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Full Length Research Paper

Soil physicochemical properties and vegetation pattern in an arid environment affected by a salt diaper

Reza Ghazavi[1,2]*, Abbasali Vali[1,2], Reza Ghasemiphassai[3] and Saied Eslamian[4]

[1]Department of Agriculture and Natural Resources of Drab, Shiraz University, Iran.
[2]Departments of Natural Resources, Kashan University, Iran.
[3]Department of soil, Shiraz University, Iran.
[4]Department of Water Engineering, Isfahan University of Technology, Iran.

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Soil degradation, most notably caused by salinization and water-logging, creates formidable problems in arid and semi-arid environments. Advancing our knowledge of salt-affected soils is a prerequisite for understanding how salinization affects environmental concerns, such as soil erosion, nutrient leaching, and lack of vegetation cover. Therefore this study investigated the impact of salt diapirs on soil physicochemical conditions, as well as explored the relationship between halophytic vegetation and soil factors, and described the composition and distribution of plant species in relationship to soil salinity. The study area was divided into three units based on different geomorphologic conditions, slopes and vegetation type. Changes in salinity, soil properties and vegetation were studied. Results showed that the proportion of clay increased while silt and sand decreased with increasing distance from salt diapirs. The presence and kind of ions in all samples consistently indicated high levels of Na, and moderate levels of Mg, Ca, and K. Based on the soil conditions, plant covers were changed to types with more resistance to salinity and water-logging. Typically, this results in a decrease in soil structure stability through degradation of soil aggregates and a variation in the composition of the vegetation toward undesirable species.

Key words: Salt diapirs, salinization, soil physicochemical properties, vegetation pattern, arid environment.

INTRODUCTION

Diapirs are geological formations that occur when a body of rock rises and pierces through overlying rocky material (Jenyon, 1986). Many studies have been done involving analyses of diapir formation in different areas in the world (Jackson and Talbot, 1986; Weinberg, 1996; Miller and Paterson, 1999; Vendeville, 2002; Jallouli et al., 2005; Pinto et al., 2005). Among the different forms of diapirisms described in the bibliography, the most numerous are those in which rock salt constitutes the rising material (Jackson et al., 1990). Although there is an extensive bibliography on diapiric formations, it is from a geological point of view (Bruno, 2000), and not in the case where soil science is concerned. Therefore, considering environmental interests in such areas, pedologic studies on the characteristics and distribution of soils in the area affected by complex diapiric formations are essential. In most regions affected by salt diapirs, salty water reaches the shallow aquifer system. This long-term phenomenon is manifested by the occurrence of salty springs and by the growth of salt grass in the inner part of the basin (Sharma, 1998). The increase of salt in the basin coming from salt diapirs can be considered one of the most important indicators of the extent of soil desertification processes.

Among the causes of desertification, salinization, which is induced by several factors, is raising the greatest concern in arid and semi arid areas (De Paz et al., 2006). Desertification is the soil degradation and loss caused by various factors, including short- and long- term climatic variations, human activities, and the natural expansion of existing deserts especially in arid, semi-arid, and dry sub-humid areas (Glenn et al., 1998; Sharma, 1998).

*Corresponding author. E-mail: Ghazavi@shirazu.ac.ir or rghazavi@yahoo.com. Tel: +98 9171887058. Fax: +98 7326343209.

Table 1. Characteristics of three different units in the study area.

Unit	Vegetation type	Slope (%)	Area (km^2)	Altitude (m)	Litology	Geomorphological form
1	*Aeluropus littoralis* (Ae.li)	>5	7.93	1000-1400	calcareous sandstone	Slow hillside
2	*Juncus gerardi* (Ju.ge)	2-5	10.57	1060-1100	Limestone, calcareous sandstone	Pediplain
3	*Halocnemum strobilaceum* (Ha.st)	<2	34.37	1020-1060	Limestone, calcareous ,sandstone	Plain

