Field Scale Mapping of Soil Salinity on Spatial Interpolation Techniques, Case Study: Khorat Basin, Nakhon Ratchasima Province, Thailand

Topic Area: GIS/RS and Other Spatial Information Technologies

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Abstract. Khorat Basin study area, Nakhon Ratchasima Province (Northeastern of Thailand) was separated by the topographical characteristics of plain, low terrace, and middle terrace. The soils physical and chemical properties were analyzed. The Electrical Conductivity (EC_e) was conducted to interpolate the following methods of GIS: Completely Regularized Spline method, Spline with tension method, Inverse Distance Weighting method, Ordinary Kriging method, Simple Kriging method, and Disjunctive Kriging method. Also, the Mean Absolute Percent Error (MAPE) method was applied to compare the interpolation methods and select the most suitable interpolation method for soil salinity. The results indicate Completely Regularized Spline is the most suitable interpolation method for soil salinity of all study sites, because it has the minimum errors when compared to the others. The percent of errors ware 36.90, 24.25, and 44.79 in plain, low terrace, and middle terrace, respectively. Likewise, the production of the soil salinity map was interpolated by Completely Regularized Spline method in the study area.

Keywords: Saline soil, Soil salinity map, GIS, Interpolation, Spline, Inverse distance weighting, Kriging

1. Introduction

The soil resource is the important factor of the agriculture. Any areas with less agricultural capacity will affect people's life in the area and also economic system as a whole. The soil problems like saline soil have occurred extensively in northeastern Thailand. Saline soil problem has to be solved with clear understanding of problem and saline soil condition. Studies and solutions have to be developed properly to make effectively use of land use more than present. Thailand has tried to develop salt-affected soil map for more than 20 years. At the beginning, however, there were merely in small scale by using aerial photos and ground surveys (Land Development Dept., 1997).

Khorat basin (Northeastern of Thailand) was counted as a salt-affected zone (Songsawat, 1994). Wichaidit (1984) study about Khorat basin soil, he found that slightly salinity soil area covered up to 15,472 km^2, moderately salinity soil area covered 4,144 km^2 and strongly salinity soil area covered 1,072 km^2. Total level covered as highly as 2,059.2 km^2 (18.17% of Khorat basin) and the tendency increased annually (Land Development Dept., 1997). Thus, Khorat basin is an interesting site to study about saline soil.

This research aimed to compare the interpolation methods in GIS for estimate soil salinity. And, soil physical and chemical properties were analyzed. The Electrical Conductivity (EC_e) was conducted to interpolate methods of GIS as Completely Regularized Spline method, Spline with tension method, Inverse Distance Weighting method, Ordinary Kriging method, Simple Kriging method, and Disjunctive Kriging method. Besides, the Mean Absolute Percent Error (MAPE) method was applied to compare the interpolation methods and selected the most suitable interpolation method for estimate soil salinity. The results were illustrated by soil salinity maps of study area.

2. Soil Salinization

Normally, process of salinity in soil is related to 6 processes as alkalization, dealkalization, salinization, desalinization, solonization and solodization. Alkalization or sometimes called solonization is the process of sodium ion accumulation in ion exchanged areas of calcium, sodium and magnesium. Dealkalization or solonization is the process of sodium ion moving out from exchanged areas, happening on relating with clay diffusion at flooded water storage. This process will make the sodium ion containing water. Salinization process is the accumulated solved salt such as sulfate chloride of magnesium, sodium and potassium (Buol, Hole and McCracken, 1989). In most salichorizon, it has happened on shallow water table, fine texture, poor drainage, and cutting side with melted layer (E level). Normally, salichorizon has happened in soil which its structure as round-head bar. This process will occur in humidity weather (Brady and Weil, 1999).

Desalinization is the transferring of solved salt from soil layer, as it happens after salinization. From soil study in California, Whittig (1959) found that ancient evolution of soil is influenced by sodium ion that A level is acid reaction and B level is based on reaction within fine texture due to there is very high clay contained with its structure as round-head bar. There is low rate of sodium exchanged in upper soil and it will increase gradually according to the depth of soil layer that make the clay dispersion and positive ion exchange are different. Besides salinization, solonization, solodization and time that influence to soil conditions, the increasing of alkaline will come from usage of divalent fertilizer.

Most saline soil occurring due to geological effects, it also contain salt source from sodium composite in stone at shallow surface soil or high salt water table areas especially at surface level (Arunin, 1982). Due to salt stone contains white salt rock, coarse and pure texture in thick layer form 1 to 2.5 cm., then his salt stone can be both salt crystal and mineral chain in sand-powered stone, clay stone and silt stone (Moormann and Breeman, 1978). When stone starts decaying, salt from stone will solve to ground water circulation and accumulate at other places as a cause of salinity in soil by evaporating of water from soil surface. The cause of salinity in shallow ground water may come from salt composite solvent scattering in soil or stone layer (Sinanuwong and Takaya, 1974). The result of decaying stone and other elements under the period of drought and semi drought include water evaporation, also the transferring of element from influencing of groundwater that relates with the changing of groundwater level found that the influencing of salt when groundwater level decrease will later generate salt layer (Al-Barrak and Al-Badawi, 1988). After that salt-tolerated plant species will occur in that area that alkaline comes from positive ion concentration in divalent in basin area of being more evaporation than rainfall volume. Nevertheless, soil reaction being higher than 8-8.5 can happen when inner water circulation is alkaline and has the related process such as decaying from oxidation reaction, ion exchange, rainfall volume, increased salt and evaporation affecting the accumulated salt in soil (Breeman, 1973).

Most saline has a coarser textured in the surface soil than subsoil is moderate-coarse as sand-soil or fine coarse clay with dry sand and lower soil is moderate-fine or very fine texture as coarse clay with sand or clay. There are clear accumulated clay particles as soil in moderate to good evolution condition that relates with soil configuration. This clearly represents the salt influencing to sodium ion in soil (Bear, 1967). Highest bulk density is always in soil of Bt horizon where there are high volume of accumulated clay particle. The water carrying capacity rate in low-moderate level means soil has water releasing capacity to be beneficial for plants on low to moderate level while humidity for plant is also the same due to most soil texture are nearly coarse to coarse level (Frenkel, 1978). Coefficient of water conductivity in soil being low may be because of influencing from Sodium ion (Klute, 1965). Moreover, slight decline along with the depth increasing in lower soil texture mean soil in lower level having more fine than upper soil texture. Then the gap among soil texture tends to decrease along with the increasing depth (Pupisky and Shainberg, 1979). From study result of comparison among concentrated solvent in soil shows that water absorption decreases owing to the direct effects of clay's texture expansion. The dispersion of clay will depend on mechanical stress as the less and more of mechanical stress is depended on the dispersion of clay and sodium exchange rate (Rowell, Payne and Ahmad, 1969).

Consequence of salt accumulation in cracked soil is such a crack volume and areas will increase while the crack width and depth tend to decrease. Soil influenced by salt will transform its characteristic such as moisture rapidly losing from its surface. Especially soil surface will crack shallowly at surface, shrinkage will occur, and soil texture gap will be less relating with higher bulk density (Lima and Grismer, 1992). Soil expansion is controlled by type and volume of clay, type of ion of being exchange, salt volume in soil, organic conductivity, iron and aluminum oxide. Besides, with limited of high conductivity, there has no dispersion of clay. Even absorption relating to clay expansion, but if absorption and concentration of solvent in soil decrease, clay may move to lower soil layer with solvent. Thus liquid flowing though soil by influencing of rainfall, land use, animal's walking may cause clay dispersion (Rowel, 1963). From soil absorption study can be found that soil condition gets better by receiving positive ion from divalent and ammonium ion. Therefore, cause of positive ion lost will come from runoff and evaporation of water while salt movement will occur whenever dry soil has capacity on absorbing run-off water. That according to this aspect if we input some positive ion to soil salt concentration will decrease with suitable water volume. The delaying of water flowing will increase ion diffusion at high level (Nielsen, Biggar and Luthin, 1966).

Composite of salt in saline soil will contain cation such as sodium magnesium calcium and potassium with anion such as chloride, sulfate, bicarbonate, carbonate nitrate in forms of sodium chloride, sodium sulfate, sodium carbonate, sodium bicarbonate, sodium nitrate, magnesium sulfate and magnesium chloride (Arunin, 1996). Most sodium and chloride ion can be found in salinity soil (Bernstein, 1964) and found that sodium types which can harm plants can be arranged from more to less as carbonate, chloride, sulfate and nitrate. Salt of calcium and magnesium which can harm plants can be arranged from most to less which is chloride, sulfate and nitrate respectively (Joffe, 1953). But dissolved salt such as gypsum, chalk, and magnesite have no effects to plant but soluble salt such as chloride, sulfate, nitrate, carbonate, bicarbonate and borate mainly harm to plants (Buringh, 1970). However, several types of salt in soil are more harmful to plants by comparing with single type of salt in soil at the same volume. Normally, plant can be more tolerate to salinity in clay than sand because clay have more ion to absorb salinity and water. The water absorption can reduce the concentration of salt in soil (Joffe, 1953). Most salt in soil in the northeastern part of Thailand is sodium chloride (Keerathekasikorn, 1984). The more organics in soil the more it can absorb calcium and magnesium (Arunin, 1996).

