Spatial variability in chemical properties of red soils, Coimbatore district, Tamil Nadu

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Abstract: The spatial structure of soil chemical properties was investigated by calculating the semivariograms to determine the variances of the estimates made by the spatial interpolation technique of kriging for surface soil samples (0-15 cm depth) collected at 23 m intervals in respect of pH, EC, organic carbon, available P, K, DTPA - extractable, Fe, Mn, Cu, Zn. The descriptive statistics of the data indicated considerable variability of soil properties. Semivariograms revealed that the data had spatial structure. pH exhibited low CV values (5.24%) but EC, available P and Mn recorded high CV values whereas other soil properties had CV between 15 and 50 per cent. pH, EC, Organic carbon and available Fe were strongly spatial dependent whereas available P, K, Mn, Cu and Zn were moderately spatial dependent. The spatial dependence was very short ranged (8.9 m) for available P. The semivariograms portray change at distances in ways that suggest grouping of soils in order to obtain uniform regions of soil properties suitable for management regimes.

Additional key words: Geostatistics, kriging, isarithmic mapping, semivariogram

Introduction

Soil spatial variability is a naturally occurring feature that is important in the identification of soil properties relative to soil productivity (Ball and Williams 1968). Since, soil properties gradually change across the landscape, the investigation of the variability of soil chemical properties with distance has become increasingly more important over the past few years. When an observation gives some information to the value or magnitude of its neighbour, such data are spatially dependent. When variables are spatially dependent, classical statistical analysis are no longer valid. One method of handling spatially dependent...
variable is using the theory of regionalized variables (Matheron 1963). The successful application of this theory to problems in mining, geology and hydrology led to the more popular name of geostatistics, of which kriging is a main branch (Delhoumme 1978).

Kriging (Webster and Burgess 1983) is now accepted by many soil scientists as an appropriate technique for estimating the values of soil properties at unsampled sites over larger blocks of land. It is then possible to interpolate any soil properties and to map the estimated values. Attempts have been made to obtain detailed information on the spatial variability of soil chemical properties (Bos et al. 1984; West et al. 1989). The present study was undertaken with the objectives i) to quantify the spatial dependence of variation in soil chemical properties of the soils by semivariogram analysis, ii) to use the spatial dependence to interpolate the values of these parameters at shorter and unrecorded sites by kriging techniques and iii) to prepare isarithmic maps of the spatially dependent parameter based on interpreted (kriged) and observed values for farm and environmental advisory services.

**Material and Methods**

**Experimental site**

The study was conducted on the red soils (Loamy-skeletal, mixed, superactive, isohyperthermic Typic Rhodustalfs) of Coimbatore district. Plot size of 151 m by 151 m were selected for the study. Surface samples (0 to 15 cm depth) were taken at the nodes of 23 m square grid. The samples were air dried and ground to pass through 2mm sieve. Soil pH and EC were estimated following standard procedures. The molybdate vandate colorimetric method was used to determine the phosphorus. Available potassium was analysed using flame emission photometer. DTPA extraction method was used to determine available Fe, Mn, Cu and Zn (Lindsay and Norwell 1978).

**Statistical Approach**

Descriptive statistics like mean, range, variance, standard deviation, coefficient of variation (CV), skewness and kurtosis were computed. The theory of regionalized variables (Matheron 1971) was used to investigate the spatial variability of soil properties. The semivariance function \( \gamma(h) \) (Journel and Huijbregts 1978) is equal to half the expected squared difference between values at locations separated by a given lag and is used to express spatial variations. On a transect where \( n \) observations were taken at regular interval \( Z_{(i)} \), where \( i + 1, 2, \ldots n \) semivariances can be calculated using the equation

\[
\gamma(h) = \frac{1}{2N_{(h)}} \sum [Z_{(i)} - Z_{(i+h)}]^2
\]

where \( \gamma(h) \) is the sample variance and \( N_{(h)} \) is number of pairs of data points separated by the distance \( h \). \( Z_{(i)} \) and \( Z_{(i+h)} \) are the values of the property at locations \( x \) and \( x+h \) separated by the vector \( h \), known as the lag. The semivariogram calculation, semivariogram function and model fitting and kriging were performed using Geostat modules that are interfaced
in IDRISI software. The linear, spherical, exponential and Gaussian models were explored to fit models to the semivariogram functions to each measured property.

