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Spatial and Temporal Variations of Some Soil Properties at Northeast Nuba Mountains, South Kordofan State, Sudan

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Abstract: ***The sources of soil variability in the study area in the Northeast Nuba Mountains were examined for a better understanding of complex relations between soil properties, environmental factors and land use systems. The regional level as affected by soil-forming factors and the local level as affected by land use were considered. Soil samples collected throughout a 2500 km²area. Analysis of Variance (ANOVA), Principal Component Analysis, cluster analysis and Variogram Modeling were applied. Soil properties exhibit a spatial dependence with regional trend. Cluster analysis, and soil classification (Pacheco and Dawoud, 1976) showed that the soils of the study area can be grouped into two main classes (Vertisols and Alfisols). Soil ECand Clay content were the best explained by regional factors of soil variation. Two levels of soil information were studied; (i) the regional level of soil spatial distribution as affected by regional trend, using elevation as a proxy for soil-forming factors and (ii) the local level of soils variation as affected by land cover. Two fixed soil layers (0-20 cm, and 20-40 cm) were used for all the analyses. Geographic analyses and visualizations were performed with GIS and the Geomantic software. Regional and local effects and their interaction accounted for 70% (based on clay) to 85% (based on pH) of the total variance. The study revealed that research on appropriate management practices for resource use should focus chiefly on processes and factors occurring at the local level, as shown by the great influence of the dynamical land use system.***

Keywords: Northeast Nuba Mountains, Spatial and Temporal Variations, Soil Variability, Analysis of Variance (ANOVA).

1. Introduction

Soils are widely different at various spatial and temporal scales. Brejda et al., (2000) and Burrough, (1993), attributed soil variation to its factor operating and their interaction. The complex relations between soil properties and environmental factors characterization and the appropriate management practices for soil resources use are essential. Interest was increased information for sampling design to ecological, environmental, agricultural studies (Stein and Ettema, 2003) and to spatial distribution of soils as well with environmental management systems (Godwin and Miller, 2003). Nevertheless, the important of accuracy from economical and high production point of view. Brejda et al., (2000) stated that soils are greatly differ on regional scale due to widely-varying soil forming factors as well as many authors have mentioned soil properties influenced by human activities at field level (Earl et al., 2003; Godwin and Miller, 2003). However, the studies showed that physical properties are usually much less variable over short distances than chemical properties. The objective of this study was to characterize the sources and scales of variability of soil properties in the study area and for how much they affect land use; using statistical and geo-statistical approach.

2. Materials and Methods

The Study Area

The study was carried at Abu Jubayha area (10° 52' 48.17" - 11° 23' 08.79" N and30° 00' 05.99" -31° 28' 04.91" E) in Northeast Nuba Mountains, South Kordofan State, Sudan. The area has been one of the famous areas for traditional and broad mechanized cultivation in the Sudan especially for rainfed cotton and sorghum. The study covered a total area of about 250,000 ha.

Soil Samples Collection

100soil sampled where collected from representatives soil profiles described using the FAO guidelines for soil description (FAO, 2006), and sampled by genetic horizons. Each sample was a bulked composite of three sub-samples taken with auger in diagonal basis. The samples were collected to represent both soil type and land cover. The geographic coordinates of each sampling point were recorded using the GPS (Garmin 12XL model) with accuracy of ± 10 m. The elevation of each sampling point was recorded. All soil samples were analyzed in the Soil laboratories at Institute of Soil Science and Site Ecology, TU Dresden-Germany, using procedures of soil analysis described in DIN Deutsche Insititüt für Normung e.v.

Laboratory Analysis

Initially, routine preparation procedures were carried to prepare the 100 soil samples for laboratory analysis. The analysis included Particle-Size Analysis using pipette method, determination of pH in water measurement was performed with a combined glass electrode in a 1:2.5 (M/V) soil suspension, measurement of the Electrical Conductivity were performed using a conductivity meter with direct reading on the scale selected. The total carbon and total nitrogen were measured by gas chromatography after appropriate calibration using substances with known C and N contents, determination of carbonates was done with Bernard calcimeter and compared with the volume of CO_2 released by pure calcium carbonate, determination of the Cation Exchange Capacity (CEC) is measured by the hexa-aminecobalttrichloride method using ICP spectrometry

Statistical and Geostatistics Analyses

The statistical and Geo-statistical analyses were generated according to Yemefack et al (2005) and based on the fact that soil parameters are different and dynamic. The variables showing significant variations were selected using descriptive statistics since they are the most soil dynamic variables. Later correlation between layer and layer variables were done. The Multivariate relationship between soil properties at each depth was performed separately using Principal Components Analysis (PCA).An agglomerative hierarchical cluster analysis based on Ward's grouping method and correlation matrix (Webster and Oliver, 1990) was conducted to group the 105 regional soil observations. All depths were used in one analysis to include the effects of vertical profile differentiation.

