Annals of Arid Zone 45(1): 9-17, 2006

Spatial Variability of Electrical Conductivity of Soils Irrigated with Brackish Water in the Arid Region of Rajasthan, India

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Abstract: Saline and/or high residual sodium carbonate (RSC) ground water is the major source of irrigation in arid region of India. Despite fallowing during rainy season or amelioration with gypsum, high salinity prevails in the irrigated soils. There is a large spatial variability in the amount of accumulated salts. Present study was taken up to characterize the spatial variability in soil salinity at three sites on farmers' fields where saline/high RSC (EC 3.6 to 8.6 dS m^{-1}, SAR 19 to 62 and RSC 1 to 19 me L^{-1}) is being used for irrigation for over ten years and some of the parcels have received gypsum for amelioration of sodicity. Salinity was measured at 5 m interval with a portable electrical conductivity meter SCT-10 using four electrodes. The data were analyzed for basic statistical parameters and transformed into natural logarithm to provide a distribution closure to normal. For two sampling directions, the semi-variogram has been calculated. The results revealed that the nugget, sill and range of the semi-variogram seemed to depend on irrigation water salinity and soil texture. The largest range (70 m) was found at Narwa where the salinity of irrigation water was less and soil was loamy sand. At Sathin-1 and Sathin-2 sites low range of 15 m and 11 m, respectively, was attributed to fine texture and high sodicity of soil.

Key words: Spatial variability, semi-variogram, kriging, saline and/or RSC ground water, arid environment.

The saline and/or high residual sodium carbonate (RSC) ground waters is the major source of irrigation in arid region of Rajasthan. Irrigation with saline/RSC water, over the years has resulted in accumulation of salts/development of sodicity in the irrigated soils. In spite of keeping the land fallow during subsequent rainy season or amending the soils with gypsum for leaching of the accumulated salts, there is salinity build up. This accumulated salinity is not uniform within the parcels receiving similar treatment (Joshi and Dhir, 1991, 1994). Because of salt accumulation and sodicity there is patchy growth of wheat crop (Joshi and Dhir, 1992). Variable accumulation of salts can be attributed to soil texture, subsoil compaction, micro-topographical variation and the agro-techniques adopted by the farmers. Large spatial variability in salinity is disadvantageous since it requires more complex design for agricultural operations (Bresler and Dagan, 1979).

Geo-statistics has been used to quantify spatial dependence variability in soil characteristics (Webster, 1985; Csillag *et al.*, 1993; Cambardella *et al.*, 1994; Grewal *et al.*, 1997; Raman *et al.*, 1983). There is need to characterize the spatial variability of salinity in saline/high RSC water irrigated soils. Therefore, study was under taken to characterize spatial variability of soil salinity at three sites on farmers fields irrigated with saline and/or high RSC water in the arid region of Rajasthan.

Materials and Methods

Environment and study sites

The study area is located in arid region of Rajasthan, which experiences strong summer during May-June (Maximum temperature 45-50°C) and mild winter in December and January (3-5°C). The mean annual rainfall of 350 mm, received in the months of July and August, is highly erratic (Coefficient of variation 52%) and uncertain. Brackish ground water, more than 100 m deep, is major source of irrigation for rabi crops.

Three sites on farmers' fields were selected for the study; one in the village Narwa situated 25 km north-west and other two sites in the village Sathin at 75 km east of Jodhpur town. The soils at Narwa village are loamy sand, 30 to 40 cm deep underlain by weak zone of $CaCO_3$ concretion classified as coarse loamy Lithic Haplocambids. At village Sathin the soils are loam and clay loam, 50 to 70 cm deep underlain by soft lime concretionary horizon classified as fine loamy Typic Haplocambids. Physico-chemical characteristics of soils and chemical characteristics of ground water at three sites are presented in Table 1. On these farms saline/high RSC water with electrical conductivity (EC) 3.6 to 8.6 dS m^{-1}, Sodium Adsorption Ratio (SAR) 19 to 62 and Residual Sodium Carbonate (SAR) 1 to 19 m e L^{-1} is being used for irrigation for more than ten years. The irrigated soils have developed sodicity with pH (1:2) 8.8 to 10.0, and salinity with EC (1:2) 1.3 to 1.7 dS m^{-1} with crusting, compaction and reduced infiltration. Some of the parcels have received gypsum for amelioration of sodicity.

