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## Spatial variability of nitrogen fractions in parts of the Indo-Gangetic alluvial plains

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*Abstract*

Spatial variability of ammonical nitrogen ($NH_4^+$–N) and nitrate nitrogen ($NO_3^-$–N) was investigated in 5600 $km^2$ area of Rohtak and parts of its adjoining districts; a part of the Indo-Gangetic alluvial plains. Seventy-two surface samples (0–15 cm) were taken at the nodes of a 10 km x 10 km grid. The unboundedness of semivariogram showed that $NH_4^+$–N is spatially dependent for all distances more than sampling distance of 10 km. The semivariogram was well expressed by power function regression model. Nugget variance was 7.97 (mg $kg^{-1})^2$ i.e. 8% of the sample variance. The semivariogram of $NO_3^-$–N was expressed by spherical model with a range of 30 km, sill 57 (mg $kg^{-1})^2$ and nugget variance 25 (mg $kg^{-1})^2$ *i.e.* 42% of the sample variance. Hence, the semivariograms were 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 $NH_4^+$–N and $NO_3^-$–N. The estimation variances obtained by block kriging for $NH_4^+$–N were 9.10 and 13.10 times less than that obtained by point kriging and classical technique, respectively. The values for $NO_3^-$–N were 8.70 and 11.0, respectively. As a result of this i) the isarithmic map by block kriging was smooth one and that by point kriging was spotty, and ii) the estimated number of samples required for $NH_4^+$–N and $NO_3^-$–N at 95% confidence level with a precision of ±10% of the true mean were 6 and 7 by block kriging as compared to 55 and 62 by point kriging, respectively.

*Additional keywords* : Geostatistical analysis, kriging, isarithmic mapping, semivariogram.

## Introduction

To evaluate the productive potential, it is essential to consider spatial variability in soil properties. 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. Their statistical analysis depends 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 dependence 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 ammonical nitrogen ($NH_4^+$–N) and nitrate nitrogen ($NO_3^-$–N) of the soils of Rohtak and its adjoining districts 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 parameter based on interpolated (kriged) and observed values for farm and environmental advisory services, and iv) to suggest optimum sampling strategy based on the results obtained.

## Materials and methods

The study area comprises of 5600 km$^2$ of the Rohtak and parts of its adjoining districts of Haryana. It lies between 20° 30' to 29° 5' 30" N latitudes and 76° 12' 30" to 76° 58' E longitudes. 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 small outliers of Alwar quartzite (Dahiya, *et al.* 1988). There is no sign of hard rock exposure in the area and is almost concealed by the wide expanse of alluvium. The climate is sub-tropical, semi-arid, continental and monsoonal type with mean annual rainfall of 535 mm. The soils are light to medium textured with alkaline reaction (pH 8.0) and the alluvium is generally calcareous. Illite and smectite together dominate the clay fractions.

Seventy-two composite surface soil samples (0–15 cm) at a grid of 10 km 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 $NH_4^+$–N and $NO_3^-$–N by extraction with 2M KCl method (Bremner 1965).

## Statistical approach

*Classical statistical analysis*: The sample statistical parameters viz. mean (m), variance, ($s^2$), standard deviation (s), coefficient of variation (CV=100 x s/m) were estimated by the usual statistical formulae (Dahiya, *et al.* 1984). The normal or log- normal distribution of the data are tested using the frequency distribution function 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).

$$N=[(t.s)/d]^2 \qquad \ldots(1)$$

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.

*Geostatistical analysis* : The theory of regionalized variables (Matheron 1971) was used to investigate the spatial variability of the two nitrogen 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 (Journel and Huijbregts 1978).

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

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 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 semivariogram model.

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

$$Z^*(x_0) = \Sigma\, \lambda_i\, Z(x_i) \qquad i = 1 \ldots\ldots, N, \qquad (3)$$

Where each estimated value $[Z^*(x_0)]$ is a weighted average of N observed values $[Z(x_i)]$ within the neighbourhood of kriging location, and $\lambda_i$ are the weights associated to the data points $Z(x_i)$. The estimation variance, $s^2k$, is estimated by :

$$s^2{}_k = \Sigma\, \lambda_i G\, (x_i, x_0) + u \qquad i = 1 \ldots.., N, \quad (4)$$

where $G(x_i, x_0)$ is the semivariance between the observed location $x_i$ and the interpolated location $x_0$.

