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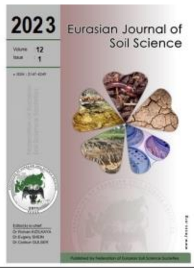

Salt accumulation in soils under furrow and drip irrigation using modified waters in Central Iran

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Abstract

The objectives of this study were i) to characterize the water and soils under different managements, ii) to evaluate the sustainability of using hypersaline soils and water, and iii) to assess possible solutions to prevent more degradation of soil and water resources. Field and laboratory analysis of the samples using eight pedons and 128 surface samples taken from grid in four pre-determined land uses; pistachio orchard abandoned, pistachio orchard with furrow irrigation, wheat and maize cropping with furrow irrigation, pistachio orchard with drip irrigation. The study area, 170 ha, comprised two distinct soil parent materials including marls (max. ECe >100 dS/m) and alluviums (max. ECe >60 dS/m). Abandoning lands caused salinity increasing due to lack of leaching by irrigation water. The maximum increase of soil salinity was in the abandoned land use (EC e =98 dS/m), where trees had been removed and there is no irrigation, followed by pistachio plantation land use (EC=11 to 34 dS/m), and wheat and maize cropping land use (EC=11-19 dS/m). The minimum rise in soil salinity was in the drip irrigation due to mixing freshwater with saline water and therefore better water quality (EC=3 dS/m at surface layer and 17 dS/m in next layer). Land use change to agriculture increased the need for irrigation and because of arid climate it mainly supplied by groundwater from deep wells. Using deep groundwater due to rock-water reaction and increasing salinity, decreased water quality in furrow irrigation and therefore it had more significant effect on soil salinity compare to drip. Comparison of the mean values of soil salinity indicators in 2018 showed that salinity has increased by 3-6 times in the furrow irrigation and at least two-fold in the drip irrigation, compared to 2002. The calculated salinity indicators also proved the soil and water resources had been degraded and present land use types are not sustainable. Possible solutions could be to minimize land use change to agriculture, to use drip irrigation with mixed saline and freshwater, and to remove salt crusts from the soil surface.

Keywords: Land degradation, Arid climate, Solute dynamics, Saline soils, Saline water, Irrrigation.

Introduction

Soil and water salinity are the most important progressive factors of soil degradation which limit food production and sustainable agriculture spatially in arid regions. Saline soils are one of the most extensive soil types found in arid and semi-arid regions, and they severely limit water availability, temporally and spatially, due to high salt accumulation (Bouaziz et al., 2020).

Although the salinity of hypersaline soils is much higher than that of saline soils, the chemical characteristics separating saline and hypersaline soils are not precisely defined (Dion and Nautiyal, 2008). Hypersaline soils include soils that contain salt accumulation at lower ranges (4–8 dS/m), that restrict the yield of many crops,

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in moderate ranges (8–16 dS/m), where only tolerant crops may yield satisfactorily, and highly hypersaline soils (ECe>16 dS/m), in which only a few very tolerant crops may yield satisfactorily (USDA, 1954).

More than 90% of Iran, which has a total area of about 1.65 Mha, is located in arid and semiarid regions where producing crops without irrigation is impossible. The use of saline groundwater to irrigate saline soils with different levels of salinity, especially in central Iran, has led to accelerated environmental degradation (Al-Muaini et al., 2019). Long term use of hypersaline water for agriculture purposes has led to further accumulation of salts in soils and conversion of salt-affected soils into hypersaline soils. Such a relationship between changes in salinity parameter associated with different types of land use has been reported in many studies (Pasternak and De Malach, 1995; Hanson et al., 2008).

The quality of irrigation water is one of the most critical factors in the management of salt-affected soils (Acar and Yilmaz, 2019). Irrigation water quality not only affects crop yield and physical soil conditions but also influences plant nutrition, irrigation system usability, and water application (Minhas et al., 2020). Therefore, analysis of irrigation water quality is essential to support suitable management for maximum crop productivity. Several parameters, including total dissolved solute content, the relative proportion of sodium to calcium and magnesium ions, pH, carbonate and bicarbonate, specific ions such as chloride, sulfate, and boron, and nitrate concentration are involved in the determination of irrigation water quality (Bauder et al., 2010). Hypersaline water is water where salinity hazard is high (0.75–2.25 dS/m) to very high (>2.25 dS/m) and this cannot be used on soils with restricted drainage. Even for salt tolerant crops, using hypersaline water requires special management (USDA, 1954). High pH, above 8.5, with high concentrations of HCO_3^- and CO_3^{2-}, causes precipitation of calcium and magnesium ions, leaving excess sodium in the soil solution. Small amounts of chloride are essential for plants, but in high concentrations it is toxic to sensitive crops (Geilfus, 2019). Low concentrations of sulfate ion in irrigation water benefit soil fertility (Bauder et al., 2010).

Soil texture diversity in vertical profile is an effective factor on soil water movement, nutrients, soil solute migrations, primary and secondary salinity. Particle size distribution (PSD) is an useful tool for soil classification. Investigation of PSD effects on soil salinity is necessary to estimate the intensity and extent of soil degradation. The more dominant fine part in particle size distribution, the higher increase in salinity ions due to the high specific level of these fine particles (Yang and Yanful, 2002; Zhao et al., 2016).

Finding crops which are resistant to salinity and are also valuable commercially is one of the important management challenges in hypersaline agriculture (Mustafa and Akhtar, 2019). Pistachio is one of the strategic crops that play a key role in people's livelihoods in arid and semi-arid regions (Moazzzam Jazi et al., 2019). Suitable EC for pistachio trees is less than 4 dS/m however, up to 8 dS/m, a suitable product is produced. Although pistachio has been produced conventionally in arid regions for a long time, a recent increase in soil and water salinity problems has caused the crop cultivation strategy used in pistachio plantations to change (Crane, 1978; Bodaghabadi et al., 2019).

The use of hypersaline soil and water for agriculture, and associated problems such as soil and water degradation in arid and semi-arid regions, has led to a variety of research focused on hypersaline agriculture and soil and water resources management (e.g. see Rhoades et al. 1992; Minhas, 1996; Tanji and Kielen, 2002; Hoffman and Shalhevet, 2007; Grattan et al., 2002; Pereira et al., 2014, Gebremeskel et al., 2018). As various studies have shown, it is not possible to use hypersaline soils and water for agriculture without taking into account sustainability and the salt balance in the root zone (Gebremeskel et al., 2018; Minhas et al., 2020). However, despite the numerous studies in the field of salinity, no study has yet been conducted on the application of hypersaline water to hypersaline soils and its long-term sustainability. This study examines the hypothesis of instability of hypersaline agriculture in arid zones. The main mechanisms involved in salt accumulation are using hypersaline waters in the arid climate and irrelevant irrigation methods. The objectives of this study were i) to characterize the water and soils quality under different managements in the studied arid region, ii) to evaluate the soils quality sustainability of using hypersaline soils and water in the arid region under study, and iii) to assess possible solutions to prevent rapid degradation of soil and water resources.

Material and Methods

Site description

The study area comprises about 170 ha located in the south west of Eyvanekey county (Semnan province) in central Iran, between latitudes 35° 19´ 39.186" to 35° 21´ 11.204" N and longitudes 51° 57´ 55.402" to 52° 02´ 4.316" E (Figure 1). Common crops in the study region are pistachio, wheat, and maize. The main section of the study area was 135 ha of pistachio orchard under five- to 60-year-old pistachio trees in different patches and two kinds of furrow and drip irrigation methods, with about 17 ha of cropland with cultivated agricultural crops of wheat and maize.

