Annals of Borno **15/16** *(1998-99), 220-236*

INFLUENCE OF PEDOLOGICAL CHARACTERISTICS AND LAND USE PRACTICES ON THE ERODIBILITY OF SOILS OF NGADABUL FLOOD PLAIN WITHIN THE MAIDUGURI METROPOLIS

by

G. I. **C. Nwaka and B. Bababe**

Abstract

Four major land units were identified based on the nature and severity of erosion. They are characterised by moderate sheet erosion with rills-in-formation (unit 1), severe sheet erosion with serious threat of gully erosion and well developed rills (Unit 3), moderate rill erosion (Unit 4) and devastation by gully erosion (Unit 2).

Adverse characteristics which have presumably contributed to the erodibility of these soils include weak horizonation, poor and weak structural development, structurelessness single grained and massive), coarse texture, very friable and very soft to loose moist consistency; low clay ratio, high bulk density, low total porosity and compactness, preponderance of quartz skeletal grains in the sand and silt fractions, low water holding capacity, and low buffering capacity, others are high pH and ESP, narrow Ca/Mg ratio, high silt/clay ratio, preponderance of silt in the physical clay, low organic matter and substantial content of exchangeable Na and Kin the face of low CEC, very low cementing capacity of physical clay, and slope gradient (2-8%).

Land use activities such as earth mining, burning, overgrazing, urbanization, irrational agricultural land preparation, cultivation of row crops, and non-application of organic and inorganic fertilizers contributed to the erodibility of these soils. Practical recommendations are put forward for the control of land degradation.

Introduction

River Ngaddabal is one of the two major rivers flowing through the metropolis. It flows northwards, having its source from the Biu Plateau. This river is seasonal and occasionally, its upsurge had left behind very serious and costly flooding and erosional disasters.

Seasonal flooding hazards and soil erosion in various forms within the flood plains of Maiduguri metropolis have in recent years attracted the attention of town planners. The flood plain within the metropolis is intensively cultivated. Other land use activities include earth-minning, livestock grazing, urban house construction and orchad growing. Owing to

Department of Soil Science, University of Maiduguri

indiscriminate land use practices and land development without adequate conservation measures, the whole flood plain is seriously threatened by active erosional degradation. Gullying has reached such a climax that houses and orchads are facing imminent collapse and total destruction. The sudden seasonal flooding makes the matter worse whenever it occurs with its resultant devastation.

Gully initiation in the study area seems to conform with the established theories, indicating that in almost all gullies, natural water courses are present. According to Hudson (1971), gully erosion occurs when a natural water course is displaced from its state of metastable equilibrium. It is assumed that in the study area, this displacement hypothesis must have occurred when man exploited the area indiscriminately, and urban development progressed without adequate conservation measures. However, the physical factors of relief and slope, the sandy nature of the lithology, heavy rainfall upstream and man-intensified run-off from house roofs contributed to the intensification of erosional degradation, especially the formation and growth of rills and gullies. Yearly observation shows that caving-in and slumping of the river banks and other man-made escavations lead to gully formation and expansion.

It is also observed that at the rate at which urban development is taking place within the flood plains in the metropolis, there is an immediate need to find corrective and controlling measures. The ultimate objective is to control effectively, or even put a stop to the continuous degradational processes. In view of this, the paper will describe the pedological characteristics and the land use practices that have contributed to, or accelerated the erosional degradation. Furthermore, the soils will be classified taxonomically, and recommendations will be made to facilitate the control of soil degradation.

Materials and Methods

Location and Extent

The survey area covers part of the flood plain extending from the Kyarimi Zoo Park to the Ring Road, enclosing the Sheraton Hotel Complex, Maduganari village, Damboa Road GRA. Schools of Health Technology and Nursing, and Shehu Garbai Primary School premises; Ministry of Education Vocational Centre, the back of Police College, Police Headquarters, Women Teachers College (Fig. I).