To define the overall tendency of variable (trend), two variables were identified by plotting PCA1 and PCA2. Depth (20-40) was used to minimize the effect of land in the regional analysis. Gamma Design software was used to generate the Semi-variogramand the experimental semi-variogramto regionalize variable spatial behavior and to test the similarity of variable (Webster and Oliver, 2001).Empirical semi-variogramfitting was determined as having high coefficient value (R2) and low (RSS). Both targeted variable maps were performed by kriging to obtain their final interpolation using ArcGIS.

To define the soil variability at the local levels**,** the analysis of variance and separation of significant means were used to show whether the soil variables are sensitive to the effects of land cover type or not. The coefficient of variable was computed as the ratio between explained variance and the total variance to evaluate the contribution of land cover effect on soil variability at each depth.

3. Results and Discussions

3.1 Regional Variability of the Soils

Tables (1 and 2) summarize the statistics of the soil variables studied at regional scale. Some variables were significantly differed from normal distribution having skewness greater than one. However, nonparametric test was performed. Variables also showed no significant difference between layers, and highly significant per locations.

Table1: Summary of the statistics of the original soil variables (100 samples)

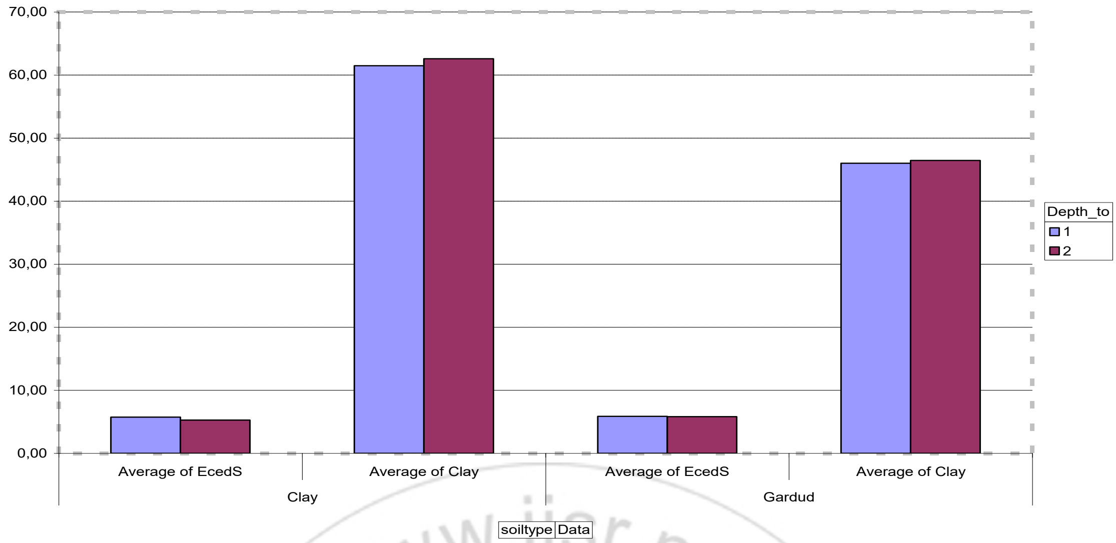
	GRAV.%	Gravel Size	SAND	C.SAND	M.SAND	F.SAND	SILT	C.SILT	M.SILT	F.SILT	CLAY
Range	0.94	7.00	70.70	18.80	34.70	38.80	29.50	20.40	19.80	13.40	83.80
Minimum	0.00	0.00	3.90	0.00	0.80	2.20	12.30	2.70	0.00	0.70	12.70
Maximum	0.94	7.00	74.80	18.80	35.50	40.80	41.80	23.10	19.80	14.10	78.30
Sum	8.84	183.00	1858.20	355.30	839.40	855.20	2541.50	1057.00	795.00	882.80	580.80
Mean	0.07	1.83	18.58	3.55	8.39	8.55	25.42	10.57	7.95	8.83	58.01
Std. Error	0.02	0.19	1.40	0.30	0.87	0.60	0.52	0.30	0.23	0.25	1.30
Std. Deviation	0.18	1.94	14.04	2.99	8.72	5.98	5.18	2.99	2.28	2.50	12.95
Variance	0.02	3.75	197.15	8.94	45.19	35.71	28.85	8.92	5.18	8.23	187.75
Skewness	3.99	0.91	2.38	1.51	2.71	3.24	0.07	0.47	0.89	-0.17	-1.71
Std. Error	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Kurtosis	18.81	-0.24	5.92	3.40	7.71	12.84	0.81	3.47	7.78	0.10	2.80
Std. Error	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48