Users of information 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 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, $S^2_{kb}$, is given by

$$s^2_{kb} = \Sigma \lambda_i G(x_i, V) + uV - G(V,V) \qquad i = 1 ....., N, \quad (4)$$

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 lag range parameter.

## Results and discusson

*Classical statistical analysis* : The content of $NH^+_4$–N varied from 7.0 to 49.0 mg $kg^{-1}$ soil with mean 22.2 and standard deviation 9.9 mg $kg^{-1}$. The corresponding values for $NO_3^-$–N were 7.0 to 42.0, 16.3 and 7.7 mg $kg^{-1}$. The CV values were 46 for $NH_4^+$–N and 47 for $NO_3^-$–N showing medium variation as per limits reported by Dahiya *et al.* (1984).

*Geostatistical analysis* : The semivariogram of $NH_4^+$–N and $NO_3^-$–N are shown in figure Ia, b. The unboundedness of the semivariogram indicates that $NH_4^+$–N is spatially dependent for all distances more than sampling distance of 10 km. The semivariogram was well expressed by power function regression model (Fig. 1a). The nugget variance was 7.97 (mg $kg^{-1}$)$^2$. It was 8% of the sample variance. For getting range and constant value of sill, sample from a still larger area should have been collected.

The semivariogram of $NO_3^-$–N had a spatial dependence up to a definite range of about 30 km. The semivariogram was bounded because the semivariance attained a constant value at a separation distance of about 30 km and well-expressed by a spherical model (Fig. 1b). Thus, any two values of this parameter were found to be mutually dependent within this separation distance and after that the values were spatially independent. So, random theory is applicable after the separation distance of 30 km. The semivariogram was bounded showing a definite sill i.e. 57 (mg $kg^{-1}$)$^2$ and range 30 km. The short range variation was 25 (mg $kg^{-1}$)$^2$ i.e. 42% of the sample variance. Grewal *et al.* (2000) reported the presence of spatial dependence of available nitrogen in 44222 $km^2$ area of Haryana with a range of 64 km. West *et al.* (1989) reported spatial dependence of total N in a 0.44 ha. rectangular pasture.

