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NUMERICAL CLASSIFICATION AND DIGITAL MAPPING OF COASTAL PLAIN SANDS OF SOUTHEASTERN NIGERIA

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ABSTRACT
The study classified the coastal plain sands of south-eastern Nigeria at the series level and modeled the classification using digital terrain attributes. The study utilized 72 secondary and 12 primary profile pits data generated from 24 and 4 locations (at 3 per location) for classification/modelling and validation respectively. The three profile pits per location represents the three topographic positions of upper, middle and lower slopes. Digital elevation model was also utilized for the generation of terrain attributes. Soil morphological characteristics were coded for suitability in statistical analysis. Hierarchical clustering was utilized in the grouping of the soil into 17 homogeneous groups referred to as soil series. Regression kriging was used to model the predicted soil series within the area covered by coastal plain sands in Akwa Ibom State. The variables that could be used in the modelling of the different classified soil series include Sand Content, aspect, flow accumulation, compound topographic index (CTI), elevation, hill shade, slope, curvature, flow direction, stream power index (SPI), profile curvature, tangential curvature (R^2 = 0.21).Out of the 17 soil series classified, 14 was successfully mapped using digital technique. It was observed that 66.7% of the classified soil series were accurately predicted using digital mapping technique. The classifications carried out numerically made use of morphological discrete variables whereas digital used empirically determined continuous variables which could be more accurate. Therefore it could be inferred that the digitally produced soil classification is more accurate and 14 soil series could be identified and mapped in the study area.

Key words: pedogenesis, digital soil mapping, soil series, hierarchical clusters, regression kriging

INTRODUCTION
The knowledge and soil information system have been found to intricately contribute more than agronomic production but inclusively land use planning, environmental concerns, socioeconomics, food security, energy security, water security, human health and military operations etc. These could be effectively applied with the aid of accurate and detailed soil map. Production of soil map fundamentally requires soil classification system with which communication of soil information would be effectively carried out (Brevik *et al*., 2016). Classification simplifies the complexity and continuum that exist in soils. The process of classification systematically utilizes knowledge of pedogenesis to arrange soils on the basis of their characteristics (Brevik and Hartemink, 2013), enclosing more similar (homogeneous) units while separating dissimilar (heterogeneous) ones to facilitate sustainable utilization and management. USDA keys to soil taxonomy hierarchically grouped soils into six taxonomic categories with series at the lowest level (Guo *et al*., 2003). Soils within a series have similar profiles, developed from similar parent materials under comparable landscape physiognomy. A major advantage of soil series is that there is very limited amount of variability, hence facilitating uniformity in management, crop yield and environmental sustainability (Simonson, 1997). Development of protocols for soil classification is complex and tedious especially in hierarchical classifications. This results from the accumulation of characteristics and accompanying increases in complexity with decreases in levels of categorization (implying increases in similarities) manifest in the criteria for hierarchical soil classification. Therefore, development of criteria for classification of soil series which is the lowest level of categorization in USDA Keys to Taxonomy could be very challenging as the range of similarity increases cumulatively. But this could be achieved more easily with the application of numerically and digitally mediated processes

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Numerical process involves the quantification of similarity among individuals based on relevant set of characteristics (Sneath and Sokal, 1973). Therefore numerical classification of soils is achieved through quantitative estimation of similarity and dissimilarity in the form of distances. Some of the methods adaptive to quantification for numerical classification include discriminant analysis (Pavlik and Hole, 1997), fuzzy logic (Zhu, 1997), decision trees (Lagacherie and Holmes, 1997), cluster analysis (Carre and Jacobson, 2009), etc. in straight courses and combinations (Guug and Kugbe, 2015). This knowledge of the soil and soil information system is more universally applicable for diverse professionals in a map especially presentations that occur at the lowest possible categorical level with minimal error (i.e., with high degree of accuracy). These are more easily achieved digitally and retrievably with quantitative and statistical methods (Brus *et al*., 2011).

Digital or predictive soil mapping is the numerical modeling activity used for the creation and population of spatial soil information systems (Minasny and McBratney, 2016). Major factor in digital soil mapping is the correlation between environmental, landscape characteristics and soil. These are captured in the digital elevation model that has shown significant relationships with soil attributes and characteristics (Obi *et al*., 2014, Minasny and McBratney, 2016). The underlying principle of the modelling process is that the soil attribute at an unvisited site can be predicted from a numerical function, localised variability characteristics and spatial dependent residuals (McBratney *et al*., 2003). Series categorical classification system minimizes the difficulties associated with soil heterogeneity, renders soil maps and survey activities more useful, facilitates cost effective production system and protects the environment. The absence of the criteria for classification of coastal plain sands of south-eastern Nigeria at the series categorical level constitutes major utilitarian constraints. Therefore, the objective of this study was to utilize the predominant pedogenic processes in the numerical classification and digital mapping of coastal plain sands of south-eastern Nigeria.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in locations underlain by coastal plain sands (CPS) in Akwa Ibom State, south-eastern Nigeria (Figure 1). The State is located between approximately latitudes 4° 30′ and 5° 30′ N and longitudes 7° 28′ and 8° 20′ E, and covers approximately 7249 km^2 out of which 70 and 5% are CPS and accompanying alluvium respectively. The climate is characterized by distinct wet (March/April to October) and dry (November to March) seasons. Rainfall distribution in a year is bimodal and high intensity with annual range of 2000 mm in the northernmost portion and 4000 mm along the coast (Udosen, 2014). Temperature is uniformly high ranging between 28 and 30 °C and relative humidity is high (ca. 75%). The area is characterized by secondary forest of predominantly wild oil palm trees of various densities, woody shrubs such as *Chromolaena odorata* and various grass undergrowth such as *Impereta cylinderica* which are indicators of land degradation (Obi, 2000).

