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Chapter 8

GROUNDWATER POLLUTION DUE TO AGRICULTURAL PRACTICES IN A SEMIARID AREA

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ABSTRACT

The increasing population and the gradually raising food consumption are two important phenomenon facient the water and the soil pollution. Excessive and uncontrolled irrigation and extensive agricultural using of chemicals in the arid and semi-arid regions play the important roles on the pollution. The aim of the study is to determine the polluting effects of the agricultural practices (the pesticide-nitrate contamination, water quality problem, corrosivity and salinity in the groundwater) in Harran Plain in semi-arid Southeastern Anatolian Region, Turkey. The groundwater quality in Harran Plain before and after the irrigation period was compared in the research. The results shown that, with regard to typical characteristics of the Harran soils, the ground water was contaminated with nitrate and pesticide (endosulfan). The corrosion tendency of the groundwater is another quality problem derived from the high soluble salts leaching through the soil profiles. The irrigation without drainage systems caused the rising of soil water level, the increasing of the soil salinity and degrading of the groundwater quality. The extensive use of pesticides/fertilizers and excessive irrigation should be avoided, farmers training must be carried out and the pest management techniques/practices must be improved immediately in a more environmentally sustainable manner.

Keywords: Groundwater quality, irrigation, corrosion, contamination, pesticide, semiarid area.

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INTRODUCTION

The anthropogenic impacts on the soil should be defined as loading with different potential pollutants such as heavy metals, organic compounds, pesticides and fertilizers. Their effects on the soil quality and plant productivity depend on the soil vulnerability and land use practices [1]. Non-point source pollutants are transported from the land by surface water and groundwater pathways since the pollutant sources cannot be attributed to one particular discharge location rather to a large area [2]; [3]. The use of uncontrolled and large amount of pesticides and fertilizer may deteriorate the soil and groundwater quality. Identifying and understanding the mechanisms controlling the fate of chemicals which are a threat for non-target organisms and one of a possible sources of contamination of water resources are still remaining to be a great public concern [4]. The study of chemical fate is, therefore, vital for both maintaining environmental quality and optimizing sustainable agricultural practices [5].

Over the last 30 years irrigated areas have increased rapidly, helping to boost agricultural output and feed a growing population. Irrigation uses the largest fraction of water in almost all countries. Globally, 70% of freshwater diverted for human purposes goes to agriculture, and irrigation water demand is still increasing because the area being irrigated continues to expand [6]. As in other semi-arid and arid parts of the world, water is a valuable resource in the Southeastern Anatolian Region (SAR). Despite the large quantities of water currently available from the Euphrates and Tigris rivers, it is becoming increasingly important to improve management of these resources as further irrigation developments in the upper tri-state (Turkey-Syria-Iraq) Euphrates-Tigris Basin progress [7]. Groundwater is an important resource in the region. The quality of groundwater is as important as its quantity, owing to the suitability of water for various purposes.

The global problem of irrigated land that is affected by saline groundwater at shallow depth is extensive. Saline groundwater is often found at shallow depth in irrigated areas of arid and semi-arid regions and is associated with problems of soil salinisation and land degradation. Ghassemi et al. [8] reviewed various estimates and concluded that, of some 230 million hectares of irrigated land around the world, approximately 45 million hectares suffer from irrigation-induced salinisation [9].

Besides the salinisation problem of the soil; nitrate and pesticide contamination, corrosiveness and high dissolved solid concentration of groundwater are the other important cases arises from the excessive irrigation. Since the 1960s, nitrate loading in both surface water and groundwater has drawn great attention worldwide. Nitrate pollution cases that exceed the threshold as recommended by the World Health Organization (50 mg NO_3^- l^{-1}) and by the USA (10 mg N l^{-1}) for drinking water have been reported in many countries such as UK, Denmark, Belgium, France [10]; [11]; USA [12]; [13]; India [14] and Turkey [15]. The agriculture-derived nitrate pollution of groundwater has become an environmental issue [16].

The semi-arid Southeastern Anatolian Region has an intensive agricultural potential and increasing population. Gradually raising food consumption related to population requires the sustained crop production. The basic aim in agriculture is to get crops in high quality and quantity to compensate for the increasing necessities. Therefore, the soil of Harran Plain was used very intensively in agriculture. A huge amount of fertilizers and chemicals were used in the agricultural activities which caused high environmental pollution in the area. The SAR especially the Harran Plain faces problems of salinity, excessive and uncontrolled irrigation, groundwater pollution [15]; [17], insufficient drainage system and increased groundwater level caused by irrigation that first started in 1995 [18]. Therefore the aim of the study is to determine the polluting effects of the agricultural practices (i.e., the pesticide-nitrate contamination, water quality problem, corrosivity and salinity in the groundwater) in Harran Plain in semi-arid Southeastern Anatolian Region, Turkey.

MATERIALS AND METHODS

Study Area

The Harran Plain is 30 km x 50 km and is situated in a region of rolling hills and broad plateau that extends south into Syria (Figure 1). It is located between 36°43’-37°10’ North latitudes and 38°47’-39°10’ East longitudes. The average altitude is approximately 375 m in the area. The plain is intensely (>90%) cultivated with cotton and has 141500 ha of irrigable land and semi-arid climate with almost no precipitation between June and September. The long-term mean annual precipitation is 284,2 mm, the temperature is 18 °C and the evaporation is 1884 mm. The general direction of the slope in the plain is from north to south, varying between 0% and 2%.