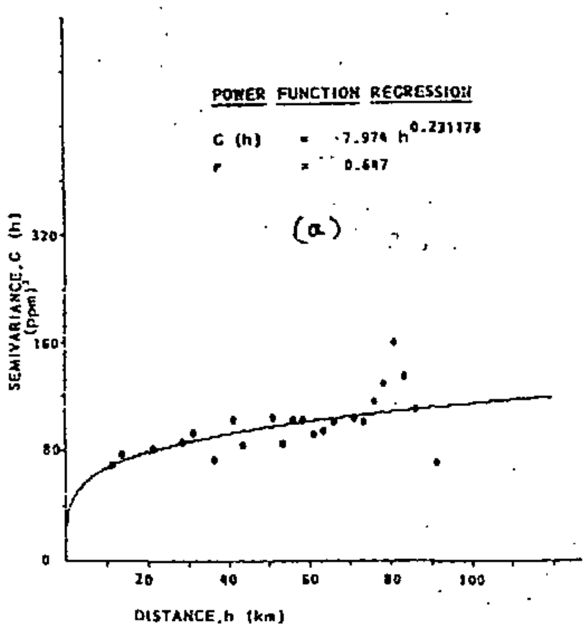


Fig. 1a. Semivariogram of $NH_4^+$–N

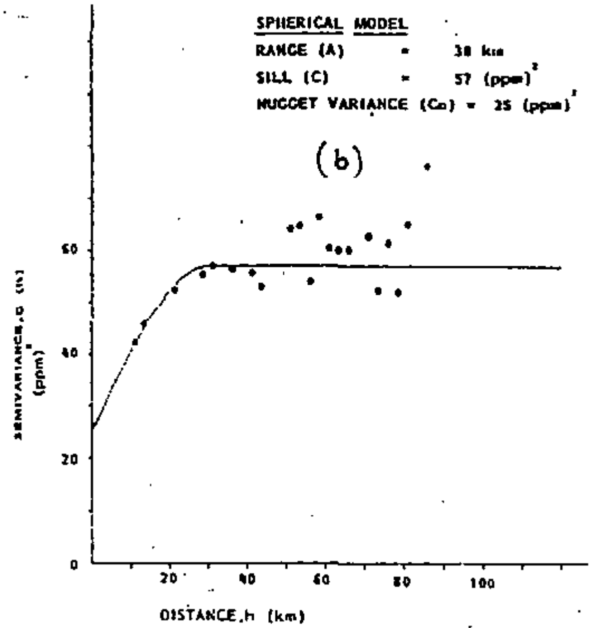


Fig. 1b. Semivariogram of $NO_3^-$–N

Since $NH_4^+$–N and $NO_3^-$–N showed spatial dependence, their additional values were generated at unrecorded sites by point and block kriging, using the semivariogram models. A block size of 24 km x 24 km was used for interpolation becuase it gave the minimum estimation variance compared to other block sizes. The observed and kriged values were used for preparing isarithmic maps of $NH_4^+$–N and $NO_3^-$–N.

The isarithmic maps prepared by point kriging were very spotty and discontinuous. This spottiness disappeared to a great extent in case of block kriged maps (Fig. 2a, b). It is seen from the figure 2a that a major part of the study area has $NH_4^+$–N level of 21–27 mg $kg^{-1}$ mostly covering Bahadurgarh, adjoining Gurgaon, Rohtak, Bhiwani, adjoining Sonepat and Gohana sub-divisions, closely followed by 15–21 mg $kg^{-1}$ mostly including Jhajjar, Kosli and Rohtak as well as some parts of adjoining Gurgaon, Rewari and Mohindergarh sub-divisions. The 27–33 mg $kg^{-1}$ levels was next in the south-east and north-west corners of the study area covering adjoining Gurgaon and Delhi and most of Meham. The $< 15$ and $> 33$ mg $kg^{-1}$ categories cover negligible area. $NO_3^-$–N levels (Fig. 2b) of 13.0 to 16.5 and 16.5 to 20.0 mg $kg^{-1}$ cover most of the study area. 13.0 and 20.0 to 23.5 mg $kg^{-1}$ categories covered some area in south (Kosli), east (Rohtak), west (Bhiwani and Rohtak) and north-east (Sonepat and Gohana).

The estimated variance obtained by block kriging was 13.1 and 11.0 times less than that obtained by classical technique and 9.1 and 8.7 times less than by point kriging for

