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SOIL AND GROUND WATER SALINITY AND THEIR RELATIONS TO PHYSIOGRAPHY[1]

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Abstract – Detailed study of soil and ground water salinity revealed that the type and degree of salinity mainly follow physiographic factors. Soils and ground water with no salinity problems are found in the fans, upper terraces and high plateaus that have very deep ground water. Soils and ground water with slight to moderate salinity problems composed of chloride-sulphate or sulphate-chloride types are found in the piedmont alluvial plains. Soils and ground water with severe to very severe salinity problems composed of the chloride type are found in the alluvial plain and lowland areas. It was concluded that, with the exception of piedmont alluvial plain and some non-gravelly parts of river alluvial fans and upper terraces, the study area was not suitable for agricultural activity, due to extreme salinity or topographic and stoniness limitations.

INTRODUCTION

Iran, with the exception of the northern Elburz mountain region, belongs to the arid and semi-arid climatic zone. It has been estimated that 25 million hectares of this country are affected by salinity and/or alkalinity [5]. This represents 15% of the total land surface, 30% of the plains and gentle sloping land, and 50% of the potentially irrigable areas.

Regional distribution of these Iranian soils is well known and problems of soil management have been discussed in many soil survey reports. However, no fundamental research work has been conducted on the type of salinity and relation of ground water salinity to soil salinity.

The purpose of this paper was to identify the type of soil salinity occurring in different physiographic units and relate it to the chemical composition of the ground water.

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1. Contribution from the Department of Soils, College of Agriculture, Pahlavi University, Shiraz, Iran. Part of this work is reported by the author in *Semi-detailed and Reconnaissance Soil Survey Report of Sarvestan Area, Fars Province (Ostan)*, Soil Institute of Iran, Ministry of Agriculture, publication No. 349, Tehran, Iran.

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MATERIALS AND METHODS

Description of the area and sampling procedure

The study area, a typical intermountain basin, is located about 40 km southeast of Shiraz, in the southern inland belt of Iran. The climate of the area is characterized by marked continentality, with very high summer temperature and rather cold winters. An analysis of temperature records during the period of 1950–1974 shows that July, with an average temperature of 28.4°C, is the warmest and January, with an average temperature of 6.2°C, is the coldest month of the year. The average rainfall of 332.3 mm reveals a Mediterranean type climate with winter rains and practically dry summers. The soil moisture regime of the studied area according to the rational system of climatic classification of Thornthwaite [10] and the system of Newhall [7] is 'xeric'.

The soils of the Sarvestan valley have been deposited under lacustrine and semi-lacustrine conditions within the valley and alluvial–colluvial fan and associated flush-plain deposits at the outer margins of the valley. This type of deposition formed following physiographic units with different salinity status (Figs. 1 and 2): lowland and alluviai plain with a severe to very severe salinity problem under lacustrine condition; piedmont alluvial plain with slight to moderate salinity problem under semi-lacustrine condition; and alluvial fan, alluvial–colluvial fan, upper terrace, and high plateau with no salinity problem at the outer margin. Based on the soil survey map of the Sarvestan Area

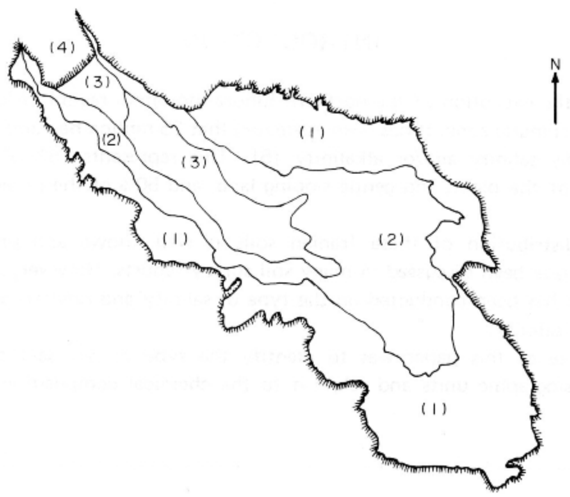

Fig. 1. Sampling locations: (1) Land with no salinity problem (alluvial–colluvial fans, river alluvial fans, upper terraces and high plateau). (2) Land with slight to moderate salinity problem (piedmont alluvial plain). (3) Land with severe to very severe salinity problem (alluvial plain and lowland). (4) Salt lake.