Desertification includes mainly the reduction of vegetative cover and species diversity, loss of soil structure, decrease in soil fertility, alteration of hydrological cycles, and reduced crop yields and livestock production (Sivakumar, 2007; Glenn et al., 1998; Sharma, 1998). Soils affected by salinity are characterized by rising water-tables and water-logging of lower lying areas in the landscape (Sharma, 1998). Sodic soils are high in exchangeable sodium, slake and disperse upon wetting. On drying, massive hard setting structures are formed, which suffer from poor soil-water relations largely related to decreased permeability, infiltration and the formation of surface crusts. An increase in salinity and sodicity directly impacts upon plant vigor through changes in osmotic potential, ion toxicities and deficiencies. Effects on vegetation can result from soil conditions such as dispersion and low permeability (Wong et al., 2004; Ghazavi et al., 2010).

High concentrations of soluble salts in the root zone impose physiologic stresses on growing plants (Maas and Hoffman, 1977). Changes in salinity and sodicity affect the soils' physical and chemical properties, which subsequently alter nutrient cycles and decomposition processes (Zsolnay, 1996; Gigliotti et al., 1997). The risk of erosion increases, while soil's physical and chemical properties are altered, impacting aggregation and nutrient cycling as well as biotic activity (Shiralipour et al., 1992; Bryan et al., 1989). Therefore, there is a clear linkage between land management practices through their effect on salinity and sodicity with soil erosion and plant production (Wong et al., 2004). Over 6% of the world's land is affected by either salinity or sodicity (Munns, 1993). Despite the large area affected by salinity and sodicity, data on the magnitude and mechanism of changes in soil properties in these degraded environments is limited. In addition, few studies are conducted to demonstrate the effect of increasing salinity by salt diapirs on soil properties and vegetation cover (Pankhurst et al., 2001). Advancing our knowledge of salt-affected soils is a prerequisite for understanding how salinity affects environmental concerns such as soil erosion, nutrient leaching, and lack of vegetation. Salt diapirs are generally considered as the primary sources for soluble salts in the area affected by them.

Therefore, the objective of this study was to characterize the relationships between vegetation, landform and soil physicochemical properties in the area affected by salt diapirs. It also assessed the impact of salt diapirs on soil properties, relationship between halophytic vegetation and soil factors as well as described, the composition and distribution of plant species in relationship with soil salinity.

MATERIALS AND METHODS

Study area

The study site named Korsia located in a catchment 15 km North-East of Darab, Fars, Iran (Figure 1). Darab is located in a semi-arid zone. According to local meteorological data measured in synoptic station at 2 km from the study area (Station Hasanabad, Darab), the area has a mean annual rainfall of 290 mm of which 85% occurred in the autumn–winter period, 13% in the spring, and only 2% in the summer. The mean annual air temperature is 22°C, ranging from 9.6°C in January to 34°C in July.

There is a salt diapir in the study area named Korsia diapir (latitudes 28°47' 28" N, longitudes 54°17'30" E), located in an area of quaternary deposits located to the south of the salt diapir with a gentle slope towards the south, and an average elevation of 1095 m above mean sea level. The soil in the study area is mostly saline and therefore unsuitable for agriculture. All the land is covered by rangeland vegetation, except for bare patches in areas where the soil salinity is very high. The vegetation in the study area consists of three growth forms of halophyte type: shrub (*Halocnemum strobilaceum*), grass (*Juncus gerardi*) and (*Aeluropus littoralis*).

Data monitoring and analyses

The study area was divided into three units, based on different geomorphologic conditions, slopes and vegetation type (Table 1 and Figure 1). The type of vegetation in the study area was determined using Bonham (1989) method. In each unit, one or two species that have maximum percentage and frequency were determined as the vegetation type. In total, three vegetation types were determined: *Aeolin litoralis* (Ae.li), *J. gerardi* (Ju.ge), and *H. strobilaceum* (Ha.st). Three 100 transects were established randomly on the slope direction at any unit (Figure 1). Along each transect, ten 5 m^2 plots were located every 5 m. Changes in salinity, soil properties and vegetation were studied in each plot. Soil samples (3 per plot) were collected from two soil depths: 0 to 20 and 20 to 40 cm. All soil samples were air-dried and passed through a 2 mm sieve prior to analysis and all samples were extracted and analyzed in duplicate. Particle size analyses were determined by the hydrometer method. pH values were

