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Assessing Leaching of Saline-sodic Soils Affected by Kaveh-Soda Factory Effluent using Georeferenced Maps in Maragheh-Bonab Plain

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***Abstract*— Relativity of soil maps may limit their utility at many aspects such as agriculture development, farming, civil engineering, urban and regional planning and forestry. Paying attention to the scale is one of the most common procedures in assessing the maps usability. The average size delineation (ASD), effective scale number (ESN), index of maximum reduction (IMR) and shape complexity index (SCI) are the maps quality criteria that can be examined. The purposes of this study were: a) to evaluate the EC and SAR maps of the farm lands affected by the Kaveh-Soda factory effluent on the basis of the above quality criteria and b) to evaluate the efficiency of continuous and intermittent methods of leaching in three Saline-Sodic soils with loam and sandy loam textures. EC maps of the area were selected and ASD, ESN, IMR and SCI were determined as 0.95 cm2, 1:26000, 1.54 and 3.33, respectively. For the SAR maps the above criteria were 1.33 cm2, 1:31000, 1.84 and 3.51, respectively. According to the above criteria there should be no limitation in their uses for developing of agricultural and civil engineering projects. It is known that optimum IMR is equal to 2, so that raising IMR of EC and SAR maps from 1.54 and 1.84 to 2 led their scale to increase from 1:34000 to 1:26000 and 1:31000, respectively and increase maps contrast as well. At the subsequent stage, efficiency of two leaching methods of saline-sodic soils was examined after knowing the usability of the maps and separating their units, as affected by Kaveh-Soda factory (Maragheh). For this purpose, PVC tubes (Lengths= 70 cm; Diameter= 10 cm) were prepared and filled with soil (5200 g sieved by 4.76 mm). The flow rate during both leaching methods was selected to be 1.25 KS of the columns. Soil columns were grouped according their EC as 1) EC= 10.38 dSm-1, with Na+= 49.64 meqL-1; 2) EC= 20.6 dSm-1, with Na+= 94.57 meqL-1; and 3) EC= 36.6 dSm-1, with Na+ = 166.11 meqL-1. Leaching water was saturated with gypsum because of it's high SAR to disperse the soil and effectively reduce the leaching efficiency. The EC of leaching water was 2.34 dSm-1. Leaching was stopped when EC of the effluent from the columns became relatively constant. The results revealed that intermittent leaching method efficiency was 8% greater than that of continuous method. The depth water need for the reclamation of the affected soils was also calculated.**

***Keywords*— Soil map; leaching; continuous; intermittent; Kaveh-Soda; Iran**

I. INTRODUCTION

Digital soil mapping as the creation and the population of a geographically referenced soil databases generated at a given resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships [1]. For soil survey to perform this important role, the mapping units must be accurately separated and represented on the map with high cartographic precision. However, the accuracy of most (if not all) soil maps is never stated; it is assumed rather than provided. Thus with no indicator of the degree of accuracy or reliability of the soil map, the user is left to guess its usefulness [2]. There are many reasons why soil data in the world for example in Croatia are rarely used, and often only descriptively, are more complex than an adequacy analysis can show. Because users' satisfaction with the current products depends mainly on how well their professional background allows them to make their own interpretations. Preconceptions from the users' own field of expertise colour their perceptions of soil data. For example, land surveyors and GIS professionals were put off by the fact that boundaries in the adjacent map sheets do not match [3].