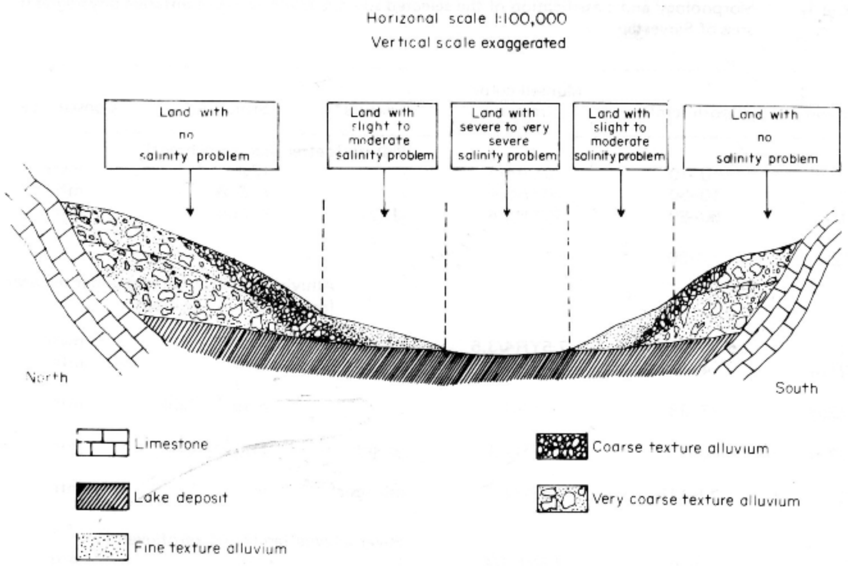

Fig. 2. Schematic cross-section showing relations between landscape and degree of salinity in the studied area.

[1] six typical profiles from each physiographic unit were selected.

The soils were described and classified (Table 1) according to *Soil Survey Manual* [8] and USDA *Soil Taxonomy* [9].

Ground water samples for analyses of their qualities were collected during the end of spring from each study site in two-liter plastic bottles after rinsing the bottle with the water being sampled. Within the valley with shallow ground water, the water was sampled directly from the studied pit and at the outer margins; with deep ground water, the water was sampled from the exposed well of a nearby area.

Chemical procedure

The following methods were used for chemical analyses of ground water and saturated soil extracts: pH was determined electrometrically by a Beckman pH-meter. Conductivity (total soluble salts) was measured by using a conductivity bridge and the results were expressed in $m\Omega^{-1}cm^{-1}$ and $\mu\Omega^{-1}cm^{-1}$ at 25°C for soil and ground water samples, respectively. Methods previously reported [11] were used to determine calcium and magnesium titration with ethylenediaminetetra acetic acid; sodium by flame photometer using NaCl for making standard solutions; chloride by titration with $AgNO_3$ with potassium chromate as indicator; sulfate by gravimetric barium sulfate procedure; and carbonate and bicarbonate by titration with 0.01 N sulfuric acid with methyl orange and phenolphthalein as indicators.

Exchangeable sodium percentage was calculated from exchangeable sodium and CEC;

Table 1. Morphology and classification of the selected soil occurring on representative physiographic area of Sarvestan

