## Impact of the Irrigation Water Use on the Groundwater Environment and the Soil Salinity

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### 1. Introduction

Aside from the positive impact of irrigation on increasing crop production, in the downstream part of a river basin, irrigation can cause salinity to build up with the increasing depth of the groundwater. The visible influence of the groundwater environment on soil resulting from irrigation can only be observed at the advanced stages of salinity buildup, when expensive measures must be implemented. Irrigation also can cause upstream and downstream problems, such as water shortages downstream, drainage problems, and the drainage of contaminants. Thus, in order to prevent soil salinization, it is very important to assess the impact of irrigation on the groundwater environment in arid and semiarid regions.

This study was conducted in a large irrigation district that covers over 130,000 ha, in which soil salinization has occurred downstream. First, we studied the impact of irrigation water use on the groundwater environment. Then, we determined the effect of irrigation water use on soil salinization downstream. The specific objectives of this study were to determine the effects of irrigation water use on the fluctuations in groundwater depth and salinity, and then to assess the impact of the groundwater environment affected by irrigation on soil salinization.

### 2. Outline of the study area

This study is based on conducting field measurements in the delta of the Lower Seyhan Irrigation Project (LSIP) area located in the Seyhan basin, Turkey (Fig.1).

The highest elevation in the LSIP is about 30 m above sea level. The topography is flat and the altitude falls from Adana to the Mediterranean with dominant clayey Vertisols (Dinç et al., 1991).

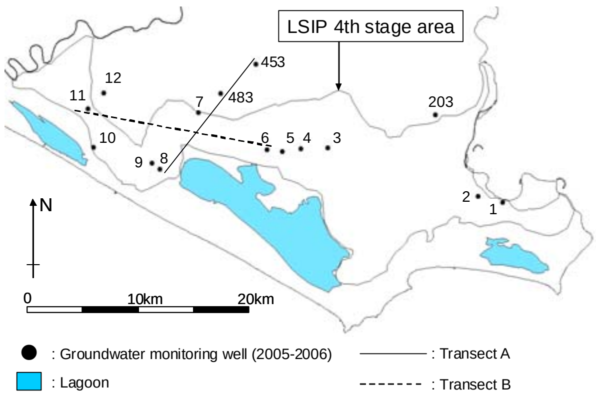


**Fig.1.** Status of area 4 of the LSIP

**Table 1** Data used in this study

| Year and area | Sample size | Measurement interval | Groundwater depth | Groundwater EC | Soil Salinity (ECe) |
|---|---|---|---|---|---|
| 1977 (area 4) | 156 | August only | | ○ | |
| 1993-1994 (areas1-3) | 572 | Monthly | ○ | ○ | |
| 2003-2004 (areas1-3) | 572 | Monthly | ○ | ○ | |
| 2005-2006 (area 4) | 15 (50*) | Monthly | ○ | ○ | ○ (2005 July) |

Symbol * shows a sample size of soil salinity (ECe) of July 2005

The construction of irrigation facilities started in the 1960s, and the district can be divided into four areas based on different stages of development. The installation of irrigation and drainage facilities in the first three areas has been completed, while the installation of the facilities in area 4 has just begun. Unlike the new developments in area 4, irrigation water leakage has increased with deterioration of the older irrigation facilities built in areas 1-3.

## 3. Materials and methods

First, we assessed the impact of irrigation water use and precipitation on the groundwater environment and then examined the effect of the groundwater environment on soil salinization. The irrigation and precipitation data were obtained from the State Hydraulic Works and General Directorate of Meteorology, respectively (Table 1). The soil salinity data, the electrical conductivity of saturated paste extracts (ECe), was measured in laboratory of Çukurova University.

Groundwater data for 2005-2006 were measured at 15 observation wells, including four wells located in area 3 (i.e., the area developed in stage 3), as shown in Fig.1. The groundwater observation wells for areas 1-3 covered the entire area.