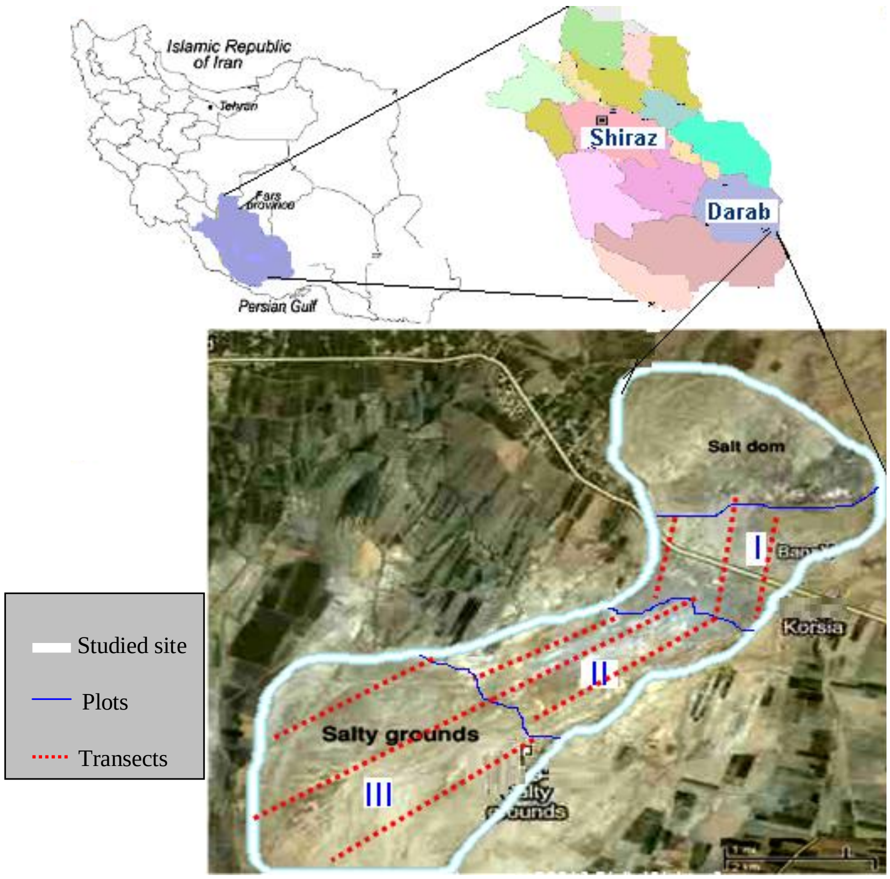

Figure 1. Sketch map of the study site and studied transects in the Darab city, Korsia basin, Fars province – Iran.

determined potentiometrically in a 1:2.5 soil-water ratio (ISRIC, 1993). Electrical conductivity was measured in saturation pastes after a 4 h equilibration. Sodium and potassium values were determined using Flam photometry method. Calcium and magnesium values in saturated entreat were measured by atomic absorption spectrophotometer (Philips PU9100X).

The list of existing species, canopy cover, production and density of plant species were measured inside each plot. The clipping and weighting method was used for measuring plant production. Clipped materials from plants were placed into an air circulating oven (at 65°C for 48 h) for dry matter (DM) determination. After drying the plants, the production in each plot was calculated per g/m, the production was then expressed in kg/ha. The line-transect method was used to measure the canopy cover (Bonham, 1989). The total cover of vegetation included both herbaceous and shrubby plants**.** Random pairs method was used to estimate plant density. The MINITAB statistical package (Minitab 14 Statistical Software) and Excel (Microsoft Office Excel 2009) were used to conduct analysis of the data. A one-way ANOVA with multiple comparisons was used to test the equality of means and to assess the differences in means between the units in the study area.

