*International Journal of Agricultural and Natural Sciences*
*E-ISSN: 2651-3617 13(2): 62-82, 2020*
*Research Article*

# LAND DEGRADATION IN THREE LOCATIONS AND SAMPLING PERIODS IN PHYSIOGRAPHIC UNITS UNDER ARABLE CROP PRODUCTION IN SUB- HUMID TROPICS OF NIGERIA

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(Received 24th April 2020; accepted 06th July 2020)

**ABSTRACT.** Understanding landscape features of cultivable agricultural lands and the influence by topographic settings and degradation has become imperative for sustainable land use planning and management. This study compared land degradation in three locations and sampling periods under arable crop production in Nsukka area. Three locations (Obukpa, Lejja and Ozi-Edem) were selected. Soil auger samples were randomly collected in triplicates fromdepth of 0-30cm in plots of 25 $m^2$ marked on the farmer's field. Soil core samples were collected at 0-10cm depth. Soil sampling was done at three repeated periods; April-May, July-August and October-November for 1st,2nd and 3rd sampling period, respectively. Soil samples were analyzed for physical and chemical properties and all data statistically analyzed as a 3 x 3 x 3factorial using Genstat statistical software. FAO method was employed in land degradation assessment. Results showed that most physical and chemical properties had significantly ($p < 0.05$) highest values at low slope relative to others,and also at first sampling period relative to other sampling periods. Degradation in Upper slope increased by 3.4 and 5.9 % over middle and lower slope, respectively. Obukpa had the highest level of degradation relative to other locations. Degradation was highest in 3rdsampling period and increasedby 8.4 and 14.9 %over2ndand 1stsampling period, respectively.Degree of degradation increased with sampling time. Appropriate conservation measures, inclusion of restorative crops in cropping systems, use of locally available materials and bio fertilizer are recommended to reduce effect of land degradation in arable soils.

**Keywords:** *slope, degradation, soil properties, land use, sub-tropic*

## INTRODUCTION

Land degradation is the result of a combination of social, political and biophysical forces operating across a broad spectrum of temporal and spatial scales but essentially arises from bad management that encourages soil erosion by wind and water. Intensification rather than extensification of agriculture is widely practiced to scale up food production. This practice has escalated land degradation [13].

In the tropics and subtropics, agricultural activities have been taking place under varying dynamic context such as physiography, agro-ecology, climate and soil conditions. The success is then strongly influenced by topographic settings, degree of human interferences and underlying biographical features [11].

It was reported that extreme pressure on landscape stability is high where there is a sharp increase in population [23] and this has been causing intensive land utilization and forest clearing for cultivation even in areas that are not practical for agriculture such as in steep hill slopes or marginal lands [38]. The greatest concern to the agriculturists in developing countries is to meet the future needs of the growing population. Land has been utilized intensively for all purposes at the expense of its suitability thereby resulting in land degradation and altering the natural ecological conservational balances in the landscape. Such imbalances pose great difficulty to soil productivity and food security [36].

In the last 50 years alone, 20% of the world's agricultural land has been irreversibly damaged due to human-induced land degradation. Thus, if the process of destruction continues at this pace, agriculture will lose 15-30% of its present productivity [18]. Land degradation is caused by poor land management practices such as slash and burn agriculture, uncontrolled livestock grazing on fragile lands, poor road construction and unplanned or poorly planned settlements in landslide-prone areas [33]. Annually colossal amounts of valuable top-soil is eroded into rivers and out to sea during heavy rains. Land degradation is a function of slope attribute, the amount of soil erosion has always been proportional to the steepness of the slope [24].

Variations in the physiography of agricultural lands have an enormous influence on soil properties and crop production. Study on the influence of different land uses and topography on soil properties in southeastern Nigeria revealed an increasing trend in soil pH, organic carbon and exchangeable bases with a decrease in slope [15]. Similar report was made for Wollo, Ethiopia [9]. Another study in northeastern Nigeriaby Ezeaku and Unagwu [13]and northeastern Ethiopia [19] also indicated that mean values of total nitrogen, organic matter and cation exchange capacity were higher in lower than upper slope land position. Report by Yimer [40]showed significant changes in soil properties on varied altitudinal ranges of Bale mountains, Ethiopia.

Other studies showed that involvement of farmers' different land use types put impact on soil fertility and productivity [19]. Their findings indicated lower soil organic carbon, total nitrogen and basic cations in cultivated lands compared to grazing or protected forest area which was attributed by continuous cultivation, absence of fallowing and erosion. Limited maintenance of soil physico-chemical health is very likely to result to poor aggregate stability, decline of soil organic matter, nutrient deficiency and unavailability to plants and stagnation of crop yields [39] and exacerbates soil degradation.

The foregoing is an indication that the soil quality is associated with biophysical setting and anthropogenic factors. Although, studies have shown effects of land use on soil properties along a toposequence [15, 6, 11, 9], there is dearth of information on degree of land degradation as influenced by location and sampling periods in physiographic units under cultivated crops. Again, soil degradation due to erosion is a major threat to sustainable agricultural production in the inland-upland continuum in Nsukka subtropical area. These necessitate the need for adequate information to intervene and solve soil degradation problem in the general area. The main objective of the study therefore is to asses land degradation as influenced by sampling period in physiographic units under cultivated crops in sub-humid tropics of Nsukka area.

## MATERIALS AND METHODS

### *Description of Study Area*

This research was carried out in three locations at Nsukka namely; Obukpa, Lejja and Ozi-Edem. These locations are in Nsukka agricultural zone of Enugu state with longitude of 6°43$^{I}$ - 6°55$^{I}$E and latitude 7°18$^{I}$ - 7°28$^{I}$N (Figure 1). The three locations were selected because they are among the major crop producing areas in Nsukka agricultural zone and are mostly affected by land degradation as was observed during the reconnaissance visits of the towns in the zone. Nsukka climate is characteristically sub-humid tropical, with mean annual total rainfall of about 1600 mm; of which distribution is bimodal, with peaks during July and October in the first and second phases, respectively. Atmospheric temperature in Nsukka is high with mean daily minimum temperatures between 21.40and 25.00°C, and mean daily maximum temperature ranges from 28.10 to 34.60°C. Relative humidity ranges between 70 and 80% [16]. The soils in Nsukka of Eastern Nigeria are generally derived from the residuum of false-bedded sand-stone or upper - coal measure formation as a result of disintegration of rock (which could be alteration by physical, chemical and biological processes) [2]. During reconnaissance visits, different land uses were identified along the physiographic units (Table 1) as being practiced by local farmers.

### *Field Methods*

*Site selection*

Three locations (Lejja, Obukpa and Ozi-Edem) in Nsukka local Government Area were selected and used for the study. Prior to the selection, reconnaissance visits were undertaken on five locations, out of which, three namely; Lejja, Obukpa and Ozi-Edem showed similarity in cropping systems (eg arable cropping: cassava/yam/ vegetable/ maize inter crops and cereal such as guinea corn cropping). The crops were observed to be grown along the landscape (physiographic units) positions – upper slope, middle slope and toe slope. Again, the three sites were observed to be experiencing erosion menace as shown by the presence of rill, sheet and gully erosions. The topographic map of the three selected locations is shown in Fig. 1, while Table 1 shows the coordinates and land use types obtained in the three locations.