Soil salinization is steadily diminishing the agriculture productivity in Iran. It has seriously caused since 1970 where problem soils have in a half of area as well as may increase [4]. Erosion is another hazard in the bare lands which may be prevailed after intensive development of industrial activity. Therefore, it is essential to remediate saline-sodic soils as affected by human activities such as miss-matched management. Most soils contain preferential flow paths that can impact solute mobility. Solutes can move rapidly down the preferential flow paths with high pore-water velocities, but can be held in the less permeable region of the soil matrix with low pore-water velocities, thereby reducing the efficiency of leaching [5]. Leaching is an easy way to decrease the soil salinity. An over-estimation of the leaching requirement (LR) would result in the application of excessive amounts of irrigation water and increased salt loads in drainage systems, which can detrimentally impact the environment and reduce water supplies. An investigation in California revealed that the reduced LR for the Imperial Valley would result in a diminished drainage [6]. The recently findings revealed that it is difficult to monitor temporal and spatial variability of elements in the field [7]. Therefore, soil columns were replaced for monitoring of soil reclamation in the laboratory analysis [8]. Leaching of salts as influenced by soil texture and water quality was studied in a column experiment with three soils, namely clay, sandy loam and loamy sand by other researchers. They reported that mass flow was mainly responsible for leaching of salts. The empirical relationship on the lines of Reeves equation was fit to the experimental data. It was concluded that the major fraction (90%) of salts was leached from the soil with one pore volume of water [9]. Using sludge for land reclamation is a shortage of land reclamation materials in other countries like Singapore. So, it would be highly desirable if sludge can be treated and used for land reclamation. However, not only adequate geotechnical properties but also environmental impact and cost-effective aspect must be considered [10]. Large numbers of scientists applied different methods for decreasing soil salinity in all of the world and in Iran too. Two leaching methods of continuous and intermittent were conducted for the reclamation of a saline soil in Pakistan. Analysis of soil samples showed that after carrying the experiments for two months, continuous leaching method removed 61.59% of salts from the top 0-60 cm soil depth, whereas the intermittent leaching method removed only 46.14% of the salts from the same depth [11].

Kaveh-Soda is one of the most important industrial factory which produces carbonate sodium. Its sludge was being stored in the large ponds. Unfortunately, one of the screens was broken down on 15 Apr., 2010 after a heavy rainfall. It caused to be created saline-sodic soils as affected by that factory effluent. The main objective is: 2) to evaluate the EC and SAR maps of the farm lands by the Kaveh-Soda factory on the basis of maps usability criteria and b) to evaluate the efficiency of two continuous and intermittent methods of leaching three saline-sodic soils with loamy and sandy loam textures.

II. Materials and Methods

A. Study Area

This study was performed in the Maragheh-Bonab plain between 46˚08´to 46˚12´ east longitude and 37˚18´ to 37˚19´ north latitude, in the North-West of Iran (East Azarbaijan) with different physiographical units of plain and alluvial plain, (Fig. 1). In the area with an approximately 855 ha, the slopes are level to gentle level.

