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PREDICTION OF CHARACTERISTICS OF COASTAL PLAIN SOILS USING TERRAIN ATTRIBUTES

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ABSTRACT
The objective of this study was to model the characteristics of coastal plain sands using terrain attributes. Representative surface soil samples of upper, middle and lower slopes were collected from 10 locations and their properties determined using standard laboratory methods. Soil properties determined include depth, sand, silt, clay, electrical and hydraulic conductivity, bulk density, pH, exchangeable calcium, magnesium, sodium, potassium and acidity, available phosphorus, organic carbon, base saturation, crystalline and amorphous iron and aluminium oxides. The terrain attributes derived from digital elevation model (DEM) include slope, aspect, curvatures, flow direction and hill shade, compound topographic index (CTI) and stream power index (SPI). Data generated were analysed using Pearson's correlation and stepwise multiple regression analysis. Slope significantly correlated with clay and pH (H_2O), while SPI and CTI correlated significantly with clay, pH, organic carbon and crystalline iron oxide. Soil properties that could be predicted using terrain attributes include clay bulk density, pH, exchangeable acidity and amorphous aluminium oxides. Terrain attributes could be useful in the prediction and knowledge of soil distribution and variability for sustainable management and optimal crop production on coastal plain sands geomorphic units.

Key words: coastal plain sands, DEM, soil characteristics, modelling

INTRODUCTION
Geogenic, pedogenic and anthropogenic processes are the determinants of soil spatial variability. It was reported that spatial variability of coastal plain sands of southeastern Nigeria originates dominantly from intrinsic factor associated with texture and mineralogy (Obi and Udoh, 2011; Obi *et al*., 2011). The texture and mineralogy of coastal plain sands bear the imprints of quartz arenite which is not rich in most plant growth nutrients, dominantly sandy and coarse textured (Chikezie *et al*., 2010). Soil variability is a major constraint for sustainable crop production due to resultant non uniformity in output. Mapping has been used to reduce this heterogeneity but not without its own inherent demerits of within site variability (Russo and Bresler, 1981). These demerits became the target of site specific cropping system. The technique of precision agriculture delineates homogenous sites for specific management. This implies localised allocation of specific inputs to optimize output and preserve natural resources based on peculiarities of delineated homogenous sites irrespective of size. This requires proper and detailed characterization of variability at scales larger than with conventional approaches. Approaches often evaluated for use in precision agriculture include kriging, fuzzy means, regression, etc. (Penížek and Borůvka, 2006; Sumfleth and Duttmann, 2008; Obi and Udoh, 2011; Saleh and Belal, 2014). These methods have achieved varying degrees of success depending on the complexity of terrain and variability.

Crop production system within the coastal plain sands geomorphic unit of southeastern Nigeria is characterised as rain fed, low input, intensive and extensive with the use of traditional hand held tools (Ibia *et al*., 2011; Obi and Udoh, 2011). Combinations of these have not resulted to more than intrinsic variability. This implied that majority of the variation in soil properties is a result of factors of soil formation (Obi *et al*., 2010; Obi *et al*., 2011), suggesting that simple methods could suffice in the evaluation of spatial variability of coastal plain sands. Odeh *et al*. (1994) confirmed this in their reported that multi linear regression modelling predicted soil properties with the aid of means covariation. Therefore, effectiveness of regression analysis was tested in the prediction of soil properties with the aid of terrain attributes (determinants of soil water dynamics). These terrain attributes bear strong relationship with soil properties and variability (Obi *et al*., 2014). The objective of this study was to predict the variability of coastal plain sands using terrain attribute.

MATERIALS AND METHODS
Site Description
The study was carried out within the coastal plain sands (CPS) geomorphic unit in Akwa Ibom State, southeastern Nigeria (Fig. 1). The state is located between l4°30' and 5°30' N and 7°30' and 8°30' E. The climate is humid tropical, characterized by distinct rainy and dry seasons. Rainfall distribution is bimodal and of high intensity with annual range that varies between 2000 mm in the hinterland and 4000 mm along the coast (Udosen, 2014). Temperatures (28-30°C) and relative humidity (~ 75%) are high. The geomorphic unit is characterized by flat terrain and low-lying lands on about 13 m above sea level coast-wards and 130 m northwards (Obi *et al*., 2014). The soils characteristically manifest dominance of sandy textured grains. The profiles vary from sand on the surface to fine loamy in the subsurface. They have low physical and chemical fertility due to dominance of low-activity kaolinitic clays and low organic matter content (Chikezie *et al*., 2010). They are well drained, deeply weathered and classified as Ultisols or Acrisol. Anthropogenic activities have transformed this previously humid tropical forest to secondary forests characterized by dominance of wild oil palm trees, woody shrubs and grass undergrowth. Land utilization is sedentary shifting cultivation with hoes and machetes (Ogban and Ekerete, 2001). The principal food crops were yam, cassava, maize and cocoyam, the dominant tree crop is oil palm.

