Point to Surface Mapping of Selected Soil Properties using Different Interpolation Techniques

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ABSTRACT

Three spatial analysis algorithms namely: inverse distance weighted (IDW), kriging, and spline, were used to interpolate soil pH and soil texture properties from sample point data. A random-point sampling was carried out to collect soil samples. Samples were analyzed in the laboratory.

Interpolation was carried out in ArcGIS 10. Root mean square error (RMSE) was calculated to evaluate the relative precision of the interpolation methods. IDW had the lowest RMSE for pH, OM, clay, and sand while kriging had the lowest RSME in silt. Spline had the highest RMSE for all of the four properties. Lower RMSE implies better interpolation result.

While the relative precision results appeared to be consistent, the analysis of variance revealed that the three interpolation methods were not significantly different ($p>0.05$) from each other. In addition, the soil map generated through kriging had the least visual appeal among the three methods.

The major outputs of the interpolation are surface maps (continuous data) of the five soil attributes. Surface maps are important material for decision making regarding land use, soil-plant compatibility, yield analysis, and soil improvement activities. Future research should take into account the topographic factors, existing vegetation and other important site properties.

INTRODUCTION

Soil mapping is an essential component of soil survey, which records properties of the soil, e.g., pH, texture, and nutrients, along with their specific locations over a landscape. Soil maps tell of the distribution of soil type in a particular area or geographical region. The maps may be thematic or designed to convey information about a single topic or theme such as texture, structure, depth, stoniness, parent material, salinity, and drainage (Machanda, *et. al.*, 2002)

Information from soil map is derived from samples collected in the field. Nowadays, field data collection is facilitated by the use of Global Positioning System (GPS) receivers which provide the coordinates of sampling points. Map is then made by interpolating point data to produce a continuous-data map or surface map of a specific soil property. Most Geographic Information System (GIS) software have tools for interpolation of point data. However, the different tools tend to provide varying results (Kravencho and Bullock, 1999; Robinson & Metternich, 2006; Lastlett, *et al.*, 1997) such

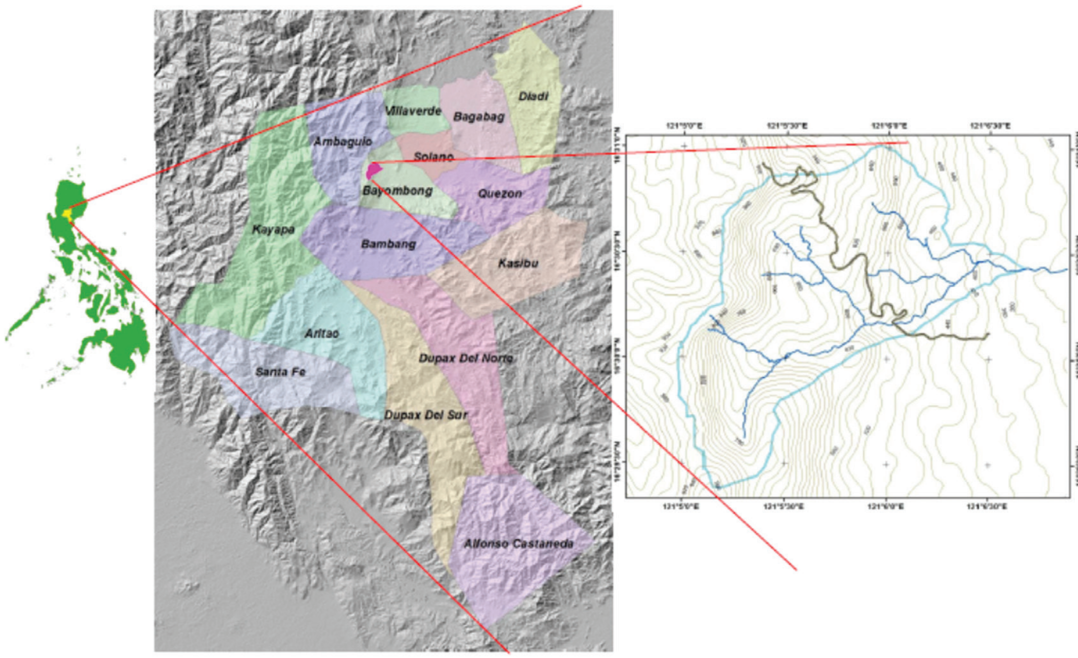

Figure 1: Location of the study

that if maps are placed side by side one can easily tell how different one from the other; hence, empirical studies are necessary in providing insights on how useful GIS tools are and what are their limitations.