The profiles of soils formed from coastal plain sands vary from sand on the surface to fine loamy in the subsurface and have low physical and chemical fertility due to dominance of low-activity kaolinitic clays and low organic matter content (Ofomata 1981; Ojanuga *et al*., 1981; Ogban and Ekerette 2001). The coarse silt and sand fractions were characterized by siliceous mineralogy. They are well drained, deeply weathered, have udic moisture and isohypertermic temperature regimes, and classified as Typic Paleudult in siliceous, isohyperthemic families (Lekwa and Whiteside 1986) according to the US Department of Agriculture Soil Taxonomy (Soil Survey Staff, 2014) corresponding to Haplic Acrisol (Hyperdystric) of the World Reference Base (IUSS, Working Group WRB, 2007).

Field Study

The study made use of both primary and secondary profile data. The Primary and secondary data were obtained from 12 and 72 different profile pits comprising upper, middle and lower slope positions prepared in 4 and 24 locations respectively. The secondary profile data were generated by Udoh (2003) and 1996-2012 project reports of the students of the Department of Soil Science and Land Resources Management, University of Uyo, Nigeria. The soil profile pits were described and sampled according to genetic horizons following the FAO (2006) guidelines or adapted to it.

Generation of Terrain Parameters

Primary terrain parameters including slope, aspect, altitude, plan, profile and tangential curvature, upslope contributing area, and secondary terrain parameters such as topographic wetness index (TWI), and stream-power indices were derived from the digital elevation model using ArcGIS 9.2. Sampling points were added as XY data. The added XY data and terrain parameters were projected into the same reference system and the values of the attributes extracted manually into a table for the study area.

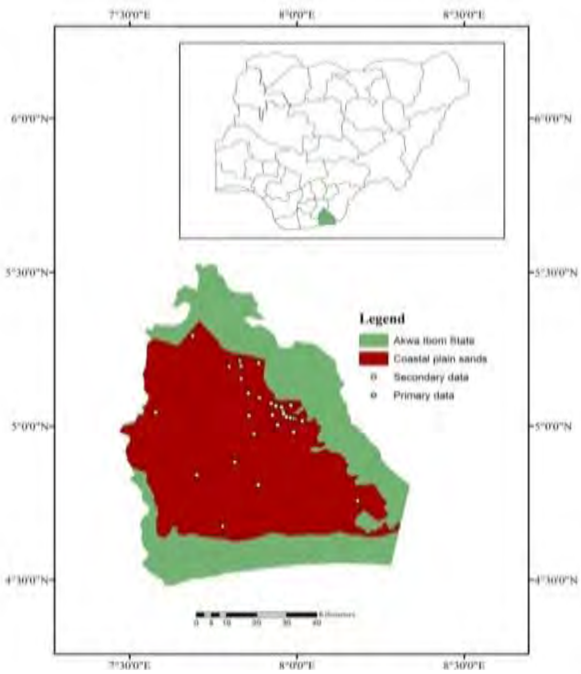

Figure 1: Map of Akwa Ibom State showing area covered by coastal plain sands

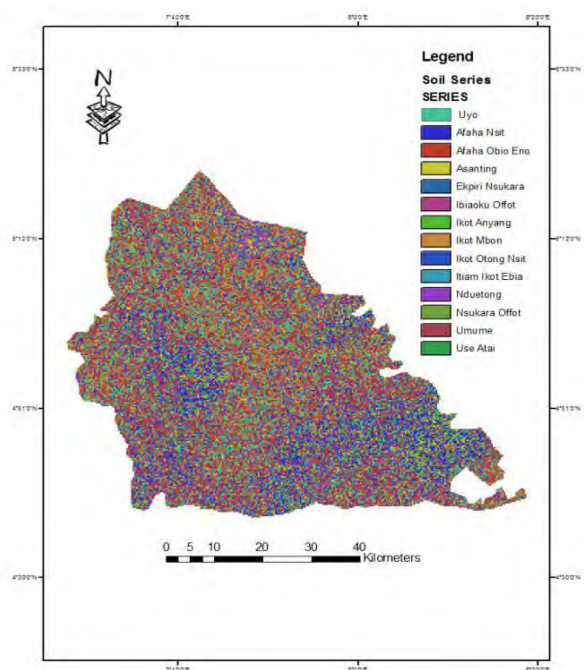

Figure 2: Digital soil series map of the study area

Statistical Analysis

The secondary profile data were used for numerical classification and digital soil mapping while primary profile data were used for validation of modeling. Topographic positions have been found to significantly influence soil characteristics (Yimer, 2017). Therefore the profile sample data were purposively divided into originating topographic positions including upper, middle and lower slopes that characterise coastal plain sands landscape. The soil morphological properties from the profile pit description including horizon depth, colour, texture, structure, consistence, mottles, concretions and boundary form were coded for suitability in statistical analysis. These coded soil properties from each topographic position were analyzed using hierarchical clustering. Cluster analysis is an unsupervised process that divides a set of objects into homogeneous units. The goal of clustering is to assign data points with similar properties to the same groups and dissimilar data points to different groups. This could be achieved either agglomeratively or divisively. In agglomerative clustering, individuals are iteratively and progressively combined into larger groups whereas divisive clustered individuals are iteratively split into smaller groups. In this process, topographic positions were iteratively split to the level of profiles.