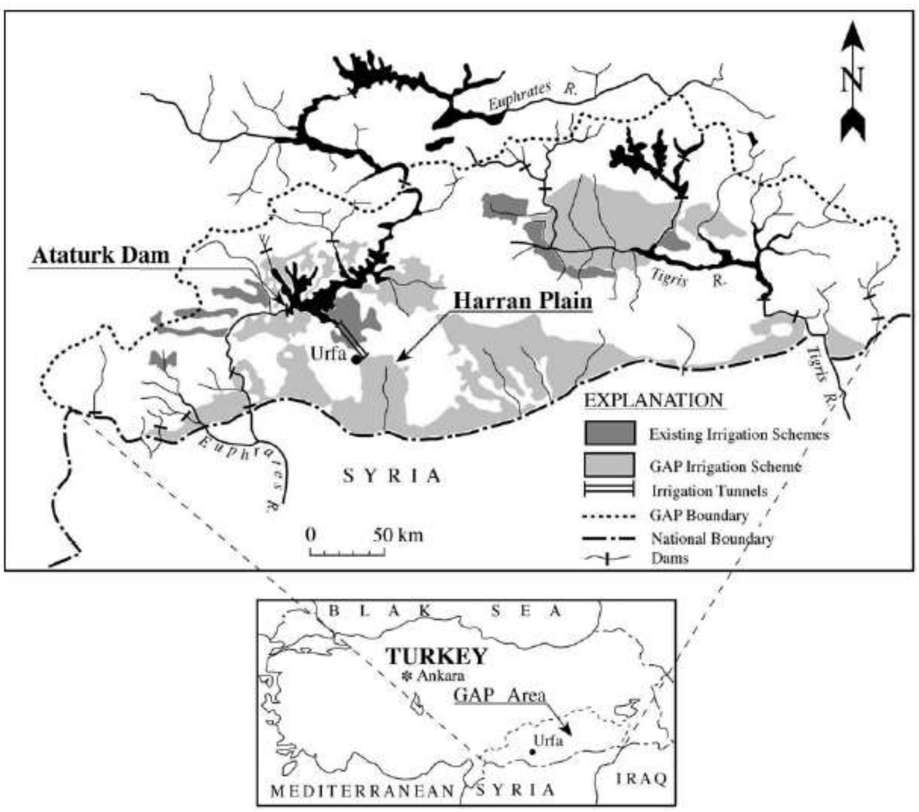

Figure 1. Location map of the Harran Plain.

The surface slope is rather flat around the towns of Harran and Akçakale and low-lying areas cause outlet problems. Most of the slopes in the northern parts are higher than those of the southern parts of the plain and surface and sub-surface drainage problems are rarely encountered [19].

Soil Properties of Harran Plain

Dark-colored or heavy-textured soils containing low levels of organic matter, which are commonly found in arid and semi-arid regions, are grouped in the vertisol order. Many soil series in the region, including the Harran series, belong to the vertisol order. Because of their high smectite content, their most significant feature is cracking, as a result of buckling during the droughty period (Figure 2). Majority of soils in the plain are classified as vertisol according to Soil Survey Staff (1999) [20]. Smectite is the dominant clay mineral in vertisols [21]. However, other clay mineral types were encountered at different levels. High levels of smectite increase the volume by 25-50 % as it gets wet and dry, causing deep cracking. Vertisols formed on basalt contain the best crystallized smectite. Kaolinites and other clay minerals were also encountered in vertisols [22]. Atasoy, [23] found Cation Exchange Capacity (CEC) of the Harran soil samples between 27.12 and 32.53 cmol/kg. The CEC was higher in the Ap horizon. CEC values of vertisols ranged between 25 and 80 cmol/kg, and base saturation levels were generally high. The lowest organic matter content was found to be 0.8 % in the Bw2 and Bss1 horizons, and the highest organic matter content was 1.1 % in the Bw1 horizon [23]. Organic matter contents in vertisols generally did not exceed 1-2 %. The average soil pH was found to be approximately 7.5. The pH values of vertisols found in Southeast Anatolia ranged between 6.0 and 8.5 [24]. Lime content was 18.20 % as the highest value in Bss1 horizon [23]. Vertisols contained secondary $CaC0_3$ in the form of powdery accumulations or concretions.

Figure 2. The cracking formation in the vertisol in Harran Plain [23].

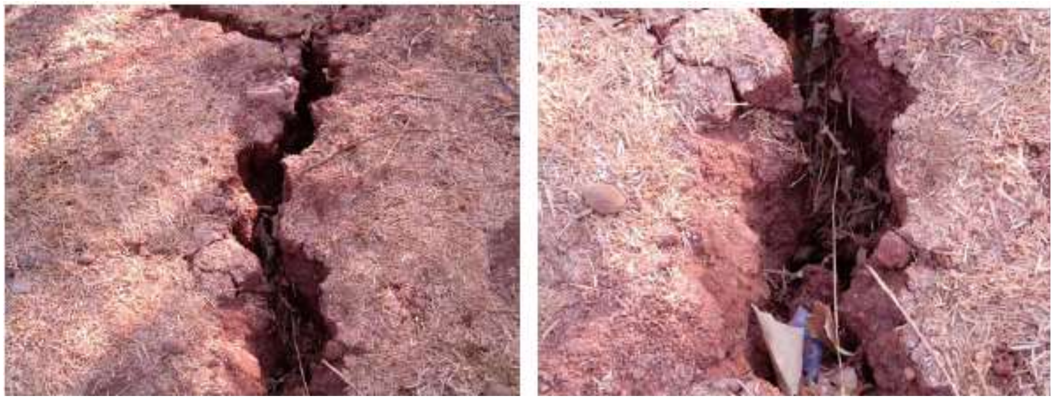

Figure 3. Deep cracks and pedoturbation inviting the movement of pollutants through the soil [23].

Vertisols in the region are generally dark reddish-brown soils. Micromorphological studies have shown that, in addition to widespread opaque volcanic minerals, dark-colored iron and manganese forming under anaerobic conditions may contribute to this coloration [25]. Clay content generally does not vary with depth, or it increases very slightly throughout the profile. Coarse prismatic structure occurs after cracking, forming the typical cracks in vertisols. These cracks are approximately 10 cm in width, and may be about 1 m in depth (Figure 3). Carbonate nodules in vertisols generally exhibit a homogenous distribution throughout the profile. However, they also accumulate in the upper and subsurface horizons, depending on soil moisture. The vertisols are suitable for cotton agriculture in Southeastern Anatolia. Their productivity and plant nutrient levels are generally good. In a study on a vertisol located in Harran Plain, it was determined that Fe-oxyhydroxides as well as silicate clays had a significant effect on phosphorus adsorption-desorption [25]. Soil samples taken from different profiles in the Harran Plain, reflect vertisol soil properties. All horizons were reddish-brown and soils were heavy with friable and plastic aggregates when moist. They have high clay content and low organic matter and contain lime ($CaCO_3$) throughout the profile [23].