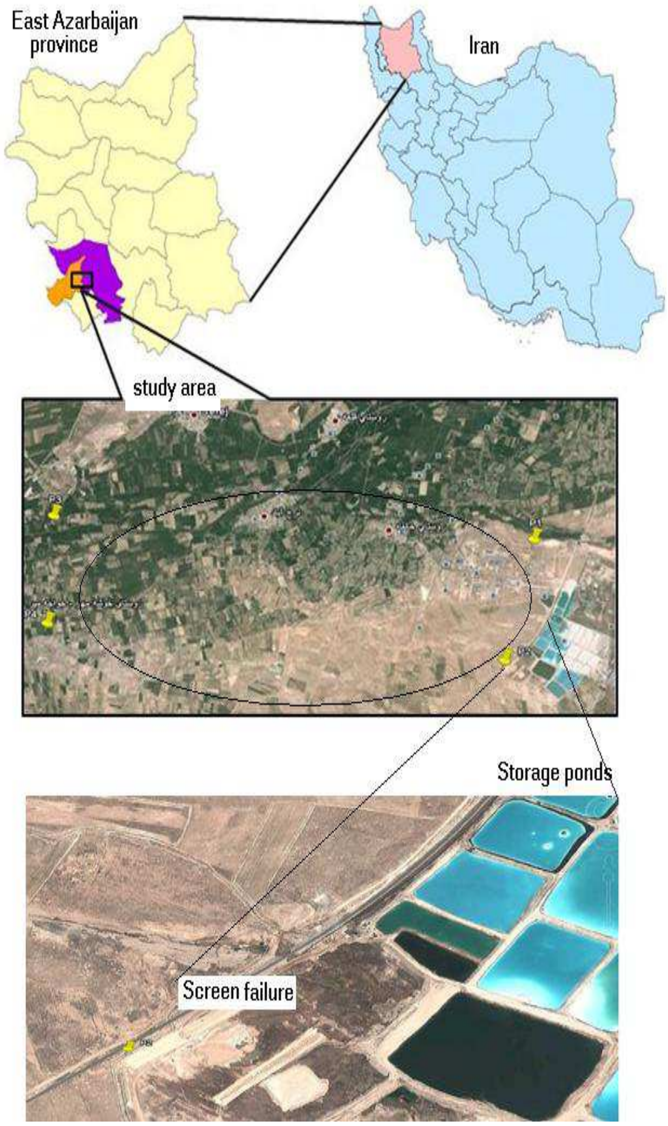

Fig. 1 Location of the study area in Eest Azarbaijan province

B. Soil EC and SAR Maps

Georeferenced maps of EC and SAR were provided according to previous investigation [12]. As it known that kriging was mainly used to prepare spatial distribution of some soil parameters such as physical [13], chemical [14], and biological [15] ones while inverse distance weighting (IDW) method was employed because of limited data was available to create maps of salinity and sodicity of the study area after the flooding occure as shown in Fig.2.

C. Criteria for Soil Maps Efficiency

The average size delineation (ASD), effective scale number (ESN), index of maximum reduction (IMR) and shape complexity index (SCI) are the maps quality criteria that were examined according to the following equations:

$$ASD = \frac{\sum_{j=1}^{m} A_j}{m} \quad (1)$$

where Aj is the area of the jth polygon and m is the total number of polygons [16].

The index of maximum reduction (IMR), that is, the factor by which the scale of the map could be reduced before ASD was equal to the minimum legible delineation (e.g., MLD—should be 0.4 cm^2 on the map), was then derived by: [16]:

$$IMR = \sqrt{\frac{ASD}{MLD}} \quad (2)$$

From this, the effective scale number (ESN) was computed as [16]:

$$ESN = NSN\left(\frac{IMR}{2}\right) \quad (3)$$

where, NSN is the nominal scale number.

The fourth index of map efficiency is the general geometry of soil polygons which was used a shape complexity index S, which is the perimeter-to boundary ratio:

$$S = \frac{P}{2\pi r}; r = \sqrt{\frac{A}{\pi}} \quad (4)$$

where, P is the polygon perimeter, A is the polygon area, and r is the radius of the circle with the same surface area. Value of S close to 1 means that the polygon is rather compact and simple. Higher values describe narrower or more branching polygons, which often mean higher positional accuracy and larger effective scale [3].