The hierarchical clustering of the soil morphological properties grouped the soils of various topographic positions into similar and dissimilar units and the possible pedogenic processes responsible for the feature of the different groups were established. The different units or groups formed from similar pedogenic processes were collated as separate soil series based on the morphological characteristics of the soil within the 100 cm depth. The occurrence or expression of all the differentiating characteristics of a particular pedon on a horizon was represented as positive (+) indicating similarity while negative (−) indicated dissimilarity. The accumulation of the (+) led to the grouping of these pedons that show similarity in these differentiating characteristics as to belonging to a series while (−) separates the pedons that possessed such sign as different (i.e. belonging to a different soil series). The hierarchical clustering of the soil morphological properties grouped the soils of various topographic positions into similar and dissimilar units and symbolically named. All statistical analyses were carried out with the aid of SAS/STAT® software version 9.2 for Windows (SAS Institute, 2011) and SPSS version 20 (IBM Corp. Released, 2011). Multiple linear regression analysis was used for the development of models used in the spatial prediction of soil properties.

According to Odeh *et al.* (1995), if multiple linear regression model results in a low coefficient of determination (R^2), then regression-kriging is applied. In this study, the modelling of soil properties with the aid of terrain parameters resulted in a very low R^2. Therefore sand content of the soils was adopted as dependent variable. According to Obi *et al.* (2014) and Obi (2015), sand is the major determinant of the pedogenesis of soils formed on Coastal Plain Sands.

Regression-kriging is described as the combination of a multiple linear regression model with simple kriging of the regression residuals (Odeh *et al*., 1995; McBratney *et al*., 2003). Regression-kriging is based on the general expression: S (x) = m(x) + é(x) + e. where S(x) is the predicted soil value, m(x) the regression component, é(x) the regression residuals interpolated by simple kriging (McBratney *et al*., 2003), and e spatially incoherent error term. Additionally, McBratney *et al*. (2003) had proposed the utilization of factors of soil formation for digital soil mapping. Subsequently, ordinary pixel-based supervised procedure was adopted for classification of soil series. The primary pedons were classified manually using the criteria defined in the hierarchical clustering to be used for the validation of digital soil map. The locations of primary soil profile pits were added as XY data to the same environment as the digital soil map produced and the corresponding soil series extracted manually. Then the soil series extracted from the digital map were compared with manual classification for the same locations. The percentage accuracy was estimated as:

$$\frac{Total\ number\ of\ soil\ series\ accurately\ classified\ digitally}{Total\ number\ of\ soil\ series\ manually\ classified} \times \frac{100}{1}$$

RESULTS

Numerical Soil Classification

The soils of the different topographic positions were clustered separately to avoid regrouping within the process. Regrouping implied unification of units or classes that were originally separated with topographic positions which is common in soils that have similarities in factors of formation. The result of the cluster analysis were summarised for the different topographic positions in Tables 1 to 3 with the contribution of the characteristics of the different horizons for membership to a particular series. The soils of the study area were clustered into 17 units (soil series) after similarity index was computed with horizon depth, colour, texture, structure, consistence, mottles, concretions and boundary forms. The 17 soil series comprised six each for upper and middle slopes and five for the lower slope. The soil series classified were typified with certain pedons which characteristics were referred to as differentiating. The series in the upper slope are Use offot, Ikot Ntuen, Itiam Ikot Ebia, Ikot Anyang, Ikot Ekpo and Uduetong Oku. Similarly, the middle slope series include Ikot Inyang, Ekpri Nsukara, Ikot Mbon, Asanting, Ikot Otong Nsit and Afaha Obio Eno. The lower slope series comprised Uyo, Umume, Nsukara Offot, Use Atai and Afaha Nsit.

Characteristics of the Different Soil Series

The different soil series were described for easy field identification using the morphological properties that were coded for the numerical classification. The representative pedons were described as typical for each series. Thus the closer the characteristics of any pedon is to the representative pedon, then the higher the probability that it belong to that soil series. Alternatively, the pedon belongs to separate soil series. Therefore, the representative pedons possess the differentiating characteristics for each soil series.