Geological and Hydrogeological Settings

The Harran Plain is built up of Eocene limestone, occurring in a graben structure bordered by large N–S orienting faults. From the bottom to the top, the area is composed of Paleocene, Eocene, Miocene, Pliocene and Pleistocene aged units (Figure 4). There are two types of aquifer in the study area. The first is a deep aquifer also called a confined aquifer, lower aquifer or Eocene aquifer. The second is an upper aquifer, also called an unconfined aquifer, shallow aquifer or Pleistocene aquifer [26]; [27]. The Paleocene aged unit consists of marl with no outcrops and its thickness is approximately 800 m. This unit is impermeable and has not formed an aquifer. The unit is cut only when drilling is performing. It is overlaid by the Eocene. The Eocene aged unit is composed of karstic, jointed, fractured limestone, and its thickness is about 300 m. This unit outcrops in the north, west and east of the study area and forms a deep and confined aquifer which is the most important aquifer of the area. Many boreholes produce water from within the unit.

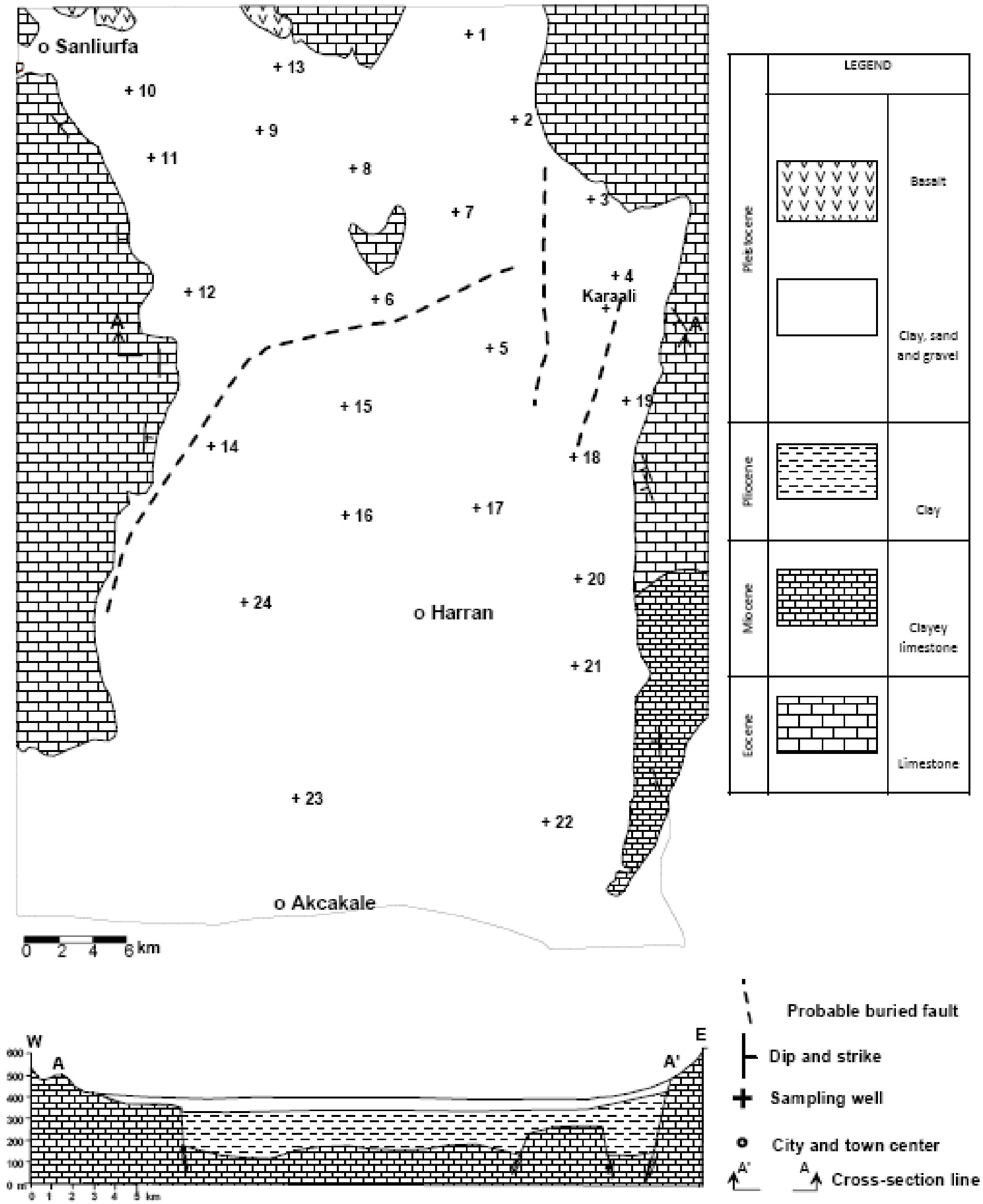

Figure 4. Geological map and cross-section of the study area (sampling wells represent the unconfined aquifer).

The yield of these wells ranges between 20 and 100 l/s. It is overlaid by the Miocene. The Miocene aged unit is composed of clayey and partly karstic limestone and its thickness is around 100 m. The yields of these wells of the unit range between 10 and 30 l/s. This unit outcrops only in the southeast of the study area. It is overlaid by the Pliocene. The Pliocene is composed of clay containing gypsum locally and its thickness is roughly 200 m. This unit has not formed an aquifer. It is overlaid by the Pleistocene. This unit forms an impermeable barrier for the Pleistocene aged unit. It is overlaid by the Pleistocene. The Pleistocene is composed of clay, sand and gravel, and its thickness is approximately 60 m. This unit is a shallow/unconfined aquifer. There are hundreds of shallow wells within this unit. After irrigation, the groundwater level in this unit almost reaches the land surface in some parts of the plain. The Pleistocene aged basalts appear on the surface of some hills in the north of the study area.