***Table 1.*** *Location physiographic units and land uses with their coordinates*

| Location | Physiographic unit | Latitude | Longitude | Altitude (m) | Land use |
|---|---|---|---|---|---|
| Lejja | US | 6.4836° N | 7.2342° E | 496.58 | Pepper/maize/cassava |
| | MS | 6.4837° N | 7.2343° E | 490.60 | Pumpkin/tomatoes |
| | TS | 6.4838° N | 7.2344° E | 439.91 | Cocoyam/cassava/ Pepper |
| Obukpa | US | 6.5315° N | 7.2380° E | 417.76 | Cassava/bitter yam |
| | MS | 6.5313° N | 7.2377° E | 414.32 | Garden egg/ tomatoes |
| | TS | 6.5311° N | 7.2375° E | 389.86 | Cocoyam |
| Ozi-Edem | US | 6.5093° N | $7.2069^0$ E | 414.28 | Pepper/maize/tomatoes |
| | MS | 6.5094° N | $7.2067^0$ E | 409.97 | Garden egg/maize/cassava |
| | TS | 6.5095° N | $7.2065^0$ E | 402.94 | Cassava/garden egg |

NB: US= upper- slope; MS = middle- slope; TS =toe -slope. (Zea mays), Cassava (Manihot esculenta), Pumpkin (Cucurbita pepo), Cocoyam (Colocasia esculenta), bitter yam (Dioscorea bulbifera), Garden egg (Solanum melongena), Tomatoes (Solanum lycopersicum)

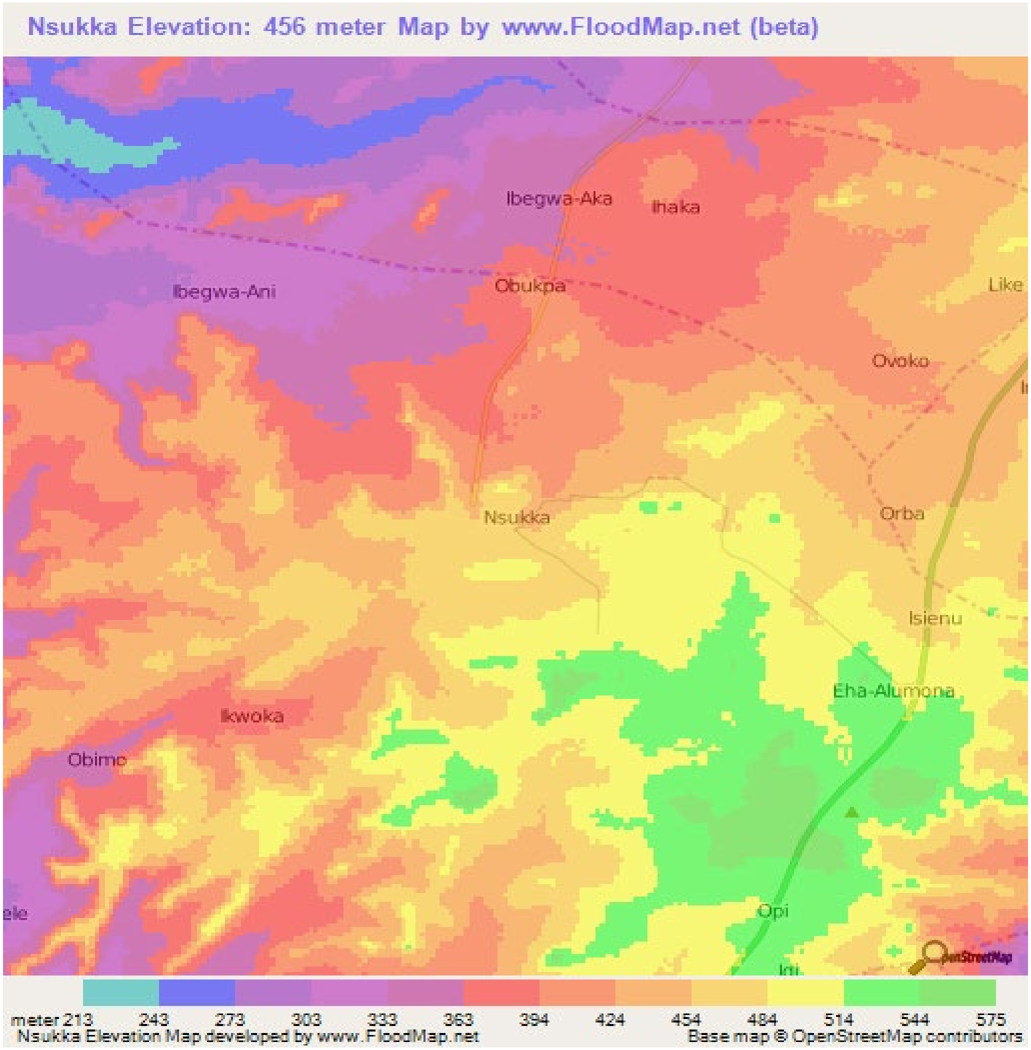


***Fig.1.*** *Elevation, Topo and Contour map of Nsukka, Nigeria.*
*The elevation map of Nsukka,Nigeria is generated using elevation data from NASA's 90m resolution SRTM data*

*Soil sampling*

Disturbed and undisturbed soil samples were taken from the field using auger and core sampler respectively. Soil auger samples were collected in three replicates at depth of 0-30 cmat random from plots of 5 × 5 m ($25m^2$) marked on the farmer's field in the physiographic units (upper slope, middle slope and toe-slope). Core samples were collected at 0-10cm soil depth. The soil sampling was done at three repeated periods; April to May for the first sampling period; July to August for the second sampling period, and October to November 2015 for the third sampling period. Eighteen (18) soil samples were collected from each location giving a total of fifty-four (54) soil samples collected for the first sampling period. A total of 162 samples were collected at the end of the three sampling periods across the locations.

*Laboratory Studies*

After each visit, soil samples were collected and put into polyethylene bag, tied and labeled and taken to the laboratory. Thereafter, they were dried, ground and sieved through 2 mm sieve. The samples were analyzed for physical and chemical properties like particle size distribution, bulk density, soil pH, organic carbon, total N and other macro elements.

*Methods for soil physical and chemical properties determination*

Particle-size distribution (PSD) was analyzed following the method by Gee and Bauder [20], bulk density by core method [3], saturated hydraulic conductivity ($K_s$) [27], soil chemical properties : soil pH (1:2.5 soil: water suspension) [29], soil organic carbon [30], total nitrogen [4], available phosphorus [18], exchangeable bases ($Na^+$, $K^+$, $Ca^{2+}$,and $Mg^{2+}$) [7], exchangeable acidity (E.A) [37] andcation exchange capacity (CEC) [35].

*Soil Degradation Assessment*

The degradation status of the soils in the various locations was assessed by field observation and determined analytical indicators to compare with the standard indicators and criteria for land degradation assess*ment according to Food and Agricultural Organization [17] as shown in Table* 2. Those indicators are; soil bulk density, content of nitrogen, phosphorus, potassium and base saturation.