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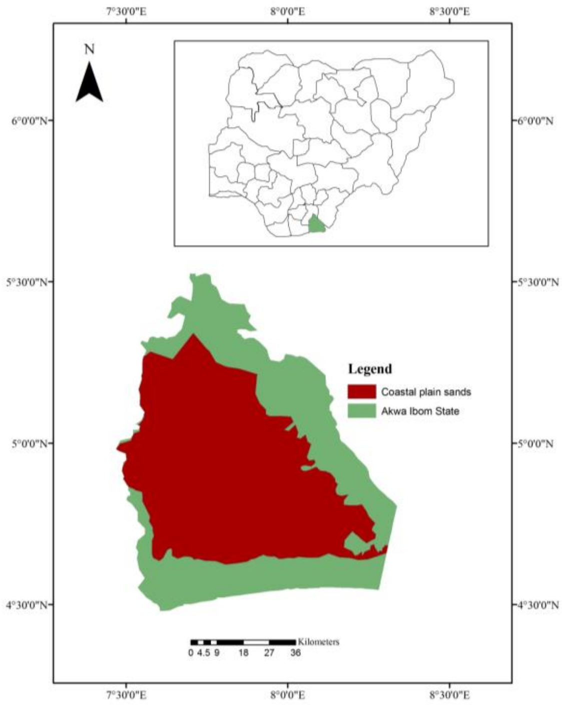

Fig. 1: Map of Akwa Ibom State showing area covered by coastal plain sands

Soil Sampling and Laboratory

A total of 10 toposequences were selected based on slope form and configuration using such criteria as steepness, length and shape (Smyth and Montgomery, 1962). Three profile pits were prepared at the upper, middle and lower positions per slope (Table 1). Genetic surface horizons alone were sampled. A total of 30 core and bulk samples were collected using cores and spade respectively and preserved in boxes and sampling bags for laboratory analysis. The 30 soil samples comprised three surface horizons from the 10 toposequences (Table 1). The samples were processed and used for the following analysis.

Particle size analysis, hydraulic conductivity and bulk density were determined using the method of Dane and Topp (2002). Soil organic carbon content was determined as described in Sparks (1996). Soil pH and electrical conductivity were determined in 1: 2.5 (solid: liquid) solution in both water potassium chloride using pH meter (McLean, 1982) and conductivity bridge (Rhoades, 1996), respectively. Exchangeable bases were extracted with Mehlich No. 3 extraction (Mehlich, 1984). Potassium and sodium contents were determined with flame emission spectrophotometer (Model FH 500, Gallenkamp London, UK), calcium and magnesium with atomic absorption spectrophotometer (AAS) (Alpha 4 model, Chemtec Analytical, Beith, UK). Available phosphorus was determined colorimetrically. Exchangeable acidity (EA) was extracted with un-buffered potassium chloride solution and titration with 0.01M-solution of sodium hydroxide to the first permanent pink endpoint as described by Anderson and Ingram (1993). Effective cation exchange capacity and base saturation were determined through summation (Anderson and Ingram, 1993. Free oxides were determined by the dithionite citrate bicarbonate (DCB) extraction (Mehra and Jackson, 1960) and amorphous oxides were extracted by ammonium oxalate extraction (McKeague and Day, 1966). Iron and Al in the extracts was measured using AAS.

Terrain Analysis

Digital terrain model (DTM) is differentiated into primary and secondary attributes. Primary terrain attributes include slope, aspect, curvatures, flow direction and hill shade while secondary terrain attributes include compound topographic index (CTI) and stream power index (SPI). The terrain attributes were generated from digital elevation model (DEM) using spatial analyst extension of Arcgis 9.2 of ESRI©. Soil sampling points (Table 1) and terrain attributes were brought into the same environment, and the terrain attributes were manually extracted (Obi *et al.*, 2014). The terrain attributes extracted include slope, aspect, curvature, flow direction and hill shade. Specific Catchment Area (As) was estimated as the ratio of upstream catchment area to cell size. The upstream catchment area equals the square of the cell size times the flow accumulation.