Table2: Summary statistics of the original soil variables (100 samples)

	pH	EC/ds	N	C to N	CaCO3	CC	CEC	Na	K	Ca	Mg
Range	4.60	20.30	0.10	46.30	17.26	2.07	112.20	1.60	2.00	58.60	25.50
Minimum	4.00	1.70	0.00	7.70	0.12	0.01	6.20	0.00	0.10	2.10	1.80
Maximum	8.60	21.90	0.10	53.90	17.38	2.09	118.40	1.60	2.10	60.80	27.30
Sum	748.70	568.60	5.00	1888.60	83.93	10.07	5051.60	45.10	38.40	2857.60	1388.50
Mean	7.49	5.69	0.05	18.89	0.84	0.10	49.53	0.45	0.38	28.58	13.89
Std. Error	0.09	0.32	0.00	0.68	0.25	0.03	1.77	0.03	0.03	1.34	0.71
Std. Deviation	0.93	3.22	0.02	6.82	2.53	0.30	17.86	0.32	0.30	13.40	7.05
Variance	0.86	10.36	0.00	46.50	6.41	0.09	318.71	0.10	0.09	179.68	49.68
Skewness	-1.75	2.55	1.56	1.61	5.80	5.80	0.40	1.16	3.74	-0.20	0.13
Std. Error	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Kurtosis	2.76	8.23	5.59	6.05	35.43	35.43	1.46	1.67	17.48	-0.18	-1.03
Std. Error	0.48	0.48	0.48	0.48	0.48	0.48	0.47	0.48	0.48	0.48	0.48

The clay and EC were selected as representative properties to compare layers. Clay is stand for physical properties and EC for chemical properties. Coefficients of determination, was calculated as the square of the correlation coefficient. The figures are moderate (0.83 and 0.49) for EC and low (0.49 to 0.047) for clay. Adjacent layers have lower correlations (0.49 for EC and 0.04 for clay)than the surface and subsurface layer. This effect is likely less for clay than on EC meaning that, the physical properties were less affected by land use.

One-way ANOVA by depth showed no significant difference nor in clay content among layers, with clay average 57%, and 63%, respectively; or with EC. Two-way factorial ANOVA (by depth and soil type) showed no effect of soil type on depth relations for EC or clay content, (Figure 1).



*1= surface 2= subsurface**Gardud soil= sandy clay loam

Figure 1: The effect of soil depth and soil types on clay and EC content

Levene's test for homogeneity of variances could not reject the null hypothesis of homogeneous variances for clay content (p = 0.06), but it was been rejected (p<0.001) for EC. Variance was significantly lower in the subsoil, most likely due to no management effects in the subsurface soil.