Soil series at the upper slope topo-positions

Characteristically, upper slope are deep, brightly coloured indicative of properly drained soils especially for coastal plain materials known to be formed from acidic plutonic igneous rocks and possesses typical characteristics of quartz arenite (Obi, 2015) with neither mottles, concretions nor impervious layers present in any of the horizons. The soils of Use Offot Series have loamy to sandy loam texture in the topsoil and sandy clay loam to sandy loam in the subsoil. Their colour ranges from dark brown (10YR $^3/_3$ moist), very dark brown (10YR $^2/_2$ moist) to brown (10YR $^4/_3$ moist) in the topsoil, becoming dark yellowish brown (10YR $^4/_6$, 10YR $^4/_4$ moist) to yellowish brown (10YR $^5/_6$, 10YR $^5/_8$ moist) with depth. The soil structure ranges from fine sub angular to coarse angular blocky in the subsoil. They are loose to friable in the topsoil when moist, slightly sticky to sticky in the subsoil and very sticky below 100 cm depths. Those of Ikot Ntuen Series are differentiated with their sandy nature in the topsoil and predominantly loamy sand in the subsoil. They are dark brown (7.5YR $^3/_3$, 7.5YR $^3/_2$ moist) in the topsoil whereas subsoil is brown (7.5YR $^4/_4$, 7.5YR $^4/_3$ moist) and strong brown (7.5YR $^4/_4$, 7.5YR $^3/_2$ moist). Below 130 cm of depth, the colour is reddish yellow (7.5YR $^6/_8$ moist). They are loose to friable in consistence with medium sub-angular blocky structures down the profile.

The soils of Itiam Ikot Ebia Series are dark brown (7.5YR $^3/_3$, 7.5YR $^3/_2$ moist) at the top, becoming strong brown (7.5YR $^4/_4$, 7.5YR $^4/_6$, 7.5YR $^5/_6$ moist), very dark brown to reddish yellow (7.5YR $^6/_8$ moist) in the lowest horizons. The upper horizons with depths above 67 cm have textures ranging from sand to loamy sand and sandy loamy texture down the profile. Characteristically, the profiles of these soils are well drained and devoid of mottles and concretions. They are friable (moist) on the surface and slightly sticky in the lower horizons. The structures of these soils are fine granular to medium sub-angular blocky in the upper horizons and fine sub angular blocky, very fine granular to fine granular with depths.

Table 1: Horizon expressions showing occurrences of each pedon on the upper slope of the toposequence of the study area

Pedon	Horizon 1	Horizon 2	Horizon 3	Horizon 4	Horizon 5	Horizon 6
			Use Offot Series			
Afaha Obio Eno	+	+	+	+	-	-
Afaha Nsit	+	+	+	+	+	-
Uyo	+	+	+	+	+	-
Ibiaku Offot	+	+	+	+	+	+
Aka Offot	+	+	-	+	-	-
Use Offot	+	+	+	+	-	+
Ikot Inyang	+	+	+	+	+	+
Ikot Obio	+	+	+	+	-	-
			Ikot Ntuen Series			
Nung Asang	+	+	+	+	-	-
Use Atai	+	+	+	+	+	+
Ikot Ntuen 1	+	+	+	+	+	+
Ikot Ntuen 2	+	+	+	-	-	-
Ntak Inyang	+	+	-	+	+	-
			Itiam Ikot Ebia Series			
Ibaoku 1	+	+	-	+	+	-
Ikot Inyang Idu	+	+	+	-	-	-
Ikot Ebia Ita	+	+	+	+	-	-
			Ikot Anyang Series			
Nsukara Offot	+	+	+	+	-	-
Umume	+	+	-	+	+	+
Ekpri Nsukara	-	+	+	+	+	+
Ikot Anyang 1	+	+	+	+	+	+
Ikot Anyang 2	+	+	+	-	-	-
Ikot Mbon	-	+	+	+	+	-
			Ikot Ekpo Series			
Use Offot	+	+	+	-	-	-
Ikot Ekpo	+	+	+	-	-	-
			Nduetong Oku Series			
Nduetong Oku	+	+	+	-	-	-
Ikot Otong Nsit	-	+	+	-	-	-
Ifa Atai	+	-	+	-	-	-

$^{+}$similarity $^{-}$dissimilarity

Table 2: Horizon expressions showing occurrences of each pedon on the middle slope of the toposequence of the study area

Pedon	Horizon 1	Horizon 2	Horizon 3	Horizon 4	Horizon 5	Horizon 6
			Ikot Inyang Series			
Afaha Nsit	+	+	+	-	-	-
Ikot Inyang	+	+	+	+	+	-
Use Offot 1	+	+	-	+	+	-
			Ekpri Nsukara Series			
Ekpri Nsukara	+	+	+	-	+	-
Use Offot 3	+	+	+	-	-	-
Nduetong Oku	+	-	+	-	+	-
Ikot Anyang	+	+	-	+	-	-
			Ikot Mbon Series			
Ikot Mbon Ikon	+	+	+	+	+	-
Ikot Ntuen	+	+	+	+	+	-
Use Offot 2	+	-	+	+	+	-
Nsukara Offot	+	-	+	+	+	-
			Asanting Series			
Asanting	+	+	-	-	-	-
Ibaoku	+	+	-	-	-	-
			Ikot Otong Nsit			
Ikot Otong Nsit	+	+	+	+	+	+
			Afaha Obio Eno			
Afaha Obio Eno	+	+	+	+	+	+
Umume	+	+	+	-	+	-
Uyo	+	+	-	-	+	-