*Aggregate degradation determination*

Aggregate degradation determination is defined as the ratio of total actual class score to potential (possible) highest score. This is mathematically calculated as:

$$\text{AD (\%)} = \frac{TAC}{PHS}\ X\ 100$$

Where AD (%) = Percent aggregate degradation

TAC = Total actual class score
PHS = Potential highest score (24)

Aggregate degradation rating values have an inverse relationship with the rating of agricultural productivity potential byEzeaku [14]. The higher the aggregate degradation, the lower the suitability and agricultural productivity (Table 3)

***Table 2.*** *Indicators and criteria for land degradation assessment*

| Criteria | Degree of Degradation | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Soil bulk density (g $cm^{-3}$) | <1.5 | 1.5-2.5 | 2.5-5 | >5 |
| Content of organic matter (g $kg^{-1}$) | >2.5 | 2-2.5 | 1.0-2 | <1.0 |
| Content of total Nitrogen element (g $kg^{-1}$) | >0.13 | 0.10-0.13 | 0.08-0.10 | <0.08 |
| K content (cmol $kg^{-1}$) | >0.16 | 0.14-0.16 | 0.12-0.14 | <0.12 |
| Content of Base Saturation (%) | >10% | 5-10% | 2.5-5% | <2.5% |
| Content of available phosphorus element (mg $kg^{-1}$) | >8 | 7-8 | 6-7 | <6 |
| Aggregate Score (%) | 0-25 | 25-50 | 50-75 | 75-100 |

Source: FAO [17] Key: Class1: None- slightly degraded; Class 2: Moderately degraded; Class 3: Highly Degraded'; Class 4: Very highly Degraded

*Table 3. Degree / class of degradation suitability and aggregate degradation ratings*

| S/N | Degree of Degradation class | Degradation class | Suitability class | Potential agricultural productivity | Aggregate degradation (%) |
|---|---|---|---|---|---|
| 1 | Non to slightly degraded soil | 1 | $S_1$ | 75-100 | 0-25 |
| 2 | Moderately degraded | 2 | $S_2$ | 50-75 | 25-50 |
| 3 | Highly degraded | 3 | $S_3$ | 25-50 | 50-75 |
| 4 | Veryhighly degraded | 4 | $N_1$ | 0-25 | 75-100 |

NB: $S_1$ : highly suitable, $S_2$: moderately suitable, $S_3$: marginally suitable, $N_1$: currently not suitable. Source: [17].

### *Statistical Analysis*

All data were statistically analyzed as a 3 x 3 x 3 factorial using Genstat statistical software. Discovery Edition 4. The means were separated using Fisher's least significant differences. The factors were; location with three rates: Lejja, Obukpa and Ozi-Edem; physiographic Units: Upper- slope, Middle- slope and Toe- slope and sampling periods : first sampling period (April/May), second sampling period (July/August) and third sampling periods (October/November).

## RESULTS AND DISCUSSIONS

### *Effect of physiographic units, sampling periods and their interactions on soil physical properties in the three study sites*

The study areas are characterized by marked topographic variations in which agriculture is practiced under flat to very steep sloping topographic lands. Again, the study areas are dominated by rain feds agricultural activities. These significantly influenced most of soil physical and chemical properties. The results of soil physical properties according to their physiographic units for the three locations are presented in Table 4. It was observed that for Lejja location, there were no significant differences for silt and total sandamong the physiographic units, while all physical properties measured at Ozi-Edem showed significant ($p < 0.05$) differences among the physiographic units except for total sand (Table 4).

The soil physical properties according to the sampling period for the three locations are presented in Table 5. It was observed that there were no significant differences for total sand at the different sampling periods across the locations while at Lejja other soil physical properties such as clay, silt, bulk density, total porosity and hydraulic conductivity showed significant ($p < 0.05$) differences at the different sampling periods across the locations. At Ozi-Edem, there were no significant differences among the three sampling periods for bulk density and total porosity. All other measured physical properties such as hydraulic conductivity showed significant differences ($p < 0.05$) among the sampling periods for all the study locations.

Clay and silt contents were significantly ($p <0.05$) higher at the toe-slopefollowed by the middle-slope, whileupper-slope had the lowest value (Table 5) in all the locations. Total sand content decreased down slope while the other particle sizes increased in the same direction. This could be due to larger size of sand and its decreased transportability while silt and clay sizes are smaller and lighter hence easily moved in suspension towards the valley bottom [32].

Clay content had significantly ($p < 0.05$) higher value(Table 5) at the first sampling period (April) for all locations while the second and third sampling period values were statistically equal. Silt content was significantly ($p < 0.05$) higher at the third sampling period (6.00, 9.00) followed by the first (5.67, 8.67) and second sampling periods value (5.67) (Table 5)for both Lejja and Obukpa. At Ozi-Edem, highest value of silt (11.17) at the first sampling period was offered followed by the second (10.67) and third sampling periods (6.33). Significantly ($p < 0.05$) higher value was recorded for total sand content at second sampling period compared to the others for the three locations (Table 5).

Bulk density was significantly ($p < 0.05$) higher(Table 4) at the upper-slope regions for all the study locations while the middle and toe-slope values were not significantly different for Lejja and Obukpa and significantly ($p < 0.05$) different for Ozi-Edem. Generally, the upper-slope had higher bulk density and this could be due to its greater sand content. Bulk density normally decreases, as mineral soils become finer[8]. Bulk density for Lejja and Obukpa were significantly ($p < 0.05$) highest at the first sampling period while the second and third sampling period values were not significantly different. This could be due to the higher sand content at the first sampling period due to more intense erosion.

Total porosity was significantly ($p < 0.05$) higher at the toe-slope regions (Table 4) for all the study locations while the middle-slope and upper-slope values were not significantly different. Increase in bulk density could be due to more compaction of finer particles that reduced porosity probablydue to machinery traction and heavy raindrops [28].

Upper, middle and toe-slopepositions along the landscape had significantly ($p < 0.05$) higher value for saturated hydraulic conductivity ($K_s$) at Lejja(Table 4).Saturated hydraulic conductivity decreases with increasing bulk density as a response of the smaller volume of coarse pores (Dee, et al., 2008) and this could explain the higher $K_s$in the toe-slope of Obukpa. Saturated hydraulic conductivity values significantly decreased in the order: 1st sampling period> $2^{nd}$ sampling period > $3^{rd}$ sampling period for all the study locations.This is to say that Lejja had: 67.37>63.18>27.33cm $hr^{-1}$,while Obukpa recorded: 42.72> 25.09>41.08 cm $hr^{-1}$ and Ozi-Edem:39.03>33.34>16.33 cm $hr^{-1}$, respectively (Table 5).

Table 6 also shows the interactive effect of physiographic units and sampling period on the soil physical properties for the three locations. It was observed that most of the soil physical properties had highest value at an interaction between the upper-slope and first sampling period except for bulk density which had highest value (1.71 g $cm^{-3}$) (Table 6) at the interaction between the toe-slope and third sampling period.

***Table 4.*** *Main effect of physiographic units on soil physical properties in the three sites*

| **Location** | **Unit** | **Clay** | **Silt** | **T. Sand** | **BD** | **TP** | **$K_{Sat}$** |
|---|---|---|---|---|---|---|---|
| | | → | **$g\ kg^{-1}$** | ← | **$g\ cm^{-3}$** | **%** | **$Cm\ h^{-1}$** |
| Lejja | US | 8.33 | 5.00 | 86.34 | 1.61 | 39.24 | 53.89 |
| | MS | 8.66 | 5.00 | 85.34 | 1.55 | 41.72 | 55.68 |
| | TS | 10.00 | 6.33 | 85.00 | 1.53 | 42.11 | 47.30 |
| | LSD(0.05%) | 0.49 | NS | NS | 0.04 | 1.62 | 4.42 |
| Obukpa | US | 12.00 | 5.33 | 82.67 | 1.63 | 38.53 | 36.08 |
| | MS | 12.16 | 7.00 | 80.84 | 1.53 | 42.68 | 31.58 |
| | TS | 12.33 | 10.83 | 76.84 | 1.49 | 43.03 | 41.22 |
| | LSD(0.05%) | NS | 0.52 | NS | 0.04 | 1.94 | 2.22 |
| Ozi – Edem | US | 20.16 | 8.17 | 71.67 | 1.24 | 50.00 | 35.61 |
| | MS | 20.67 | 8.82 | 70.51 | 1.22 | 53.89 | 26.05 |
| | TS | 21.00 | 11.33 | 67.67 | 1.17 | 55.89 | 27.08 |
| | LSD(0.05%) | 0.51 | 0.52 | NS | 0.06 | 6.74 | 1.86 |

NB: BD = bulk density TP = total porosity $K_S$ = hydraulic conductivity, T.sand = total Sand, US = upper-slope, MS = middle-slope, TS = toe-slope, NS= not significant