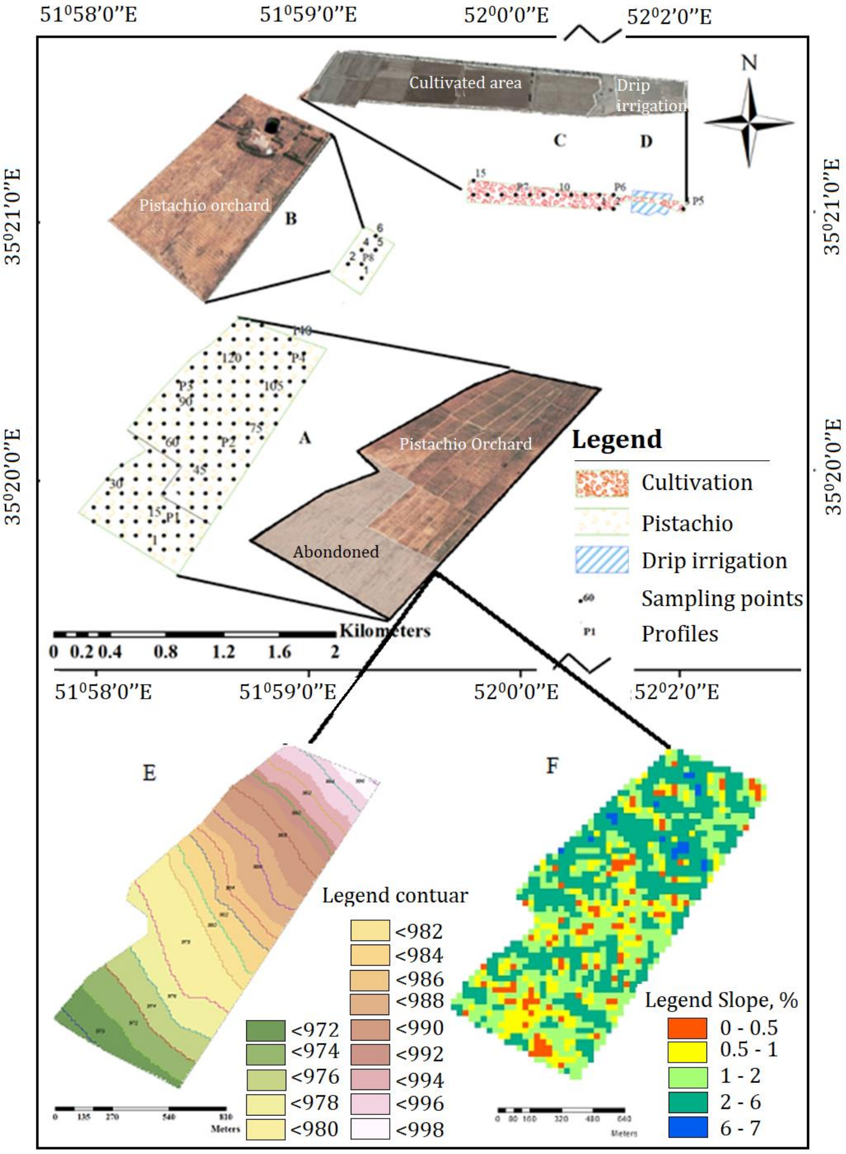

Figure 1. Soil samples location and land use (21 Oct. 2018) (above); Land use 1 & 2 in two different fields: A &B left above; Land use 3&4: C&D right above, slope (below left) and elevation (below right) maps

The geology comprises an admixture of coarse igneous and pyroclastic rock fragments in the north-western section of the Eyvanekey alluvial fan, originating from the Alborz Mountain Chain, along with the remnants of eroded marls originating from the southern Neogene formations. Patches of the alluviums have overlaid the marls in the middle parts of the area where they meet. The overall slope (about 1.5%) of the study area is flat with no effective slope aspect direction. There are some artificially established slopes in the opposite direction to the direction of the main slope, created to lead rainwater into the irrigation channels under the pistachio trees. Based on the Köppen climate classification system, the study area is classified as having a dry (B) climate (Köppen, 1931). The coldest month was January with 2.9 degrees and the warmest month was July, with 29.7 degrees. The average Min. T was recorded in January as -3.4 °C and the Avg. Max. T was recorded as 38.7 °C in July. The spring and summer rainfall in the study area is between 30% and 70% of the mean annual precipitation, which is less than 50% of the threshold (mean annual precipitation +140 mm), which, in combination with temperature of less than 18 °C, is classified as BWk. The reference evapotranspiration of the study area is 944.53 mm, which is much higher than its annual precipitation (127 mm), and the mean annual temperature is 16.6 °C. The annual aridity index (AI) in the region is equal to 0.135, which has caused it to be classified as an arid region. According to the mean annual soil temperature at a depth of 50 cm (17.6 °C), based on the climatic data and using The Natural System Model (NSM) software, soil moisture and temperature regimes were identified as Aridic and Thermic, respectively (Newhall and Berdanier, 1996; Table 1). The soil thermal regime was characterized as thermic (> 270 days soil temperature at a depth of 50 cm was >8 ⁰C). Also, due to the long period that the soil moisture control section was recorded to be dry during the year, the soil moisture regime was determined as subdivision of aridic regime; weakly aridic which means that Soil Moisture Control Section is dry for more than half of the time that T > 5 ⁰C (Soil Survey Staff, 2014).

Table 1. Monthly climatic data, soil climate and aridity index of Eyvanekey for Year (2018)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Avg. T (°C)	2.9	5.8	10.2	15.8	22.3	26.9	29.7	28.4	24	18.1	10.4	4.9	16.6
Min. T (°C)	-3.4	-0.9	3	8.2	14	18.1	20.7	19.4	15.1	10	3.1	-1.5	8.8
Max. T (°C)	9.3	12.6	17.5	23.5	30.6	35.8	38.7	37.4	33	26.3	17.8	11.3	24.48
P (mm)	28	20	20	14	11	1	0	0	2	8	11	12	127
ET (mm)	1.6	7.0	24.0	56.7	118.6	163.4	195.5	171.5	115.6	64.8	20.8	5.2	944.5
P – ET (mm)	26	13	-4	-43	-108	-162	-196	-172	-114	-57	-10	7	-818
Aridity Index	17.50	2.86	0.83	0.25	0.09	0.01	0.00	0.00	0.02	0.12	0.53	2.31	0.13
Soil Temp. regime	Thermic (>270 days soil temperature at the depth of 50 cm is > 8 °C)												
Soil Mois. Regime	Weak Aridic (Soil Moisture Control Section is dry for more than one half of the time that T> 5 °C)												

Soil and water sampling

After the study area had been selected, in order to understand the existing problems in the study area and determine sampling strategy four field observations were carried out to check for the existence of salt crusting and the presence of rock fragments during November, 2018. Soil survey showed that there is high variation of EC in furrow irrigation, 4-70 dS/m and a narrow variation range of EC in drip irrigation method, 3-16 dS/m. Also salt crusting was observed clearly in the abandon area (about 30 percent of study area) and its margin with pistachio trees. Amount and also size of rock fragments was completely different in the different sites. Portable devices were used to evaluate the initial spatial distribution of moisture content, pH, and EC along the transecting and traversing areas. Before laboratory analysis and profile description the spatial and temporal sampling design was prepared, based on the results of field observations combined with information on land use, climate, management, and the geology of the area (Geological Survey and Mineral Exploration of Iran, 2011). We decided to go to the field in wet season to investigate salt movement and its interaction with rain and a grid design soil sampling used as a tool to find salt spatial changes in the study area. A sampling strategy was produced so that all the factors influencing soil salinity dynamics (irrigation methods, crop types, and land use) were included.

