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Three-Dimensional Variation of Electrical Conductivity in a Paddy Rice Soil Based on the Disjunctive Kriging Method

[1, 2]Li Hongyi, [1]Wu Cifang, [3]Li Fanghao and [4]Shi Zhou
[1]College of Public Administration, Zhejiang University, Hangzhou 310029, China
[2]School of Tourism and Urban Management, Jiangxi University of Finance and Economics, Nanchang 330013, China
[3]Department of Land and Resources of Jiangxi Province, Nanchang 330013, China
[4]College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310029, China

Abstract: The aim of the study was using the disjunctive kriging method to analyze the three dimensional variation of soil electrical conductivity in a costal saline land in the Yangste delta of China. Fifty six soil apparent Electrical Conductivity (ECa) profiles, which inversed by the procedure that combine the EM38 linear model, were selected as the datum source of 3D spatial variability. Firstly, for facilitating the selection of crops risk evaluation threshold value, ECa was transferred to ECe according to the experience model. Secondly, the ECe distribution at the ten layers was transformed with a standard normal distribution by lognormal transformation. At last, the spatial variability of soil electrical conductivity of the all 10 layer was predicted by the disjunctive kriging method and the layers were stacked one by one. It presented a superior visualization of spatial distribution of ECe in 3D space directly that 2D interpolation can't achieve. The higher ECe, the higher the salinity is. From the top surface map, the spatial distribution of soil salinity can be easily recognized, which is helpful in management on fertility, analyzing experimental data to reduce subjective judgment and developing and applying agronomic practices.

Keywords: Disjunctive kriging, electrical conductivity, saline soils, three-dimensional variation

INTRODUCTION

Soil salinity, both natural and man-made, is widespread in the world and presents problems for agriculture. It retards the growth of crops and constrains production. In severe cases salinization causes land to be abandoned. Salts can rise to the soil surface by capillary transport from the water table and then accumulate as a result of evaporation. In many places they are concentrated by irrigation with salty water or by over-irrigation and the raising of saline ground water. According to Funakawa and Kosaki (2007) the most serious threat for many crops is the presence of soluble salts in the subsoil between 1 and 2 m deep.

In the coastal land with which we are concerned, however, the salt profile of the upper 100 cm is a good diagnostic of the suitability of the soil for arable crops (Yu *et al.*, 1996). So, anyone assessing soil for farming needs to consider simultaneously the lateral and vertical variation in salt concentration. He or she needs to be able to describe and map three-dimensional distributions.

The three-dimensionality of soil is widely acknowledged, but almost all of the study only surveyed the variation at the soil surface. Some studies for the purpose of three dimensions, which also only mapped the lateral variation of individual properties (Samra and Gill, 1993; Oliver and Webster, 2006). Variability of soil nitrate in an agricultural field was analyzed by the three dimensional ordinary kriging methods (Meirvenne *et al.*, 2003). But these types of study are quite few in soil science.

We have explored the use of apparent Electrical Conductivity (ECa) measured with an EM38 conductivity meter. We then used geo statistics to predict the conductivity between sampling points in coastal saline paddy land in the Yangste delta of China.

MATERIALS AND METHODS

Sampling: The land in the coastal zone of Zheijang province south of China's Hangzhou Gulf of the Yangtse delta is formed of recent marine and fluvial deposits. Over the past 30 years much of this zone has been enclosed and reclaimed for agriculture. For this study we chose a field of 2.22 ha in the north of Shangyu City that was reclaimed in 1996 and used for paddy rice. 56 soil profiles were collected after the rice was harvested. Ninety-six EM38 readings were taken at each site: the receiver end of the EM38 was aligned in the four directions of the compass in both the horizontal (EM_H) and vertical (EM_V) coil-mode configurations

Corresponding Author: Wu Cifang, College of Public Administration, Zhejiang University, Hangzhou 310029, China

