Sway of slope position on soil properties, moisture content characteristics,

and soil stability in abak river basin, akwa ibom state, nigeria

ABSTRACT

Mechanisms acting in the retention of soil moisture and formation of soil aggregate is influence by slope position, these features meditates many soil physical, chemical and biological processes that facilitate stable soil structure. A study was conducted to assessed slope position influence and moisture content on soil properties and aggregate stability in Abak River Basin, Akwa Ibom State, Nigeria. Five locations were selected for the study, in each location, three slope positions were identified, the upper, middle and lower slopes, soil samples were collected from 0 – 30cm depth from each slope position, giving a total of fifteen soil samples and were taken to the laboratory for analyses. Results showed that all slope positions had moderate acidity. Bs increased down the slope, while Al did not follow a definite pattern along the different physiographic position of the Basin. Water stability aggregate for the three slope positions were not statistically different, but the seemingly least among the slope position was that of the upper slope. Both dry and wet aggregate size distribution werer dominted by small mcro aggregate for all slope positions. Organic matter content to some extent lead to increase in aggregate stability with the most pronounced effect occurring in the middle slope. Adoption of management practices that geared towards increase in organic matter and moisture cotent of the soil for sustainable environment and crop growth are required for soil aggregate formation.

Keywords: Sway slope position, moisture characteristics, aggregate size distribution, aggregate stability indices.

INTRODUCTION

Slope is element derives from geomorphic processes that causes and retard the convergence or divergence of fluxes of materials on the landscape (Essien et al., 2025a). Soils differ in their charcteristics primarily because of slope, slope exert greater impact on the composition of soil properties as rainfalls leach the top soil nutrient down the steep slope, that could enhance aggregate formation (Ogban *et al.*, 2022). Soil aggregate stability is an important factor influencing soil fertility sustainability and crop production (Amezketa, 1999). Soil aggregates can be formed by both aggregation and fragmentation processes, it is a group of primary soil particle that coheres to each other more strongly than other surrounding particles (Six *et al*., 2004; Ibanga *et al.,* 2025).

The relative abundance of aggregates at each possible size, after breaking the soil into individual aggregates in a prescribed way is the usual representation of the characteristics size distribution (Sam *et al*, 2025a). Similarly, an abundance index may indicate stability, as the fraction of soil materials that remains aggregated after a specified disruptive procedure (Essien and Ogban, 2018). Soil aggregate are the basic unit of soil structure and are composed of primary particles and bonding agents (Haynes *et al*., 1991), while soil structure is an important property that meditates many soil physical and biological processes and control soil organic matter (SOM), decomposition (Sam *et al*., 2025b ; Ogban *et al*., 2016; Mark *et al*., 2024).

Organic matter is considered a major binding agent that stabilizes soil aggregates (Essien *et al*., 2025a; Simeon and Essien, 2023; Essien *et al*., 2024a). Stability depends on the binding mechanisms of clay and organic matter, such as chemical bonding by organic compounds and physical binding of particles by fungal hyphae and plant roots (Angens, 1998). Soil organic matter can be physically protected from microbial decomposition through sorption to clay minerals (Essien *et al*., 2023 ; Hassink *et al*, 1993) and encapsulation within soil aggregate ( Golchin *et al*., 1994 ; Essien *et al*., 2024b), other stability indices relate more directly in terms of the mechanical energy per soil mass that must be applied to achieve a certain result such as aggregate rupture (Essien *et al*., 2019).

Analysis of soil aggregate may be use to know the stability of soil and severity of erosion on aggregate (Essien *et al*., 2024c), also dry aggregates may be used to estimate possible wind erosion effects, while wet analysis may be more appropriate to evaluate or predicts erosion due to rainfall impact and run-off. The stability of wet aggregates can be related to surface-seal development and field infiltration as water stable fractions may restrict water entry and form surface seals (Loch, 1994). Through these erosion and sealing effects as well as the relationship between aggregation and structural features such as macrospores, aggregates analysis may help us to understand most aspects of soil water behavior, including runoff, infiltration and distribution as well as soil aeration and root growth. Increasingly, aggregates properties are being used in models that predict soil hydraulic water retention and saturated hydraulic conductivity (Rieu and Sposito, 1991 ; Ogban and Essien, 2016 ; Essien *et al*., 2024c).

Abak River Basin is characterized by gentle and steep slopes and is one of the areas with spectacular soil erosion features, intensive crop production has also taken place in the Basin in recent years. Soil characterization in relation to soil management for crop production and erosion control has been conducted in a large area of the state (Petters *et al*., 1989) and such studies in Abak River Basin are scarce. The aim of the study is to evaluate effect of slope position on soil physical properties, organic carbon and aggregate stability in Abak River Basin in Akwa Ibom State, Southeastern, Nigeria.