3.3 Principal Components Analysis (PCA).

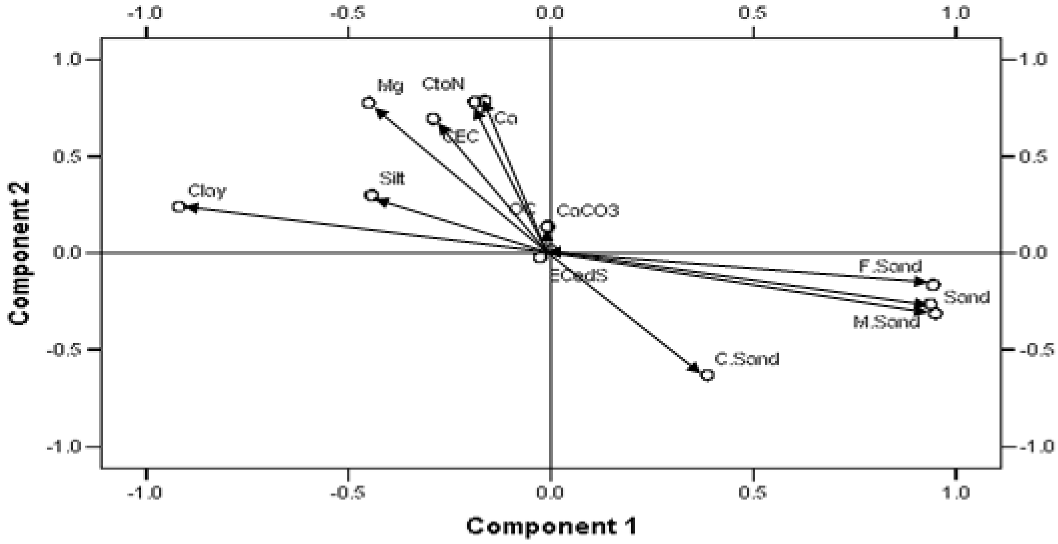
Table 3 shows the result of the Principal Component Analysis (PCA) of first five PCs of 14 standardized soil variables values analyzed. They were explained over 90% of the total variation in both surface and subsoil surface. The first two components explain 59.8%; and 56.3% of the variances in the surface and sub-surface respectively. The light discrepancy indicates that less multiple correlations between soil properties in the subsoil layer than in the topsoil layer. Approximately, the two layers seem similarly. The top soil was relatively affected by management and/or other external natural effects.

Table 3: The Principal Component Analysis (PCA) Result

	PC1	PC2	PC3	PC4	PC5
0-20 cm					
Eigenvalues	6.613	2.964	1.721	1.303	0.992
variance%	41.328	18.524	10.755	8.144	6.201
Cumulative%	41.328	59.852	70.607	78.751	84.952
20-40 cm					
Eigenvalues	5.832	3.18	2.528	1.345	0.996
variance%	36.45	19.875	15.798	8.408	6.223
Cumulative%	36.45	56.325	72.123	80.531	86.753

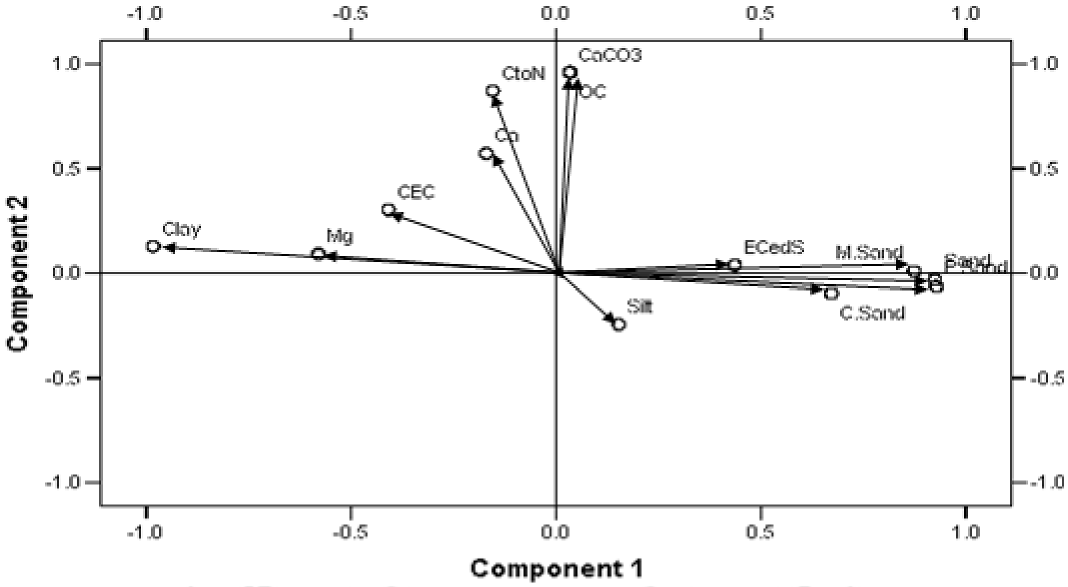
Figure 2 and 3show the plots of the first two components PCs for the surface and subsurface separately. The first axis, explains about 40%of the total variation, shows the maximum single discrimination of the soil variables. For the two layers this axis is controlled by clay content and EC at opposite ends. The second component, by definition orthogonal to the first, and here explaining about 20% of the total variation, mostly explain the interaction between the two main controlling factors of the first component, namely magnitude of the adsorption complex (physical components) and the component related to the soil solution (chemical component).