Characteristics of saline soil dispersion in Thailand can be classified into 2 main categories as inland saline soil and coastal saline soil. Inland saline soil can be found in northeastern and central region. Each saline soil is created by location, salt type, dispersion and geomorphology (Arunin, 1996).

Generally, classification of salinity follows EC_e standard excepted salinity soil classification in northeastern part due to salt accumulation is not scattering systematically throughout the areas but it changes owing to season change (Arunin, 1996).

Table 1. Classification of soil salinity by EC_e standard consideration (US Salinity Laboratory Staff, 1954)

EC_e (dS/m)	Salinity level	Consequence of salinity to plant
0-2	Non salinity	No effects to plant
2-4	Slightly salinity	Limited growth in plant that sensitive to salinity
4-8	Moderately salinity	Limited growth in several types of plant
8-16	Strongly salinity	Only salinity plant can be grown
> 16	Very strongly salinity	Only tolerate salinity plant can be grown

3. Interpolation Methods

Interpolation predicts values for cells in a raster from a limited number of sample data points. It can be used to predict unknown values for any geographic point data: elevation, rainfall, chemical concentrations, noise levels, and so on. The illustration on the left shows a point dataset of known rainfall-level values. The illustration on the right shows a raster interpolated from these point.

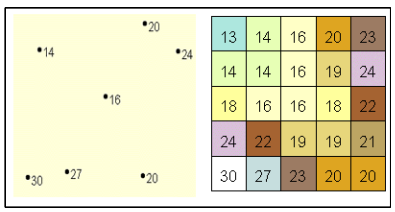

Figure 1. A raster interpolated from these points
(http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

The assumption that makes interpolation a viable option is that spatially distributed objects are spatially correlated; in other words, things that are close together tend to have similar characteristics. For instance, if it is raining on one side of the street, you can predict with a high level of confidence that it is also raining on the other side of the street. You would be less certain if it was raining across town and less confident still about the state of the weather in the next county.

Using the previous analogy, it is easy to see that the values of points close to sampled points are more likely to be similar than those that are farther apart. This is the basis of interpolation. A typical use for point interpolation is to create an elevation surface from a set of sample measurements.

In the following illustration (Figure 2.), each symbol in the point layer represents a location where the elevation has been measured by interpolating, the values between these input points will be predicted.

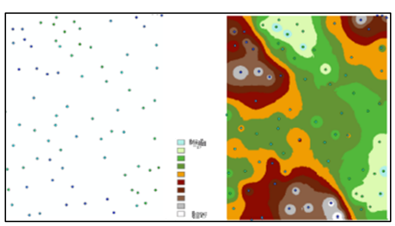

Figure 2. The values between these input points will be predicted
(http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

3.1 Inverse Distance Weighted (IDW)

IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted.
The general formula is:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \quad (1)$$

where $Z(s_0)$ is the value we are trying to predict for location s_0, N is the number of measured sample point surrounding the prediction location that will be used in the prediction, λ_i are the weights assigned to each measured point that we are going to use. These weights will decrease with distance, $Z(s_i)$ is the observed value at the location s_i

The formula to determine the weights is the following:

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \qquad \sum_{i=1}^{N} \lambda_i = 1, \quad (2)$$

As the distance becomes larger, the weight is reduced by a factor of p, s_0, and each of the measured locations, s_i

The power parameter p influences the weighting of the measured location's value on the prediction location's value; that is, as the distance increases between the measured sample locations and the prediction location, the weight (or influence) that the measured point will have on the prediction will decrease exponentially.

The weights for the measured locations that will be used in the prediction are scaled so that their sum is equal to 1.

*1) The Power functio*n

The optimal power (p) value is determined by minimizing the root mean square prediction error (*RMSPE*). The *RMSPE* is the statistic that is calculated from cross-validation. In cross-validation, each measured point is removed and compared to the predicted value for that location. The RMSPE is a summary statistic quantifying the error of the prediction surface. Geostatistical Analyst tries several different powers for IDW to identify the power that produces the minimum RMSPE. The diagram below (Figure 3.) shows how Geostatistic Analyst calculates the optimal power. The RMSPE is plotted for several different powers for the same dataset. A curve is fit to the points (a quadratic Local Polynomial equation), and from the curve the power that provides the smallest *RMSPE* is determined as the optimal power.

Weights are proportional to the inverse distance raised to the power value p. As a result, as the distance increases, the weights decrease rapidly. How fast the weights decrease is dependent on the value for p. If $p = 0$, there is no decrease with distance, and because each weight λ_i will be the same, the prediction will be the mean of all the measured values. As p increases, the weights for distant points decrease rapidly. If the p value is very high, only the immediate few surrounding points will influence the prediction.

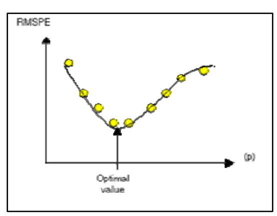

Figure 3. Geostatistical Analyst calculates the optimal power
(http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

2) The search neighborhood

Because things that are close to one another are more alike than those farther away, as the locations get farther away, the measured values will have little relationship with the value of the prediction location. To speed calculations you can discount to 0 the more distant points with little influence. As a result, it is a common practice to limit the number of measured values that are used when predicting the unknown value for a location by specifying a search neighborhood. The specified shape of the neighborhood restricts how far and where to look for the measured values to be used in the prediction. Other neighborhood parameters restrict the locations that will be used within that shape. In the following image, five measured points (neighbors) will be used when predicting a value for the location without a measurement, the yellow point (Figure 4.)

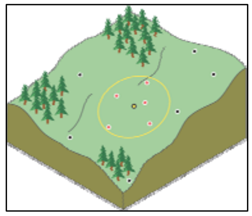

Figure 4. Five measured points (neighbors) will be used when predicting a value for the location without a measurement (http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

The shape of the neighborhood is influenced by the input data and the surface you are trying to create. If there are no directional influences on the weighting of your data, you'll want to consider points equally in all directions. To do so, you'll probably want the shape of your neighborhood to be a circle. However, if there is a directional influence on your data, such as a prevailing wind, you may want to adjust for it by changing the shape of your neighborhood to an ellipse with the major axis parallel with the wind. The adjustment for this directional influence is justified because you know that locations upwind from a prediction location are going to be more similar at remote distances than locations that are perpendicular to the wind.

3.2 Radial Basis Functions (RBF)

RBF methods are a series of exact interpolation techniques; that is, the surface must go through each measured sample value. There are five different basis functions is Thin-plate spline, Spline with tension, Completely regularized spline, Multiquadric function and Inverse multiquadric function.

Each basis function has a different shape and results in a slightly different interpolation surface. RBF methods are a form of artificial neural networks.

RBFs are conceptually similar to fitting a rubber membrane through the measured sample values while minimizing the total curvature of the surface. The selected basis function determines how the rubber membrane will fit between the values. The diagram below (Figure 5.) demonstrates conceptually how an RBF surface fits through a series of elevation sample values. Notice in the cross section that the surface passes through the data values.

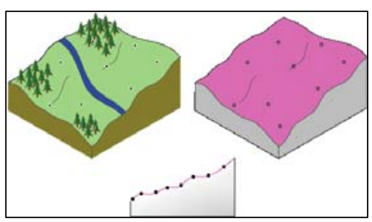

Figure 5. Demonstrates conceptually how an RBF surface fits through a series of elevation sample values (http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

Being exact interpolators, the RBF methods differ from the Global and Local Polynomial interpolators, which are both inexact interpolators that do not require the surface to pass through the measured points. When comparing an RBF to the IDW method, another exact interpolator, IDW will never predict values above the maximum measured value or below the minimum measured value as you can see in the cross section of a transect of sample data below (Figure 6.).

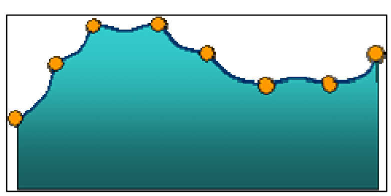

Figure 6. The cross section of a transect of sample data (http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

However, the RBFs can predict values above the maximum and below the minimum measured values as in the cross section below (Figure 7.).

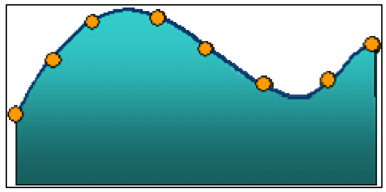

Figure 7. The minimum measured values as in the cross section (http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

The optimal parameters are determined using cross validation in a similar manner as shown for IDW and Local Polynomial interpolation.

(1) When to use Radial Basis Functions

RBFs are used for calculating smooth surfaces from a large number of data points. The functions produce good results for gently varying surfaces such as elevation.

The techniques are inappropriate when there are large changes in the surface values within a short horizontal distance and/or when you suspect the sample data is prone to error or uncertainty

2) The concepts behind Radial Basis Functions

In Geostatistical Analyst, RBFs are formed over each data location. An RBF is a function that changes with distance from a location.

For example, suppose the radial basis function is simply the distance from each location, so it forms an inverted cone over each location. If you take a cross section of the XZ plane for Y = 5, you will see a slice of each radial basis function. Now, suppose you want to predict a value at Y = 5 and X = 7. The value of each radial basis function at the prediction location can be taken from the figure above, given by the values Φ1, Φ2, and Φ3, which simply depend on the distance from each data location. The predictor is formed by taking the weighted average w1Φ1 + w2Φ2 + w3Φ3 + …

Now the question is how to determine the weights? So far, you have not used the data values at all. The weights w_1, w_2, w_3, and so on, are found by requiring that, when the prediction is moved to a location with a measured value, the data value is predicted exactly. This forms N equations in N unknowns and can be solved uniquely. Thus, the surface passes through the data values, making predictions exact.

