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**ORIGINAL RESEARCH ARTICLE**

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**Determination of Soil Microaggregates Indices of Gully Erosion on Some Arable Lands in Yola South Local Government Area, Adamawa State, Nigeria**

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**ABSTRACT**

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The study aimed at determining soil microaggregates indices of gully erosion on some arable lands in Yola South LGA, Adamawa State, Nigeria. Three arable lands were selected, namely Yolde pate, Mbamba and Bole where gullies were randomly selected based on the gully distributions. The nature and characteristics such as age, shape, size, pattern, position, activity, stage and continuity of the gullies were observed and soil samples were collected along the gully wall layers (top, middle and bottom). The collected samples were prepared for soil micro-aggregates analysis in the laboratory and also soil microaggregates indices were calculated respectively. The results revealed that 12 gullies were identified characterized with small to large size having annular and dendritic pattern facing NW, SW and NE in an active and continuous process of development. The microaggregate indices of all the areas shows that the soils have high susceptibility to erosion with CDR > 15 %. At Yolde pate area CDR and CDI varied from 77.17-40.42 % and 69.17-33.92 % while at Mbamba 74.32-42.44 % and 78.74-39.45 % and Bole 71.62-45.58 %. However, the erosion susceptibility decreased from top to bottom of the gullies due to increase in CFI values at Bole and Yolde pate areas. To realize improve soil micoraggregate stability in the area, It is therefore recommended that farmers should adopt the use of organic materials incorporation and improve proper land use management.

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## Introduction

Micro-aggregates are formed from the collapse of macro-aggregates and are regarded as soil aggregates less than 250  $\mu\text{m}$  in size. They are more typically found in disturbed or cultivated soils (Yan *et al.*, 2009). The microaggregate is a valuable soil property that affects the movement and storage of water, aeration, erosion, biological activity and the growth of crops (Lal and Stewart, 2012). Microaggregate stability, when used as a tool for predicting soil erosion hazards, takes into account only the aspect of such hazards that are due to the soil inherent erodibility. Agassi and Bradford (1999) have found that erodibility varies with soil textures, aggregate stability, shear strength, soil structures, infiltration capacity, soil depth, bulk density and soil organic matter. However, soil erosion in areas of very intense rainfall has been estimated using water-dispersible clay and its indices. Factors that influence aggregate stability are essential in evaluating the ease with which soils erode by water and/or wind, the potential of soils to crust and/or seal, soil permeability, quasi-steady state infiltration rates, and seedling emergence and in predicting the capacity of soils to sustain long-term crop production (Udom and Adesodun 2016). Erodibility indices like clay dispersion ratio, clay dispersion index, clay flocculation index have been employed by different authors (Oguike and Mbagwu, 2009; Chris-Emenyonu and Onweremadu, 2011) to assess the soil erodibility. Igwe (2005) has remarked that the clay-dispersion ratio and clay dispersion index are good indices for predicting erodibility in soils of south-eastern Nigeria. The relevance of microaggregate stability for assessing potential erosion hazards lies, therefore, on the effects of dispersion on soil hydrophysical processes. Dispersion generally induces processes that are related to soil erodibility such as very fast crusting, slow infiltrability, and great mobility of particles in

water (Le Bissonnais, 2006). Therefore, microaggregate dispersion is a precondition for soil erosion to be complete. There is evidence from the United States that WDC and CDR can be good estimators of erodibility of some soils in Ohio (Bajracharya *et al.*, 1992). According to Igwe and Udegbumam (2008), CFI is a perfect index for predicting soil erodibility and a useful micro-aggregate index. Soils high in CFI are well aggregated and will not easily disperse in water. In Yola South LGA, a report of recent research conducted by Sadiq, *et al.*, (2019a) soil erosion is one of the most devastating phenomena affecting soil resources and food availability due to heavy rainfall, deforestation and steep slope. Similar result was revealed by Sadiq, *et al.*, (2019b) that Yola South LGA, of Adamawa State is among the soil degraded region most especially in the tropics as a result of different anthropogenic factors (land use, deforestation, overgrazing), cultural factors (continuous cropping, poor soil management), physico-edaphic factors (soil compaction, soil erosion) and hydro-climatic factors (high amount of rainfall, flooding, sedimentation, offsite and onsite effects of soil erosivity). However, no any research conducted or any relevant information is available on these microaggregate indices for the soils of Yola South LGA, Adamawa. Therefore, understanding the rate of stability of microaggregate in gully affected soils will surely provide information that will enable agriculturists, engineers and other land-users to timely know the areas prone to erosion and to choose effective control measures and embrace sustainable landuse practices that will help to check the menace in the future. It is based on this backdrop, this study saddled to determine the microaggregate indices of gully a some selected arable lands in Yola South LGA, Adamawa State, Nigeria.