***Table 5.*** *Main effect of sampling period on soil physical properties in the three*

| **Location** | **sampling period** | **Clay** | **Silt** | **T.Sand** | **BD** | **TP** | **$K_S$** |
|---|---|---|---|---|---|---|---|
| | | → | **($g\ kg^{-1}$)** | ← | **$g\ cm^{-3}$** | **%** | **$Cm\ ^{h-1}$** |
| Lejja | 1st | 9.00 | 5.67 | 85.33 | 1.62 | 42.28 | 67.37 |
| | 2nd | 8.66 | 5.67 | 85.67 | 1.54 | 41.72 | 62.18 |
| | 3rd | 8.33 | 6.00 | 85.67 | 1.53 | 39.08 | 27.33 |
| | LSD(0.05%) | 0.49 | 0.17 | NS | 0.04 | 1.62 | 4.42 |
| Obukpa | 1st | 12.67 | 8.67 | 78.66 | 1.58 | 42.11 | 42.72 |
| | 2nd | 11.33 | 5.67 | 83.00 | 1.53 | 40.55 | 25.09 |
| | 3rd | 12.33 | 9.00 | 78.67 | 1.54 | 41.60 | 41.08 |
| | LSD(0.05%) | 0.19 | 0.52 | NS | 0.04 | 1.94 | 2.22 |
| Ozi – Edem | 1st | 21.00 | 11.17 | 67.83 | 1.23 | 55.18 | 39.03 |
| | 2nd | 20.67 | 10.67 | 68.66 | 1.21 | 50.83 | 33.34 |
| | 3rd | 20.33 | 6.33 | 73.33 | 1.19 | 53.75 | 16.33 |
| | LSD(0.05%) | 0.51 | 0.52 | NS | NS | NS | 1.86 |

NB: BD = bulk density TP = total porosity $K_S$ = hydraulic conductivity, T.sand = total Sand, NS= not significant

***Table 6.*** *Interactive effects of physiographic units and sampling period on soil physical properties in the three study sites*

| Location | Unit | sampling period | Clay | Silt | | CS | FS | BD g/cm$^{-3}$ | TP % | $K_S$ Cm h-$^{1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | → | → | g kg$^{-1}$ | ← | ← | | | |
| | US | 1st | 9.00 | 4.00 | | 46.00 | 45.50 | 1.58 | 40.25 | 69.75 |
| Lejja | US | 2nd | 8.00 | 5.00 | | 45.00 | 42.50 | 1.57 | 40.88 | 67.51 |
| | US | 3rd | 8.00 | 6.00 | | 42.00 | 43.00 | 1.49 | 44.03 | 24.41 |
| | MS | 1st | 9.00 | 4.00 | | 43.50 | 41.00 | 1.44 | 45.45 | 73.27 |
| | MS | 2nd | 8.00 | 5.00 | | 43.50 | 41.50 | 1.51 | 43.02 | 63.48 |
| | MS | 3rd | 8.00 | 6.00 | | 42.00 | 40.50 | 1.65 | 37.86 | 30.30 |
| | TS | 1st | 12.00 | 6.00 | | 43.50 | 44.00 | 1.56 | 41.13 | 59.07 |
| | TS | 2nd | 10.00 | 6.00 | | 42.50 | 42.00 | 1.56 | 41.26 | 55.56 |
| | TS | 3rd | 9.00 | 7.00 | | 40.50 | 41.50 | **1.71** | 35.35 | 27.27 |
| | | LSD(0.05) | 0.86 | 0.86 | | 0.86 | 0.86 | 0.08 | 2.80 | 7.65 |
| | US | 1st | 12.00 | 5.00 | | 49.00 | 46.50 | 1.68 | 36.60 | 41.91 |
| | US | 2nd | 9.00 | 5.00 | | 37.00 | 49.00 | 1.59 | 40.13 | 28.45 |
| | US | 3rd | 11.00 | 6.00 | | 36.00 | 49.00 | 1.62 | 38.87 | 37.88 |
| Obukpa | MS | 1st | 13.00 | 8.00 | | 38.00 | 45.50 | 1.50 | 43.90 | 39.20 |
| | MS | 2nd | 12.00 | 6.00 | | 35.00 | 47.00 | 1.54 | 41.76 | 17.68 |
| | MS | 3rd | 12.00 | 9.00 | | 28.00 | 47.00 | 1.54 | 42.39 | 37.88 |
| | TS | 1st | 13.00 | 13.00 | | 34.00 | 29.50 | 1.43 | 45.82 | 47.06 |
| | TS | 2nd | 13.00 | 7.00 | | 28.00 | 46.00 | 1.60 | 39.75 | 29.12 |
| | TS | 3rd | 13.00 | 12.00 | | 30.00 | 45.50 | 1.43 | 43.53 | 47.47 |
| | | LSD(0.05) | 0.93 | 0.19 | | 0.91 | 0.89 | 0.08 | 3.35 | 3.85 |
| | US | 1st | 20.00 | 10.00 | | 32.00 | 44.00 | 1.11 | 58.00 | 50.43 |
| | US | 2nd | 11.00 | 9.00 | | 32.00 | 51.00 | 1.18 | 55.50 | 41.24 |
| Ozi– Edem | US | 3rd | 20.00. | 5.00 | | 29.50 | 45.00 | 1.21 | 54.20 | 15.15 |
| | MS | 1st | 21.00 | 10.00 | | 31.50 | 39.00 | 1.19 | 55.10 | 30.01 |
| | MS | 2nd | 21.00 | 10.00 | | 27.00 | 44.50 | 1.24 | 53.2 | 27.45 |
| | MS | 3rd | 20.00 | 6.00 | | 24.50 | 45.50 | 1.24 | 53.3 | 20.71 |
| | TS | 1st | 21.00 | 13.00 | | 27.00 | 37.00 | 1.26 | 52.50 | 36.78 |
| | TS | 2nd | 21.00 | 11.00 | | 22.00 | 39.00 | 1.22 | 43.80 | 31.33 |
| | TS | 3rd | 21.00 | 8.00 | | 26.00 | 42.50 | 1.24 | 53.70 | 13.13 |
| | | LSD(0.05) | 0.89 | 0.19 | | 0.91 | 0.93 | 0.09 | 11.67 | 3.215 |

NB: BD = bulk density TP = total porosity Ks = hydraulic conductivity FS = fine sand CS = coarse sand. UP = upper-slope, MS = middle-slope and TS = toe-slope

***Effect of physiographic units, sampling period and their interactions on soil chemical properties in the three study sites***

The soil chemical properties according to their physiographic units and sampling periods for the three locations are presented in Table 7. It was observed that for Lejja, Obukpa and Ozi-Edem, there were no significant differences for EA, OM, $K^+$ and $Na^+$ among the physiographic units. However, soil pH, total nitrogen, $Ca^{2+}$, $Mg^{2+}$, CEC, base saturation and available phosphorus were significantly different ($p < 0.05$).

The soil chemical properties according to the sampling period for the three locations are presented in Table 8. It was observed that there were no significant differences for soil pH, $K^+$, and $Na^{2+}$ at the different sampling periods. At Lejja and Ozi-Edem, there were no significant differences among the three sampling periods for CEC, organic matter and total nitrogen.

Soil pH had significantly ($p <0.05$) higher value at toe-slope regions for all the study locations. Exchangeable acidity was significantly ($p <0.05$) higher at the middle-slope followed by the toe-slope with the middle-slope having the lowest value for Ozi-Edem. Exchangeable acidity was only found significant at Obukpa among the various sampling periods where the third and second sampling periods had the lowest value. The increase of soil pH down the slope may be attributed to possible loss of basic cations down the slope which finally accumulate at the lowland [32,26].