$^{+}$similarity $^{-}$dissimilarity

Soils of Ikot Anyang series were first encountered in Ikot Anyang, then in Ikot Mbon Ikono, Nsukara Offot, Umume and Ekpri Nsukara of Akwa Ibom State. Their topsoils are sandy, loamy sand and sandy loam in texture but with depth, they are sandy clay loam. All the soils are loose to friable in the upper horizons when moist, friable to slightly sticky in the subsoils but sticky to very sticky in the lower horizons. Their structure ranges from very fine crumb to medium sub-angular blocky in the upper horizons. In the lower horizons, their structure comprise fine sub-angular blocky, medium sub-angular blocky to coarse sub-angular blocky. They show dark brown (7.5YR $^{3}/_{3}$ moist), very dark brown (7.5YR $^{3}/_{1}$ moist) and brown (7.5YR $^{4}/_{4}$, 7.5YR $^{5}/_{3}$ moist) colour in the topsoils, brown (7.5YR $^{4}/_{4}$. 7.5YR $^{4}/_{3}$ moist) and strong brown (7.5YR $^{4}/_{6}$ moist) colour is seen in the subsoils but reddish yellow (7.5YR $^{6}/_{8}$ moist) in the lowest horizons.

Table 3: Horizon expressions of each pedon on the lower slope of the study area

Pedon	Horizon 1	Horizon 2	Horizon 3	Horizon 4	Horizon 5	Horizon 6
			Uyo Series			
Use Offot 2	+	+	+	+	+	-
Uyo 1	+	+	+	+	-	-
Afaha Obio Eno	+	+	+	+	+	-
Uyo 2	+	+	+	+	-	-
			Umume Series			
Umume 1	+	+	+	+	-	-
Umume 2	+	+	+	+	-	-
Ibiaku Offot	+	+	-	-	-	-
Uyo 6	+	+	+	+	-	-
Ikot Obio	-	+	+	+	-	-
			Nsukara Offot Series			
Nsukara Offot	+	+	-	+	+	-
Ekpri Nsukara	+	+	+	+	+	-
Ikot Anyan 1	+	+	+	-	+	-
			Use Atai Series			
Ikot Mbon Ikon	+	+	-	-	+	+
Use Offot 1	+	+	+	+	-	-
Use Atai	+	+	+	+	+	+
Ikot Anyan 1	+	+	+	+	+	+
Ikot Ntuen	+	+	+	-	+	-
			Afaha Nsit Series			
Ikot Antono	+	+	+	+	+	-
Nduetong	+	+	+	+	+	+
Ibaoku	+	+	+	+	+	+
Afaha Nsit	+	+	+	+	+	-
Ntak Inyang	+	-	+	+	-	-

$^{+}$similarity $^{-}$dissimilarity

The soils of Ikot Ekpo series were encountered in the upper slope position of some parts of Use Offot but majorly in Ikot Ekpo area of Akwa Ibom State and are characterized by dark brown colour (7.5YR $^{3}/_{2}$, 7.5YR ¾ moist) and becoming strong brown (7.5YR $^{4}/_{6}$, 7.5YR $^{5}/_{8}$ moist) with depth. They are sandy loamy in nature with a fine or thin granular to medium sub angular structure. They are loose to friable in consistence but slightly sticky with depth. The soils of Nduetong series are characterized by dark brown (7.5YR $^{3}/_{3}$, 7.5YR ¾ moist) colouration in the upper horizons of the soil profile with brown colour (7.5YR $^{4}/_{6}$, 10YR $^{4}/_{3}$ moist) in the subsoils. Their topsoils consist mainly of sandy loam and loamy sand texture while the subsoil texture ranges from sandy loam to sandy clay loam. Above 40 cm depth, the soils in this series are basically granular and crumby in structure but fine sub angular blocky and medium sub angular blocky down the profile. No concretions or mottles were present as the soils were well drained. They are loose to friable in consistence but became slightly sticky down the profile.

Soil Series at the middle slope topo-positions

Soils of Ikot Inyang series were encountered on the middle slope position of Afaha Nsit, Ikot Inyang and some parts of Use Offot. The soils are well drained, non-mottled and non-concretionary (Vine, 1970). This is evident in their colours which ranges from dark brown (10YR $^{3}/_{3}$) and dark yellowish brown colours (10YR ¾, 10YR $^{4}/_{4}$, 10YR $^{4}/_{6}$) to yellowish brown colours (10YR $^{5}/_{6}$, $^{5}/_{8}$) down the profile. They are characterized by loamy sand and sandy loam textures in the surface horizons but sandy clay loam in the subsoils with medium granular, medium sub angular blocky and fine or thin granular structures in the surface soils. However, the structure in all the sub soils of this series is coarse angular blocky. They are friable in the topsoils becoming slightly sticky to sticky down the soil profile.

Pedons of Ekpri Nsukara series are deep and well drained. This is because neither water table nor any other impenetrable layer was encountered even at 200 cm. Jungerius (1964) classified soils formed from coastal plain sand parent material as deep and porous and derived from sandy deposits. They are loose to friable in the upper horizons but gradually slightly sticky down the profile. They have dark brown colours (7.5YR $^{3}/_{3}$, 7.5YR $^{3}/_{2}$) in the surface horizons, brown (7.5YR $^{4}/_{4}$, 7.5YR $^{4}/_{3}$) and strong brown (7.5YR $^{5}/_{6}$, 7.5YR $^{5}/_{8}$) in the subsoils. They have sandy to loamy sand texture in the upper horizons with sandy loam to sandy clay loam in the lower horizons. Their structure ranges from fine sub angular blocky, fine crumb structure to coarse angular blocky, coarse sub angular blocky and medium sub angular blocky.