RESULTS

Soil physical properties

The soil particle size distribution at 0 to 20 and 20 to 40 cm depth are shown in Table 2. Clay content in the 0 to 20 cm in Unit 1 is less than 12%. The results of the analysis showed that the amount of clay increased with increasing distance from salt diapir. The clay content in the 0 to 20 cm in unit 2 was between 19.56 and 24.2% with a mean of 21.4%. Increasing clay was accompanied by decreasing silt and sand percentage. Mean difference of the clay was statistically significant ($P<0.05$) among three units, while the mean difference of silt was not significant ($P<0.05$). The amount of sand decreased from Unit 1 to 3. The mean difference was significant between Unit 1 and the other units ($P<0.05$). Changes in clay, silt and sand percentage were less considerable for 20 to 40 cm depth.

No significant difference was observed between clay, silt and sand percentage in Units 1 and 2. Significant differences in percentages of clay and sand between Units 2 and 3 were observed. Infiltration rate decreased with increasing distance to the salt diapir. A significant difference was observed between the infiltration rate for three units ($P<0.05$).

The infiltration rate increased with depth in Units 1, 2, and 3. Infiltration rate increased from 8.59 to 10.86 mm/h in Unit 1 and from 3.48 to 5.65 mm/h in Unit 3, respectively.

Table 2. Soil physical characteristics in the three different units of the study area.

Unit	Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	Infiltration rate (mm/h)
1	0-20	11.6[a]	55.42[a]	32.98[a]	8.59[a]
	20-40	[x]14.6	[x]51.44	[x]33.96	[x]10.86
2	0-20	21.44[b]	56.08[a]	22.48[b]	6.34[b]
	20-40	[x]14.44	[x]53.08	[x]32.48	[y]7.32
3	0-20	25.6[c]	58.54[a]	15.86[b]	3.48[c]
	20-40	[y]16.6	[x]60.44	[y]22.96	[y]5.65

Values in a column for a parameter with different superscripts are significantly different at P < 0.05.

Table 3. Selected chemical soil characteristics in the soil in the study area.

Unit	Soil depth (cm)	Mg ($MeqL^{-1}$)	Ca ($MeqL^{-1}$)	K ($MeqL^{-1}$)	Na ($MeqL^{-1}$)	pH	EC (dsm^{-1})
1	0-20	10.5	11	2.9	573.9	8.03	43.68
	20-40	6.5	14.5	3.76	430.12	8.03	33.6
2	0-20	10	13.5	3.9	593.9	7.69	48.56
	20-40	7.2	15	3.65	491.3	7.6	39.32
3	0-20	9.5	12.5	3.4	656.9	7.97	68.32
	20-40	7	14	3.7	599.2	7.96	51.32

Table 4. Soil moisture content and standard its division in two studied depths.

Unit	Depth (cm)	Soil moisture (%)
1	0-20	10.7±1.54
	20-40	14±1.48
2	0-20	18.4±2.31
	20-40	20.65±2.46
3	0-20	17.67±1.84
	20-40	21.5±2.14

Overall, the higher infiltration rate of subsoil than topsoil is mostly related to the higher amounts of coarse particles, especially sand contents of subsoil comparison with topsoil.

Soil chemical properties

The concentration of soluble salts, electrical conductivity (EC) and pH variability are shown in Table 3. Salt-affected soils differed in their chemical properties with other soils. Salinity may affect the vegetation type and density. Interpretation of soil ions contents from the study area indicated relatively moderate levels of Mg, Ca, K and high levels of Na in all soil samples. Mean value of Na indicated that the rate of Na increased from units 1 to 3 (573.9, 593.9 and 656.9 $MeqL^{-1}$, respectively for units 1, 2 and 3 in top soil; 430.12, 491.3 and 599.2 $MeqL^{-1}$ for units 1, 2 and 3, respectively). Corresponding EC were 43.68, 48.56 and 68.32 dsm^{-1} for topsoil of units 1, 2 and 3, respectively and 33.6, 39.32 and 51.32 dsm^{-1}, respectively for units 1, 2 and 3 in the sub soil.

