Annals of Arid Zone 40(4): 405-411, 2001

Geostatistical Analysis of Zinc Fractions in Surface Soil of Alluvial Plains

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Abstract: Spatial variability of exchangeable zinc (Ex-Zn) and carbonate zinc (Carb-Zn) was investigated in 5600 km^2 area of Rohtak and parts of its adjoining districts in the Indo-Gangetic alluvial plains of north-west India. Seventy two surface samples (0-15 cm) were taken at the nodes of a 10 km x 10 km grid. The semivariogram of Ex-Zn showed that this zinc fraction is spatialy dependent up to a distance of 30 km within the study area, and therefore, should be used for interpolation by kriging techniques. The semivariogram of Carb-Zn showed no spatial dependence of this fraction, indicating its random distribution. Hence, the semivariogram of Ex-Zn was used for interpolation of values between the grids by point and block kriging. The observed and kriged values were used to draw isarithmic maps of Ex-Zn. The estimation variance obtained by block kriging was 7.5 times less than that obtained by point kriging. As a result of this the isarithmic map by block kriging was a smooth one and that by point kriging was spotty, and the estimated number of samples required for Ex-Zn at 95% confidence level with a precision of ±10% of the true mean was only 6 by block krigning as compared to 57 by point kriging.

Key words: Geostatistical analysis, zinc fractions, alluvial plains.

In order to evaluate the production potential of a given area, it is important to consider spatial variability in soil properties within an area. Invariably soil properties display spatial dependence, i.e., properties at one site are statistically dependent on those at nearby sites. This fact has not been taken into account in most of the previous studies on soil variability. Rather, their statistical analysis depended mainly upon classical statistical methods, which assume that soil properties do not exhibit spatial dependence (Beckett and Webster, 1971; Dahiya *et al.*, 1984). In recent years, there have been important advances in geostatistical methods for the detection and characterisation of spatial dependence (Dahiya et al., 1984; Webster, 1985). This relatively new approach affords a means of quantifying the spatial dependency among sampling points for a given variable by semivariogram analysis and additionally, also allows unbiased interpolation of values by kriging techniques, which is not possible by classical statistical methods.

The present study was undertaken with the objectives: (i) to quantify the spatial dependence of variation in exchangeable zinc (Ex-Zn) and carbonate Zinc (Carb-Zn) of the soils of a large area in the Indo-Gangetic alluvial plains by semivariogram analysis; (ii) to use the spatial dependence, if any, to interpolate the values of these parameters at shorter and unrecorded sites by kriging techniques; (iii) to prepare isarithmic maps of the spatially dependent parameters based on interpolated (kriged)

Table 1. Comparison of statistical parameters for Ex-Zn using different approaches

Statistical parameter	Ex-Zn
Classical techniques	
Mean (m)	0.50
Variance (S^2)	0.03
Standard deviation (S)	0.20
Point kriging	
Mean (m)	0.45
Variance (S^2_k)	0.03
Standard deviation (S_k)	0.20
Block kriging	
Mean (m_{kb})	0.45
Variance (S^2_{kb})	0.004
Standard deviation (k_b)	0.06
Ratio	
S^2/S^2_k	1.30
S^2/S^2_{kb}	7.50
S^2_k/S^2_{kb}	7.50

and observed values for farm and environmental advisory services; and (iv) to suggest optimum sampling strategy.

Materials and Methods

The study area (5600 km^2 of Rohtak and its adjoining districts in Haryana) lies between 28°30′ and 29°5′ 30"N latitude and 76°12′ 30" and 76°58′E longitude. The landscape, a part of the Indo-Gangetic alluvial plains, has been formed by alluvial deposition brought by the Himalayan rivers. The alluvial deposits consist of sand, silt and clay with occasional gravel beds, with the exception of few small outliers of Alwar quartzite (Dahiya *et al.*, 1988). There is no sign of hard rock exposure in the area, which is almost concealed by the vast expanse of alluvium. The climate is sub-tropical, semi-arid, continental and monsoonal, with mean annual rainfall of 535 mm. The soils are light to medium textured and alkaline (pH 8.0) and the alluvium is generally calcareous. Illite and Smectite are the dominating clay minerals.

