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Spatial variability analysis of some soil properties in the irrigation block of Sardar Sarovar canal command of Gujarat

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Abstract : In the study, quantitative estimates were made on the degree of spatial variation of surface and sub-surface properties of the command area. A total of 99 samples were collected at regular intersection of 4 km x 4 km of a square grid covering an area of 25800 ha of 9A/7 irrigation block of the Sardar Sarovar Canal Command. The descriptive statistics of the data indicated considerable site variability for soil pH, $CaCO_3$ content and surface organic matter. The directional semi-variogram of surface and sub-surface soil properties indicated that there was no effect of direction. The isotropic semi-variograms of surface and sub-surface soil pH, sub-surface $CaCO_3$ and surface organic matter were best fitted to spherical model and of surface $CaCO_3$ was best fitted to linear model which indicated that the data are have spatial structure. The range of spatial dependence was 2.6 to 3.0 km for soil pH, 5.2 to 8.0 km for $CaCO_3$ and 16 km for organic matter. Using the spherical variogram kriged estimates were computed by ordinary kriging and contour maps were prepared. The difference between measured and estimated values were small and the standard deviation of the estimated values was also small which indicated that the model was adequate.

Additional key words: *$CaCO_3$ soil pH, geo-statistics, kriging, semi-variogram*

Introduction

Spatial variability is an inherent and dynamic feature of soil. It may be both vertical (within a pedon) and horizontal (across the landscape). The soil variability has been of great concern to the researchers in the past as it plays an important role in design of field experiments, management of soils and in evaluation of the productivity potential. Soil scientists have exclusively studied soil variability in the past as it is important source of external variation, which affect the crop yield (Montgomery 1913; Beckett and Webster 1971). The proper characterization of spatial variation of soil properties has many practical implications such as fertility management, sampling scheme and soil mapping (Webster 1985). The salt affected area under the Sardar Sarovar canal command needs special attention for its sampling and mapping which may be useful for, 1) accurately estimating the pattern of changes in the soil properties under the influence of canal irrigation, 2) estimating the variation in yield because of variation in soil properties, and 3) studying the variations in these properties over distance will be helpful for delineating size and uniformity of soil management units.

In recent years, there have been important advances in geo-statistical methods for the detection and characterization of spatial dependence (Dahiya *et al.* 1984; Webster 1985). This relatively new approach affords a means of quantifying the spatial dependence among the sampling points for a given variable by semi-variogram analysis and additionally also allows unbiased interpolation of values by kriging techniques. Kriging is unbiased estimate with a minimum and known variance (Journel and Huijbregts 1978;

Burgess and Webster 1980). Isarithmic maps made by kriging are alternatives to conventional soil maps where properties can be measured at closed spacing. Some attempts have been made (Raman 1981; Raman *et al.* 1983) for characterizing the salinity variation using geo-statistics. In this study an attempt has been made to 1) determine the structure of spatial dependence of surface and sub-surface soil pH and $CaCO_3$ content and surface soil organic matter content of 9A/7 irrigation block of the Sardar Sarovar Canal Command in Jambusar taluka of Bharuch district of Gujarat; 2) examine and interpret semi-variograms of these soil properties, and 3) prepare an isarithmic map of spatially dependent parameter based on interpolated (kriged) and observed values.

Materials and Methods

The study area *i.e.* 9A/7 irrigation block of Sardar Sarovar Canal Command covering 25,800 ha, lies between 72^0 32' to 72^0 44' E and 21^0 57' to 22^0 14' N. The area is surrounded by the Gulf of Khambhat in the west, Mahisagar river on the north and Dhadar river in the south. These soils are fine, hyperthermic, montmorillonitic in nature. The mean annual rainfall of this area is 650 mm. The area is sampled by using 1:50,000 scale toposheet of SOI with a soil profile (sample point) within 4 km x 4 km grid. A total of 99 soil samples were collected randomly each from 0-30 cm, 30-90 cm and > 90 cm depth at a regular intersection of 4 km x 4 km of a square grid. The location of x and y intersects were determined by measuring the distance into the block area. The final layout is shown in figure1.