Measurement of field salinity

Narwa: A 25 x 120 m plot was selected that showed more or less uniform soil moisture between areas completely wet and very dry. The moisture status of the soil was decided on its color, softness and bulk electrical conductivity, viz. completely dry

Table 1. Characteristics of the soils and ground water

	Narwa	Sathin-1	Sathin-2
Soils texture	Loamy sand	Loam	Clay loam
Soil pH (1:2)	8.75-9.5	9.6-10.3	9.8-10.0
Mean ECa (mS cm^{-1})	0.47	1.32	1.73
CV (%)	26	34	15
Mean EC (1:2) (mS cm^{-1})	0.55	1.62	1.17
Ground water			
EC (dS cm^{-1})	3.6	8.6	4.0
SAR	19	62	22
RSC (me L^{-1})	1	19	8
Crop	Wheat	Mustard	Mustard

soils were characterized by readings less than 100 micro S m^{-1}. The wheat crop was sown in the plot. Border strip flooding method was used for irrigation. Major irrigation channels were dug at length x = 23, 34 and 80 meters, and width y = 11 meters.

Sathin-1: A 30 x 59 m plot recently sown with mustard crop was selected for this study. In the year 1997, the northern part of the plot received gypsum @ 100% of soil gypsum requirement (GR), where as the southern part was without gypsum. On the surface strong crusting was observed due to salinity and sodicity. There were big clods that disperse only during the rainy season. Nevertheless after plowing these are again formed and remain during the crop season. Border strip flooding method was used for irrigation. Channels for irrigation were dug at x = 8, 16 and 24 m length as well as y = 5.5, 15.5, 22.7, 31, 39.5 and 49 m width.

Sathin-2: A 46 x 89 m plot sown with mustard was selected. In the year 1997, the western part of it received gypsum @ 50% of soil GR, the eastern part @ 100% of soil GR and southern part was without gypsum. Border strip flooding method was used for irrigation. Irrigation channels were dug at x = 4, 12.5, 20, 29, 36.5, 43, 51, 58, 66, 73.5, 81 and 90 m length as well as y = 5, and 31 m width . The mustard crop was sown recently and the seedlings had just emerged at the time of measurements.

Salinity was measured with a portable electrical conductivity meter, SCT 10, using four electrodes, having outer electrode distance 102 cm and inner electrode distance of 9 cm. The electrodes were pushed to a depth of 13 cm, which is suitable for characterizing the salinity of the 0-40 cm layer.

There were measurement transect(s) parallel to the x and y axis of the plots. The points were set up in such a manner that would allow the interpretation of short-distance variability also. As the electrical conductivity meter averages the conductivity of 1 m long soil block, this was selected as minimum measurement distance. Otherwise measurement was made roughly every 5 m.

Laboratory analysis: Parallel with the instrumental measurements at one-tenth of the points bulk soil samples (0-40 cm) were taken from 2 holes at each point. EC and pH of irrigation water samples and the soil samples (1:2 soil-water extract) were determined. The soil EC values were used to calibrate the field salinity meter to the real soil salinity. Irrigation water samples were also analyzed for cation and anion composition, and SAR and RSC were calculated according to Richards (1954).

Geo-statistical parameters: The field measurement data were analyzed for basic statistical parameters and transformed into natural logarithm to provide a distribution closer to normal. For the two sampling directions, semi-variogram was calculated for describing spatial variation. The parameters of the semi-variogram were checked for their ability to help in the spatial interpolation.

Variogram computation and statistical tests were performed for each site. It may be recalled that variogram characterizes the variance of the increment of a random function z between two locations separated by a distance h and is defined as given below:

$G(h) = 1/2\ E\ [\{z(x+h)-z(x)\}2]$

In practice couple of points are gathered in an arbitrary number of classes and G(h) is computed by discrete summation as:

$G(h) = [E\{z(x_i\ +h)-z(x_i)^2\}/2.\ N(h)$

where, G(h) is the semi-variogram, N(h) is the number of pairs of $z(x_1)$ at a separate distance.

The sample variogram was then plotted with h on the abscissa and G(h) (semi-variance) on the ordinate and the resulting functions were fitted to exponential model. The characteristics of semi-variogram such as, nugget (Y intercept), sill (point of leveling off) and range (distance at which point become independent) were derived.

Results and Discussion

Some of the salient characteristics of the study sites are presented in Table 1. The soil salinity (ECa) was highest at Sathin-1 and was followed by Sathin-2 and Narwa. The soils of both the sites at Sathin are highly alkaline.