An area with varying topographical configuration, vegetation, and farming practices was designated for the study so that soil properties collected from the sampling points distributed over the landscape can be assumed to vary from point to point. The Barobbob Watershed in Bayombong, Nueva Vizcaya, an important watershed ecologically and economically, was selected as the case study area. While the watershed is primarily intended for water supply, most of it is being used for agriculture as there is a large community of farmers that reside or farm within this watershed. While an existing tenure system allows families to manage individual land parcels and farmers are receiving technical assistance such as agroforestry training, it can be observed in the area that land degradation is occurring as manifested in stream water and forest cover. With the foregoing, it is deemed important that soil survey and mapping be conducted in the watershed to generate information useful for land use planning. As resources for this activity is minimal, soil survey and mapping must utilize certain GIS-based interpolation techniques for a surface map to be produced out of a small number of soil sampling points.

The study aimed to: a) compare three surface interpolation tools namely, inverse distance weighted (IDW); kriging and spline; and b) identify the best technique based on accuracy, anomaly and visual appeal of maps.

METHODOLOGY

Location, Land Cover and Climate of the Study Area

The study was conducted in Barobbob Watershed in Bayombong, Nueva Vizcaya. Its geographical location can be described as: within 121°4’57” and 121°6’43” east longitude, and within 16°29’22” and 16°31’2” north latitude (Figure 1).

The land cover of the watershed is predominantly forest. Farms are planted to various agricultural crops including fruit trees. Timber trees are often seen as an important component of farms (Ngampiboonwet, 2014).

Bayombong lies within the Philippine Climatic Type 3, described as relatively dry from November to April and relatively wet during the rest of the year. The mean annual rainfall in this town is around 3,080 mm based on more than a century of data (1900 to 2009) while the mean monthly temperature is 23.25°C during the same period (Vallesteros and Sarmiento, 2014).

Soil Survey

Thirty-two samples were collected from within 20 cm soil depth. The coordinates of the sample points were recorded using a GPS receiver at an average accuracy of 4 m. Sample points were selected randomly. Twenty-two samples were used in interpolating the point data while 10 samples were used in evaluating the results of interpolations (Figure 2).

Less than one-half, in terms of area, of the watershed was covered by sampling or around 221 ha based on maximum bounding rectangle with a dimension of around 1,788 m x 1,237 m. The coordinates of the lower left corner of the rectangle was 121.09 east longitude and 16.50 north latitude.

The samples were collected along trails, streams and road for convenience of collection.

After proper preparation, the samples were brought to a laboratory for analysis. Organic matter content (%), pH, and texture (%sand, %silt, and %clay) were observed.