Specific catchment area $(As) = \frac{(a * c^2)}{c}$ (1)

where a = flow accumulation, and c = cell size.

Compound topographic index $(CTI) = \ln\left(\frac{As}{\tan Slope}\right)$ (2)

Stream power index (SPI) = Sediment transport index and Sediment Transport Index $(STI) = As * \tan Slope$ (3)

Statistical Analysis

The relationships between the distribution and variability of soil properties and terrain attributes were evaluated with correlation analysis. The capacity of the terrain attributes to predict CPS properties using terrain attributes was assessed with stepwise multiple regression analysis. Predicted and observed soil properties were compare using analysis of variance and significantly different means were compared with least significant difference ($p < 0.05$). Further evaluation of the accuracy of prediction was carried out using root mean square error (RMSE) and normalized root mean square error (NRMSE). Root mean square error compares predicted and observed values through the aggregation of residual to a single measure of predictive power. Normalization transforms RMSE into dimensionless quantities for suitability and comparison of variables with different units. Statistical analysis system (SAS)/STAT® software version 9.2 for Windows (SAS Institute, 2011) was used to perform the analyses.

Table 1: Coordinates and altitudes of profile pits sampling sites

	Upper			Middle			Lower		
	Coordinates		Altitude	Coordinates		Altitude	Coordinates		Altitude
Locations	Longitude	Latitude	(m)	Longitude	Latitude	(m)	Longitude	Latitude	(m)
NtakInyang	7°55'478"	5°04'688"	52	7°55'492"	5°04'709"	41	7°55'498"	5°04'722"	41
NdueotongOku	7°55'895"	5°03'755"	43	7°55'889"	5°03'772"	36	7°55'890"	5°03'790"	36
Ibaoku	7°56'542"	5°03'787"	60	7°56'547"	5°03'803"	53	7°56'549"	5°03'826"	53
IkotAyang	7°57'554"	5°03'456"	38	7°57'540"	5°03'451"	31	7°57'533"	5°03'449"	31
IkotNtuen	7°57'331"	5°02'957"	60	7°57'340"	5°02'962"	45	7°57'352"	5°02'957"	45
EkpriNsukara	7°57'619"	5°02'451"	65	7°57'606"	5°02'441"	56	7°57'597"	5°02'423"	56
IbiakuOffot	7°58'016"	5°02'064"	63	7°58'017"	5°02'077"	57	7°58'011"	5°02'089"	57
Use Offot	7°58'286"	5°02'447"	61	7°58'290"	5°02'463"	52	7°58'296"	5°02'483"	52
Nsukara-Offot	8°00'072"	5°01'284"	71	8°00'060"	5°01'289"	67	8°00'050"	5°01'290"	67
Use Atai	7°58'468"	5°03'132"	61	7°58'465"	5°03'115"	55	7°58'472"	5°02'140"	55

RESULTS AND DISCUSSION

Effect of Terrain Attributes on the Distribution and Variability of Soil Properties

The terrain attributes considered in this study include slope, aspect, curvature, flow direction, hill shade, stream power index (SPI) and compound topographic index (CTI). The result shown in Table 2 revealed that aspect, flow direction and hill shade did not correlate with any of the soil properties measured and may not significantly influence the characteristics of CPS. The terrain attributes that significantly correlated with the highest number of soil properties were SPI and CTI. These terrain attributes (SPI and CTI) respectively significantly correlated with hydraulic conductivity (r = –0.41 and 0.40, $p < 0.05$), $pH_{(water)}$ (r = 0.61 and –0.67, $p < 0.01$) and $pH_{(KCl)}$ (r = 0.46 and –0.45, $p < 0.05$). They equally (SPI and CTI) respectively significantly correlated with organic carbon ((r = 0.49 and –0.44, $p < 0.05$), base saturation (r = 0.40 and 0.38, $p < 0.05$) and crystalline iron oxide (r = 0.42 and 0.42, $p < 0.05$). Additionally, SPI significantly correlated with crystalline aluminium oxide (r = 0.46, $p < 0.05$).