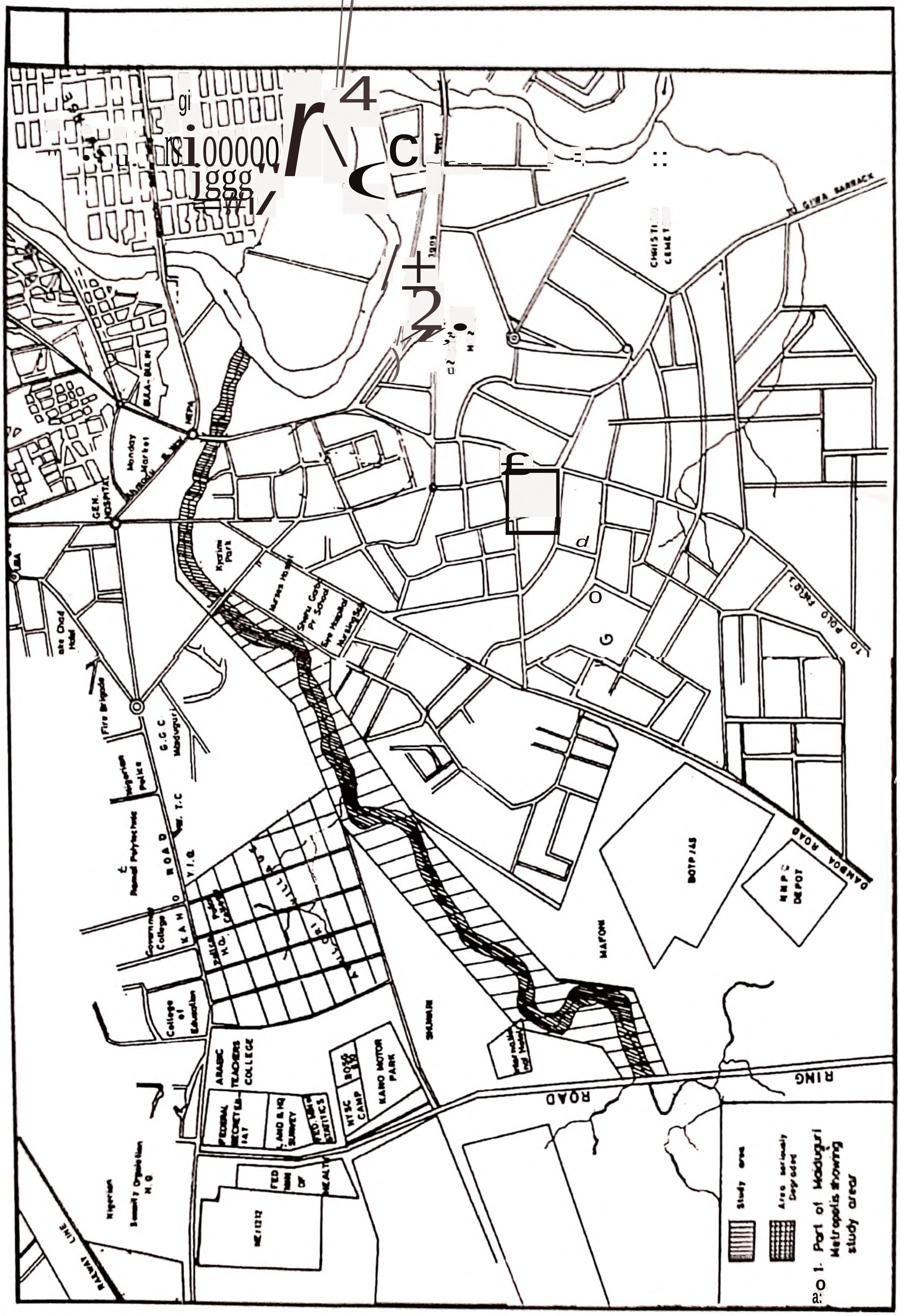

Fig. 1. Part of Maiduguri Metropolis showing study areas

The Mai Ibrahim Road forms the northern boundary, while the Ring Road forms the southern boundary. The Police College, Police Headquarters and the Maduganari Village border the survey area on the west. The Schools of Health Technology and Nursing, Damboa Road GRA, and the NNPC village border the survey area on the east. The portion of the survey area under serious degradation measures is about $2km^2$, being about 5km long and 400m wide, including the main river course. Extension and intensification of urban development without appropriate, corresponding and adequate control measures will definitely get more areas engulfed.

Environmental Features

Climate in Maiduguri is generally semi-arid, with moderately-wide seasonal and diurnal variations in temperature. The maximum annual temperature is about 35C, mean minimum annual temperaturue is about 17.7C, while mean annual temperature is about 27.3°C. Mean annual rainfall is about 820mm, and rainy season lasts for about 110 days (Meterological Dept., International Airport, Maiduguri, 1986-1995).

Rainfall maxima are usually recorded in the early evening and the early morning, the former being commonly associated with thunderstorms. Precipitation is usually very low, and falls of 75-100mm per day are often recorded. Hail is extremely rare. Although the duration of rainy season is short, most of the rain-fall is characterised by a high kinetic energy for the first 10 to 20 minutes. This observation is confirmed by Ohu *et al.*, (1994) who reported rainfall intensities of about 180-240mm/hr for Maiduguri.

Mean slope ranges between 2 to 8%. In few places, it is up to 10 to 15%. Geologically, the survey area is covered by thick heterogeneous alluvial sandy deposits, with occasional aeolian sandy deposits of degraded and reminant sand dunes (Islands).

Field Studies

The grid method of soil survey was used for the mapping, and for this purpose a topographic map of Maiduguri metropolis (1:2000) was acquired. The study area was marked out and augered at the scale of 1:5000. Soil changes, land use variations, and erosional degradation intensities were studied during the augering. Four mapping units were established and four representative profile pits were sited, studied and characterised. Soil samples were collected from all the genetic horizons for laboratory analysis. Bulk density samples were collected with core samplers before and after infiltration studies. What could have been the fifth mapping unit could not be mapped as they are scattered in sand islands (pockets) of aeolian origin.

Laboratory Analysis

The laboratory analyses included particle size distribution by hydrometer method, with calgon as dispersant, bulk density by core method, and particle density by pycnometer method.