Classical statistical analysis

The mean (m), standard deviation (s) and coefficients of variation (CV = 100 x s/m) were computed by using descriptive statistics.

Geo-statistical analysis

The theory of regionalized variables (Matheron 1971) was used to investigate the spatial variability analysis. The semi-variance function, $\gamma(h)$ is expected square difference between values at location separated by a given lag and is used to express spatial variations (Journel and Huijbregts 1978).

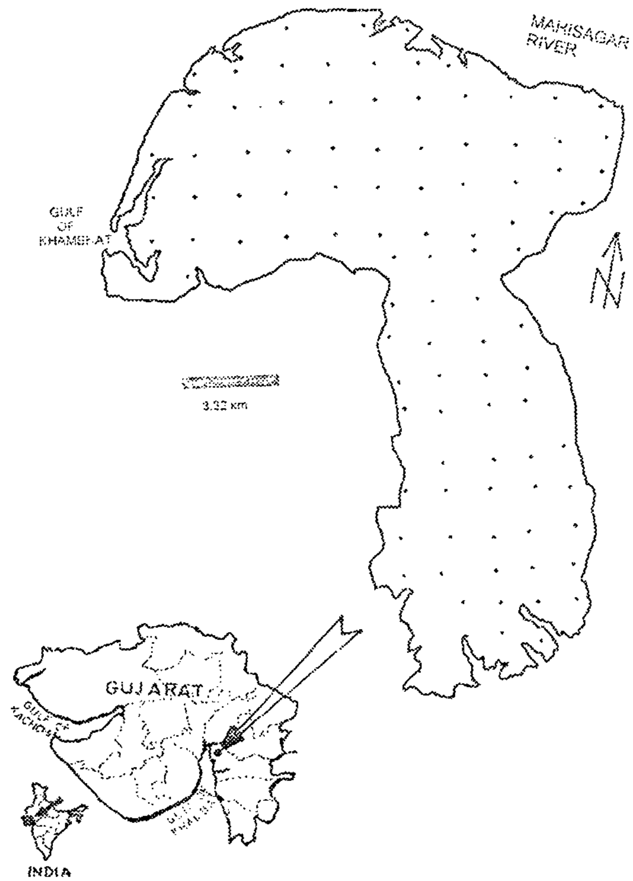


Fig. 1. Location of the study area with sampling points

$$\gamma(h) = \tfrac{1}{2}\, n(h) \sum_{i=1}^{n(h)} [Z(x_i) - Z(x_i+h)]^2$$

Where $\gamma(h)$ is the sample semi-variance and n (h) is the number of pairs of the observations at a separation distance h. $Z(x_i)$ and $Z(x_i+h)$ are the measured values of the regionalized variables at locations x and x + h separated by the vector h, known as lag. The semi-variogram was plotted with h on abscissa and $\gamma(h)$ i.e. semi-variance on the ordinate and resulting function was fitted to linear, spherical and exponential theoretical models. Characteristics of the semi-variogram such as nugget, sill and range were tabulated for surface and sub-surface soil properties and provided the basis for interpretation. Using the appropriate semi-variogram, the field grid points were kriged and plots were made of these kriged values. In cross validation, the estimates were compared to the original observation in order to test if the hypothetical variogram model and neighbourhood search parameter will accurately reproduce the spatial variability of sampled observations. The geo-statistical analysis was performed by using GEO-EAS 1.2.1 (EPA 1991).

Results and Discussion

Classical statistical analysis :

Descriptive statistics of the soil properties (Table 1) *i.e.* mean, standard deviation (SD), maximum, minimum and coefficient of variation (%) showed that in all the cases mean of pH and $CaCO_3$ increases in the magnitude with depth. Wilding (1985) described a classification scheme for identifying the extent of variability for soil properties based on their CV values in which CV values of 0-15, 16-35, and >36 indicate little, moderate, and high variability, respectively. The results indicated low variability among the pH values within soil profile and high variability among organic matter (OM) and $CaCO_3$ values. The coefficient of variation ranged from 5.39 per cent for the pH at 90 to 150 cm to 6.14 per cent for the pH at 30-90 cm depth indicating low within site variability of the soil pH. The CV for surface OM is 33.08 percent and in case of $CaCO_3$, CV is ranging from 48.24 per cent for 90 to 150 cm to 84.39 per cent for 0-30 cm depth indicating considerable high within site variability of the $CaCO_3$.