Interpolation Techniques

Only one map layer or feature data was created. The values for each of the soil

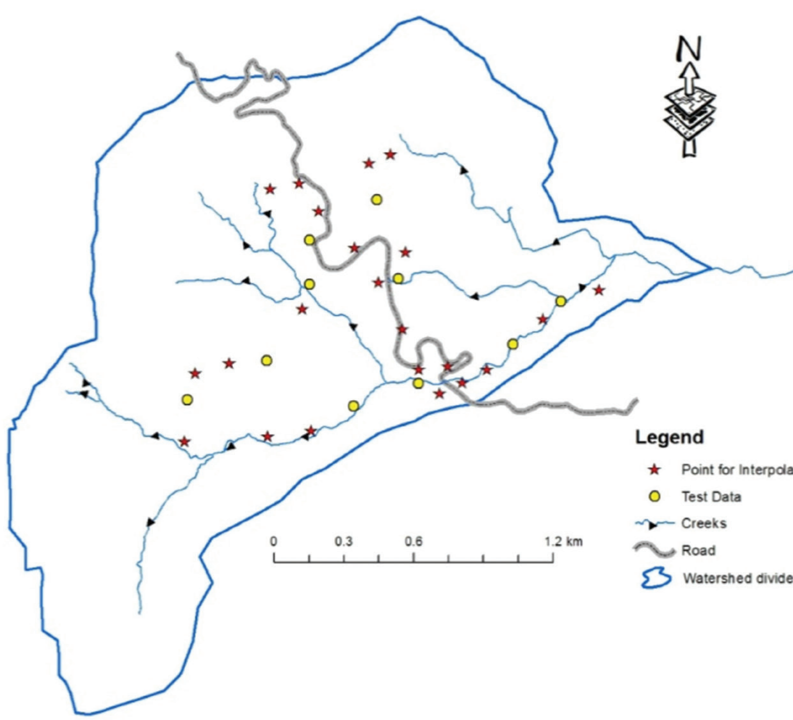

Figure 2. Location of the 32 soil sample points

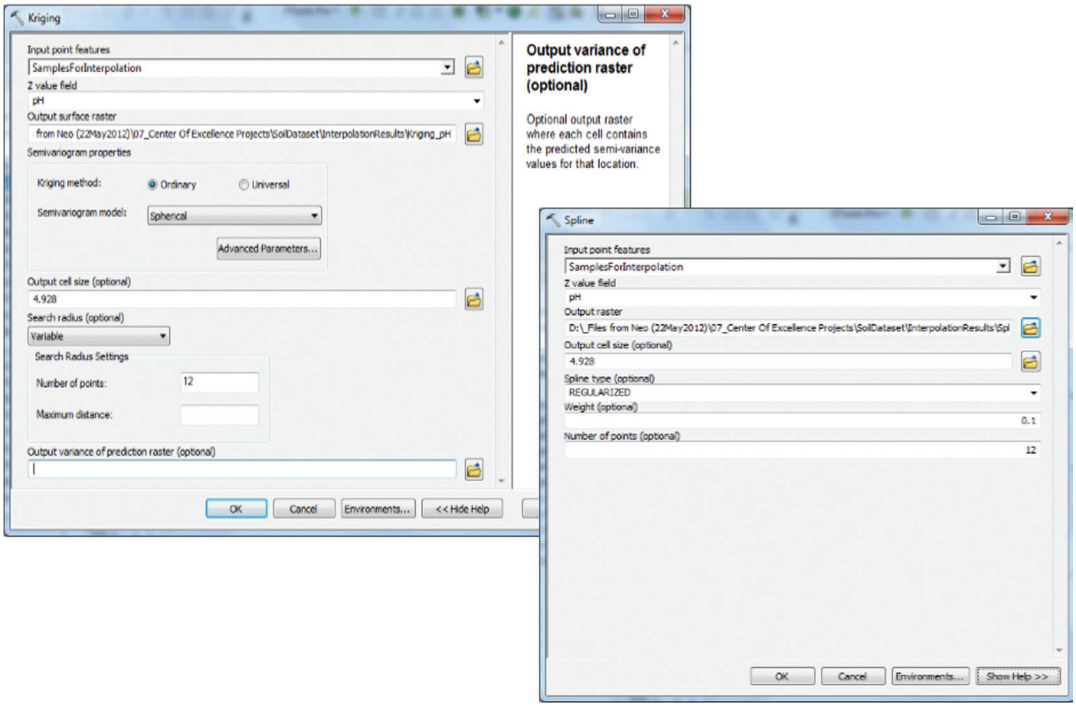

Figure 3. Sample command boxes of kriging and spline

properties were entered into the attribute table of the map layer. Default parameters in the interpolation techniques were used. Sample command boxes of kriging and spline showing the default parameters are shown in Figure 3. The surface interpolation tools are available under the Spatial Analyst tool of ArcGIS 10.

Statistical Analysis

Several statistics were calculated to analyze the data. Descriptive statistics consisting of mean, minimum, maximum and standard distribution were calculated to describe and summarize the properties of 32 samples. Pearson's correlation coefficient was calculated in order to identify significant relationships between two soil properties such as pH, %OM, and % sand, % silt and % clay.

To compare and evaluate the three different interpolation techniques the root mean square error (rmse) was calculated.

Analysis of variance was calculated to determine whether the three different interpolation techniques performed similarly or not. Values were taken from 10 sample points, which are similar to the test data for the analysis of variance.

Soil Series

Secondary data on soil series was retrieved from the Bureau of Agricultural Research. The map shows that the watershed lies in two soil series, namely, Maligaya clay loam and Sibul clay (Figure 4). Sibul clay, often described as upland soil, comprises an area of 313.49 ha or equivalent to 74.64% of the total area of the watershed. The external drainage of this soil is good but the internal drainage is poor (Dagdag, *et al.*, 1963). On the other hand, the remaining 106.5 ha (25.36%) falls under the Maligaya clay loam. Soil of this series is developed from alluvial deposits, and often described as soil of plains and valleys. Internal drainage of this soil is generally poor (Dagdag, *et al.*, 1963).

RESULTS AND DISCUSSION

Soil Properties

Table 1 shows the result of 32 samples for mean, minimum, maximum, and standard deviation. The average OM content of the samples was 4.76%. In general, the OM content was relatively high and this can be attributed to tree cover in most of the sample points. Trees contribute relatively large amount of organic matter through litter fall.

The soil pH in the sampled area ranged from 5.0 to 8.2 which could be categorized as slightly acidic to slightly alkaline. The average soil pH was 6.4 or slightly acidic.