The radial basis function in this example is a special case of the multiquadric RBF. Geostatistical Analyst also allows you to use other RBFs such as completely regularized splines, thin plate splines, splines with tension, and inverse multiquadric. Often, the difference between these is not great, but you may have reason to choose one or you can try several and use cross-validation to select one. Each of the RBFs has a parameter that controls the *smoothness* of the surface.

For all methods except inverse multiquadric, the higher the parameter value, the smoother the map; the opposite is true for inverse multiquadric.

3) Spline

The basic form of the minimum curvature Spline interpolation imposes the following two conditions on the interpolant:

- The surface must pass exactly through the data points.
- The surface must have minimum curvature the cumulative sum of the squares of the second derivative terms of the surface taken over each point on the surface must be a minimum.

The basic minimum curvature technique is also referred to as thin plate interpolation. It ensures a smooth (continuous and differentiable) surface, together with continuous first-derivative surfaces. Rapid changes in gradient or slope (the first derivative) can occur in the vicinity of the data points; hence, this model is not suitable for estimating second derivative (curvature).

The basic interpolation technique can be applied by using a value of zero for the (weight) argument to the Spline function.

The REGULARIZED option modifies the minimization criteria so third-derivative terms are incorporated into the minimization criteria. The {weight} argument specifies the weight attached to the third-derivative terms during minimization. Higher values of this term lead to smoother surfaces. Values between 0 and 0.5 are suitable. Using the

REGULARIZED option ensures a smooth surface together with smooth first-derivative surfaces. This technique is useful if the second derivative of the interpolated surface needs to be computed.

The TENSION option modifies the minimization criteria so first-derivative terms are incorporated into the minimization criteria. The {weight} argument specifies the weight attached to the first-derivative terms during minimization, referred to as phi in the literature. A weight of zero results in the basic thin plate Spline interpolation. Using a larger value of weight reduces the stiffness of the plate, and in the limit as phi approaches infinity, the surface approximates the shape of a membrane, or rubber sheets, passing through the points. The interpolated surface is smooth. First derivatives are continuous but not smooth.

The Spline function uses the following formula for the surface interpolation:

$$S(x,y) = T(x,y) + \sum_{j=1}^{N} \lambda_j R(r_j) \tag{3}$$

where j = 1, 2, ..., N, N is the number of points, λ_j are coefficients found by the solution of a system of linear equations, r_j is the distance from the point (*x,y*) to thejth point, T(*x,y*) and R(r) are defined differently, depending on the selected option.

For the REGULARIZED option:

$T_{(x,y)} = a_1 + a_{2x} + a_{3y}$

$$R(r) = \frac{1}{2\pi}\left\{ \frac{r^2}{4}\left[\ln\left(\frac{r}{2\tau}\right) + c - 1\right] + \tau^2\left[K_o\left(\frac{r}{\tau}\right) + c + \ln\left(\frac{r}{2\pi}\right)\right]\right\} \tag{4}$$

and for the TENSION option: $T_{(x,y)} = a_1$

$$R(r) = -\frac{1}{2\pi\varphi^2}\left[\ln\left(\frac{r\varphi}{2}\right) + c + K_o(r\varphi)\right] \tag{5}$$

Where τ^2 and Φ^2 are the parameters entered at the command line, r is the distance between the point and the sample, K_o is the modified Bessel function, c is a constant equal to 0.577215, a_i are coefficients found by the solution of a system of linear equations.

For computational purposes, the entire space of the output raster is divided into blocks or regions equal in size. The numbers of regions in x and in y directions are the same, and they are rectangular in shape. The number of regions is determined by dividing the total amount of points in input point dataset by the value specified for the number of points. For data less uniformly distributed, the regions may contain a significantly different number of points, with the value for the number of points being only the rough average. If in any region, the number of points is smaller than eight, the region is expanded until it contains a minimum of eight points.

3.3 Kriging

Kriging methods depend on mathematical and statistical models. The addition of a statistical model that includes probability separates kriging methods from the deterministic methods described in Deterministic methods for spatial interpolation. For kriging, you associate some probability with your predictions; that is, the values are not perfectly predictable from a statistical model. Consider the example of a sample of measured nitrogen values in a field. Obviously, even with a large sample, you will not be able to predict the exact value of nitrogen at some unmeasured location. Therefore, you not only try to predict it, but you also assess the error of the prediction.

Kriging methods rely on the notion of autocorrelation. Correlation is usually thought of as the tendency for two types of variables to be related. For example, the stock market tends to make positive changes with lower interest rates, so it's said that they are negatively correlated. However, the stock market is positively autocorrelated, which means it has correlation within itself. In the stock market, two values will tend to be more similar if they are only one day apart, as opposed to being one year apart. This is related to a basic principle of geography. Things closer together tend to be more similar than those that are farther apart. The rate at which the correlation decays can be expressed as a function of distance.

The autocorrelation is a function of distance. This is a defining feature of geostatistics. In classical statistics, observations are assumed independent, that is, there is no correlation between observations. In geostatistics, the information on spatial locations allows you to compute distances between observations and to model autocorrelation as a function of distance.

Also notice that, in general, the stock market goes up with time, and this is termed *trend*. For geostatistical data you have the same terms, and they are expressed in the following simple mathematical formula:

$$Z(\mathbf{s}) = \mu(\mathbf{s}) + \varepsilon(\mathbf{s}), \tag{6}$$

Where Z(**s**) is the variable of interest, decomposed into a deterministic trend μ(**s**) and a random, autocorrelated errors form ε(**s**). The symbol s simply indicates the location; think of it as containing the spatial x- (longitude) and y- (latitude) coordinates. Variations on this formula form the basis for all of the different types of kriging. Start on the right and move left.

No matter how complicated the trend in the model is, μ(**s**) still will not predict perfectly. In this case, some assumptions about the error term ε(**s**) are made; namely, you would expect them to be 0 (on average) and that the autocorrelation between ε(**s**) and ε(**s** + **h**) does not depend on the actual location s, but only the displacement **h** between the two. This is necessary to ensure replication so you can estimate the autocorrelation function. For example, in the following Figure 8.

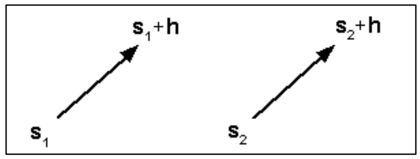

Figure 8. Random errors at location-pairs connected by the arrows are assumed to have the same autocorrelation (http://www.gis.com/whatisgis/index.cfm [access 2007 Feb 21])

Next, examine the trend. It can be a simple constant; that is, μ(**s**) = m for all locations s, and if μ is unknown, then this is the model on which Ordinary Kriging is based. It can also be composed of a linear function of the spatial coordinates themselves; for example:

μ(**s**) = ÃŸ0 + ÃŸ1x + ÃŸ2y + ÃŸ3x2 + ÃŸ4y2 + ÃŸ5xy, (7)

Where this is a second-order polynomial trend surface and is just linear regression on the spatial x- and y-coordinates. Trends that vary, and where the regression coefficients are unknown, form models for Universal Kriging. Whenever the trend is completely known (that is, all parameters and covariates known), whether constant or not, it forms the model for Simple Kriging.

Now, look at the left side of the decomposition, Z(**s**) = μ(**s**) + ε(**s**). Transformations on Z(**s**) can be performed. For example, it can be changed to an indicator variable, where it is 0 if Z(**s**) is below some value (for example, 0.12 ppm for ozone concentration) or 1 if it is above some value. You may want to predict the probability that Z(**s**) is above the threshold value, and predictions based on this model form Indicator Kriging. You can make general unspecified transformations of the Z(**s**), and call them $f_i(Z(\mathbf{s}_i))$ for the *i*th variable. You can form predictors of functions of variables; for example, if you want to predict at location $\mathbf{s}_0$, then you form the Disjunctive Kriging predictor of $g(Z(\mathbf{s}_0))$ using data $f_i(Z(\mathbf{s}_i))$.

Finally, consider the case where you have more than one variable type, and you form the models $Z_j(\mathbf{s}) = \mu_j(\mathbf{s}) + \varepsilon_j(\mathbf{s})$ for the *j*th variable type. Here, you can consider a different trend for each variable; and besides autocorrelation for the errors $\varepsilon_j(\mathbf{s})$, you also have cross correlation between the errors εj(**s**) and εk(**s**) for the two variable types. For example, you can consider the cross correlation between two variables like ozone concentration and particulate matter, and they need not be measured at the same locations. Models based on more than one variable of interest form the basis of cokriging. You can form an indicator variable of Z(**s**), and if you predict it using the original untransformed data Z(**s**) in a cokriging model, you obtain Probability Kriging. If you have more than one variable of interest, you can consider Ordinary Cokriging, Universal Cokriging, Simple Cokriging, Indicator Cokriging, Probability Cokriging, and Disjunctive Cokriging as multivariate extensions of the different types of kriging described earlier.