Horizon	Depth (cm)	Munsell color (moist)	Texture*	Structure*	Consistence*
			Plateau (petrocalcic xerochrept)		
A1	0–10	10YR4/3	l	f2gr	mvfr
B2	10–50	10YR5/4	l	m2abk	mfr
C1ca	50–80	10YR5/4	gl–gsil	m2abk	mfr
C2ca	>80				
			Alluvial–colluvial fan and upper terraces (calcixerollic xerochrept)		
A1	0–4	7.5YR4/3.5	l	f1pl†f1gr	mvfr
B21ca	4–17	7.5YR4/4	l	f2sbk	mfr
B22ca	17–38	5YR4/4	cl	m1pr†m3abk	mfi
B23ca	38–72	5YR4/4	gc–gcl	f1pr†m2abk	mfi
IIC	72–115	5YR4/4	gsic–gsicl	m	mfr
			River alluvial fan (typic xerofluvent)		
A1	0–25	7.5YR4/4	l	f1gr	mfr
IIC1	25–47	7.5YR4/4	gsl	f1sbk†m	mfr
IIIC2	47–87	5YR4/4	gsl	m	mfr
IVC3	87–120	7.5YR4/4	gl	m	mfr
			Piedmont alluvial plain (xerollic calciorthid)		
Ap	0–8	5YR4/4	sic–sicl	m1sbk†m1gr	mfr
B21ca	8–25	5YR4/4	sic	m3abk	mfi
B22ca	25–40	5YR4/3	c	m3sbk	mfi
IIC1cs	40–110	5YR4/3	c–cl	m1sbk	mfi
IIC2cs	110–150	7.5YR5/3	cl	m	mfi
			Alluvial plain (gypsic salorthid)		
Asa	0–8	5YR4/3	sic	m2gr	mfr
C1sa	8–20	5YR4/3	c–sic	m1sbk†m1gr	mfr
C2sa	20–55	7.5YR4/4	cl–sicl	m3sbk	mfr
C3sa	55–90	5YR5/4	cl–sic	m3abk	mfi
C4sa	90–120	5YR4/4	cl	m1sbk	mfi
C5sa	120–145	5YR6/4	cl–sicl	m	mfi
			Lowland (aquollic salorthid)		
C1sa	0–10	5YR5/4	cl	m2gr	mfr
C2sa	10–55	5YR4/4	cl	f1sbk†m2gr	mfr
C3sa	55–70	5YR4/6	c	m2sbk	mfr
C4sa	70–100	5Y 4/3–4/6	cl	m	mfr

*Symbols used according to abbreviation given in *soil survey manual*. U.S. Dept. Agric. Handbook No. 18, pp. 139–140 (1951).

†Indicated primary structure that parts to secondary structure when disturbed.

Table 1 continued

Boundary*	Other components
cs	Calcareous; abundant fine roots
cs	Calcareous
–	Calcareous; with many secondary calcium carbonate powder/pocket and concretions
	Hard, massive, carbonate accumulation (Petrocalcic horizon)
cs	Calcareous; abundant fine roots
cs	Calcareous; with few secondary calcium carbonate; plentiful fine roots
cs	Calcareous; with many secondary calcium carbonate; few fine roots; 1–2 per cent fine gravel
gs	Calcareous; with common secondary calcium carbonate; 15–25 per cent fine and coarse gravel
–	Calcareous; 50–70 per cent fine and coarse gravel
cs	Calcareous; abundant fine roots; about 5 per cent fine gravel
cs	Calcareous; plentiful fine roots; 5–10 per cent fine gravel
cs	Calcareous; 50–60 per cent fine and coarse gravel
–	Calcareous; 10–15 per cent fine gravel
cs	Calcareous; plentiful fine and coarse roots
cs	Calcareous; with common secondary calcium carbonate; few fine roots
cs	Calcareous; with many secondary calcium carbonate
ds	Calcareous and gypsiferous; common gypsum crystal
–	Calcareous and gypsiferous; common gypsum crystal
gs	Calcareous; very saline; few fine roots
cs	Calcareous; very saline
cs	Calcareous; very saline
cs	Calcareous; very saline; many gypsum crystal and mycelia
gw	Calcareous; very saline; common gypsum crystal and mycelia
–	Calcareous; very saline; few gypsum crystal and mycelia
gs	Calcareous; extremely saline; f1f mottles of 5Y5/2
gs	Calcareous; extremely saline; c2d mottles of 5Y6/4 and 5Y5/2
cs	Calcareous; extremely saline; m2d mottles of 5Y5/2.5
–	Calcareous; extremely saline

and, for samples with high soluble salts, from the sodium adsorption ratio [11].