Seventy two composite surface soil samples (0-15 cm) at a grid of 10 x 10 km were collected. From each location, five samples were taken randomly and mixed together to get a composite sample. These were analysed for Ex-Zn by extraction with 1 M Mg $(NO_3)_3$ and Carb-Zn by 1 M NaOAC (pH 5.0) method (Tessier *et al.*, 1979).

Statistical approach

Classical statistical analysis: The sample statistical parameters (mean, m, variance, s^2, standard deviation, s, coefficient of variation, CV = 100 x s/m) were estimated following Dahiya *et al.* (1984). The hypothesis that the data are normally or log-normally distributed was tested by using the frequency distribution function. It was done by constructing cumulative probability plots on normal probability paper (Dahiya *et al.*, 1984). The straight lines of such plots indicate normal frequency distribution of the original values of the variable or its transformed values.

The number of samples required to estimate the mean, within specified limits of the true mean, was calculated using equation given by Cline (1944):

$$n = [(t.s)/d]^2 \quad ...(1)$$

where,
n is the estimated sample size required to be within d units of the mean, and
t is the student's t value for the desired confidence level of the estimate.

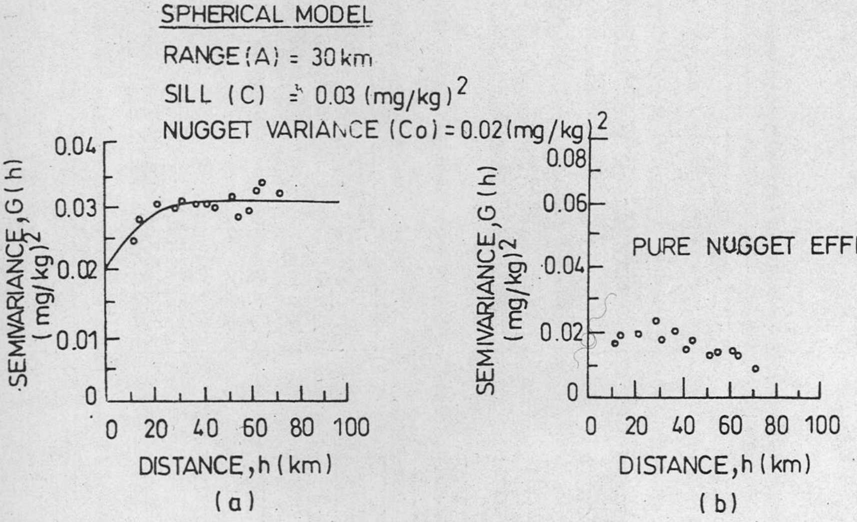

Fig. 1. (a) Semivariogram of exchangeable-zinc, (b) Semivariogram of carbonate-zinc.

Geostatistical analysis: The theory of regionalized variables (Matheron, 1971) was used to investigate the spatial variability of the two zinc fractions. The semivariance function, G(h), is expected square difference between values at locations separated by a given lag and is used to express spatial variations (Journal and Huijbregts, 1978):

$$G(h) = 1/2N(h)\ \Sigma[Z(x_i) - Z(x_i+h)]^2 \quad i = 1 \ldots, N(h) \qquad \ldots(2)$$

where,
G(h) is the sample semivariance and N(H) is the number of pairs of data points separated by the distance (h). $Z(x_i)$ and $Z(x_i + h)$ are the values of the property at locations x and x+h separated by the vector h, known as the lag. A plot of G(h) vs h is sample semivariogram and a model fitted to it is the semivariogram model.

