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Full Length Research Paper

Monitoring and assessing of changes in soil and groundwater salinity of Yemisli Irrigation District of Turkey using low quality irrigation water

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Low irrigation efficiency, high saline irrigation water, heavy soil texture, lack of adequate field drainage systems may cause soil salinity and drainage problems in irrigated agriculture. The mentioned problems are major treats for the sustainability of irrigated agriculture. This study carried out in 2007 was undertaken in 7,110 ha of area under the directive of Yemisli Irrigation Association (YIA) in Lower Seyhan Plain, on Southern coastal plains in Turkey. Growers in the area use low quality irrigation return flows of up-stream areas for irrigation. Irrigation method commonly used in the region is flood irrigation with low field irrigation efficiency. This work examines if using low quality of irrigation water causes drainage and soil salinity problem. For this purpose, a year around survey of 55 groundwater observation wells was carried out. Groundwater depths in the observation wells in February, March, June, July and October were measured. Salinity of the water samples collected from the wells was measured as electrical conductivity (ECw at 25°C). Additionally, soil samples from 0 to 30, 30 to 60 and 60 to 90 cm depths at 34 randomly selected sites were analyzed for soil salinity (ECe at 25°C) and alkalinity (SAR). The mean groundwater depth was the minimum (0.97±0.29 m) in March, before starting of the irrigation season. In October, following completion of the irrigation season, the groundwater depth was the highest (1.59 ± 0.13 m). Groundwater EC, greater than 20 dS m^{-1}, was noted commonly. In 93% of the study area, ECw was higher than 5 dS m^{-1}. Mean soil salinity ECe was higher below 1 m depth compared with that of surface layers. Likely occurrence of soil alkalinity (that is, sodium effect) was greater in sub-soil below 30 cm depth compared with surface layers. The results of the study showed that the soils of the area may become salt or even sodium affected in the future unless the present practice of irrigation management is changed.

Key words: Irrigation management, drainage, observation wells, water table, EM38, spatial and temporal variability.

INTRODUCTION

Improved management of soil and water resources has become essential for overcoming the effects of drought with increasing reoccurrence, very likely due to global warming. Increasing and sustaining high crop yields is possible only by good management of soil and water resources. Due to high investment costs of irrigation and drainage systems, likely engineering errors in both planning and application stages would increase the cost even higher (Cetin and Özcan, 1999). Therefore, detailed surveys of soil-water-plant-atmosphere relations are needed for implementing drainage and irrigation projects.

Capabilities of soils differ depending on their classified types, physical and chemical characteristics (Cetin and Özcan, 1999). It is therefore very important to assess whether existing soil productivity can be sustained with the planned irrigation system and management. There are numerous examples of irrigation projects exist, where

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soils completely lost their productivity due to salinity, alkalinity and drainage problems. Soil salinity may also develop depending upon topography, existing natural drainage characteristics, climate, distance to sea, and chemical characteristics of the main soil material (Amezketa, 2006).

Agricultural lands would lose their productivity if necessary precautions are not taken to prevent soil salinity that may develop with improper irrigation practices. Availability of water resources alone is not sufficient for a good irrigation practice; water quality should also be suitable for sustaining soil productivity (FAO, 2001; Cetin and Kirda, 2003; Kaman et al., 2011). Agricultural demand of water in Turkey is the highest compared to municipal and industrial allocations (Cetin and Özcan, 1999; Gündoğdu, 2004; Cetin et al., 2007a). On the other hand, it should be noted that irrigation efficiency is very low and needs to be improved in most of the irrigation schemes present in Turkey. Effective use of water allocated for agricultural use could therefore result in significant savings of the scarce water resources (FAO, 2001; 2002). Development, conservation and improved management of water resources are essential for reducing adverse effects of future drought periods to occur under scenarios of global warming (Büyükcangaz and Değirmenci, 2002).

It is a widely known fact that high soil and water salinity adversely affect crop development and yielding. Therefore, groundwater depth and its salinity and likely enhancing effect on soil salinity are to be surveyed to sustain crop productivity in irrigated areas. Depending on the survey results, recommendations may be formulated to improve existing management practices if there are risks of unfavorable conditions endangering good crop productivity. Groundwater depth and salinity can be surveyed by installing groundwater observation wells of 3 to 4 m depth (Cetin and Diker, 2003).