Calibration of field salinity meter

Under field condition, moisture content, texture and soluble salt concentration affect the electrical conductivity (ECa) in soils. Amongst these factors, in irrigated fields, the moisture is most heterogeneous. Following equations were developed between bulk electrical conductivity (ECa) and electrical conductivity in 1:2 soil water extract (EC_2) for calibration of field salinity meter:

Narwa: $EC_2=0.6269\ ECa+0.2667\ (R^2 = 0.557)$

Sathin-1: $EC_2=0.829\ ECa+0.6679\ (R^2 = 0.967)$

Sathin-2: $EC_2=0.054\ ECa+1.07\ (R^2 = 0.182)$

In Narwa field loamy sand texture was favorable for redistribution of water, therefore the precision of calibration equation is within acceptable limits. There is also good precision of the calibration equation for the salinity at Sathin-1 because loam texture favored redistribution of moisture. But at Sathin-2 the irrigation was given recently and because of clay loam soil the redistribution of the moisture was still in process. This resulted in large differences in the ECa values. The calibration equation developed for Sathin-2 is not acceptable and therefore the ECa values must be interpreted as indicators of variation both in salinity and moisture content.

Semi-variograms

The Plot of h vs. G(h) indicating semi-variogram for the three sites is presented in Fig.1. The parameters of semi-variogram namely nugget, sill and range for the three sites are presented in Table 2. The nugget represents the undetectable experimental error and field variation within the minimum sampling space. The semi-variograms showed small nugget variation indicating practically no measurement error with the exception of the Sathin-2. Low nugget value at each site was attributed to uniformity with respect to the inherent soil characteristics. The sill represented total spatial variation. The spatial variability of soil properties is attributed to the intrinsic and extrinsic factors. In the present study, the intrinsic factor has been dominated by the extrinsic factors namely the quality of irrigation water and the method of irrigation which has

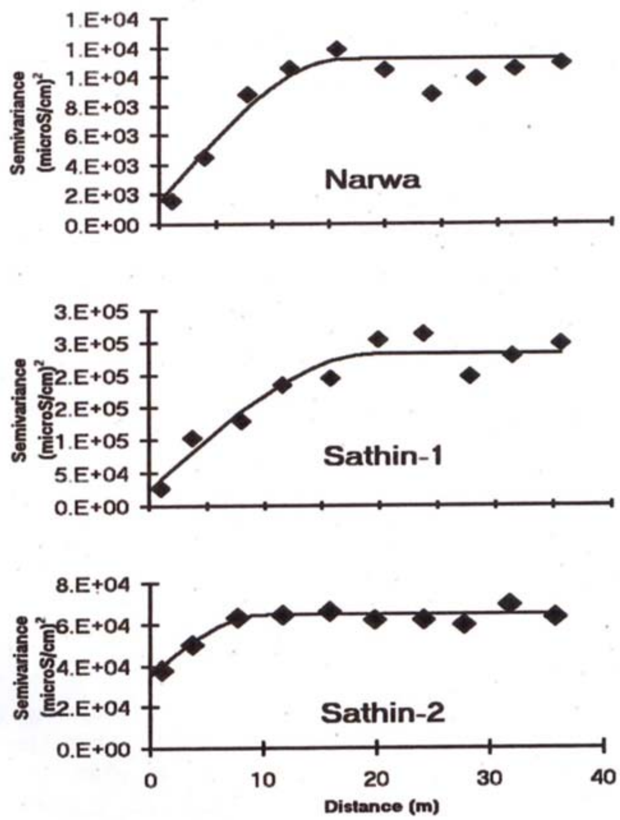

Fig 1. Plot of h vs. G(h) indicating semi-variogram for the three sites.

been reflected in higher values of sill. This is contrary to the observation of Cambardella *et al.* (1994) who observed moderate dependence of soil variability on the extrinsic factors. The small ratio of sill-nugget to nugget at Sathin-2 is due to the patchy distribution of moisture. The semi-variograms calculated for the two major directions showed considerable differences in their range only at Narwa due to temporary pounding of saline irrigation water in the irrigation channel. The values of range indicated that spatial based variation in salinity was up to 70 m at Narwa and 15 m and 11 m, respectively, at Sathin-1 and Sathin-2.

Kriging

After the estimates of semi-variogram were obtained the parameters were used for kriging, which takes into account the correlation between adjacent samples while estimating the interpolated value without bias and with minimum variance. The pattern of distribution of EC at the three sites is discussed below.