Organic matter was only significantly different ($p <0.05$)at Lejja among the various sampling periods with the third sampling period being significantly higher than the second sampling period which was statistically equal with the first sampling period. This should be expected as the lowlands are enriched of the plant nutrients by flood waters. This is in agreement with earlier reports [1, 25,12].

Significantly ($p < 0.05$) higher value was recorded for total nitrogen at toe-slope compared to the middle and upper-slope regions at Lejja location. This could be associated to the process of washing soil nutrientelements downslope by runoff waters. This accords earlier reports [1, 25, 12]. Ozi Edem and Obukpa recorded highestvalue of nitrogen at the upper-slope compared to the middle and toe-slope regions, and could be due to minimal water erosion at the upper slope.

Exchangeable $Ca^{2+}$ and $Mg^{2+}$ were the only cations that were significantly different both among the physiographic units and the sampling periods for all the study locations. It was observed that for both $Ca^{2+}$ and $Mg^{2+}$, toe-slope regions in Ozi Edem and Lejja had significantly ($p < 0.05$) higher values when compared to the other physiographic units. At Obukpa, upper-slope had highest value for $Mg^{2+}$. The higher $Ca^{2+}$ and $Mg^{2+}$ contents at thetoe-slope could be as a result of runoff carrying the cations down the slope. This is synonymous with the results of Pillai and Natarajan [34].

Among the various sampling periods, $Ca^{2+}$ had significantly ($p < 0.05$) highest value at the third sampling period for Ozi-Edem while $Mg^{2+}$ had the highest value at the second and first sampling periods for Lejja and Obukpa, respectively. The value of $Ca^{2+}$, $Mg^{2+}$ and $Na^+$ decreases irregularly along the physiographic units through mid-slope and toe-slope which could be as a result of runoff. Higher value of $Ca^{2+}$, $Mg^{2+}$ and $Na^+$ at TS could beattributed to elements eroded from upper-slope during run off and deposited on flood plains by flood water [31].

Generally, toe-slope soils were having significantly ($p< 0.05$) higher base saturation than upper-slope indicating high degree of leaching in upper slopes. These findings are in concurrence with previous results [34]. Among the sampling periods, CEC was significantly highest (16.27 cmol $kg^{-1}$) at the third sampling period for Ozi-Edem,while base saturation was highest in the following order: second (96.97 %)> first (96.15 %) > third (93.82 %) sampling periods for Lejja, Obukpa and Ozi-Edem, respectively (Table 8). This variation could be due to slight differences in the land use at various locations. Obukpa location had highest value of % base saturation may be due to higher vegetation cover of the land surface.

Available phosphorus at Lejja was significantly ($p < 0.05$) higher at the middle-slope followed by the toe-slope and upper-slope. High available phosphorus at the middle-slope could be due to higher biological activities and accumulation of organic matter in the middle-slope [21]. At Obukpa, available phosphorus concentration followed the order upper-slope > middle-slope > toe-slope while at Ozi-Edem the reverse occurred. Increase and decrease of phosphorus along the physiographic units could be attributed to run off and leaching.

Among the sampling periods, the second sampling period of available phosphorus was significantly ($p < 0.05$) higherthan the first sampling period but was not significantly different to the third sampling period for Obukpa. While the third sampling period was significantly higher than the first sampling period this was found statistically equal to the second sampling period for Ozi-Edem. High phosphorus availability could be attributed to higher organic matter content in the soils.

The interactive effect of physiographic units and sampling period on the soil chemical properties for the three locations is presented in Table 9. Results show that most properties such as base saturation (96.81%) had highest value at an interaction between the toe-slope and first sampling period.

***Table 7.*** *Main effect of physiographic units on soil chemical properties in the three study sites*

| Location | Unit | Soil pH H₂0 | Soil pH KCL | EA cmol kg-1 | OM (g kg-1) | TN (g kg-1) | Exchangeable Bases (cmolkg-) Ca²⁺ | Mg²⁺ | K⁺ (cmol kg-1) | NA²⁺ | CEC | B.S % | AP mg kg-1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | US | 5.1 | 4.35 | 1.20 | 6.9 | 0.6 | 12.05 | 1.14 | 0.05 | 0.03 | 14.15 | 94.70 | 7.01 |
| Lejja | MS | 5.27 | 4.54 | 1.67 | 6.6 | 0.9 | 14.05 | 1.30 | 0.07 | 0.02 | 16.18 | 97.91 | **26.27** |
| | TS | **5.50** | **4.79** | 1.45 | 7.3 | 1.7 | **12.68** | 1.60 | 0.07 | 0.03 | 15.47 | 93.10 | 11.04 |
| | LSD(0.05%) | 0.17 | 0.16 | NS | NS | 0.1 | 0.34 | 0.26 | NS | NS | 0.35 | 0.27 | 0.27 |
| | US | 4.70 | 3.88 | 1.47 | 9.4 | 1.0 | 12.05 | 1.80 | 0.06 | 0.03 | 14.57 | 96.14 | 20.08 |
| Obukpa | MS | 4.87 | 3.97 | 1.84 | 9.6 | 0.8 | 12.80 | 1.57 | 0.06 | 0.03 | 15.10 | 95.41 | 12.11 |
| | TS | **5.15** | **4.42** | 1.91 | 8.3 | 0.7 | 12.95 | 1.52 | 0.06 | 0.03 | 15.57 | 94.87 | 9.81 |
| | LSD(0.05%) | 0.17 | 0.16 | NS | NS | 0.1 | 0.28 | 0.31 | NS | NS | 0.36 | 0.31 | 0.27 |
| | US | 4.49 | 3.80 | 1.40 | 23.2 | 1.2 | 12.60 | 1.97 | 0.08 | 0.02 | 15.70 | 93.66 | 6.41 |
| Ozi–Edem | MS | 4.52 | 3.89 | **1.87** | 22.6 | 1.1 | 12.70 | 1.73 | 0.08 | 0.02 | 15.10 | 90.48 | 4.53 |
| | TS | **4.64** | **3.95** | 1.77 | 22.6 | 0.9 | **13.80** | 1.64 | 0.08 | 0.02 | 15.57 | 95.98 | 6.86 |
| | LSD (0.05%) | NS | NS | 0.35 | NS | 0.1 | 0.40 | 0.28 | NS | NS | 0.45 | 0.25 | 0.26 |

***Table 8.*** *Main effect of sampling period on soil chemical properties in the three study sites*

| Location | Sampling period | Soil pH H₂0 | Soil pH KCL | EA cmol kg-1 | OM g kg-1 | TN g kg-1 | Exchangeable Bases (cmolkg-) Ca²⁺ | Mg²⁺ | K⁺ cmolkg-1 | NA²⁺ | CEC | B.S % | AP mg kg-1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st | 5.42 | 4.57 | 1.60 | 7.5 | 0.7 | 12.92 | 1.33 | 0.06 | 0.03 | 15.23 | 95.08 | 14.77 |
| Lejja | 2nd | 5.25 | 4.58 | 1.40 | 7.3 | 0.7 | 12.82 | **1.50** | 0.06 | 0.03 | 15.00 | **96.97** | 14.77 |
| | 3rd | 5.20 | 4.52 | 1.33 | **5.9** | **1.8** | 13.05 | 1.20 | 0.06 | 0.02 | 15.30 | 94.55 | 14.78 |
| | LSD(0.05%) | 0.17 | NS | **NS** | 0.6 | 0.1 | NS | 0.26 | NS | NS | NS | 0.27 | NS |
| | 1st | 5.05 | 4.15 | 1.63 | 9.7 | 1.0 | 12.95 | **1.87** | 0.06 | 0.03 | 15.67 | 96.15 | 10.93 |
| Obukpa | 2nd | 4.72 | 4.07 | 2.03 | 8.0 | 0.5 | 12.10 | 1.50 | 0.06 | 0.02 | 14.40 | 94.75 | 11.31 |
| | 3rd | 4.95 | 4.05 | 1.50 | 9.5 | 1.0 | 12.83 | 1.52 | 0.06 | 0.03 | 15.17 | 95.51 | 10.88 |
| | LSD(0.05% | 0.17 | NS | 0.19 | NS | **NS** | 0.28 | 0.31 | NS | NS | 0.36 | 0.31 | 0.27 |
| | 1st | 4.57 | 3.88 | 1.90 | 23.0 | 1.0 | 12.90 | 1.87 | 0.08 | 0.02 | **16.27** | 93.36 | 4.58 |
| Ozi–Edem | 2nd | 4.48 | 3.87 | 1.80 | 22.4 | 0.9 | 12.87 | 1.83 | 0.08 | 0.02 | 15.93 | 92.94 | 4.51 |
| | 3rd | 4.58 | 3.88 | 1.87 | 23.0 | **1.2** | **13.33** | 1.63 | 0.08 | 0.01 | 16.08 | 93.82 | 8.70 |
| | LSD (0.05%) | NS | NS | NS | **NS** | 0.1 | 0.40 | NS | NS | NS | **NS** | 0.25 | 0.26 |