Soil reaction (pH) and electrical conductivity (EC) were determined using a pH-meter and EC meter in I:I soil to liquid ratio; organic carbon by Walkley Black method, exchangeable cations by neutral Ammonium Acetate extraction, exchange acidity (Al+ H) by IN.KCI extraction, and effective cation exchange capacity (ECEC) by summation of exchangeable cations and exchange acidity. Percentage base saturation (PBS) and exchangeable sodium percentage (ESP) were calculated as percentages of sum of exchangeable bases (TEB) and sodium to ECEC respectively. Ca/Mg ratio was calculated as ratio between exchangeable calcium and magnesium. Silt/clay ratio was also calculated. All analyses were carried out using standard routine procedures (Klute 1986; Page *et al* 982; IITA 979).

Results and Discussion

Morphological Characteristics

Field observations show that the study area is entirely engulfed by erosional degradation of various types and degrees, ranging from moderate sheet with rills-in-formation (Unit 1), severe sheet erosion with serious threat of gully erosion and well developed rills (Unit 3), moderate rill erosion (Unit 4), and serious threat of gully erosion (hazardous) (Unit 2).

Morphological descriptions of the profiles are shown in the appendix (Pedons 1 to 4 represent Units I to 4 respectively). The parameters that affect erosion include structure, texture, and consistency, etc. The structure is generally weakly developed in the top soil, and structureless (massive and single grained) in the subsoil. Consistency of wet soil is generally non-sticky non-plastic, very friable when moist; and soft, loose and occasionally hard when dry. The structure and consistency reflect the very sandy texture of the soils; loam sand in the top soil and sandy to sandy loam in the subsoil. These are juvenile soils with A-AC-C-2C-3C type of horizonation. The multiple C horizons point to lithological breaks and variations, and also their depositional history.

The weak structural development and structurueless single grain or massive, sandy textural class and poor consistency naturally render the soils very erodible. Highly compact deep subsoil observed in some of the pedons may constitute a hindrance to the percolation of water, and consequently lead to surface runoff.

Particle Size Distribution

The particle-size composition contributes significantly to erodibility. Our data (Table 1) show that sand fraction greatly dominates, ranging from 65 to 97%. Sand content showed a significantly high correlation with total soil loss, except for soils with sand content above 85%, which showed relatively low erodibility. Furthermore, Bryan (1968) observed that the relationship is probably not valid for soils with sand content below 40% as well. Our data showed that sand content is not up to 85%, except in some deep sub-horizons in pedons 1,2 and *4*. On the other hand, sand content in the soils studied is more than 40%. This indicates that these soils are highly vulnerable to the erosivity of surface water flow, and to the dispersive action of the percolating water. Clay fraction is very low (0.5– 16.6%). Although clay distribution is irregular, confirming the alluvial nature of the parent material, lower values are recorded in the lower horizons. The content of silt is quite significant (9-25%), especially in the upper horizons, and could contribute (in association with a high content of fine sand) in reducing water infiltration by sealing up the pores and enhancing runoff.

It is also noted that the irregular distribution of clay with depth ruled out downward clay migration - a process which could combine with clay formation *in situ*, to promote aggregation. Moreover, lower content of clay in the deeper horizons could promote slumping and massive carving-in once there is flooding. Intensified run-off with high erosivities is caused by larger volume of water collected from the roofs of the numerous houses. This phenomenon could enhance rill formation which later could develop into gullies when unchecked.

Silt/clay ratio is high, indicating the preponderance of silt. Preponderance of silt fraction, coupled with low organic carbon content could reduce the cementing ability of the physical clay (silt+ clay), leading to weak aggregation. Low clay ratio, calculated by dividing% clay by the sum of% sand + % silt confirms the high erodibility of these soils.

Bulk Density, Particle Density and Total Porosity

Analytical data in Table 2 show that the values for bulk density are generally high, especially in compact horizons. The overall high bulk density points to the compactness of the soil despite the sandy texture, and reflects the degree of weak structuring and massiveness. The high bulk density has resulted in low total porosity (28.9-38.5%) under field moisture condition, and 36.7-43.2% at field capacity. Such low total porosity could negatively affect water infiltration and enhance surface flow. Nwaka and Bababe (1992) reported moderately-rapid to low infiltration rates for these soils. Moreover, field observation showed the intensity of sheet and rill erosion.

Table 1
Particle Size Distribution (Hydrometer Method)