Table 2. Summary of the modeled spherical semi-variogram parameters of ECa

Site	Nugget	Sill	Major range (m)	Minor range (m)	Mean kriging standard deviation
Narwa	0.001	0.063	70	12	0.125
Sathin-1	0.010	0.120	15	15	0.196
Sathin-2	0.013	0.100	11	11	0.088

Narwa: In the eastern side of the plot, irrigated earlier, the EC was low (Fig. 2). Although there was no clear check-board-like appearance of the map, but the conductivity contours resemble the pattern of ridged subplots in which the irrigation water was kept.

Sathin-1: The EC contours showed 1000 to 1300 $\mu S\ cm^{-1}$ in entire field, which received full gypsum dose (Fig. 3). The EC values were higher (1600-1900 $\mu S\ cm^{-1}$) in the southern part where gypsum was not applied.

Sathin-2: The distribution of EC in the plot (Fig. 4) somewhat smooth variation in the east-west direction than in the north-south is attributed to the presence of irrigation channels.

Sampling distance and kriging standard deviation

The relationship between distance of gridlines and kriging standard deviation for a selected interior point in the grid has been presented (Fig. 5). From this figure it is possible to determine the distance of regular gridlines, which is necessary to provide a permissible kriging standard deviation. The magnitude of kriging standard deviation of the irrigated plots is similar to the standard deviation of bulk soil electrical conductivity values measured (Table 1), which is corresponding to the value of the sill of variogram. The importance of the range and nugget of the semi-variogram is smaller in this case. In order to reach an approximate 155 relative error of the measurement of soil ECa, the following gridline distance can be calculated based on the average ECa values of the plots.

Narwa: 470 micro S/cm*0.15 = 70; which correspond to ECa 7.5 m distance

Sathin-1: 1320 micro S/cm*0.15 = 198; which correspond to ECa 2.0 m distance

Sathin-2: 1730 micro S/cm*0.15 = 260; which correspond to ECa 10.0 m distance

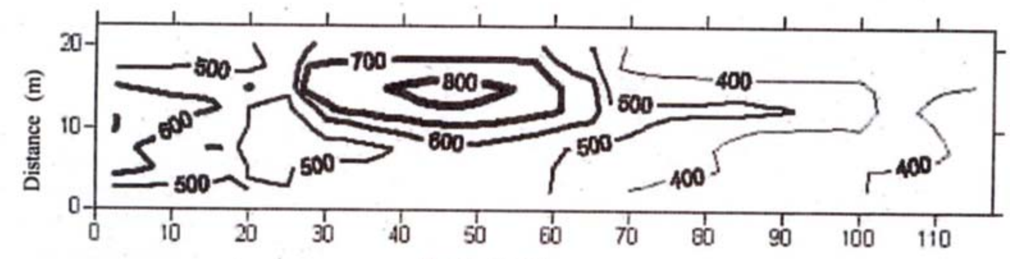

Fig. 2. Distribution of salinity at Narwa.

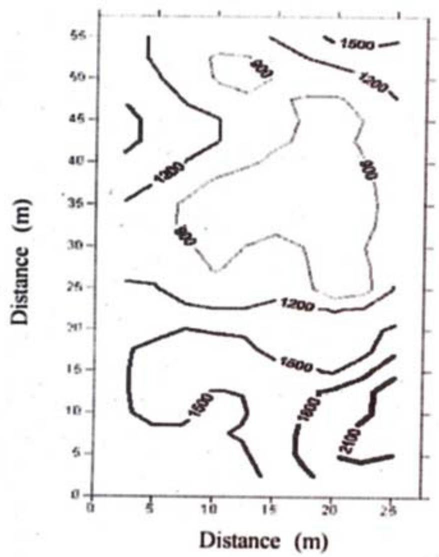

Fig. 3. Distribution of salinity at Sathin-1.

The salinity of irrigation water had a determining effect on the magnitude of soil salinity, but its effect was exaggerated by the presence of fine textured soils. The nugget of the semi-variogram clearly showed the effect of clay loam texture resulting in slow and incomplete distribution of moisture and salt. Similarly range of the variogram also decreased with an increase in fineness of soils. The nugget, sill and range seemed to depend on salinity of irrigation water and soil texture. The channels carrying saline water for irrigation were in contact with saline water for longer and thus accumulated more salt than the field proper. The largest value of range at Narwa indicated less intensive sampling than at Sathin-1 (15 m) and Sathin-2 (11 m). In order to attain 15% precision of ECa of the mean plot the distance of the regular sampling gridline is required to be at least 7.5, 2.0 and 10.0 m for Narwa, Sathin-1 and Sathin-2 plots, respectively. This difference is closely related to the overall heterogeneity of the plots. The