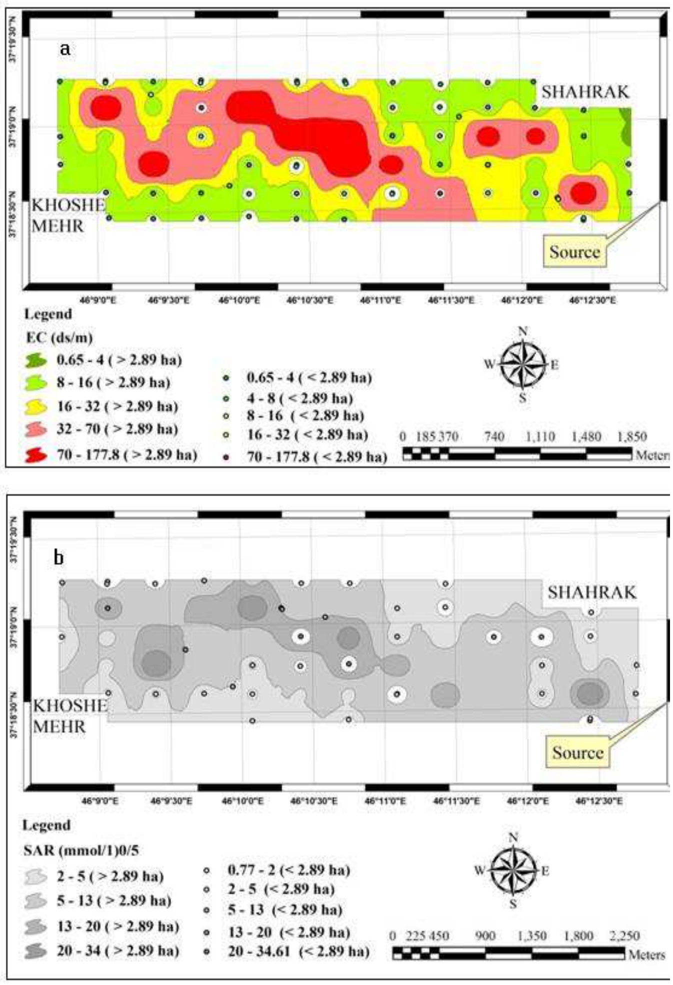

Fig. 2 Maps of EC and SAR in the study area [12]

D. Sampling of Soil and Water

The field work was carried out with a semi-detailed survey through the whole study area. Soil samples were collected due to accuracy testing of created maps as before. For this purpose, 52 soil samples (0-25 cm depths) provided according to randomized algorithm. Water sample were collected from the well in the area which would be used for leaching in the laboratory.

E. Physical and Chemical Analysis

Soil samples were air dried and then sieved through a 2-mm mesh. Some common physical and chemical properties including texture, bulk density and particle density, EC, pH and SAR were determined. To avoid the microbial growth, extracts were kept at 4˚C.

Reference [17] revealed that in view of the possible need or for the amendments during the reclamation of soils having excess neutral salts and a high SAR of soil solution (saline-sodic soils). The effect of gypsum application for salt leaching in a saline-sodic soil well understands. Therefore, water needed for leaching was the saturated with the gypsum provided from Sofian region at Km 23 tabriz.

F. Experimental Design and soil Columns

Completely Randomized Design (CRD) with 2 treatments (continuous and intermittent leaching methods) and 2 replications was conducted. PVC tubes (Lengths= 70 cm; Diameter= 10 cm) were prepared and filled with soil (5200 g sieved by 4.76 mm). The prepared and the appropriate equipments are presented in Fig. 3. In terms of practical soil and water management, the studies revealed that relatively simple means can be useful to predict the water quality in soils, their discharge to ground water, and the hazard of soil structure deterioration. Breakdown curves were the most important indictors [18]. The flow rate during both leaching was adjusted to be 1.25 K_S of the columns. Leaching water was saturated with gypsum because it's high SAR to avoid the soil dispersion and reduce the leaching efficiency. The EC of the leaching water was 2.34 dSm^{-1} after saturation with gypsum. Leaching was stopped when EC of the effluent from the columns became relatively constant.

1) *Continuous Leaching Method:* Soil columns were saturated at first via the leaching water (EC= 2.34 dSm^{-1}) from the beneath. Leaching was then started using water from the top surface of the columns. The effluents were collected at constant interval periods (60 minutes) and their volume and EC were determined. Leaching was stopped when its EC reached to about 4 dSm^{-1}.

2) *Intermittent Leaching Method:* In this method, the total consumed water determined from the continuous method was divided to 4 portions and each portion was applied continuously from the top, with 24 hr standing time between the portions.