Ikot Mbon Ikono Series has favourable structure (i.e., fine or thin crumb, fine or thin subangular blocky and medium subangular blocky) and is easily permeable to air, water and plant roots. This is evident in the dark brown colours at the surface horizons of the soil. (7.5YR $^{3}/_{1}$, 7.5YR ¾ and 7.5YR $^{3}/_{2}$). The value of the colours of the surface horizons also indicates they are enriched with organic matter which improves soil structure and increases water and nutrient holding capacity. They are sandy, loamy sandy and sandy clay loam in texture. They are friable in consistence but becoming slightly sticky to sticky down the profile.

Asanting Series occupy the middle slope topographic positions and are characterized by their sandy texture with sandy loam in some of the lower horizons. Their colour ranges from dark brown (7.5YR $^3/_3$ moist), brown (7.5YR $^4/_4$, 7.5YR $^5/_4$ moist) and strong brown (7.5YR $^5/_6$, 7.5YR $^5/_8$ moist) in the upper and middle horizons but are reddish yellow in the lower horizons (7.5YR $^6/_6$, 7.5YR $^6/_8$ moist). These soils are friable and slightly sticky down the profile. They have medium sub-angular blocky, medium angular blocky, fine/thin sub angular blocky, very fine granular and fine or thin granular structures.

Soils of Ikot Otong Nsit were seen on the middle slope of this location with textures ranging from sand, loamy sand to sandy loam and sandy clay loam. Soils of this series are loose to friable in the upper horizons but slightly sticky to sticky in the lower horizons. They have brown colours (7.5YR $^4/_3$ moist) in the upper horizon, strong brown (7.5YR $^4/_6$, 7.5 YR $^5/_6$ moist) in the middle horizons with strong brown and reddish yellow (7.5YR $^5/_8$, 7.5YR $^6/_8$ moist) in the lowest horizons. They have very fine to fine granular structures in the upper horizons, medium granular and coarse sub-angular structure in the middle horizons with coarse sub-angular blocky structure in the lowest horizons. Mottles and concretions were not seen in the profile.

Afaha Obio Eno Series is characterized by sandy loam to loamy sand textured topsoils with sandy clay loam subsoils. They are loose to friable but becoming slightly sticky to very sticky downs the profile. They have dark brown colours (7.5YR $^3/_2$, 7.5YR $^3/_3$ moist) in the upper horizons with brown (7.5YR $^4/_4$) and strong brown colours (7.5YR $^5/_6$, 7.5YR $^5/_8$) in the middle and in the lower horizons, they are reddish yellow (7.5YR $^6/_6$, 7.5YR $^6/_8$ moist). They are fine or thin granular in the uppermost horizons but medium sub angular blocky, coarse angular blocky and coarse sub angular blocky structure down the profile. Mottles and concretions were absent in all the pedons.

Soil Series at the lower slope topo-positions

The Uyo Series are soils found mainly on the lower slopes of the toposequence with loamy sand to sandy loam texture in the upper horizons, sandy loam to sandy clay loam in the subsurface horizons and sandy clay in the lower horizons. Their colour ranges from dark brown (10YR $^3/_3$, moist), dark yellowish brown (10YR $^3/_4$ moist) to very dark grayish brown (10YR $^3/_2$ moist), in the uppermost horizon becoming yellowish brown (10YR $^5/_6$ moist). Dark brown (10YR $^3/_3$, moist) and strong brown (7.5YR $^5/_8$ moist) down the profile. However at the lower horizon, they are either yellow (10YR $^7/_6$ moist) or red (2.5YR $^5/_6$ moist) in colour. They are all friable in the topsoils, but slightly sticky to sticky down the profile. Structurally, they vary from medium sub angular blocky, fine granular, coarse granular to very fine granular from the top to the bottom of the soil profile. Soils of these series were located in Afaha Obio, some parts of Uyo, and some parts of Use Offot.

Umume series are characterized by loamy sand, sandy loam to sandy clay loam texture throughout the profiles. They were encountered along the lower slopes and valley bottom positions on the topography. These soils are mostly dark brown (7.5YR $^3/_2$, moist) in the topsoils, with some of them which are very dark grayish brown (2.5YR $^3/_2$, moist) to brown (7.5YR $^4/_3$ moist). However down the profile, they become brown (7.5YR $^4/_4$ moist), strong brown (7.5YR $^5/_6$ moist) to dark grayish brown (10YR $^4/_2$ moist) and gray (10YR $^6/_1$ moist) showing that there is fluctuation of water table in the lower horizons. High water table was encountered in one of the soils of this series. The soils are mostly friable with a loose consistence in one of the soils in the series. In the subsoils, they are slightly sticky to sticky in consistence. Their structure vary from fine sub angular blocky, medium sub angular blocky, coarse angular blocky to coarse sub angular blocky from the top to the bottom of the profile.

