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EVALUATION OF THE GROUNDWATER LEVELS AND SALINITY IN IRRIGABLE AREAS USING GEOGRAPHICAL INFORMATION SYSTEM (GIS)

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Abstract

Efforts on the management of water resources, especially irrigation and drainage, in arid-semiarid areas are extremely important for the sustainability of irrigated agriculture. Groundwater level should be constantly monitored and kept at the desired level in the project which is achieve the expected benefits from investments made for this goal. The research was done in right bank irrigation area which is located in Southeast Turkey, Suruc Plain in 2017. The spatial and temporal fluctuations of the groundwater table depth and groundwater salinity were measured in the course of five-month-periods; from July to October. The results of depth (m) and salinity (µmhos cm^{-1}) of the groundwater observation wells were mapped using geographical information system (GIS). The results showed that groundwater was not found in many observation wells, while groundwater depth reached to a critical threshold level (<1 m) in wells with water from the mid-irrigation period (July) to the end (September and October). The groundwater depths were determined 0.0%, 0.34% for <1 m (risk for field crops cultivation) in July and August during maximum applied water for irrigation and was fluctuated between 68.35% and 96.81% for >2 m (risk free for drainage) from July to October in the study area. The groundwater salinity was found to be less than 2250 µmhos cm^{-1} at the research area. Depending on the research findings, it was noted that there were not any waterlogging, drainage and salinity problems stemming from the rise of groundwater table due to short-term irrigated agriculture in the plain.

Key words: Groundwater monitoring, mapping, groundwater depth, groundwater salinity, irrigation, GIS

INTRODUCTION

The full realization of sustainable agriculture is achieved by ensuring proper water and salt balance in the plant root zone. Otherwise, salts that are one of the main factors limiting agricultural production lead to limitation of water uptake by plants and a proportional increase of sodium ion relative to other cations. Thus, it causes deterioration of physical properties of soil, low hydraulic conductivity and decreasing infiltration rate because of the disintegration of clay colloids. As a consequence, groundwater increases in soil where decreases in permeability capacity and the risk of salinization rise to high level.

Around 50 percent of irrigated cultivation in arid and semi-arid regions (954 million ha) effected different levels of salinity problems. In the Mediterranean basin, salinity in many arid and semi-arid areas threatens irrigated agriculture (Aragues *et al.,* 2011). In Turkey, 4.2 million hectares of land covered with wetness problem. However, every year 1.5 million hectares of irrigable land in the world is worsened by salinization (FAO, 1988; Szabolcs, 1991; Gucdemir and Sonmez, 2008). The total amount of irrigable land is 12.5 million hectares in Turkey, showing that the situation is serious.

The major cause for the rise of groundwater table depth (GWTD) in the area is the intensive use of furrow irrigation system for long periods of time, coupled with poor drainage systems (Dinka and Dilsebo, 2010), in irrigated agricultural areas, low irrigation water quality, lack of appropriate irrigation techniques (Aragues *et al.,* 2011), and excessive irrigation (Cetin and Kirda, 2003). The rise of groundwater more rapidly than expected is caused by (i) poor water management (ii) crop pattern and (iii) land and soil structure as expressed by Bahceci (2008). GWTD is a dynamic variable, both in space and time (Dinka, 2010). Shallow GW levels tend to fluctuate at greater frequency and extent compared to deep ones (Helmuth *et al.,* 1997). GWTD can fluctuate daily, seasonally, annually, and over long periods in response to a variety of conditions (variation of precipitation, climate change, rate of irrigation, and pumping) (Hecker et al., 1998). GWTD rises due to increasing GW storage from different sources, such as infiltration from rainfall, recharge due to stream seepage, canal infiltration, seepage surface flow, etc. (Akther *et al.,* 2009).

In addition, irrigation return flows with irrigated area by surface irrigation systems is often without considering their quality during periods of insufficient water. In such conditions, if the groundwater levels rise to the plant root zone and reach critical values, it is stated that irrigation efficiency drops due to a problem in water management (Cetin and Diker, 2003). According to Qadir and Oster (2004), the new approach in the planning of irrigation and drainage systems involves to development of applications that minimize water use and infiltration and provide a more effective use of water. If these applications are not implemented, many irrigation projects can be affected in a bad way.. In addition, leaching salts can reach underground and surface water resources and contribute to environmental pollution (Douaik *et al.,* 2006).