Soil Depth (cm)	*Coarse Sand*	*Fine Sand*	*Total Sand >0.05mm*	*Silt <0.05mm*	*Clay <0.002mm*	*Text-ural Class*	*Silt/ Clay*	*CR*
P1:								
0-10	25.8	50.5	76.3	13.8	9.9	SL	1.39	0.11
10-43	32.0	43.1	75.1	13.1	11.7	SL	1.12	0.13
43-71	28.5	53.2	81.7	12.1	6.2	LS	1.95	0.07
71-103	32.7	43.6	76.3	13.8	9.9	SL	1.39	0.11
103-143	52.5	34.2	86.7	9.6	3.7	S	2.59	0.04
143-250	3.2	63.5	66.7	23.4	10.0	SL	2.34	0.11
P2:								
0-12	40.3	30.3	70.3	15.7	14.0	SL	1.12	0.16
12-32	31.9	24.7	56.6	26.9	16.5	SL	1.63	0.20
32-66	30.0	41.8	71.8	20.6	16.6	SL	1.24	0.20
66-110	32.0	49.0	81.0	17.0	2.0	LS	18.0	0.02
110-147	15.3	58.5	73.8	18.8	7.4	LS	2.54	0.08
147-180	72.6	24.8	97.4	1.9	0.7	S	2.71	0.01
180-229	93.3	4.3	97.6	1.9	0.5	S	3.80	0.01
229-260	85.2	12.4	97.6	1.9	0.5	S	3.80	0.01
P3:								
0-18	18.1	42.0	60.1	25.7	14.2	SL	1.81	0.17
18-59	14.6	51.7	66.3	21.3	12.4	SL	1.72	0.14
59-85	10.7	50.6	61.3	23.8	14.9	SL	1.60	0.18
85-142	10.9	58.1	69.0	19.6	11.4	SL	1.72	0.13
142-184	11.0	57.1	68.1	28.8	3.1	SL	9.29	0.03
184-280	15.4	56.3	71.7	22.1	6.2	SL	3.55	0.07
280-300	8.2	66.9	75.1	17.6	7.3	SL	2.41	0.08
300-550	10.2	61.9	72.1	22.6	5.3	SL	4.26	0.06
P4:								
0.16	13.8	61.9	75.7	12.1	11.2	SL	1.08	0.13
16-34	11.8	54.9	66.7	25.9	7.4	SL	3.5	0.08
34-99	26.2	41.3	67.5	21.3	11.2	SL	1.98	0.13
99-155	49.5	20.5	70.0	20.9	9.1	SL	2.29	0.10
155-192	25.0	53.2	78.2	16.3	5.5	LS	2.96	0.06
192-225	50.7	21.0	71.7	19.6	8.7	SL	2.25	0.10
225-280	47.7	46.6	94.3	4.6	1.1	S	4.18	0.01

SL- Sandy loam, LS - Loamy sand, S- Sand
CR - Clay ratio

Table 2
Bulk Density, Particle Density and Total Porosity

Soil Depth	*Bulk Density* *(g/cm^3)* *at FM*	*at FC*	*P. Density* *(g/cm^3)* *at FC*	*Moisture* *at FC* %	*Total Porosity* *at FM* %	*at FC* %
P1:						
0-10	1.47	1.45	2.54	17.6	42.1	42.9
10-43	1.67	1.60	2.56	15.7	34.8	37.5
43-71	2.06	1.70	2.67	14.5	23.0	36.3
71-103	1.71	1.69	2.68	13.2	36.2	36.9
103-143	2.07	1.56	2.58	4.2	19.8	39.5
143-25	1.69	-	2.47	-	31.6	-
Mean	1.73	-	2.58	-	31.3	38.6
P2:						
0-12	1.56	1.49	2.59	16.7	39.8	42.5
12-32	1.56	1.46	2.56	14.6	39.1	43.0
32-66	1.79	1.43	2.67	12.0	33.0	46.4
66-110	1.68	1.58	2.63	5.1	36.1	40.0
110-147	1.61	1.50	2.68	1.4	40.0	44.0
147-180	1.66	-	2.73	-	39.2	-
180-229	1.67	-	2.75	-	39.3	-
229-260	1.61	-	2.76	-	41.7	-
Mean	1.64	-	2.67	-	38.5	43.2
P3:						
0-18	2.17	1.69	2.72	-	20.2	37.9
18-59	2.27	1.70	2.65	-	14.3	35.8
59-85	1.65	1.55	2.75	-	40.0	43.6
85-142	2.12	1.64	2.59	-	18.2	36.7
142-184	1.99	-	2.51	-	20.7	-
184-280	1.97	-	2.59	-	23.9	-
280-300	1.08	-	2.67	-	59.6	-
300-350	1.63	-	2.49	-	34.5	-
Mean	1.86	-	2.62	-	28.9	38.5
P4:						
0-16	1.44	1.40	2.65	-	45.7	47.2
16-34	1.45	1.41	2.63	-	44.9	46.4
34-99	1.81	1.56	2.62	-	30.9	39.7
99-155	2.11	1.65	2.62	-	19.5	37.0
155-192	1.95	1.61	2.65	-	26.4	39.2
192-225	1.94	-	2.71	-	28.4	-
225-280	1.7	-	2.75	-	39.2	-
Mean	1.69	-	2.66	-	33.6	41.9

FM- Field Moisture State, FC- Field Capacity

Particle density ranged from 2.58 to 2.66g/cm (mean values). This indicates that sand and silt fractions may consist mainly of quartz skeletal grains. Quartz has a density of.about 2.66g/cm and a low affinity for water, resulting in low water holding capacity in sandy. soils. This preponderance of quarts grains could enhance slumping, inhibit aggregation and lower aggregate stability. It could also be opined that as these soils are weakly structured to structureless, most of the total porosity could be non-aggregate voids. This high non-aggregate porosity, coupled with low water holding capacity could render these soils more vulnerable to the dispersive effect of water.