Geo-statistical analysis:

The isotropic semi-variogram for the surface and sub-surface soil pH, sub-surface $CaCO_3$ and surface organic matter are best fitted to spherical model and for surface $CaCO_3$ is best fitted to linear model and shown in figure 2. There was no difference by the direction as evident from the directional variograms. The key parameters of the semi-variogram are presented in table 2. The intercept *i.e.* nugget variance which is the estimate of γ h = 0, provides an indication of short distance variation. The range of

Table 1. Descriptive statistics of the surface and sub-surface soil properties

Variables	No. of samples	Minimum	Maximum	Mean	SD*	CV**(%)
pH (0-30 cm)	99	7.15	9.15	8.27	0.447	5.405
pH (30-90 cm)	99	7.23	9.25	8.34	0.513	6.146
pH (90-150 cm)	99	7.13	9.25	8.36	0.451	5.397
$CaCO_3$ (0-30 cm)	99	0.55	17.80	5.49	4.63	84.395
$CaCO_3$ (30-90 cm)	99	0.93	19.70	6.50	4.56	70.154
$CaCO_3$ (90-150 cm)	99	2.70	27.40	9.88	4.77	48.242
OC (0-30 cm)	99	0.15	1.05	0.68	0.225	33.08

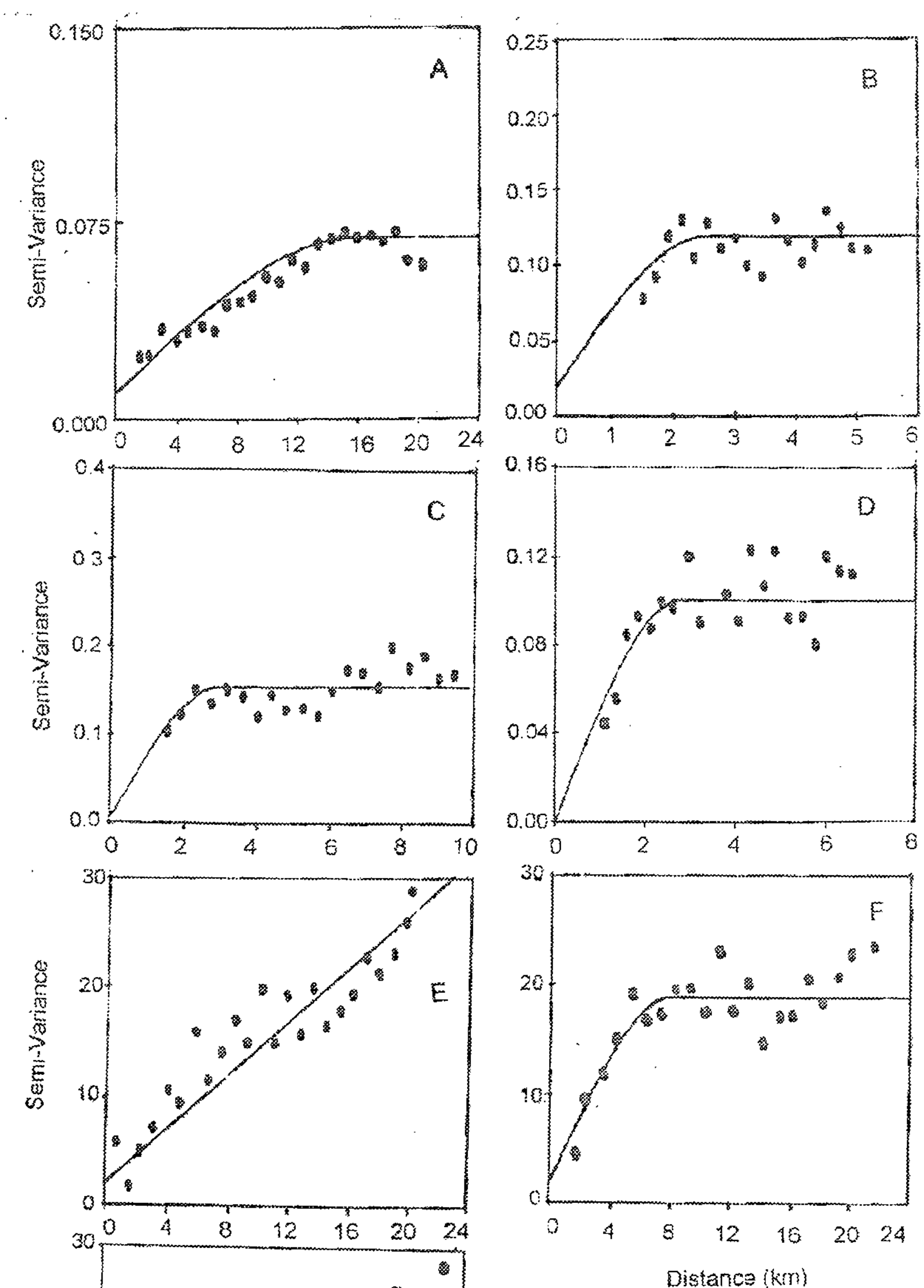
* Standard Deviation; ** Coefficient of Variation

