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Development of pedotransfer functions for coastal plain soils using terrain attributes

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ABSTRACT

This study investigated the influence of terrain attributes and soil water content on soil genesis and developed pedotransfer functions (PTFs) for the coastal plain soils. A two-stage sampling procedure was adopted in the study. In the first stage, a total of 408 samples were collected along twelve toposequences, while in the second stage, 64 representative soil samples were collected on typical upper, middle and lower slope positions. Particle size fractions, bulk density, hydraulic conductivity, organic carbon, field capacity water content (FWC), permanent wilting point (PWP), and available water content (AWC) were determined. Elevation, slope, aspect, curvatures, flow direction and hill shade, compound topographic index (CTI) and stream power index (SPI) were derived from a digital elevation model. The data were analyzed using correlation, principal component and stepwise multiple regression. There was significant correlation ($p < 0.01$) between FWC and hill shade and CTI. Permanent wilting point and AWC significantly correlated ($p < 0.01$) with aspect, tangent curvature and CTI. Principal components classified were permeability, retention, solute distribution, soil water stress, soil water loss, and solute transport and water storage factors. Soil water content and saturated hydraulic conductivity were modeled and root mean square error (RMSE) ranged from 0.01 to 2.31%, indicating high predictability. Rainfall intensity was estimated at 0.82 cm h^{-1}, while the saturated hydraulic conductivity was 0.23 cm h^{-1} indicating that 256.5% of the rainfall results in overland flow and redistribution of material. The role of terrain attributes involves the development of pedogenic structural and textural features and movement of clay downslope more laterally than vertically within the landscape.

1. Introduction

Topography significantly affects earth surface moisture characteristics and soil properties (Behrens et al., 2010; de Brain and Stein, 1998; King et al., 1999; McBratney et al., 2003; Seibert et al., 2007; Stolt et al., 1993; Venterea et al., 2003). It influences both endogenic and exogenic soil forming factors and plays a crucial role in the spatial distribution of soils and their properties (Debella-Gilo et al., 2007; Moore and Hutchinson, 1991; Schaetzl and Anderson, 2005).

Several studies have established predictive relationships between some quantitative environmental variables from digital terrain analysis (DTA) and soil properties (Gessler et al., 1995; McKenzie and Austin, 1993; Odeh et al., 1994). Some of these variables which include elevation, slope, aspect, curvature, compound topographic (wetness) index and stream power index (Irvin et al., 1997) are generated through the analysis of digital elevation models (DEMs). They include elevation, slope, aspect, curvature, compound topographic (wetness) index and stream power index (Irvin et al., 1997).

Slope has been described as the single most important element of surface form. The influence of gravitational force on a landscape is dependent on slope angle which drives geomorphic processes (Evans, 1972) through its influence on water flow rate, velocity of colluvial material and infiltration into soils. The compound topographic index (CTI) has been used to describe the effects of topography on location and size of saturated areas (Moore et al., 1993) and more accurately characterizes the spatial variability of soil properties due to surface hydrology (Moore et al., 1993). It incorporates the hydrological upstream contributing area and slope (Quinn et al., 1995). The CTI has great potential as ancillary data in studies of soil properties in relation to overland flow and soil water (Schaetzl and Anderson, 2005). The stream power index (SPI) is closely related to the topographic wetness index (TWI) and is used to estimate the erosive power of the terrain.

Water dynamics in the soil profile are governed by many factors that change vertically with depth, laterally across landforms and temporally with seasons (Swarowsky et al., 2011). The soil water content of a landscape is encapsulated in the DTA as a component of the environmental variables that influence pedogenesis and variability of soil properties. Soil water plays a dominant role in the transport of solutes over both short and long distances. Eluviated soil particles, primarily of clay size, transported over short distances by pore water contribute to the

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formation of illuvial horizons and influence overall physical, chemical, microbial and biological processes within the soil profiles driven by ever-changing meteorological conditions (Böhner and Selige, 2006). The soil water component, as a factor in pedogenesis is characterized by field capacity water content (FWC), permanent wilting point (PWP) and available water content (AWC) (Gaiser et al., 2000; van den Berg et al., 1997).

Griffiths et al. (2009) measured the effects of both elevation and aspect on forest soil characteristics in the Oregon Cascade Mountains, United States of America and found that the contents of soil organic matter (OM), labile carbon (C), and mineralizable nitrogen (N) were significantly greater at higher elevations than at lower elevations. Tsui et al. (2004) observed significant differences between slope positions for soil properties in a lowland rainforest in southern Taiwan and stated that soil pH, available phosphorus (P), exchangeable calcium (Ca) and potassium (K), and DTPA-extractable manganese usually increased downslope, whereas organic C, available K, exchangeable sodium (Na), and DTPA-extractable iron tended to decrease. Sidari et al. (2008) reported that the contents of OM and microorganisms and activity of enzymes related to soil microbiological activity were lower on a north-facing slope than on those with southerly aspect probably due to topographic, aspect-induced microclimatic differences.