Sampling was performed using two complementary approaches. The first approach comprised surface sampling to investigate spatial changes in salinity, in which five samples were taken, with about 4 kg of soil being taken from the four corners and centre of a square with sides of 4 m (making five samples in total), using a grid design with 100 m intervals between the sampled squares. The subsamples were thoroughly mixed, and then a 3 kg sample of the mixture was transferred to the laboratory. In the second approach, in order to investigate variation in soil properties by depth, eight profiles (P1 – P8) were dug and described from four different pre-determined land use examples (a pistachio orchard abandoned due to water scarcity (P1 in Figure1 A), a more than 20-year-old pistachio orchard with a furrow irrigation system (P2, P3 and P4 in Figure1 A, plus P8 in Figure 1 B), farms of wheat and maize with a furrow irrigation system (P6 and P7 in Figure1 C), a five-year-old pistachio orchard with a drip irrigation system (P5 in Figure1 D)). Sampling was carried out at 10 cm intervals, with consideration soil genetic layers, to a depth of 1 m from the soil surface. In total, 128 samples from the upper 20 cm of sampling points, plus 80 samples from eight soil profiles, were collected for laboratory analysis. The soil horizons described in each profile and the soil profiles were classified following Keys to Soil Taxonomy (Soil Survey Staff, 2014). Additionally, ARC GIS software was used to design a grid based on 100 m intervals in the study area to collect soil samples and it was also used to map soil salinity spatial variability using inverse distance weighing. Furthermore, irrigation water sources, including three very deep wells (>200 m depth), were sampled in November 2018 for detailed laboratory analysis after several field measurements. The fresh surface water (EC < 1 dS/m) for mixing with saline water in drip irrigation is provided from a small river near to the study area. The mixing ratio varies between 20 to 50% depending on fresh water availability. In addition to annual rainfall approximately 200 to 300 mm irrigation water is used to sustain the pistachio and other crops.

Laboratory Analysis

All soil samples were air dried and passed through a 2 mm sieve in preparation for processing in the laboratory. ECe and pHe and pHsp were determined by using an EC/pH meter (Jenway 3540). Concentrations of Na^+ and K^+ in the saturated extracts were determined using a flame-photometer. Mg^{2+} and Ca^{2+} were measured by complexometry, and Cl^-, HCO_3^-, and CO_3^{2-} were measured using the titration method (Zhao et al., 2016). Soil saturation percentage was determined by oven drying the saturated soil paste. In-situ soil water content was measured using a portable soil moisture meter (PMS-714). The same methods were used to analyse the water samples. Particle size distribution was measured using the hydrometer method after the removal of soluble salts (Gee and Bauder, 1986). Rock fragments (with diameter >2 mm) were determined by weighing samples before and after sieving. Soil organic carbon (SOC) was measured using the wet combustion method (Walkley and Black, 1934). $CaCO_3$ was determined using calcimetry analysis (Dreimanis, 1962) and gypsum was measured by using precipitation with acetone and reading the EC of the precipitated gypsum (USDA, 1954).

Calculation of Salinity and Sodicity indices

Table 2 summarizes the different indicators of salinity and sodicity for soil extracts and water, including the Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC), Residual Sodium Bicarbonate (RSBC), the Permeability Index (PI), and the Kelly Ratio (KR), which were calculated to assess the suitability of the soil and water for agricultural use. Also in order to compare soil quality changes with reference year, salinity and sodicity factors along with soil organic carbon used as soil quality parameters (Table 2).

Table 2. Salinity parameters with formulas, units, recommendation salinity parameters ranges for agricultural using and sources

Parameters	Symbol	Formula	Units	Limits	Water/Soil	References
Electrical Conductivity	EC	-	dS/m	0.25-3	Water	Fipps (2003)
Electrical conductivity (saturation extract)	EC	-	dS/m	0-4	Soil	Ayers and Westcot (1985)
Calcium	Ca^{2+}	-	meq/l	0-20	Both	Ayers and Westcot (1985)
Magnesium	Mg^{2+}	-	meq/l	0-5	Both	Ayers and Westcot (1985)
Sodium	Na^{+}	-	meq/l	0-40	Both	Ayers and Westcot (1985)
Sodium adsorption ratio	SAR	$SAR=\frac{Na^+}{\sqrt{Ca^{2+}+Mg^{2+}}}$	-	0-9	Soil	Ayers and Westcot (1985)
Sodium adsorption ratio	SAR	$SAR=\frac{Na^+}{\sqrt{Ca^{2+}+Mg^{2+}}}$	-	1-26	Water	Fipps (2003)
Bicarbonate	HCO_3^-	-	meq/l	0-10	Both	Ayers and Westcot (1985)
Chloride	Cl^-	-	meq/l	0-30	Both	Ayers and Westcot (1985)
Alkalinity/ Basicity	pH	-	-	6.5-8.4	Both	Ayers and Westcot (1985)
Magnesium adsorption ratio	MAR	$MAR=\frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}}\times 100$	%	<50	Soil	Raghunath (1987)
Residual sodium carbonate	RSC	$RSC=(HCO_3^-+CO_3^{2-})-(Ca^{2+}Mg^{2+})$	meq/l	<2.5	Soil	CFC (1975)
Residual sodium bicarbonate	RSBC	$RSBC=(HCO_3^- + Ca^{2+})$	meq/l	<1.25	Soil	Eaton (1950)
Permeability index	PI	$PI=\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+}\times 100$	%	>6.5	Both	Doneen (1964)
Kelly ratio	KR	$KR=\frac{Na^+}{Ca^{2+}+Mg^{2+}}$	meq/l	<1	Both	Sundaray et al. (2009)

Statistical Analysis

A Completely Randomized Design (CRD) was used to investigate the effects of land-use type on soil salinity and Duncan's multiple range test (DMRT) performed to indicate the significance of the differences between the land use types. Also, a one sample t-test, was performed to statistically compare surface soil salinity (0-20 cm) between the sample and reference year (2002) and changes in water salinity compared to the reference year (2008). Comparison of the means and standard deviations of the measured parameters in different land use areas and different irrigation methods were carried out using SPSS software (Ver. 26, George and Mallery, 2019).

Results

Groundwater Depth and Variation in Quality

Three very deep wells, 200 m provide the irrigation water in the study region. In 2002 the groundwater table in study area was 50 meters and over time, due to the imbalance between low re-charges (precipitation) and high discharge (water pumping from the groundwater), the groundwater table fell to below 200 m. Comparisons of the irrigation water soluble ions measured in 2008 and 2018 are given in Table 3. According to the Wilcox irrigation classification diagram (based on EC and SAR) (USDA, 1954), the water used for irrigation was classified as very high salinity water, 6.31-7.08 dS/m (C4) that is not suitable for irrigation in the study area (Table 3). Regarding SAR, the water was classified as S1 and S2 (9.33-11.12), which refers to low to medium sodium levels that are hazardous in fine textured soils with high CEC. In drip irrigation the extracted groundwater is mixed with fresh water, resulting in a 50% reduction in the EC and SAR of drip irrigation water, compared to irrigation water sources used currently, and to 2008. The salinity hazard attributed to all water resources other than drip irrigation has increased significantly (7.27%, 14.38%, and 1.9%) relative to the average EC in 2008. However, the overall classification (C4) has remained constant and the sodium hazard (SAR) has reduced considerably (about 13% in Well No. 2 and about 1.59% in Well No. 3 Table 3).

In respect of concentrations of anions and cations in the analysed samples, considerable changes were observed relative to 2008. Concentrations of calcium and sulphate have increased, 17%–49% and 39%–51%, respectively, in the case of furrow irrigation water sources (Wells 1, 2, and 3) while concentrations of sodium, magnesium, bicarbonate, and chloride have mainly decreased (between 1.5% and 18%) or show only a small increase (between 1.35% and 4.55%) in some cases (Table 3). Of course, in the case of drip irrigation water the concentrations of all cations and anions have decreased, between 2% and 68%, due to mixing with fresh water (Table 3), and the maximum decreases were associated with sodium (68%) and chloride (60%). One-sample t-test was used to compare the irrigation water salinity indicators and soluble ions in 2018 to the 2008 and the results showed significant difference for HCO_3^-compared (Table 3).