Physico-chemical Properties

Soil reaction is strongly alkaline in the upper 100cm of the soil (pedon 1), and in the deep subsoil of pedon 3 (Table 3).

Table 3
Chemical Properties

Soil Depth (cm)	pHw 1:25	EC /:/ dsm⁻¹	Org. C %	Ca"	Mg?"	K cmol(+)	Na' kg'	ECEC	PBS %	ESP %	Ca/ Mg
P1:											
0.10	8.6	0.17	0.73	12.04	1.83	2.38	0.36	18.4	90.2	1.96	7:1
10-43	8.6	0.08	0.54	18.97	2.64	1.28	0.41	26.5	87.9	1.55	7:1
43-71	9.1	0.10	0.77	12.04	0.81	2.08	0.69	17.4	89.7	3.96	15:1
71-103	9.1	0.12	0.73	39.98	6.90	1.79	0.69	50.7	97.6	1.36	6:1
103-143	7.6	0.08	0.73	3.36	0.61	0.72	0.52	8.5	60.1	6.11	6:1
143-250	7.6	0.010	0.70	3.45	4.49	0.82	0.71	12.9	73.6	5.52	3:4
Mean	8.4	-	0.70	14.96	2.88	1.51	0.56	22.4	-	-	5:1
P2:											
0-12	7.1	0.04	0.80	2.24	2.03	0.56	0.33	7.8	66.5	4.30	1:1
12-32	5.9	0.03	0.80	3.67	1.22	0.22	0.32	10.2	53.0	5.9	3:1
32-66	6.6	0.02	0.64	3.06	2.23	0.21	0.36	9.3	63.3	3.89	3:2
66-110	6.4	0.02	0.73	4.08	1.02	0.41	0.38	7.9	74.7	4.82	4:1
110-147	6.4	0.02	0.73	2.45	2.23	0.21	0.37	8.5	62.2	4.37	1:1
147-180	6.8	0.06	0.22	0.41	1.22	0.08	0.28	3.8	52.5	7.38	1:3
180-229	7.2	0.02	0.29	0.61	1.02	0.05	0.29	4.4	45.1	6.64	1:2
229-260	7.6	0.04	0.29	0.82	0.81	0.13	0.28	4.4	45.9	6.31	1:1
Mean	6.8	-	0.56	2.17	1.47	0.23	0.33	7.0	-	-	3:2
P3:											
0-18	6.9	0.02	1.07	4.28	2.03	1.03	0.34	10.1	76.2	3.37	2:1
18-59	6.3	0.05	0.96	5.30	2.84	0.54	0.49	14.0	65.6	3.51	2:1
59-85	7.5	0.04	0.99	6.12	2.84	0.82	0.53	13.3	77.5	3.98	2:1
85-142	8.5	0.09	0.78	12.65	2.64	2.18	0.52	21.2	84.9	2.45	5:1
142-184	8.4	0.13	0.32	18.36	2.84	1.56	0.83	28.0	84.3	2.97	6:1
84-280	8.6	0.09	0.69	21.01	1.02	1.03	0.54	25.2	93.7	2.14	20:1
280-300	9.0	0.20	0.19	3.47	2.03	0.46	0.57	10.1	64.5	5.63	5:3
300-350	8.3	0.09	0.29	14.89	3.25	1.00	0.80	21.9	90.9	3.65	5:1
Mean	7.9	-	0.66	10.76	2.44	1.08	0.58	18.0	-	-	4:1
P4:											
0-16	7.3	0.04	1.05	3.06	5.48	0.92	0.37	12.2	80.4	3.03	1:2
16-34	5.8	0.03	0.70	2.45	2.45	0.67	0.35	8.9	68.6	3.93	1:1
34-99	6.6	0.03	1.11	1.22	3.86	0.26	0.37	7.3	93.5	5.06	1:3
99-155	6.8	0.03	0.45	1.45	2.44	0.38	0.40	8.1	70.3	4.96	1:2
155-192	6.2	0.03	0.54	3.06	2.64	0.38	0.41	9.3	69.9	4.41	5:4
192-225	7.4	0.02	0.46	3.47	2.84	0.38	0.52	10.0	72.0	5.20	5:4
225-280	7.4	0.03	0.51	1.87	1.22	0.18	0.33	6.4	56.3	5.16	3:2
Mean	6.8	-	0.69	2.37	3.02	0.45	0.39	8.9	-	-	2:3

PBS - Percentage Base Saturation, ESP - Exchangeable Sodium Percentage.

Alkaline reaction increases the dispersability of soil aggregates and promotes massiveness in soils. Such a condition could enhance slumping and hence, erodibility of the soils. NaOH and other sodium salts have been found to play a key role in the physical and chemical dispersion of particles (Baver 1972).

In pedons 2 and 4 where reaction is more or less neutral, erodibility was not retarded. It could thus be opined that neutrality in reaction cannot retard erodibility, especially when accompanied by preponderance of sand fraction, low CEC and low organic matter.

The content of organic matter is generally low, varying between 0.2% and 1%. This low content could be attributed to the burning practice, overgrazing, surface wash or sheet erosion, and even to wind erosion. Low organic matter content, coupled with sandy texture has greatly contributed to the aggregate.instability, which is a factor that promotes erodibility.