Irrigation is essential in areas where inadequate and erratic rainfall pattern during summer months coincide with crop development. Therefore, high crop productivity can only be ensured with irrigation in such areas. However, it should be noted that excess irrigation would cause rising of groundwater and soil salinity if preventive measurements are not taken (Cetin and Kırda, 2003). Extend of salt accumulation in plant root zone depends on the method of irrigation (Tuzcu et al., 1988). Risks of soil salinity exist under lack of good irrigation management even if there is good quality of water. Rising of groundwater to plant root zone with capillary rise during irrigation season implies that irrigation efficiency in the area is very low; hence, the groundwater is recharged with irrigation water (DSĐ, 1982; Cetin and Diker, 2003).

Lower Seyhan Plain (LSP) which is among the largest irrigated areas in Turkey was opened to irrigation first with the construction of Seyhan Regulator in 1942, and the irrigated areas extended further with construction of the Seyhan Dam in 1956 (Cetin and Özcan, 1999).
Presently, irrigated area in LSP is 133 431 ha, although total irrigable land available is 174 088 ha (Cetin and Kırda, 2003; Cetin and Özcan, 1999). Annual flow of Seyhan River which is the only water resource existing in the area is 6.3 km^3. Although the flow capacity of Seyhan River is more than adequate for irrigating the complete area, there are 40 657 ha of land still waiting for development of irrigation systems which would bring fresh irrigation water to the area directly from the Seyhan Dam (Cetin and Özcan, 1999). Farmers of the area presently utilize irrigation return flows (IRF) in drainage ditches, coming from up-stream irrigated areas. They all use flood irrigation with low irrigation efficiency. Because the area under study is outside of the completed irrigation scheme, there are no groundwater observation wells for monitoring impact of presently used irrigation practice on soil salinity and crop productivity. The study undertaken therefore aims at evaluating what effect surface-flood irrigation, utilizing low quality IRF, would have on soil salinity and groundwater depth.

MATERIALS AND METHODS

Experimental area

This study was implemented in an area under the directorate of Yemisli Irrigation District having 7,110 ha of land with high potential of crop production. It is located within Southern latitudes of 36° 43' 32" to 36° 38' 07" and Eastern longitudes of 35° 20' 08" to 35° 27' 12" in South-eastern direction of the city Adana, close to the Mediterranean (Figure 1). The area has Mediterranean climate with cool and rainy winters, hot and dry summers. The month August is the hottest month with long-years average temperature of 28.1°C, and January is the coolest with temperature of 18.8°C. Annual average precipitation is 775 mm. In the experimental year, the month July is the hottest month with temperature of 35.3°C and annual precipitation is 676 mm.

Soils of very heavy clay texture present in the area are largely alluvial fillings of land depressions. The low permeability of the soils is the major constraint to farming practices. Source of irrigation water largely used in the area is obtained through diverting of low quality IRF from the drainage ditches, coming from up-stream areas (ECw, 1.2 to 4.0 dS m^{-1}). The topographic survey of the area showed that the altitude of the study area was within the range of 0.97 to 6.28 m with an average of 2.37 m. The farm land between Yemisli village and the main drainage channel P2-D1 was the lowest area (Figure 2). Source of irrigation water was solely low quality water diverted from the drainage channel P2-D1 (Figure 2). Because of the low altitude of the access point of the drainage channel P2-D1, a pumping station was constructed for facilitating out-flow of returning excess irrigation water from the study area and the drainage water coming from the up-stream irrigated areas. If the pumping station was not operational, water ponded in nearby area reached a depth of 0.75 m. It was noted that the pumping station was turned off intentionally if there was not enough water in the drainage ditches for diverting for irrigation. For controlling drainage and preventing salt accumulation in the area, the proper operation of the pumping station requires close monitoring of farm lands as for both groundwater depth and soil salinity.