The type of salinity, based on the composition of anions and cations present in the saturated soil extract and ground water, was determined according to the Russian system [3]. In this system soil salinity is estimated on the basis of three major criteria: the chemistry (type) of salinization, the degree of salinity and the depth of the upper saline horizon. The chemistry (type) of salinization is determined by anion and cation composition.

X-ray diffraction was carried out on the sub-samples of effervescence salts, puffed layer, and profile wall salts, using a Philips apparatus with Cukα radiation.

RESULTS AND DISCUSSION

Soil salinity and its relation to physiography

A detailed study of salinity in the selected basin revealed that the distribution of salts mainly followed physiographic factors [1, 2]. In general, three regions with different degrees and types of salinity were distinguished.

(a) Land with no salinity problems. This area includes alluvial-colluvial fans, river alluvial fans, upper terraces and high plateau. The salt content in all horizons is less than 4 $m\Omega^{-1}cm^{-1}$ and usually does not reach 1 $m\Omega^{-1}cm^{-1}$. The ionic composition according to the Russian system [3] is of the chloride-carbonate and magnesium-calcium or calcium-magnesium salinity types (Table 2).

Soils are well drained and ground water is very deep (30 m).

(b) Land with slight to moderate salinity problem. These are soils of the piedmont alluvial plain, which are more or less affected by salinity. The salt content generally varies between 4–8 $m\Omega^{-1}cm^{-1}$ in the upper meter of the soil (Table 2). The origin of salts is mostly due to application of brackish irrigation water. Ground water is deeper than 3 meters. Among the ions of the saturation extract Cl^-, SO_4^{2-}, and Na^+ are dominant. Soil salinity according to the Russian classification is generally of the sulfate-chloride or chloride-sulfate and calcium-magnesium or magnesium-sodium type.

(c) Land with severe to very severe salinity problem. These are alluvial plains and lowland soils on early and late lake deposits. Due to their high salinity (sometimes more than 100 $m\Omega^{-1}cm^{-1}$) they are not used for agricultural activities. Natural drainage conditions are unfavorable and a highly saline and alkaline ground water table is present between the depth of 50 cm and 3 m.

Sodium and chloride make up the major ionic composition of the soil solution. In the Russian system they are generally considered as a chloride and magnesium-sodium type of salinity (Table 2).

The lowland areas, temporarily flooded with very saline and alkaline lake water during the winter period but dry in summer, frequently accumulate salts on the soil surface which form a white crust. Accumulation of salts at or in the upper horizons also occurs due to evaporation of very saline and alkaline ground water present at shallow depth.

X-ray diffraction of the effervescence salts, puffed layer, and profile wall salts shows a more or less uniform composition of halite (NaCl), gypsum ($CaSO_4.2H_2O$), calcite ($CaCO_3$), thenardite ($NaSO_4$), and kieserite ($MgSO_4.H_2O$) (Fig. 3).

Ground water salinity and its relation to physiography

Detailed examination of the ground water showed a clear zonation with regard to physiography. In addition, ground water salinity is directly related to soil salinity. As a consequence three different ground water zones were distinguished: very deep and non-saline ground water (less than 1000 $\mu\Omega^{-1}cm^{-1}$) found in physiographic areas of fans, upper terraces and high plateau; moderately deep and moderately saline ground water (1000–8000 $\mu\Omega^{-1}cm^{-1}$) found in the piedmont alluvial plain; and finally very shallow and extremely saline and alkaline ground water (about 70,000 $\mu\Omega^{-1}cm^{-1}$ or higher and SAR values up to 200) found in the alluvial plain and lowland soils (Table 3).

According to the Russian system [3] the very deep ground water is of carbonate–sulfate and magnesium–calcium type. Traversing to the lowland area the carbonates gradually precipitate and concentration of sulfates increases; therefore the ground water becomes progressively of the chloride–sulfate and then sulfate–chloride type and finally in the alluvial plain and lowlands area a chloride type. Changes in the chemical composition manifest a typical zonation (Fig. 4) as follows.