This study was designed to establish the relationship between terrain attributes and soil water content, and their effect on the genesis of the coastal plain soils, and to develop pedotransfer functions (PTFs) for soil water content using terrain attributes and particle size fractions (PSFs). It has been reported that the development of PTFs for soils showing a narrow range of texture is important in the improvement of their performance (Bruand et al., 2003; Salchow et al., 1996), and that such improvements are usually greatest for coarse-textured soils (Al Majou et al., 2008) which dominate the coastal plains.

2. Materials and methods

2.1. Study site

The study was carried out in an area underlain by the coastal plain sands in Akwa Ibom State, southeastern Nigeria (Fig. 1). The state is located between latitudes 4° 30′ and 5° 30′ N and longitudes 7° 30′ and 7° 56′ E, and covers an area of 8412 km^2 out of which 75% is on the coastal plain sands (Petters et al., 1989; Sivanesan and Waller, 1987). The climate is humid tropical, characterized by distinct rainy (April to October) and dry (November to March) seasons. Rainfall distribution in a year is bimodal (with peaks in July and

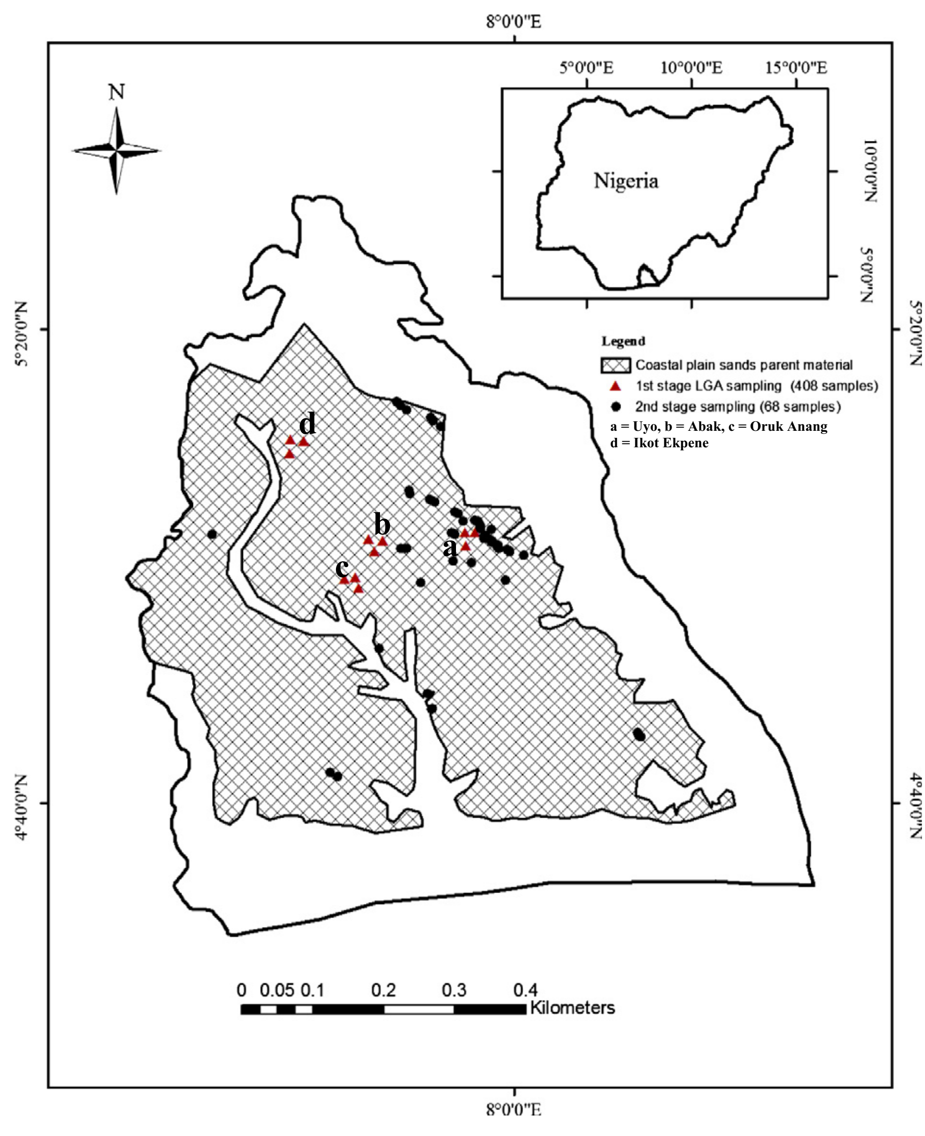

Fig. 1. Map of Akwa Ibom State showing sampling points on coastal plain sands.