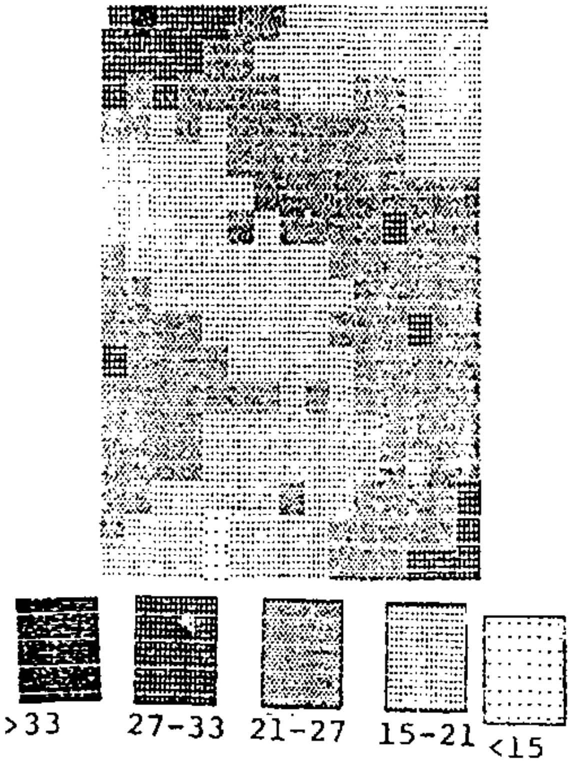


**Fig. 2a. Isarithmic map of $NH_4^+$–N obtained by block kriging with block size 24 x 24 km**

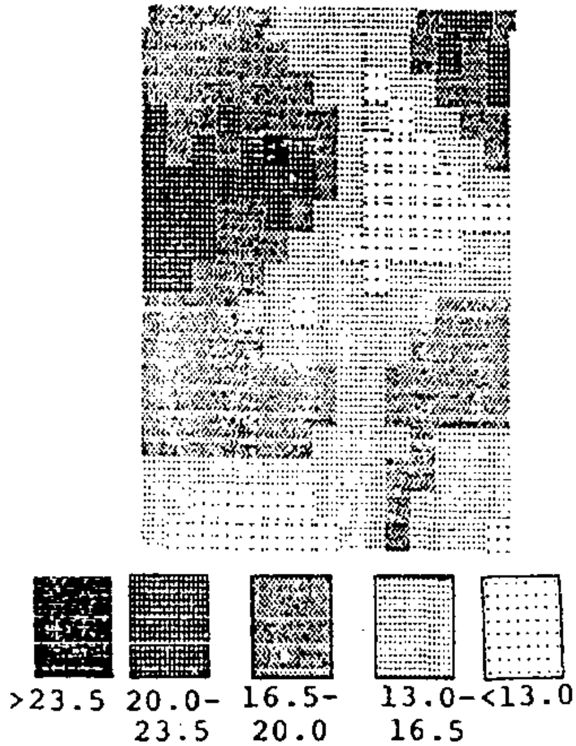


**Fig. 2b. Isarithmic map of $NO_3^-$–N obtained by block kriging with block size 24 x 24 km**

$NH_4^+$–N and $NO_3^-$–N, respectively (Table 1). It demonstrates a many fold improvement in estimation precision by block kriging over the classical and point kriging 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 estimation 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 analysed data can be used for designing an optimal sampling scheme for a given parameter (Webster 1985). The statistical parameter of observed and kriged estimates of $NH_4^+$–N and $NO_3^-$–N (Table 1) were used in equation 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. The sample size of $NH_4^+$–N and $NO_3^-$–N within ± 10% of the true mean at 95% confidence level gave only 6 and 7 samples for block kriging and 55 and 62 for point kriging, respectively for future sampling, provided the semivariogram model is known.

**Table 1. Comparison of statistical parameters for $NH_4^+$–N and $NO_3^-$–N using different approaches.**

| Statistical parameter | $NH_4^+$ – N | $NO_3^-$ – N |
|---|---|---|
| **Classical technique** | | |
| Mean (m) | 22.5 | 16.3 |
| Variance ($s^2$) | 98.0 | 59.4 |
| Standard deviation (s) | 9.9 | 7.7 |
| **Point kriging** | | |
| Mean ($m_k$) | 21.8 | 16.4 |
| Variance ($s^2{}_k$) | 68.4 | 46.8 |
| Standard deviation ($s_k$) | 8.3 | 6.8 |
| **Block kriging** | | |
| Mean ($m_{kb}$) | 21.7 | 16.4 |
| Variance ($s^2{}_{kb}$) | 7.5 | 5.4 |
| Standard deviation ($S_{kb}$) | 2.7 | 2.3 |
| **Ratio** | | |
| $s^2/s^2{}_k$ | 1.4 | 1.3 |
| $s^2/s^2{}_{kb}$ | 13.1 | 11.0 |
| $s^2{}_k/s^2{}_{kb}$ | 9.1 | 8.7 |

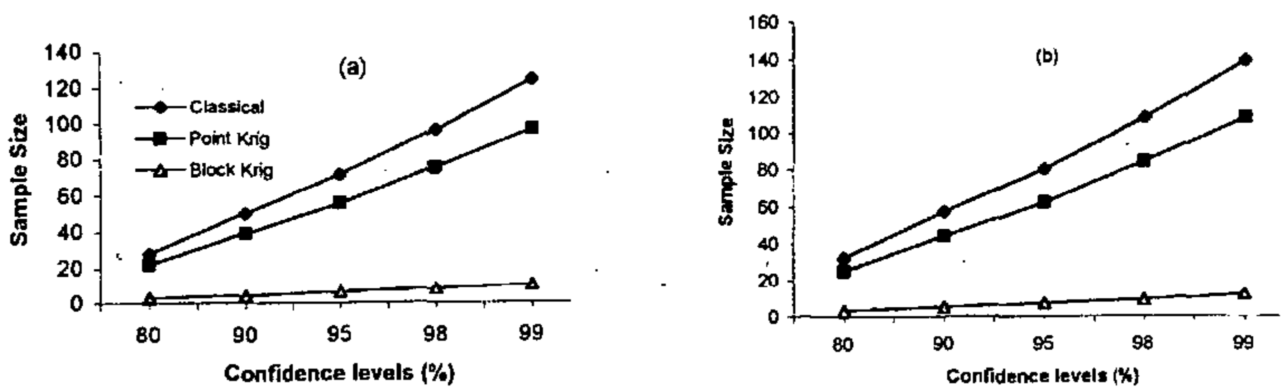


**Fig. 3. Number of samples required for $NH_4^+$–N and $NO_3^-$–N at different confidence levels.**

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