These indices of compound topography and stream power combine in the modification of soil characteristics (distribution and variability) through their participation in the turbation process and moisture or solute dynamics within the profile. Both attributes were found very useful in the characterization of soil spatial variability (Moore *et al*., 1993; Quinn *et al*., 1995; Schaetzl and Anderson, 2005). The CTI has great potential as ancillary data in studies of soil properties in relation to overland flow and soil water. For instance, it has been used to describe the effects of topography on any location, estimate size of saturated areas and characterise soil spatial variability (Debella-Gilo *et al*., 2007). The SPI incorporates the hydrological upstream contributing area and slope in the estimation of the erosive power of the terrain.

Other terrain attributes studied included slope and curvature and both correlated with two soil properties each. Slope significantly correlated with clay content (r = –0.39, $p < 0.05$) and $pH_{(water)}$ (r = 0.54, $p < 0.01$). These suggest that clay accumulate at the lowest portion of the landscape as a result of erosivity factor. For this geomorphic unit of the coastal plain sands, Obi *et al*. (2014) reported dominance of coarse fragments and higher rainfall rate higher than infiltration.

The consequence is the overall movement of clay fraction to the lowest portions within the landscape to the extent that some profiles manifest significantly higher content from the surface (uncharacteristically). The contrast in the way that slope related with clay content and pH is equally explained by previous report from Obi (2015) that the major determinant of the pH of coastal plain sands is the sand fractions. Coastal plain sands are referred to as acid sands and its pH is more dependent on the Al^{3+} rather than the H^{+}. Hence locations with higher clay content are less acidic compared to the upper portions as expressed in the highly significant positive correlation between pH and slope. Coastal plain sands are known for dominance of crystalline Al oxides on the profiles of poorly drained lower slope position compared to well-drained uplands with dominance of crystalline Fe oxides (Lekwa and Whiteside, 1986).

Table 2: Relationship between terrain attributes and some soil properties

	Slope	Aspect	Curvature	Flow direction	Hill shed	SPI	CTI
Depth	0.26	0.13	0.04	0.21	0.17	0.35	-0.29
Sand	-0.06	-0.14	0.08	-0.22	-0.20	-0.15	0.13
Silt	-0.25	-0.2	0.03	-0.18	-0.19	-0.32	0.32
Clay	-0.39*	-0.10	0.03	0.04	-0.18	-0.413	0.40*
Hydraulic conductivity	-0.25	0.08	0.02	0.18	0.07	-0.363	0.34
Bulk density	-0.16	-0.18	0.02	-0.20	-0.24	-0.24	0.22
pH_{H2O}	0.54**	-0.30	0.17	-0.02	-0.33	0.61**	-0.67**
pH_{KCl}	0.32	-0.01	0.08	0.26	0.02	0.46*	-0.45*
Exchangeable calcium	0.15	0.15	-0.29	-0.23	0.16	0.19	-0.18
Exchangeable magnesium	0.06	0.08	0.28	-0.08	0.02	0.04	-0.13
Exchangeable Sodium	-0.04	-0.23	0.28	0.21	-0.23	-0.03	-0.05
Exchangeable Potassium	-0.15	0.03	0.08	0.10	0.09	0.14	0.06
Exchangeable acidity	0.16	-0.14	0.31	-0.22	-0.06	0.07	-0.18
Available phosphorus	0.06	-0.07	-0.09	-0.15	0.00	0.04	-0.04
Electrical conductivity	-0.22	-0.20	-0.21	0.34	-0.27	-0.30	0.32
Organic carbon	0.37	-0.21	0.32	-0.14	-0.05	0.49**	-0.44*
Base saturation	-0.24	0.06	-0.20	-0.28	-0.00	-0.40*	0.38*
Crystalline iron oxide	0.30	-0.29	0.38*	-0.09	-0.26	0.42*	-0.41*
Crystalline aluminium oxide	0.30	-0.07	-0.19	0.17	-0.02	0.46*	-0.29
Amorphous iron oxide	0.12	-0.04	0.43*	-0.12	-0.03	0.27	-0.26
Amorphous aluminium oxide	-0.08	0.06	-0.30	0.32	0.098	0.14	0.07

SPI = Stream power index, CTI = compound topographic index; *, ** = significant at 5% and 1% respectively

Topographic convergence and divergence are first order controls on the hillslope and catchment hydrological response. Curvature is the terrain attribute used in studying flow convergence and divergence. Total curvature significantly ($p < 0.05$) correlated with crystalline (r = 0.38) and amorphous (r = 0.43) iron oxide. Curvature has been found to be associated with soil aggregate stability (Zádorová *et al*., 2011). Iron oxides contribute to stabilization of soil organic matter and aggregation (Barthès *et al*., 2008). These implied that the relationship between sesquioxides and curvature could explain to a large extent variability of soil aggregate stability (Maniyunda *et al.*, 2015). The stronger relationship expressed with amorphous compared with crystalline iron oxide may be associated with its nature as a form of clay. Colloidal sized clay has been found to constitute some sesquioxides in the amorphous form (Ojanuga, 1985). Clay and organic matter had strong influence on movement and distribution of the forms of sesquioxides in the soils.