Clay is predominant in the area having an average of 38.47%. Sand comes as second while clay was least. Percent clay content values were highly dispersed with a SD of 17.41. Maximum value was also observed in clay. According to McCauley *et. al.,* (2008) soils high in clay are generally higher in organic matter content than sandy soils.

Soil texture is one of the most important characteristics which influences soil physical properties and has great significance in land use management. Based on the proportion of sand, silt, and clay, soil textural grade was determined. The textural grade varies from clay to sandy loam or there were six textural grades recorded based on the 32 samples. None of the samples were found to be under any of the silt-dominated classes.

Correlation analysis involving the 32 samples revealed weak relationship between pH and % OM; between pH and % sand, % silt or % clay; and between % OM and % sand, % silt or % clay. This result implies high variation of soil properties among the samples.

Consistency with Recorded Soil Series

The soils in Barobbob Watershed fall under two soil series, namely, Maligaya clay loam and Sibul clay (Figure 4). Majority (25) of the samples were within Maligaya clay loam and the rest (7) of the samples were within Sibul clay. While there were six different textural classes based on individual samples, the average values (% sand, % silt and % clay) of samples were computed for each of the sample groups, namely, those falling within Maligaya clay loam and those falling within Sibul clay, in order to analyze whether the field data's textural grade matches that of the soil series.

Based on the average values for % sand, % silt and % clay, the soil textural class was clay loam. It turned out that most of the samples collected within Sibul clay series were not clay but rather clay loam. This inconsistency appeared to be the result of micro changes in texture across landscape or the difference in sampling depth between the old and the present surveys.

Surface Interpolation

Three surface interpolation techniques were used in order to transform point data into a continuous data format. Each of the five soil properties (pH, % OM, % Sand, % Silt, and % Clay) was interpolated using IDW, kriging and spline. The interpolated soil maps of all properties are shown in Figures 5 to 9 while the RMSE values are shown in Table 3.

Table 1. Summary of laboratory results

Statistics	pH	%OM	%Sand	%Silt	%Clay
Mean	6.4	4.76	32.75	28.78	38.47
Min	5.0	1.26	9.00	11.00	3.00
Max	8.2	13.4	61.00	48.00	67.00
SD	0.89	2.69	16.47	7.76	17.41