4. Data and Methodology

4.1 Study sites and sampling

There were 3 selected areas for collecting soil sample. Each site covers 1 km^2 and use grid sampling size 200x200 m. In sampling site was divided in 2 types; 1) training point (36 points) and 2) reference point (6 to 12 samples). The specific sampling at depth level 0-5 cm. and soil samplings follow design soil sampling point in the each study site by using GPS and compass for specifies the sampling point position and soil samplings by drilling equipments and sampling bag.

4.2 Soil properties analysis

After collected the soil sampling from field work, soil properties such as Electrical Conductivity (EC_e), Texture, Moisture, Organic matter (OM), Soil reaction (pH), Soluble Cations; Sol. Na^+, Ca^{++}, Mg^{++} and K^+, Sodium Absorption Ratio (SAR) were analyzed by saturation extract.

4.3 Data manipulation

Co-ordinates sampling site data from field sampling and soil properties analysis results were input to GIS data with ESRI ArcGIS Desktop Version 9.1 and Geostatistical Analyst Extension. The 6 interpolation methods such as 1) Completely Regularized Spline, 2) Spline with tension, 3) Inverse Distance Weighting, 4) Ordinary Kriging, 5) Simple Kriging and 6) Disjunctive Kriging were selected for Field Scale Mapping of Soil Salinity.

The interpolation results were verified by Mean Absolute Percent Error (MAPE) method. It will ensure by the reference point and report as percent of deviation for compare and conclude the interpolation method at suitable for estimating soil salinity of the each study area. The equation of MAPE can be expressed as below. Thus, the Electrical Conductivity (EC_e) was conducted to interpolate. The interpolation results were verified by Mean Absolute Percent Error (MAPE) method. It will ensure by the reference point and report as percent of deviation for compare and conclude the interpolation method at suitable for estimating soil salinity of the each study area. The equation of MAPE can be expressed as below.

$$MAPE = \frac{1}{N}\sum_{i=1}^{N} \left| \frac{T_i - F_i}{T_i} \right| \times 100 \qquad (8)$$

Where N is Number of Data, T is Target Data. F is Forecast Data.

5. Limitation

Samplings in the study areas used grid table sampling causing problems in reaching sampling points especially in scrub or swamp. Saturation Extract method was a standard method for soil taxonomy and general soil salinity level separation but required a plenty of time in soil saturation (45). In adding distilled water process for constant soil moisture, if adding too much, it would cause variation results which would use in following measurements: Electrical Conductivity (EC_e), Soil reaction (pH), Soluble Cations; Sol. Na^+, Ca^{++}, Mg^{++} and K^+. The experiment shall be done carefully by slowly adding distilled water as well as stirring with spatula until it was well done.

Most estimating correction in GIS used Root Mean Square Error (RMSE). This research, however, had selected Mean Absolute Percent Error (MAPE) due to its clear percentage correction result. In spite of high percentage of errors caused by soil conductivity reverse variation to percentage of errors.

6. Results and discussions

6.1 Characteristics of Study Area

6.1.1 Plain

The plain study site was located in Non Ta Then sub-district, Non Daeng district. Most of this area is paddy field. The North and Northeast are scrub. The East and Southeast connected with highway no. 2 and grove wood. The Northwest and Southwest are small swamp, scrub, and lay with high voltage electricity line. The North in study site area is scrub. The West, East, and middle to Southeast were covered with grass. Other study site area was clearly found soil stain on the soil surface.

6.1.2 Low Terrace

The low terrace study site was located in Thung Swang sub-district, Prathai district. All of this area is paddy field. The Northwestern area connected with highway no. 207. The East connected with Ban Khi Lek School and scrub. The western in study site area found paddy stubble (left after harvesting). And the eastern of study site area found grove wood.

6.1.3 Middle Terrace

Middle terrace of the study area is situated in paddy fields in the area of Prathai sub-district, Prathai district. The northwestern area connected to highway No. 207 and the eastern area closed to grove wood. The northwestern in study site area found small scrub and the whole area was also covered with grass.

6.2 Soil Properties Analysis

From 48 sampling points divided into 36 training points and 12 reference points, the results as below:

6.2.1 Plain

Most sampling points found level of salinity as moderately salinity and very strongly salinity. Soil textures were generally medium-textured soils and moisture was 8.44% in average. An amount of organic matter (OM) in soil was approximately 6.04 g/kg as well as soil reaction (pH) was between 4.1 to 8.2 which mostly had soluble cations with high sodium chloride (NaCl). The ratio of Sodium Absorption Ratio (SAR) in soil was ranged between 9.02 to 115.62, normally counted as saline-sodic soil and saline soil. Surface areas were covered mainly with grass.

6.2.2 Low Terrace

Most sampling points found level of salinity as moderately salinity. Soil textures were generally coarse-textured soils and moisture was 9.16% in average. An amount of organic matter (OM) in soil was approximately 6.38 g/kg as well as soil reaction (pH) was between 3.7 to 8.2 which mostly had soluble cations with high sodium chloride (NaCl). The ratio of Sodium Absorption Ratio (SAR) in soil was ranged between 9.52 to 118.63, normally counted as saline-sodic soil and saline soil. Surface areas were covered mainly with grass.

6.2.3 Middle Terrace

Most sampling points found level of salinity as slightly salinity and non salinity. Soil textures were generally fine-textured soils and moisture was 10.65% in average. An amount of organic matter (OM) in soil was approximately 8.23 g/kg as well as soil reaction (pH) was ranged from 3.7 to 8.3 which mostly had soluble cations with high sodium chloride (NaCl). The ratio of Sodium Absorption Ratio (SAR) in soil was ranged from 6.11 to 62.61, normally counted as normal soil. Surface areas were covered mainly with grass.

6.3 Soil Salinity Interpolation

The results for each method of soil salinity interpolation in study area could be summarized as follows: (Appendix A)

6.3.1 Plain

1) Completely Regularized Spline

Salinity level could be divided as:

- Non salinity 180,061.09 m^2 or 18.01% of the study site found extensively in the North, South, West and East in the study site.
- Slightly salinity 96,238.12 m^2 or 9.62% of the study site found radically around Non salinity area.
- Moderately salinity 191,031.58 m^2 or 19.10% of the study site found channel characteristic area between strongly salinity and slightly salinity areas.
- Strongly salinity 216,186.36 m^2 or 21.62% of the study site found radically around very strongly salinity area.
- Very strongly salinity 316,482.85 m^2 or 31.65% of the study site found extensively in northwestern, southwestern, northeastern, and southeastern areas respectively. Besides, it can be found in small areas in the South of the study site.

2) Spline with tension

Salinity level could be divided as:

- Non salinity 180,061.09 m^2 or 18.01% of the study site found extensively in the North, West, South and East in the study site.
- Slightly salinity 96,238.12 m^2 or 9.62% of the study site found radically around non salinity area.
- Moderately salinity 191,031.58 m^2 or 19.10% of the study site found channel characteristic area between strongly salinity and slightly salinity areas.
- Strongly salinity 216,186.36 m^2 or 21.62% of the study site found radically around very strongly salinity area.
- Very strongly salinity 316,482.85 m^2 or 31.65% of the study site found extensive area in northwestern, southwestern, northeastern, and southeastern study sites respectively. Besides it can be found in small areas in the South of the study site.

3) Inverse Distance Weighting

Salinity level could be divided as:

- Non salinity 3,462.30 m^2or 0.35% of the study site found in small areas in the North of the study site.
- Slightly salinity 14,716.27 m^2 or 1.47% of the study site found radically around non salinity area in the North of the study site. Besides they were found in some small areas in the North and the West of the study site.
- Moderately salinity 187,767.23 m^2 or 18.78% of the study site found extensively in the West and the North of the study site. Besides it could also be found in small areas throughout the study site.
- Strongly salinity 536,007.37 m^2 or 53.60% of the study site found largely and continuously in the whole area. Other salinity level could generally be found inside moderate saline areas.
- Very strongly salinity 258,046.83 m^2 or 25.80% of the study site found extensively in northwestern, southeastern and northeastern study site. Besides they were found in some small areas in the Southwest and the South of the study site.

4) Ordinary Kriging

Salinity level could be divided as:

- Non salinity 18,639.84 m^2 or 1.86% of the study site found small areas in the North of the study site.
- Slightly salinity 42,594.78 m^2 or 4.26% of the study site found radically around non salinity area in the North of the study site. Besides they were found in some small areas in the West of the study site.
- Moderately salinity 211,263.59 m^2 or 21.13% of the study site found radially around slightly salinity area in the West and the North of the study site. And it also found extensively and horizontally from the Central to the Southeast of the study site. Besides they were found in some small areas in the East and the Southwest of the study site.
- Strongly salinity 453,056.52 m^2 or 45.31% of the study site found channel characteristic between very strongly salinity area and moderately salinity area.
- Very strongly salinity 274,445.27 m^2 or 27.44% of the study site found extensively in northwestern, southeastern and northeastern study sites. Besides they were found in some small areas in the South and the Southwest of the study site.

5) Simple Kriging

Salinity level could be divided as:

- Non salinity 10,965.05 m^2 or 1.10% of the study site found small areas in the North of the study site.
- Slightly salinity 42,594.78 m^2 or 3.65% of the study site found radically around non salinity area in the North of the study site.
- Moderately salinity 242,366.10 m^2 or 24.24% of the study site found radically around slightly salinity area in the North and the West of the study site. And it also found extensively and horizontally from the Central to the Southeast of the study site. Besides they were found in some small areas in the East and the Southwest of the study site.
- Strongly salinity 427,133.92 m^2 or 42.71% of the study site found channel characteristic between very strongly salinity area and moderately salinity area.
- Very strongly salinity 283,052.95 m^2m2 or 28.31% of the study site found extensively in northwestern, southeastern and northeastern study sites. Besides they were found in some small areas in the South and the Southwest of the study site.