Cropping pattern

During the year (2007) when the study was implemented, the major crops grown in Yemisli area were wheat (*Triticum* spp) and cotton

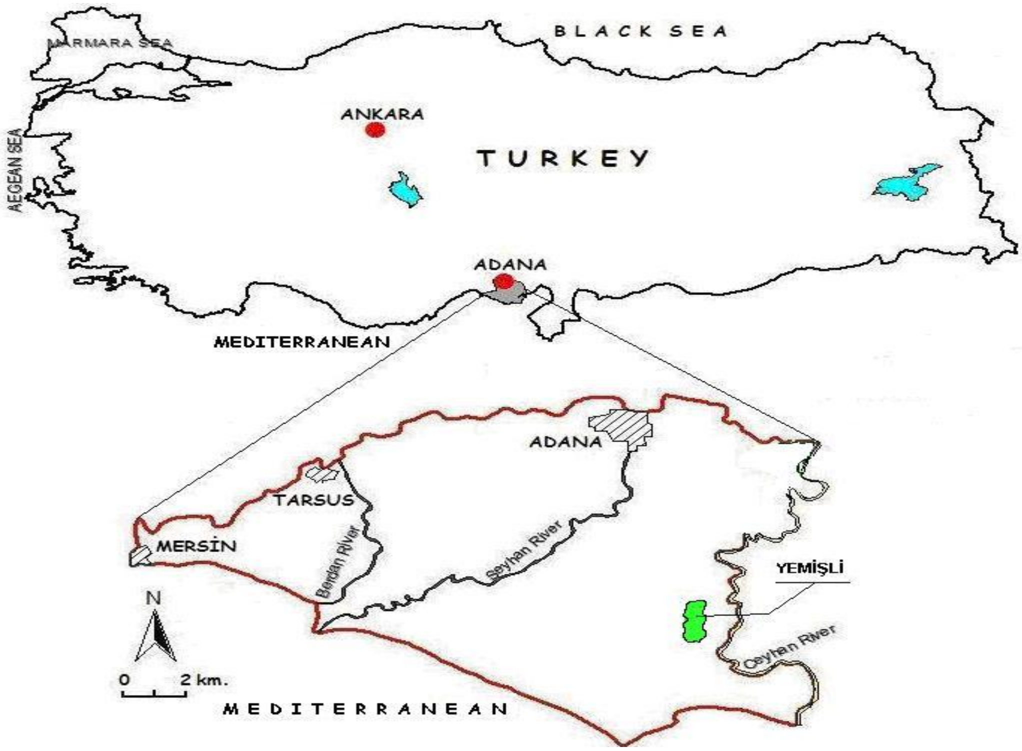

Figure 1. Geographical location of the study areas in Turkey.