## Materials and Methods

### Study Area

The study was conducted in Yola-South Local Government Area of Adamawa State, Nigeria, where three arable lands were selected namely Yolde pate, Mbamba and Bole. Yolde Pate area lies between Latitudes 9° 11'N and- 9° 13' N of the Equator and between Longitudes 12° 26'E and 12° 28' E of the Greenwich Meridian with an elevation of 157-162 m above mean sea level,, Mbamba area lies between Latitudes 9° 10'N - 9° 11' N of the Equator and between Longitudes 12° 31' E and 12° 33' E of the Greenwich Meridian having an elevation ranges from 166-196 m, and Bole area lies between Latitudes 9° 8'N and 9° 10' N of the Equator and between Longitudes 12° 28'E and 12° 31' E of the Greenwich Meridian with an elevation ranges from 175-219 m respectively (Sadiq and Vahyala, 2023).

### Gully site selection

At each of the selected arable lands gullies were randomly selected based on the gully distributions covering at least 70 percent of the total gullies in each area. At Yolde pate four (4) gullies were selected while at Mbamba three (3) gullies and Five (5) were selected at Bole accordingly.

### Determination of the nature and characteristics of the gullies

The nature and characteristics of the gullies were obtained through field observation where the age, shape, size, pattern, position, activity, stage and continuity of the gullies were observed.

### Soil sampling and analysis

Soil samples were collected along the gully wall layers (top, middle and bottom) based on the technique employed in accordance with (Suraj, 1998; Shu'aibu, 2002; Buwa, 2003; Lazarus et. al., 2012 and Mallam, et al., 2016). The collected soils

samples from the top middle and bottom of the gully walls were air-dried, crushed using a wooden mortar and pestle, and then sieved through a 2 mm mesh and subjected to laboratory analyses. Particle size distribution was determined by the Bouyoucos hydrometer method using water and calgon methods as described by Gee and Or, (2002).

### Determination of microaggregate stability indices

Erosion indices were calculated using the following formulae as proposed by Bouyoucos (1951) and Gee and Bauder, (1986) and described by Igwe and Ejiofor (2005), Rasheed (2016) and Oguike and Utin, (2018) respectively.

**Clay dispersion index (CDI)** =  $\{[\% \text{ clay (H}_2\text{O)}] / [\% \text{ clay (calgon)}]\} \times 100$

**Clay flocculation index (CFI)** =  $[\% \text{ clay (calgon)}] - [\% \text{ clay (H}_2\text{O)}] / [\% \text{ clay (calgon)}] \times 100$

**Clay Ratio** =  $\text{Sand (calgon)} / \text{Total \% silt + \% clay (calgon)} \times 100$

**Clay dispersion ratio (CDR)** =  $\{(\% \text{ silt + \% clay (H}_2\text{O)}) / (\% \text{ silt + \% clay (calgon)})\} \times 100$

If the CDR value is above 15% the soils are erodible, but when it is below 15% the soils are not readily susceptible to erosion. The higher the CDR and CDI, the higher the ability of the soil to disperse while the higher the CFI, the better aggregated the soil. The clay dispersion ratio was used to determine the erodibility of the soils. Hence, soils with a clay dispersion ratio greater than 15% are erodible, and with less than 15% are not erodible as described by (Oguike and Utin, 2018).

### Data Analysis

The data obtained was subjected to descriptive statistical analysis where means and percentage values were presented accordingly.