6) Disjunctive Kriging

Salinity level could be divided as:

- Non salinity 48,643.83 m^2 or 4.86% of the study site found extensively in the North of the study site.
- Slightly salinity 66,005.01 m^2 or 6.60% of the study site found extensively in the West of the study site and found radically around non salinity area in the North of the study site. Besides they were found in small areas in the East of the study site.
- Moderately salinity 270,260.48 m^2 or 27.03% of the study site found extensively and horizontally from northern and southern study site and found radically around slightly salinity area in the West and the East of the study site.
- Strongly salinity 331,864.59 m^2 or 33.19% of the study site found extensive channel characteristic between Very strongly salinity area and moderately salinity area.
- Very strongly salinity 283,226.09 m^2or 28.32% of the study site found extensively in northwestern, southeastern and northeastern study sites. Besides they were found in some small areas in the South and the Southwest of the study site.

The study results found that methods of Completely Regularized Spline and Spline with tension are relatively similar in very strongly salinity areas which are large areas in northwestern, southeastern, northeastern and southwestern study site. Non salinity areas are found in the North, South, East, West and Central of the study site. And in slightly salinity to very strongly salinity areas found radically between very strongly salinity and non salinity areas.

Ordinary Kriging, Simple Kriging and Disjunctive Kriging methods were resulted relatively similar and likely similar to Completely Regularized Spline and Spline with tension. But they had more details of salinity levels. Inverse Distance Weighting method was resulted differently from mentioned methods. Most areas were moderately salinity areas and some other salinity levels intruded into the areas in small areas.

6.3.2 Low Terrace

1) Completely Regularized Spline

Salinity level could be divided as:

- Non salinity 7,459.83 m^2 or 0.75% of the study site found in some small areas in the East of the study site.

- Slightly salinity 76,314.55 m^2 or 7.63% of the study site found extensively in the East of the study site. Besides, they were found in some small areas in the West of the study site.

- Moderately salinity 290,434.39 m^2 or 29.04% of the study site found extensively and horizontally from northeastern to southeastern study site. Besides they were found in some small areas in the North, West, East and South of the study site.

- Strongly salinity 326,680.27 m^2 or 32.67% of the study site found extensively and horizontally from northern to southern study site. Besides they were found in some small areas in the West of the study site.

- Very strongly salinity 299,110.96 m^2 or 29.91% of the study site found extensively and horizontally from western to northwestern study site. Besides they were found in some small areas in the Central and South of the study site.

2) Spline with Tension

Salinity level could be divided as:

- Non salinity 2,883.94 m^2 or 0.29% of the study site found in some small areas in the East of the study site.

- Slightly salinity 68,048.82 m^2 or 6.8% of the study site found extensively in the East of the study site.

- Moderately salinity 262,098.85 m^2 or 26.21% of the study site found extensively and horizontally from northeastern to southeastern study site. Besides they were found in some small areas in the North, West, East and South of the study site.

- Strongly salinity 371,623.17 m^2 or 37.16% of the study site found extensively and horizontally from northern to southern study site. Besides they were found in some small areas in the West of the study site.

- Very strongly salinity 295,345.22 m^2 or 29.53% of the study site found extensively and horizontally from western to northwestern study site. Besides they were found in some small areas in the Central and South of the study site.

3) Inverse Distance Weighting

Salinity level could be divided as:

- Non salinity 5,408.03 m^2 or 0.54% of the study site found in some small areas in the East of the study site.

- Slightly salinity 54,488.66 m^2 or 5.45% of the study site found extensively in the East of the study site. Besides they were found in some small areas in the West of the study site.

- Moderately salinity 278,953.39 m^2 or 27.9% of the study site found extensively and horizontally from northeastern to southeastern study site. Besides they were found in some small areas in the North, West, East and South of the study site.

- Strongly salinity 361,623.49 m^2 or 36.16% of the study site found extensively and horizontally from northern to southern and also covered to eastern study site. Besides they were found in some small areas in the West of the study site.

- Very strongly salinity 299,526.43 m^2 or 29.9 % of the study site found extensively and horizontally from western to northwestern study site. Besides they were found in some small areas in the Central and South of the study site.

4) Ordinary Kriging

Salinity level could be divided as:

- Slightly salinity 74,303.82 m^2 or 7.43% of the study site found in some small areas in the East.

- Moderately salinity 211,290.30 m^2 or 21.13% of the study site found extensively and horizontally from northeastern to southeastern study site. Besides they were found in some small areas in the North of the study site.

- Strongly salinity 416,717.30 m^2 or 41.67% of the study site found extensively and horizontally from northern to southern and also covered to eastern study site.

- Very strongly salinity 297,688.58 m^2 or 29.77% of the study site found extensively and horizontally from western to northwestern study site. Besides they were found in some small areas in the South of the study site.

5) Simple Kriging

Salinity level could be divided as:

- Slightly salinity 40,327.20 m^2 or 4.03% of the study site found in some large areas in the East of the study site.

- Moderately salinity 250,575.00 m^2 or 25.06% of the study site found extensively and horizontally from northeastern and eastern to southeastern study site. Besides they were found in some small areas in the North of the study site.

- Strongly salinity 418,549.53 m^2 or 41.85% of the study site found extensively and horizontally from northern to southern and also covered to eastern study site.

- Very strongly salinity 290,548.27 m^2 or 29.05% of the study site found extensively and horizontally from western to northwestern study site. Besides they were found in some small areas in the South of the study site.

6) Disjunctive Kriging

Salinity level could be divided as:

- Slightly salinity 49,388.26 m^2 or 4.94 %of the study site found in some large areas in the East of the study site.
- Moderately salinity 231,901.92 m^2 or 23.19% of the study site found extensively and horizontally from northeastern and eastern to southeastern study site. Besides they were found in some small areas in the North of the study site.
- Strongly salinity 416,587.50 m^2 or 41.66% of the study site found extensively and horizontally from northern to southern and also covered to eastern study site.
- Very strongly salinity 302,122.32 m^2 or 30.21% of the study site found extensively and horizontally from western to northwestern study site. Besides they were found in some small areas in the South of the study site.

The study results found that methods of Completely Regularized Spline, Spline with tension and Inverse Distance Weighting are relatively similar. The very strongly salinity to non salinity areas were rearranged orderly from very strongly salinity areas in the West to non salinity areas in the East. On top of that the results from these three methods provided more details of salinity level.

Furthermore, Ordinary Kriging, Simple Kriging and Disjunctive Kriging methods were also resulted relatively similar. The areas with very strongly salinity and slightly salinity were rearranged orderly from very strongly salinity areas in the West to slightly salinity areas in the East. On top of that non salinity areas were not found in the results of the three methods.

6.3.3 Middle Terrace

1) Completely Regularized Spline

Salinity level could be divided as:

- Non salinity 255,806.98 m^2 or 25.58% of the study site found in large areas ranged horizontally from northern to western. Besides, they were found in some small areas in the North, South and East of the study site.
- Slightly salinity 669,298.86 m^2 or 66.93% of the study site found in large areas covered mostly throughout the study site in the East of the study site.
- Moderately salinity 74,894.16 m^2 or 7.49% of the study site found in some small areas in the Southeast of the study site.

2) Spline with tension

Salinity level could be divided as:

- Non salinity 225,356.29 m^2 or 22.54% of the study site found in large areas ranged horizontally from northern to western. Besides, they were found in some small areas in the North, South and East of the study site.
- Slightly salinity 717,603.99 m^2 or 71.76% of the study site found in large areas mostly throughout the study site in the East.
- Moderately salinity 57,039.72 m^2 or 5.7% of the study site found in some small areas in the Southeast of the study site.

3) Inverse Distance Weighting

Salinity level could be divided as:

- Non salinity 333,769.04 m^2 or 33.38% of the study site found in large areas ranged horizontally from northern to western. Besides, they were found in some small areas in the North, South and East of the study site.
- Slightly salinity 623,043.90 m^2 or 62.3% of the study site found in large areas mostly throughout the study site in the East.
- Moderately salinity 43,187.06 m^2 or 4.32% of the study site found in some small areas in the Southeast of the study site.

4) Ordinary Kriging

Salinity level could be divided as:

- Non salinity 147,931.20 m^2 or 14.79% of the study site found in large areas ranged horizontally from northern to western. Besides, they were found in some small areas in the North, South and East of the study site.
- Slightly salinity 852,068.80 m^2 or 85.21% of the study site found in large areas mostly throughout the study site in the East.

5) Simple Kriging

Salinity level could be divided as:

- Non salinity 105,837.98 m^2 or 10.58% of the study site found in large areas ranged horizontally from northern to western. Besides, they were found in some small areas in the North, South and East of the study site.
- Slightly salinity 894,162.02 m^2 or 89.42% of the study site found in large areas mostly throughout the study site in the East.

6) Disjunctive Kriging

Salinity level could be divided as:

- Non salinity 137,499.68 m^2 or 13.75% of the study site found in large areas ranged horizontally from northern to western. Besides, they were found in some small areas in the North, South and East of the study site.