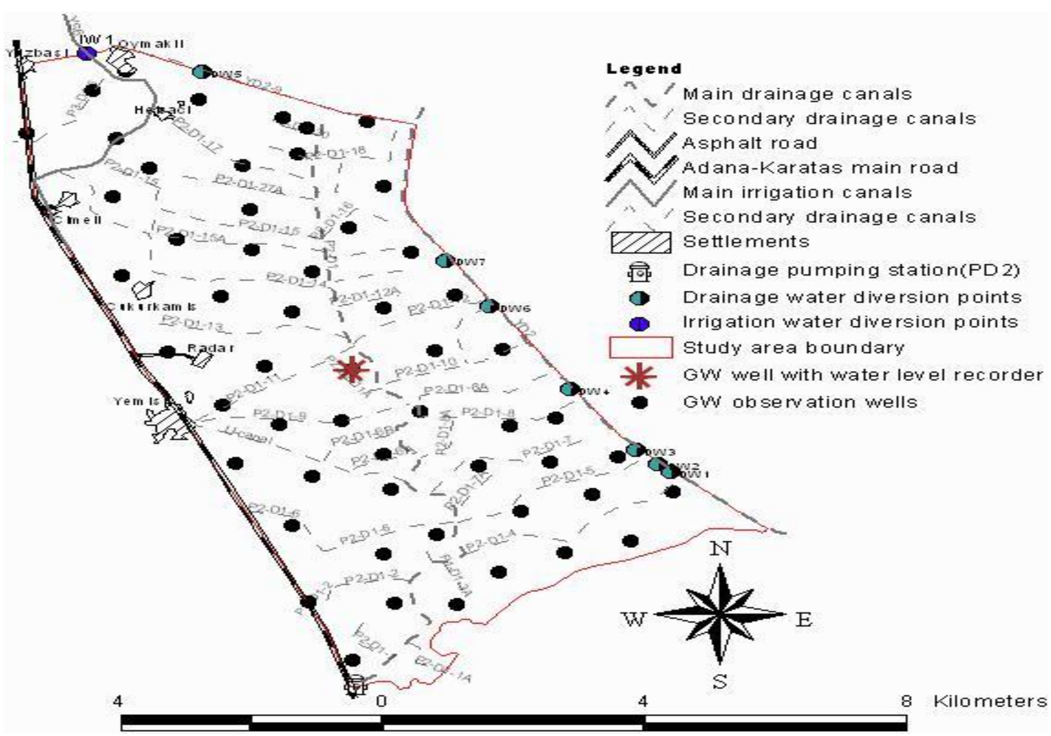

Figure 2. Groundwater observation wells and water diversion sites in the Yemisli Irrigation District.

(*Gossypium hirsutum* L.) (Table 1). Maize (*Zea mays* L.), planted following the harvest of wheat, has the secondary importance.

Wheat of 38.2% planted area, grown during winter from November to May, is not irrigated. Cotton grown during summer, from April t o

Table 1. Cropping pattern (%) in the Yemisli Irrigation District.

Crop	Areal coverage (%)
Cotton	51.9
Wheat	38.2
2nd crop corn	9.7
Forage	7.0
Citrus	1.0
Melons	0.5
Others	1.4

May, had the largest acreage of 51.9%. Cotton and others crops of secondary importance like water melon (*Citrullus vulgaris*) were all irrigated with surface-flood irrigation with low irrigation efficiency.

Soil and groundwater sampling

Although the farm-lands under the directorate of YID have been irrigated for over 40 years, they had neither a designed operational irrigation scheme nor they had drainage net-work. There was no information available on the extent of drainage problem and soil salinity. The flood irrigation methods presently under use need to be improved and the excess irrigation application to be prevented for limiting expansion of drainage problem (Cetin and Diker, 2003). Therefore a net-work of 55 observation wells was constructed for monitoring fluctuations of groundwater depth and its salinity (Figure 2). Locations of observation wells were selected by considering irrigation and crops grown, soil characteristics and farm management. Additionally the locations were further defined based on Explorist 600 Reference Manual (Thales, 2005), and their coordinates were determined as UTM using GPS equipment based on ED50 datum.

The groundwater depth and its salinity as electrical conductivity (ECw, dS m^{-1}) were monitored 5 times (2 February, 9 March, 7 June, 21 July and 17 October) in 2007, following the procedure described by Cetin and Diker (2003). Additionally soil salinity was surveyed using EM38 equipment and the collected data were transformed to the usual soil extract salinity (ECe, dS m^{-1}) with proper field calibration. Additionally, soil samples collected from randomly selected 34 sites at depths 0 to 0.3, 0.3 to 0.6 and 0.6 to 0.9 m were analyzed for sodium absorption ratio (SAR).

Data analysis

The collected data during the study on groundwater depth and its salinity, soil SAR and salinity were mapped using geographical information system (ArcView 3.0a GIS) (ESRI, 1996) using the procedure described by (Cetin and Diker, 2003; Ritzema et al., 1996; Keckler, 1995). Changes of areal coverage (%) of soil salinity, groundwater depth and its salinity were calculated through the year and tabulated.

RESULTS AND DISCUSSION

Groundwater depth distribution

Seasonal changes of areal coverage (%) of groundwater depth are shown in Table 2. The lowest groundwater as 0.97 m was observed in March, following the rainy winter season. At the completion of irrigation season in October, the groundwater was subsided to a depth of more than 1.5 m, with an areal coverage of 75% (Table 2). However, the area with groundwater depth less than 1.5 m was more than 95% in July when irrigation was at its peak. Demir and Antepli (2004) also reported that the month of July was the peak season of irrigation in the area. Because of excess irrigation water application and wide-spread use of inefficient flood irrigation, the drainage problem is the highest in July as also confirmed by Cetin et al. (2007a; b) and Demir and Antepli (2004). The existing drainage problem was further increased when farmers closed the main drainage channel P2-D1 to facilitate diversion of irrigation water. Therefore, the drainage problem prevailed throughout the whole irrigation season, late June, July and early August. Apparently, drainage problem occurring during irrigation season did not adversely affect crop development. However, soil salinity developing within the surface layers requires attention.