## Results and Discussions

### *Nature and characteristics of the sampled gullies of the Study Area*

The results on the nature and characteristics of the gully units in the study areas are presented in Table 1. At Mbamba area with identified three gully units were characterized with 24 years, 14 years and 25 years of developmental aged having U-shape and medium size in an annular pattern facing North-west (NW) position. In addition, the gullies were all at their active and at development stage in a continuous process. Furthermore, Bole sub-system was described with five (5) gully units having an ages of 15, 46, 35,8 and 40 characterized with U-shape except unit 4 (BLG 04) with V-shape. Gully unit 1, 2, and 3 are classified as large size while unit 4 and 5 as small and medium facing South-west (SW) position with an activeness and continuous process. The dendritic pattern was observed at unit 1 and 4 and while linear and annular were noticed at unit 2 and 3 respectively. Moreover, Yolde pate sub-system with four (4) recognized gully units with 20, 12, 7 and 13 ages of occurrence with U-shape found at unit 1 and 2 and V-shape at unit 3 and 4. Unit 1 and 4 was classified with medium size while unit 2 and 3 as large and small. All the gullies operates in annular pattern except unit 4 moved linearly in an active process except unit 1. The stages shows that unit 1 is at healing, 2 and 4 at development and 3 at formation in a continuous process.

### *Classification of soil of soil microaggregates of Mbamba study area*

Results of soil microaggregates of Mbamba Study are presented in Table 2. The results revealed that % clay + % silt in calgon was higher in clagon solution with values ranged from 16.25 -22.62 % than in water solution with values ranged from 7.40-12.90 % in all the layers of gully unit 1. In addition, top and bottom layers are less susceptible to erosion due to low

values of CDI (39.45 % and 42.19 %) and CDR (45.53 % and 42.44 %) compared to middle layer having value of CDI (67.68 %) and CDR (62.65 %) making it more susceptible to erosion. This could be connected to low sand content (87.10 %) coupled with high % clay + % silt (12.90 %) under water solution which are more and easily detachable. Similar finding was reported by Osujieke *et al.*, (2020) in Mbano, South-east Nigeria that the soils are susceptible to erosion. The CR and CDF values were ranged from 5.15-3.42 % and 60.54-32.31 %. The CFI also shows that top and bottom layers may resist erosion than the middle layer having less aggregate stability.

At unit 2 gully of the area % clay + % silt in both calgon and water solutions increases with from top to bottom layers (14.3-22.19 % and 6.60-15.60 %) with gradual decrease in sand content. The CDI and CDR were found to have increase from top to bottom layers of the gully ranged from 65.25-69.74 % and 46.15-70.30 % characterized with more susceptibility to erosion from top to bottom of the gully. In contrast, CR and CFI decreased slightly (5.99-3.50 % and 34.74-30.25 %) from top to bottom of the layers classified with decreased in aggregate stability making it less resistant to erosion. The higher the CFI value the better the aggregate stability of the soil and the more the soil to withstand erosional formation and development.

Thus, soil microaggregate it is a valuable soil property that affects the movement and storage of water, aeration, erosion, biological activity and the growth of crops (Lal and Stewart, 2012). It may also be to evaluate or predict the effects of various agricultural practices, such as tillage and organic matter additions, including soil erosion (Udom and Anozie, 2018). Similar trends in the increased of % clay + % silt for both calgon and water solutions were recorded

from top to bottom of gully unit 3 of Mbamba area with values varied from 16.60-21.34 % and 11.50-15.86 %. Likewise, CDI and CDR values increases with depth ranged from 55.62-78.74 % and 69.27-74.32 % while in contrast the CR and CFI decreased abruptly (5.02-3.68 % and 44.37-21.25 %) respectively. Soils with high DR and

CDR are known to be weak structurally and can easily erode (Igwe and Udegbumam, 2008). These micro-aggregates indices described the soil of the gully unit 3 with more erosion vulnerability down the layers having more poor stability accordingly.

**Table 1:** Physiographic Features, Activities and Stages of the studied Gully units at subsystems

STUDY SITE	GULLY UNIT	AGE	SHAPE	SIZE	PATTERN	POSITION	ACTIVITY	STAGE	CONTUINITY
<b>MBAMBA</b>	MBG001	24	U-shape	Medium	Annular	NW	ACTIVE	Development	Continuous
	MBG002	14	U-shape	Medium	Annular	NW	ACTIVE	Development	Continuous
	MBG003	25	U-shape	Medium	Annular	NW	ACTIVE	Development	Continuous
<b>BOLE</b>	BLG001	15	U-shape	Large	Dendritic	SW	ACTIVE	Formation	Continuous
	BLG002	46	U-shape	Large	Linear	SW	ACTIVE	Development	Continuous
	BLG003	35	U-shape	Large	Annular	SW	ACTIVE	Development	Continuous
	BLG004	8	V-shape	Small	Dendritic	SW	ACTIVE	Formation	Continuous
	BLG005	40	U-shape	Medium	Dendritic	SW	ACTIVE	Development	Continuous
<b>YOLDE PATE</b>	YPG001	20	U-shape	Medium	Annular	NE	INACTIVE	Healing	Continuous
	YPG002	12	U-shape	Large	Annular	NE	ACTIVE	Development	Continuous
	YPG003	7	V-shape	Small	Annular	NE	ACTIVE	Formation	Continuous
	YPG004	13	V-shape	Medium	Linear	NE	ACTIVE	Development	Continuous