Table 3. Laboratory Analysis and the Salinity Indicators of the Irrigation Water Sources in 20 Nov. 2018 (groundwater depth 230 m) and 19 Oct. 2008 (groundwater depth 180 m)

Indicators	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO^-_3	CO_3^{2-}	Cl^-	SO_4^{2-}	Class
Furrow Irrigation water well 1	41.22	0.15	18.5	9.0	1.90	0	40.0	24.5	C_4S_2
Furrow Irrigation water well 2	39.03	0.15	23.5	11.5	1.90	0	45.0	23.9	C_4S_1
Furrow Irrigation water well 3	41.22	0.15	19.5	11.0	2.10	0	40.5	20.5	C_4S_2
Drip irrigation	12.67	0.09	11.5	4.5	2.25	0	17.5	7.5	C_4S_1
Averages of Reported results for 2008	39.27	-	15.8	11.0	2.30	0	44.4	19.37	C_4S_2
Changes of water salinity parameters relative to year 2008 %									
Indicators	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO^-_3	CO_3^{2-}	Cl^-	SO_4^{2-}	Class
Furrow Irrigation water well 1	3.78		17.09	-18.18	-17.39	0	-9.91	39.24	-
Furrow Irrigation water well 2	-1.74		48.73	4.55	-17.39	0	1.35	40.84	
Furrow Irrigation water well 3	3.78		23.42	0	-8.70	0	-8.78	51.11	
Drip irrigation	-68.10		-27.22	-59.09	-2.17	0	-60.59	-53.48	

Indicators	EC	pH	SAR	PI	KR
Furrow Irrigation water well 1	6.64	7.76	11.12	61.99	1.50
Furrow Irrigation water well 2	7.08	7.55	9.33	54.58	1.12
Furrow Irrigation water well 3	6.31	7.58	10.56	59.49	1.35
Drip irrigation	2.73	7.57	4.48	49.43	0.79
Averages of Reported results for 2008	6.19	7.64	10.73	61.73	1.47
Changes of water salinity parameters relative to year 2008 %					
Indicators	EC	pH	SAR	PI	KR
Furrow Irrigation water well 1	7.27	1.57	3.63	0.42	2.04
Furrow Irrigation water well 2	14.38	-1.18	-13.05	-11.58	-23.81
Furrow Irrigation water well 3	1.94	-0.79	-1.58	-3.63	-8.16
Drip irrigation	-55.9	-0.92	-58.25	-19.93	-46.26

The measured pH also decreased, (0.79% – 1.18%) in the water of Wells 2 and 3 and drip irrigation water, compared to the value reported for 2008. Furthermore, all other indicators of irrigation water quality such as SAR, PI, and PK decreased between 1.58% and 58.25% compared to 2008, except for Well No. 1.

Soil Salinity Profiles

Table 4 shows the soil horizons described in each profile and the classification of the studied profiles. The highest values of EC and the ions of Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} were measured in the surface layer of the profile located in an abandoned area (P1) but values decreased with depth (Table 4). The ECe and the Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} ions in profiles P2 and P3 were considerably lower (10% to more than 90%) than P1 but, they showed similar trends in profiles P5 and P6, which were located under pistachio trees and in maize cultivation using a furrow irrigation system. Irregular trends of variations were observed in the case of the other profiles (P3, P4, P5, P7, and P8) (Figure 1 and Table 4). Although, Na^+ was the predominant cation in all profiles, the predominant anion changed between SO_4^{2-} and Cl^- in different layers of the profiles (Table 4).

Soil Salinity Indicators

The mean values of the results of the soil laboratory analysis and the calculated salinity and sodicity indicators in the surface soil samples (0-20 cm) from four land uses are presented in Table 5. Comparison of the mean values of the measured ECe (in 2018) with those of 2002 indicated that it increased by at least two to more than eight times in areas with drip irrigation and abandoned areas. The consequences of increasing salinity are reduced yields and soil and water quality in the study area. Pistachio orchards yield 500 kg/ha up to 2000 kg/ha depending on productive year or non-productive year of pistachio.

In spite of the increase in the ECe values, the pH of different land use areas showed decreases between 0.2 and 0.5. The SOC in topsoil decreased by more than 2.5 times compared to the average content in 2008, although the calcium carbonate equivalent (CCE) increased (23% – 40%), irrespective of land use type, (Table 6).

Furthermore, the results obtained from a one sample t-test to compare the changes in soil salinity under two irrigation methods with 2002 showed that there was a significant difference between both irrigation methods and the year 2002 ($p < 0.05$).

Table 4. Morphological and physiochemical results of soil profiles.

Horizon	Depth cm	pHe	EC mS/cm	OC %	$CaCO_3$ %	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^- (meq/l)	CO_3^{2-}	Cl^-	SO_4^{2-}	SP
P1: Loamy-skeletal, mixed, active, thermic Gypsic Haplosalids														
^Apyz	0-17	7.00	98	0.73	15	1120	5	497	272	1	0	1573	321	37
^ACyz	17-32	7.04	55	0.47	15	587	6	88	215	1	0	715	180	33
^C1z	32-42	7.44	27	0.27	14	396	32	15	40	1	0	261	221	27
2C2z	42-61	7.39	18	0.15	15	234	20	18	15	1	0	148	139	31
2C3z	61-105	7.43	12	1.32	14	168	13	34	12	1	0	86	140	24
P2: Fine-loamy, mixed, active, thermic Gypsic Haplosalids														
Apyz	0-35	7.95	34	1.01	13	496	16	43	89	11	0	303	330	37
Bw1	35-55	7.80	12	0.37	13	176	3	29	9	2	0	60	155	32
Bw2	55-85	7.69	7	0.27	16	92	1	20	13	1	0	35	89	37
Bk1	85-100	7.66	9	0.27	19	114	1	34	13	1	0	58	104	43
P3: Coarse-loamy, mixed, superactive, calcareous, thermic Typic Torrifluvents														
Ap1	0-20	7.81	11	0.49	14	129	2	41	33	2	0	67	136	30
Ap2	20-40	7.34	8	0.60	15	95	1	31	14	2	0	32	108	34
2O	40-55	7.60	15	>50	13	178	1	59	26	5	0	100	158	63
3C1	55-70	7.44	13	0.44	13	178	1	47	27	2	0	75	174	38
4C2	70-100	7.21	12	0.19	11	137	2	40	18	1	0	82	115	26
P4: Coarse-loamy, mixed, superactive, calcareous, thermic Typic Torriorthents														
Ap	0-30	7.66	5	0.30	11	73	1	17	7	1	0	29	68	26
AC	30-60	7.45	5	0.19	12	61	1	11	7	1	0	28	52	26
C	60-110	7.57	5	0.18	11	101	1	11	3	1	0	27	88	28
P5: Loamy-skeletal, mixed, active , calcareous, thermic Typic Torriorthents														
Ap	0-30	8.10	3	0.35	17	26	1	10	6	2	1	9	32	21
C1	30-43	7.22	17	0.27	18	179	1	50	50	1	0	139	140	31
C2	43-64	7.18	15	0.21	18	156	1	59	36	1	0	121	130	29
2BAb	64-100	7.22	14	0.14	20	147	1	65	28	0	0	132	109	49
P6: Fine-loamy, mixed, superactive, thermic Sodic Haplocambids														
Ap1	0-25	7.52	19	0.45	19	223	2	54	47	2	0	168	155	36
Ap2	25-50	7.53	15	0.38	20	184	2	46	35	7	0	127	132	37
AB	50-60	7.61	8	0.25	21	138	1	28	20	1	0	41	144	44
Bw1	60-80	7.44	8	0.20	21	127	1	28	10	0	0	34	131	40
Bw2	80-110	7.42	7	0.19	21	127	0	27	13	1	0	27	139	35
P7: Fine-loamy, mixed, superactive, thermic Sodic Haplocambids														
Ap	0-40	7.43	11	0.46	17	138	1	37	19	1	0	66	127	38.6
Bw	40-73	7.45	7	0.21	20	90	1	31	16	0	0	36	101	35.9
2C	73-80	7.37	8	0.18	21	86	1	41	5	0	0	41	91	32.8
3C	80-110	7.47	8	0.20	22	90	1	25	38	1	0	40	113	40.5
P8: Loamy-skeletal, mixed, superactive , calcareous, thermic Typic Torrifluvents														
Ap	0-30	7.50	11	0.28	12	146	1	27	6	0	1	66	113	27.3
2C1	30-51	7.40	12	0.15	12	141	1	44	10	0	1	83	112	21.8
3C2	51-67	7.23	11	0.24	12	119	1	44	17	0	1	82	99	24.6
4C3	67-110	7.45	9	0.19	13	88	1	34	15	1	0	55	82	24.1