***Table 9.** Interactive effect of physiographic unit and sampling period on soil chemical properties in the three study sites*

| Location | Unit | Sampling period | Soil pH | | EA | OM | TN | Exchangeable Bases (cmol $kg^{-}$) | | | | | | AP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $H_2O$ | KCL | Cmol $kg^{-1}$ | (g $kg^{-1}$) | | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ Cmol $kg^{-1}$ | $NA^{2+}$ | CEC | B.S % | mg $kg^{-1}$ |
| | US | 1st | 5.03 | 4.10 | 1.30 | 7.4 | 0.6 | 12.20 | 1.10 | 0.05 | 0..03 | 14.10 | 94.81 | 7.96 |
| | US | 2nd | 4.95 | 4.20 | 1.00 | 7.2 | 2.0 | 12.30 | 1.10 | 0.05 | 0.03 | 14.00 | 96.20 | 7.93 |
| | US | 3rd | 5.30 | 4.75 | 1.20 | 6.0 | 0.6 | 12.10 | 1.20 | 0.08 | 0.02 | 14.35 | 93.10 | 5.13 |
| Lejja | MS | 1st | 5.50 | 4.65 | 1.90 | 7.4 | 0.8 | 14.30 | 1.60 | 0.06 | 0.03 | 16.2 | 98.68 | 23.28 |
| | MS | 2nd | 5.25 | 4.60 | 1.80 | 7.2 | 2.7 | 14.10 | 1.20 | 0.07 | 0.03 | 15.90 | 96.72 | 23.31 |
| | MS | 3rd | 5.05 | 4.35 | 1.10 | 5.1 | 1.0 | 14.20 | 1.10 | 0.08 | 0.02 | 15.65 | 98.32 | 32.21 |
| | TS | 1st | 5.70 | 5.25 | 1.60 | 7.2 | 3.1 | 12.70 | 1.30 | 0.07 | 0.04 | 15.40 | 98.68 | 13.06 |
| | TS | 2nd | 5.55 | 4.95 | 1.11 | 7.5 | 0.6 | 12.50 | 2.45 | 0.07 | 0.03 | 15.10 | 97.98 | 13.06 |
| | TS | 3rd | 5.25 | 4.45 | 1.30 | 6.6 | 3.9 | 13.10 | 1.30 | 0.07 | 0.02 | 15.40 | 94.16 | 7.00 |
| | | LSD(0.05) | 0.29 | 0.28 | 0.54 | 2.8 | 0.2 | 0.58 | 0.45 | 0.00 | 0.00 | 0.61 | 0.47 | 0.46 |
| | US | 1st | 4.85 | 3.90 | 1.80 | 10.2 | 1.2 | 12.40 | 2.50 | 0.06 | 0.03 | 15.30 | 91.88 | 9.38 |
| | US | 2nd | 5.00 | 4.15 | 1.60 | 1.8 | 0.5 | 11.80 | 1.40 | 0.06 | 0.02 | 13.90 | 95.49 | 14.92 |
| | US | 3rd | 4.75 | 3.85 | 1.70 | 9.9 | 1.2 | 12.20 | 1.50 | 0.06 | 0.03 | 14.50 | 95.04 | 4.39 |
| Obukpa | MS | 1st | 4.80 | 3.85 | 1.60 | 10.0 | 0.9 | 13.40 | 1.50 | 0.05 | 0.04 | 15.60 | 96.06 | 13.58 |
| | MS | 2nd | 4.60 | 4.05 | 1.30 | 8.7 | 0.6 | 11.70 | 1.90 | 0.05 | 0.03 | 14.60 | 93.57 | 9.23 |
| | MS | 3rd | 4.70 | 3.75 | 2.60 | 9.9 | 0.9 | 13.30 | 1.30 | 0.06 | 0.03 | 15.20 | 96.61 | 4.71 |
| | TS | 1st | 5.50 | 4.70 | 1.10 | 8.9 | 0.9 | 13.05 | 2.05 | 0.06 | 0.04 | 16.10 | 94.52 | 9.84 |
| | TS | 2nd | 4.55 | 4.00 | 2.66 | 7.2 | 0.4 | 12.80 | 1.20 | 0.06 | 0.02 | 14.80 | 95.19 | 9.80 |
| | TS | 3rd | 5.40 | 4.55 | 1.80 | 8.7 | 0.9 | 13.00 | 1.90 | 0.06 | 0.03 | 15.80 | 94.89 | 2.24 |
| | | LSD(0.05) | 0.29 | 0.28 | 2.00 | 3.2 | 0.1 | 0.49 | 0.54 | 0.00 | 0.01 | 0.63 | 0.53 | 0.46 |
| | US | 1st | 4.65 | 3.95 | 2.00 | 22.6 | 01.0 | 12.10 | 2.10 | 0.08 | 0.02 | 15.20 | 94.08 | 4.30 |
| | US | 2nd | 4.50 | 3.90 | 1.60 | 22.2 | 1.0 | 12.10 | 2.20 | 0.09 | 0.02 | 15.20 | 94.75 | 4.20 |
| Ozi– Edem | US | 3rd | 4.75 | 4.00 | 1.80 | 24.8 | 1.5 | 13.70 | 1.60 | 0.08 | 0.02 | 16.70 | 92.15 | 10.73 |
| | MS | 1st | 4.6 | 3.90 | 1.60 | 23.1 | 1.2 | 12.80 | 1.80 | 0.08 | 0.02 | 16.50 | 89.20 | 4.71 |
| | MS | 2nd | 4.50 | 3.90 | 2.00 | 22.2 | 1.1 | 12.90 | 1.70 | 0.09 | 0.02 | 16.50 | 89.22 | 4.67 |
| | MS | 3rd | 4.45 | 3.85 | 2.00 | 22.4 | 1.1 | 12.40 | 1.70 | 0.08 | 0.01 | 15.24 | 93.04 | 4.20 |
| | TS | 1st | 4.45 | 3.80 | 1.80 | 23.2 | 1.4 | 13.80 | 1.70 | 0.08 | 0.02 | 16.10 | 96.81 | 4.72 |
| | TS | 2nd | 4.45 | 3.80 | 2.00 | 22.8 | 1.2 | 13.60 | 1.60 | 0.08 | 0.02 | 16.10 | 94.85 | 4.67 |
| | TS | 3rd | 4.55 | 3.80 | 0.61 | 21.9 | 1.0 | 14.00 | 1.60 | 0.08 | 0.02 | 16.30 | 96.28 | 11.19 |
| | | LSD(0.05) | 0.13 | 0.32 | 0.61 | 2.8 | 0.1 | 0.69 | 0.49 | 0.00 | 0.01 | 0.78 | 0.44 | 0.45 |

NB: OM = organic carbon, TN = total nitrogen, CEC = cation exchange capacity, AP = available phosphorus, BS = base saturation, EA = exchangeable acidity, US=upper-slope, MS middle-slope and TS= toe-slope

***Degree of degradation class scores of the soil properties at the three locations based on sampling periods***

This revealed that soil physical and chemical properties degraded differently under the different physiographic units. The soil properties degradation score ranges from 1, 2 through 3 to 4, representing non-slightly degraded, moderately degraded through highly degraded to very highly degraded, respectively. Soil properties with the highest-class score of degradation class 3 (highly degraded) and class 4 (very highly degraded) are total nitrogen, exchangeable $K^+$, base saturation and available phosphorus. The implication is that most arable crops will not perform optimally since they need these basic elements more in the soil.