**Table 2:** Soil microaggregate indices of the sampled gully units at Mbamba area

Location Gully Unit	Mbamba Layers	Particle size Distribution using CALGON					Particle size Distribution using WATER					Microaggregates Indices			
		% Sand	% Clay	% Silt	Total (% Clay+ %Silt)	Total (% Sand + % Clay+ %Silt)	% Sand	% Clay	% Silt	Total (% Clay+ %Silt)	Total (% Sand + % Clay+ %Silt)	CDI	CDR	CR	CFI
MB 001	TOP	83.75	8.11	8.14	16.25	100.00	92.60	3.20	4.20	7.40	100.00	39.45	45.53	5.15	60.54
	MIDDLE	79.41	11.17	9.42	20.59	100.00	87.10	7.56	5.34	12.90	100.00	67.68	62.65	3.85	32.31
	BOTTOM	77.38	12.56	10.06	22.62	100.00	90.40	5.30	4.30	9.60	100.00	42.19	42.44	3.42	57.80
MB 002	TOP	85.7	6.59	7.71	14.3	100.00	93.40	4.30	2.30	6.60	100.00	65.25	46.15	5.99	34.74
	MIDDLE	78.88	9.66	11.46	21.12	100.00	86.30	6.40	7.30	13.70	100.00	66.25	64.86	3.73	33.74
	BOTTOM	77.81	12.76	9.43	22.19	100.00	84.40	8.90	6.70	15.60	100.00	69.74	70.30	3.50	30.25
MB 003	TOP	83.4	8.45	8.15	16.60	100.00	88.50	4.70	6.80	11.50	100.00	55.62	69.27	5.02	44.37
	MIDDLE	81.93	10.07	8.00	18.07	100.00	89.00	6.70	4.30	11.00	100.00	66.53	60.87	4.53	33.46
	BOTTOM	78.66	14.35	6.99	21.34	100.00	84.14	11.30	4.56	15.86	100.00	78.74	74.32	3.68	21.25

**Table 3:** Soil microaggregates indices of the sampled gully units at Bole area

Location Gully Unit	Bole Layers	Particle size Distribution using CALGON					Particle size Distribution using WATER					Microaggregates Indices			
		% Sand	% Clay	% Silt0	Total (% Clay+ %Silt)	Total (% Sand + %Clay+ %Silt)	% Sand	% Clay	% Silt	Total (% Clay+ %Silt)	Total (% Sand + % Clay+ %Silt)	CDI	CDR	CR	CFI
BL 001	TOP	86.12	6.38	7.50	13.88	100.00	90.14	4.56	5.30	9.86	100.00	71.47	71.03	6.20	28.52
	MIDDLE	78.38	11.52	10.10	21.62	100.00	85.68	7.89	6.43	14.32	100.00	68.48	66.23	3.62	31.51
	BOTTOM	77.01	10.26	12.73	22.99	100.00	87.55	4.56	7.89	12.45	100.00	44.44	54.153	3.34	55.55
BL 002	TOP	84.48	9.47	6.05	15.52	100.00	92.1	4.23	3.67	7.9	100.00	44.66	50.90	5.44	55.33
	MIDDLE	78.16	12.01	9.83	21.84	100.00	84.46	8.98	6.56	15.54	100.00	74.77	71.15	3.57	25.22
	BOTTOM	80.47	10.33	9.20	19.53	100.00	87.65	6.57	5.78	12.35	100.00	63.60	63.23	4.12	36.39
BL 003	TOP	84.47	9.6	5.93	15.53	100.00	89.26	7.34	3.40	10.74	100.00	76.45	69.15	5.43	23.54
	MIDDLE	79.78	10.32	9.90	20.22	100.00	89.77	5.67	4.56	10.23	100.00	54.94	50.59	3.94	45.05
	BOTTOM	79.18	10.05	10.77	20.82	100.00	88.88	4.34	6.78	11.12	100.00	43.18	53.41	3.80	56.81
BL 004	TOP	87.96	6.56	5.48	12.04	100.00	91.99	4.56	3.45	8.01	100.00	69.51	66.52	7.30	30.48
	MIDDLE	80.48	10.61	8.91	19.52	100.00	87.66	6.67	5.67	12.34	100.00	62.86	63.21	4.12	37.13
	BOTTOM	77.56	11.12	11.32	22.44	100.00	89.77	5.67	4.56	10.23	100.00	50.98	45.58	3.45	49.01
BL 0045	TOP	86.01	8.8	5.19	13.99	100.00	89.98	5.67	4.35	10.02	100.00	64.43	71.62	6.14	35.56
	MIDDLE	82.53	10.3	7.17	17.47	100.00	89.07	5.46	5.47	10.93	100.00	53.00	62.56	4.72	46.99
	BOTTOM	81.1	9.48	9.42	18.90	100.00	87.55	4.56	7.89	12.45	100.00	48.10	65.87	4.29	51.89