The calculated indicators for soil salinity showed that, as for ECe, the highest values of SAR, MAR, RSBC, PI, and KR were observed in the abandoned land, which was followed by pistachio orchards, cultivated lands, and drip irrigation. SAR, RSBC, and KR indicators were very high in all types of land use, but MAR, RSC, and PI indicators were in the suitable range for all land uses. Concentrations of all anions and cations were very much higher than their applicable range for agricultural use (Table 5). The standard deviations for the measured parameters are very high in some cases, which demonstrates very high variability in the measured parameters (Table 5) and as expected, the standard deviation is low for the parameters that have low variability.

Considering the changes in ECe compared to 2002, during the 16 years to 2018 the largest increase has been observed in the area of abandoned land. In agreement with the increased means of ECe, the maximum values for the means of Ca^{2+}, Na^+, and Cl^- ion concentrations and SAR, MAR, RSBC, PI, and KR were all obtained in the abandoned land. Conversely, the minimum values of the parameters mentioned were determined in the land under drip irrigation.

Table 5. Comparison the means and standard deviations of some soil properties and salinity indicators in surface soil samples under different land-uses and different irrigation methods.

	OC	CCE	K^+	Ca^{2+}	Mg^{2+}	Na^+	Cl^-	HCO_3^-	CO_3^{2-}
	%		meq/l						
				Land use 1 Abandoned					
Mean	0.20	16.1	4.9	101.4	24.4	523.8	829.3	3.1	0.6
Std.dev	0.11	1.8	4.3	98.7	50.9	461.5	843.9	3.2	1.5
				Land use 2 Pistachio					
Mean	0.22	13.7	10.9	94.9	18.2	372.9	497.5	5.6	1.1
Std.dev	0.15	2.0	13.1	60.7	33.4	506.1	970.5	3.7	1.6
				Land use 3 Crop land					
Mean	0.19	17.5	2.2	73.4	15.0	205.2	35.1	1.1	0.6
Std.dev	0.09	1.1	1.8	46.2	8.3	129.4	49.4	0.3	0.5
				Mean of Total furrow land uses 1,2 and 3					
Mean	0.19	15.3	7.58	20.86	97.9	434.0	630.2	4.16	0.11
Std.dev	0.13	2.4	9.56	41.42	80.3	471.4	903.8	3.59	0.18
				Land use 4 Drip irrigation					
Mean	0.15	18.8	0.7	51.9	7.0	121.7	44.5	1.3	0.8
Std.dev	0.11	0.8	0.3	21.3	3.7	81.1	93.5	1.2	0.3
				Mean of the reported results for soil analyses 2002 (reference year)					
Mean	0.50	10.5							
Std.dev									

Continued	EC	pH	SAR	MAR	RSC	RSBC	PI	KR
	dS/m			%	meq/l		%	meq/l
				Land use 1 Abandoned				
Mean	57.3	7.3	74.3	16.4	-127.6	96.6	73.1	6.1
Std.dev	39.2	0.3	71.5	10.2	138.0	101.7	17.0	8.2
				Land use 2 Pistachio				
Mean	43.8	7.5	58.1	12.5	-109.6	59.0	64.7	5.3
Std.dev	40.6	0.4	106.2	18.6	43.2	56.2	18.8	13.0
				Land use 3 Crop land				
Mean	24.2	7.6	28.7	8.2	-86.0	37.3	68.8	2.3
Std.dev	16.8	0.22	10.8	8.6	21.8	2.0	5.8	0.5
				Mean of Total furrow land uses 1,2 and 3				
Mean	49.2	7.4	63.7	14.1	-117.6	76.5	68.7	5.5
Std.dev	39.8	0.4	88.0	14.8	99.1	82.5	17.8	10.5
				Land use 4 Drip irrigation				
Mean	17.4	7.6	22.9	10.8	-90.6	33.4	54.9	2.3
Std.dev	9.5	0.4	14.5	7.7	30.2	8.1	26.1	1.5
				Mean of the reported results for soil analyses 2002 (reference year)				
Mean	8.02	7.8						
Std.dev								

Table 6. One-sample t-test comparison of the means of salinity indicators and soluble ions in irrigation water samples to the reference year, 2008.

Water Sources	Test Value (Reference Year)	t	df	Sig. (2-tailed)	Mean Difference	Confidence Interval of the Difference 95%	
						Lower	Upper
EC	6.19	2.182	2	0.161	0.48667	-0.4730	1.4463
Na^+	39.27	1.671	2	0.237	1.22000	-1.9209	4.3609
Ca^{2+}	15.80	3.077	2	0.091	4.70000	-1.8724	11.2724
Mg^{2+}	11.00	-0.655	2	0.580	-0.50000	-3.7862	2.7862
HCO_3^-	2.30	-5.000	2	0.038*	-0.33333	-0.6202	-0.0465
CL^-	44.40	-1.614	2	0.248	-2.56667	-9.4074	4.2741
SO_4^{2-}	19.37	2.888	2	0.102	3.59667	-1.7620	8.9553
pH	7.64	-0.152	2	0.893	-0.01000	-0.2921	0.2721
SAR	10.73	-0.744	2	0.534	-0.39333	-2.6680	1.8813
PI	61.73	-1.398	2	0.297	-3.04333	-12.4079	6.3213
KR	1.47	-1.327	2	0.316	-0.14667	-0.6221	0.3288

Comparison of the mean values for types of land use (abandoned, pistachio furrow, and crop land), with the mean values of ECe in 2002 also showed they increased more than six times (Table 5). The results of univariate analysis of ECe under different land uses showed that there was a significant difference between the ECe of different land uses (sig = 0.004 and $p < 0.05$). Because the difference between land uses was significant, Duncan's multiple range test (DMRT) used to indicate the significance of the differences between the land use types. The results showed that the difference between the mean values of ECe for land use 1 (abandoned) compared to land use 2 (pistachio orchard) was not significant but the mean value of ECe in land use 4 (drip irrigation) differed significantly from the ECe in abandoned and pistachio orchard land-uses. The mean of ECe in furrow irrigation on all land uses was intermediate (p=0.05, Figure 2). To assess the sustainability of the agriculture in the study area, we compared data obtained in 2018 with the data from soil and water analyses over the past 16 years (Tables 3 and 6). During these years ECe increased sharply, while pH and OC decreased, demonstrating that salinity is tending to increase, a trend which can cause soil degradation over time.