Spatial and temporal groundwater salinity distribution

The areal means of groundwater salinity in February, March, June and July were respectively 25.6, 20.7, 24.5, 22.5 and 29.3 dS m^{-1}. The measured groundwater salinity was high considering that the salinity of irrigation water diverted from the drainage ditches was merely 1.2 to 4.0 dS m^{-1}. The observed salinity of groundwater in areas where the state funded irrigation schemes have not yet been constructed was not uncommon Cetin and Özcan (1999). The State Hydraulic Works also confirmed that the groundwater salinity was rather high in areas of the Lower Seyhan Plain where the irrigation schemes were to be completed in the IV. Irrigation Development Stage of the area (DSĐ, 1982). The groundwater salinity was even higher than 20 dS m^{-1}, a value nearly half of the salinity of the Mediterranean Sea (Table 3). The high groundwater salinity suggests that the sea water intrusion in the area may be very likely process. The areal coverage of groundwater salinity greater than 5 dS m^{-1}, a critical threshold value in drainage engineering (DSĐ, 1982; Cetin and Özcan, 1999; Cetin and Kırda, 2003; Kaman et al., 2011), was 93% (Table 3).

The groundwater salinity was greater than 10 dS m^{-1} in 78.2% of the area throughout the irrigation season (Table 3). The high salinity of groundwater, if not prevented, adversely affects soil permeability, may cause alkalinity and accumulation of salts in areas having drainage problem (FAO, 2001; Cetin and Kırda, 2003; Demir and Antepli, 2004). At the completion of the irrigation season, 42% of the area had groundwater salinity higher than 30 dS m^{-1}. The salinity of drainage water flowing out at the pumping station in February and March was respectively 16.3 and 15.3 dS m^{-1}. However, the salinity of drainage water at the same sites in June and July was only 1.5

Table 2. Areal coverage (%) with different groundwater depths (m).

Time	Areal mean	Range of groundwater depth (m)			
		< 1.0	1.0 - 1.5	1.5 - 2.0	>2.0
		Areal coverage (%)			
February	1.29 ± 0.24	9.5	73.2	16.8	0.5
March	0.97 ± 0.29	64.4	29.5	5.3	0.8
June	1.14 ± 0.15	16.2	81.7	2.1	0.0
July	1.08 ± 0.27	35.7	59.6	3.7	1.0
October	1.59 ± 0.13	0.0	23.8	75.6	0.6

Table 3. Areal coverage (%) with different groundwater salinity (ECw, dS m^{-1}) values.

Time	Areal mean	Range of groundwater salinity (ECw, dS m^{-1})					
		< 2	2 - 3	3 - 5	5-10	10-30	>30
		Areal coverage (%)					
February	25.62 ± 15.66	0.1	0.4	1.2	5.9	62.5	30.0
March	20.65 ± 15.19	0.2	1.3	5.3	19.2	52.9	21.1
June	24.54 ± 16.62	0.5	0.6	1.8	10.8	56.1	30.1
July	22.52 ± 16.10	1.1	1.8	4.0	14.8	52.8	25.4
October	29.30 ± 19.20	0.5	0.9	1.9	9.4	44.5	42.8

of irrigation water diverted from the drainage ditch showed an increasing trend from 0.9 dS m^{-1} in June, at the start of irrigation season, to 1.5 dS m^{-1} in September, near completion of the irrigation season. Although diverted from the drainage ditch, the salinity of irrigation water was acceptably low and it effectively diluted ground water salinity during the irrigation season. The relatively low groundwater salinity observed in the Northern part of the study area could be attributed to rather high quality of fresh irrigation water (0.40 dS m^{-1}) diverted to these areas from the location IW1 (Figure 3).

Areal extent of soil salinity and sodicity

Soil salinity (ECe, dS m^{-1}) assessed with proper calibration of EM38 data (Kaman et al., 2008; Cetin et al., 2009) was mapped (Figure 4). The ranges of salinity and their respective areal coverage were tabulated (Table 4). It was noted that the salinity in subsoil deeper than 1 m was higher compared to the salinity of surface layers (Table 4). The observed behavior was attributed to salt leaching process to deeper zones owing to excess irrigation water application.