Table 2. Summary of the semi-variogram of spatial variability of surface and sub-surface soil properties

Variables	Nugget	% of Sill	Range	Sill	Variance
pH (0-30 cm)	0.020	20.0	2.6	0.10	0.199
pH (30-90 cm)	0.005	3.33	3.0	0.15	0.263
pH (90-150 cm)	0.00	0	2.8	0.10	0.204
$CaCO_3$ (0-30 cm)	2.00	-	5.2	-	21.480
$CaCO_3$ (30-90 cm)	2.00	11.76	8.0	17.00	20.827
$CaCO_3$ (90-150 cm)	3.20	16.84	6.0	19.00	22.770
OC (0-30 cm)	0.010	16.67	16.0	0.060	-0.501

Model : Spherical $\gamma(h) = C0 + 0.5\,C1[(3h/a) - (h/a)3]$ for $h < a$

$= C0 + C1$ for $h > a$



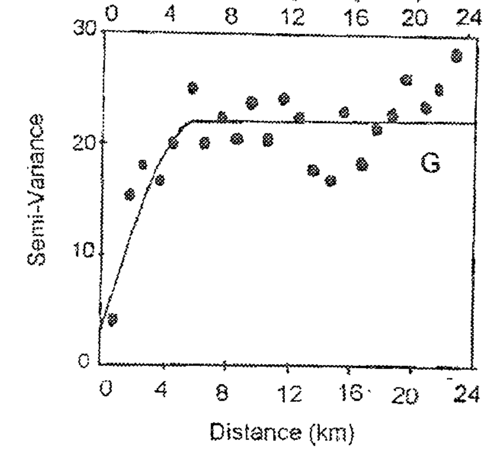


Fig. 2. Isotropic semi-variogram for soil properties of Irrigation Block 9A/7
[A - OM (0-30 cm), B - pH (0-30 cm),
C - pH (30-90 cm), D - pH (90-150 cm),
E - $CaCO_3$ (0-30 cm), F - $CaCO_3$ (30-90 cm
G - $CaCO_3$ (90-150 cm)]

semi-variance is the distance (h) at which the γ attains maximum value (sill). At and beyond this distance, the sample becomes spatially independent and uncorrelated with each other. The range of the semi-variogram which indicates the size of the zone of influence (Matheron 1963), *i.e.* the size of area in which the samples are statistically associated with a sample from the center of the area.