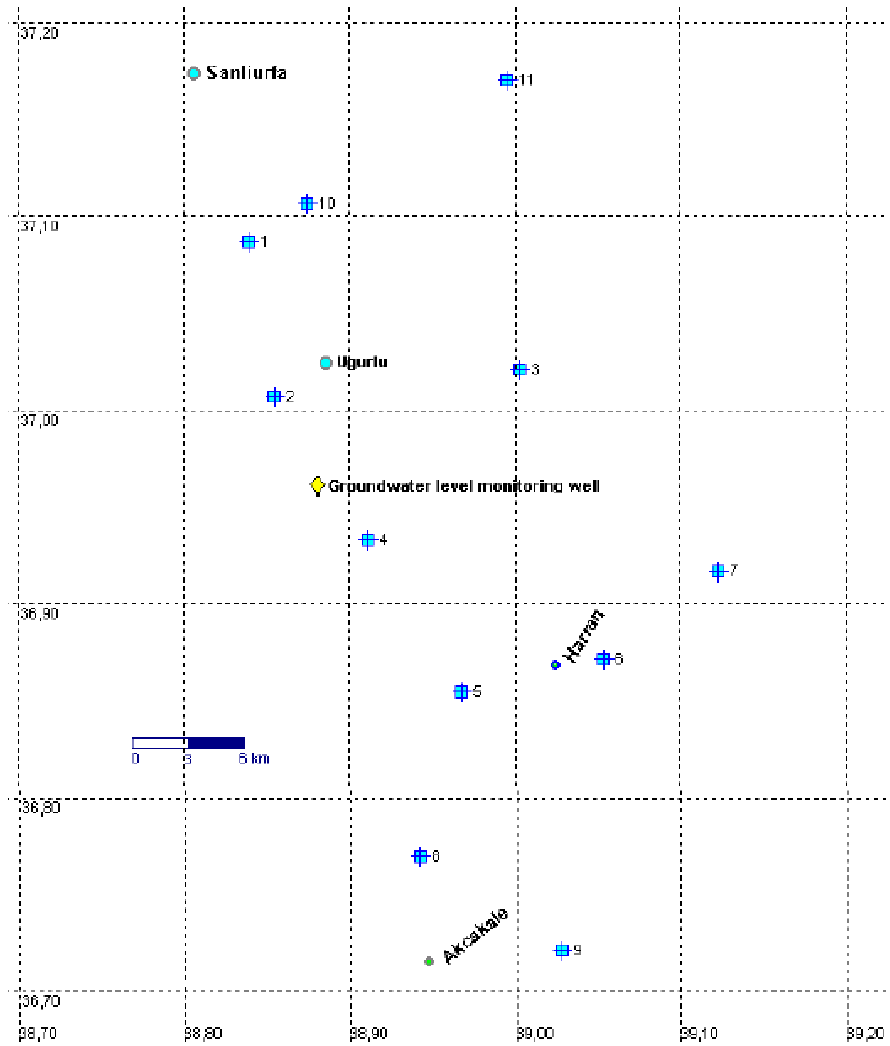

Figure 5. Monitoring wells representing the confined (deep) aquifer.

Sampling and Analyses

The groundwater samples (from confined and unconfined aquifer) were taken from the Harran Plain. The study was carried out between 2006 and 2009 [15]; [17]; [23]; [28]; [29]. Samples from unconfined aquifer were taken monthly from 24 representative observation wells which were drilled on the Pleistocene aged unit during the 2006 water year used in

Turkey and in the entire northern hemisphere, which starts on 1 October of a year and ends on 30 September of the next year, and takes the name of the latter year. Except for well no. 4, the depths of the sampled wells range from 20 to 80 m. The groundwater samples from confined (deep) aquifer were taken monthly from 11 representative observation wells (Figure 5) which were drilled on the Eocene aged unit between November-2008 and July-2009.

EC, temperature, pH and groundwater level were measured with YSI 6600 sonde, SevenGo pro-SG7 conductivity meter, a portable pH meter and an electric contact meter immediately after sampling in the field. Sampling and measurement procedures were carried out in accordance with:

- D4448-01 Standard Guide for Sampling Ground-Water Monitoring Wells [30],
- Water Quality-Sampling-Part 2: Guidance on sampling techniques [31] and
- Groundwater Well Sampling [32].

Concentrations of SO_4^{2-} and NO_3^- were determined with a Merck Nova 60 photometer. Analyses were conducted in the laboratory using the standard methods as suggested by the American Public Health Association [33]. The accuracy of the chemical analysis was verified by calculating ion-balance errors where the errors were generally below 5%.

RESULTS AND DISCUSSION

Nitrate Contamination of Groundwater

Nitrate concentration in the groundwater samples from unconfined aquifer ranges from min. 1.3 mg/L in the north of the area to max. 806 mg/L in the center of the area with an average value of 164 mg/L. In particular nitrate which is the most common contaminant in groundwater was well above the maximum admissible concentration of 50 mg/L for the quality of water intended for human consumption in almost all groundwater samples. Nitrate contamination maps of the unconfined aquifers were shown in Figure 6.

Since the 1960s, nitrate loading in both surface water and groundwater has drawn great attention worldwide [34]. Nitrate pollution cases that exceed the threshold as recommended by the World Health Organization (50 mg NO_3^- L^{-1}) and by the USA (10 mg N^- L^{-1}) for drinking water have been reported in many countries [3]. The pollution of groundwater in areas of high agricultural activity is a consequence of farming practices using large quantities of fertilizers and pesticides. Nitrate leaching in the unsaturated zone due to rain or irrigation is directly related to the leaching of the soil, although the degree of its impact does depend on the amount of water involved [35]. The heavy use of nitrogen (N) fertilizer for intensive farming and cropping systems with low N use efficiency are often responsible for nitrate overloading into groundwater [10].