Exchangeable calcium is low in pedons 2 and 4, but high to moderate in pedons I and 3. Exchangeable Mg is moderate in an the soils. Exchangeable K is high to very high in pedons 1 and 3, low in pedon 2, and moderate in pedon 4. Exchangeable Na is moderate in all the soils.

Although percentage base saturation (PBS) is high to very high, occasionally moderate in the subsoil, effective cation exchange capacity (ECEC) is generally low, and occasionally high in some horizons. Exchangeable sodium percentage (ESP) has not reached the critical value of 15%; consequently, the soils are not sodic. Moreover, the electrical conductivity (EC) values are lower than 4dsm, so the soils are not saline. The later conclusion was based on the assumption that ECe = EC(1: I) x 2.2, or that EC I:1 is less than 2. It could be opined that as these soils have generally low buffering capacity, the Na content could contribute significantly to the dispersion of the soil particles and to their erodibility, especially as the soils are sandy. Sharard *et al.*, (1972) demonstrated that certain soils (low to medium plasticity clays and clays containing montmorrillonite) are structurally unstable, easily dispersed and therefore highly erodible. In addition, soils rich in soluble and exchangeable sodium are usually highly susceptible to erosion. Imeson and Kwaad (1980) used ESP as an indicator to assess intensity of erodibility. According to their findings, the subsoils of gullied soils had higher ESP than the soils yet to be affected. Our data showed that pedon 1 sited in an area with moderate sheet erosion and rills just forming had lower ESP than the other pedons (2,3 and 4) sited in areas, and threatened more by sheet, rill and gully erosion.

Parsons *et al.*, (1962) used narrow Ca/Mg ratio as an indicator of increased leaching and weathering. Akamigbo (1983) showed that Ca/Mg ratio was narrower at the edges of gullies, indicating that the processes of leaching and weathering are probably more intensive at exposed faces of the gully. Our data showed that Ca/Mg was very narrow in pedons 2, 3 and 4, and relatively narrower than in pedon 1. This confirms the field observation that pedons 2, 3 and 4 of land units 2,3 and 4 respectively, are more susceptible to erosional degradation.

Soil Classification

The soils were classified according to the USDA classification system-Soil Taxonomy (1991) and FAO/UNESCO legend (1984). Texturally, there are two major different types of soils: the loamy sand to sandy loam soils, and the sandy soils. The loamy sand to sandy loam soils are derived from the colluvioalluvial sandy deposits, while the sandy soils are derived from the aeolian sandy deposits. The former form about 95% of the soils, while 5% of the area is occupied by the later.

All the soils derived from the colluvio-alluvial sandy deposits are classified as Fluvents, principally because of the organic carbon content that decreases irregularly with depth. The Ustic moisture regime makes them to qualify as Ustifluvents. Pedon 1, which seems to be water saturated for longer period within 1.5m keys, out as Aguie Ustifluvent, while pedons 2, 3 and 4 key out as Typic Ustifluvents. The minor soils of aeolian sand origin could be classified as Typic Ustipsamments, or Alfie Ustipsamment for those with iron oxide lammalea. All these soils could be classified at family level as sandy, siliceous, hyperthermic Typic or Aguie Ustifluvents, and Typic Ustipsamments or Alfie Ustipsamments. According to the FAO Legend, these soils classify as Eutric Fluvisols (pedons 1, 2, 3 and 4) and Eutric Arenosols (for soils of aeolian sand origin).

The soil genesis, morphological, physical and chemical characteristics, lack of aggregate stability, high dispersion ratio, high erosion ratio, low degree of aggregation and state of aggregation, and low to moderate basic infiltration rates render them highly susceptible to erosional degradation.

Land Use Practice

Field scudies have shown that in the study area and in the Ngadda flood plain (another flood plain passing through the metropolis) sheet, rill and gully erosion and occasional flooding have not only evolved into serious engineering problems, but are also associated with serious socio-economic problems. In addition, they have serious and deterent implications on urban development and the safety oflives of the people. Land use activities such as wide-spread earth mining, bush burning, indiscriminate urban housing expansion, overgrazing, uncontrolled land preparation practices for the cultivation of cereals (planted on furrows or small ridges), non-application of chemical or organic fertilizers to improve the nutrient status, and lack of anti erosion measures have all combined to accelerate the erosional hazard.

The most severe erosion observed in the area occurs on exposed road cuttings, river banks, faces of burrow pits or other man-made excavations; In some places, owing to earth work and land slide, the slope gradient has been made more acute. It is also observed that. urbanisation, accompanied by indiscriminate construction of houses has increased the volume and erosivity of the rain-water.

Conclusion

By grid mapping, four major land units were identified based on nature and severity of erosion. They are characterised by moderate sheet erosion with rills-in-formation (Unit 1), severe sheet erosion with serious threat of gully erosion, and well developed rills (Unit 3), moderate rill erosion (Unit 4) and devastated by gully erosion (Unit 2).