The soil salinity was higher than 8 dS m^{-1} in 25% of the area during irrigation-offseason (Table 4). The area under severe salinity (ECe>8 dS m^{-1}) however decreased from 26.5% to 7 to 10% in surface layer of 1 m depth during the irrigation season (in June and July) (Table 4). One of the reason may be that the fresh irrigation water (ECw <0.4 dS m^{-1}) diverted from the point IW1 was intentionally allowed to flow directly into the drainage ditches and therefore improved drainage water quality used in the area. Therefore, the salinity in the plant-root zone, during irrigation season, was not at a level to adversely affect plant development. Because of low irrigation efficiency in the up-stream areas (Cetin et al., 2007a; Demir and Antepli, 2004), water quality in drainage ditches carrying IRF was not at a level unacceptable (ECw, 1.1 dS m^{-1}) for irrigation. Additionally, the farmers of the study area also followed excess irrigation practice, similar to those in the up-stream areas. It was interesting to note that soil salinity had wider spread before the starting of the irrigation season (Table 4 and Figure 4) indicating that the winter rains were not sufficient for leaching out of the previous year's salt accumulation.

Figure 5 showed that soil alkalinity, as described with soil extract SAR values, increased in sub-soil where both groundwater and soil salinity were higher than in surface layer of 0.3 m depth. The SAR values in over 37% (2631 ha) of the study area was higher than 13 in sub-soil layer of 0 to 0.9 m.

Conclusion

Management problems associated with use of low quality of irrigation water were discussed. The soil salinity and alkalinity may develop in areas with shallow groundwater. The soil alkalinity must be closely monitored for sustaining the existing soil productivity. Easy access of drainage-water out-flow must be ensured and maintained