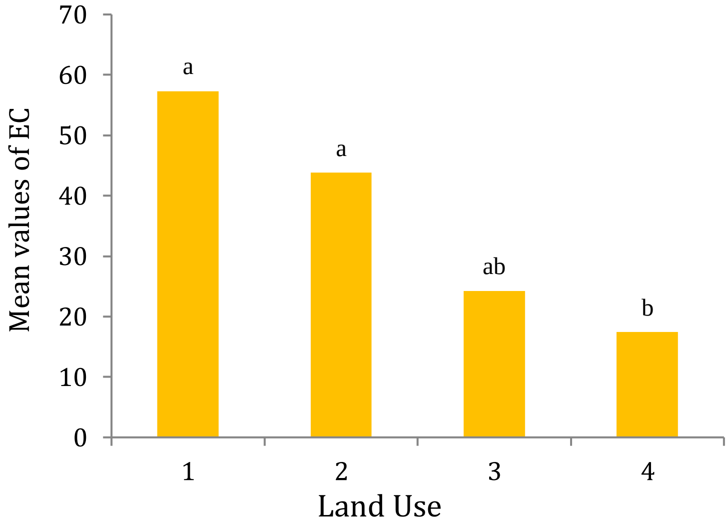

Figure 2. Comparison of EC mean values (128 samples, 0-20 cm) between different land uses by using Duncan's Post Hock test, at %5 level confidence, 2018. Land use 1: abandoned, 2: Pistachio, 3: Cultivated land, 4: Drip irrigation

Spatial variability in surface soil

Figure 3 illustrates the spatial variability of ECe (as the basic indicator of salinity) in the surface soil samples (upper 20 cm) of the pistachio orchards (Figure 1 A and B). All of the study area was classified as hypersaline soil (ECe > 4 dS/m). The highest values of ECe were observed at the middle of the orchard, which is under planted pistachio trees, followed by the abandoned area located on the downward slope that receives the runoff water which has passed through the higher saline area. The area with salinity class of 4–8 dS/m covers about 33% of the studied plot (~ 35 ha). About 20% of the land (21 ha) was found to contain 8–16 dS/m and about 15% of land (16 ha) was classified with salinity of 16–32 dS/m. Areas with salinity greater than 32 dS/m occupied about 8% to less than 1% of the land (Figure 3).

In addition, a comparison of the mean values of surface soil samples analysed for different land uses in 2018 with the mean of the reported results 2002 demonstrates that SOC decreased by at least two to more than three times in all land use types. While the CCE increased in all land use types (Table 5), this is possibly the result of the precipitation of carbonates from irrigation water or from CO_2 deposition in the soil solution. However, mean values of ECe in 2018 increased more than two to seven times in different land use types, compared to 2002. Statistical comparison of the measured ECe in surface soil samples, under both irrigation methods, was significant ($p = 0.0$, $p= 0,023$ and $p< 0,05$).

Discussion

Environmental characteristics

Classification of the study area as an arid region (based on AI classes) means that annual precipitation can only compensate for 13% of potential evapotranspiration (UNEP, 1997). The highest ET occurred in the summer season and exceeded more than 195.5 mm in July. Intensifying agricultural use of the land around the study area and land-use change from dry rangelands to cropping lands and extension of fruit tree plantations, the area that is pistachio cultivated and under drip irrigation is about 5 years old, has increased the need for water, but this can only be obtained from the groundwater. The amount of rainfall slightly exceeds evapotranspiration in three months only (January, February, and December) of each year. Lack of rainfall, along with increased abstraction of groundwater, has depleted groundwater, falling water table from 50 m under 200 m during 20 years, and reduced water quality (Tables 2 and 3). Furthermore, the existence of saline marl formations leads to excessive salinization of groundwater and an increased accumulation of surface salt by irrigation water, diffusion and also capillary movement (Table 3). The hot and arid climate combined with other environmental parameters demonstrate the unsuitability of the study area for agricultural purposes.

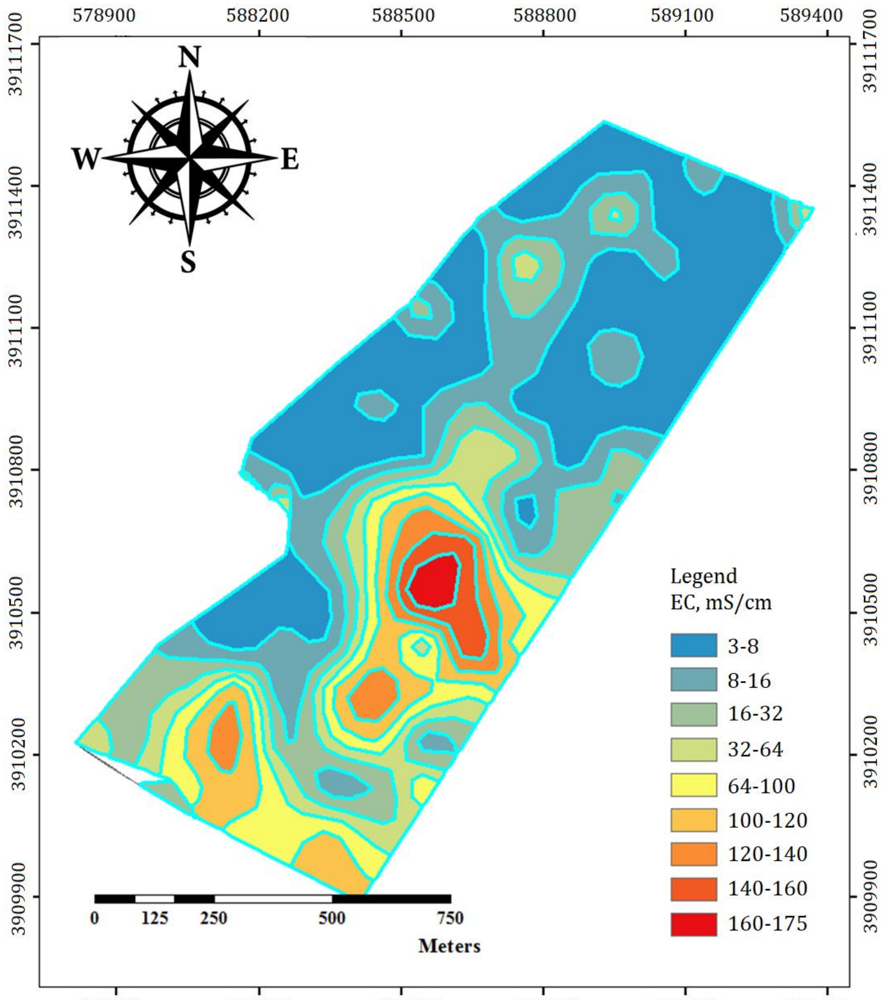

Figure 3. Map of spatial variability of surface soil salinity (0-20 cm) in the studied pistachio orchard, 21 Oct. 2019.

Water Quality

Based on the standards cited in Table 2, the EC of all the water sources was more than twice that of the standards defined by Fipps (2003). The concentrations of Ca^{2+} and Na^{+} in furrow irrigation water were close to the upper limits of the standards with maximum values of 23.5 meq/l for Ca^{2+} and 41.22 meq/l for Na^{+} (Table 3). Mg^{2+} concentration was double the standard limit for irrigation water (9 to 11.5 meq/l), but among the anions HCO_3^- was below the standard limit while the Cl^- concentration was much higher (40 to 45 meq/l) than the upper limit (30 meq/l) (Ayers and Wescot, 1985). Although the calculated SAR values were relatively high, all were in the standard range defined by Fipps (2003), not an acute water quality problem. The PI in the water was in the normal range (Doneen, 1964) but the KR index that should be <1 (Sundaray et al., 2009) was very high (Table 3). However, in the case of drip irrigation water, which is a mix of fresh and saline water, all of the measured and calculated parameters were within the standard range so using it for irrigation does not pose a serious risk.