Morphologically, these soils derived from colluvio-alluvial sandy deposits are characterised by A-AC-C-2C-3C type of horizonation. These soils are coarse textured-sandy loam to sand, with very friable, very soft to loose consistency when moist, and low clay ratio. Structure is very poor ranging from weak subangular blocky in the top soil, to structureless single grained and massive in the subsoil.

Total porosity is low, reflecting the compactness of the soil. Bulk density is very high in some top soil and subsoil horizons, leading to low porosity, reduced penneability and surface flow. Particle density which varied from 2.58 to 2.66g/cm points to the preponderance of quartz skeletal grains in the sand and silt fractions, culminating in low water holding capacity, poor consistency status and low buffering capacity.

The alkaline reaction in pedons 1 and 3 could increase the dispersability of the soil particles and promote massiveness, and consequently enhance slumping and erodibility. In pedons 2 and 4 where the reaction is more or less neutral, erodibility was not reduced in the face of high sand content, low organic matter and low ECEC, and moderate content of K. High silt clay ratio indicates the predominance of silt in the physical clay (silt plus clay) which, coupled with high sand content and very low organic matter, reduces the cementing capacity of the physical clay and renders the soils vulnerable to the dispersive action of water.

Using ESP as an indicator of erodibility, it could be concluded that unit 1, with lower ESP, is relatively less eroded than units 2, 3, and 4. Using also narrow Ca/Mg as an indicator of increased leaching.and weathering and hence erodibility, it could be noticed that Ca/Mg ratio was narrower in the more intensively eroded units 2, 3 and 4, than less eroded unit I. These juvenile soils with poor morphological, physical and chemical conditions and highly erodible are classified as sandy, siliceous, hyperthennic Typic and Aquic Ustifluvents (USDA) or Eutric Fluvisols (FAQ)

The land use activities such as earth mining burning, over-grazing, urbanisation, irrational agricultural land preparation, cultivation of row crops, non-application of organic and inorganic fertilizers contributed actively to the erodibility of the soils. Other areas not covered by the study and severely threatened by erosion include, the Police College and Ramat Polytechnic. Urgent attention is required in the Police College area in order to avert loss of lives and property.

Recommendations

1. The gullies that run-down to the river and the river banks require mechanical protection by way of erecting permanent concrete structures, which will check slumping and carving-in through interception, diversion and collection of surface and sub-surface run-offs that empty into the river.

2. Rational agricultural land use practices, would however be required to prevent reoccurence of the process of removal of surface soil by run-off water.

3. Other non-agricultural activities such as excarvation of earth and brick-making which aggravated the erosion problems should be abolished in the study area. However, there may be a sociopolitical implication in this measure, therefore a possible alternative may be to confine brick making to specific location, rather than the dotted activities along the valley. Alternative location for this industry can be sited on a place less vulnerable to erosion at the outskirts of the metropolis.

4. Grazing activities are presently very common and must be controlled.

5. The unpredictable seasonal flooding can be controlled by building diversional reservoir up stream, outside the metropolis.This reservoir can be opened to divert the flood from reaching the metropolis whenever the flood occurs.

6. Reforestation is complementary to other measures to be taken. Emphasis must be placed on planting fruit and wood trees in the flood plain.

7. Cultivation of annual crops within the area should be suspended in order to encourage better development of grass cover.

8. The use of chemical fertilizers on these soils should be encouraged in order to prevent further deterioration of soil fertility and soil structural condition.

9. The built-up areas within the flood plain should be provided with concrete drainage channels which can effectively collect the increased raindrops from the house roofs.

References

Akamigbo, F.OR. (1988). Influence of Pedological Processes on Gully Formation in South Eastern Nigeria." *Niger J. Soil Science* Vol. **4:**112-127.

Baver, L.D. (1928). The Relation of Exchangeable Cations to the Physical Properties of Soils: *J. AM. Soc. Agron.* 20:921-941.

Bryan, R. B. (1968). "The Development, Use and Efficiency oflndices of Soil Erodibility" *Geoderma,* **2(1)**5-26.

FAO/UNESO, *Legend World Soil Resources Report* 60. FAO of UN Rome I I 8pp.

Imeson, A.C. and F.O.M., Kwaad, (1980). "Gully Types and Gully Prediction." *Kon. Ned. Aardr. Gen. Geogr. Tijdschr.* XIV, No. 5, 430-441.

UTA, 1979 Selected Methods for Soil and Plant Analysis. *Manual Series* No. 1 Ibadan, Nigeria.

Hudson, **N.W.** *(1971) Soil Conservation,* B.T. Bataford Ltd., London W.I.

Klute, A.I. (1986). *Methods of Soil Analysis.* **Part** I. Second Edition. AM. Soc. of Agronomy, Madison, Wisconsin, USA.

Nwaka, G.I.C. and B. Bababe, (1989). "Soil Studies of the Ngaddabal flood plain within Maiduguri Metropolis for Erosion Control." Annual conference, Soil Science Soc. of Nigeria, Nsukka, Nigeria.

Ohu, J.O., E.I. Ekwue and LS. Atiwurcha, (1994). "A Portable Rainfall Simulator for Soil Erosion Research." *Journal of Arid Agriculture.* Vol. **3-7**: 105-112.