**MATERIALS AND METHODS**

**Study Area**

This research was conducted in Abak River Basin in Akwa Ibom State, Southeastern, Nigeria. The Abak River Basin covers a total area of about 413. 5 km2, and is bounded by latitudes 4o20I and 5 o12IN and longitudes 7 o31I and 8 o11IE (Petters *et al.,* 1989). The area is characterized by a humid tropical climate based on Koppen’s classification. The climate is divided into two seasons, the wet or rainy season, which lasts from April to October, and dry season, which last from November to February.

The rainfall varies from 2500 – 4000 mm with average daily temperature ranges from 26oC to 28 oC. Solar radiation varies from 6 to 15 mm per day. The relative humidity ranges from 75 to 95 %, while evapotranspiration ranges from 4.11 to 4.95 mm (Udosen, 2008). The study area comprises of rough and intensely dissected terrains which comprises of largely poorly consolidated sand and parent materials with landscape comprising steep sided hills, valleys, slopes and sharp crest ridges.

The vegetation of the study area is typical of the rainforest belt of Nigeria and the vegetation is however being replaced by secondary forest predominantly of wild palm tree woody shrubs and various grasses under growth. Poor management and improper land use has led to forest depletion which result in soil degradation and low productivity yield (Sam *et al.,* 2025b). Land use comprises mainly cultivation of crops, such as cassava, yam, maize, cocoyam,Telferia, okro, pepper, melon, garden egg etc. (Akata *et al*., 2025; Akpan *et al*., 2025; Ben *et al.* 2024; Akata *et al*., 2024).

**Field Methods**

The study was conducted in Abak River Basin in Akwa Ibom State, Nigeria. Five locations were selected for the study, in each toposequences, three slope positions were identified, the upper, middle and lower slopes, soil samples were collected from 0 – 30 cm depth from each slope position, giving a total of fifteen (15) soil samples. The soil samples were air-dried, and used for physical and chemical analysis. Core soil samples were collected with the used of core cylinders measuring 7.2 cm long and 6.8cm internal diameter, which was used for the determination of saturated hydraulic conductivity and bulk density.

**LABORATORY ANALYSIS**

**Physical Analysis**

Particle size analysis was determined using the Bouyoucos hydrometer method after dispersing the soil with sodium hexametaphosphate solution, as described by Dane and Topp (2002). Saturated hydraulic conductivity was determined using the constant head permeameter methods as described by Dane and Topp (2002). The saturated hydraulic conductivity was calculated using the equation below.

Where

Ksat = Saturated hydraulic conductivity (Cm/min),

Q = discharge rate (Cm3)

L = length of Soil Column (Cm)

h = change in hydraulic head (Cm)

A = Cross – sectional area through which the flow takes place

t = time taken to collect Q (Min)

Bulk density was determined by the method described by Dane and Topp (2002). Soil samples were oven – dried at a temperature of 105oC to a Constant Mass and bulk density was calculated using the equation below:

Where

𝓁b = bulk density (MgM-3)

Ms = dry soil mass (kg),

Vt = total volume soil (M-3), this was calculated from the internal dimension of the cylinder.

Total porosity was calculated from particle density relationship as follows:

Where

*f* = Total porosity (m3m-3)

𝓁b = bulk density (MgM-3)

𝓁s = particle density (MgM-3), which is assumed to be 2.65 m3m-3.

Macro porosity was calculated from the values of total porosity and field water capacity of the soil as follows:

Where

*f*a = macro porosity (m3m-3)

*f*t = Total porosity (m3m-3)

Ꝋv = volumetric water content (m3m-3).

Available water capacity: Field water content was determined using the approximate method described by Dane and Topp (2002). The determination was done with the core cylinders based on the fact that “the content of water, on a mass or volumes basis” remains in a two (2) or three (3) days after having been wet and after free drainage is negligible (Essen *et al*., 2025b). Field Water Content (FWC) was calculated using the equation;

Where

FWC = field water content

M (s+c)i = initial mass of saturated soil + core

M (s+c)f = final mass of oven dried soil + core

Permanent Wilting Point (PMP): Plants were grown in a containers of uniform soil that are sealed to limit loss other than that by transpiration, they were kept adequately watered until the third set of leaves appears at which time of watering ceases.

To ensure that wilting is permanent, plants were placed overnight in a dark humid chamber when all the leaves remain wilted in the morning permanent wilting point has been reduced. Soil water content/water potential were determined by the Sunflower method).

