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TEMPORAL AND SPATIAL VARIATIONS OF GROUNDWATER LEVEL AND SALINITY: A CASE STUDY IN THE IRRIGATED AREA OF MENEMEN PLAIN IN WESTERN TURKEY

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Abstract

The aim of the study was to determine the temporal and spatial variations in the level and salinity of groundwater. In 2011 and 2012, in the rainy season, before the irrigation season, during the irrigation season and after the irrigation season the depth of groundwater was measured and at the same time groundwater samples were taken from each well. According to the results obtained, groundwater salinity was high in the years of the study, and its level was high in the rainy period and the irrigation period, but low before irrigation and after the irrigation period.

Keywords

ground water level, ground water salinity, spatial, temporal, Gediz

1. Introduction

It is a prerequisite of sustainable irrigated agriculture that irrigation should be done in such a way as to be effective and productive without damaging the environment. The most important role in meeting the world's need for food is played by areas of irrigated agriculture. It is a prerequisite of sustainable irrigated agriculture that it should be done in such a way as to be effective and productive without damaging the environment. Agricultural irrigation, especially when it is done with unsuitable techniques and in unsuitable amounts, can cause problems of salinity and alkalinity related to rising groundwater levels, especially in areas with topographic insufficiencies. Saline groundwater causes a reduction in the uptake of water from the soil by roots because of an increase of osmotic pressure in soil solutes, giving rise to a decrease in crop yield and quality. Soil productivity is affected by soil physical properties that play a crucial role in planning drainage systems. Improper planning of drainage systems can create high water table problems, and in turn, an unsuitable environment for plant growth. Therefore, drainage systems should be well planned and monitored regularly. It is labor-intensive and time-consuming to determine the spatial and temporal changes in drainage parameters such as ground water level, elevation, hydraulic gradient and salinity by conventional methods over large areas. Geographical information systems (GIS) and geostatistical analysis can be used to assess the spatial and temporal changes efficiently and rapidly [1].

Uninformed and uncontrolled irrigation in the Menemen Plain area, low efficiency of field irrigation practices and leaking from the canal network have caused the groundwater level to rise. In July, the month of the most intense irrigation, groundwater levels in the left bank irrigation area of the Menemen Plain do not fall below 101-150 cm in the 80.4% of the area close to the sea, and in 1.7% they do not fall below 51-100 cm [2]. Before management of the system was handed over to the irrigation association, average groundwater depths were approximately 186 cm and salinity was 2.65 dSm^{-1}, while after the handover, these figures were 148 cm and 3.14 dSm-1 [3]. The aim of this study is to determine temporal and spatial variation in the level and salinity of groundwater in the part of the Izmir-Menemen Plain left bank irrigation area which is close to the Aegean Sea with the use of the Geographical Information System and geostatistical methods.

2. Material and method

The Menemen Irrigation System is situated in the Gediz River basin in the west of Turkey, between 38º26'-38º40' north and 26º40'-27º07' east. The basin's alluvial base is divided into two by a narrowing at Emiralem, to the west of the city of Manisa. The part between this point and the sea is the Menemen plain. It lies at 10.3 m above sea level. At the site of the study, the soil has a fine loam texture, and is insufficiently to poorly drained and salty-alkaline, over the Gediz alluvial base. Cotton and grain are grown on most of the land [4]. The Menemen plain has a Mediterranean climate, with hot dry summers and cool wet winters. According to data collected over many years, total annual precipitation is 539.8 mm. Average temperature is 16.90C. In the two years of the study, 2011 and 2012, total precipitation was 812 mm and 624 mm respectively [5].