In the irrigated areas, determination, continuous monitoring and mapping of groundwater depth and quality are essential for proper management of water and soil resources (Kaul *et al.,* 2011; Faoglia *et al.,* 2007). Observing and evaluating GWTD in irrigation areas is important in order to: (i) observe changes of the GWTD due to excess rainfall and irrigation (ii) determine the vulnerable areas or areas that are likely to be so (iii) make proper irrigation planning (iv) take the necessary precautions (Aslan and Gundogdu, 2007). Groundwater level and its salinity can be monitored via 3-4 m deep drainage observation wells in planted or non-planted farmlands (Kaman *et al.,* 2011). State Hydraulic Works (DSI) in Turkey regularly checks the groundwater levels in irrigated areas.

Many studies have been conducted applying various techniques for monitoring groundwater level and salinity in large areas of irrigated lands (Cetin *et al.,* 2010; Karatas *et al.,* 2013; Kaman *et al.,* 2013). These kinds of researches are laborious and expensive to carry out (Karatas *et al.,* 2013). The results about the variability of the data taken from large areas without time loss during collection is quickly and effectively possible to obtain using GIS. In addition, usage of GIS and geoistatic methods can lead to better decision making and helping specify distribution of variable parameters (Wylie *et al.,* 1994; Cetin and Diker, 2003).

In recent years, a highlight on the groundwater's physical and chemical properties has been drawing more and more attentions from scientists. Dash *et al.* (2010) applied geostatistics method and GIS technique to analyze the spatial variability of groundwater depth and quality parameters and found that groundwater depths in 43% were lower than 20 m, salinity levels in 69% of the study area were higher than 2.5 dS m^{-1} in the national capital territory of Delhi. Hu *et al.* (2000, 2009) studied the depth of groundwater, salt, and nitrate contents of Quzhou County in North China Plain and Yinchuan Plain in Northwest of China. They also used kriging method to estimate the unobserved points and indicated that those observed items were in a spatial correlation in a given spatial range. Dinka *et al.* (2013) determined the spatial and temporal variability of groundwater depth in GIS (Arcview 3.3) environment. Observations revealed a serious flood problem. The groundwater (GW) depth is extremely shallow (<1 m below ground) in most of the observation wells throughout the entire season and varied spatio-seasonally. Kaman *et al.* (2016) mapped the results of depth and salinity analysis of the groundwater wells using GIS in Akarsu Irrigation District which is located in Southern Turkey, Lower Seyhan Plain in 2007 hydrologic year. The results showed that groundwater reached to a critical threshold level in February because of heavy rains. It was noted that there were not any drainage problems in May. In July, however, the drainage problem was the worst. On the other hand, average groundwater salinity levels were higher in May (early irrigation season) than July and October. The areas in which groundwater salinity was higher than the critical level (i.e., EC > 5 dS m-1) covered 19.2% of the total area in May, 17.7% in July, and 15.5% in September. Cetin and Ozcan (1999) expressed reasons for high level of GW such as over irrigation, leakage of the channels, lack of farm development and farmer education services, unsufficient drainage network and artesian conditions in the same region. In addition, spread of the areas where groundwater salinity was higher than 5 dS m^{-1} which is considered as the critical EC level, was 18% in beginning of irrigation period and 32% in the end of irrigation in Bafra Plain (Cemek *et al.,* 2006).

The Suruc Plain opened for irrigation by DSI 3 years ago. Irrigation water which comes from the Euphrates River has a very good quality and its salinity is around EC = 0.35 dS m^{-1}. Although it is thought that salinity will not be a problem in soil when irrigation water salinity is considered. It is estimated that the groundwater level will increase under uncontrolled irrigation and drainage conditions. Especially, topography will be able to collect water leaking from high grounds of the land to low in closed basins and cause salinization in the research area. The mentioned problems therefore adversely affected crop yields in the area. For sustainable agricultural production and water management, groundwater depth, groundwater salinity and soil salinity in such project areas need to be constantly monitored and kept within permissible limits. This study aims to monitor the groundwater depth and salinity in observation wells throughout the growing season in research area which is located in GAP region of Southeast Turkey, Suruc Plain. Then, the spatio-temporal changes of data were analyzed, assisted by Geographical Information Systems (GIS) using the Inverse Distance Weight (IDW) interpolation technique.