Results in Table 11 show the overall aggregate degradation class score. The aggregate degradation scores varied from 37.5 to 66.7% representing moderate ($S_2$) to marginally suitable ($S_3$) land within the upper slope to toe slope continuum across the three locations.

Using the % aggregate score (AS) to group the soils, it was observed that the soils were highly and moderately degraded across the three sampling periods along the physiographic units. Obukpa up-slope in the 3$^{rd}$ sampling period has the highest aggregate score (66.7) while Ozi-Edem up-slope and toe-slope (3$^{rd}$ sampling period) has the least aggregate score (37.5). The 1$^{st}$ sampling period has the highest level of degradation followed by the 2nd sampling period and least at the 3$^{rd}$ sampling period.

***Table 10.*** *Degree of degradation class scores of the three study areas based on sampling period and physiographic units across the location*

| **April/May** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Lejja** | | | **Obukpa** | | | **Ozi – Edem** | | |
| **Physiographic Unit** | **US** | **MS** | **TS** | **US** | **MS** | **TS** | **US** | **MS** | **TS** |
| Bulk density | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| Organic matter | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total Nitrogen | 4 | 3 | 1 | 4 | 3 | 3 | 4 | 4 | 4 |
| Exchangeable $K^+$ | 4 | 4 | 4 | 4 | 4 | 4 | 1 | 1 | 1 |
| Base saturation | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Available phosphorus | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 |
| **% aggregate Score** | **58.3** | **45.8** | **41.7** | **54.2** | **50,0** | **45.8** | **50.0** | **50.0** | **50.0** |
| **July/August** | | | | | | | | | |
| Bulk density | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| Organic matter | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| Total Nitrogen | 4 | 1 | 1 | 4 | 4 | 4 | 1 | 1 | 1 |
| Exchangeable $K^+$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Base saturation | 1 | 1 | 1 | 1 | 1\ | 1 | 1 | 1 | 1 |
| Available phosphorus | 2’ | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 |
| **% aggregate Score** | **58.3** | **45.8** | **41.7** | **59.3** | **54.2** | **54.2** | **50.0** | **50.0** | **50,0** |
| **October/November** | | | | | | | | | |
| Bulk density | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| Organic matter (%) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total Nitrogen | 1 | 1 | 1 | 4 | 3 | 3 | 1 | 1 | 1 |
| Exchangeable $K^{+4}$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Base saturation | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Available phosphorus | 4 | 1 | 3 | 4 | 4 | 4 | 1 | 4 | 1 |
| **% Aggregate Score** | **50.0** | **41.7** | **50.0** | 66.7 | **62.5** | **58.3** | **37.5** | **50.0** | **37.5** |

NB: Aggregate scores:-1. Non - slightly degraded soil (0- 25 %). 2. Moderately degraded soil (25-50%). 3. Highly degraded soil (50-75%). Very highly degraded soil (75-100 %). US= upper slope, MS= middle slope and TS=toe-slope

***Table 11.*** *Percentage aggregate score of the degradation class of the physiographic units in the three locations*

| Location | Physiographic Unit | % Aggregate Score | Degree of Degradation Class |
|---|---|---|---|
| | US | 58.3 | Highly Degraded |
| Lejja | MS | 45.8 | Moderately Degraded |
| | TS | 41.7 | Moderately Degraded |
| | US | 54.2 | Moderately Degraded |
| Obukpa | MS | 50.0 | Highly Degraded |
| | TS | 45.8 | Moderately Degraded |
| | US | 50.0 | Highly Degraded |
| Ozi – Edem | MS | 50.0 | Highly Degraded |
| | TS | 50.0 | Highly Degraded |
| | US | 58.3 | Highly Degraded |
| Lejja | | | |
| | MS | 45.8 | Moderately Degraded |
| | TS | 41.7 | Moderately Degraded |
| | US | 58.3 | Highly Degraded |
| Obukpa | MS | 54.2 | Highly Degraded |
| | TS | 54.2 | Highly Degraded |
| | US | 50.0 | Moderately Degraded |
| Ozi – Edem | MS | 50.0 | Highly Degraded |
| | TS | 50.0 | Moderately Degraded |
| | US | 50.0 | Highly Degraded |
| Lejja | MS | 41.7 | Moderately Degraded |
| | TS | 50.0 | Highly Degraded |
| Obukpa | US | 66.7 | Highly Degraded |
| | MS | 62.5 | Highly Degraded |
| | TS | 58.3 | Highly Degraded |
| Ozi - Edem | US | 37.5 | Moderately Degraded |
| | MS | 50.0 | Highly Degraded |
| | TS | 37.5 | Moderately Degraded |

NB: Aggregate scores:-1. Non - slightly degraded soil (0- 25 %). 2. Moderately degraded soil (25-50 %). 3. Highly degraded soil (50-75%). Very highly degraded soil (75-100 %). US= upper slope, MS= middle slope and TS=toe-slope

### *Effect of location, physiographic unit and sampling period on the degree of degradation*

The degree of degradation across locations, physiographic units and sampling periods are shown in figure 2-4. Figure 2 shows degree of degradation across physiographic units. The up-slope had the highest level of degradation followed by the middle-slope and least at the toe-slope. The up-slope had the highest level of degradation with a percent increase of 3.4 and 5.9 over the middle slope and toe-slope which had the lowest level of degradation. The mean % AS of the middle-slope was 2.6% higher than the toe-slope.

Upper slope being more degraded when compared to toe-slope, an implication that up- slope to be more prone to erosion. It has been shown that steeper land is more erosion prone [5] and a more level landscape reduces the chance of extreme soil erosion [22].

Percent aggregate score in relation to the degree of degradation across locations is shown in Fig 3. Obukpa had the highest level of degradation with a percent increase of 0.62 and 10.8 over Lejja and Ozi-Edem, respectively. However, the mean % AS of Lejja was 10.2% higher than Ozi-Edem with the lowest % AS. The overall degradation score obtained in the upper-slope at Obukpa was higher (56.1%) than Lejja (48.0%) and Ozi -Edem (47.2%), representing a difference of 13.2% and 24.6% respectively. Also the aggregate degradation score for Obukpa is higher than Ozi -Edem by 13.1%. Given these, it can be said that Ozi -Edem upper-slope is less prone to degradation when compared to Obukpa and Lejja that have less vegetation covers.

In terms of sampling periods, figure 4 shows the recorded mean % aggregate score of 463.5%, 454.2% and 445.8% for third, second and first sampling periods, respectively. The third sampling period had the highest level of degradation with a percent increase of 7.56 and 13.7 over the second and first sampling periods, respectively. The mean % AS of the second sampling period was 50.% higher than the first sampling period. This shows the increment of degradation status of the soils: Oct/Nov > July/Aug > April/May. This phenomenon may be associated to soil erosion and leaching as well as other anthropogenic influences like crop harvesting and animal grazing.