The catchment area of the Gediz basin is 17 000 km^2, and the surface water potential is 2.0 $km3yr^{-1}$ [6]. The main source of water of the Lower Gediz basin, including the Menemen Left Bank irrigation system, is the Demirkopru Dam, fed by the Gediz River, and the Marmara Lake. The Menemen Left Bank irrigation system consists of the left main canal which is connected to the Emiralem regulator, and six secondary canals. The system was constructed in 1944, and irrigates an area of 16 585 ha. The area of the present study covers 2560 ha at the end of the Menemen Left Bank Irrigation area and is 7 km from the Aegean Sea. In this area, 67 groundwater observation wells were dug based on

1/25000 digitised soil series maps. The wells were dug so that there was one for each 100 ha. Groundwater observation wells were located at 100, 300, 600 and 1000 m intervals in two of the 100 ha areas whose soil series showed little or great variation (Figure 1). The wells were generally opened to a depth of 3.80 m, but at some points they were dug shallower due to pebbles. In the wells, PVC pipes were used with a diameter of 63 mm and with holes of 2 mm diameter spaced at intervals of 5 cm. The locations of the observation wells were recorded with the Global Positioning Systems. In January, April, June, August and October of 2011 and 2012, groundwater (GW) levels were measured and water samples were taken from the same wells to measure electrical conductivity (EC). January and April represented the period affected by rain, June the pre-irrigation season, August the irrigation season, and October the post-irrigation season. EC (dSm-1) was established according to Standard Method 2510 B with the use of an electrical conductivity device [7].

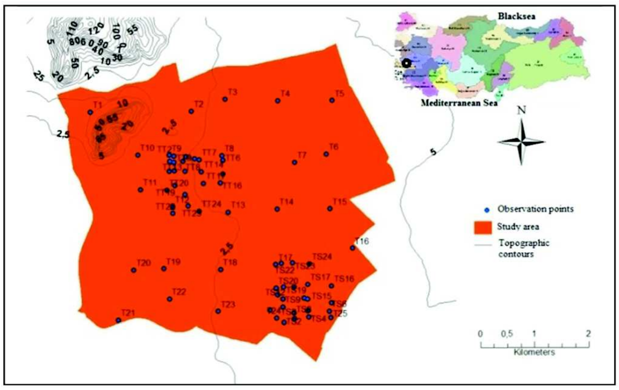

Figure 1. Location of study area with sampling points and topographic contours at 2.5 m intervals. Surface elevations are in meters above sea level.

The program ArcGIS 10.2 CBS was used for geostatistical modelling [8]. Using this program, groundwater level and EC maps were created for each period from the original data. Data were analyzed in three steps: (i) normality tests were conducted to test the hypothesis which assumes that each property is normally distributed (Kolmogorov-Smirnov); (ii) descriptive statistics including arithmetic mean, standard deviation and coefficient of variation, CV, were calculated, and (iii) semivariogram analysis and complementary kriging interpolations were conducted for each variable. A proper transformation (log-transformation) was applied based on the result of the normality tests conducted using JMP 5.0.1 [9]. Geostatistical software (GS+7.0, [10]) was used to construct semivariograms and spatial structure analysis for variables. One of spherical, gaussion, exponential, and linear models was fitted to the experimental semivariograms by the least square fitting technique. Root mean squared error, coefficient of determination, and visual fitting were considered in selecting the models. Nugget variance expressed as the percent of total semivariance was used to judge the spatial dependency of variables. If the rate was equal or lower than 25%, variables were considered as strongly dependent, between 25 and 75% moderately dependent, and greater than 75% weakly dependent [11].

3. Results and dıscussıon

Ground water level

Tables 1-3 show the descriptive statistics, the semivariogram model and its parameters and the cross validation results for groundwater depth values measured in 2011 and 2012.

Table 1. Descriptive statistics for the ground water level by seasons (cm)
aStandard deviation, b Coefficient of variation

Year	Seasons	Mean	Minimum	Maximum	SD^a	CV^b	Skewness	Kurtosis
2011	January	***91***	***0***	214	55	***60.2***	0.16	-0.80
	April	141	73	222	40	31.7	0.31	-0.90
	June	145	29	310	48	33.4	0.55	0.80
	August	133	76	201	33	***25.0***	-0.03	-1.04
	October	***186***	70	***313***	51	27.6	0.16	0.05
2012	January	140	***10***	256	55	***39.5***	-0.20	-0.49
	April	144	75	247	43	30.0	0.47	-0.75
	June	156	69	310	44	28.4	0.70	1.49
	August	***128***	17	248	45	35.1	-0.23	-0.13
	October	***197***	129	***313***	35	***17.9***	0.40	0.80

In 2011, groundwater levels showed a variability of 0-313 cm, monthly averages 91-186 cm, and coefficients of variation 25.0-60.2%. In 2012 these values were 10-313 cm, 128-197 cm and 17.9-39.5% respectively. Groundwater levels rose in the rainy period (January) and the irrigation period (August), and fell in the pre-irrigation (June) and post-irrigation (October) periods. This shows that rain and irrigation both cause the groundwater level to rise.