THE STUDY AREA

The study was conducted at Southeastern Anatolia Region within Suruc Plain, the province of Sanliurfa of Turkey (Fig. 1). The study area is ssituated 497 m above sea level in Suruc Plain, bound by 36 ° 70’-37 ° 25 , N latitudes and 38 ° 10’-38 ° 70’ E longitudes. The plain has a slope of 0.005 in the northwest-southeast direction. The research was carried out in 6440 ha in the area which was opened to irrigation by DSI at Suruc Plain in 2017.

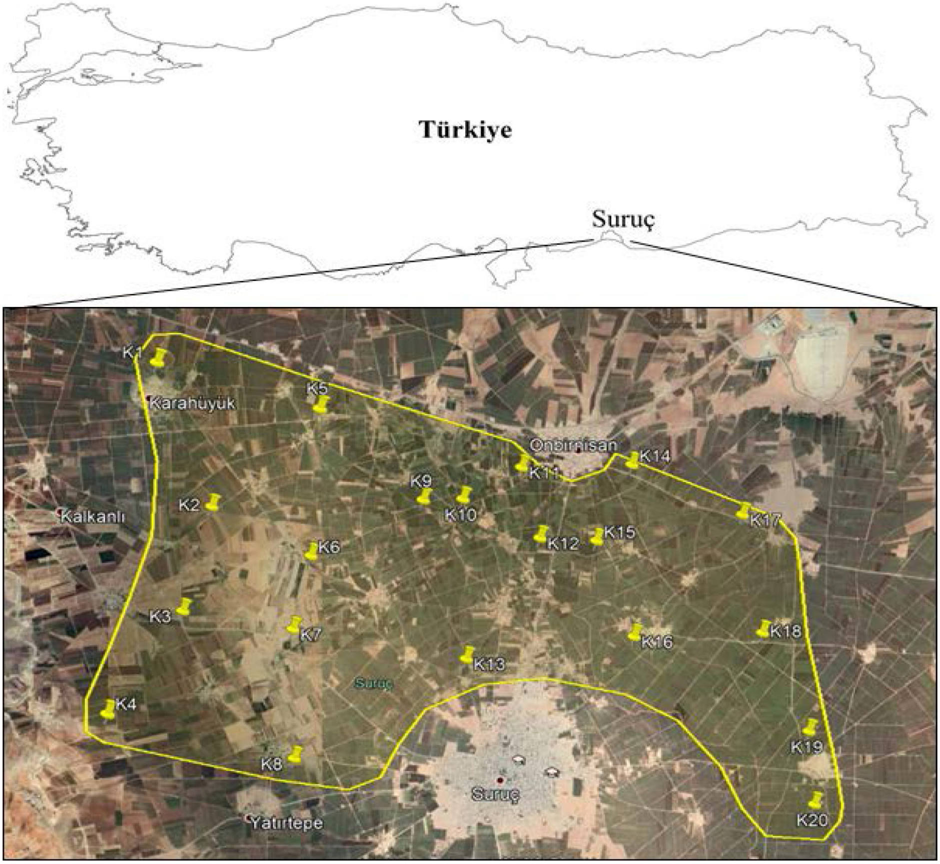

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Figure 1. Geographical location of the study areas in Turkey, spatial distrubition of GW observation wells