Concentration of Mg decreased from unit 1 to 3. Higher concentrations of Mg were observed in the top soil compared to the sub soil. The difference in Ca and K between the top soil and the sub soil was low. Soil salinity was increased from unit 1 to 3. Also, Unit 1 was the nearest to salt diapir than the other units, physical and geomorphological characteristics of the study basin (slope, infiltration, soil physical parameter) caused salinity transference via sub-surface. The intensity of soil acidity or alkalinity is expressed in pH, which indicated relatively stable values throughout the different depths, and negligible variability at each Unit of the study site (Table 3). The value of pH was higher in Unit 1 and near the salt diapir (8.03 and 8.03 at Unit 1, 7.69 and 7.62 at Unit 2, 7.97 and 7.96 at Unit 3 for 0 to 20 and 20 to 40 cm depths respectively) but these differences were not statistically significant (P<0.05).

Soil moisture regime

Soil moisture variability is shown in Table 4. Soil moisture

Table 5. Summary of vegetation analysis versus soil condition in the study area.

Unit	Altitude (m)	Slope %	Soil texture			Vegetation type	Density steam/ha	Canopy cover (%)	EC (dsm^{-1})
			Clay	Silt	Sand				
1	1100-1400	>5	13.1	53.43	33.47	*Aeluropus littoralis*	7084.16	20.21	38.64
2	1060-1100	2-5	17.94	54.58	27.48	*Juncus gerardi*	5485.19	11.12	43.94
3	1020-1060	<2	21.1	59.49	19.41	*Halocnemum strobilaceum*	6102.09	41.75	59.82

was 10.7, 18.4 and 17.67% for 0 to 20 cm and 14, 20.65 and 21.5% for 20 to 40 cm in Unit 1 to 3, respectively.

Vegetation analysis

The summary of the vegetation analysis is presented in Table 5. *H. strobilaceum*, *J. gerardi* and *A. litoralis* were the ubiquitous species, respectively in Units 1, 2 and 3. The three vegetation communities distinguished are thus explained.

Aeluropus community

Aeluropus is a genus of grass in the Poaceae family. Two species of *Aeluropus* were found in Unit 1, namely *Aeluropus lagopoides* and *Aeluropus littoralis*. Both species are salt excretive grasses that grow in patches of mats in highly saline and moistened soil.

Juncus community

Juncus is a genus in the plant family Juncaceae*. Juncus* is recorded as being salt-tolerant and can out-compete other species in the saline conditions. It is a wide spread species, tolerant of high salinity that are found in both inland and littoral sabkhas. Increased dry-land salinity of low lying areas in the study area has seen an increase in the abundance of these species.

Salsola-Halocnemum community

These shrubs have succulent leaves and vary greatly in their palatability to animals. They can grow in salt and have water logging tolerance. Some of the other species in this association are: *A. lagopoides, Petrosimonia birandii, Kochia prostrata, Cynodon dactylon, Agropyron cristatum, Atriplex lasiantha,* and *Reaumuria alternifolia*. *Halocnemum* association occurs on highly saline sites which are in many cases waterlogged at certain times of the year. Change in vegetation type showed that salinity was an important factor in affecting the distribution of halophytic vegetation in the study area. As the result showed, the amount of clay and silt increased and the general slope decreased from Unit 1 to 3. Electrical conductivity was 38.64 $ds.m^{-1}$ at Unit 1 and increased to 59.82 $ds.m^{-1}$ at Unit 3. According to soil condition, plant vegetation type was changed to a plant more resistant to salinity and water-logging. This result can be helpful for salinity management. The approach to salinity management for more than 2 decades has been focussed on using vegetation types and distribution patterns to eliminate the supply of water which causes the mobilisation of salt in catchments.

