in terms of both quantity and quality. The political will to enact this law should be strengthened. Finally, the implementation of the sanctions foreseen in the existing regulations should be ensured in the field. For example, measures such as closing unauthorized groundwater wells, implementing tiered tariffs for farmers who consume excessive water, or imposing punishment on businesses that discharge pollutants should be applied without compromise.

In conclusion, protecting groundwater quality in the Harran Plain is only possible with a holistic water management approach. This approach should combine infrastructure improvements (drainage, pressurized irrigation) with institutional coordination and farmer training; and decision-making should be based on scientific data. As monitoring and research studies have shown, improvements in water quality can be achieved when the right measures are implemented after problems are identified. To make these gains permanent and to align agricultural production in the plain with environmental sustainability, the proposed steps should be taken as soon as possible. The experience of the Harran Plain contains valuable lessons for agricultural regions with similar climates and conditions, and applying these lessons is of great importance for the future of our water resources.

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### Author Contribution

Conceptualization: MIY, Data Curation: ADA, Formal Analysis: ADA, Investigation: ADA, MIY, Methodology: MIY, Project Administration: MIY, Resources: ADA, Visualization: MIY, Writing -original draft: MIY, Writing -review and editing: ADA.

## Conflict of Interest

No potential conflict of interest was reported by the authors

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