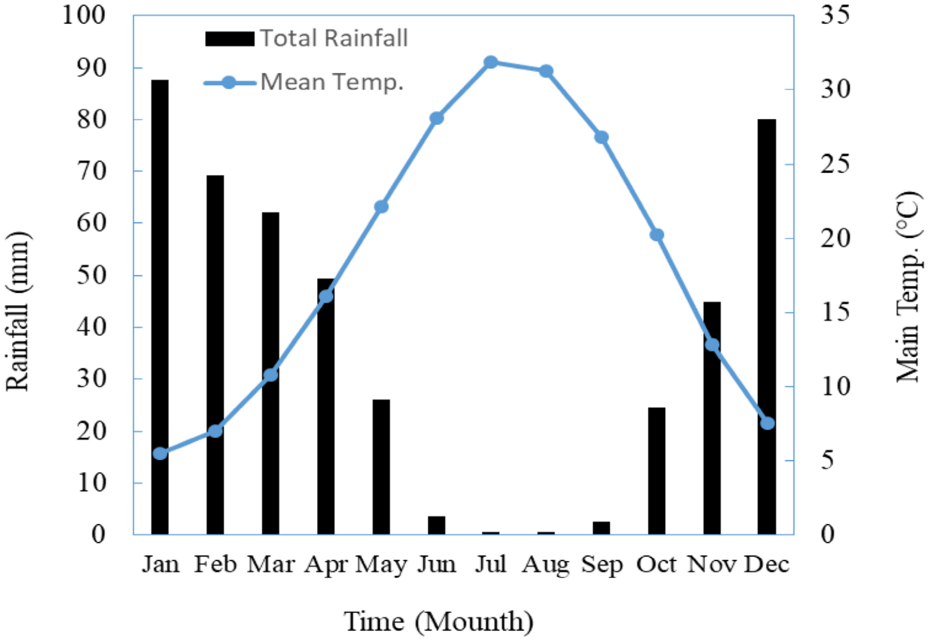
Soil samples were taken for some physical and chemical analyzes as 30 cm layers from close to observation wells in the research area. When the results of the analysis were examined, it was found that the clay content ranged from 37% to 73%, silt, 15%-34% and sand, 8%-38%. While clay content increases towards the lower layers, silt content decreases. As understood from the results of the analysis, clay contents of the soils in region are quite high. Soils with a high clay content are considered heavy soils. Heavy soils are generally defined as having a high water holding capacity and low water permeability. The chemical properties of soil such as lime and organic matter were determined average 30.45-32.07% and 0.95-1.58%, respectively.

Two different sand-gravel aquifers identified from the hydrogeological studies, which are generally separate from each other by an impermeable clay layer, except for the basalt aquifer. This clay layer has a thickness of 60-80 m and spreads along the whole plain as in the first Aquifer layer. Likewise, this aquifer layer spreads along the entire plain. The second aquifer layer consists mainly of sand-gravel material which contains more fine graine silt and clay. In this unit, the porosity is not well developed because of the consolidation due to the material that is approximately 150-180 m thick. Hydrological parameters were found to be significantly smaller. Generally, the wells drilled in this aquifer yielded 0.3-5.0 L s^{-1}, yield and 0.02-0.2 L s^{-1} m^{-1}, a specific yield. Hydraulic conductivity and transmissivity values are very low (Kirmizitas, 2003).

Suruç district has a surface area of 66,043 hectares; approximately 80% of this area is used as agricultural area. Even though cultivation of field crops are maked intensively in the district, fruits and vegetables are also produced. When the products declared by Suruç Food, Agriculture and Livestock District Directorate in 2017 are examined, it is stated that cotton and corn cultivation increase in each year (19.1%) in irrigated regions. Winter wheat, barley and lentil cultivation (32.4%) countinue to be used intensively in the regions that have not yet been opened for irrigation.

Suruc Plain is under the influence of continental climate characteristics of Southeastern Anatolia Region. Summer season is hot and dry and winter is cold and less rainy. The most important characteristic of the continental climate is a big difference between the average temperatures of the warmest and coldest months. The differences of temperature mostly affect agriculture (Anonymous, 2000). According to the long-term weather data, the mean annual temperature of the area is 18.3°C, the average maximum and minimum temperatures are 24.4°C and 12.6°C, respectively. In research area, the average annual temperature for the 2017 study period was 18.5°C, average maximum and minimum temperatures were measured in July with 40.7°C and in January with 2.8°C, respectively. While avarage annual rainfall value is abouth 451.3 mm in the region for long term, a total of rainfall with 363.8 mm has taken below normal in the 2017 working period. Under these climatic conditions, irrigation equipment for crop production is required in summer in the region, and even in winter sowing in some periods (Fig. 2).

According to the GAP-Suruc Project Planning Report prepared by DSI in 2000, the Suruc Plain Pumped Irrigation System pumped water from the Atatürk Dam Lake and was planned to be irrigated 10391 ha area with the California System, 84423 ha area with sprinkler irrigation system. All main channels are controlled with downstream and total main channel length is 340 km. Two main pumping stations (Stage 1, P1 and Stage 2, P2), four sub pump stations (P3, P4, P5, P6), three sprinkler irrigation (YP1, YP2, YP3) for 9 pump stations.