DISCUSSION

The major concern of the farming community regarding salinization of farmland is that the area of useful land being salinised continues to increase. Major causes of land degradation in the study area are soil erosion, salinization, and desertification which also affect native vegetation due to salinization. This study showed that each year, salt diapirs add a lot of ions to the inner part of the basin and causes physical and chemical soil degradation. Increase of soil moisture in the deeper layers can be related to the amount of sodium. High levels of sodium restrict water holding capacity. In areas where sodium levels are high, when the soil dries out, hard massive structures form which look like round-topped columns. These columns do not allow roots to penetrate, so the only water and nutrients which are available to plant roots come from the small surface area surrounding these structures. The plants are thus allowed only a small percentage of the total possible volume of soil in which to grow. Other studies have shown that salinity, pH, moisture and available nitrogen were the major soil factors responsible for variations in the pattern of vegetation (Li et al., 2008; Sánchez-Lizaso et al., 2008). Sodium prevents soil clay particles from gathering together into small aggregates (soil flocculation), consequently poor drainage and water logging occurred. Managing the mechanism which mobilises salt in catchments is a basic requirement for the control of salinisation. Transporting agents that accumulate the salts from salt diapirs to the other parts of the basin usually include water and wind.

Wind erosion involves detachment of salt particles from the salt diapirs surface by either the wind stream itself or by the bombardment of the soil surface by the soil particles which already exist in the wind stream. Once they are detached, salt particles can be transported by