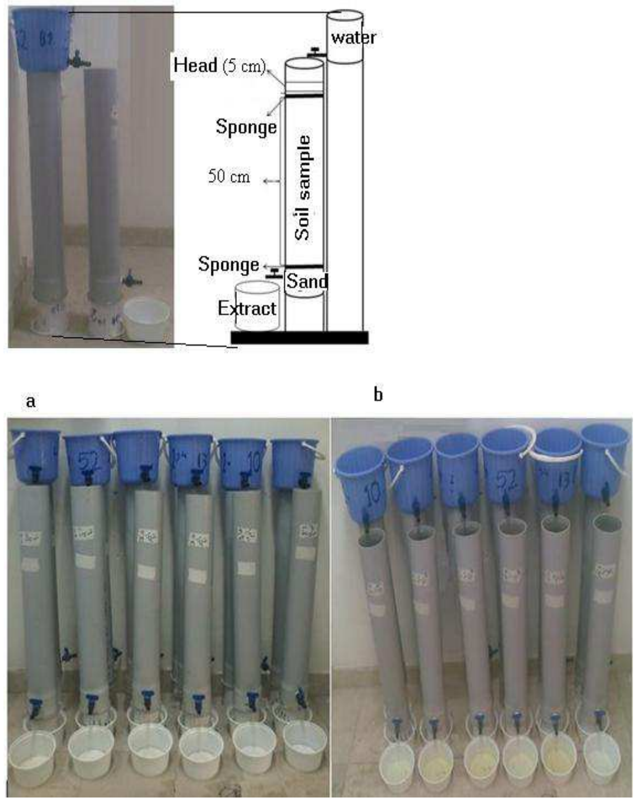

Fig. 3 A scheme of soil column and leaching soils. a) Continuous; and b) intermittent methods

III. Results and Discussions

A. Assessing the Maps efficiency

EC and SAR maps were prepared on the scale of 1:34000 each with five mapping units. They also had 77 and 54 mapping delineations, respectively, as shown in Fig. 4. ASD was measured for EC and SAR maps 0.95 cm^2 and 1.33 cm^2, respectively.

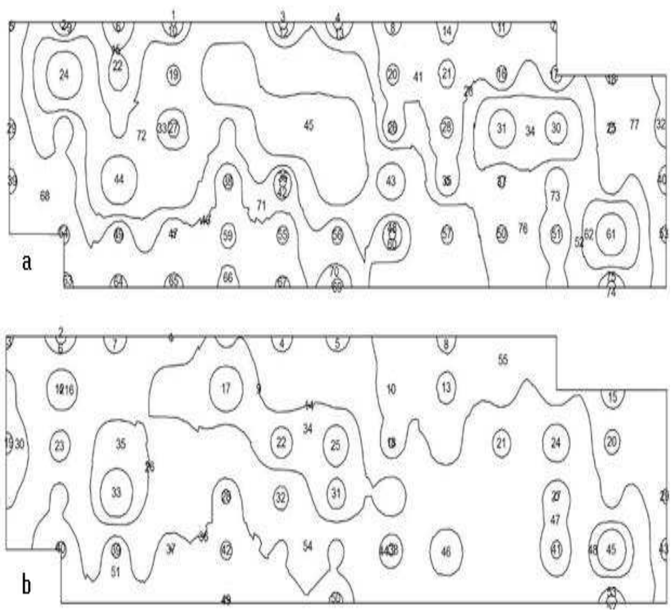

Fig. 4 Scheme of the number of map delineations: a) EC map; b) SAR map

Optimum intensity of the delineation in a proper map is 5% while, the intensity of both maps was calculated 42% and 30%, respectively. It was the most important agent to have unclear maps (Fig. 4). Area of delineations was then measured using GIS shape file. Results showed that only 20 delineations of EC map and 15 delineations of SAR map could be presented, because the other delineations had area less than MLD (Fig. 2).