Source: Author’s own elaboratrion

Figure 2. Total precipitation and mean temperature of research area in long-term

MATERIAL AND METHODS

Piezometer installation and monitoring

GWTD monitoring was carried out using piezometer tubes. A total of 20 new PVC tubes (ϕ=50 mm and length=2 to 3 m) were re-installed in June 2017 in order to characterize the seasonal behaviour and spatial variability of GWTD of the study area. The piezometers are all PVC tubes and fairly distributed in the area. The PVC tubes were installed manually using auger tubes.

The research was carried out through five-month-period: July, August, September, October and November. During this period, the groundwater depths in the observation wells were measured monthly and the salinity values of the water samples were measured with electrical conductivity (EC) measurements.

Water levels were monitored using a graded contact gauge that provides sound and light signals when it touches water in the tube. Care was taken to collect the GW levels in all tubes within a minimum possible time. New observation wells that were broken or deteriorated due to agricultural operations were replaced with new ones throughout the year. The positions of twenty observation wells were determined in the field which were representative and reliable. Field data in “Magellan Explorist 600” (Thales, 2005) device was evaulated and the UTM coordinates of observation wells in the research area were found via GPS taking Datum=ED50 as a base.

Data analysis and mapping

The obtained data were analyzed in an excel spreadsheet. The spatio-seasonal maps of GWTD were produced in ArcGIS (Ver. 10.3) using the Inverse Distance Weight (IDW) interpolation technique and groundwater depth and salinity maps were obtained for the months in the study period. The areal extent data were evaluated by using generated maps. Explanations were made about the problems and information related to the groundwater height of the research area in study period (July, August, September, October and November).

RESULTS AND DISCUSSION

Piezometers placed in different parts of the cultivation areas were monitored and recorded monthly in average for groundwater increases during the study period (Fig. 3). Groundwater was found in seven of the observation wells but was not detected in others. The average groundwater depths in these observation wells varied between 0.86 m in September and 2.12 m in July. During September and October at the end of the irrigation season and in the mid-irrigation period, W5, W6, W10, W11 and W12 piezometers have very shallow GWDT (<1.0 m) below the ground but its values below 1.5 m at the beginning of irrigation (July). In the irrigation season, groundwater depth for field crops and fruit trees is required to be less than 1.0-1.2 m and 1.2-1.6 m, respectively. To reduce the risk of salinity in autumn, groundwater level should be kept below 1.4 m on sandy and clay soils and 1.70 m on silty soils (Van Hoorn and Van Alphen, 1994). GWTD below the critical level (1.5 m) recommended for especially industrial crops (Kahlown *et al.,* 2005). In general, the groundwater level of the research area is very deep but varies seasonally and positively in other parts. Over irrigation, surface flow conditions, weakness of natural drainage conditions and very flat topography conditions influenced these variables.

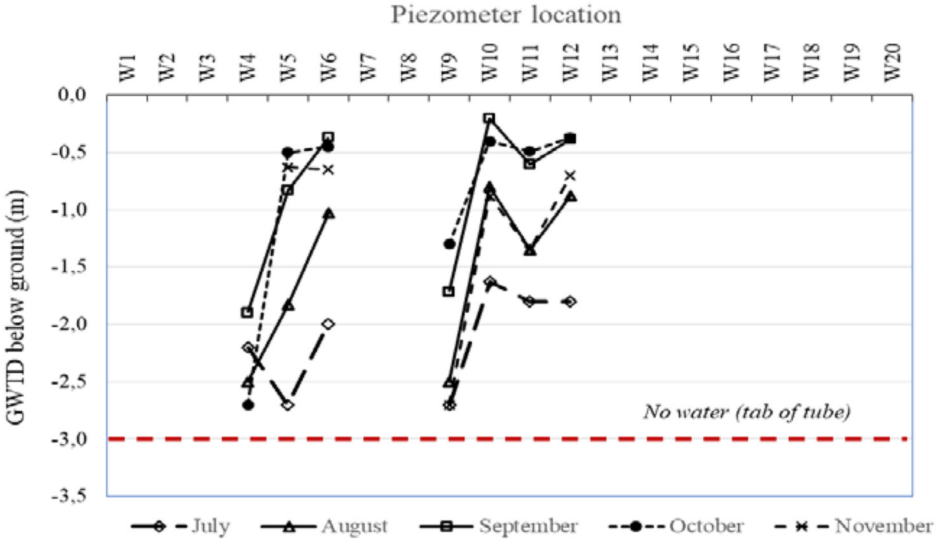


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Figure 3. Seasonal and spatial variation of GWTD for all piezometers (2017)