- Slightly salinity 862,500.32 m^2 or 86.25% of the study site found in large areas mostly throughout the study site in the East.

Consequently, the study results found that methods of Completely Regularized Spline, Spline with tension and Inverse Distance Weighting are relatively similar. Most area were found slightly salinity to non salinity areas. Slightly salinity areas covered most of the study site areas. And non salinity areas were found largely ranging from northern to western study site. They were also found in small areas in the North, South and East of the study site. Besides, moderately salinity areas could be found in the Southeastern of the study site. On top of that the results from these three methods provided more details of salinity level.

Furthermore, Ordinary Kriging, Simple Kriging and Disjunctive Kriging methods were also resulted relatively similar. Most areas were ranged from slightly salinity to non salinity. Slightly salinity areas covered most of the areas and non salinity areas were found largely ranging from the North to West. On top of that non salinity areas were not found in the results of the three methods.

6.4 Validation of Interpolation method

The validation results of interpolation method by Mean Absolute Percent Error (MAPE) method in term of study area was illustrated as follows: (Appendix B)

6.4.1 Plain

1) Completely Regularized Spline

This method had an average error for 36.90%. The points which had an error less than 25% were AR20, AR52, AR21, AR02, AR11, AR34, and AR12. The points which had an error between 25-50% were AR01 and AR23. The point which had an error between 50-75% is AR10. The point which had an error between 75-100% is AR32. And the point which had an error more than 100% is AR50.

2) Spline with tension

This method had an average error for 41.66%. The points which had an error less than 25% were AR52, AR20, AR21, AR02, and AR12. The points which had an error between 25-50% were AR10, AR01 and AR23. The point which had an error between 50-75% was AR11. The point which had an error between 75-100% was AR50. And finally the points which had an error more than 100% were AR32 and AR34.

3) Inverse Distance weighting

This method had an average error for 74.80%. The points which had an error less than 25% were AR01, AR12, AR21, AR52, and AR23. The points which had an error between 25-50% were AR02, AR20, and AR50. The points which had an error between 50-75% were AR11 and AR10. And finally the points which had an error more than 100% were AR32 and AR34.

4) Ordinary Kriging

This method had an average error for 80.89%. The points which had an error less than 25% were AR12, AR23, and AR52. The points which had an error between 25-50% were AR21, AR01, AR20, and AR02. The point which had an error between 50-75% was AR50. And finally the points which had an error more than 100% were AR10, AR32, AR11, and AR34.

5) Simple Kriging

This method had an average error for 74.89%. The points which had an error less than 25% were AR12, AR52, AR23, AR21, and AR20. The points which had an error between 25-50% were AR01 and AR02. The points which had an error between 75-100% were AR10 and AR50. And finally the points which had an error more than 100% were AR11, AR32, and AR34.

6) Disjunctive Kriging

This method had an average error for 52.44%. The points which had an error less than 25% were AR23, AR52, AR20, and AR12. The points which had an error between 25-50% were AR21, AR10, AR01, and AR02. The point which had an error between 50-75% was AR50. And finally the points which had an error more than 100% were AR32, AR11, and AR34.

6.4.2 Low Terrace

1) Completely Regularized Spline

This method had an average error for 24.25%. The points which had an error less than 25% were BR13, BR04, BR45, BR05, BR43, BR54, BR35, BR03, and BR25. The point which had an error between 25-50% was BR55. The point which had an error between 50-75% was BR40. And finally the point which had an error more than 100% was BR44.

2) Spline with tension

This method had an average minimum error for 38.25%. The points which had an error less than 25% were BR03, BR54, BR43, BR45, BR05, BR13, BR35, BR25, and BR04. The point which had an error between 25-50% was BR55. And finally the points which had an error more than 100% were BR40 and BR44.

3) Inverse Distance Weighting

This method had an average minimum error for 45.66%. The points which had an error less than 25% were BR54, BR03, BR45, BR43, BR35, BR05, BR13, and BR25. The point which had an error between 25-50% was BR04. The point which had an error between 50-75% was BR55. And finally the points which had an error more than 100% were BR40 and BR44.

4) Ordinary Kriging

This method had an average minimum error for 50.86%. The points which had an error less than 25% were BR25, BR45, BR54, BR43, BR05, BR03, BR35, and BR13. The point which had an error between 25-50% was BR04. The points which had an error between 50-75% were BR55 and BR40. And finally the point which had an error more than 100% was BR44.

5) Simple Kriging

This method had an average minimum error for 54.65%. The points which had an error less than 25% were BR43, BR25, BR54, BR45, BR05, and BR03. The points which had an error between 25-50% were BR13, BR04, and BR35. The point which had an error between 50-75% was BR55. And finally the points which had an error more than 100% were BR40 and BR44.

6) Disjunctive Kriging

This method had an average minimum error for 57.12%. The points which had an error less than 25% were BR54, BR45, BR05, BR25, BR43, and BR03. The points which had an error between 25-50% were BR13, BR04, and BR35. The point which had an error between 50-75% was BR55. And finally the points which had an error more than 100% were BR40 and BR44.

6.4.3 Middle Terrace

1) Completely Regularized Spline

This method had an average error for 44.79%. The point which had an error less than 25% was CR51. The points which had an error between 25-50% were CR15, CR22, and CR31. The point which had an error between 50-75% was CR30. And finally the point which had an error between 75-100% was CR41.

2) Spline with tension

This method had an average error for 54.18%. The point which had an error less than 25% was CR51. The points which had an error between 25-50% were CR15, CR22, and CR31. The point which had an error 50-75% was CR30. And finally the point which had an error more than 100% was CR 41.

3) Inverse Distance Weighting

This method had an average error for 45.67%. The point which had an error less than 25% was CR51. The points which had an error between 25-50% were CR15, CR31, and CR22. The point which had an error between 50-75% was CR30. And finally the point which had an error between 75-100% was CR41.

4) Ordinary Kriging

This method had an average error for 85.36%. The points which had an error between 25-50% were CR51, CR15, CR31, and CR22. The point which had an error between 50-75% was CR30. And finally the point which had an error more than 100% was CR41.

5) Simple Kriging

This method had an average error for 89.89%. The points which had an error between 25-50% were CR51, CR31, CR15, and CR22. The point which had an error between 50-75% was CR30. And finally the point which had an error more than 100% was CR41

6) Disjunctive Kriging

This method had an average error for 88.90%. The points which had an error between 25-50% were CR51, CR31, CR15, and CR22. The point which had an error between 50-75% was CR30. And finally the point which had an error more than 100% was CR41.

6.5 Soil Salinity Map

Plain areas found that Completely Regularized Spline method had least percentage of errors which was 36.90%. The next methods were Spline with tension with 41.66 percentages of errors, and then Disjunctive Kriging method with 52.44% of errors. After that there were Inverse Distance Weighting method with 74.80% of errors, and last but not least Simple Kriging method with 74.89% of errors, and finally Ordinary Kriging method with maximum percentage of errors, 80.89% respectively.

Low terrace areas found that Completely Regularized Spline method had least percentage of errors which was 24.25%. The next methods were Spline with tension with 38.25 percentages of errors, and then Inverse Distance Weighting method with 45.66% of errors. After that there were Ordinary Kriging method with 50.86% of errors, and last but not least Simple Kriging method with 54.65% of errors and finally Disjunctive Kriging method with 57.12% of errors respectively.

Middle terrace areas found that Completely Regularized Spline method had least percentage of errors which was 44.79% of errors, and the next one was Inverse Distance Weighting method with 45.67% of errors, and then Spline with tension method with 54.18% of errors. After that there were Ordinary Kriging method with 85.36% of errors, and last but not least was Disjunctive Kriging method with 88.90% of errors and finally Simple Kriging with maximum percentage of errors which was 89.89% respectively.

Table 2. Compare the interpolation methods for Electrical Conductivity (EC_e) interpolate

Unit (%)

Interpolation Methods	Plain	Low Terrace	Middle Terrace
Completely Regularized Spline	36.90	24.25	44.79
Spline with tension	41.66	38.25	54.18
Inverse Distance Weighting	74.80	45.66	45.67
Ordinary Kriging	80.89	50.86	85.36
Simple Kriging	74.89	54.65	89.89
Disjunctive Kriging	52.44	57.12	88.9

Consequently, Completely Regularized Spline method could be used similarly and effectively for estimating soil salinity in all areas compared with all 6 interpolation methods in this research.