Water Stable Aggregates was determined using wet sieving method as described by Dane and Topp (2002). Soil aggregates was separated into different sizes by sieving through a nest of 2mm, 1mm, 0.5 mm, 0.25 mm, 0.1 mm and 0.05 mm sieves, oven dried for 24 hours at 105oC, weighed and mechanically dispersed in 50 ml hexametaphosphate solution and each fraction was sieved and size distribution of the sand fraction determined.

Where

As = Water stable aggregates (%)

Msoil(t) = Total mass of whole sample sand (g)

Msand = oven dry weight of sand (g)

Msand(t) = Mass of sand in the whole soil sample (g)

Mean weight diameter of dry and wet aggregate (MWDD and MWDW), respectively were calculated from the data of aggregate size distribution using the equation (Van Bavel, 1949 cited in Essien *et al.*, 2019):

Where

Xi = Mean diameter of each sieve (cm)

Wi = proportion of total ratio (%)

n = number of sieves used.

**Aggregate Size Analysis**

Soil aggregates were determined using wet and dry sieving methods as described by Six *et al*. (2000). Soil aggregates were separated into different sizes by sieving through a nest of 2.0 mm, 1.0 mm, 0.5 mm, 0.1 mm, 0.25 mm and 0.05 mm sieves and then placed it on nest of sieves andallowed it to soak for 5 mimutes. The soaked soils was wet, sieved by lowering it into and out of waterfor fifteen minutes, then the soil remainingon the sieve was transferred into moisture can and oven dried for twenty for hours at 105oC, weighed and mechanically dispersed in 50 ml hexametaphosphate solution and each fravtion was sieves to determine the size distribution of the sand fraction.

**Chemical Analysis**

Soil pH was determined using 1:2.5 soil and water suspension and the pH value read with a glass electrode pH meter. Organic carbon was measured in the soil samples/aggregates sizes by the dichromate wet oxidation method of Walkley and Black as described by (Nelson and Sommers, 1982). Available phosphorus was extracted by Bray PI method and P determined in the extract by the blue colour method . Total nitrogen was determined by the macro – kjeldahl digestion and distillation method as modified by Udo *et al.,* (2009).

Exchangeable bases (Ca, Mg, Na and K) were extracted using normal Ammonium Acetate (NH4OAC) solution (Thomas, 1982). The available K and Na were determined by flame photometry method.

Free Oxides: Total free oxides was extracted with citrate buffer, amorphous form by ammonium oxalate or NaOH solution, and the organic form by the pyrophosphate solution and the crystalline Fe and Al was equally determined (Udo *et al.,* 2009).

**Statistical Analysis**

The data generated for physical and chemical properties of the soil were summarized using descriptive statistic, as well as Pearson correlation analysis to establish relationship between aggregates, organic matter and soil properties in Abak River Basin.

**Results and Discussion**

**Effect of slope position on soil physical properties in the study area**

The reults of soil physical properties in the study area, presented in Table 1, showed that at the upper slope, coarse sand ranged from 664 to 778 gkg-1 with mean value of 726 ± 37 gkg-1 (CV = 5 %) ; fine sand ranged from 44 to 128 gkg-1 with a mean valueof 75 ± 25 gkg-1 (CV = 36 %) ; total sand ranged from 752 to 822 gkg-1 with a mean value of 792 ± 25 gkg-1(CV= 3 %) **;** silt ranged from 20 to 68 gkg-1 with a mean of 40 ± 20 gkg-1(CV = 50 %) and clay ranged from 152 to 182 gkg-1 with a mean value of 168 ± 11 gkg-1 (CV = 8%). At the middle slope, coarse sand ranged from 678 ± 772 gkg-1 with mean value of 733 ± 29 gkg-1 (CV = 4 %), fine sand ranged from 42 to 124 gkg-1 with a mean value of 67 ± 26 gkg-1 (CV = 38%), total sand ranged from 764 ± 822 gkg-1 with a mean value of 797 ± 21 gkg-1 (CV = 3 %); silt ranged from 20 to 58 gkg-! With a mean value of 36 ± 16 gkg-1 (CV =46 %) and clay ranged from 120 to 180 gkg-1 with a mean value of 163 ± 19 gkg-1 (CV = 11 %). At the lower slope, coarse sand ranged from 689 to 764 gkg-1 with a mean value of 728 ± 27 gkg-1 (CV = 4%). Fine sand ranged from 44 to 123 gkg-1 with a mean value of 69 ± 26 gkg-1 (CV = 37 %), total sand ranged from 762 to 812 gkg-1 with a mean value of 791 ± 19 gkg-1 (CV = 2 %), silt ranged from 20 to 58 gkg-1 with a mean of 37 ± 15 gkg-1 (CV = 39 %) and clay ranged from 148 to 192 gkg-1 with a mean value of 172 ± 15 gkg-1 ( CV = 9 %).