The variables were projected differently around axis showing different correlation. The clay on both surface and subsurface was projected in the left (positive) side with strong correlation axis. In other hand the EC projected at near zero at surface soil axis and in the left side and with a short distance from the origin of the axis in the subsoil. Based on direction, distance and angle of variable arrows in correspond with PCA axis, the clay was increased in one direction, has similar rate of change and strong correlation with the components. The EC has different abundance level, different direction, different rate of change and week correlation with both PCA component in the top layer and subsoil (Yemefack, 2005).



*Surface depth (0-20 cm)

Figure 2: Plot of components 1 and 2 at the two sampling depths

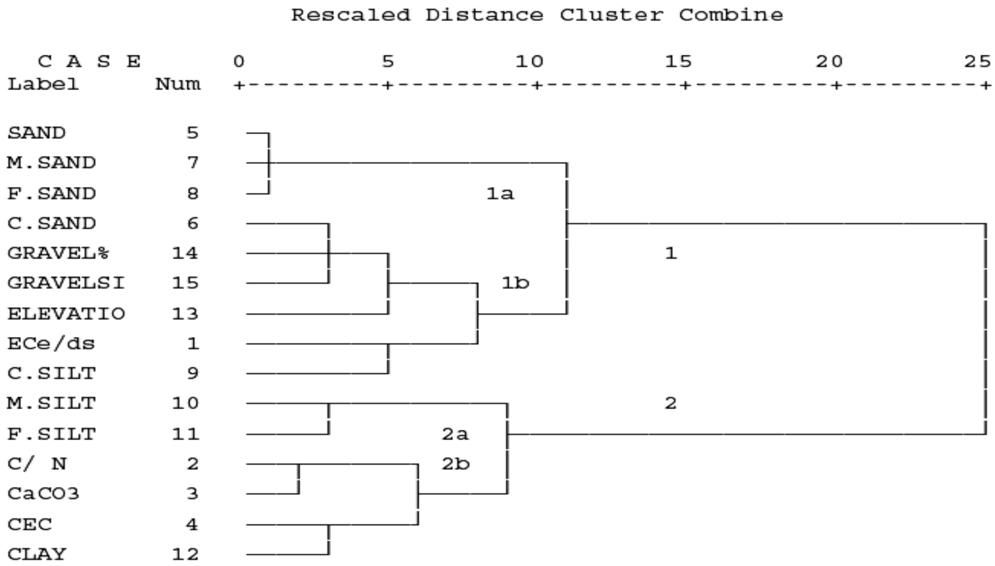


*Subsurface depth (20-40 cm)

Figure 3: Plot of components 1 and 2 at the two sampling depths

3.4 Numerical Classification of Soil Profiles

The hierarchical numerical classification system was used to reveal the various levels of similarities and allow a variable number of groupings. Figure 4shows the dendro-gram resulting from the application of Ward's method on the correlation matrix of 15 soil parameters collected in two different soil depths. The 105 soil samples were aggregated in two groups at the highest level. Each group was subdivided into two subgroups at the next level. The dissimilarity decreases within subgroup looked similar to Yemefack (2005) finding in South Cameron and the WRB (World reference Base for Soil Resources) groups. Classes at the first two levels showed a good correlation with the Pacheco and Dawoud (1976) soil classification groups and subgroups.



.* Note that the indications of groups are given in figures (1 and 2), while those of subgroups are given in a combination of figures and letters

Figure 4: Dendrogram of 100 soils sample grouping based on 15 soil parameters measured at the two soil depths

3.5 Overall Trend

With help of semi-variogram, the spatial variability of each of the soil features studied (Clay and EC) was analyzed. There was spatial correlation for the two objects under consideration. The form of the spatial correlation of the clay was spherical. A linear relationship was observed for EC. The variogram of EC showed dependence to about 550m, whereas that for clay showed dependence up to 333m (Figure 5).