Soils of Nsukara Offot series were encountered in three locations within the study area. These locations include Ekpri Nsukara, Nsukara Offot and some parts of Ikot Anyang. They occur on the lower slope of the toposequence. Characteristically, they are dark brown (7.5YR $^3/_2$ moist) to brown (7.5YR $^5/_4$ moist) in the upper horizons, becoming brown (7.5YR $^4/_3$ moist) and strong brown (7.5YR $^5/_8$, 7.5YR $^5/_6$ moist) with depth then gradually turns reddish yellow (7.5YR $^6/_8$, 7.5YR $^7/_8$ moist) at about 150cm. Their texture ranges from sandy loam to loamy sand becoming sandy loam to sandy clay loam with depth. Fine sub angular blocky to medium sub angular blocky, coarse angular blocky and coarse sub angular blocky structure is seen in the profile having friable to sticky consistence.

Use Atai series show brown (7.5YR $^4/_4$ moist), dark brown (7.5YR $^3/_2$ moist), very dark gray (7.5YR $^3/_1$, 2.5YR $^2/_2$ moist) in the upper horizons of the soil profile with brown colour (7.5YR $^4/_6$, 10YR $^4/_3$ moist) in the sub soils. The soils consist mainly of sandy loam and sandy clay loam with fine sub angular blocky and medium sub angular blocky structure down the profile. No concretions or mottles were present in these soils as they were well drained. They are loose to friable in consistence but slightly sticky down the profile.

Afaha Nsit Series are sandy textured and were encountered on the lower slopes topographic positions of Ibaoku, Afaha Nsit, Nduetong, Ntak Inyang and Ikot Antono sites with different shades of brown from the top to the bottom of the profiles (7.5YR $^3/_2$, 7.5YR ¾, 7.5YR $^4/_3$, 10YR $^5/_4$, 10YR $^5/_3$, 7.5YR $^5/_6$, 7.5YR $^5/_8$ moist) indicating the soils in this series are

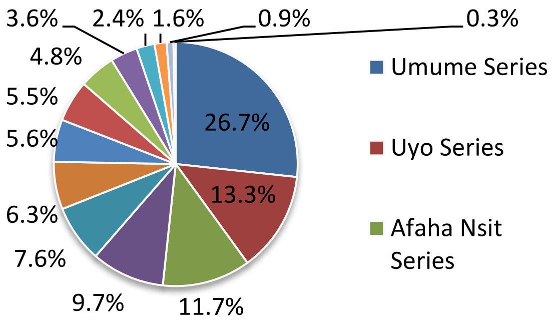

Figure 3: Distribution of soil series within the study area

well drained throughout the year. These soils have medium sub angular blocky structure with few fine thin sub-angular blocky and coarse sub-angular blocky structure. They are mostly loose to friable at the topsoil with only one of the soils (Ikot Antono) which was slightly sticky in the uppermost horizon with slightly sticky consistence in the sub soil.

Modeling of Soil Property

The regression of sand content for the study area against the terrain attributes yielded the following model:

Sand content = 88.176 + 0.008[aspect] + 0.39[flow accumulation] + 0.372[CTI] + 0.027[elevation] + 0.001 [hillshade] + 3.3X10 − 6[slope] + 1.35X10-10[curvature] − 0.005[flow direction] − 0.262[SPI] − 3.360[profile curvature] − 9.221[tangential curvature] ($R^2 = 0.21$).

Digital Mapping of Soil Series

The pixel-based supervised classification predicted 14 soil series (Figure 2). The distribution of these soil series is shown (Figure 3). Umume is the most common soil series covering an estimated area of 1356.1 km^2 representing 26.7% whereas Ikot Otong Nsit series was the least (15.2 km^2 representing 0.3%). Validation of the digital soil map produced was done with the aid of secondary data points that were geo referenced. The classifications done with the secondary profile pits were compared with classification that originated from the digital soil map. The result shown in Table 4 revealed that 66.7% of the soil mapping units was accurately predicted by the digital soil map.

DISCUSSIONS

The process of soil survey is targeted on the central purpose of grouping similar soil units and at the same time separating dissimilar ones to enhance sustainable utilization and management. This could be more effective if survey made use of classification at the lowest level of categorization which is soil series for USDA Soil Taxonomy. In cases of existing classification system, the procedure is simpler, otherwise a classification system becomes a precursor to soil map. The soil survey that has end product as soil map is achieved through establishing classes for the soil entities using either expert knowledge or numerical classification (Dale *et al*., 2006). Classification is normally achieved through ensuring that pedons with very similar characteristics belong to the same class. Numerical classification has simplified the process through quantification of similarity within a collection of horizons and subsequently pedon to form homogeneous entities (classes) and proven successful in Nigerian soils (Ogunkunle and Brimoh, 1992). The quantification of similarities in the characteristics of different horizons and the accumulation of such similarities leads to assignment of pedon into homogeneous units. There are existing reports that soils at different topographic positions are intrinsically different in characteristics and have been used as the first criteria for differentiation of Nigerian soils at the series level (Moss, 1957; Smyth and Montgomery, 1962). These resulted in the 17 soil series comprising six each for upper and middle slopes and five for lower slopes. These soil series possess distinctive characteristics which could easily be morphologically distinguished in the field for effective and accurate mapping.