Bulk density at the upper slope ranged from 1.14 to 1.55 Mgm-3 with a mean value of 1.33 ± 0.16 Mgm-3 (CV = 12.23 %). The middle slope ranged from 1.04 to 1.61 Mgm-3 with a mean value of 1.36 ± 0.18 Mgm-3 (CV = 13.37 %), while the lower slope ranged from 1.17 to 1.55 Mgm-3 with a mean value of 1.39 ± 0.15 Mgm-3 (CV = 10.54 %).

Macro porosity ranged from 0.26 to 0.43 m3m-3ss with a mean value of 0.38 ± 0.06 m3m-3 (CV = 16.59 %), at the upper slope at the upper slope=; 0.22 to 0.41 m3 m-3 with a mean of 0.33 ± 0.06 m3 m-3 (CV = 16.94 %) at the middle slope and at the upper slope, total porosity ranged from 0.42 to 7.85 m3 m-3 with a mean of 0.1.96 ± 3.06 m3 m-3 (CV = 155. 90 %); at the middle slope, total porosity ranged from 0.39 to 3.00 m3 m-3 with mean value of 0.98 ± 1.06 m3 m-3 (CV = 108. 70 %) and at the lower slope, it range from 0.42 to 1.30 m3 m-3 with mean value of 0.64 ± 0.35 m3  m-3 (CV = 54. 35 %) . Total porosity was inversely proportional to bulk density.

Saturated hydraulic conductivity (Ksat) at the upper slope ranged from 0.57 to 5.41 cm min-1 with mean value of 3.21 ± 1.54 cm min-1 (CV = 47.84 %) The values at the middle slope ranged from 0.40 to 6.12 cm min-1 with mean value of 3.39 ± 2.33 cm min-1 (CV = 68.69 %) and at the lower slope, values of Ksat  ranged from 0.49 to 4.87 cm min-1 with mean value of 2.42 ± 1.35 cm min -1 (CV = 55.90 %). Ksat at the lower slope was lowest compared to those of the upper and middle slope probably because of the high water table at the slope position.

**Efect of soil chemical properties in Abak River Basin**

The results of effect of slope on soil chemical properties are presented in Table 2. In the upper slope, the pH ranged from 5.24 to 5.63 with mean of 5.40 ± 0.13 (CV = 2.50 %) , middle slope ranged from 5.24 to 5.44 with mean of 5.38 ± 0.06 (CV = 1.17 %) and 5.25 to 5.49 with mean of 5.37 ± 0.08 (CV = 1.51 %) at the lower slope. Moderately acidic reaction was recorded for all slope position Values of electrical conductivity (EC) ranged from 0.024 to 0.29 dsm-1 with mean of 0.027 ± 0.02 dsm-1 (CV = 6.793 %) at the upper slope; 0.024 to 0.029 dsm-1 with mean of 0.027 ± 0.002 dSm-1 (CV = 7.066 %) at the middle slope and 0.025 to 0.029 dsm-1 with mean of 0.027 ± 0.002 dsm-1 (CV = 5.87 %) at the lower slope. For the studied soils, EC was low and far less than 0.15 dsm-1, which is recommended by Parfitt *et al*. (1995).

Organic matter ranged from 9.7 to 31.0 g kg-1 with mean value of 17.2 ± 8.1 g kg-1 (CV = 47.2 %) at the upper slope; 3.4 to 43.1 g kg-1 with mean value of 20.6 ± 12.3 g kg-1 (CV = 59.4 %) at the middle slope and 1.7 to 27.9 g kg-1 with mean value of 14.6 ± 9.6 g kg-1 (CV = 65.8 %) at the lower slope. Value of available P ranged from 0.09 to9.33 mgkg-1 with a mean value of 6.20 ± 2.89 mgkg-1 (CV = 46.60 %) at the upper slope; 1.87 to 13.07 mgkg-1 with a mean value of 7.01 ± 3.86 mgkg-1 (CV = 55.12 %) at the middle slope and 0.47 to 14.47 mgkg-1 with a mean value of 7.33 ± 5.25 mgkg-1 (CV = 71.66 %) at the lower slope. Ca ranged from 1.6 to 10 cmolkg-1 with a mean value of 42 ± 3.2 cmolkg-1 (CV = 75 %) at the upper slope; 1.2 to 10.4 cmolkg-1 with a mean value of 4.3 ± 2.9 cmolkg-1 (CV = 66.9 %) at the middle slope and 3.2 to 8.8 cmolkg-1 with mean value of 5.3 ± 2.3 cmolkg-1 (CV = 42.4 %) at the lower slope.