Terrain Attributes and Prediction of Soil Properties

The soil properties that were predicted using terrain attributes include bulk density, pH, exchangeable acidity and amorphous aluminium oxide. The terrain attributed used in the prediction of the soil properties are slope, SPI, flow direction and curvature. There was no significant difference between the observed and predicted soil properties (Table 3). The RMSE for the models ranged between 0.53 and 18.88 whereas NRMSE range between 0.03 and 0.51. The terrain attribute that could be used in modelling clay content of coastal plain sands is stream power index. Stream power index is an estimate of effects of rainfall intensity and scouring inflow rate on runoff formation, soil erosion and solute transport on the surface runoff (Guo *et al*., 2010). Stream power index is used to estimate the erosive power of the terrain and had previously been found to significantly correlate with clay content and influence its distribution and variability (Obi *et al*., 2014). Slope and compound topographic index were found to influence bulk density of the CPS. Slope and CTI had been found to influence the distribution of soil particle size fractions (psf) through gravitational and surface hydrological processes (Schaetzl and Anderson, 2005). Bulk density is a manifestation of the arrangement of psf and these are predominantly functions of topography and soil water.

The pH and exchangeable acidity of the soils were predicted using flow direction and SPI (Table 3). The observed and predicted pH in water (5.14 cmol kg^{-1}), KCl (4.74 cmol kg^{-1}) and exchangeable acidity (0.71 cmol kg^{-1}) had relatively low R^2 that ranged between 0.15 and 0.21. This does not imply futile modelling process because the predicted and observed is unity and significant at 5% probability level. The predictors (SPI and flow direction) are contributors to the erosive power of terrains and solute transport (Obi *et al*., 2014). These processes of erosivity and solute transportation have intrinsic capacities to modify psf. Particle size fractions has been reported to play significant role in the pedogenesis and acidification of coastal plain sands profiles (Obi, 2015). Total curvature was found to significantly influence the distribution and variability of amorphous aluminium oxide and was predicted with the least normalized root mean square error (3.0%). This signified that the prediction could be achieved with very high degree of accuracy. Curvature is used to study convergence and divergence in a terrain and as sesquioxides tend to sizes of clay, they could act like charged particles, become influenced by curvature and possibly converge with clay particles. This could be confirmed with the reported significance of aluminium oxides in the acidification of lower slope profile on coastal plain sands geomorphic units (Lekwa and Whiteside, 1986).

Table 3: Prediction of soil properties using terrain attributes

	Modelling			Model validation				
Variable	Model*	P level	R^2	Observed	Predicted	LSD	RMSE	NRMSE
Clay	18.80912 – 4.70177(SP1)	0.02	0.17	9.87	9.87	1.74	1.87	0.19
Bulk density	–32.27541 – 0.00000186(slope) – 2.21051(CTI)	0.01	0.45	1.05	1.05	0.13	0.53	0.51
pH(H_2O)	1.08693 + 0.01099(Flow direction) + 1.84400(SPI)	0.03	0.21	5.14	5.14	0.46	0.92	0.19
pH(KCl)	0.56652 + 0.01344(Flow direction) + 1.84764(SPI)	0.04	0.15	4.74	4.74	0.53	1.01	0.21
Exch. acidity	0.19174+0.01052(Flowdirection)	0.02	0.18	0.71	0.71	0.44	0.83	1.16
Amorphous aluminum oxide	591.83230 – 1.06966e-7(Curvature)	0.03	0.16	632.7	632.7	225.24	18.88	0.03

*SPI = stream power index, CTI = compound topographic index

CONCLUSION The distribution and variability of clay, bulk density, pH, exchangeable acidity and amorphous aluminium oxide on coastal plain sands were predicted using terrain attributes but with low coefficients (< 50%). The predictability of the soil properties may have been found to be low as manifested in the R^2, yet the modelling is successful because the chance of accuracy is high. The terrain attributes that could be useful in the prediction and management of some coastal plain soil properties for optimal crop production and environmental sustainability include stream power index, slope, compound topographic index, flow direction and curvature.

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