The zone of influence (range) of soil pH was in the range of 2.6 to 3.0 km and that for $CaCO_3$ was ranging from 5.2 km (0-30 cm) to 8.0 km (30-90 cm). The shorter range of pH and $CaCO_3$ in the surface soils represents the influence of both the precipitation and dissolution of $CaCO_3$ due to the crop (root exudation) and fertilizer application (Yost *et al.* 1982) and influence of rainfall. Whereas in the sub-surface (>90 cm) soils, because of no or insignificant dilution and only the active process of precipitation causing less variation hence results wider range. In case of surface organic matter, the zone of influence is 16 km, which is larger range as compared to other soil properties.

The variance of pH was smaller for surface soils than the sub-surface soil (30-90 cm). The major difference between the semi-variogram of surface and sub-surface soils were in the amount of variations occurring over small distance (nugget). The estimates of the normalized semi-variance for the smallest distances are 20.0 per cent for surface soils, 3.33 per cent for sub-surface (30-90 cm) and zero nugget for sub-surface (90-150 cm) soil pH. The variance in case of surface organic matter is 0.501 and estimates of the normalized semi-variance for smallest distance is 16.67 per cent and in case of $CaCO_3$, variance is between 20 to 22 per cent. The semi-variance is almost same for surface and sub-surface soils.

Using the original data and semi-variogram models, the kriged estimates were computed by ord inary kriging. The estimated and observed values were used for preparing the contour maps (Figures 3 a & b). The contours were smooth and continuous. The means of variance of the measured and kriged value are given in table 3. The average absolute difference between kriged estimates a nd that of the measured value for soil pH was 0.008 in the surface soil and 0.01 in the sub-surface (90-150 cm) soil, that For $CaCO_3$ it was 0.027 in surface soil and 0.023 in sub-surface soil (30-90 cm) and that for OM was 0.007 in surface soil. The standard deviation for soil pH was 0.011, 0.018 and 0.015, respectively for surface and sub-surface soils (30-90 & 90-150 cm) and that for $CaCO_3$ was 0.108, 0.177 and 0.212, respectively for surface and sub-surface soils. The standard deviation for OM was 0.007 for surface soils. As the difference and standard deviation are small for all soil properties, the models are judged to be adequate.

Table 3. Comparison of statistical parameters for measured and kriged values of the soil properties

Parameters	Measured value	Estimated value	Difference	Ksd*
		pH (0-30 cm)		
Mean	8.272	8.264	-0.008	0.354
SD	0.447	0.333	0.365	0.011
		pH (30-90 cm)		
Mean	8.351	8.340	-0.010	0.390
SD	0.517	0.412	0.385	0.018
		pH (90-150 cm)		
Mean	8.363	8.363	0.01	0.312
SD	0.452	0.339	0.345	0.015
		$CaCO_3$ (0-30 cm)		
Mean	5.493	5.465	-0.027	2.135
SD	4.635	3.963	1.958	0.108
		$CaCO_3$ (30-90 cm)		
Mean	6.505	6.482	-0.023	2.832
SD	4.564	3.655	2.789	0.177
		$CaCO_3$ (90-150 cm)		
Mean	9.885	9.912	0.027	3.525
SD	4.771	3.178	4.700	0.212
		OM (0-30 cm)		
Mean	0.680	0.682	0.001	0.148
SD	0.225	0.161	0.164	0.007

*Kriged standard deviation

The surface organic matter, the surface and sub-surface pH and $CaCO_3$ (Figure 3) exhibited a sharp gradient from north to south with maximum at or towards the Dhadar River. However, a localized loop of high $CaCO_3$ was observed towards the northeast part of the irrigation block (Figure 3b).