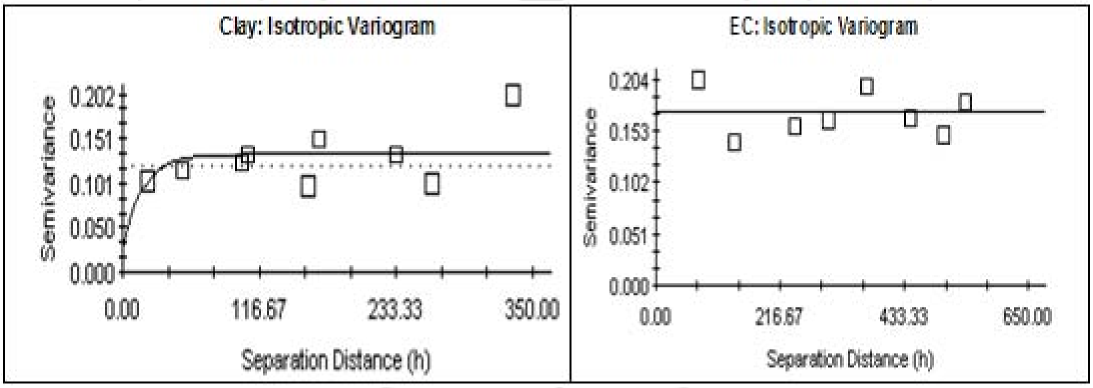


Figure 5: Vario-gram modeling from the original values of Clay content and EC

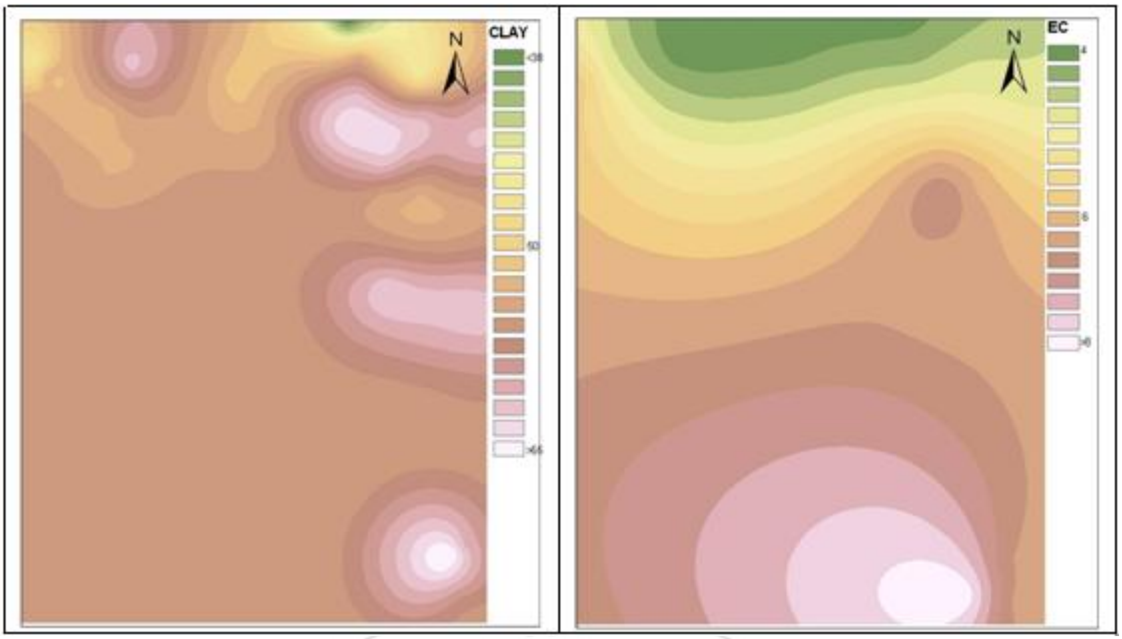


Figure 6: Shows interpolation maps for the two soil original variables (clay % and EC, 20-40 cm layer) done by ordinary kriging

The relative effects of the regional trend and local samples can clearly be seen for the two variables in figure 6.

4. Conclusion

4.1 Soil Variability at Regional Level

Three soil forming factors - rainfall, geology and elevation - were analyzed in relation to soil variability. The distribution pattern of rainfall showed a clear non-uniform pattern. The Northwest part (550 - 700 m ASL) received a distinctly higher annual rainfall than the Southeast lowlands. This variation may ascribe to the orographic effect. The spatial pattern of this rainfall distribution was quite similar to the soil distribution pattern, with more weathered soils found at the higher elevations with greater rainfall.