In all periods of the study years, groundwater levels showed a normal distribution, and the model which best fitted the data was the spherical isotropic semivariogram model. Range values varied in 2011 from 1100 to 2723 m, and in 2012 from 1000 to 4570 m. This model was also used in an evaluation in Turkey of groundwater levels of the Mustafakemalpaşa irrigation area and the Bafra Plain [12, 13]. Degrees of spatial dependence varied between 13.6% (June) and 50.0% (August) in 2011 and 15.8% (June) and 42.4% (August) in 2012. In April and June 2011 and April and October 2012, spatial dependence was classed as strong, and in the other months as moderate. Groundwater levels were classified as strong in spatial dependence classification in April and June 2011 and April and October 2012 and moderate for the other months.

The proportion of areas where the groundwater levels were above 90 cm was 40.5% in January 2011, 1.4% and 1.5% in April and June 2011, 4.7% in January 2012, and 5.2% in August 2012. The proportion of areas where the two-year average was over 180 cm was found to be, in order of periods, 92.7, 88.6, 85.5, 97.6 and 60.1% (Figure 2). From the point of view of drainage and salinity, a groundwater depth of up to 2 m is seen as risky [14].

Table 2. Parameters of isotropic best fit semivariogram models of ground water level by seasons

Year	Seasons	Nugget (C_0)	Sill (C_0+C)	Range (m)	C/C_0+C	r^2	Spatial Dependency		Model
							%	Class	
2011	January	1186	3380	***2723***	0.649	0.626	34.8	moderate	Spherical
	April	378	1587	1819	0.762	0.608	23.8	strong	Spherical
	June	389	2845	2668	0.863	0.927	***13.6***	strong	Spherical
	August	512	1025	1702	0.500	0.637	***50.0***	moderate	Spherical
	October	1000	2300	***1100***	0.565	0.642	43.5	moderate	Spherical
2012	January	1050	3796	2690	0.723	0.820	27.7	moderate	Spherical
	April	357	1991	2000	0.820	0.610	17.9	strong	Spherical
	June	945	2258	***4570***	0.581	0.652	41.8	moderate	Spherical
	August	865	2036	2060	0.575	0.589	***42.4***	moderate	Spherical
	October	185	1172	***1000***	0.842	0.735	***15.8***	strong	Spherical

Table 3. Results of cross-validation for ground water level

Year	Seasons	ME	RMS	MS	RMSS	ASE
2011	January	-0.803	40.0	-0.0099	0.89	43.4
	April	-0.498	29.7	-0.0088	0.91	29.9
	June	-0.436	33.5	-0.0033	0.99	31.9
	August	0.154	29.1	0.0029	1.05	27.6
	October	0.417	48.5	0.0045	1.08	47.4
2012	January	-0.091	46.8	0.0003	1.05	42.9
	April	-0.420	29.2	-0.0085	0.90	30.4
	June	-0.210	42.4	-0.0018	1.10	37.3
	August	-0.198	35.3	-0.0023	0.92	36.7
	October	0.907	27.7	0.0181	1.00	26.7