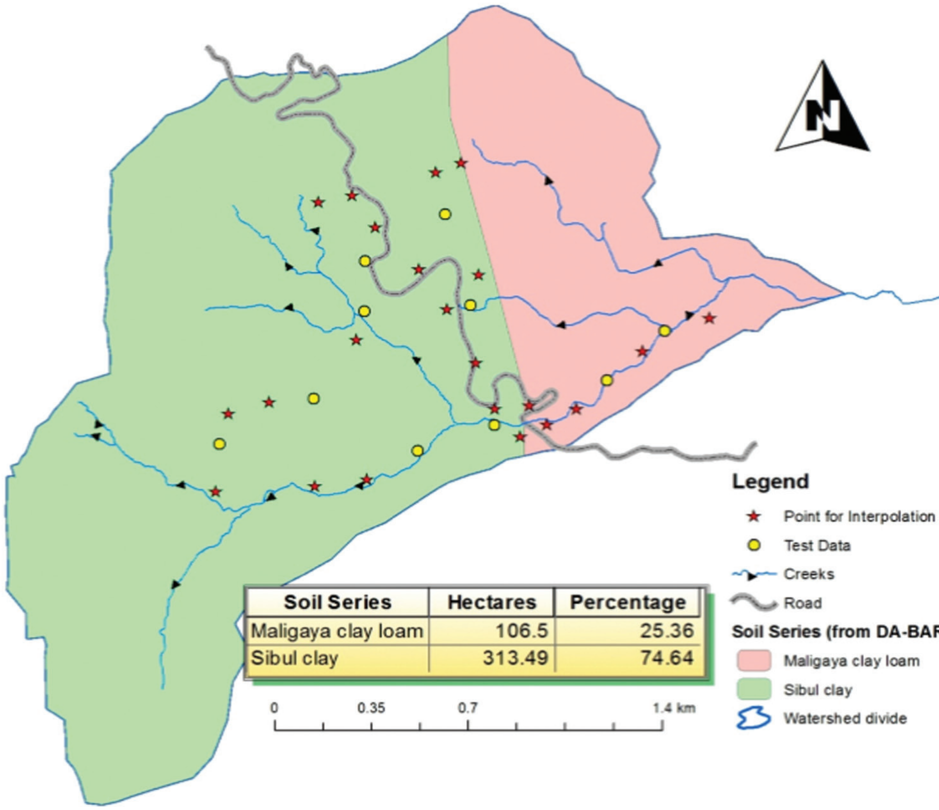

Figure 4. Map of soil series of Barobbob Watershed

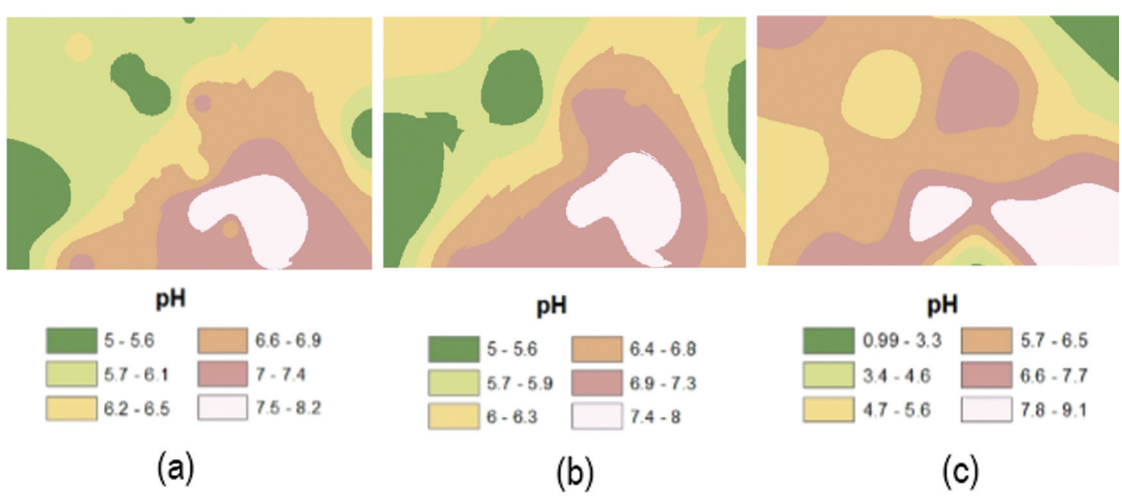

Figure 5. Interpolated pH maps: (a) IDW, (b) kriging, (c) spline

In case of pH, there appeared to be a higher similarity between IDW and kriging (Figure 5). The minimum and maximum values conformed to the samples, which was 5.0 and 8.2, respectively. The spline map for pH showed minimum value (0.99) that was too far from the minimum value of input data, and the maximum was quite large (9.1) compared to the input data. Figure 6 shows the interpolation of % clay. Kriging interpolation appeared to be different from that of IDW and spline in terms of roundness of boundary as there were sharp edges in polygons. The minimum value in kriging was too high (36 vs. 16 in the input data) while that of spline was negative (-112), which was not acceptable.

Figure 7 shows the interpolation for % Silt. IDW and kriging maps were quite comparable but the spline result contained negative values. Figure 8 shows the interpolation for % sand while Figure 9 shows the surface maps of organic matter. IDW is consistent on conformity with the minimum and maximum values of the interpolated values. Spline generates negative values.

Visual appeal of the maps could be used as additional criterion for selecting the best interpolation technique. Generation of smooth surface was inherent to IDW and spline (Childs, 2004).Because of the smoothness