Except for HCO_3^-, there was no significant difference in the salinity indicators and soluble ions of irrigation water samples taken from Wells 1, 2, and 3 compared to 2008 (Table 3 and 6). The values of EC, Na^{+}, and Mg^{2+} remained relatively constant (Sig > 0.05, Tables 6). However comparison of the concentrations of Ca^{2+}, SO_4^{2-} and Cl^- values with 2008 in Table 3 showed that Ca^{2+} and SO_4^{2-} concentrations have increased while Cl^- concentration has decreased. Dominant anion changed from chloride to sulfate compounds possibly due to the fall in the water table and changes in the composition of the water that is passing through the deeper geological formations. The increased Ca^{2+} and SO_4^{2-} may account for the small decrease in pH values caused by sulfate (Ahmed et al., 2013, Table 3). Evaporation, the water-rock reaction and the weathering of carbonate and silicate minerals are the main factors that changed the chemical quality of ground water in study area. Saline marl formations parent material could be the cause of the predominance of calcium and ground water salinity. Saline alluviums parent material could be the main source of chlorine ions in soil and water system. Calcium is largely responsible for water hardness and decreasing ground water quality. The amount of Ca^{2+}

increased in ground water compare to reference year due to water contact with certain rocks and minerals, especially limestone and gypsum. Also soil $CaCO_3$ increased compare to reference year but as it is insoluble in water so it does not cause hardness whereas calcium bicarbonate is readily soluble in water and causes the hardness of the water by dissolving Ca^{2+} ions in it. Although the contribution of groundwater to soil salinization depends on its depth from soil surface and groundwater near the soil surface contributes effectively to salinization, arid climate and high evaporation could change this fact. The depth of ground water in study area is near 230 m but still there is strong linear relation between groundwater and soil salinity due to high evaporation and capillary movement. In land use 1 this correlation is even stronger than other land uses due to lack of irrigation no water is added from above and interaction between ground water and soil salinity is more. Also, the capillary movement and the existence of texture discontinuity caused more salinity in this land use. In land use 4 the relationship is weak due to mixed irrigation water with fresh water. In land use 4 even if there was a good relationship between ground water and soil salinity it is gone because modified irrigation water is added from above. The result showed positive relationship between the increase in soil salinity and the increase in salinity in groundwater and irrigation water, and as a result, the amount of salinity ions. There is high connection between soil and water ion chemistry and the order of abundance of cations and anions in both soil and water was same ($Na^+ > Ca^{2+} > Mg^{2+}$, $Cl^- > SO_4^{2-} > HCO_3^-$). Demir et al. (2009) stated that the results of studies of the depth and quality of groundwater should be made available to producers so that decisions can be made to maintain the stability of current minimum soil and water characteristics before the development of agriculture in affected areas.

Soil Quality

The studied soils were classified as soil orders Aridisols and Entisols in the first category of the American soil classification system (Table 4, Soil Survey Staff, 2014). The presence of salic and gypsic horizons is characteristic of arid zone soils and restricts many common agricultural uses. The layered sedimentary characteristic, also indicates that several discontinuities exist between parent materials in different soil layers, which may contain large amounts of coarse fragments which limit capillary movement of water within the soil. However, the main sources of water in the furrow irrigation system are hypersaline, the use of which will intensify soil salinization, as has been emphasized in various studies (Pereira et al. 2002, 2009; Qadir and Oster, 2004; Hoffman and Shalhevet, 2007). Considering the extent of study area (170 ha), the depth of irrigation water used (at least 200 mm), EC of irrigation water (7 dS/m) and high evapotranspiration (> 944 mm) a total amount of about 90 kg/ha salt is adding to soil. Regarding that drainage, runoff and leaching are very scarce due to limited rainfall and low slope almost all of the added salt accumulates in soils and due to increase in osmotic pressure restricts water availability for plants.

Dissolved salt variation had different pattern in soil profiles due to different land use, management factors, parent materials and irrigation methods. Table 4 shows the changes of anions and cations for soil profile horizons. This help us to determine the depth of salt accumulation, the mobility of anions and cations, the most mobile ions and the salt transfer agent, which can be the result of upward movement of salt by the capillary movement of groundwater or downward movement through leaching. Particle size distribution is a distinctive feature that separates soil families. Although the fine fraction of the studied soil is loamy, a large amount of coarse fragments shows a sharp difference between the profiles of the marl formation and those of the alluvial formation. These differences have led to higher salt accumulation in the finer particle size classes due to there being less leaching and high capillary rise. The worst case scenario happened in P1 in land use 1 with high amount of clay and without irrigation. Due to high specific surface of fine particle size more saline ions absorbed and the highest amount of EC was observed in this soil profile. The subsoil horizons have coarse texture and high gravel percentage than surface horizon. The maximum accumulation of soluble salts due to high evaporation and capillary rise has occurred near the soil surface that layers are fine texture and have low gravel percentage and after depth of 40 cm, values show a sharp decrease trend due to coarse texture and more gravel percentage. Numerous coarse and fine sediment layers and also high gravel percentage in the subsoil layers observed in profile 8, Land use 1. Against Continuous evaporation, the most amounts of soluble anions and cations were observed in the fine texture horizon which is located under the surface layers with coarse texture and high rate of salt leaching. Furrow Irrigation in P2 in land use 2 with fine loamy texture and without gravels has caused the maximum accumulation of anion chlorine and sodium cation to be about 10 to 20 cm deep instead of the soil surface. Of course, calcium and magnesium cations, as well as anion sulfate after chlorine and sodium, have significant amounts, which did not show many changes with depth and this is expected due to their lower solubility and mobility compared to sodium and chlorine. P 3 in land use 1 and P4 in land use 2 are similar in terms of soil characteristics and classification. Soil texture in both profiles is coarse loamy but in P3, lack of irrigation had led to accumulation of salts and increased salinity compared to P 4 and the total amount of soluble cations and anions in P4 with coarse-textured soils and furrow irrigation is much less than in fine-textured soils. Profiles 6 and 7 inland use 3 with furrow irrigation are located on marl materials, but alluvial materials are also partially mixed. With Attention to fine soil texture, low gravel percentage, agricultural operations, such as soil plowing and irrigation, distribution of salts is mainly at the surface or in the depth of water infiltration. Profile 5 is located in land use 4 and due to continuous wetness by drip irrigation salt leached from surface layers and from a depth of 30 cm onwards a sharp increase in Sodium and chlorine concentrations are observed.

The results of Zhao et al. (2016) showed that there is a significant linear relationship between particle size distribution and soil salinity; different soil textures and their combination in the soil profile play an important role in soil salinity changes. Likewise, many studies of water in abandoned areas (Demir et al., 2009; Qian et al., 2017; Yu et al., 2018) have found that the highest accumulations of Na^+ and Cl^- occurred in the surface layers (Table 4), but they wash out easily with irrigation.

The soil organic carbon content had low amounts in all land uses and irrigation methods. Although OC amount changed slowly compare to reference year but it had large effect on soil physical properties that are important for soil fertility and therefore soil quality. Decreasing OC had negative effect on the soil pore structure, water dynamics, soil hydraulic properties and soluble ion movements and therefor soil quality decreased compare to reference year. Also, Loss of soil organic carbon content limited the soil's ability to provide nutrients for sustainable plant production and led lower yields compare to reference year. The potential effects of SOC in arable topsoil on soil PSDs and soil pore structure which may influence soil hydraulic properties, plant water supply and the physical conditions for root growth was mentioned in other studies (Fukumasu et al., 2022) .