Kriging was performed using the procedure described by Journel and Huijbregts (1978) and Burgess and Webster (1980). Punctual kriging which is an exact interpolator (Delhommme 1978) represented by equation 2 was used to estimate values of soil chemical properties for unsampled locations.

\[
Z(x_0) = \sum \lambda_i Z(x_i)
\]

where each estimated value \([Z(x_0)]\) is a weighted average of the observed values \([Z(x_i)]\) within the neighborhood of kriging location and \(\lambda_i\) are the weights on each sampling location of the data points \(Z(x_i)\). Values for each property were kriged on a regular grid with a block average of 12 m and with a maximum radius of 17 m.

### Results and Discussion

#### Descriptive statistics

The experimental area of red soils was of medium heterogeneity in most of the soil properties. The pH was neutral and exhibited low CVs (5.24 %). Available K, P and Mn showed CV between 15 and 50 per cent (Table 1).

#### Geostatistical analysis

Semivariograms were computed for each soil properties using 10 lag and the parameters (nugget, sill and range) for the best fitting models (spherical, exponential and linear model) were estimated. Semivariogram models and model parameters for soil chemical properties are given in Table 2. The nugget to sill ratio, which is referred to as the relative nugget effect (Isaaks and Srivastava 1989), enables comparison of the relative size of the nugget.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>SD</th>
<th>CV (%)</th>
<th>Kurtosis</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH(1:2)</td>
<td>6.40</td>
<td>7.70</td>
<td>6.88</td>
<td>0.36</td>
<td>5.24</td>
<td>0.13</td>
<td>0.96</td>
</tr>
<tr>
<td>EC (dS m⁻¹)</td>
<td>0.01</td>
<td>0.14</td>
<td>0.04</td>
<td>0.03</td>
<td>77.36</td>
<td>2.59</td>
<td>1.68</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>0.03</td>
<td>0.41</td>
<td>0.19</td>
<td>0.08</td>
<td>45.93</td>
<td>-0.31</td>
<td>0.34</td>
</tr>
<tr>
<td>Available P (kg ha⁻¹)</td>
<td>2.24</td>
<td>44.80</td>
<td>12.28</td>
<td>8.88</td>
<td>72.38</td>
<td>4.25</td>
<td>1.94</td>
</tr>
<tr>
<td>Available K (kg ha⁻¹)</td>
<td>75.00</td>
<td>250.00</td>
<td>139.80</td>
<td>29.70</td>
<td>21.26</td>
<td>3.48</td>
<td>1.09</td>
</tr>
<tr>
<td>Available Fe (ppm)</td>
<td>0.27</td>
<td>0.95</td>
<td>0.58</td>
<td>0.16</td>
<td>27.71</td>
<td>-0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>Available Mn (ppm)</td>
<td>1.18</td>
<td>12.24</td>
<td>4.89</td>
<td>4.05</td>
<td>82.91</td>
<td>-1.74</td>
<td>0.32</td>
</tr>
<tr>
<td>Available Cu (ppm)</td>
<td>0.05</td>
<td>0.10</td>
<td>0.07</td>
<td>0.01</td>
<td>15.05</td>
<td>0.45</td>
<td>0.58</td>
</tr>
<tr>
<td>Available Zn (ppm)</td>
<td>0.14</td>
<td>0.47</td>
<td>0.21</td>
<td>0.05</td>
<td>26.81</td>
<td>7.81</td>
<td>2.14</td>
</tr>
</tbody>
</table>
effect among soil properties. To define distinct classes of spatial dependence for the soil properties, ratios similar to those reported by Cambardella et al. (1994) were used. If the ratio is \( \leq 25 \) per cent, the variable is considered strongly spatial dependent if the ratio is between 25 and 75 per cent, the variable is considered moderately spatial dependent.

Semivariograms indicated strong spatial dependence for pH, EC, organic carbon and available Fe than the other properties. pH had the lowest Nugget-to-sill ratio. Available P, K, Mn, Cu and Zn exhibited moderate spatial dependence. Available P revealed the highest nugget-to-sill ratio, with a value of 64%.

The range of influence for each soil properties is given in Table 2. Theoretically, this value is considered to be the distance beyond which observations cease to be spatially dependent (Vieria et al. 1983). pH and EC was spatially correlated to a distance ranging from 87 and 85 m. The organic carbon exhibited spatial dependence for lags 30 m.

Soil properties like available potassium exhibited relative short range of 38 m and micronutrient cations (Fe, Mn, Cu, Zn) values ranged from 22 to 28 m. The spatial dependence was very short ranged (8.9 m) for available phosphorus. The short range indicates that continuous measurement of available P is essential in proper characterization of variability.