To assess the impact of the groundwater environment affected by irrigation water on soil salinization, LANDSAT TM data for July 2005 was used to identify salt-affected fields. Salt-affected fields were identified and classified by established method (Kume et al., 2007) using the field measurement data and the soil map (Dinç et al., 1991).

## 4. Results and Discussion

### 4.1 Fluctuation of groundwater depth

The effect of irrigation water use on groundwater depth was analyzed for all four areas. Two peaks occurred in the fluctuations of the groundwater depths in areas 1-3 during 1993-1994 and 2003-2004 (Figs.2 and 3). The increase began in May and remained high until August with irrigation, and decreased from September to October in the absence of irrigation.

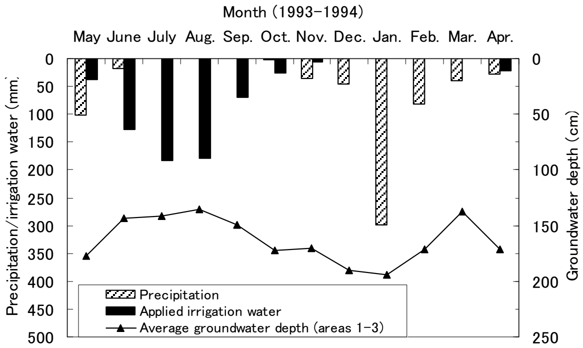


**Fig.2.** Fluctuation in the groundwater depth for areas 1-3 during 1993-1994

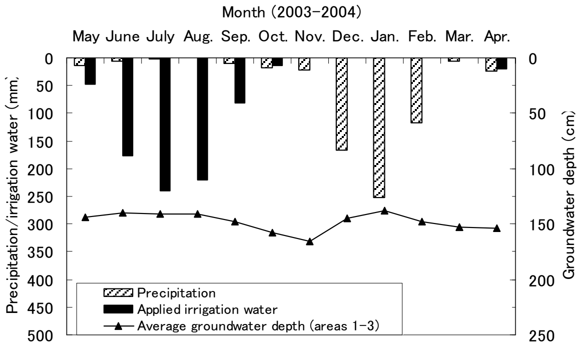


**Fig.3.** Fluctuation in the groundwater depth for areas 1-3 during 2003-2004

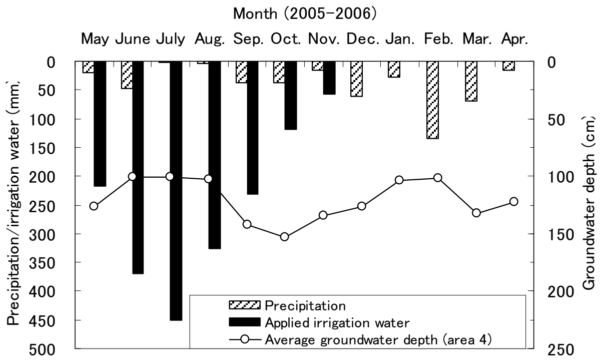


**Fig.4.** Fluctuation in the groundwater depth for area 4 during 2005-2006

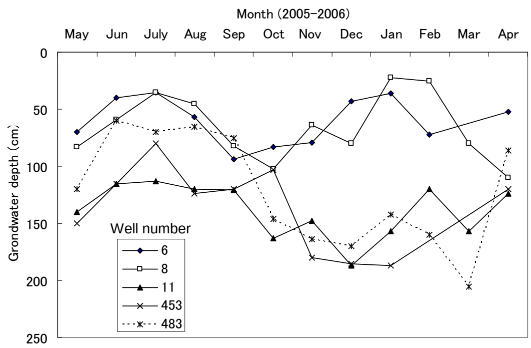


**Fig.5.** Fluctuation in the groundwater depth along transects A and B

**Table 2** Descriptive statistics of groundwater EC

| | Sample size | Average EC ($dS\ m^{-1}$) | Standard deviation ($dS\ m^{-1}$) | Maximum EC ($dS\ m^{-1}$) | Minimum EC ($dS\ m^{-1}$) |
|---|---|---|---|---|---|
| 1977 (area 4) | 156 | 46.8 | 40.6 | 276.0 | 1.2 |
| 1993-1994 (areas 1-3) | 574 | 1.3 | 2.1 | 24.0 | 0.2 |
| 2003-2004 (areas 1-3) | 574 | 0.8 | 0.8 | 12.0 | 0.1 |
| 2005-2006 (area 4) | 15 | 12.4 | 19.6 | 78.6 | 0.5 |

An increase in the groundwater depth with precipitation occurred from November to March. Nevertheless, even with approximately 300 mm of precipitation, the groundwater depth decreased in January (1993-1994) for unknown reasons.

From these results, we found two peaks in the groundwater depth, which increased from May to August with irrigation, decreased from September to October, and increased from November to April with precipitation. The pattern of the fluctuation in the groundwater depth did not change with the elevation at different locations (data not shown). The average groundwater depth for 2003-2004 was shallower than for 1993-1994, which was likely attributed to the higher irrigation water use and increased leakage from decrepit irrigation facilities.