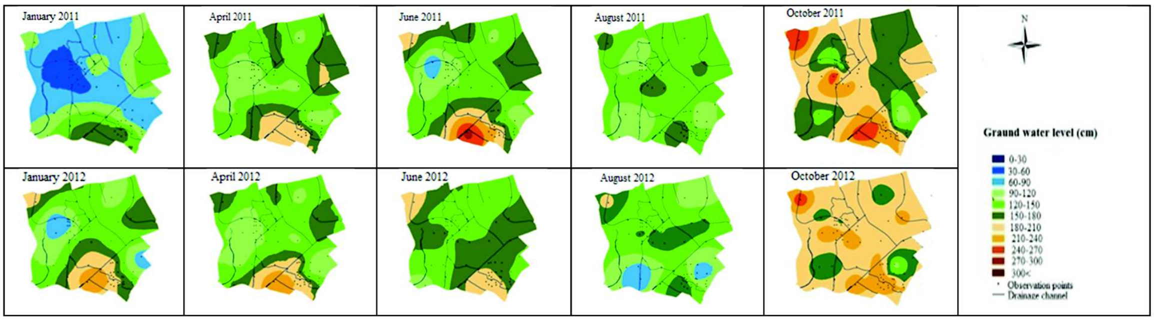

Figure 2. Spatial and temporal variation in groundwater levels for 2011and 2012

Ground water salinity

Tables 4-6 show the descriptive statistics, the semivariogram model and its parameters and the cross validation results for groundwater EC values measured in 2011 and 2012.

Because groundwater salinity values showed log-normal distribution, transformation was applied before calculating the semivariogram. EC values showed consistency with the isotropic characteristic and the spherical semivariogram model. Range values varied between 3345 and 3790 m in 2011, and 2388 and 3049 m in 2012. Degrees of spatial dependence varied between 15.5% (January) and 45.9% (August) in 2011, and 21.5% (August) and 41.8% (October) in 2012. January 2011 and August 2012 were classed as strong regarding spatial dependence, and the other months as moderate.

Table 4. Descriptive statistics for the ground water salinity by seasons, (dSm^{-1})
[1]Standard deviation, [2]Coefficient of variation

Year	Seasons	Mean	Minimum	Maximum	S.D.[1]	C.V.[2]	Skewness	Kurtosis
2011	January	7.58	0.78	33.72	7.5	98.8	1.76	2.85
	April	6.66	0.54	43.83	7.6	114.7	2.85	9.61
	June	7.69	1.06	38.25	7.7	101.9	1.87	3.39
	August	7.24	0.73	29.09	7.0	97.0	1.63	2.09
	October	7.58	1.06	30.83	7.9	103.9	1.58	1.54
2012	January	6.89	0.72	58.18	8.6	125.2	3.71	18.20
	April	7.01	0.64	29.60	6.8	97.1	1.62	1.96
	June	6.90	0.76	24.46	6.7	96.7	1.40	0.77
	August	7.47	0.64	46.36	8.5	114.3	2.40	6.67
	October	7.00	0.90	42.45	8.1	115.7	2.45	6.66

Nowhere in the study area was groundwater salinity found to be in the low or moderate classes. In terms of groundwater EC content classification, it was found that in 2011, proportional field quantities varied between 2.4% (August) and 9.0% (April) in class

III, between 3.7% (August) and 6.5% (October) in class IV, and between 84.3% (October) and 94.8% (August) in class V. The equivalent values for 2012 were 2.0% (October) – 5.6% (August), 3.8% (April) – 11.2% (August) and 83.2% (August) –94.4% (June). It can be seen that no water of class I and II salinity was found in the study area, but that class V water was widespread (>80%). Areas with class III and IV salinity were generally in the south-east of the area. Spatial distribution of groundwater salinity was similar in the two years of the study, with no great differences between the years (Figure 3). In similar studies carried out in Turkey, it was found that groundwater salinity on the Lower Seyhan Plain was 28.8, 18.4 and 24.9 dSm^{-1} in May, July and September 2006 respectively [15], and greater than 2 dSm-1 on only 5-7% of the area in Tokat-Kazova [16], in the right bank irrigation area of the Bafra Plain, which has a sea water entry, it varied between 1.36 and 11.9 dSm^{-1}, with an average of 4.18 dSm^{-1} [17].