IMR for the EC and SAR maps was measured 1.54 and 1.82 where they were less than the index of optimum reduction (equal to 2). Therefore, the scales of both maps have to be increased. On the other hand, three delineations of EC map and also five delineations of SAR map may not be presented at prepared scale (Fig. 5). ESN was also calculated for EC and SAR maps 1:26000 and 1:31000, respectively. SCI of the prepared maps revealed that it was 3.33 and 3.49 as weighting average. Finally, the above criteria were used to assess the mapping units' purity and their kind of soil surveying which were summarized in Tables 1 and 2. Statistical analysis revealed that there is no significant between the estimated and actual data of SAR. According to diagnosis for kind of soil surveying [19], results showed that both maps had consociation condition. They don't have non-limiting dissimilar component which led to be homogenous maps.

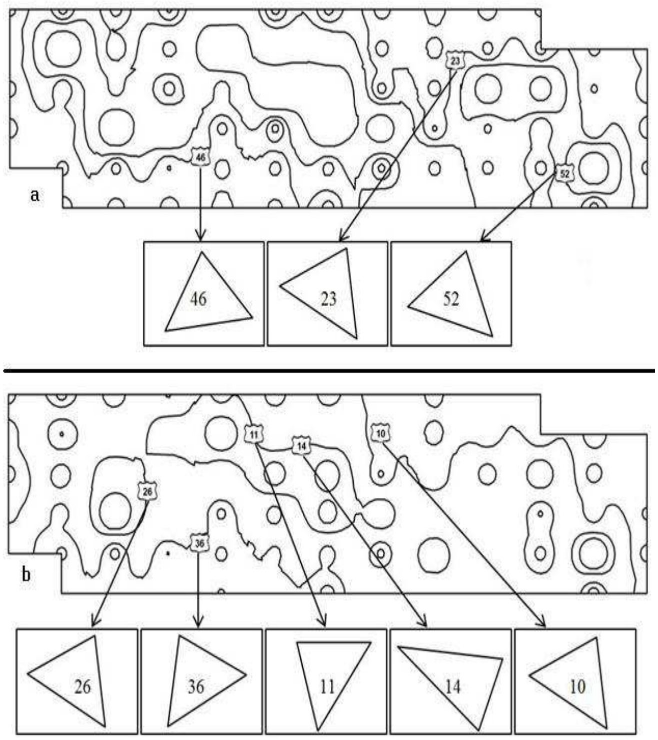

Fig. 5 Merged delineations with adjacent polygons: a) EC map; b) SAR map

TABLE I
PURITY PERCENTAGES OF EACH MAPPING UNITS FOR THE EC MAP

Mapping Unit	**Subdivisions (dsm^{-1})**	**No. of Delineations**	**Total area (ha)**	**EC (dSm^{-1})**	**Area of delineations (ha)**	**Purity percentage**	
						purity	**Non-purity**
1	< 4	40	28.9	< 4	28.9	100	
2	4-16	57	291.58	< 4	28.99		9.94
				4-16	262.6	91.06	
3	16-32	32	311.25	< 4	3.2		1.03
				4-16	32.96		10.91
				16-32	219.84	70.63	
				32-70	41.87		13.45
				> 70	12.36		3.97
4	32-70	14	348.04	4-16	0.81		0.23
				16-32	4.51		1.29
				32-70	248.39	71.37	
				> 70	94.33		27.1
5	>70	70	94.33	> 70	94.33	100	

TABLE III
PURITY PERCENTAGES OF EACH MAPPING UNITS FOR THE SAR MAP

Mapping Unit	**Subdivisions (SAR)**	**No. of Delineations**	**Total area (ha)**	**SAR $(mmoll^{-1})^{0.5}$**	**Area of delineations (ha)**	**Purity percentage**	
						purity	**Non-purity**
1	< 2	18	13.28	< 2	13.28	100	
2	2-5	32	258.85	< 2	13.11		5.06
				2-5	245.74	94.94	
3	5-13	30	622.98	< 2	1.8		0.29
				2-5	25.75		4.08
				5-13	449.22	70.63	
				13-20	120.09		19.27
				> 20	26.39		4.24
4	13-20	14	146.55	13-20	120.09	81.94	
				> 20	26.45		18.06
5	>20	7	26.46	> 20	94.33	100	

B. Soil and Water Properties

Summary of water chemical properties is shown in Table 3. Leaching water in this research work classified as C2S2. It was saturated with gypsum prior to be applied. Soil were grouped according their EC as 1) EC= 10.38 dSm^{-1}, with Na^{+}= 49.64 $meqL^{-1}$; 2) EC= 20.6 dSm^{-1}, with Na^{+}= 94.57 $meqL^{-1}$; and 3) EC= 36.6 dSm^{-1}, with Na^{+} = 166.11 $meqL^{-1}$. Their physical and chemical properties are summarized in Table 4.