Kriging was done using the procedures described by Journel and Huijbregts (1978) and Burgess and Webster (1980). Point kriging, which is an exact interpolator (Delhome, 1978) respresented by eq. (3), was used to estimate values of a spatially dependent variable at unsampled locations:

$$Z^*(x_o) = \{\Sigma\lambda_i\ Z(x_i)\} \quad i = 1 \ldots, N, \qquad \ldots(3)$$

where,
each estimated value $[Z^*(x_o)]$ is a weighted average of N observed values $[z(x_i)]$ within the neighbourhood of kriging location, and λ_i are the weights associated to the data points $z(x_i)$. The variance, s^2_k, is estimated by:

$$S^2_k = U + \Sigma\ [\lambda_i G\ (x_i, x_0)] - i = 1\text{-}N \qquad \ldots(4)$$

where,
$G(x_i, x_o)$ is the semivariance between the observed location x_i and the interpolated location x_o, U is lagrange parameter.

Users of informaiton on soil are often interested in average estimates of discrete areas or blocks (e.g., management units) rather than point estimates. In block kriging the kriged value Z* for any block V is

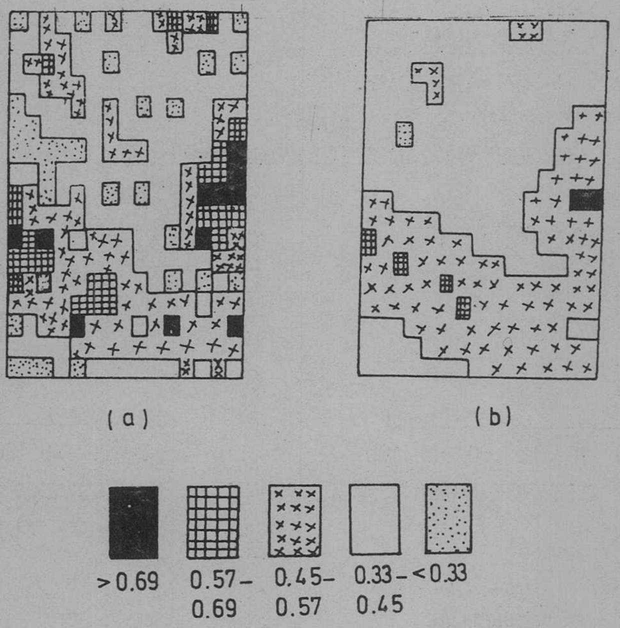

Fig. 2. (a) Isarithmic map of exchangeable-zinc obtained by point kriging, (b) Isarithmic map of exchangeable-zinc obtained by block kriging with block size 24 x 24 km.

a weighted average of the observed values $z(x_i)$ in the neighbourhood of block i.e.,

$$Z^*V = \Sigma[\lambda_i Z(x_i)] \qquad i = 1........, N \qquad ....(5)$$

The estimation variance,

$$S^2_{kb} = \Sigma\lambda_i \; G\;(x_i,V) + UV - G\;(V,V) \qquad i = 1\text{-}N \qquad ....(6)$$

where,

$G(x_i,V)$ is the average semivariance between the sample points x_i in the neighbourhood and those in block V. G (V,V) is the average semivariance between all points within V (i.e., within block variance) and uV is the lagrange parameters.

Results and Discussion

Classical statistical analysis

The content of Ex-Zn varied from 0.2 to 0.9 with m = 0.5 and s = 0.2 mg kg^{-1}. The corresponding values for Carb-Zn were 0.06 to 1.05, 0.17 and 0.12 mg kg^{-1}. The CV values were 38 for Ex-Zn and 73 for Carb-Zn, showing medium variation as per limits reported by Dahiya *et al.* (1984). Paz *et al.* (1997) reported medium variation for HC1-Zn (CV = 46) and EDTA-Zn (CV = 48) within a 1.8 ha plot. Grewal and Dahiya (1998) also reported medium variation of DTPA-Zn (CV = 61) in a very large area (42,222 km^2) comprising the whole of Haryana state.

The straight lines of the original data on the probability plots showed that the two zinc fractions were normally distributed within the study area, indicating thereby that the original data can be used for further statistical analysis without any transformation.