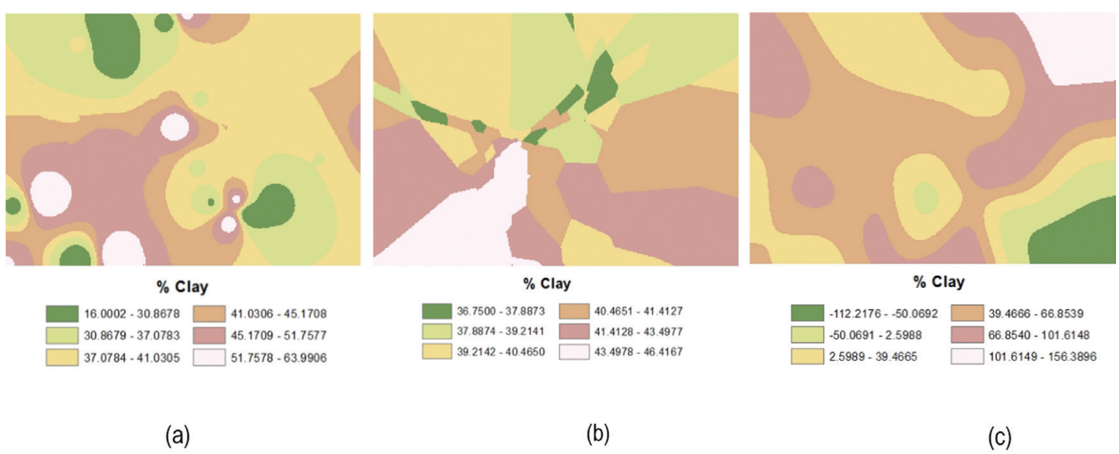

Figure 6. Interpolated clay maps: (a) IDW, (b) kriging, (c) spline

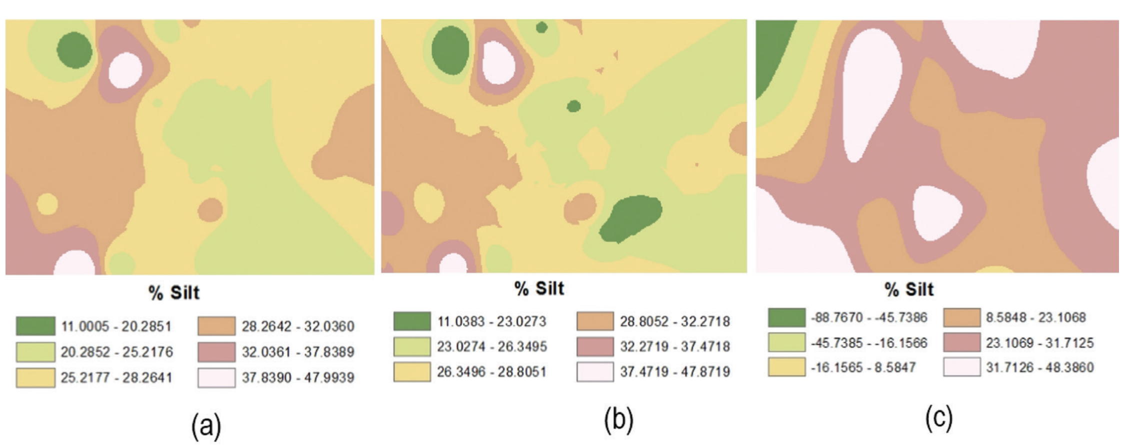

Figure 7. Interpolated silt maps: (a) IDW, (b) kriging, (c) spline

Table 2. RMSE for the three interpolation techniques

Soil Properties	RSME		
	IDW	Kriging	Spline
pH	0.7013	0.7283	0.8119
%OM	2.3350	2.7220	2.7770
%Sand	17.9150	18.7807	20.9002
%Silt	5.9530	5.5180	8.2800
%Clay	20.5460	21.8700	23.7210