The same analysis conducted in area 4 during 2005-2006 revealed a similar fluctuation and pattern of groundwater depth as seen in areas 1-3. The two peaks resulted from the increase in irrigation water and precipitation (Fig.4). The average groundwater depth shown in Fig.4 includes data from wells 12, 203, 453, and 483 in area 3 representing irrigated and nonirrigated fields. In order to assess the effect of location and irrigation status on the fluctuation in the groundwater depth, we evaluated wells along two transects (A and B) shown in Fig.1, and plotted the fluctuation in groundwater depth individually (Fig.5).

Observation wells 6 and 8 were located in nonirrigated fields and wells 11, 453, and 483 were in irrigated fields. These results show clear groundwater fluctuation with the same two peaks seen in areas 1-3. Observation wells 6 and 8 were located in the lowest part of the district, and the groundwater depth remained quite shallow throughout the observation period.

## 4.2 Changes in groundwater salinity

The groundwater electrical conductivity (EC) in areas 1-3 dropped between 1993-1994 and 2003-2004, and in area 4 it dropped between 1977 and 2005-2006 (Table 2), most probably due to the development of drainage facilities and use of excess irrigation water. The standard deviation of the EC in area 4 during 2005-2006 was high. The large variation can be attributed to the construction of the main drainage canal, which is in the boundary between areas 3 and 4.

The groundwater flow and EC follows the slightly sloping terrain, with decreasing elevation from Adana to the Mediterranean coast along the LSIP area (Donma et al., 2004) (Fig.6). This result was likely due to the ease of access to irrigation water, the ease of drainage, and the convection of salt from upstream to downstream.

The scatterplots of the groundwater EC values for 15 observation wells from 1977 to 2005-2006 produced a linear relationship with $R^2$=0.61, as shown in Fig.7, in which the EC values for 1977 were estimated using the Kriging method (Delhomme, 1978) due to the lack of observation wells. The groundwater EC decreased in area 4, and was influenced by the distance from the drainage canal and type of land use, matching the high standard deviation of the groundwater EC for 2005-2006 (Table 2).

The Na+ and sodium adsorption ratio (SAR) showed a positive relationship with the groundwater EC (Figs.8 and 9), and were plotted on almost the same regression line in both 1977 and 2005-2006. High EC values, over 4.0 $dS\ m^{-1}$, were still observed at some spots in 2005-2006 in area 4 with an average SAR of 17.6 (a SAR of 13.0 equals an exchangeable sodium percentage (ESP) of 15.0) (Tanji, 1990; Ghassemi et al., 1995). The value for sodium-rich soil is over 15.0. Therefore, sodium most probably tends to accumulate on soil particles in the soils of area 4 due to the high SAR levels.