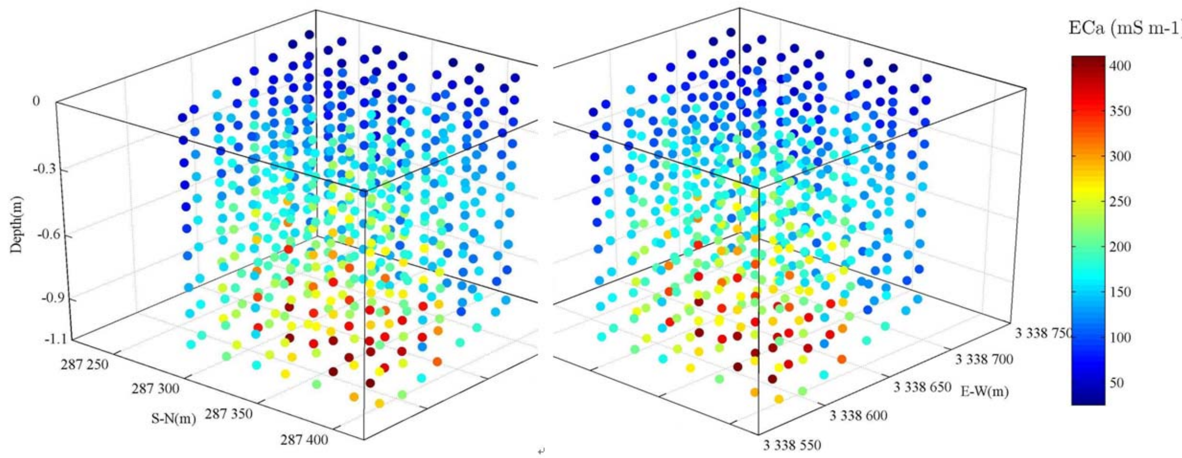

Fig. 1: Conductivities at 56 positions predicted from EM38 linear model; the two sides of the Figure form a stereogram which should be viewed with a pocket-stereoscope

and at heights of 0, 10, 20, 30, 40, 50, 60, 75, 90, 100, 120 and 150 cm above the soil surface.

Disjunctive kriging method: Disjunctive Kriging (DK) is one example of a nonlinear estimator (Carr *et al.*, 1986). In general, nonlinear estimators take the form:

$$Z^*(X_0) = \sum_{i=0}^{N} f_i[Z(X_i)] \tag{1}$$

where, $Z^*(X_0)$ is an estimated value of a random function at a location, X_0. Moreover, f_i is any measurable function. For example, suppose f_i has the form:

$$f_i[Z(X_i)] = \lambda_0 + \lambda_i Z(X_i) \tag{2}$$

which is a linear function? If $X_0 = 0$, then Eq. (1) is obtained.
Suppose, as another example, f_i has the form:

$$f_i[Z(X_i)] = A_i + B_i Z(X_i) + C_i Z(X_i)^2 + \ldots + \theta_i Z(X_i)^N \tag{3}$$

Then f_i is a nonlinear function of Z (X). This function is known exactly once coefficients, A_i, B_i, C_i, … , θ_i, are computed. As was stated earlier, any measurable function will suffice for f_i; hence, Eq. (2 and 3) is simply examples.

For DK, the function, f_i, is chosen to achieve the objective forwarded in the introduction to this study. Specifically, we desire the probability density of an estimated random variable at a particular location.

Table 1: Descriptive statistics of electrical conductivity at different depth

Depth (m)	mS/m Max.	Mean	Min.	S.D*	CV** (%)
0.05	206.98	104.49	25.33	52.23	49.99
0.15	228.54	119.53	40.15	52.41	43.85
0.25	244.96	133.00	50.58	51.95	39.06
0.35	260.70	146.95	59.24	50.10	34.10
0.45	286.12	159.90	55.39	52.02	32.53
0.55	311.94	173.30	51.38	53.18	30.69
0.675	354.01	190.66	54.08	63.58	33.35
0.825	366.39	197.68	60.33	65.10	32.93
0.95	398.48	218.72	67.13	87.02	33.79
1.10	410.61	236.69	56.56	83.84	31.42

*: Standard deviation; **: coefficients of variations

Thus, the nonlinear equation of the DK procedure, f_i, is chosen not only to yield an estimate, $Z^*(X_0)$, of a random function at location, X_0, but also to provide the probability density of this estimate as well.