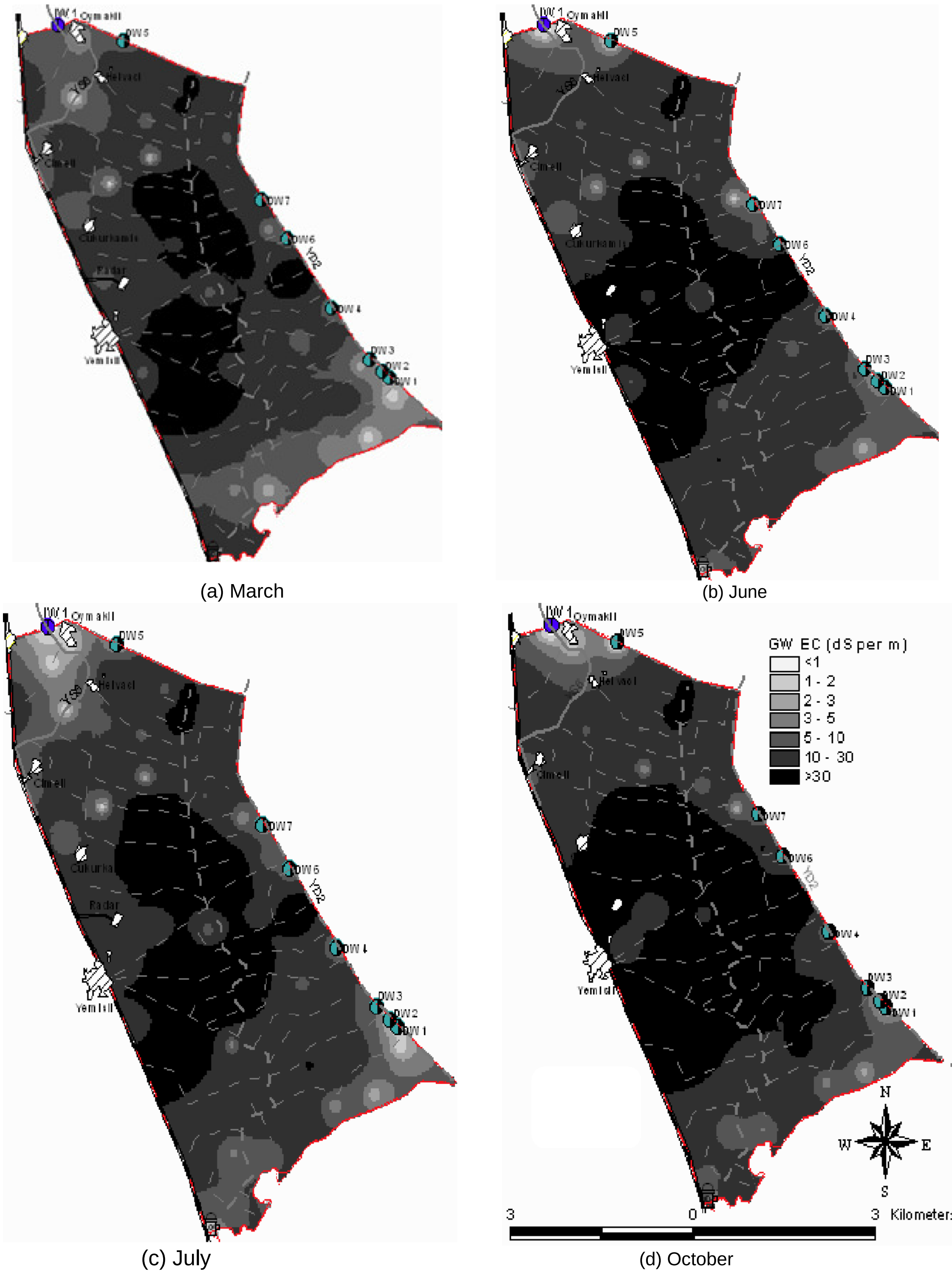

Figure 3. Spatial and temporal distribution of groundwater salinity (ECw, dS m^{-1}).