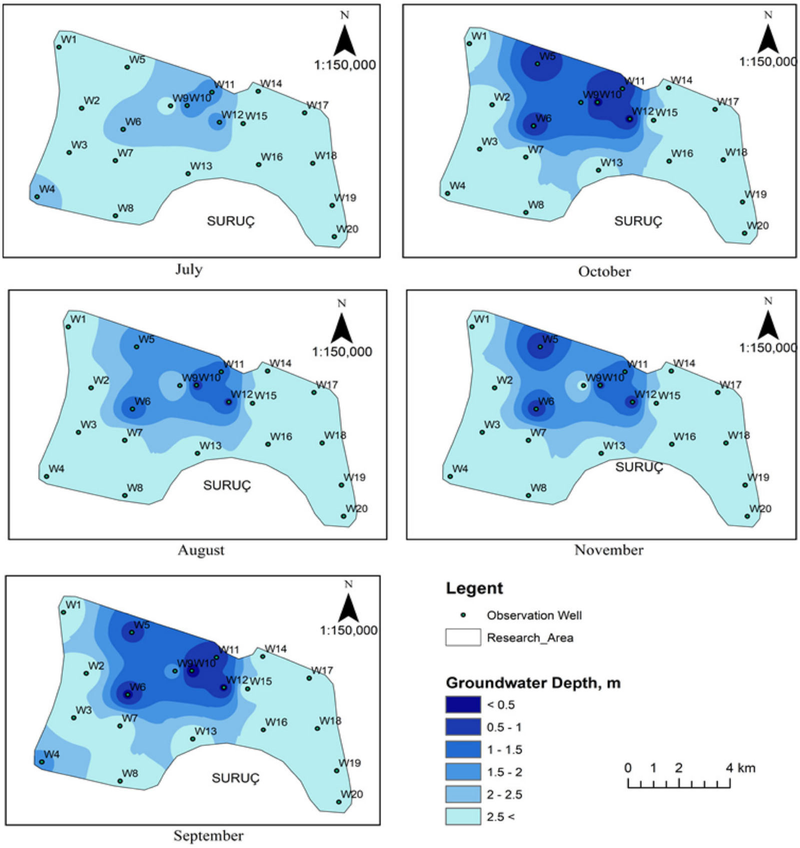
Change in groundwater depht

Groundwater depth maps show the spational distribution of the groundwater depth from the soil surface. Groundwater depths and salinity were analyized during irrigation period and mapped with GIS. According to the groundwater samples taken from all observation wells, closest level to soil surface was measured as 0.20 m in W10 (Fig. 3) and the average depth was found 0.89 ±0.4 m in September. The groundwater depth (<1 m) was not measured before the irrigation season, but covered 6.7% and 9.5% of the research area in September and October. Areas with drainage problems (<1.5 m) were calculated as 5.5% in August, 22.6% in September and 23.99% in October. The percentage of areas with no risk of drainage problems (2.0 m <) due to the depth of groundwater in the study area varied between 96.81% in July and 68.35% in September during the season. This trend has slowly increased from September to October (68.73%) and November (74.04%), which can be explained by rainfall. The research findings, irrigation losses during summer and leaks caused by the change of the stream bed and no drainage system increased the groundwater. Similar results were supported by other studies (Cetin *et al.,* 2007; Kamanve *et al.,* 2016).

Table 1. Areal coverage with different groundwater depths.