The major determinant of pedogenesis of coastal plain sands has been reported to reside in the characteristics of the particle size fractions (Obi, 2015) and will proceed to influence other morphological properties. A major contributor to the understanding of soil characteristics is the soil colour. It could infer dominant peodogenic activities in the soil. For instance increase in brightness indicates increase in the rate of movement of water within the profile (properly drained), whereas poorly or imperfectly

Table 4: Manual and digital soils series classification of the secondary pedons

S/No	Primary profile ID	Manual classification	Digital classification	Remark
1	Uyo Obio 1	Itiam Ikot Ebia series	Ibiaoku Offot series	NAP
2	Uyo Obio 2	Afaha Nsit series	Afaha Nsit series	AP
3	Uyo Obio 3	Afaha Nsit series	Afaha Nsit series	AP
4	Etip Ediene 1	Asanting series	Asanting series	AP
5	Etip Ediene 2	Asanting series	Asanting series	AP
6	Etip Ediene 3	Afaha Nsit series	Asanting Series	NAP
7	Ata Obio Ediene 1	Itiam Ikot Ebia series	Itiam Ikot Ebia series	AP
8	Ata Obio Ediene 2	Itiam Ikot Ebia series	Itiam Ikot Ebia series	AP
9	Ata Obio Ediene 3	Ikot Mbon Ikono series	Ikot Mbon Ikono series	AP
10	Edem Iyere 1	Nduetong series	Nduetong series	AP
11	Edem Iyere 2	Itiam Ikot Ebia series	Nduetong series	NAP
12	Edem Iyere 3	Ikot Ntuen series	Nduetong series	NAP

NAP- not accurately predicted; AP- accurately predicted drained soils are characterised by dull colours. These brightly coloured soils are found in the upland/upper and middle slope soils and poorly/imperfectly drained soils occupy lowlands/wetlands which are common among lower slope soils. Yang *et al*. (2001) reported that the lightness of soil mainly correlates to the organic matter accumulation, humification and carbonatization processes, and its correlation to climate can only be found in the humid-arid extratropical belt. The humidity and surface roughness of soil have so strong influence on soil colour that there are great errors on the measurement of soil colours in the field. The changes in soil temperature from the surface downwards affect the colour of the soil and manifest soil characteristics as a result of pedogenesis (Terefe *et al*., 2005). There is a gradient of soil colour that decreases in brightness from the well drained upper slope positions that are characterised by dominance of sesquioxides under oxidizing conditions in contrast to improperly drained deficiency in oxygen and predominance of reduction reactions. The mechanism that produces the dark coloration of the soil (both mineral and organic matter) demands an environment which is alternately strongly reducing and weakly oxidizing. The former condition is produced biologically with the aid of the excess moisture and easily decomposable organic matter while the latter is formed by temporary decrease in moisture and available energy. The presupposition of low organic matter due to very high mineralization rate and similarities in most other environmental conditions will describe a peculiar scenario for coastal plain sands of southeastern Nigeria. Schwertmann (1983) stated that hematite containing soils (usually with associated goethite) have mostly hues between 5YR and 10R, whereas goethite-containing soils with no hematite have hues between 7.5YR and 2.5Y. Orange colours with a hue of 7.5YR and a value of $\geq$ 6 are often due to lepidocrocite. Ferrihydrite can be distinguished from goethite by its more reddish hue (5-7.5YR) and from lepidocrocite by its lower value ($\leq$ 6). These mineral-specific colours, however, also vary somewhat with concentration, crystal size, degree of cementation, and possibly isomorphous substitution. Poorly crystalline goethite, lepidocrocite, and ferrihydrite may have lower values than better crystalline specimens, and cementation also leads to lower values. Small hematite crystals are bright red (2.5YR-10R), whereas the colour of larger crystals or crystal aggregates may reach into the red purple (RP) range. The pedogenic processes that dictate the colours of the soil significantly influence other morphological properties (including horizon depth, texture, structure, consistence, mottles, concretions and boundary forms) and soil classification (Senjobi and Ogunkunle, 2011).

The regression analysis that was used for modeling soil classes in the study area with the use of sand which have been reported to be the major determinant of pedogenesis of the coastal plain sands (Obi, 2015) indicated a good relationship with terrain attributed. These terrain attributes include aspect, flow accumulation, elevation, hill shade, curvature, flow direction, SPI, profile curvature and tangential curvature. The role of climate (temperature and precipitation) in the pedogenic processes of coastal plain sands is significantly associated with the terrain attributes as reported in Obi *et al*. (2014). The digital soil mapping process produced a map that was not very different from the field method of soil classification using the numerical classification. The processes involve in the digital classification is found to be more accurate than the manual / numerical and the fourteen soil series are the available soil series that could be classified in the study area. This could be explained with the fact that sand content and the terrain attributes used in the digital soil mapping were empirically determined with continuous variables compared with morphologically determined variables that were largely subjective, discrete and could be less accurate.

CONCLUSION

Hierarchical clustering and digital soil mapping classified 17 and 14 soil series, respectively out of which 66.7% of the prediction was accurate. These are indications that the use of morphological characteristics (discrete in nature) in the classification could be accurate but very subjective when compared with digital procedure that makes use of continuous variables that were not subject to judgement of the experimenter. This is, therefore, a confirmation of the effectiveness and superiority of the digital soil mapping (DSM) compared to numerical hierarchical classification for grouping of soil series within the coastal plain sands.

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