These different geological combinations have participated to develop different soils with no sharp boundary between them(i.e. no strong relationship with soil distribution pattern).However, this assumption needs further mineralogical investigation to prove the exact relation between these soils and their parent materials.

4.2 Soil Variability at the Local Levels.

Summary statistics for soil variables are shown in tables 4. Most of the soil variables showed little variation (p=0.05) at the shallowest soil depth (0-20 cm), which seem not in favor of the hypothesis that the effect of land use on soil properties was most effective near the soil surface. In fact, this result was expected as in the rainfed traditional farming minimum tillage used to be practiced without addition of fertilizers and this normally have minimal effect on soil chemical properties which were tested in this study.

Table 4: Results of laboratory Analysis for Two depths (0-20 1nd 20-40 cm)

	PH	ECds	N	C/N	CaCO3	OC	CEC	Na	K	Ca	Mg	GRAV%	Gravel Siz	SAND	C.SAND	M.SAND	F.SAND	SILT	C.SILT	M.SILT	F.SILT	CLAY
Range	3.6	15.2	0.1	26.3	17.07	2.0484	78.2	1.1	1.9	58.2	24.4	0.91	6	70.7	10.5	34.6	38.6	26.4	17.1	11.7	10	59.3
Minimum	4.8	1.9	0	9.1	0.12	0.0144	6.2	0	0.2	2.5	2.1	0	0	3.9	0	0.9	2.2	12.3	6	0	0.7	12.7
Maximum	8.4	17.1	0.1	35.4	17.19	2.0628	84.4	1.1	2.1	60.8	26.5	0.91	6	74.6	10.5	35.5	40.8	38.7	23.1	11.7	10.7	72
Sum	372.5	281	2.7	888.4	39.46	4.7352	2451.8	16.1	23.3	1416.1	678.9	3.37	82	886.8	179.5	345.9	361.3	1257.2	558.2	382.2	321.7	2856
Mean	7.45	5.619	0.055	17.768	0.7892	0.094704	49.035	0.322	0.466	28.322	13.577	0.0674	1.64	17.736	3.591	6.919	7.226	25.145	11.164	7.643	6.434	57.119
Std. Error	0.114	0.405	0.002	0.842	0.3554	0.04265	2.574	0.03	0.046	1.947	1.007	0.0219	0.26	2.182	0.38	1.03	1.017	0.755	0.406	0.308	0.343	1.89
Std. Devia	0.804	2.8634	0.0175	5.9561	2.51316	0.30158	18.1993	0.211	0.3244	13.7639	7.1214	0.15489	1.838	15.4258	2.6855	7.2833	7.1917	5.3405	2.8705	2.1813	2.4269	13.3612
Variance	0.646	8.199	0	35.475	6.316	0.091	331.216	0.045	0.105	189.444	50.714	0.024	3.378	237.955	7.212	53.046	51.72	28.521	8.24	4.758	5.89	178.521
Skewness	-2.047	2.401	1.313	0.813	6.051	6.051	-0.055	1.018	3.587	-0.036	0.139	4.027	0.682	2.326	0.917	2.613	3.081	-0.246	1.708	-1.054	-0.488	-1.735
Std. Error	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337
Kurtosis	4.147	6.894	4.212	0.201	38.958	38.958	-0.383	1.884	15.853	-0.074	-0.991	20.421	-0.781	5.662	0.369	6.955	10.683	0.511	5.357	2.378	-0.142	3.09
Std. Error	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662