GWTD, m	July		August		September		October		November	
	Area									
	ha	%	ha	%	ha	%	ha	%	ha	%
< 0.5	-	-	-	-	42	0.66	24	0.38	-	-
0.5-1.0	-	-	22	0.34	427	6.67	606	9.48	161	2.52
1.0-1.5	-	-	329	5.15	977	15.27	904	14.14	557	8.70
1.5-2.0	204	3.19	1039	16.25	579	9.05	465	7.27	943	14.74
2.0-2.5	1243	19.43	950	14.86	1130	17.66	844	13.20	828	12.94
2.5 <	4949	77.38	4056	63.41	3242	50.69	3552	55.53	3908	61.10

Source: Author's own elaboratrion



July

October

August

November

September

Source: Author's own elaboratrion

Figure 4. Spatial and temporal distribution of GW depth

The extent and severity of the areas having drainage problems can be seen in Figure 2, as well. At the beginning of the irrigation season, GWTD is shallower than 1.5 m. (W8,10,11,12 in July), in the north of the study area. Then, the trend is increased and spread towards August, September and October (Fig. 4.). While the above mentioned observation wells increased, the spread was towards northwest which is located W6 and W5 wells that is thought to be due to excessive irrigation and topographic conditions. However, this decline in November was connected to the lack of plant water consumption and precipitation. Generally, the groundwater depth levels that were quite shallow in all areas at the beginning of the season, remained at the same level in the east, south and southwest parts at the end of the irrigation season.

Groundwater salinity

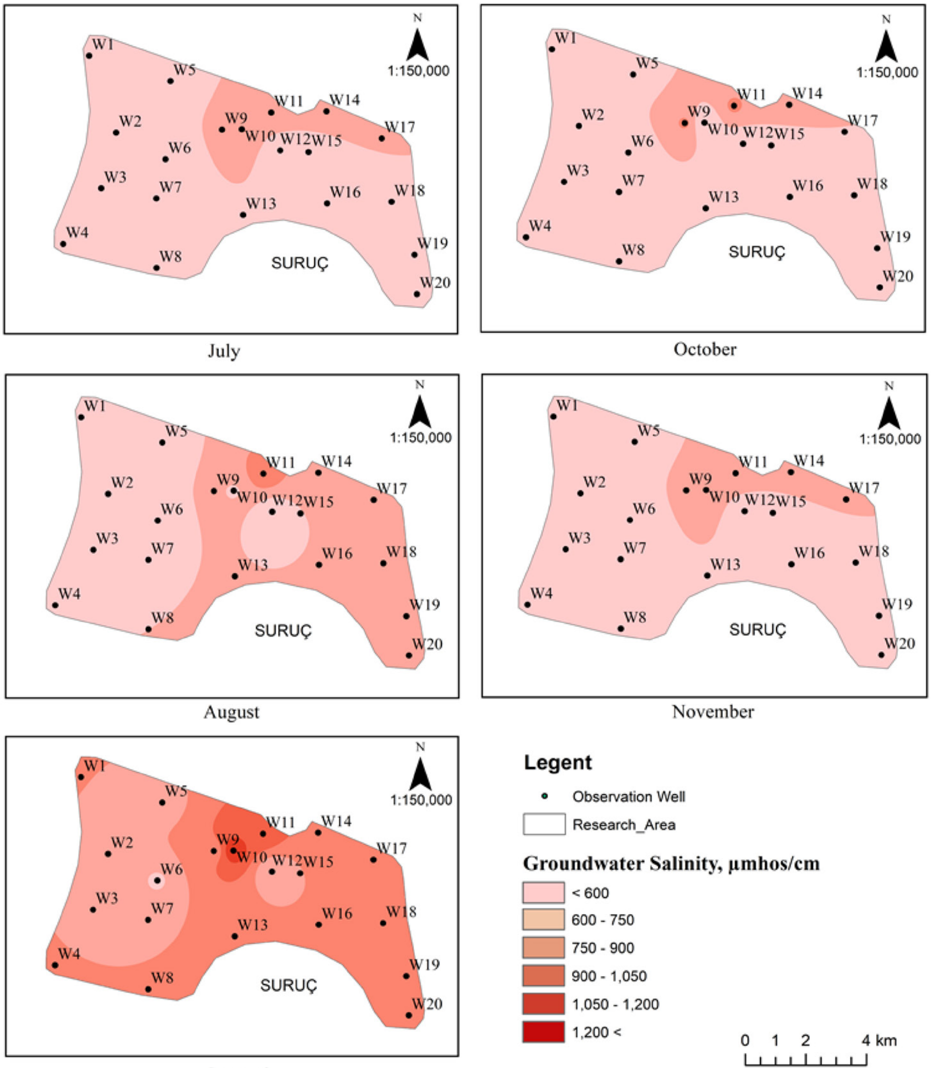
The average groundwater salinity increased from the beginning of the irrigation period (652 μmhos cm^{-1} in July) to the end (810 μmhos cm^{-1} in September). Groundwater salinity decreased due to excessive irrigation and surface runoff leaks. When the spatial and temporal changes were examined, groundwater salinity values showed the highest distribution in the end of irrigation period, similarly. Groundwater salinity values mostly decreased because of leaching towards the end of the irrigation season in November-October (Fig. 4). Spread of the areas, where groundwater salinity was higher than 5 dS m^{-1} (5000 μmhos cm^{-1}) which is considered as the critical EC level for drainage engineering work (Cetin and Ozcan, 1999; Cetin and Kirda, 2003).