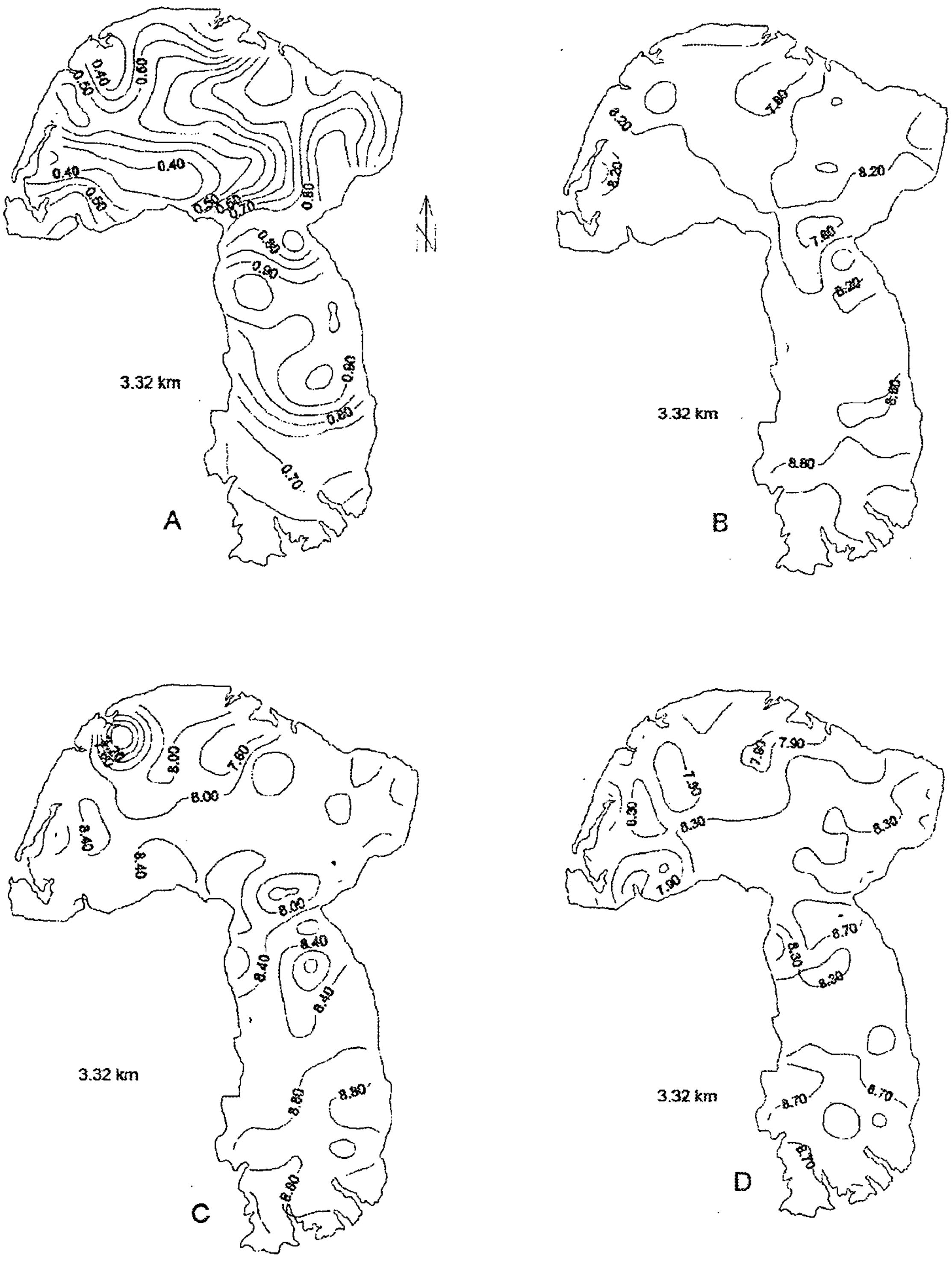


Fig. 3 a. Contour maps of kriged estimates of soil properties of the irrigation block of Sardar Sarovar Canal Comman(
A. OM (0-30 cm), B. pH (0-30 cm), C. pH (30-90 cm) and D. pH (90-150 cm)