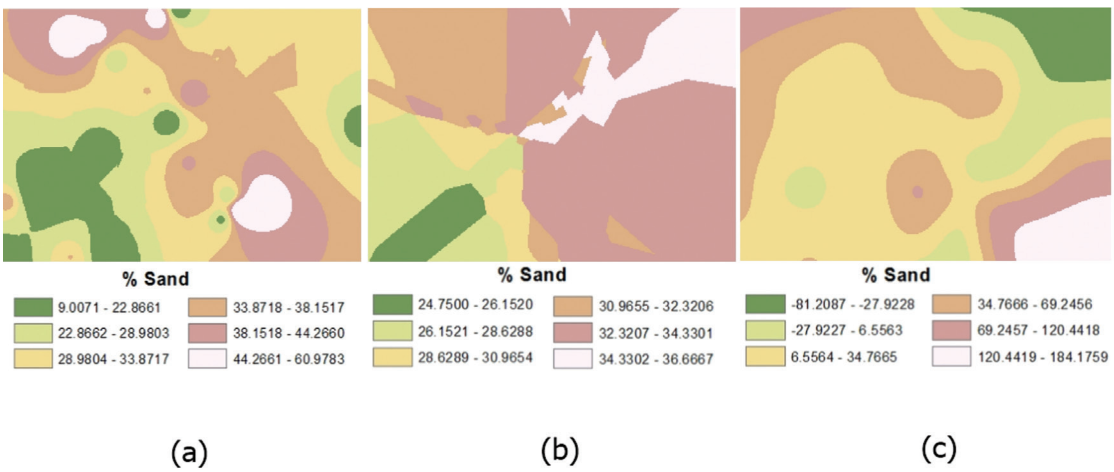

Figure 8. Interpolated sand maps: (a) IDW, (b) kriging, (c) spline

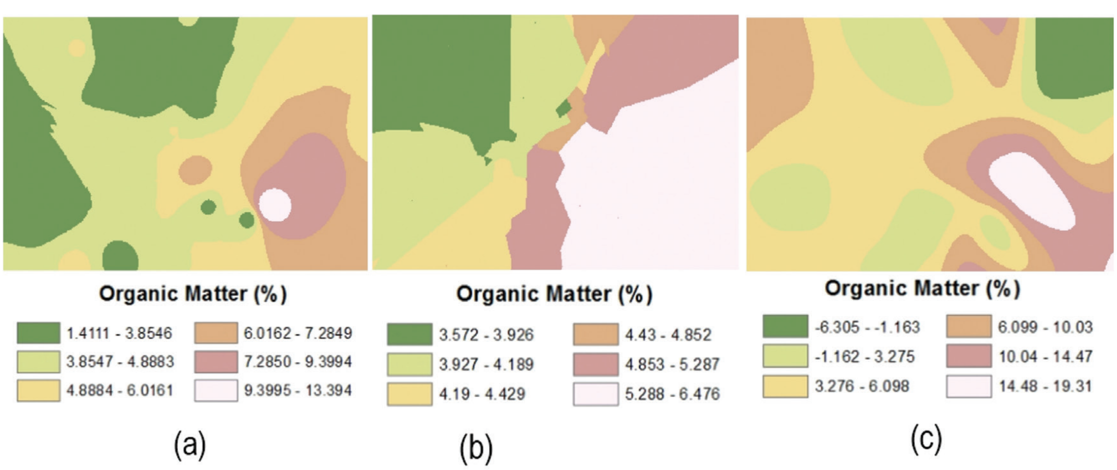

Figure 9. Interpolated OM maps: (a) IDW, (b) kriging, (c) spline

and roundness of the boundaries of the polygons, IDW and spline were better than kriging. It seemed that sharp boundaries were infrequently occuring in properties.

Accuracy Interpolation

The study used RSME (Robinson and Matternicht, 2006 and Warrick *et al.*, 1988) in assessing the accuracy of the surface interpolation of different soil properties. Smallest RSME values were recorded in IDW in four (4) of five (5) properties, namely, pH, % OM, % Sand, and % Clay (Table 2). On the other hand, the minimum RMSE was recorded for % Silt in kriging. Accuracy of interpolation varies in literature. Several studies found IDW to be more accurate than other interpolation techniques (Weber and England, 1992; Wollenbaught *et al.*, 1994 and Gothway *et al.*, 1996). Likewise, several studies found that kriging was better than IDW and other methods (Leenaers *et al.*, 1990 and Kravenchenko & Bullock, 1999). Morever kriging was often used for applications in soil science and geology (Childs, 2004).

Maximum RMSE values were observed for all properties in spline. In addition, Robinson and Metternicht (2006) found that spline surpassed kriging and IDW for interpolating soil organic matter.

Analysis of variance (ANOVA) revealed that the predicted values for the three spatial interpolation techniques were not significantly different from each other at 95% level of significance. It implies that any of the three interpolation techniques can be used unless other statistical criteria such as RMSE is considered.