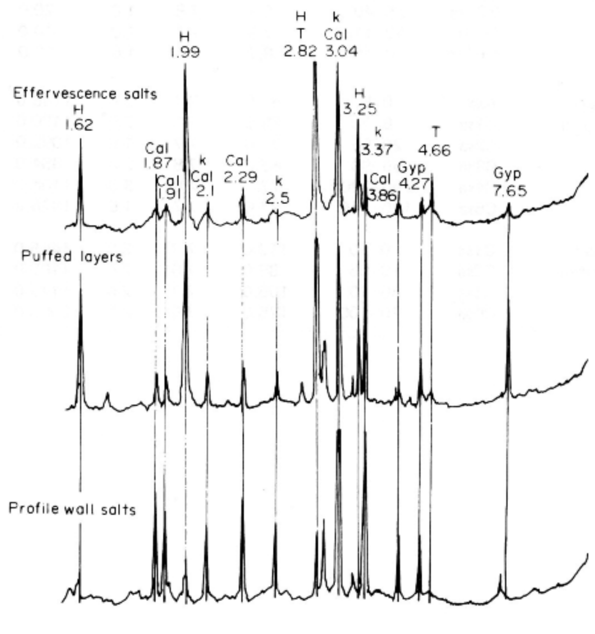

Fig. 3. X-ray diffractions of some typical salts. Cal, calcite; Gyp, gypsum; H, halite; K, kieserite; and T, thenardite.

Table 2. Chemical composition and salinity type of selected soils occurring on representative physiographic areas of Sarvestan

Physiography	Soil sub group	Horizon	Depth	EC×10³	pH	Anions and cations			
						HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2++}
			cm	$m\Omega^{-1}cm^{-1}$		m-equiv/lit			
Plateau	Petrocalcic xerochrept	Al	0–10	0.45	7.8	3.5	1.0	–	2.0
		B2	10–50	0.47	7.9	2.5	2.0	–	2.5
		C1ca	50–80	0.48	8.0	2.5	2.0	–	2.0
Alluvial–colluvial fan and upper terraces	Calcixerollic xerochrept	A1	0–4	0.47	8.0	3.1	2.0	0.6	2.8
		B21ca	4–17	0.46	7.9	2.4	2.1	0.9	2.4
		B22ca	17–38	0.45	7.9	2.5	2.0	1.2	1.6
		B23ca	38–72	0.40	8.0	2.5	2.4	0.8	2.0
		IIC	72–115	0.41	8.0	2.5	2.0	0.7	2.0
River alluvial fan	Typic xerofluvent	A1	0–25	0.55	7.9	2.5	2.4	–	2.5
		IIC1	25–47	0.42	7.9	2.5	2.4	–	2.0
		IIIC2	47–87	0.33	8.0	2.3	2.2	–	1.5
		IVC3	87–120	0.31	8.0	2.5	1.5	–	1.5
Piedmont alluvial plain	Xerollic calciorthid	AP	0–8	4.5	7.6	2.0	15.0	30.0	21.0
		B21ca	8–25	5.6	7.6	2.0	22.0	33.0	21.0
		B22ca	25–40	5.1	7.8	1.0	20.0	34.0	19.0
		IIC1s	40–110	7.8	7.7	1.0	40.0	39.0	22.0
		IIC2cs	110–150	8.2	7.7	1.0	55.0	41.0	30.0
Alluvial plain	Gypsic salorthid	Asa	0–8	81.0	7.5	2.0	1146.0	60.0	86.0
		C1sa	8–20	89.0	7.5	2.0	1420.0	82.0	86.0
		C2sa	20–55	74.0	7.7	1.5	1092.0	87.5	62.0
		C3sa	55–90	62.0	7.8	2.5	854.0	88.5	62.0
		C4sa	90–120	77.0	7.8	3.0	1108.0	120.0	64.0
		C5sa	120–145	72.0	7.7	1.5	1025.0	71.5	70.0
Lowland	Aquollic salorthid	C1sa	0–10	112.0	7.7	2.0	1405.0	75.0	76.0
		C2sa	10–55	88.0	7.6	2.5	1162.0	85.5	70.0
		C3sa	55–70	105.0	7.7	2.0	1143.0	92.0	76.0
		C4sa	70–100	125.0	7.5	2.0	2065.0	87.0	87.0