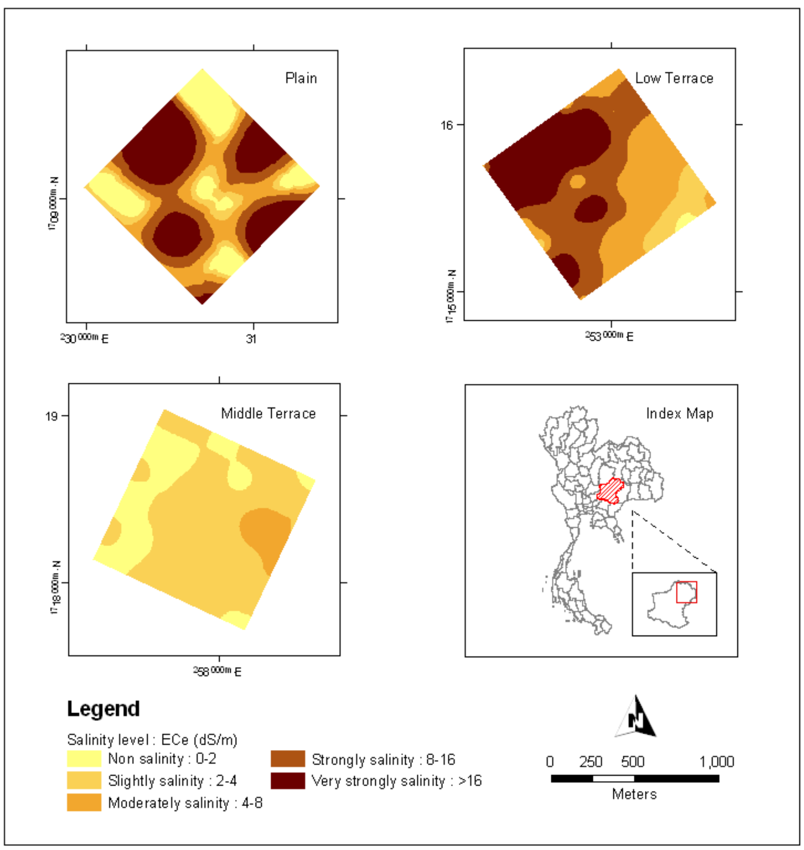

Figure 9. Results of soil salinity by using Completely Regularized Spline interpolation

7. Recommendations

The plain and low terrace areas mostly had strongly salinity and very strongly salinity soil which plants could not be used to cultivate leading to environmental decay. However, the problems could be solved by engineering, agricultural and integrated methods (Land Development Dept., 1997).

While the middle terrace areas were found that soil salinity levels were mostly slightly salinity to non salinity which could be used to cultivate but with low yields. The saline soil problems could be solved by flattening land, inputting organic matter, adding green manure fertilizer, planting salt tolerant line of rice or economic crops (Yamclee, (2005).

Saline soil areas should be utilized according to their status and should not abandon them. Suitable plants for certain areas shall be planted such as salt tolerant plants, or compatible with salt; since uncover land would have more salinity level.

Due to the research managed in small areas, further research shall experiment in wider areas using other interpolation methods in Geographic Information System (GIS) that had not been selected in this research. Each method would be suitable for certain types of area either small or large areas. Besides model of Kriging method could be calibrated to reduce errors which shall be studied later.

When studies with other interpolation methods or use data in other season or study in other areas at have different parameters, the result would have been much different from this research.

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Appendix A

Table a. Soil salinity interpolation in plain areas

Completely Regularized Spline		
Salinity level	Area (m2)	% of Area
Non salinity	180,061.09	18.01
Slightly salinity	96,238.12	9.62
Moderately salinity	191,031.58	19.1
Strongly salinity	216,186.36	21.62
Very strongly salinity	316,482.85	31.65
Total	1,000,000.00	100

Ordinary Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	18,639.84	1.86
Slightly salinity	42,594.78	4.26
Moderately salinity	211,263.59	21.13
Strongly salinity	453,056.52	45.31
Very strongly salinity	274,445.27	27.44
Total	1,000,000.00	100

Spline with tension		
Salinity level	Area (m2)	% of Area
Non salinity	180,061.09	18.01
Slightly salinity	96,238.12	9.62
Moderately salinity	191,031.58	19.1
Strongly salinity	216,186.36	21.62
Very strongly salinity	316,482.85	31.65
Total	1,000,000.00	100

Simple Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	10,965.05	1.1
Slightly salinity	36,481.98	3.65
Moderately salinity	242,366.10	24.24
Strongly salinity	427,133.92	42.71
Very strongly salinity	283,052.95	28.31
Total	1,000,000.00	100

Inverse Distance Weighting		
Salinity level	Area (m2)	% of Area
Non salinity	3,462.30	0.35
Slightly salinity	14,716.27	1.47
Moderately salinity	187,767.23	18.78
Strongly salinity	536,007.37	53.6
Very strongly salinity	258,046.83	25.8
Total	1,000,000.00	100

Disjunctive Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	48,643.83	4.86
Slightly salinity	66,005.01	6.6
Moderately salinity	270,260.48	27.03
Strongly salinity	331,864.59	33.19
Very strongly salinity	283,226.09	28.32
Total	1,000,000.00	100

Table b. Soil salinity interpolation in low terrace areas

Completely Regularized Spline		
Salinity level	Area (m2)	% of Area
Non salinity	7459.83	0.75
Slightly salinity	76314.55	7.63
Moderately salinity	290434.39	29.04
Strongly salinity	326680.27	32.67
Very strongly salinity	299110.96	29.91
Total	1000000.00	100.00

Ordinary Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	0.00	0.00
Slightly salinity	74303.82	7.43
Moderately salinity	211290.30	21.13
Strongly salinity	416717.30	41.67
Very strongly salinity	297688.58	29.77
Total	1000000.00	100.00

Spline with tension		
Salinity level	Area (m2)	% of Area
Non salinity	2883.94	0.29
Slightly salinity	68048.82	6.80
Moderately salinity	262098.85	26.21
Strongly salinity	371623.17	37.16
Very strongly salinity	295345.22	29.53
Total	1000000.00	100.00

Simple Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	0.00	0.00
Slightly salinity	40327.20	4.03
Moderately salinity	250575.00	25.06
Strongly salinity	418549.53	41.85
Very strongly salinity	290548.27	29.05
Total	1000000.00	100.00

Inverse Distance Weighting		
Salinity level	Area (m2)	% of Area
Non salinity	5408.03	0.54
Slightly salinity	54488.66	5.45
Moderately salinity	278953.39	27.90
Strongly salinity	361623.49	36.16
Very strongly salinity	299526.43	29.95
Total	1000000.00	100.00

Disjunctive Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	0.00	0.00
Slightly salinity	49388.26	4.94
Moderately salinity	231901.92	23.19
Strongly salinity	416587.50	41.66
Very strongly salinity	302122.32	30.21
Total	1000000.00	100.00

Table c. Soil salinity interpolation in middle terrace areas

Completely Regularized Spline		
Salinity level	Area (m2)	% of Area
Non salinity	255806.98	25.58
Slightly salinity	669298.86	66.93
Moderately salinity	74894.16	7.49
Strongly salinity	0.00	0.00
Very strongly salinity	0.00	0.00
Total	1000000.00	100.00

Ordinary Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	147931.20	14.79
Slightly salinity	852068.80	85.21
Moderately salinity	0.00	0.00
Strongly salinity	0.00	0.00
Very strongly salinity	0.00	0.00
Total	1000000.00	100.00

Spline with tension		
Salinity level	Area (m2)	% of Area
Non salinity	225356.29	22.54
Slightly salinity	717603.99	71.76
Moderately salinity	57039.72	5.70
Strongly salinity	0.00	0.00
Very strongly salinity	0.00	0.00
Total	1000000.00	100.00

Simple Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	105837.98	10.58
Slightly salinity	894162.02	89.42
Moderately salinity	0.00	0.00
Strongly salinity	0.00	0.00
Very strongly salinity	0.00	0.00
Total	1000000.00	100.00

Inverse Distance Weighting		
Salinity level	Area (m2)	% of Area
Non salinity	333769.04	33.38
Slightly salinity	623043.90	62.30
Moderately salinity	43187.06	4.32
Strongly salinity	0.00	0.00
Very strongly salinity	0.00	0.00
Total	1000000.00	100.00

Disjunctive Kriging		
Salinity level	Area (m2)	% of Area
Non salinity	137499.68	13.75
Slightly salinity	862500.32	86.25
Moderately salinity	0.00	0.00
Strongly salinity	0.00	0.00
Very strongly salinity	0.00	0.00
Total	1000000.00	100.00

Appendix B

Table d. The validation results of interpolation method in plain areas

Completely Regularized Spline				
MARK	EC_e	Predicted	Error	Error (%)
AR50	1.95	0.69	2.64	135.25
AR52	47.31	50.16	2.85	6.01
AR20	31.23	31.18	0.05	0.16
AR32	3.17	5.77	2.60	82.12
AR21	23.34	21.69	1.65	7.08
AR10	3.73	1.39	2.34	62.69
AR11	3.94	4.57	0.63	16.09
AR01	29.07	19.20	9.87	33.95
AR34	2.14	1.72	0.42	19.53
AR23	6.62	3.80	2.82	42.62
AR12	10.10	7.80	2.30	22.74
AR02	55.04	47.03	8.01	14.55
Total Error (%)				36.90

Ordinary Kriging				
MARK	EC_e	Predicted	Error	Error (%)
AR50	1.95	3.01	1.06	54.20
AR52	47.31	38.40	8.91	18.84
AR20	31.23	22.42	8.81	28.22
AR32	3.17	9.01	5.84	184.17
AR21	23.34	17.05	6.29	26.96
AR10	3.73	7.77	4.04	108.39
AR11	3.94	11.43	7.49	190.14
AR01	29.07	20.94	8.13	27.95
AR34	2.14	7.96	5.82	272.10
AR23	6.62	7.61	0.99	15.03
AR12	10.10	11.11	1.01	10.03
AR02	55.04	35.94	19.10	34.70
Total Error (%)				80.89