Mg ranged from 0.53 to 3.33 cmolkg-1 with mean value of 1.41 ± 1.06 cmolkg-1 (CV = 75.11 %) at upper slope; 0.40 to 3.47 cmolkg-1 with mean value of 1.41 ± 0.97 cmolkg-1 (CV = 68.54 %) at the middle slope and 1.07 to 2.93 cmolkg-1 with mean value of 1.71 ± 0.75 cmolkg-1 (CV = 44.10 %) at the lower slope.

Na ranged from 0.04 to 0.80 with mean value of 0.22 ± 0.30 cmolkg-1(CV = 135.86 %) at upper slope; 0.06 to 0.80 cmolkg-1 with mean value of 0.22 ± 0.30 cmolkg-1 (CV = 137.47 %) at the middle slope and 0.05 to 0.11 cmolkg-1 with mean value of 0.08 ± 0.02 cmolkg-1 (CV = 26 %) at the lower slope. Na content was generally low, indicating the inability of the soil to be dispersed. K ranged from 0.04 to 0.62 cmolkg-1, with mean of 0.30 ± 0.20 (CV = 67.60 %) at the upper slope; 0.13 to 0.39 cmolkg-1 with mean of 0.27 ± 0.09 (CV = 34. 41 %) at thhe middle slope and 0.09 to 0.41 cmolkg-1 with mmean of 0.25 ± 0.12 (CV = 48.04 %) at the lower slope. These values of exchangeable K were low considering the standards of Udo *et al.* (2009).

Ca and Mg increased down the slope as a result of the movement of their soluble forms from the upper slope down the lower slope. Tian and Broussard (1992) also found that soils on summit position contain less exchangeable Ca and Mg, due to leaching. Soils can significantly accumulate these soluble ions such as Ca, Mg, K and Na from the summit and deposited on the footslope position where leaching is weaker and soil enrichment is stronger. The differences of these cations along the slopes was also observed by Ijah *et al.* (2023).

Amorphous of Fe ranged from 308 to 553 mgkg-1 wth a mean of 414 ± 87.74 mgkg-1 (CV = 21. 19 %) at the upper slope; 317.17 to 505 mgkg-1 with a mean of 419.05 ± 58.15 mgkg-1 (CV = 13. 88 %) at the middle slope and 363.5 to 500 mgkg-1 with a mean of 427.99 ± 57.24 mgkg-1 (CV = 13.37 %)at the lower slope. Crystalline of Fe ranged fom 563.83 to 820 mgkg-1 with mean value of 712.56 ± 88.48 mgkg-1 (CV = 12.42 %) at the upper slope; 597.80 to 811.10 mgkg-1 with mean value of 706. 33 ± 72.73 mgkg-1 (CV = 10.30 %) at the middle slope and 600.2 to 800.20 mgkg-1 with mean value of 78.77 ± 62.61 mgkg-1  (CV = 8.71 %) at the lower slope. Values of amorphous of Fe slightly increased from the upper to the lower slope, which irregular levels of crystalline of Fe was found for all slope position perhaps as a result of differences in soil properties.

Amorphous of Al ranged from 56.38 to80.42 mgkg-1 with mean value of 69.39 ± 8.31 mgkg-1 (CV = 11.97 %) at the upper slope; 62.09 to 98.22 mgkg-1 with mean value of 80.85 ± 13.09 mgkg-1 (CV = 16.19 %) at the midde slope and 56.49 to 88.10 mgkg=1 with mean value of 73.43 ± 12.06 mgkg-1 (CV = 16.42 %) at the lower slope. Crystalline Al ranged from 87.71 to 199.03 mgkg-1 with mean valueof 133.99 ± 41.56 mgkg-1 (CV = 31.01 %) at the upper slope; crystalline Al ranged from 99.89 to 208.86 mgkg-1 with mean value of 144.82 ± 42.10 mgkg-1 (CV = 29.07 %) at the middle slope and 99.98 to 170.30 mgkg-1 with man value of 123.49 ± 28.42 mgkg-1 (CV = 23.02 %) for the lower slope. Values of amorphous and crystalline Al did not follow a definite pattern along the different slope position.

**Effect of Slope position on soil moisture content characteristics**

The results of effect of slope on soil moisture characteristics in Table 3, revealed that field water capacity (FWC) had minimum value of 0.09 %, maximum value of 0.35 %, with mean value of 0.17 ± 0.08 %, (CV = 43.59 %) in the upper slope; minimum value of 0.14 %, maximum value of 0.29 %, with mean value of 0.18 % ± 0.04 %, (CV = 24.84 %) in the lower slope and minimum value of 0.09 %, maximum value of 0.49 %, with mean value of 0.20 ± 0.14 %, (CV = 72.78 %) for lower slope position.