TABLE IIIII
CHEMICAL PROPERTIES OF THE LEACHING WATER

EC (dSm^{-1})	**pH**	**Na^{+} (meq-1)**	**Mg^{2+} + ca^{2+} (meq-1)**	**SAR**
0.65	8.37	9.7	0.93	14.2

C. Leaching Fraction and Efficiency

Passing of 1.5 PV leaching water in continuous method had 15% less efficiency compared to intermittent method (Fig 6.a). Experimental data resulted by application of continuous and intermittent leaching methods in three kinds of saline soils are presented in Fig. 6 (b-d). According to the obtained results, intermittent method has better efficiency than the continuous method for salt removal. Reference [6] represents the same results of this work. Results showed that soil salinity and sodicity will be loosed with increasing of PV at three soil groups too.

D. Generalizing Laboratory Data to Field

This is the most important output which may be abrupt and clear for application by the farmers, researchers, and stakeholders. Consociation maps and homogenous soils are needed to have possibility for generalizing the experimental data to the practical field units. Water requirements and also soil salinity changes by application of both approaches are summarized in Table 5.

TABLE IV
SUMMARY OF THE SOIL PHYSICAL AND CHEMICAL PROPERTIES

Soil Physical Properties								
Soil No.	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Texture**	**ρb (gcm^{-3})**	**ρp (gcm^{-3})**	**Porosity (%)**	**Ks $Cmhr^{-1}$**
1	53.69	28.38	17.93	Sandy loam	1.31	2.49	47	2.4
2	52.04	28.72	19.24	Sandy loam	1.35	2.38	46	2.56
3	50.23	31.38	18.39	Loam	1.28	2.33	51	2.64

Soil Chemical Properties						
Soil No.	**Ca^{2+} ($meql^{-1}$)**	**Mg^{2+} ($meql^{-1}$)**	**Na^{+} ($meql^{-1}$)**	**EC (dSm^{-1})**	**pHp**	**SAR**
1	41.49	2.4	49.64	10.38	7.4	10.6
2	111.97	10.72	94.57	20.6	7.9	12.07
3	166.42	16.64	166.11	36.6	7.75	17.36