CDI: Clay Dispersion Index (%), CDR: Clay Dispersion Ratio (%), CR: Clay Ratio (%), CFI: Clay Flocculation Index (%)

### **Classification of soil of soil microaggregates of Bole study area**

Results of soil Microaggregates indices of Bole area were depicted in Table 3. At Bole gully unit, total % clay + % silt of calgon solution increases from top to bottom layers of the gully (13.88-22.99 %) which was higher than water solution (9.86-14.32 %). The CDI, CDR and CR indices were found to have decreased down the layers ranging from 71.47-44.44 %, 71.03-54.13 % and 6.20-3.34 % respectively. These values revealed that the affinity of the soil susceptible to erosion decreases with decreased in CDI, CDR and CR values down the layers while its affinity to resist erosion increases due to increase in CFI values varied from 23.54-56.81 %. Thus, the higher the CFI value the better the stability of the soil making it more resistant to erosion. Igwe and Udegbumam (2008), CFI is a perfect index for predicting soil erodibility and a useful micro-aggregate index. Soils high in CFI are well aggregated and will not easily disperse in water (Osujieke1 *et al.*, 2020)

Conversely, an irregular variation of % clay + % silt in both calgon and water solutions were observed within the layers of gully unit 2 of Bole area as shown in Table 4.81. These variations revealed that middle layer of the gully had more % clay + % silt in calgon and water solutions (21.84 % and 15.54 %) with low sand content (78.16 % and 84.46 %) making more susceptible to erosion with higher values of CDI (74.77 %), CDR (71.15 %) and lowest values of CR (3.57 %) and (25.22 %) respectively. This might be attributed to intensive cultivation in the area which makes the soil very loose. Thus, Aggregate size and stability was lower in the land under cultivation compared to forest and fallow (Tangtrakampong and Vityakan, 2002). Hence, the greater CDI and CDR values the higher the soil susceptibility to erosion and the

lower the CDF value the poor the stability of the soil which make more prone to erosion.

In dissimilarity, gully unit 3 of the area shows increase in total % clay + % silt contents in both calgon and water solution within the layers with valued varied from 15.33-20.82 % and 10.74-11.12 %. The micoraggregates values of CDI, CDR and CR were found to have decreased from 76.45-43.18 %, 69.15-53.41 % and 5.43-3.80 % meanwhile CFI have increased down the layers from 23.54-56.81 % respectively. The behaviors of these indices recognized the gully unit to have more stability of its aggregates and resistance to erosion from top layer to bottom layer. However, the soil is still considered as more erodible due to high values of CDR exceeding the critical limit of > 15 %. These results agreed with the conclusion of Chakrabarti (1990) who said that soils susceptibility to erosion is significantly related to the clay dispersion ratio. Similar trend of increased in % clay + % silt in calgon (12.04-22.44 %) and water (8.01-12.34 %) solutions were observed at gully unit 4. Also the CDI, CDR and CR were decreased down the layers of the gully with recorded values varied from 69.51-50.98 %, 66.52-45.58 % and 7.30-3.45 % characterizing the soil with more resistance to erosion with depth. In contrast, the CFI increases within the layers (30.48-49.01 %) suggesting better aggregate stability of the soil. Likewise, at gully unit 5 of Bole area an increased in in % clay + % silt in calgon (13.99-18.90 %) and water (10.02-12.45 %) solutions were recorded. CDI, CDR and CR values were all decreased from top to bottom layers having ranged values of 64.43-48.10 %, 71.62-65.87 % and 6.14-4.29 % signifying more ability of the soil to withstand erosion down the layers of the gully, although, the CDR > 15 % is considered more erodible. The CFI value increased from 35.56-51.89 % also demonstrating the ability of the soil to resist erodibility due