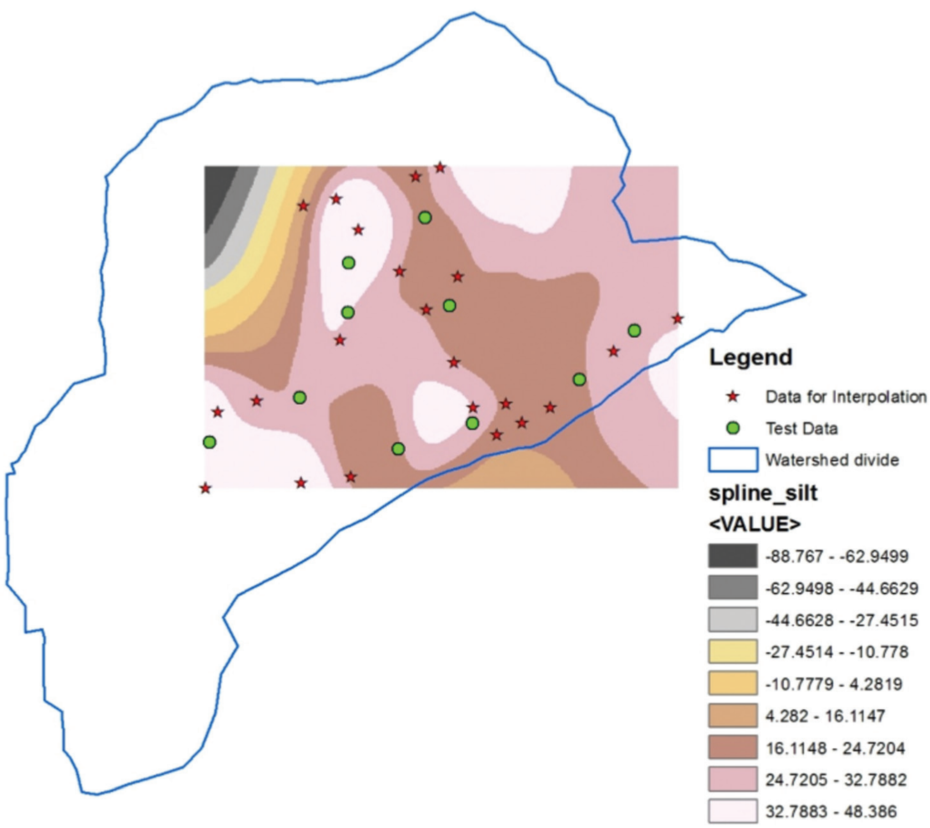

Figure 10. Spline interpolation of %Silt showing negative values

Table 3. Values of % sand, %silt, and %clay from spline interpolation

Sample No.	%Sand	%Silt	%Clay	Total
1	-66.8663	26.0843	140.7820	100.0000
2	-30.7681	26.9290	103.8390	99.9999
3	85.2281	-60.2950	75.0669	100.0000
4	169.3230	27.1161	-96.4389	100.0002
5	127.4320	20.0561	-47.4881	100.0000
6	-5.5633	14.4000	91.1633	100.0000
7	58.8312	-46.9988	88.1675	99.9999

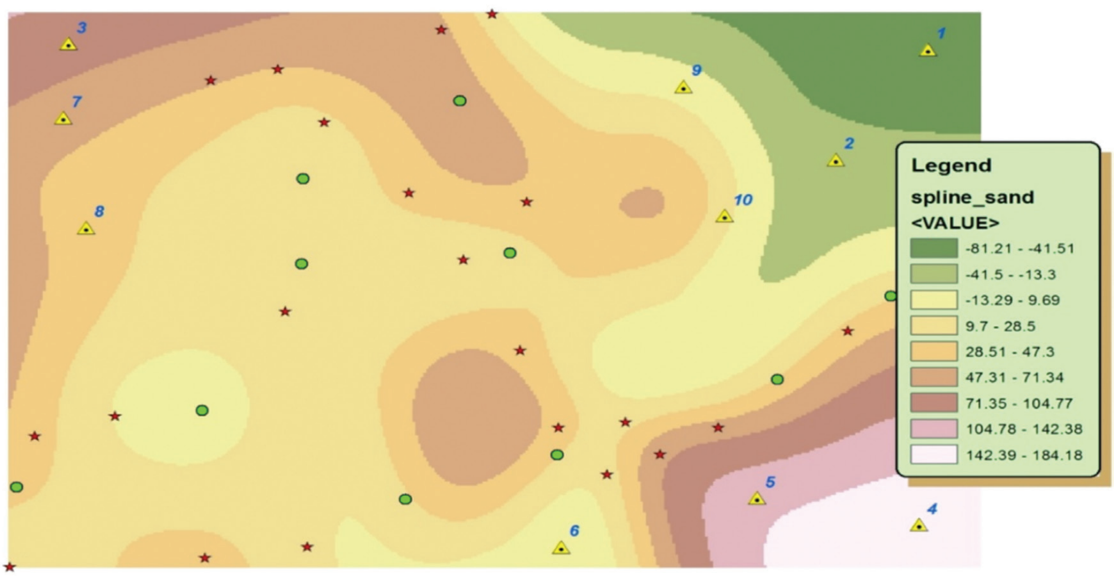

Figure 11. Example of spline interpolation (sand) showing evaluation points (triangle) on total percentage of soil separates

Anomaly in Spline Interpolation

As what has been shown in Figures 5 to 9, spline generated negative values. As input points are shown over the surface map, it can be seen that negatives values occurred in areas where data sources are scanty (Figure 10). This might be remedied by even distribution of sample points. However, data collection for even or systematic distribution of samples was much difficult.

The summation of % Sand, % Silt, and % Clay must total to 100% (Table 3). The negative values that came out in spline would eventually result to a total percentage of less than 100. However, the total percentage based on 10 sample points, turned out to be close to 100% (Figure 11). This happened because of extremely high value in one separate was matched by extremely low value in another separate. This condition proves that spline may not perform well in interpolation using highly scattered input data.

CONCLUSION AND RECOMMENDATIONS

Inverse Distance Weighted (IDW) interpolation technique appears to be the best among the three techniques of generating surface data from points. While spline technique produces maps with good visual appeal, it has tendency to produce extreme values (negative and very large values) especially in areas where input points are scanty.

The following future activities are recommended: 1) explore the effect of sample point distribution (systematic to highly randomized) on the accuracy of interpolation; 2) explore the effect of sampling intensity; and 3) explore spatial statistics tools in ArcGIS for delineation of surface where interpolation based on a given point data set is accurate at some acceptable level.

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