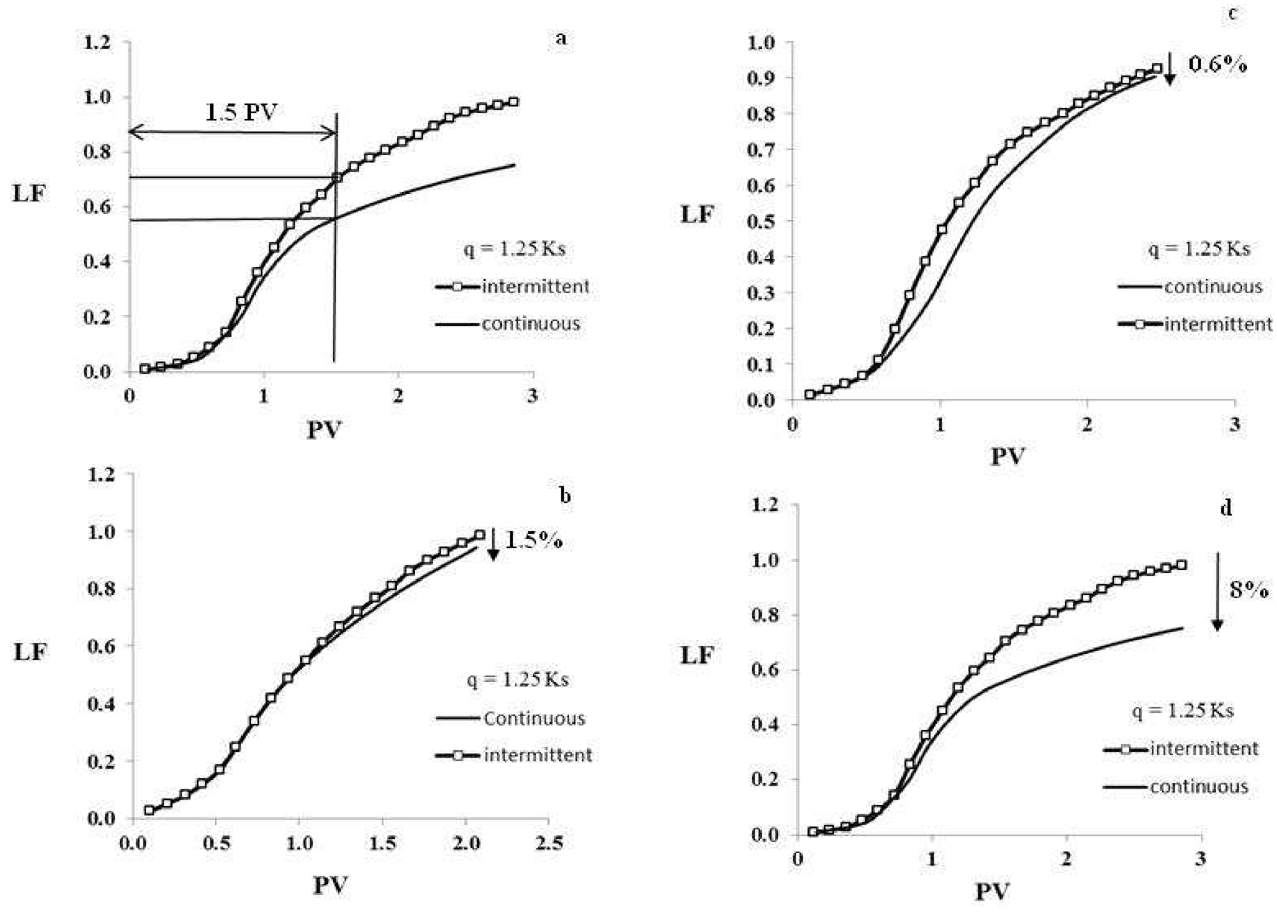

Fig. 6 a) Leaching Fraction vs PV at two methods; b) soil with EC= 10.38; c) soil with EC= 20.6; d) soil with EC= 36.6

TABLE V
EFFECT OF LEACHING WATER FOR DECREASING SOIL SALINITY

Soil No.	EC^{a} (dSm^{-1})	EC^{b} (dSm^{-1})	EC^{c} (dSm^{-1})	Water requirement (1000 m^3ha^{-1})
1	10.38	3.4	2.92	2.43
2	26.6	3.37	3.17	2.91
3	36.6	3.87	3.45	3.38

a: initial soil salinity; b: soil salinity using continuous method; c: soil salinity using intermittent method

IV. Conclusions

Soil survey, or more properly, soil resource inventory, is essential for determining the pattern of more objectives and presenting it in understandable and interpretable form to various aspects such as soil pollution and studying of any environmental accident. Area-class polygon soil map is one kind of the survey with a class name, and each class in turn being described in a legend which was used in this research work for converting the experimental data to the practical form. Leaching fraction has direct relationships with the velocity of leaching water. It is more obvious in intermittent method than continuous approach.

Although, gypsum released positive effect on leaching efficiency of saline-sodic soils, other amendments such as sulphur and sulphuric acid may be proposed for this purpose.

Intermittent method compared to the continuous method had better output with equal consuming of water for the leaching.

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