RESULTS

Electrical conductivity inverse procedure with the linear model: In our earlier study, the mean error of the electrical conductivity prediction method by the EM38 linear model is 38.44% (Li *et al.*, 2008). It is a valuable tool for noninvasive measure soil electrical conductivity profiles for further 3D interpolation at field scales and larger.

In this study, the linear model with the inverse procedure was adopted to predict the depth electrical conductivity of the 56 sites at the depth of 5, 15, 25, 35, 45, 55, 67.5, 82.5, 95 and 110 cm (Fig. 1). Table 1 showed the descriptive statistics of the prediction result. The maximum and mean of ECa was increased with the increase of soil depth. The deeper the depth is, the larger the soil average ECa is. With the increase of soil

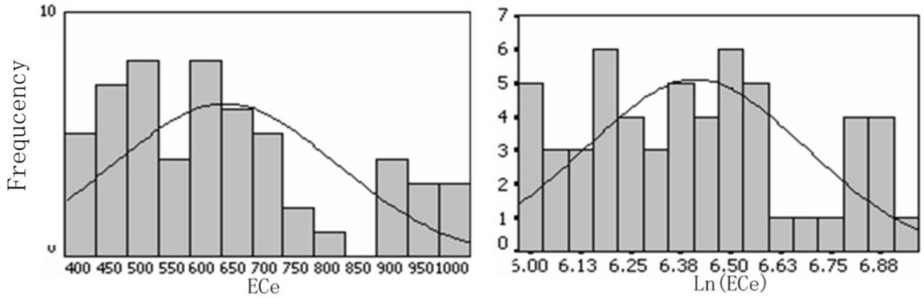

Fig. 2: Histograms on original scales (left) and on transforming to natural logarithms (right)depth, coefficients of variations became more and more small.

Raw variogram transformation: To facilitate the threshold value selection of crops risk evaluation, in this research, ECa was transferred to ECe conductivity values according to the experience model (Abdel Ghany *et al*., 2000), Eq. (1), firstly:

$$ECe = 128.1 + 212.9ECa \tag{4}$$

DK without losing information in estimation, so, requires rather stronger assumptions than other method (Webster and Oliver, 2001). Take the ECe at the depth of 1.10 m as example, the problem in this case and almost in any case is that the variable is not normal distributed and therefore it has to be transformed from the original distribution into a standard normal distribution.

The ECe distribution (any distribution) is transformed into another variable with a standard normal distribution N (0, 1) by a function named 'the anamorphosis function' and the transformation itself is called anamorphosis. In common use there are lognormal transformation, square root transformation, arcsine transformation, arccosine transformation and graph parallelism (Chen *et al*., 2004).

As to our example data, the raw distribution of ECe is shown as Fig. 2 is the transformed Normal distributions, when using lognormal transformation.

Variogram function of layer at depth 1.1 m, in the case of one dimension is defined as γ (h):

$$\gamma(h) = \begin{cases} 0, & h=0 \\ 0.908\left\{0.5(h/129) - 0.5(h/129)^3\right\}, & 0 < h \le 129 \\ 0.908 & \end{cases} \tag{5}$$

In which h is the lag distance? Then, The ECe at the other nine layers was transformed by the same method as above mentioned.

Three dimension variation of soil electrical conductivity: Figure 3 is our solution in which we view the layers obliquely from above in sequence, starting at the base 110 cm deep and adding one layer at 0.55, 0.15, 0.05 m and showing the vertical variation on the southern and eastern faces of the field as the layers are added.