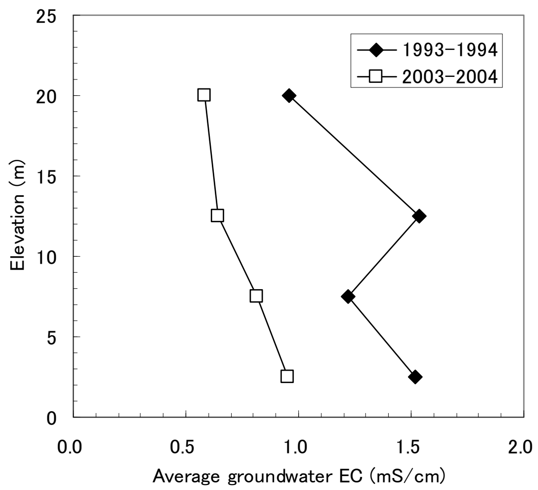


**Fig.6.** Groundwater EC classified according to the elevation of the monitoring wells

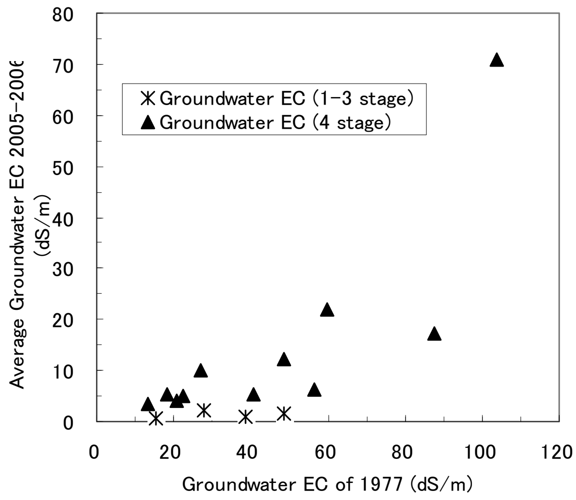


**Fig.7.** Relationship between groundwater EC in 1977 and 2005-2006

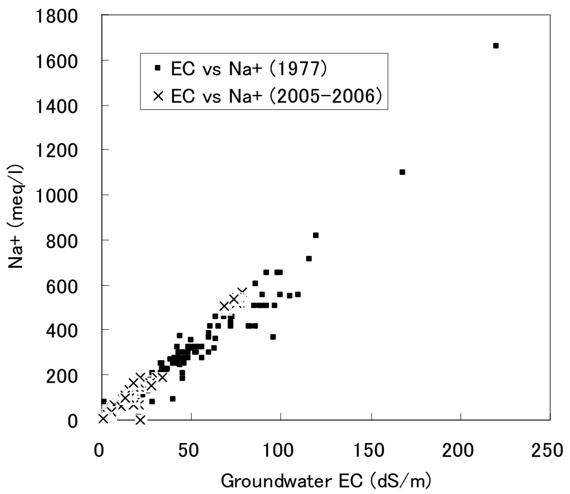


**Fig.8.** Relationship between groundwater EC and $Na^+$ for 1977 and 2005-2006

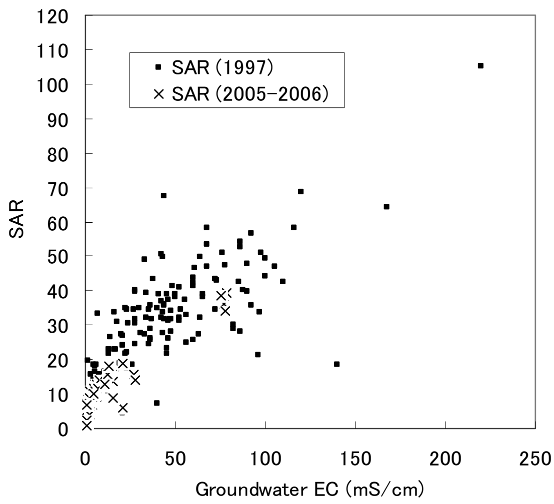


**Fig.9.** Relationship between groundwater EC and SAR for 1977 and 2005-2006

### 4.3 Spatial distribution of soil and groundwater salinity in area 4

Soil salinization occurs in area 4 due to the high groundwater depth and its high EC. Distribution map of the groundwater EC in area 4 in1977 was estimated by Kriging technique (Fig.10). The groundwater EC showed a linear relationship, that is, a similar pattern, from 1977 to 2005-2006 (Fig.7). Therefore, the distribution pattern of groundwater EC in 2005–2006 was similar to that in 1977.

Many plant species have been affected by ECe values above the threshold limit of 4.0 mS/m (US salinity laboratory staff, 1954), and ECe values above 7.7 dS $m^{-1}$ is a threshold limit of cotton. Therefore, we classified salt affected fields in three classes, ECe<4.0 dS $m^{-1}$, 4.0 dS $m^{-1}$<ECe<7.7 dS $m^{-1}$, and 7.7 dS $m^{-1}$<ECe. The percentages of three salinity class in area 4 were 44%, 21%, and 35%, respectively. This result revealed that high soil salinity fields, more than 7.7 dS $m^{-1}$, still exist in area 4 (Fig.11), most probably due to the development of irrigation and drainage facilities.