	PH	ECds	N	C/N	CaCO3	OC	CEC	Na	K	Ca	Mg	GRAV%	Gravel Siz	SAND	C.SAND	M.SAND	F.SAND	SILT	C.SILT	M.SILT	F.SILT	CLAY
Range	4.6	20.3	0	46.3	17.26	2.0712	106.8	1.6	1.7	55	25.5	0.98	7	62.3	16.4	33	20.7	26.9	14.3	16.4	12.6	59.1
Minimum	4	1.7	0	7.7	0.12	0.0144	11.6	0	0.1	2.1	1.8	0	0	4.3	0.2	0.8	2.4	14.9	2.7	3.4	1.5	17.2
Maximum	8.6	21.9	0.1	53.9	17.38	2.0856	118.4	1.6	1.8	57.1	27.3	0.98	7	66.6	16.6	33.8	23.2	41.8	17	19.8	14.1	76.3
Sum	376.3	287.7	2.2	1000.2	44.47	5.3364	2497.2	29	15.1	1441.5	709.6	3.27	81	769.4	175.8	293.5	293.9	1284.2	498.8	412.8	360.9	2944.8
Mean	7.525	5.754	0.044	20.003	0.8894	0.106728	49.943	0.58	0.302	28.831	14.193	0.0654	1.62	15.389	3.516	5.869	5.877	25.685	9.975	8.257	7.218	58.897
Std. Error	0.148	0.504	0.001	1.058	0.3643	0.043715	2.55	0.051	0.035	1.862	0.995	0.0224	0.29	1.775	0.466	0.868	0.625	0.715	0.426	0.332	0.357	1.782
Std. Devia	1.0441	3.5654	0.0096	7.4783	2.57591	0.309109	18.0321	0.3613	0.2506	13.1697	7.033	0.15845	2.049	12.5526	3.2923	6.139	4.4161	5.0583	3.009	2.3494	2.5252	12.601
Variance	1.09	12.712	0	55.925	6.635	0.096	325.157	0.131	0.063	173.442	49.464	0.025	4.2	157.567	10.839	37.687	19.502	25.586	9.054	5.52	6.377	158.785
Skewness	-1.638	2.595	0.357	1.94	5.747	5.747	0.885	0.743	4.73	-0.396	0.122	4.084	1.088	2.351	1.849	2.852	2.481	0.473	-0.487	2.46	0.067	-1.722
Std. Error	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337
Kurtosis	2.171	8.648	-0.359	7.79	35.934	35.934	3.388	0.616	27.713	-0.157	-1.049	19.37	0.159	5.984	4.783	9.388	6.262	1.219	1.203	11.184	0.091	2.828
Std. Error	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662	0.662

In several cases the total variation, as measured by the sample standard deviations and ranges, was lower than at regional level, indicating that the local level plots include less variation due to land use. Similarly then onparametric test for variables by depth was absolutely corresponded with this result revealed that most soil variables were not sensitive to the effects of depth (Table 5 and 6).

Table 5: Parametric test(Kruskal Wallis) per depth

Test Statistic (a,b)

	pH	ECedS	N	C to N	CaCO3	OC	CEC	Na	K	Ca	Mg
Chi-Square	3.861	0.183	11.411	3.568	0.112	0.112	0.033	17.172	21.207	0.195	0.165
df	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	0.049	0.669	0.001	0.059	0.738	0.738	0.855	0.000	0.000	0.659	0.684
	Gravel %	Gravel Size	Sand	C.Sand	M.Sand	F.Sand	Silt	C.Silt	M.Silt	F.Silt	Clay
Chi-Square	0.208	0.104	0.958	0.320	1.390	0.841	0.058	2.291	0.407	2.229	0.785
df	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	0.648	0.747	0.328	0.572	0.238	0.359	0.809	0.130	0.524	0.135	0.376

a.Kruskal Wallis Test

b.Grouping variable: Depth

Table 6: Parametric test(Kruskal Wallis) per Sites

Test Statistic (a,b)

	pH	ECedS	N	C to N	CaCO3	OC	CEC	Na	K	Ca	Mg
Chi-Square	1.231	7.667	4.504	14.839	12.762	12.762	15.453	5.026	2.520	21.015	15.957
df	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	0.540	0.022	0.105	0.001	0.002	0.002	0.000	0.081	0.284	0.000	0.000
	Gravel %	Gravel Size	Sand	C.Sand	M.Sand	F.Sand	Silt	C.Silt	M.Silt	F.Silt	Clay
Chi-Square	18.958	21.151	18.756	15.702	18.205	11.558	5.439	3.682	10.417	13.865	19.136
df	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	0.000	0.000	0.000	0.000	0.000	0.003	0.066	0.159	0.005	0.001	0.000

a.Kruskal Wallis Test

b.Grouping variable: SiteA

On the contrary the result of factorial ANOVA by land use /land cover and soils type showed high response with most of the variables. Furthermore this result confirmed the effect of Land Cover/Land Use on topsoil, that been hidden by deepest and high fertile soil. In other word the two measured depths were belonging to one layer. Atlocal level result showed that land use/land cover was a major source of temporal variability of soil properties and processes. That soils constituents undergo important changes in different soil classes, bare (cultivated),fallow, light forestry(grazing) and medium and dense forest (virgin). However, the magnitude of these changes varies from one property to another.

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