more formation of aggregates within the layers. This result is not similar with the finding reported by Igwe and Udegbonam, (2008) who explained CFI shows the ability of the soils to resist dispersion in water where the CFI values of the ultisol soils in Southern Nigeria are low and a direct inverse of CDR.

#### *Classification of soil microaggregates of Yolde Pate study area*

Results on microaggregates indices of Yolde pate area are presented in Table 4. At gully unit 1, the results shows that total % sand + % silt particle size distribution using calgon was higher at all the three layers (39.06 %, 25.38 % and 20.36 %) than the one obtained using water (28.34%, 10.23 % and 8.23 %). In contrast, the sand content was greater by using water (71.66 %, 89.77 % and 91.77 %) than calgon (60.94 %, 74.62 % and 79.64 %). In addition, microaggregates indices revealed that clay dispersion index (CDI %) and clay dispersion ratio (CDR) are found to be > 15 % in all the three identified layers with CDI values of 63.97 %, 50.44 % and 35.10 % and CDR values of 72.55 %, 40.30 % and 40.42 % respectively. The clay ration was found to have increase with depth (1.56 % top, 2.94 % middle and 3.91 % bottom layers) while in contrast clay flocculation index (CFI) increases down the layers. It is imperative to explain that these variations of the indices show that the affinity of soil erosion susceptibility of the gully is higher at the top layer which decreases with depth and the aggregate stability of the soil increases with depth. Generally, the presence of clay material provides the required bondage between the varying soil particles resulting in the formation of more stable aggregates which makes them less susceptible to erosion. (Osujieke1 et al., 2020).However, clay absence reduces the capacity of the soil particles to bind together and form aggregates that can resist the shearing

force of flowing water, thus making the soils vulnerable to soil erosion. This is in compliance with the finding of Parfitt and Salt (2001), who have indicated that higher clay content of soils reduces erodibility. Hence, soils with low clay content are more prone to erosion and have lower binding forces and poor cohesion. This is because the higher the CDI and CDR the higher the erosion susceptibility while the higher the CFI value the better aggregate stability of the soil to resist erosion formation and development.

Similar trends of high % of clay + silt content using calgon (35.02 %, 26.02 % and 19.75 %) than in water (20.14 %, 15.65 % and 8.01 %) were recorded at gully unit 2 of Yolde pate with high sand % in water solution (79.86 %, 84.35 %, and 91.99 %) compared to calgon solution (17.18 %, 13.03 % and 9.58 %) as described in Table 4.82. It is a known fact that calgon dissolves more particles in suspension than water. The microaggregates indices of CDI and CDR were found to be > 15 % within all the three (CDI= 69.17 %, 43.64 % and 33.92 %, CDR = 57.50 %, 60.14 % and 40.55 %) identified layers of the gully which decreases with depth. Conversely, the CR and CFI are found to have increases with depth signifying better aggregate stability of the soil to resist erosion impediment down the profile. This could be attributed to decrease of micro particles (clay and silt) percent down the layers. Amezketa, (1999) noted that good soil structure, known by the presence of well-formed and stable aggregates, is the most desirable of all soil attributes for sustaining agricultural productivity and for preserving environmental quality. From the context above, a good understanding of the aggregate stability of tropical soils and its relationship can be comprehended.

**Sadiq, et. al.,**

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Sadiq (2020) have reported that soils having high clay and silt content are the most erodible of all soils as they are easily detached; tend to crust, and produce high rates of runoff.