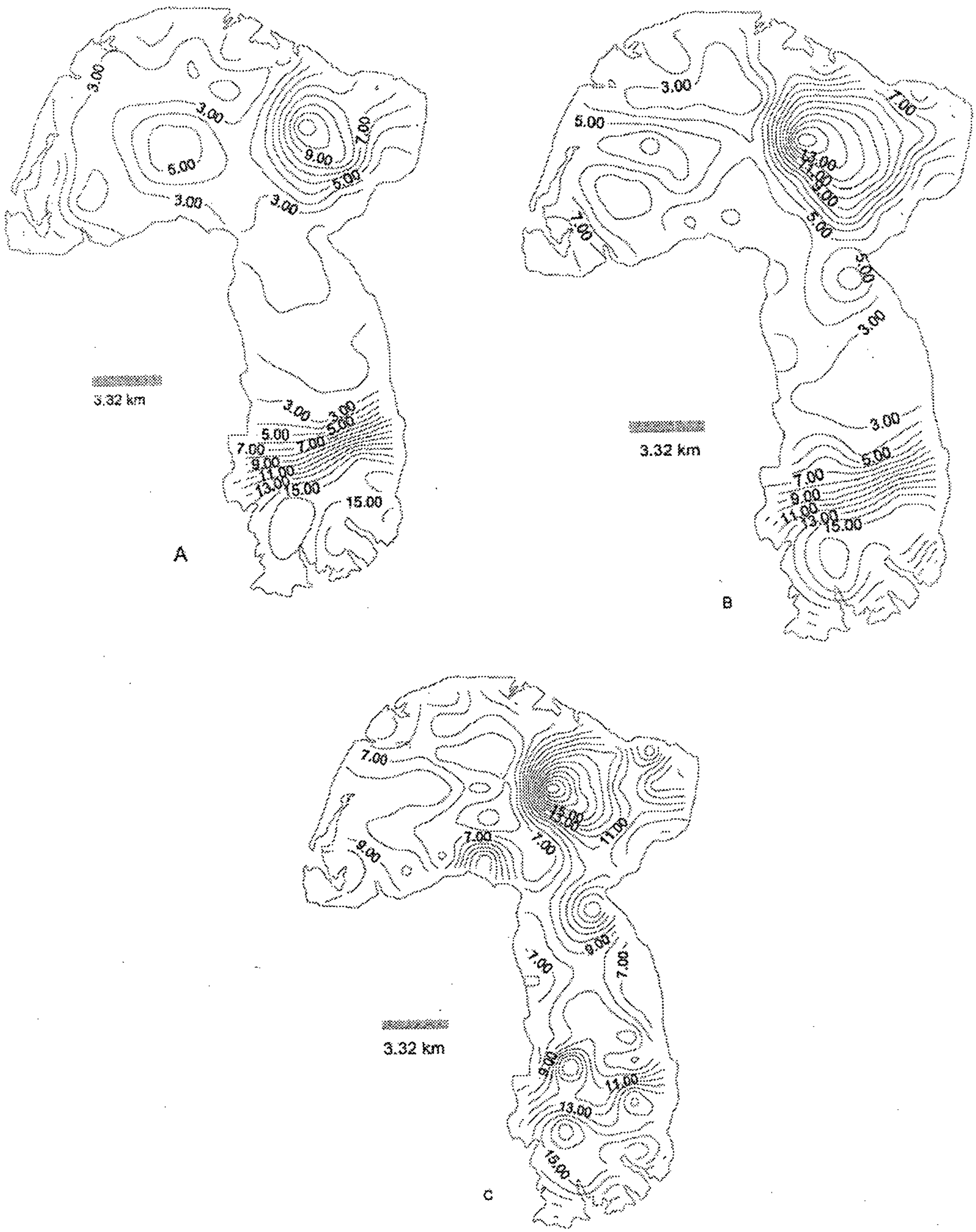


Fig. 3 b. Contour maps of kriged estimates of soil properties of the irrigation block of Sardar Sarovar Canal Command A. $CaCO_3$ (0-30 cm), B. $CaCO_3$ (30-90 cm) and C. $CaCO_3$ (90-150 cm)

The results of this study emphasizes that the soil properties (pH, $CaCO_3$ and OM) of irrigation block have spatial dependence. The pattern of spatial variability indicates the influence of crop, fertilizer management and rainfall on soil pH and surface $CaCO_3$ content and hydro-geological impacts on sub-surface $CaCO_3$ content over space and depth. The contour maps would serve as a benchmark to monitor the changes in the soil properties under the influence of Sardar Sarovar Canal Command in future.

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