Table 2 continued

Anions and cations										
Mg^{2++}	Na^+	ESP	Cl/SO_4	HCO_3/Cl	HCO_3/SO_4	Salinity type	Na/Mg	Na/Ca	Mg/Ca	Salinity type
2.0	0.5	–	>1	>1	>1	Chloride–carbonate	<1	< 1	1	Mg–Ca
0.5	0.5	–	>1	>1	>1	" "	>1	< 1	<1	" "
3.0	0.5	–	>1	>1	>1	" "	<1	< 1	>1	Ca–Mg
2.0	0.8	–	>1	>1	>1	" "	<1	<1	<1	Mg–Ca
1.2	0.8	–	>1	>1	>1	" "	<1	<1	<1	" "
3.2	0.9	–	>1	>1	>1	" "	<1	<1	>1	Ca–Mg
2.2	0.75	–	>1	>1	>1	" "	<1	<1	>1	" "
2.8	0.5	–	>1	>1	>1	" "	<1	<1	>1	" "
2.0	0.8	–	>1	>1	>1	" "	<1	<1	<1	Mg–Ca
1.5	0.8	–	>1	>1	>1	" "	<1	<1	<1	" "
1.5	0.5	–	>1	>1	>1	" "	<1	<1	1	" "
2.0	0.6	–	>1	>1	>1	" "	<1	<1	<1	Ca–Mg
15.0	12.0	7.1	>1	<1	<1	Chloride–sulfate	<1	<1	<1	Mg–Ca
24.0	19.0	8.1	>1	<1	<1	" "	<1	<1	>1	Ca–Mg
19.0	16.0	10.3	>1	<1	<1	" "	<1	<1	1	" "
28.0	32.0	10.5	>1	<1	<1	" "	>1	>1	>1	Mg–Ca
35.0	30.0	14.0	>1	<1	<1	Sulfate–chloride	<1	>1	>1	Na–Mg
92.0	1000.0	59.5	>1	<1	<1	Chloride	>1	>1	>1	Mg–Na
202.0	1200.0	59.4	>1	<1	<1	"	>1	>1	>1	" "
152.0	975.0	57.8	>1	<1	<1	"	>1	>1	>1	" "
122.0	750.0	53.3	>1	<1	<1	"	>1	>1	>1	" "
174.0	975.0	56.1	>1	<1	<1	"	>1	>1	>1	" "
144.0	875.0	58.0	>1	<1	<1	"	>1	>1	>1	" "
144.0	1250.0	63.8	>1	<1	<1	"	>1	>1	>1	" "
160.0	1000.0	57.7	>1	<1	<1	"	>1	>1	>1	" "
166.0	1000.0	57.0	>1	<1	<1	"	>1	>1	>1	" "
246.0	1850.0	68.2	>1	<1	<1	"	>1	>1	>1	" "

Table 3. Chemical composition and salinity type of ground water from representative physiographic areas of Sarvestan