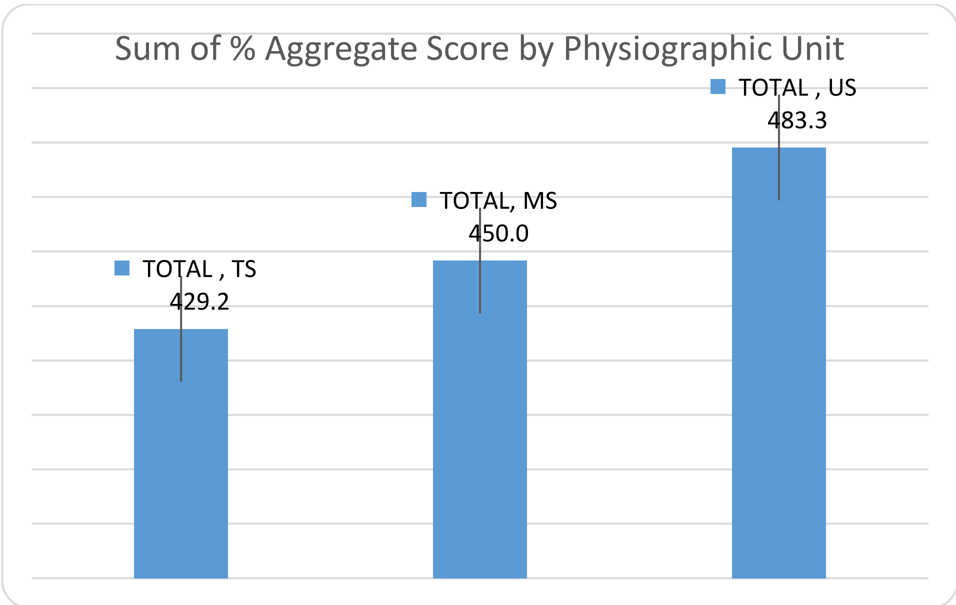


***Fig. 2.*** *Percent aggregate score in relation to degree of degradation across the physiographic units in the study locations*

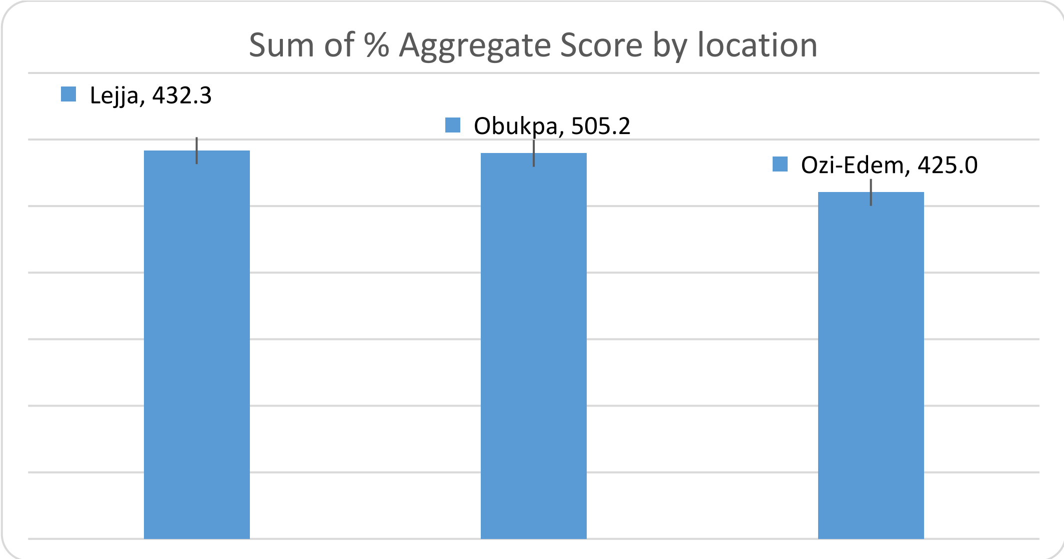


***Fig. 3.*** *Percent aggregate score in relation to the degree of degradation across the three study locations*

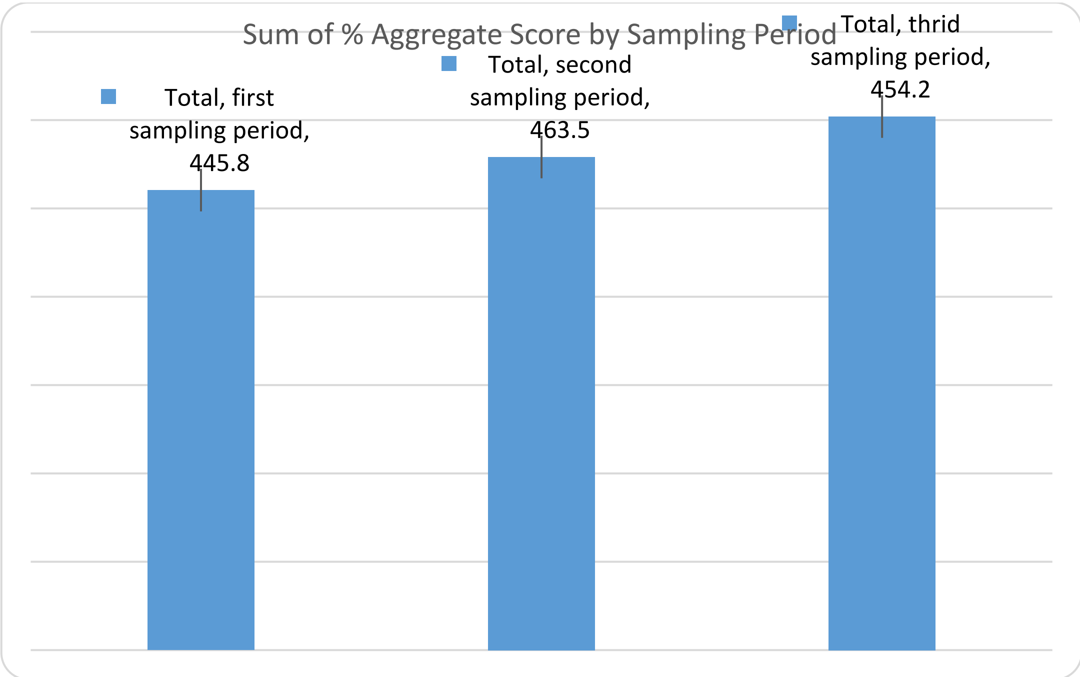


***Fig. 4.*** *Degree of degradation across the sampling periods in the three study areas*

## CONCLUSION

The results revealed that the study areas were moderately and highly degraded. The physical and chemical properties varied within the various physiographic units with the lower slope having higher nutrient contents due to minimal degradation relative to middle and upper slopes; suggesting that toe slope land could be better utilized for crop production. In terms of location, Obukpa had the highest level of soil degradation followed by Lejja and Ozi-Edem having the lowest degradation and were not significantly different. Highest soil degradation was recorded during October/November periods relative to July/August and April/May periods.

Farmers need monitoring tools such as local level monitoring approach to help them assess the status of their soils since most farming soils in the study locations are vulnerable to erosion and by the time that degradation becomes visible and irreversible, it might be too late or very expensive to reverse it.There is potential for possible increase in crop yield if appropriate soil management practices are applied in the study locations. Therefore, integrating the following activities such as appropriate soil conservation measures, inclusion of restorative crops in cropping systems, use of locally available materials, and use of bio fertilizers are recommended to combat soil degradation problems and exploring the potential crop productivity. This study under pines the need for adequate information to intervene and solve soil degradation problems in the sub-humid tropics of Nigeria.

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