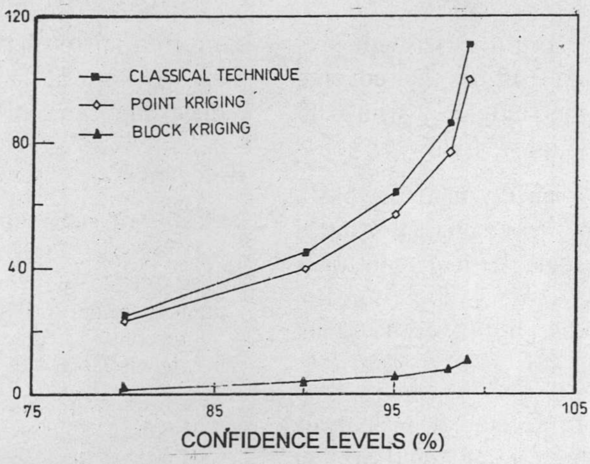

Fig. 3. Number of samples required for exchangeable-zinc at different confidence levels.

Geostatistical analysis

The semivariogram of Ex-Zn was bounded having a definite sill, i.e., 0.03 (mg $kg^{-1})^2$ with range 30 km and nuget variance 0.02 (mg $kg^{-1})^2$(Fig. 1). The semivariogram was well described by sepherical model (Fig. 1). Paz *et al.* (1997) reported a definite sill of 3.4 and 0.52 (mg $kg^{-1})^2$ for HC1-Zn and EDTA-Zn, respectively, for a 1.8 ha plot. The range was approximately 50 m. Grewal and Dahiya (1998) reported the spatial dependence of DTPA-extractable zinc having semivariogram of definite sill of 0.196 (mg $kg^{-1})^2$ and range 155 km for the Haryana state. The semivariogram of Carb-Zn was having pure nugget effect. So, this fraction was randomly distributed for all sampling spacings more than the sampling distance of 10 km. The spatial independence of this fraction was reported by Wopereis *et al.* (1988) for a study area of one hectare only.

The ratio of nugget variance to sill expressed in percentages can be regarded as a criterion to classify the spatial dependence of soil properties. If this ratio is less than 25%, the variable has strong spatial dependence and if it is between 25 and 75%, the variable has moderate spatial dependence; otherwise, the variable has weak spatial dependence (Cambardella *et al.*, 1994). The ratio of nugget variance to sill for the Ex-Zn was 67%, indicating that it was moderately spatial-dependent.

Since Ex-Zn showed spatial dependence, its additional values were generated at unrecorded sites by point and block kriging, using the semivariogram model (Fig. 1a). A block size of 24 x 24 km was used for interpolation because it gave the minimum estimation variance compared to other block sizes. The observed and kriged values were used for preparing isarithmic maps of Ex-Zn (Fig. 2).

The isarithmic map prepared by point kriging (Fig. 2a) was very spotty and discontinuous. This spottiness disappeared to a great extent in case of block kriged map (Fig. 2b). The block kriged map shows that there is a general tendency of increasing levels of Ex-Zn from north-west to south-east. The category 0.33 to 0.45 mg kg^{-1} covered the major part of the study area with 0.45 to 0.57 mg kg^{-1} closely following it.

The estimated variance obtained by block kriging was 7.5 times less than that obtained by point kriging (Table 1). It demonstrates many-fold improvement in estiamtion precision by block kriging over the point krigning method.

The results from geostatistical analysis of the data show that kriging could explain most of the variation in the original data. Practically, it means that if a variable is spatially dependent, the esatimation of variance by the classical method is not a reliable parameter for the interpretation of the data. Similar inference was made by a number of workers for several soil properties (Dahiya *et al.*, 1984; Webster, 1985; Grewal and Dahiya, 1998; Goderya, 1998).

Designing an optimal sampling scheme

Geostatistically analyzed data can be used for designing an optimal sampling scheme for a given parameter (Webster, 1985). The statistical parameter of observed and kriged estiamtes of Ex-Zn (Table 1) were used in Eq. 1 for calculating the number of samples required to improve precision within ±10% of the true mean at 90, 95 and 99% confidence levels. Figure 3 compares sample number (at different confidence levels) for three statistical approaches. For example, it can be seen from Fig. 3 that to estimate the mean of Ex-Zn within ±10% of the true mean, only six samples would be required for block kriging and 57 for point kriging for future sampling, provided the semivariogram model is known. This would considerably reduce the sampling efforts and cost.

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