The results showed that no significant problems were observed in terms of groundwater salinity, but it was found between 250 and 2250 μmhos cm^{-1} in the research area. In addition, 250-750 μmhos cm^{-1} covered 97.14% in July and 98.14% in August and decreased to 37.33% in September. It started to rise in October and November (Table 2.).

Table 2. Areal covarage with different GW salinity

Salinity, μmhos cm^{-1}	**July**		**August**		**September**		**October**		**November**	
	Area									
	ha	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
< 250	-	-	-	-	-	-	-	-	-	-
250 – 750	6213	97.1	6298	98.5	2388	37.3	6369	99.6	6396	100.0
750 – 2250	183	2.9	98	1.5	4008	62.7	27	0.4	-	-
2250 <	-	-	-	-	-	-	-	-	-	-

Source: Author's own elaboratrion



July

October

August

November

September

Source: Author's own elaboratrion

Figure 5. Spatial and temporal distrubition of GW salinity

The grounwater salinity level of 750-2250 µmhos cm^{-1} was 62.67% in September at the end of the irrigation period. In the Mediterranean basin, salinity in many arid and semi-arid areas thereatens irrigated farming (Aragues *et al.*, 2011). A similar situation may be encountered for the research area that place Southeast Anatolia in Turkey have arid-semi arid climate zone in the future.

Salinity in the irrigated areas may be the results of poor irrigation management and use of surface irrigation methods of low efficiency and salinity of irrigation water. Consequenly, alkalinity and salinity problems may occur after many years with no drainage system in the region (FAO, 2001).

CONCLUSION AND RECOMMENDATIONS

As a result of this study, during the irrigation season most of the observation wells (except seven point) did not find GW in the research area. GWTD was not at the critical depth of (<1 m) at the beginning of the irrigation season, but it came up in August when irrigation was at its peak. After that it exceeded this depth and covered the research area of 7.33% in September and 9.85% in October at the end of irrigation period. There is no significant problem (>5000 µmhos cm^{-1} or 5 dS m^{-1}) in terms of groundwater salinity values. Seasonal groundwater depth changes of observation wells may vary in summer and spring depend on topography. In these evaluations, plant water uptake, river leaks, increased ET and GW recharge, technical problems of the pumping infrastructure and artesian pressure is taken into consideration.

In recent years, a highligth on sources of GW recharge or rise of GWTD such as rainfall, runoff, flooding, irrigation return flows from fields, recharge from villages, seepage/leakage from night storage reservoirs and canals, inter-aquifer flows and climate change are drawing more and more attention from scientists. Therefore, detailed investigations that include the entire possible causes of GW rise are highly recommended. Long-term over irrigation has a cumulative effect on the rise of the water table and can cause waterlogging in the effective root zone with saturated water conditions and associated problems. Thus, efforts on the management of water resources, especially irrigation and drainage, in such areas are extremely important for the sustainability of irrigated agriculture.

The areas where the groundwater is closer than 2 m to ground link with capillary rise may occur in the upper soil layers and lead to salinization between irrigation periods or during periods of low rainfall should be examined in temporal and spatial changes in GIS environments. It is necessary to increase the number of observation wells especially in rural areas for developing. As a result, there is no problem for GW depth and sality levels in the research area because of the area’s recent opening of irrigation. However, it is understood that the groundwater heights increase in some local areas and the problem is specific to that site. Problems may arise in case of poor water management withouth modern irrigation methods and dreinage systems in the plain for future.

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