Permanent wilting point (PWP) had minimum value of 0.07 %, maximum value of 0.16 %, with mean of 0.12 ± 0.04 %, (CV = 34.02 %) at the Upper slope; minimum value of 0.10 %, maximum value of 0.17 %, mean of 0.13 ± 0.03 %, (CV = 20.08 %) at the middle slope and a minimum value of 0.01 %, maximum value of 0.17%, mean of 0.10 ± 0.04 %, (CV = 43.40 %) at the lower slope. There was no definite trend of PWP along Basin; this may have been caused by localization differences in soil moisture prior to factors other than slope position.  
Available water capacity (AWC) had minimum value of 0.01,, maximum value of 0.26 %, with mean value of 0.08 ± 0.07 (CV = 93. 34 %) at the upper slope; minimum value of 0.01 to 0.18 % with mean value of 0.05 ± 0.05, (CV = 99.98 %) at the middle slope and minimum value of 0.01, maximum of 0.38 %, with mean value of 0.10 ± 0.14, (CV = 125. 45 %) at the lower slope. Available water capacity decreased down the slope, which was especially manifested during the period of water shortage.

**Effect of slope position on dry and wet aggregate size distribution**

The results effect of slope positon revealed that both dry and wet aggregate size distribution were dominated by small macro aggregates (0.25 to 2.00 mm) for all slope positions. However, various aggregate size were irregularly distributed along the River Basin as no definite trend was observed for the three slope positions. Dominance of small macro aggegates over micro aggregates ( ˂ 0.05 and 0.25 mm) were observed and is a good indicator of structural stability in all slope position in Abak River Basin. The study area is tropical rain forest, also due to the fact that on a slopy land, water erosion detach and transport the unstable aggregate and aggregate remaining may be due to their resistance to impact of water erosion. There was no significant differences of various aggregate sizes among the three slope positions.

**Effect of slope position on aggregate stability indices**

Mean values of some indicators of aggregate stability are presented in Table 5. The results showed that dry mean weight diameter (MWDd) was 1.28 ± 0.33 mm (CV = 25.81 %), 1.5 ±0.57 mm (CV = 38.25 %) and 1.40 ± 0.66 mm (CV = 46.75 %) for upper middle and lower slope, respectively. Wet mean weight diameter (MWDw) was 2.33 ± 0.86 mm (CV = 36.93 %), 2. 14 ± 0.56 mm (CV = 26.43 %) and 1.55 ± 0.58 mm (CV = 37.40 %) for upper, middle and lower slope, respectively. Water stability aggregate (WSA) was 6.94 ± 2.04 % (CV = 29.36 %), 5.69 ± 1.15 % (CV = 20.25 %) and 5.72 ± 1.81 % (CV = 31.69 %) for upper, middle and lower slope, respectively. The results revealed that there were irregular differences in MWDd and MWDw.

**Relationship between selected soil properties and indices of aggregate stability**

The results showed that MWDd correlated significantly, negatively with WAS (r = -0.379\*, P ≤ 0.05), MWDw correlated significantly, negatively with Am. Fe (r = - 0.673\*\*, P ≤ 0.01). Clay correlated significantly, negatively with K (r = - 0.552\*\*, P ≤ 0.01). Bd correlated significantly, positively with Cry. Fe (r = 0.396\*, P ≤ 0.05). OC correlated significantly, positively with K (r = 0.465\*\*, P ≤ 0.01). Ca correlated significantly, positively with Mg (r = 0.998\*\*, P ≤ 0.01). Na correlated significantly, positively with Am. Fe (r = 0.476\*\*, P ≤ 0.01).

**Table 1: Soil Physical Properties Affected by Slope Position in Abak** River **Basin**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | | | |
| Location Cs Fs Ts Silt Clay Bd Mp Tp Ksat  gkg-1  Mgm-3 m3m-3 m3m-3  cmmin-1 | | | | | | | | | |
| Upper Slope | | | | | | | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 664  778  726  37  5 | 44  128  75  25  36 | 752  822  792  25  3 | 20  68  40  20  50 | 152  182  168  11  8 | 1.14  1.55  1.33  0.18  12.23 | 0.26  0.43  0.38  0.06  16.59 | 0.42  7.85  1.96  3.06  155.90 | 0.57  5.41  3.21  1.54  47.84 |
| Middle Slope | | | | | | | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 670  772  733  28  4 | 42  124  67  25  38 | 764  822  767  24  3 | 20  54  36  16  46 | 120  180  163  19  11 | 1.04  1.61  1.36  0.17  13.37 | 0.22  0.41  0.32  0.06  16.94 | 0.39  3.00  0.97  1.06  108.70 | 0.49  4.87  2.40  1.32  55..90 |
| Lower Slope | | | | | | | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 689  764  725  27  4 | 44  123  67  26  37 | 762  812  790  19  2 | 20  58  37  15  39 | 148  192  172  15  9 | 1.17  1.55  1.38  0.15  10.54 | 0.29  0.40  0.35  0.04  12.47 | 0.42  1.20  0.64  0.35  54.35 | 0.40  6.10  3.39  2.33  68.68 |