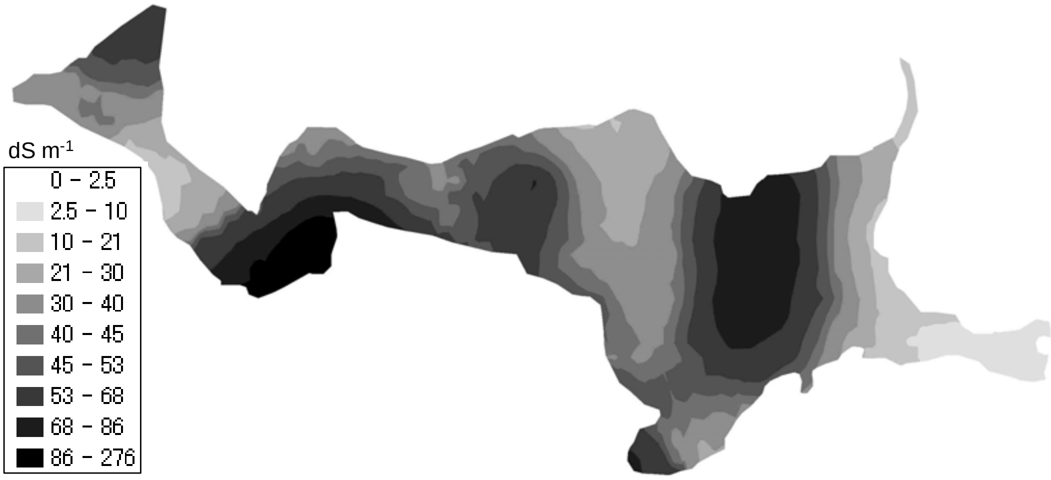


**Fig.10.** Distribution of the groundwater EC in area 4 in 1977

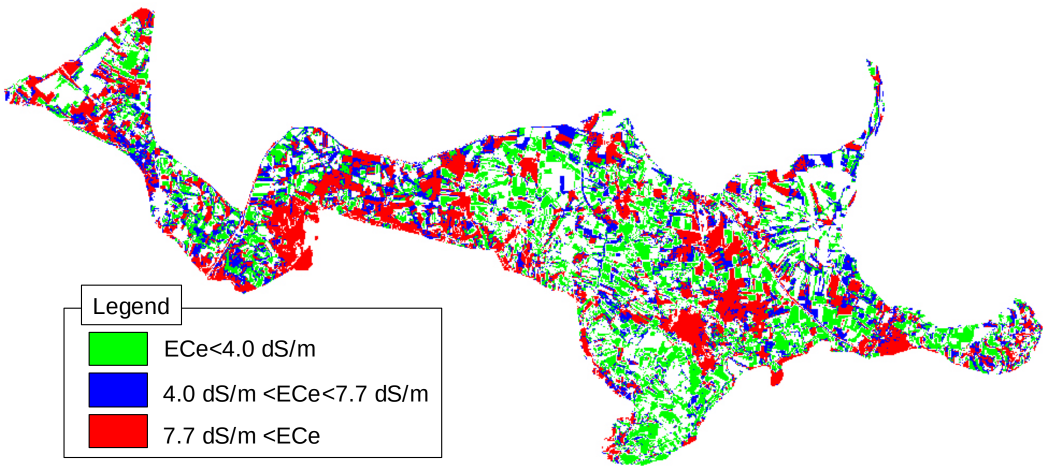


**Fig.11.** Estimated ECe in July 2005

Finally, we examined relationship between ECe of July 2005 and groundwater EC of 1977. The ECe data used here was measured at 50 point in area 4 in July 2005. The groundwater EC values, which agree with ECe of 50 points, were estimated by interpolated data using Kriging technique as shown in Fig.10. The scatter plots showed linear relationship between them (Fig.12). A comparison of the distributions also showed that salt-affected fields corresponded to high groundwater EC areas (compare Figs. 10 and 11).

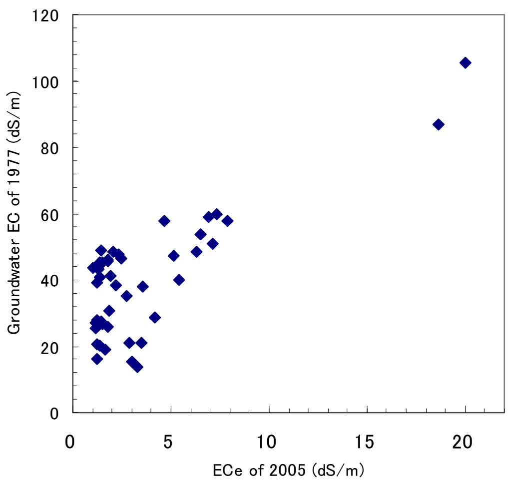


**Fig.12.** Relationship between ECe of 2005 and groundwater EC of 19777

## 5. Conclusion

First, we studied the impact of irrigation water use on groundwater fluctuation and second, analyzed the changes in groundwater EC and its quality. Third, we examined the impact of irrigation water use on soil salinization induced by the groundwater environment, which was affected by irrigation.

The fluctuations in the groundwater depths in all four areas had two peaks, one in the irrigation season and one in the rainy winter, irrespective of land use. The groundwater depth in 2003-2004 was higher than in 1993-1994 owing to decrepit irrigation facilities and excess irrigation water use. The groundwater EC decreased with time in areas 1-4. However, the standard deviation of the groundwater EC in area 4 was large because of the status of irrigation and location.

Salt-affected fields of 2005 corresponded to the area of high groundwater EC of 1977 in area 4. Although the salt-affected field of whole LSIP was reduced by excess use of irrigation water and drainage facilities, 35% of stage 4 is still affected by high salinity. Based on the EC, Na+, and SAR of the groundwater environment, we postulated that sodium accumulates on soil particles in the salt-affected fields.

Our study showed that irrigation water use upstream in the LSIP affects the fluctuation of groundwater depth downstream in the LSIP, which is area 4. Excess irrigation water use upstream reduces the groundwater depth downstream. Some fields in area 4 are below sea level and those areas were waterlogged, with insufficient drainage facilities. Therefore, irrigation water use in areas 1-3 in summer causes deterioration in the groundwater environment in area 4, and promotes soil salinization.

## 6. References


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