Irrigation and fertilization practices influenced the nitrate concentrations in the groundwater in Harran Plain. Increased groundwater level of confined (deep) aquifer caused by irrigation that first started in 1995 was shown in Figure 7.

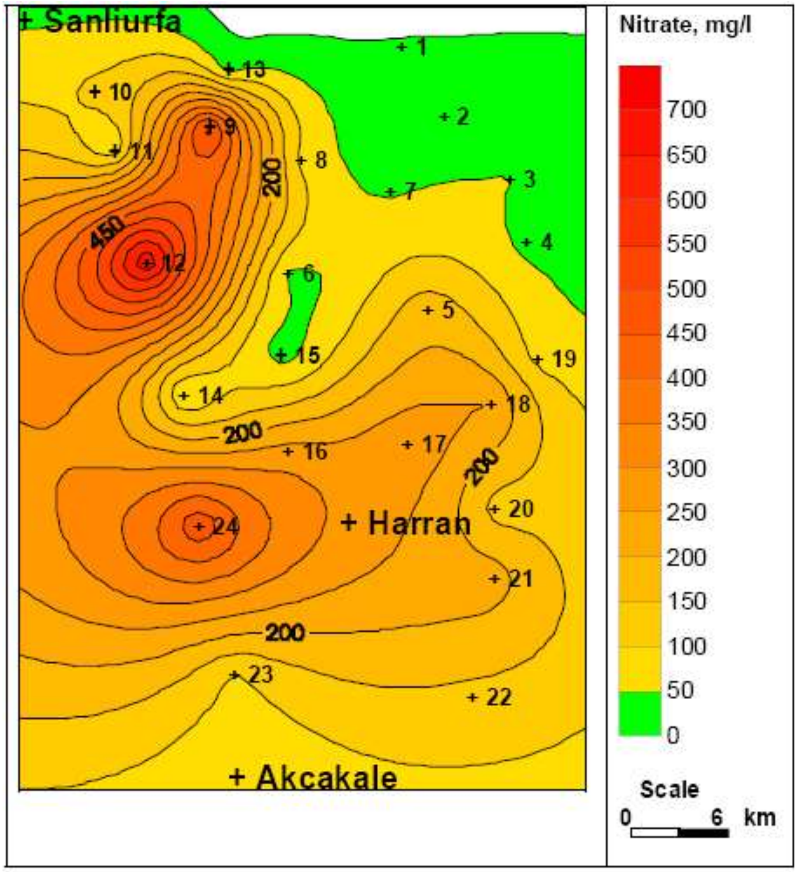

Figure 6. Nitrate contamination map of the unconfined aquifer [15].

Intensive use of artificial fertilizers in agricultural practices with excessive and uncontrolled irrigation contributed the nitrate leaching through the groundwater. Nitrate pollution of groundwater in Harran plain, is of particular concern because of the large number of people in semi-arid plain relying on groundwater for drinking. NO_3^- in water supplies can cause ecological damage and health risk. Several studies evidence adverse effects of high NO_3^- levels, most notably methemoglobinemia, stomach cancer and non-Hodgkin's Lymphoma especially in infants less than six months of age [36].

Andrade and Stigter [37] signified that the problem of groundwater contamination by agricultural practices was considered by the European Environment Agency [38] as an area of no progress in the European Union (EU), despite the adoption of European Council Directive 91/676/EEC in 1991. Known as the Nitrates Directive, its aim was to reduce the nutrient load of agriculture on surface and groundwater, but its implementation by the member states has proven extremely difficult, due to a number of factors, such as: i) the power of the agricultural lobby e.g. [39]; ii) the lack of cooperation between environmental and agricultural agencies; iii) the complexity of the contamination process, involving other sources of nitrate and iv) the lack of comprehensive monitoring networks [40].

Due to the potentially serious environmental and health impacts of nitrate pollution, there have been several studies that investigated the economic and environmental impacts of different N practices that may reduce nitrate pollution.

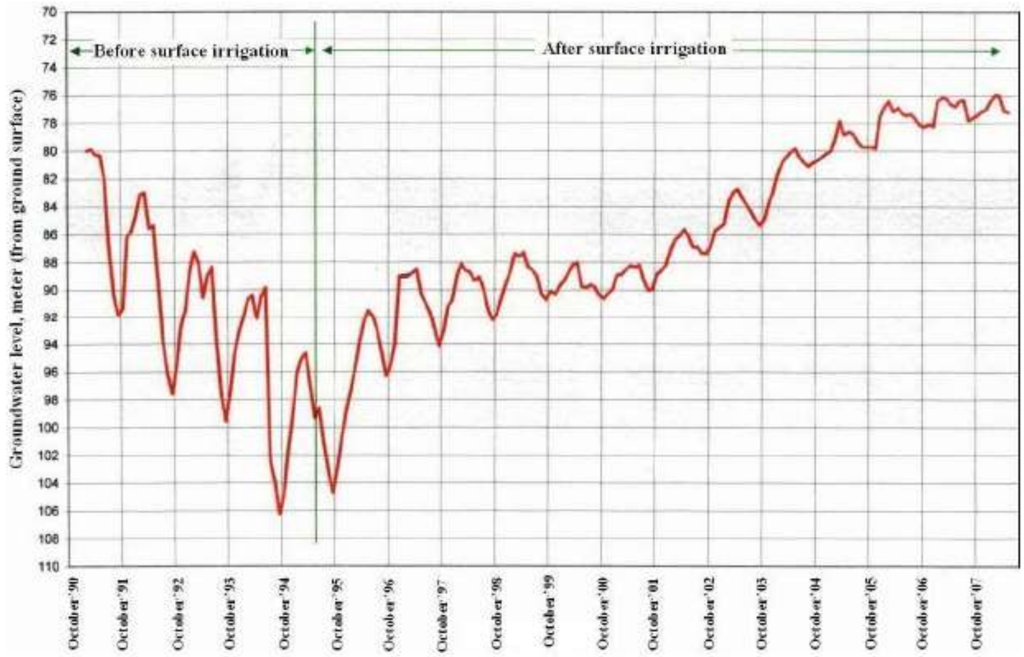

Figure 7. Increased groundwater level in confined (deep) aquifer after irrigation period [45].