**Table 4:** Soil microaggregates indices of the sampled gully units at Yolde pate area

Location Gully Unit	Yolde Pate Layers	Particle size Distribution using CALGON					Particle size Distribution using WATER					Microaggregates Indices			
		% Sand	% Clay	% Silt	Total (%Clay+ %Silt)	Total (% Sand + % Clay+ %Silt)	% Sand	% Clay	% Silt	Total (%Clay+ %Silt)	Total (% Sand + % Clay+ %Silt)	CDI	CDR	CR	CFI
YP 001	TOP	60.94	15.46	23.6	39.06	100.00	71.66	9.89	18.45	28.34	100.00	63.97	72.55	1.56	36.02
	MIDDLE	74.62	11.24	14.14	25.38	100.00	89.77	5.67	4.56	10.23	100.00	50.44	40.30	2.94	49.55
	BOTTOM	79.64	10.14	10.22	20.36	100.00	91.77	3.56	4.67	8.23	100.00	35.10	40.42	3.91	64.89
YP 002	TOP	64.98	17.84	17.18	35.02	100.00	79.86	12.34	7.80	20.14	100.00	69.17	57.50	1.85	30.82
	MIDDLE	73.98	12.99	13.03	26.02	100.00	84.35	5.67	9.98	15.65	100.00	43.64	60.14	2.84	56.35
	BOTTOM	80.25	10.17	9.58	19.75	100.00	91.99	3.45	4.56	8.01	100.00	33.92	40.55	4.06	66.07
YP 003	TOP	62.94	18.06	19.00	37.06	100.00	71.40	12.30	16.3	28.60	100.00	68.10	77.17	1.69	31.89
	MIDDLE	71.67	14.65	13.68	28.33	100.00	83.50	6.70	9.80	16.50	100.00	45.73	58.24	2.52	54.26
	BOTTOM	78.62	10.13	11.25	21.38	100.00	83.10	8.45	8.45	16.90	100.00	83.41	79.04	3.67	16.58
YP 004	TOP	64.83	18.73	16.44	35.17	100.00	75.88	9.56	14.56	24.12	100.00	51.04	68.58	1.84	48.95
	MIDDLE	82.9	13.83	3.27	17.10	100.00	89.99	8.78	1.23	10.01	100.00	63.48	58.53	4.84	36.51
	BOTTOM	80.71	13.45	5.84	19.29	100.00	88.00	8.60	3.40	12.00	100.00	63.94	62.20	4.18	36.05

In addition, at gully unit 3 the % of clay + silt content using calgon was high than the water solution with the following corresponding of 37.06 %, 28.33 % and 21.38 % and 28.60 %, 16.50 % and 16.90 % which decreased down the layers of the gully. The top and bottom layers of the gully has greater susceptibility o erosion characterized with higher values of CDI (68.10 % and 83.41 %) and CDR (77.17 % and 79.04 %) and poor aggregate stability defined with CFI of 31.89 % and 16.58 % respectively. It is the middle layer having less susceptibility to erosion with better aggregate stability. By implication this gully will continue to initiates more rapidly and expand extensively over a short period of time due to overlying and underlying of weak layers at both surface and sub-surface. There is evidence from the United States that WDC and CDR can be good estimators of erodibility of some soils in Ohio (Bajracharya et al., 1992). Thus, any of DR, CDR and WDC could be used in predicting erodibility of some the soils as was reported by Igwe (2005).

At gully unit 4, the CDI and CR values increases with depth ranged from 51.04-63.94 % and 1.84-4.84 %) with an irregularity in CDR values (58.53-68.58 %). In addition, CFI values decreased within the layers (48.93 %, 36.50 % and 36.03 %). These variation could be connected textural variability of clay particles in calgon and water solutions which are determinant factors for aggregate stability of the soil. These results revealed that soil erodibility increases within the layers as the stability of the aggregate decreases. This scenario will leads to accelerated formation and development of this gully unit as the other factors (rainfall, vegetation) remain constant rejuvenating g the gully unit to large unit gully. Generally, higher clay ratio indicates lower binding influence due

to clay and therefore greater susceptibility to erosion.

### Conclusions

The soil microaggregates indices of the studied areas shows that the areas were under high erosion susceptibility that leads to formation and development of small to large gullies ravaging hectares of arable lands in the area. In all the selected areas the CDR and CDI were greater than the critical limit (> 15 %). However, it could be noted that at Bole and Yolde pate areas as the CDR and CDI reduced from top to bottom the CFI increases describing better aggregate stability and in consequence increasing the resistant of the soil to erosion. It is recommended that farmers in the areas should adopt the use integrated nutrient management through incorporation of organic materials and employ effective and proper land use management and agronomic practices

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