Physiography	Location	Source	EC×10⁶	pH	Anions and cations						SAR	Cl/SO₄	HCO₃/Cl	HCO₃/SO₄	Salinity type	Na/Mg	Na/Ca	Mg/Ca	Salinity type
					HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2++}	Mg^{2+}	Na^+									
			$\mu\Omega^{-1}cm^{-1}$		m-equiv/liter														
Alluvial–colluvial fan	1	Qanat	396	7.8	1.9	0.6	2.2	2.0	1.5	0.6	0.4	<1	>1	>1	Carbonate–sulfate	<1	<1	<1	Mg–Ca
Piedmont alluvial plain	2a	Qanat	2281	7.5	3.0	4.8	16.3	9.0	9.8	4.9	1.6	<1	<1	<1	Chloride–sulfate	<1	<1	>1	Ca–Mg
Piedmont alluvial plain	2b	Well (20 m)	6880	7.8	2.8	60.0	27.5	26.2	33.5	30.0	5.5	>1	<1	<1	Sulfate–chloride	<1	>1	>1	Na–Mg
Piedmont alluvial plain	2c	Well (20 m)	7303	7.2	4.0	46.0	42.0	24.8	33.9	32.0	5.9	>1	<1	<1	Sulfate–chloride	<1	>1	>1	Na–Mg
Alluvial plain	3	Ground-water (270 cm)	66,808	7.2	2.8	970.0	205.0	48.0	122.0	800.0	86.8	>1	<1	<1	Chloride	>1	>1	>1	Mg–Na
Lowland	4	Ground-water	77,155	6.2	1.0	1246.0	308.0	52.0	174.0	1275.0	200.0	>1	<1	<1	Chloride	>1	>1	>1	Mg–Na

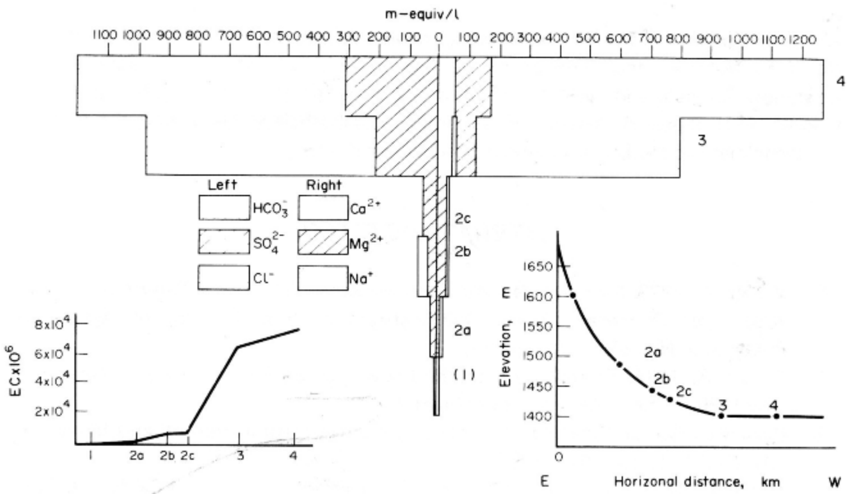

Fig. 4. Chemical composition of the groundwater in a longitudinal section from alluvial–colluvial fans (1), over piedmont alluvial plain (2a–c), to the alluvial plain (3) and finally to the low land (4).

Zone of carbonate accumulation in the alluvial–colluvial fan.
Zone of chloride–sulfate salinization in the piedmont alluvial plain.
Zone of sulfate–chloride salinization in the piedmont alluvial plain.
Zone of chloride salinization in the alluvial plain and lowland.

In this evolution sequence the carbonates and bicarbonates precipitate in the form of $CaCO_3$. Since chlorides are mainly associated with sodium [4], the sulfate precipitates in the form of $CaSO_4$. With increasing concentration of NaCl the Mg-salts will precipitate [6]; therefore, some of the sulfate may precipitate in the form of magnesium sulfate.

Based on the above findings the possible management implications of the study area could be summarized as follows:

1. *Land with no salinity problems.* With exception of dry farming in the non-gravelly parts of the river alluvial fans and some regions of the upper terraces, these areas due to their very high stoniness and topographic limitations are not suitable for agricultural activity. Their reclamation is not technically and economically feasible at the present time. These lands could only be used as nomadic pasture land.

2. *Land with slight to moderate salinity problems.* Under a good management system these lands could be used intensively for agriculture especially for cereals farming.

3. *Land with severe to very severe salinity problems.* Under present conditions, due to their extremely high salinity status and very poor drainage condition, these lands are not suitable for any agricultural activity. Their limitations might be reduced or eliminated if further studies prove it economically feasible.

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