CS= Coarse sand ; Fs = Fine sand ; Ts = Total sand ; Bd = Bulk density ; Mp = Macro porosity ; Tp = Total porosity ; Ksat = Saturated hydraulic conductivity.

**Table 2: Soil Chemical Properties Affected by Slope Position in Abak River Basin**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Exchangeable Bases Am. Cry. Am. Cry.  Location pH OM Av.P Ca Mg Na K Fe Fe Al Al  gkg-1 mgkg-1 cmolkg-1 mgkg-1 | | | | | | | | | | | |
| Upper Slope | | | | | | | | | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 5.28  5.68  5.40  0.13  2.50 | 9.7  31.0  17.2  8.1  47.2 | 0.90  9.33  6.20  2.89  46.60 | 1.6  10.0  4.2  3.2  75.0 | 0.53  3.33  1.41  1.06  75.11 | 0.04  0.80  0.22  0.30  135.86 | 0.04  0.62  0.30  0.20  67.60 | 308.00  553.00  414.06  87.74  21.19 | 563.33  820.00  712.56  88.48  12.42 | 56.38  80.42  69.39  8.31  11.97 | 87.71  199.03  133.99  41.56  31.01 |
| Middle Slope | | | | | | | | | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 5.24  5.44  5.38  0.063  1.175 | 3.4  43.4  20.6  12.8  59.4 | 1.87  13.07  7.05  3.86  55.12 | 1.2  10.4  4.3  2.9  66.9 | 0.40  3.47  1.41  0.97  68.54 | 0.06  0.80  0.22  0.30  137.47 | 0.13  0.39  0.29  0.09  34.41 | 317.17  505.00  419.05  58.15  13.88 | 597.80  811.10  706.33  72.73  10.30 | 62.09  98.22  80.85  13.09  16.19 | 99.89  208.86  144.82  42.10  29.07 |
| Lower Slope | | | | | | | | | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 5.26  5.48  5.37  0.081  1.51 | 1.7  27.9  15.0  9.6  66.0 | 0.47  14.47  7.38  5.26  71.66 | 3.2  8.9  5.3  2.3  42.5 | 1.08  3.01  1.71  0.75  44.20 | 0.05  0.11  0.08  0.02  26.00 | 0.09  0.41  0.25  0.12  48.04 | 363.50  500.00  428.99  58.25  13.37 | 600.20  800.20  719.77  62.81  8.71 | 56.49  88.10  75.43  12.08  16.42 | 99.98  170.30  125.02  28.42  23.02 |

OM = Organic matter; Av. P = available phosphorus, Ca = calcium, Mg = magnesium; Na = sodium; K = potassium; Am Fe = Amorphous of ion; Cry Fe = Crystalline of ion; Am Al = Amorphous of Aluminum; Cry Al = Crystalline of Aluminum

**Table 3: Moisture Characteristics Affected by Slope Position in Abak River Basin**

|  |  |  |  |
| --- | --- | --- | --- |
| Location FWC PWP AWC  % | | | |
| Upper Slope | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 0.09  0.35  0.17  0.08  43.58 | 0.07  0.16  0.12  0.04  32.02 | 0.01  0.26  0.08  0.07  92.32 |
| Middle Slope | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 0.14  0.29  0.18  0.04  24.85 | 0.10  0.17  0.13  0.03  20.08 | 0.01  0.18  0.05  0.05  99.98 |
| Lower Slope | | | |
| Min  Max  Mean  Std. dev. (±)  CV (%) | 0.09  0.49  0.20  0.14  72.78 | 0.01  0.17  0.10  0.04  43.40 | 0.01  0.38  0.10  0.14  125.45 |

FWC = Field Water Capacity; PWP = Permanent Wilting Point; AWC = Available Water Capacity