Most of these studies have focused on the economic and environmental effects of different timing and rate practices that reduce pollution levels in water bodies [41]; [42]; [43]. Based on simulation data, these studies found that restrictions on N timing and application rates, targeted toward intensively managed farms with surplus N, can significantly cut leaching and runoff at relatively low cost [44].

Pesticide (Endosulfan) Contamination of Groundwater

Endosulfan is a chlorinated pesticide ($C_9H_6Cl_6O_3S$) of the cyclodiene group. It is composed of two stereoisomers of alfa (α) and beta (β) endosulfan in approximate ratio of 70:30 [46]. It is being used extensively throughout the world for the control of numerous insects in many of food and non-food crops [47]; [48]. Because of its persistence and toxicity, endosulfan contamination poses a significant environmental concern [49]. Extensive use of this pesticide more than a decade for cotton plantation in the Harran plain, southeast of Turkey is great concern regarding the potential transport in the environment.

Residual alfa endosulfan was determined in 7 wells (in unconfined aquifer) around the Harran Plain; however, beta endosulfan was generally below the detection limit. Alfa endosulfan concentrations in the groundwater were higher than that of beta endosulfan. This was due to the higher proportion of alfa isomer than beta isomer (70:30) in the content of technical endosulfan used extensively in Turkey, including the Harran plain. Therefore, the amount of residual alfa endosulfan in the environment was expected to exceed the beta endosulfan [50].

The use of uncontrolled and large amount of pesticides may deteriorate the soil and groundwater quality. It is thought that endosulfan reached groundwater in Harran plain, making it unsuitable as a source of drinking water, because of its extensive agricultural application. Meeting with the residual endosulfan in the groundwater is primarily related to the adsorption-desorption mechanisms in the Harran soils. Atasoy et al. [17] indicated that endosulfan adsorbed highly on the clayey Harran soils. Adsorption rates of alfa and beta endosulfan for different initial concentrations were ranged between 82% and 91% on the Harran vertisols. However, the range of 13 to 23% desorption rate on the soil exhibited the probability of endosulfan movement in the soil [17]. Alfa and beta endosulfan can move down the profile and can reach to the sub horizons and finally to the groundwater. Atasoy [50] signified that, high adsorption and then medium desorption tendency on the Harran soils was attributed to poor physical bonding (as Van der Waals force) between endosulfan molecules and soil particulates. Physical adsorption occurred between nonpolar and/or hydrophobic pesticides and soil [51]. Furthermore, adsorbed endosulfan on the upper soil particles may pass through the deep cracks (which formed in Harran vertisols during the droughty period) (Figure 3) to lower horizons. Just as pollutants may drift horizontally to nontarget areas, they may also be moved vertically to subsoil by pedoturbation [25].

Andrade and Stigter [37] noticed that the groundwater contamination by pesticides can result from incorrect or poor control on their use and application [52], from leaching after application due to subsequent rainfall or from inappropriate disposal methods [53]. The properties of the involved substances, their behaviour in the soil environment and the aquifer characteristics and vulnerability are also important factors [54]. If the pesticide and metabolite degradation rates exceed their percolation rates through the soil, contamination of groundwater is less probable [55], but the occurrence of preferential flow increases the pesticide contamination risk [56].

Irrigation Water Quality, Salinity and Drainage Problems

The Harran Plain covers the important residential areas like Sanliurfa City center, Harran and Akcakale districts. The requirements of drinking, usage and irrigation water is provided from groundwater in 1500 km^2 of plain area. The groundwater quality in the plain for irrigation was assessed by Yesilnacar and Gulluoglu [15]. They specified that 41.7% of the well waters (in the unconfined aquifer) were high salinity and have low sodium characteristic, which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium. 29.2% of the well waters were medium salinity and have low alkalinity hazard, 20.8% of the well waters were high salinity and have low alkalinity hazard. This can be suitable for plants having good salt tolerance and it also restricts suitability for irrigation, especially in soils with restricted drainage. 8.3% of the well waters were very high salinity and have medium alkalinity hazard.

Saline groundwater is often found at shallow depth in irrigated areas of arid and semi-arid regions and is associated with problems of soil salinisation and land degradation. Harran plain has semi-arid climate and poorly drained soils because of the high (>60%) clay content [23]. Indications of saline deposits have been observed on the low part of the plain. Salt deposits in the Harran soil (Figure 8) resulting from excess irrigation (Figure 7), high evaporation rates and poor drainage, accumulated in shallow groundwater and migrated down in the course of time and then reached the well screens.

Figure 8. Salinization problem on the Harran soil [23].

Deficiency of drainage network in the farmlands was the most important factor on the salinity of soil and groundwater. Moreover, surface irrigation with these waters (saline groundwater) on heavier textured soil of the area usually leads to build up of salinity and sodicity problems and thus unsustainable crop yields. Therefore, there is need to adopt specialized and efficient methods of irrigation like micro irrigation which can help in attaining the twin objectives of higher productivity and optimum use of water [57].

The conventional solution is to maintain a deeper water-table through provision of engineered drainage disposal systems, but the sustainability of such systems is disputed. This shallow groundwater should, however, be seen as a valuable resource, which can be utilised via capillary rise (i.e. sub-irrigation). In this way, it is possible to meet part of the crop water requirement, even where the groundwater is saline, thus decreasing the need for irrigation water and simultaneously alleviating the problem of disposing of saline drainage effluent. Management of conditions within the root zone can be achieved by means of a controlled drainage system [9].