From the top surface map, the spatial distribution of soil salinity can be easily recognized, which is helpful in management on fertility, analyzing experimental data to reduce subjective judgment and developing and applying agronomic practices. The contour map of soil electrical conductivity displayed a spatial distribution with a high salinity level in the east corner and low salinity level in the west and northern corner of the field. The high salinity level in the east edge was induced by the salinity in the groundwater. As there were some fish ponds east of the field and plenty of groundwater can be filtered into the east edge of the study area, the upward transport of salts with evaporate resulted in the high salinity content.

CONCLUSION

In this study, the linear response model of the EM38 ground conductivity meter to variations of soil ECa with depth was used to inverse the electrical conductivity depth profiles from aboveground EM38 measurements. It is a valuable tool for noninvasive assessment of soil electrical conductivity profiles for further 3D interpolation in large region. Fifty six profiles were inversed in this study. It was shown that the maximum, mean and median of ECa was increased with the increase of soil depth. The deeper the depth is, the larger the soil average ECa is.

Take the ECe at the depth of 1.1 m as example, the problem in this case and almost in any case is that the variable is not normal distributed. The ECe distribution (any distribution) is transformed into another variable with a standard normal distribution by lognormal transformation.

At last, the spatial variability of soil electrical conductivity of the other 10 layer was predicted by the DK method and the EC layers were stacked one by one (Fig. 3). It presented a superior visualization of spatial distribution of ECe in 3D space directly that 2D

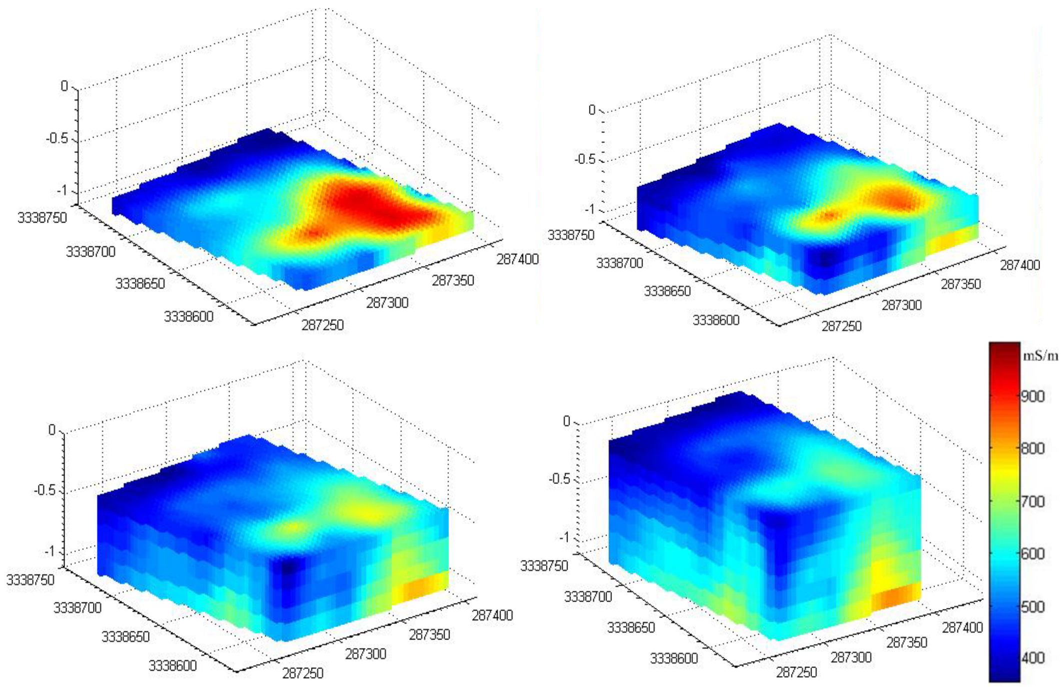

Fig. 3: Three dimensional space distribution of soil ECe by disjunctive kriging

interpolation can't achieve. The variability of ECe can be described more clearly in 3D space. The higher ECe, the higher the salinity is. From the top surface map, the spatial distribution of soil salinity can be easily recognized, which is helpful in management on fertility, analyzing experimental data to reduce subjective judgment and developing and applying agronomic practices.

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