Spline with tension				
MARK	EC_e	Predicted	Error	Error (%)
AR50	1.95	0.21	1.74	89.27
AR52	47.31	48.12	0.81	1.70
AR20	31.23	29.35	1.88	6.04
AR32	3.17	6.45	3.28	103.53
AR21	23.34	20.76	2.58	11.05
AR10	3.73	2.80	0.93	25.01
AR11	3.94	6.39	2.45	62.30
AR01	29.07	21.37	7.70	26.48
AR34	2.14	4.47	2.33	108.68
AR23	6.62	4.74	1.88	28.37
AR12	10.10	7.86	2.24	22.17
AR02	55.04	46.63	8.41	15.27
Total Error (%)				41.66

Simple Kriging				
MARK	EC_e	Predicted	Error	Error (%)
AR50	1.95	3.50	1.55	79.49
AR52	47.31	37.49	9.82	20.76
AR20	31.23	23.73	7.50	24.02
AR32	3.17	8.73	5.56	175.39
AR21	23.34	17.91	5.43	23.26
AR10	3.73	6.68	2.95	79.09
AR11	3.94	9.84	5.90	149.75
AR01	29.07	20.16	8.91	30.65
AR34	2.14	7.65	5.51	257.48
AR23	6.62	8.15	1.53	23.11
AR12	10.10	10.31	0.21	2.08
AR02	55.04	36.51	18.53	33.67
Total Error (%)				74.89

Inverse Distance Weighting				
MARK	EC_e	Predicted	Error	Error (%)
AR50	1.95	2.72	0.77	39.35
AR52	47.31	37.78	9.53	20.14
AR20	31.23	23.15	8.08	25.87
AR32	3.17	10.87	7.70	242.77
AR21	23.34	20.68	2.66	11.38
AR10	3.73	6.74	3.01	80.72
AR11	3.94	6.82	2.88	73.12
AR01	29.07	26.46	2.61	8.99
AR34	2.14	9.42	7.28	340.23
AR23	6.62	7.99	1.37	20.67
AR12	10.10	11.04	0.94	9.34
AR02	55.04	41.28	13.76	25.01
Total Error (%)			74.80	

Disjunctive Kriging				
MARK	EC_e	Predicted	Error	Error (%)
AR50	1.95	0.96	0.99	50.61
AR52	47.31	42.60	4.71	9.96
AR20	31.23	27.65	3.58	11.48
AR32	3.17	6.35	3.18	100.35
AR21	23.34	17.38	5.96	25.53
AR10	3.73	4.77	1.04	27.92
AR11	3.94	8.58	4.64	117.64
AR01	29.07	19.78	9.29	31.95
AR34	2.14	6.50	4.36	203.61
AR23	6.62	6.33	0.29	4.38
AR12	10.10	11.40	1.30	12.89
AR02	55.04	36.89	18.15	32.98
Total Error (%)				52.44

Table e. The validation results of interpolation method in low terrace areas

Completely Regularized Spline				
MARK	EC_e	Predicted	Error	Error (%)
BR45	4.04	4.15	0.11	2.66
BR44	3.17	6.94	3.77	118.81
BR55	2.82	3.99	1.17	41.51
BR35	3.12	3.32	0.20	6.28
BR25	8.76	7.19	1.57	17.98
BR05	22.91	23.64	0.73	3.17
BR43	37.74	39.28	1.54	4.09
BR54	5.61	5.26	0.35	6.18
BR13	5.15	5.16	0.01	0.29
BR04	5.23	5.37	0.14	2.62
BR03	8.62	7.75	0.87	10.11
BR40	1.18	2.09	0.91	77.29
Total Error (%)				24.25

Ordinary Kriging				
MARK	EC_e	Predicted	Error	Error (%)
BR45	4.04	4.18	0.14	3.51
BR44	3.17	12.54	9.37	295.65
BR55	2.82	4.52	1.70	60.14
BR35	3.12	3.64	0.52	16.74
BR25	8.76	8.63	0.13	1.54
BR05	22.91	25.53	2.62	11.45
BR43	37.74	34.70	3.04	8.07
BR54	5.61	5.97	0.36	6.35
BR13	5.15	6.16	1.01	19.52
BR04	5.23	6.64	1.41	27.02
BR03	8.62	9.65	1.03	11.92
BR40	1.18	2.93	1.75	148.40
Total Error (%)				50.86

Spline with tension				
MARK	EC_e	Predicted	Error	Error (%)
BR45	4.04	4.26	0.22	5.44
BR44	3.17	9.76	6.59	207.87
BR55	2.82	4.38	1.56	55.43
BR35	3.12	3.53	0.41	13.23
BR25	8.76	7.54	1.22	13.90
BR05	22.91	24.37	1.46	6.37
BR43	37.74	36.89	0.85	2.26
BR54	5.61	5.50	0.11	1.93
BR13	5.15	5.73	0.58	11.21
BR04	5.23	6.09	0.86	16.35
BR03	8.62	8.55	0.07	0.76
BR40	1.18	2.65	1.47	124.20
Total Error (%)				38.25

Simple Kriging				
MARK	EC_e	Predicted	Error	Error (%)
BR45	4.04	4.35	0.31	7.79
BR44	3.17	10.98	7.81	246.35
BR55	2.82	4.69	1.87	66.36
BR35	3.12	4.50	1.38	44.29
BR25	8.76	8.26	0.50	5.68
BR05	22.91	25.66	2.75	12.02
BR43	37.74	35.65	2.09	5.53
BR54	5.61	5.99	0.38	6.83
BR13	5.15	6.43	1.28	24.76
BR04	5.23	6.99	1.76	33.70
BR03	8.62	9.80	1.18	13.65
BR40	1.18	3.41	2.23	188.77
Total Error (%)				54.65

Inverse Distance Weighting				
MARK	EC_e	Predicted	Error	Error (%)
BR45	4.04	4.39	0.35	8.74
BR44	3.17	10.59	7.42	234.03
BR55	2.82	4.82	2.00	71.04
BR35	3.12	3.45	0.33	10.59
BR25	8.76	6.98	1.78	20.29
BR05	22.91	25.56	2.65	11.56
BR43	37.74	34.23	3.51	9.29
BR54	5.61	5.42	0.19	3.30
BR13	5.15	6.09	0.94	18.34
BR04	5.23	6.60	1.37	26.14
BR03	8.62	9.29	0.67	7.82
BR40	1.18	2.68	1.50	126.85
Total Error (%)				45.66

Disjunctive Kriging				
MARK	EC_e	Predicted	Error	Error (%)
BR45	4.04	4.32	0.28	6.94
BR44	3.17	12.06	8.89	280.31
BR55	2.82	4.39	1.57	55.68
BR35	3.12	4.64	1.52	48.77
BR25	8.76	7.81	0.95	10.84
BR05	22.91	25.27	2.36	10.31
BR43	37.74	33.63	4.11	10.90
BR54	5.61	5.78	0.17	2.96
BR13	5.15	6.47	1.32	25.60
BR04	5.23	7.13	1.90	36.34
BR03	8.62	10.55	1.93	22.42
BR40	1.18	3.24	2.06	174.41
Total Error (%)				57.12

Table f. The validation results of interpolation method in middle terrace areas

Completely Regularized Spline				
MARK	EC_e	Predicted	Error	Error (%)
CR41	0.43	0.85	0.42	96.53
CR51	2.85	2.28	0.57	20.03
CR31	3.40	2.03	1.37	40.28
CR30	10.51	5.16	5.35	50.88
CR22	6.26	4.24	2.02	32.29
CR15	5.27	3.75	1.52	28.75
Total Error (%)				44.79

Ordinary Kriging				
MARK	EC_e	Predicted	Error	Error (%)
CR41	0.43	1.73	1.30	301.69
CR51	2.85	1.93	0.92	32.33
CR31	3.40	2.16	1.24	36.55
CR30	10.51	3.83	6.68	63.54
CR22	6.26	3.63	2.63	42.03
CR15	5.27	3.37	1.90	36.05
Total Error (%)				85.36

Spline with tension				
MARK	EC_e	Predicted	Error	Error (%)
CR41	0.43	1.03	0.60	140.13
CR51	2.85	2.16	0.69	24.35
CR31	3.40	2.08	1.32	38.93
CR30	10.51	4.75	5.76	54.84
CR22	6.26	4.02	2.24	35.74
CR15	5.27	3.63	1.64	31.09
Total Error (%)				54.18

Simple Kriging				
MARK	EC_e	Predicted	Error	Error (%)
CR41	0.43	1.84	1.41	328.83
CR51	2.85	2.01	0.84	29.50
CR31	3.40	2.15	1.25	36.80
CR30	10.51	3.81	6.70	63.79
CR22	6.26	3.63	2.63	42.02
CR15	5.27	3.25	2.02	38.42
Total Error (%)				89.89

Inverse Distance Weighting				
MARK	EC_e	Predicted	Error	Error (%)
CR41	0.43	0.85	0.42	98.62
CR51	2.85	2.38	0.47	16.42
CR31	3.40	2.10	1.30	38.15
CR30	10.51	4.85	5.66	53.88
CR22	6.26	3.84	2.42	38.59
CR15	5.27	3.78	1.49	28.35
Total Error (%)				45.67

Disjunctive Kriging				
MARK	EC_e	Predicted	Error	Error (%)
CR41	0.43	1.78	1.35	314.77
CR51	2.85	1.96	0.89	31.20
CR31	3.40	2.18	1.22	35.98
CR30	10.51	3.50	7.01	66.69
CR22	6.26	3.45	2.81	44.94
CR15	5.27	3.17	2.10	39.80
Total Error (%)				88.90