Corrosivity Case of Groundwater

Corrosion which tends to increase the concentrations of certain metals in drinking or irrigation water is one of the most important quality problems as it can affect public health and public acceptance of water supply and the cost of providing safe water. Atasoy and Yesilnacar [29] investigated the corrosion tendency of groundwater (in unconfined aquifer) in Harran Plain. They noticed the negative Langelier Index values (indicating the corrosion tendency of water) which ranged from −0.07 to −1.22 for all the representing wells except for well no S4. The corrosive tendency of the wells were arranged as; S22>S21>S17. Well no S4 has positive Langelier Index (0.03). Therefore, it has a scale formation tendency. Well no 4 is closer to Karaali Hot Springs. Langelier Indices are found significantly correlated with the sulfate concentration of groundwater.

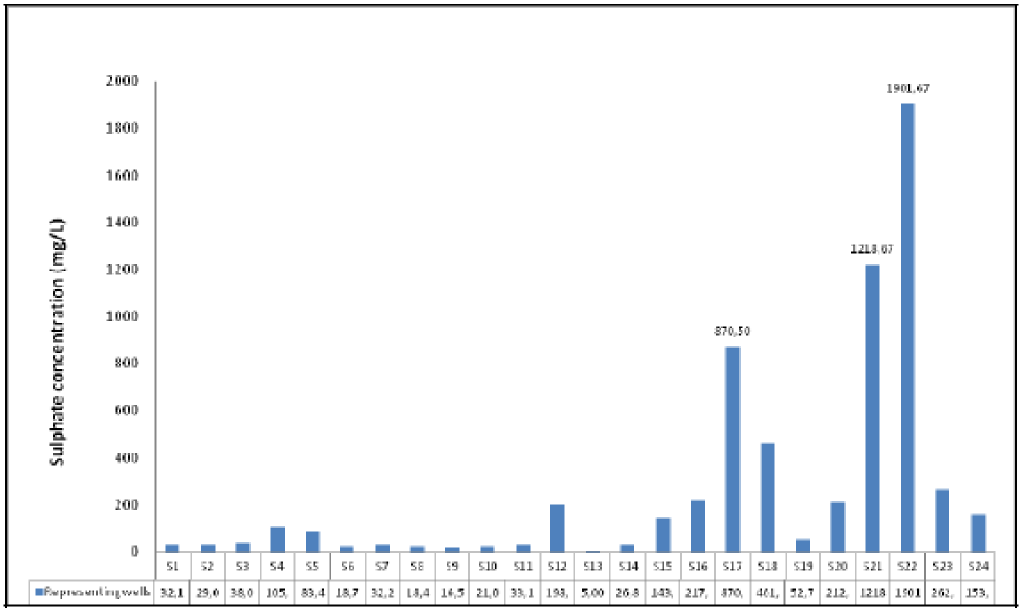

Figure 9. Annual mean of sulfate concentration in the wells (in unconfined aquifer).

Annual mean of sulfate concentration in the wells are presented in Figure 9. Higher sulfate concentrations result from thin gypsiferous layers within the Pliocene aged deposits. In particular, gypsum and anhydrite appear in evaporite deposits in the center of Anatolia and in the Southeast Anatolia [58]. The sulfate pollution can be the result of sulfate containing fertilizers. Devadas et al. [59] specified Sarada River basin, India as a centre for agriculture like the Harran Plain, Turkey. Agricultural practice is intensive and long-term without any control of using chemical fertilizers for higher crop yields in both study area. Fertilizers used contain sulfate with other ions. Hence, high sulfate concentration in some wells in Harran Plain can be explained also by the intensive agricultural activities [29].

Atasoy and Yesilnacar [29] revealed that the wells in the vicinity of Harran and in the south of Harran have more corrosive characteristic than the others. The amount of CO_2 from the soil zone respiration and high sulfate concentrations in the wells were important factors affecting corrosiveness.

According to Gallardo and Tase [60], some measures should be taken in advance to prevent spreading of the pollution front. They suggested to Local authorities to carry out a permanent advisory campaign to promote good agricultural practices by collaborating with the farmers. For example, farmers might be encouraged to plant crops that can accumulate sizeable amounts of nutrients, while replacing or minimizing the use of highly leachable fertilizers. They also suggested the periodic monitoring of groundwater quality that is necessary in order to assess the effectiveness of the programs.

Pollution of Abundant Confined (Deep) Aquifer

There are two types of aquifer in the study area. The first is a deep aquifer also called the confined, lower or Eocene aquifer. The second is an upper aquifer, also called the unconfined, shallow or Pleistocene aquifer. The monitoring results for confined aquifer illustrated that contaminated wells with nitrate and high electrical conductivity (EC) are located in the vicinity and generally in the south part of Harran Plain (Figure 10 and Figure 11).