Table 5. Parameters of isotropic best fit semivariogram models of ground water salinity by seasons

Year	Seasons	Nugget (C_0)	Sill (C_0+C)	Range (m)	C/C_0+ C	r^2	Spatial Dependency		Model
							%	Class	
2011	January	0.168	1.086	3410	0.845	0.624	15.5	strong	Spherical
	April	0.473	1.278	***3790***	0.805	0.852	37.0	moderate	Spherical
	June	0.360	1.049	3554	0.689	0.886	34.3	moderate	Spherical
	August	0.477	1.040	3680	0.541	0.897	45.9	moderate	Spherical
	October	0.344	1.101	***3345***	0.688	0.700	31.2	moderate	Spherical
2012	January	0.406	1.009	3018	0.598	0.804	40.2	moderate	Spherical
	April	0.366	0.938	2538	0.610	0.824	39.0	moderate	Spherical
	June	0.393	0.977	2948	0.598	0.829	40.2	moderate	Spherical
	August	0.247	1.147	***2388***	0.785	0.625	21.56	strong	Spherical
	October	0.442	1.057	***3049***	0.581	0.614	41.8	moderate	Spherical

Table 6. Results of cross-validation for ground water salinity

Year	Seasons	ME	RMS	MS	RMSS	ASE
2011	January	-0.011	6.71	-0.118	1.24	6.05
	April	0.184	7.15	0.009	0.93	7.63
	June	-0.230	7.49	-0.118	1.22	6.99
	August	0.055	6.63	-0.048	0.94	7.69
	October	-0.136	7.01	-0.084	1.03	7.36
2012	January	-0.017	8.10	-0.060	1.07	7.24
	April	0.020	6.65	-0.089	1.11	7.20
	June	-0.009	6.25	-0.065	1.04	6.94
	August	-0.144	7.83	-0.121	1.19	7.68
	October	-0.162	6.97	-0.003	0.85	7.35

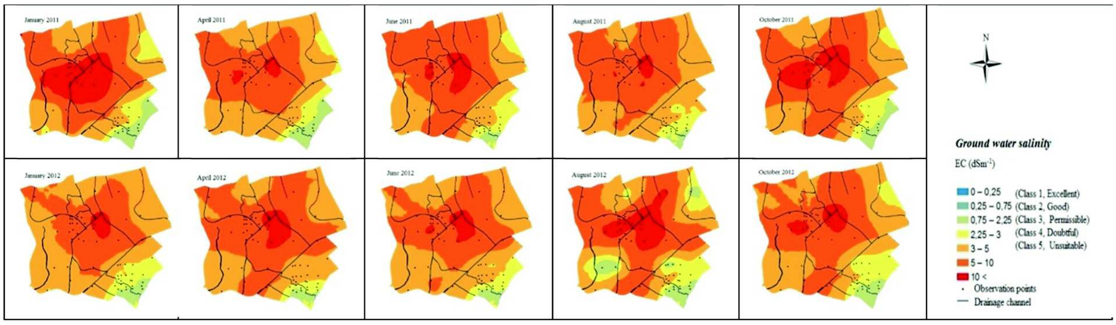

Figure 3. Spatial and temporal variation in EC of groundwater in 2011 and 2012

4. Conclusıon

Spatial dependence in groundwater levels before and after the irrigation season was strong; in groundwater salinity values it was generally moderate. Geostatistical range values for ground water level were 1000 m and 2350 m for groundwater salinity, which, when evaluated together, must be taken as 1000 m. The nugget effects of ground water level and ground water salinity were generally high. Sea effects and drainage differences were found in the study area. Groundwater levels rose in the rainy (January) and irrigation (August) periods, and fell in the pre-irrigation (June) and post-irrigation (October) periods. During the irrigation season, groundwater levels of 90-150 cm were found in 80% of the area. After the irrigation season, groundwater levels in 70% of the area fell to below 180 cm. Groundwater salinity was greater than 3.00 dSm^{-1} in 90% of the study area. Furrow irrigation was practiced in the study area. Collecting water charges by land area irrigated rather than by water volume causes a fall in water application ratio of 50-60%. The mistaken practices of farmers in soil and water management cause the groundwater to rise and its salinity to increase. The performance of the existing drainage system in the study area in face of the high level and salinity of the groundwater should be evaluated, effective work should be carried out, and the practice of blocking drainage canals in order to collect water for use in irrigation should be stopped.

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