**Table 4: Effect of slope position on wet and dry aggregate size distribution**

|  |
| --- |
|  |

Aggregate size Upper Slope Middle Slope Lower Slope

|  |
| --- |
|  |

Dry Aggregate Distibution

˃ 2 mm 7.8 b 9.5a 7.5 b

1 mm 14.7 a 12.2 a 11.1 a

0.5 mm 8.2 a 7.5 a 9.7 a

0.25 mm 11.2 a 13.4 a 12.6 a

0.1 mm 2.5 a 4.1 a 3.4 a

˂ 0.05 mm 2.2 a 2.2 a 1.6 a

Wet Aggregate Distriibution

˃2 mm 3.8 a 3.8 a 4.5 a

1 mm 5.3 a 6.6 a 5.6 a

0.5mm 8.2 a 9.7 a 11.3 a

0.25 mm 15.7 a 17.5 a 14.4 a

0.1 mm 5.5 ab 6.1 a 3.8 b

˂ 0.05 mm 1.3 a 1.5 a 1.4 a

|  |
| --- |
|  |

**Table 5: Indices of Aggregates Stability of Soils along Abak River Basin**

|  |  |  |  |
| --- | --- | --- | --- |
| Location MWDd MWDw WSA  (mm) (mm) % | | | |
| Upper Slope | | | |
| Mean  Std. dev. (±)  CV (%) | 1.27  0.32  25.82 | 2.32  0.87  36.93 | 6.94  2.04  29.36 |
| Middle Slope | | | |
| Mean  Std. dev. (±)  CV (%) | 1.50  0.58  38.26 | 2.14  0.57  24.42 | 5.69  1.15  20.24 |
| Lower Slope | | | |
| Mean  Std. dev. (±)  CV (%) | 1.40  0.65  46.75 | 1.55  0.58  37.40 | 5.78  1.82  31.69 |

MWDd = Mean weight diameter dry

MWDw = Mean weight diameter wet

WSA = Water stability aggregate

**Table 6: Correlation Matrix of Selected Soil Properties and Indices of Aggregate Stability in Abak River Basin**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | MWDd | MWDw | WSA | Clay | Bd | OC | Ca | Mg | K | Na | AM. Fe | Cry. Fe |
| MWDd | 1.000 |  |  |  |  |  |  |  |  |  |  |  |
| MWDw | 0.093 | 1.000 |  |  |  |  |  |  |  |  |  |  |
| WSA | -0.379\* | 0.130 | 1.000 |  |  |  |  |  |  |  |  |  |
| Clay | 0.048 | 0.145 | 0.135 | 1.000 |  |  |  |  |  |  |  |  |
| Bd | 0.178 | -0.246 | -0.133 | 0.324 | 1.000 |  |  |  |  |  |  |  |
| OC | -0.028 | -0.090 | 0.184 | -0.202 | -0.292 | 1.000 |  |  |  |  |  |  |
| Ca | -0.178 | 0.060 | 0.230 | -0.049 | -0.181 | -0.3061 | 1.000 |  |  |  |  |  |
| Mg | -0.218 | 0.055 | 0.259 | -0.054 | -0.203 | -0.296 | 0.998\*\* | 1.000 |  |  |  |  |
| K | -0.073 | 0.017 | -0.076 | -0.552\*\* | -0.044 | 0.465\*\* | -0.186 | -0.166 | 1.000 |  |  |  |
| Na | 0.011 | -0.179 | -0.012 | 0.020 | -0.071 | -0.280 | -0.275 | -0.264 | 0.088 | 1.000 |  |  |
| AM. Fe | -0.125 | -0.673\*\* | -0.058 | 0.181 | 0.318 | -0.228 | -0.162 | -0.149 | -0.170 | 0.476\*\* | 1.000 |  |
| Cry. Fe | 0.206 | -0.002 | -0.140 | 0.060 | 0.396\* | -0.357 | 0.174 | 0.163 | -0.109 | 0.089 | 0.014 | 1.000 |

MWDd = Mean weight diameter dry; MWDw = Mean weight diameter wet; WSA = Water stability aggregate; Bd = Bulk density; OC = Organic carbon; Ca = calcium, Mg = magnesium; K = potassium; Na = sodium; Am Fe = Amorphous of ion; Cry Fe = Crystalline of ion.

**CONCLUSION**

Slope position effect on soil moisture characteristics and aggregate stability revealed that various aggregate sizes were irregularly distributed along the Basin as no definite trend was observed for the three slope position. There was no significant difference in organic matter among the three slope position. Values of amorphous of Fe slightly increased from the upper to the lower slope, which irregular levels of crystalline of Fe was found for all slope position perhaps as a result of differences in soil properties. There was a decrease in root zone soil water for the upper slope position compared to both middle and lower slope positions, which was manifested during the period of water shortage.

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