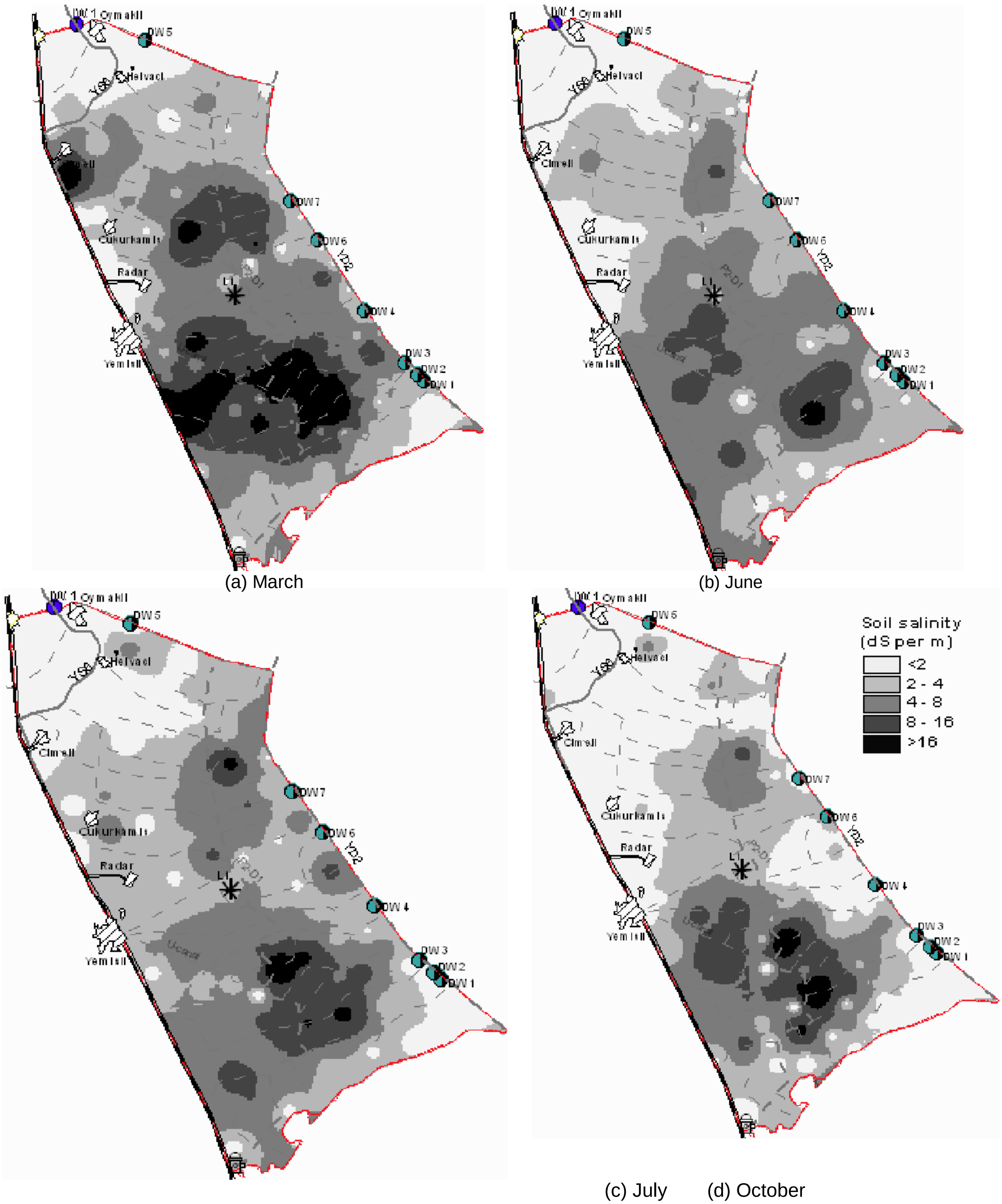

Figure 4. Spatial and temporal distribution of soil salinity of 0-1 m (ECe, dS m^{-1}).

and 1.0 dS m^{-1}, respectively. The salinity with pumping of the drainage water, if needed. The study highlighted factors that influenced groundwater level and salinity (that is, seasonal irrigation, the quality of irrigation water and

Table 4. Areal coverage (%) with different soil salinity (ECe, dS m^{-1}) values.

Time	Depth (m)	Areal mean	Range of soil salinity (ECe, dS m^{-1})			
			< 4	4 - 8	8-16	> 16
			Areal coverage (%)			
March	0 - 1	6.79 ± 6.46	44.1	29.3	18.2	8.3
	0 - 2	7.39 ± 6.07	33.5	32.2	25.1	9.2
June	0 - 1	4.17 ± 2.66	55.9	36.2	7.4	0.4
	0 - 2	5.62 ± 3.76	39.9	36.5	22.2	1.4
July	0 - 1	4.31 ± 3.20	59.7	30.6	8.7	1.1
	0 - 2	6.22 ± 4.79	39.8	32.4	23.4	4.4
October	0 - 1	3.64 ± 3.84	72.1	17.9	8.6	1.4
	0 - 2	5.58 ± 5.32	52.3	25.9	16.9	5.0

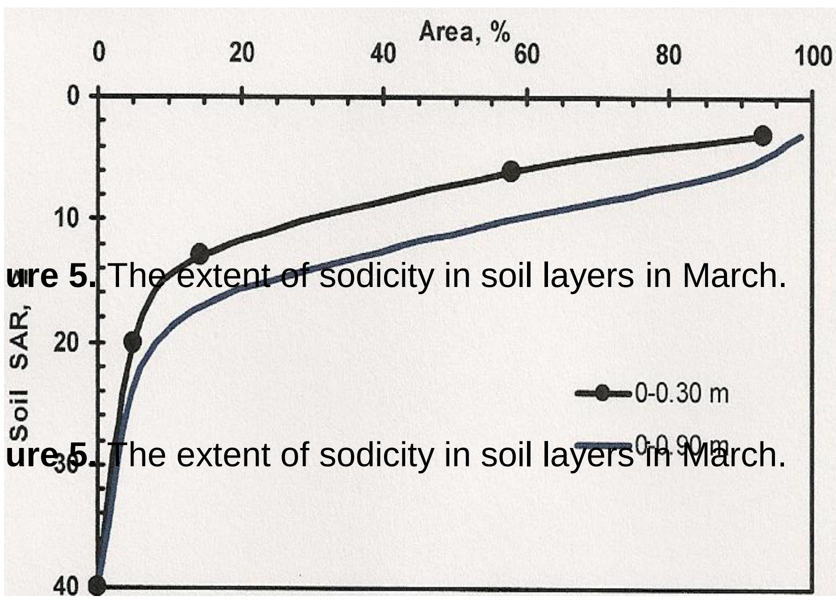

Figure 5. The extent of sodicity in soil layers in March

cropping patterns). Thus, with a likely continuation of intensive irrigation, it is important to continue monitoring groundwater wells, especially where the shallow ground-water depth, moderate and/or high groundwater salinity as well as soil salinity and sodicity are preponderant, to take preventive measures in time.

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