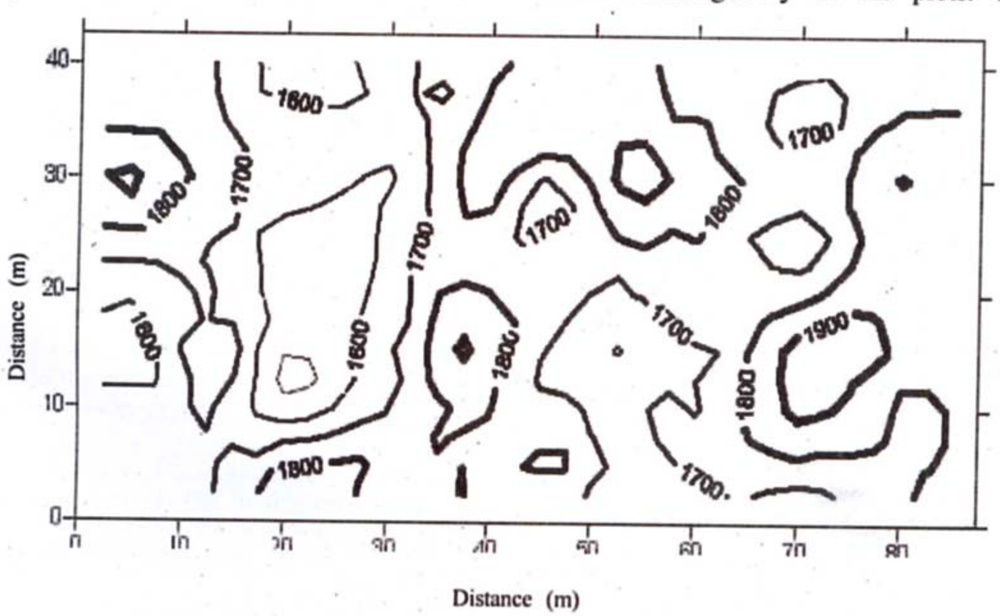

*Fig. 4. Distribution of salinity (micro S/cm*0.15) at Sathin-2.*

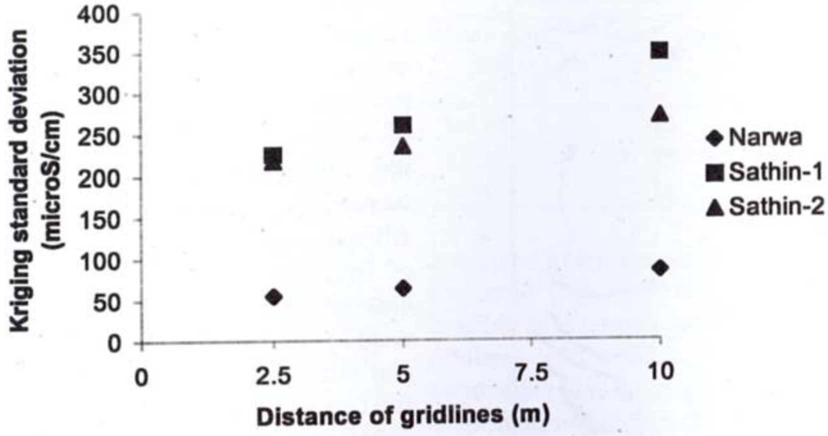

Fig. 5. Relationship between the distance of regular square gridlines with sampling points in the intersections and the kriging standard deviation of an interior point.

largest sampling distance is permissible in the most smoothly varying Sathin-2 plots.

Thus the above results revealed that the nugget, sill and range seemed to depend on salinity of irrigation water, soil texture and method of irrigation. The channels carrying saline water for irrigation were in contact with saline water for longer and thus accumulated more salt than the field proper. This large spatial variability in salinity should be considered because it requires more complex design for management of the salt affected soils.

Acknowledgements

The research has been carried out under the Indo-Hungarian intergovernmental collaborative project for the year 1998-2000. We are grateful to the Hungarian Academy of Sciences, Budapest, and to the Department of Science and Technology, Government of India, New Delhi, for financial support. We are also grateful to Dr. A.S. Faroda, the then Director, CAZRI, Jodhpur, and Prof. Tamas Nemeth, Director, RISSAC, Budapest, for providing facilities for smooth conduct of the project. Technical support from Mr. P.C. Bohra is also gratefully acknowledged.

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