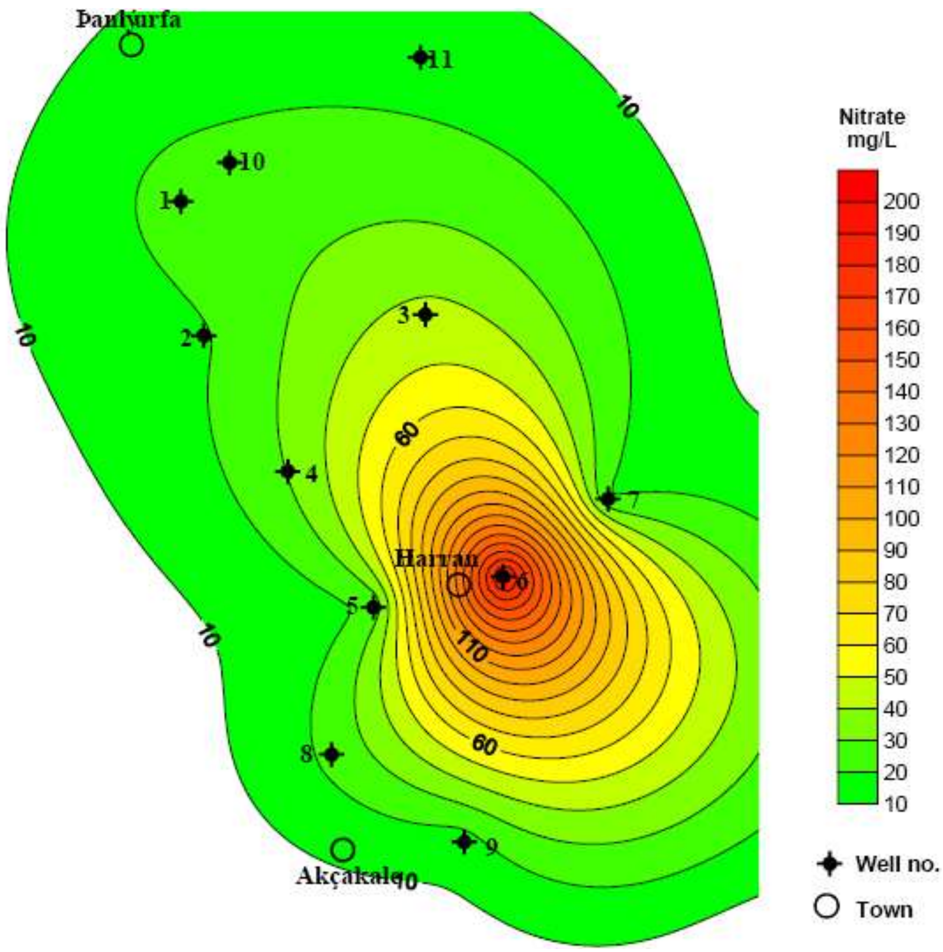

Figure 10. Nitrate contamination map of the confined aquifer .

The groundwater in the plain was good-quality before the irrigation period (1995) [61]. With regard to determination of groundwater quality in the upper aquifer after irrigation, Yesilnacar et al. [62] and Yesilnacar and Gulluoglu [15]; [63] showed that the highest EC values (6870-8235 µS/cm) were observed in the vicinity of Harran and in the south part of Harran Plain where the land slope is almost zero. Previous studies [18]; [64] have reported soil salinity of these areas to be fairly high as well. After the irrigation period, primarily the shallow (unconfined) aquifer and then the deep aquifer were contaminated with nitrate and dissolved solids. Likewise, the other contaminants such as pesticides and heavy metals are thought to reach the deep aquifer. Furthermore, dissolved salts accumulated in shallow groundwater migrated down in the course of time and then reached the confined aquifer. Several dissolved ions especially sulfate (from dissolved salts+sulfate containing fertilizers) corroded the well equipment and consequently, abundant and high quality water of deep aquifer has been contaminated locally.

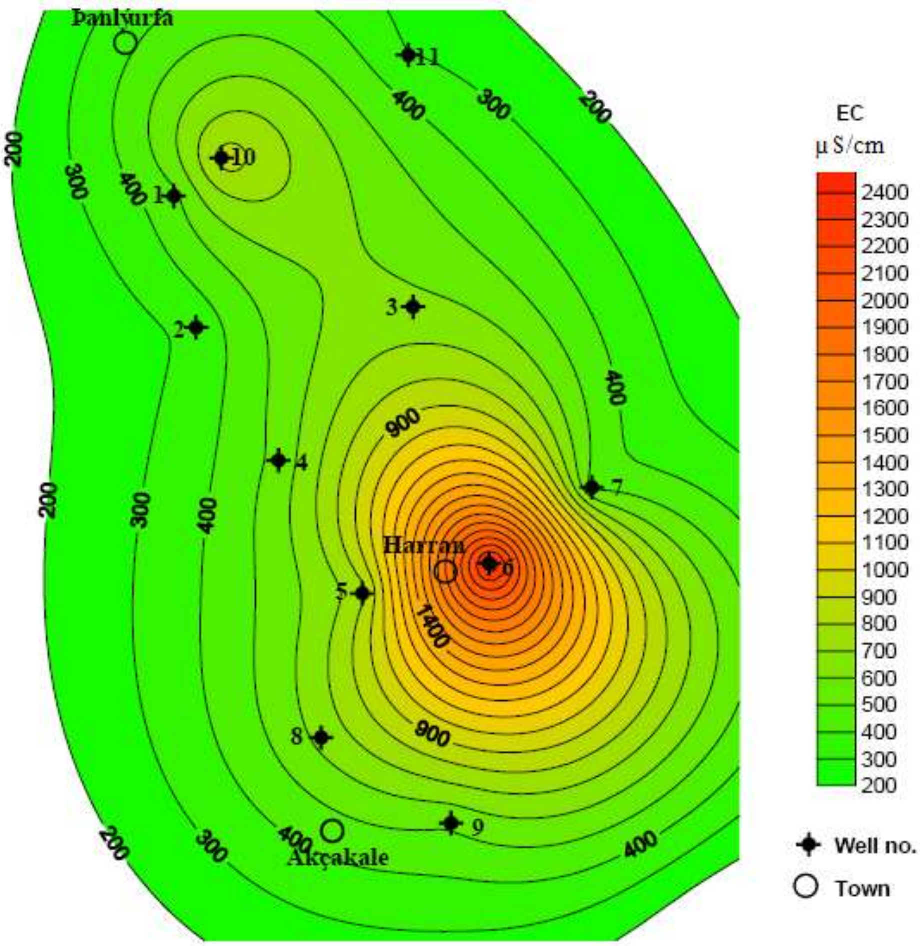

Figure 11. Spatial distribution of the EC in groundwater in confined aquifer.

CONCLUSION

The excess irrigation in the Harran Plain that was a good example of the semiarid area which suffers from the agricultural pollution, caused the leaching of the contaminants to the groundwater. Hence, the permanent agricultural activities introduced a long term risk of soil degradation and groundwater contamination due to the fertilizers, salts and pesticides leached downward. In order to inspect the vulnerability of groundwater and soil to different contaminants, necessary countermeasure must be taken immediately as follows:

- Excessive irrigation and extensive use of fertilizers, pesticides and other chemicals should be restricted.
- Sub-surface and main drainage systems should be properly constructed in the irrigated lands.
- Farmers and water users training must be carried out in a continuous manner.
- The monitoring processes must be applied continuously act of increasing the number of water and soil quality parameters.
- Pest management techniques/practices and fertilization programs must be improved in a more ecologically sustainable manner.

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