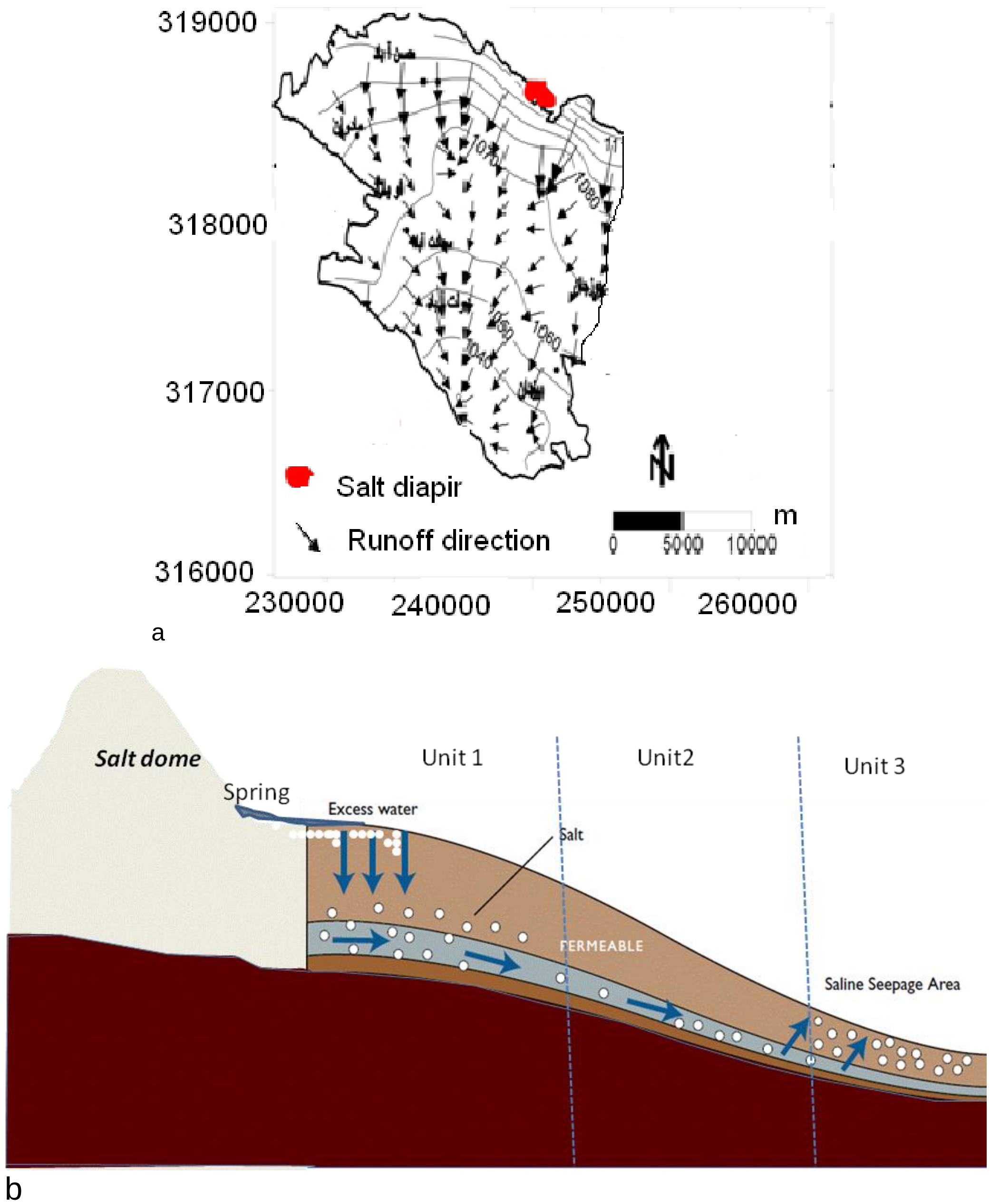

Figure 2. a) Topographical map, runoff direction and b) Schematic of the study area and saline transportation via sub-surface water.

the wind stream and deposit in the inner parts of the basin. The potential for wind erosion is the highest in the studied salt diapir, because the soils are bare and dry. Occurrences of salty springs in the area caused salts in the parent material (salt diapirs) to be dissolved by the water moving through the soil and to be transported by sub-surface groundwater flow (Figure 2). The sub-surface water with the dissociated salt ions will percolate through the shallow soil, moving laterally as it moves downward through the vadose zone to the water table. The presence of salt migrating through the soil may increase the soil density as the soil accumulates in the pores, thereby reducing permeability. The accumulated salinity in soil allows lower moisture retention as well as retardation of water uptake by plants, both of which compromise plant growth and soil erosion control.

Development of soil salinity is a long-term, but can be controlled by good management of both surface and groundwater resources. Biological and structural methods are used to control soil salinity. Generally, structural controls work faster than biological controls in order to lower water tables and improve accessibility in discharge areas. Unfortunately, structural controls are usually more expensive than biological ones and are not always completely effective. The salinization process involves a set of complex changes required at the catchment scale to control the movement of the salts including:

(a) Controlling the water movement that transports the salts. In discharge areas, surface and subsurface water management or relief wells are sometimes used to control saline seeps, if the conditions are appropriate. In recharge areas, surface water management may be used if ponding is a problem. Water of the saline spring can conduct to some pools. After transpiration of water, the remaining saline can be used for a domestic or industrial consumption. Numerous studies have been published about desalinating of subsurface water (Al-Wazzan et al., 2002; Karagiannis et al., 2008).
(b) Protecting remnant vegetation on salt diapirs and in the saline area of the basin. This provides soil erosion control and has the added benefit of helping to maintain the biodiversity and heritage values of the landscape. Vegetation structures have a strong impact on soil properties, water availability and distribution, and soil and water quality (Ghazavi et al., 2008). Using plants to remove extra salt out of the soil is proposed in different areas of the world (Dehghani et al., 2010; Kotzer, 2005). While there is more to be done scientifically, many of the existing ideas are still not being used as widely as they need to be. Integrated catchment management is an existing system which requires application of all its principles to achieve integrated salinity management. Management of salinisation will involve the application of a suite of biological and engineering options which, collectively, will achieve both a reduction in recharge across the range of landscape management units in a catchment and constrain groundwater discharge (seepage) to a manageable quantity of water in acceptable locations in the catchment.

Conclusion

This study showed that salt diapirs could add a lot of ions to the inner part of the study basin. The net effect of these changes generally is a decrease in soil structural stability via degradation of soil aggregates and a variation in the pattern of the vegetation toward undesirable species. The salinization process affects agricultural production, surface and groundwater qualities and their uses, the natural ecosystems of streams and landscapes and public infrastructure (roads, bridges and urban amenities).

Thus, there are many potential benefits to managing salinization, and these need to be included in any cost-benefit analysis of management options. Further research however, is necessary to identify salt diapir impact on soil physical and chemical properties. More soil physical parameters and geological condition as hydraulic conductivity and geological condition could be integrated to develop the impact of salt diapir on soil condition and vegetation cover.

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