The spatial structure of the data varied between parameters. In the case of soil properties such as available K, Cu and Zn (Fig. 2b, e,f) were defined by spherical model. For other properties like pH, EC, organic carbon, available P, Fe and Mn were described by exponential model (Fig.1a,b,c and Fig.2a, c and d). Spherical model was used to allow direct comparison

### Table 2. Isotropic semivariograms parameters for soil properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Model</th>
<th>Semivariance</th>
<th>Nugget (%)</th>
<th>Range</th>
<th>Spatial class</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (1:2)</td>
<td>Exponential</td>
<td>-0.003</td>
<td>0.139</td>
<td>2.16</td>
<td>S</td>
</tr>
<tr>
<td>EC (dS m(^{-1}))</td>
<td>Exponential</td>
<td>-0.809</td>
<td>12.707</td>
<td>6.37</td>
<td>S</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>Exponential</td>
<td>-14.057</td>
<td>85.424</td>
<td>16.46</td>
<td>S</td>
</tr>
<tr>
<td>Available P (kg ha(^{-1}))</td>
<td>Exponential</td>
<td>-58.222</td>
<td>90.122</td>
<td>64.60</td>
<td>S</td>
</tr>
<tr>
<td>Available K (kg ha(^{-1}))</td>
<td>Spherical</td>
<td>-131.294</td>
<td>410.542</td>
<td>31.98</td>
<td>M</td>
</tr>
<tr>
<td>Available Fe (ppm)</td>
<td>Exponential</td>
<td>-0.003</td>
<td>0.019</td>
<td>15.79</td>
<td>S</td>
</tr>
<tr>
<td>Available Mn (ppm)</td>
<td>Exponential</td>
<td>-5.788</td>
<td>16.702</td>
<td>34.65</td>
<td>M</td>
</tr>
<tr>
<td>Available Cu (ppm)</td>
<td>Spherical</td>
<td>-37.071</td>
<td>99.682</td>
<td>37.19</td>
<td>M</td>
</tr>
<tr>
<td>Available Zn (ppm)</td>
<td>Spherical</td>
<td>-0.001</td>
<td>0.002</td>
<td>50.00</td>
<td>M</td>
</tr>
</tbody>
</table>

Nugget = (nugget semivariance/total semivariance) \( \times 100 \); S = Strong spatial dependence (\%Nugget < 25); M = Moderate spatial dependence (\%Nugget between 25 and 75)
of the nugget, sill and range among different soil parameters. Exponential models do not exhibit a finite range but for practical purposes, there is a point beyond which the semivariance stops increasing.

**Kriging**

Since all the soil properties exhibited spatial structure, analysis was extended to kriging values for unsampled locations. Contour maps of measured and interpolated values for soil properties are presented in figures 3, 4 and 5. Kriged P values ranged from 4 to 26 kg/ha. High soil P values were observed from mid-field toward the SW and SE (Fig 4a). Phosphorus is more available at pH 6.5 for mineral soils. The mean pH value of the field was 6.88 (Table 1), which was neutral with normal availability of P to the plants. Soil K ranged from 100 to 170 kg/ha (Fig. 4b), with the largest values in the SE quadrant. Kriged Fe values ranged from 0.4 to 0.75 ppm. High Fe values were observed in SW quadrant (Fig. 5a). Soil Mn kriged values ranged from 2.00 ppm in SW quadrant to 9.00 ppm in the SE quadrant (Fig. 5b). Available Cu and Zn ranged from 0.06 to 0.08 ppm and 0.16 to 0.32 ppm, respectively. Large levels of Cu and Zn were exhibited in the SE quadrant of the field (Fig. 5c and d).

![Fig. 1. Semivariograms for soil properties](image)

(a) pH (1:2) (b) EC (c) Organic carbon
Spatial variability in soil properties

Fig. 2. Semivariograms for soil chemical properties: (a) Available P; (b) Available K; (c) Available Fe; (d) Available Mn; (e) Available Cu; and (f) Available Zn
From this study we can come to conclusion that pH, EC, OC and Available Fe are strongly spatial dependent whereas available P, K, Mn, Cu and Zn exhibited moderate spatial dependence. Thus geostatistical techniques are useful in evaluating the variation in soil properties and also to determine up to which lag they are spatially dependent.
Spatial variability in soil properties

Fig 4. Contour maps of kriged values of Available (a) Phosphorus and (b) Potassium (kg/ha)

Fig 5. Contour maps of kriged values of available micronutrients (a) Fe; (b) Mn; (c) Cu; and (d) Zn (ppm)
References


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