To assess the interaction between different types of land use and changes in salinity, the relations between land use and management should be considered (Taghadosi and Hassanlou, 2017). The study area was under four different types of land use, and results of the analysis of representative soil pedons from each land use type are given in Table 4. The significant differences found showed that changes in land use affect variations in ECe and the result of Taghadosi and Hassanlou (2017) also showed that soils under different land uses have different degrees of sensitivity to salinity. Drip irrigation Land-use was distinctly different from abandoned land and pistachio orchards land uses (Figure 2). Among the land use types in the current study, the highest values of ECe, anions, and cations, were obtained from the abandoned land, which was followed by pistachio orchards, cropland, and drip irrigation produced the lowest values. Qian et al. (2017) examined the most important factors affecting salinity in different land uses and cover types and found that soil salinity in the region was most affected by groundwater salinity and vegetation cover; the least important factor was the distance to the nearest irrigation canal. Comparison of the means of the measured and calculated parameters of all land use types under furrow irrigation with those under drip irrigation revealed that furrow irrigation has led to more severe soil degradation than drip irrigation. This has been identified in many studies of the relationship between salinity and different irrigation management systems (Pereira et al., 2007; Devkota et al., 2015; Miao et al., 2015; Gebremeskel et al., 2018).

Sodium and chloride, which are predominant in all the water samples, were present in lower amounts in this irrigation system. By attention to ECe spot variation in the area under drip irrigation, the problem of salt movement from highly saline areas and therefore the spread of salinity through the whole study area is not observed attributed to water being sprayed near the roots. In drip irrigation, salinity increased between rows of plants due to lack of irrigation, but constant wetting of the area around the roots maintains lower salinity thereby saving water and increasing crop yield. Regardless of the salinity of the soil and the type of crop, there is a generally positive relationship between water use efficiency and the drip irrigation method, and applying drip irrigation in many cases increased crop production in hypersaline soils (Phene, 1986; Pasternak and De Malach, 1995; Burt and Isbell, 2005; Hillel, 2000; Dudley et al., 2008; Hanson et al., 2008; Minhas et al., 2020). It should be noted that, contrary to the findings of this study, there are studies that believe that furrow irrigation can be very efficient if additional measures, such as land levelling and improvements to soil structure, are undertaken (Pereira et al., 2002; Darouich et al., 2014).

It seems that convincing farmers to increase water quality by mixing saline water from wells with fresh water, replacing the furrow method with drip irrigation, as well as using ice to wash off surface salts and direct them out of the root zone will improve conditions.

Increasing salinity parameters (such as ECe, SAR, KR, RSCB) and generally high concentrations of cations and anions, compared to the normal range for agricultural use and 2008, indicate a progressive trend of degradation and decrease of soil quality in the study area. High values of SAR in some parts were associated with poor water infiltration and increased water loss by evaporation due to waterlogging. However, RSC showed a reverse trend, with a negative value in all land uses, demonstrating that there no excess HCO_3^- or CO_3^{2-} anions are available to react with Na^+ and produce sodium carbonate, which causes a rapid increase of soil pH. The decrease in means of pH values compared to 2002 can be attributed to these negative values of RSC, which may be the result of the changing composition of irrigation water from sodium- and chloride-dominated to calcium- and sulfate-dominated water, due to the extraction of water from increasingly deeper levels.

Although all segments of the soils in the pistachio orchard were hypersaline, salt was not evenly distributed through the different locations. The uneven salt distribution is mainly due to the difference in the composition of parent materials; fine-textured saline and gypseous marls contain high accumulations of salt but less salt accumulates in gravelly alluvial deposits inter-bedded between eroded marls (Table 4). There is an area with extremely high salinity in the central part of the pistachio orchard that acts as a salt source for the surrounding areas, and needs to be managed to prevent the movement of salt into adjacent regions.

As mentioned above, saline soils and water have predetermined definitions, but these do not work for hypersaline soils and water. In arid regions such as Iran, hypersaline environments have existed for centuries and saline agriculture has been established on them for many years. In the study area, during the last 60 years, some areas of the land have been abandoned due to severe reductions in yield, but in other parts farmers still continue with saline agriculture as in the past, without special changes in management. Salinity tolerance pistachios is 8.4 dS/m and pistachio is sensitive spatially in early vegetative growth. With increasing the average salinity of the root zone (ECe) from 4 to 10 dS/m, the pistachio yield potential percentage decreases from 100 to 50. According to our studies, farmers will face severe declines in yield in all parts of the country in the near future, due to soil and water degradation, and if they do not change their ways they will be forced to abandon more areas. In many parts of the world that are located in arid regions and faced with problems of hypersalinity these definitions have been examined and land use type, land suitability, yield, and irrigation methods have been assessed or changed in order to develop the best management methods (Pasternak and De Malach, 1995; Hanson et al., 2008; Minhas et al., 2020). Changing land use in the study area is very difficult due to farmers' heavy dependence on their lands to meet their needs and, indeed, their very survival (Cheraghi, 2004; Taghadosi and Hassanlou, 2017).

Conclusion

The sustainability of hypersaline agriculture around the world is not very well studied. The availability of land suitable for agriculture in the studied arid region is scarce. Mismanagement of the saline and hypersaline soils and water accelerates the degradation and abandonment of agriculture. To improve the existing fragile conditions, and to develop adequate management methods, it is essential to characterize soils and irrigation water quality and to monitor changes. Due to the high sensitivity of the economic and social conditions in these arid regions, special management is needed to sustain agriculture. Using hypersaline water in hypersaline soils should be controlled precisely, using scientific approaches. Full characterization of the environment, soils, and water play the most important role in achieving suitable management approaches. Taking into consideration all the measured characteristics in the soils along with the calculated soil salinity indicators, all of the soils have become severely degraded, especially in the abandoned and pistachio plantation areas. Increasing salinity parameters (such as ECe, SAR, KR, RSCB) and generally high concentrations of cations and anions, compared to reference year indicate a progressive trend of soil. High values of SAR in soil were associated with poor water infiltration and increased water loss by evaporation due to waterlogging. The parent material of the soil are saline marl and alluviums therefore soil is contain considerable amount of saline ions. Although all segments of the soils in the pistachio orchard were hypersaline, salt was not evenly distributed through the different locations. The uneven salt distribution is mainly due to the difference in the composition of parent materials; fine-textured saline and gypseous marls contain high accumulations of salt but less salt accumulates in gravelly alluvial deposits inter-bedded between eroded marls. Among the types of land use, abandonment of the land was associated with the worst degradation while the best was drip irrigation water, pistachio plantations had the next highest level of salt accumulation after the abandoned areas. Maize and barley cultivation systems were less saline than pistachio plantations due to their use of more irrigation water. Land use change from dry rangelands to cropping lands has increased the need for irrigation water. The study area is located in arid climate which the amount of rainfall slightly exceeds evapotranspiration and irrigation water is mainly supplied by groundwater from deep wells. Using deep well irrigation led to sink water table, besides degrading the water quality. A large amount of residual salt in the soil becomes active and the high rate of evaporation caused soil salinization reaches the surface by capillary movement. The analysis result indicated a gradual change of salinity and chemical composition of irrigation water from sodium- and chloride-dominated to calcium- and sulfate-dominated water, due to the extraction of water from increasingly deeper levels. All of the measured and calculated parameters for water sources were far from the standard range for irrigation and in the opposite in the case of drip irrigation water, which is a mix of fresh and saline water, all of them were within the standard range. Comparison of the means of the measured and calculated parameters of all land use types under furrow irrigation with those under drip irrigation revealed that furrow irrigation has led to more severe soil degradation than drip irrigation. The land use status quo intensifies the hazard of irreversible land degradation in the not so distant future. Possible solutions to this challenge, which would prevent rapid degradation, could include reconsidering the present forms of land use, limiting the further change of rangelands to conventional agriculture, and changing irrigation systems to drip irrigation. Removal of salt crusts from the soil surface at the end of the dry season may also help to reduce the hazard of salinization. Introducing other agricultural systems, such as greenhouse crops that have lower water requirement along with producing higher incomes for farmers, may be another solution. Providing management solutions appropriate to the conditions found in arid regions needs much more detailed studies.

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