Page, A.L., R.H. Miller and D.R. Keeney, (1982). *Methods of Soil Analysis* Part I (Second Edition) AM. Soc. of Agronomy Madson, Wisconsin, USA.

Parsons, R.B., W.H. Schotters and F.F. Reicken, (1962). "Soils of Indian Mounds in Northeastern Iowa as Benchmarks for Studies of Soil Genesis", *Soil Sci. Soc. Am. Proc.* 491-496.

Sharard, J.L., R.S. Decker and N.L. Ryker, (1972). "Piping in Earthdam of Dispersive Clays." *Proceedings of the ASCE Specially Conference on the Performance of Earth and Earth Supported "Structures.* Purdu University pp 589-629.

SSS, (1991). *Key to Soil Taxonomy.* Fourth Edition SMSS Technical Monograph No. 6 Blaksbury, Virginia 422pp.

Van Wambeke, AR. (1982). "Criteria for Classifying Tropical Soils by Age". *J. Soil Sci.,* 13: 124-32.

Walter, M.W. (1967). "Length of the Rainy Season in Nigeria." *Niger geogr, J,* 10: 123-125.

APPENDIX: MORPHOLOGICAL CHARACTERISTICS

Pedon and Location	Horizon and Depth (cm)	Colour (Moist)	Mottling	Texure	Structure	Consistency	Bdry	Remarks
1	2	3	4	5	6	7	8	9
		Aquic ustifluvents						
Pedon I	APL:0-10	10YR 5/3	—	LS	f-m lsbk	wposo,mrfr,ds	gw	fl rts, cl-2 pores
Located behind	AP2: 10-43	10YR 5/3	—	LS	f-mlsbk	wposo,mrfr,ds	gs	clrts,c2&1qtz gravels
school & Health Technology,		IOYR 5/3	—	SL	Fl sbk	wposo,mrfr,ds	cs	f3rts, IOYR 7/4 sand Pockets, c1&2 quartz gravels, ml &2 pores
Maiduguri about	CE: 71-103	10YR 7/6	I0YR 7/6 C2 ft			wposo,mrfr,ds	as	fl rts, f2 concretions (sesquoxide) c1 pores
100m from Mai	2C2: 103-143	10YR 4/2	—	LS	mlsbk	wposo,mrfr,dsh	as	layered, 7.5YR 6/6 bands,
Ibrahim Road		10YR 5/3	—	LS	om	wposo,mfr,ds		5YR 6/6 sesquoxide lamellae
		10YR 8/6	—	SL				
	3€3: 143-250	10YR 6/4	—	S	om	wposo,mrfr,dh		CI &2 pores, f3 rts
		Typical Ustifluvents						
Pedon 2	APE: 0-2	IOYR 5/4	7.5YR 4/4c d	FS	om	wposo,mrfr,dh	as	flrts
On the easten side	AC: 12-32	10YR 7/4	—	FS	osg	wposo,ml,dl	as	—
of the river bank	2C1: 32-66	10YR 7/4	—	CS	osg	wposo,ml,dl	cs	—
near an orchad	2C2: 16-110	IOYR 7/6	!0YR 4/4 c1	CS	osg	wposo,ml,dl	cs	—
and opposite the	3C3: 110-137	IOYR 5/3	—	LFS	flsbk	wposo,mrfr,ds	cw	ml&2 pores, f rts
brick fumace.	3C4:137-180	IOYR 5/3	7.5YR 4/6 cld	LFS	m2sbk	wposo,mrfr,dh	cs	f2rts, ml&2 pores
About 20m from	3C5:180-219	10YR 5/4	7.5YR 4/6 mld	LFS	m2sbk	wposo,mrfr,dh	gs	
the gully (river bank)	3C6:219-266	IOYR 5/4	mld	LFS	On.	wposo,mrfr,dvhs	—	c1 pores, very compact

1	2	3	4	5	6	7	8	9
Pedon 3		***Typic Ustifluvent (Eutric Fluvisols)***						
Located behind the Police College about 50m from the river bank	Ap I: 0-18	10YR 4/2	—	LS	f-m2sbk	wposo mvfr,ds	ds	c1rts, ml pores
	Ap 2: 18-59	I0YR 4/2	—–	SL	f-mlsbk	wpss, mvfr, d&h)	gw	m1 pores, few subrounded qts gravels.
	AC: 59-85	10YR4/3	—–	SL	Mlsbk	wposs,mrfr, dh	cs	m1 & 2 pores, flrts
	C1: 85-142	I0YR 4/4	I0YR 6/8, c2ft	SL	MIsbk	wposs,mvfrdsh	gs	flrts, ml&2 pores, some ant nests.
	2€2: 142-184	I0YR 5/4	—–	LS	f-ml sbk	wposo,mvfr,ds	cs	common root hairs.
	3C3: 184-280	I0YR 5/6	c2d (I0YR 6/8)	LS	mlsbk	wposo,mvfr,ds	as	—
	4C4:280-300	10YR 7/6 dry	—–	FS	osg	wposo, ml, dl.	as	many mica flakes
	5C5: 300-350	I0YR 6/4	—–	SL	om	wposs, mvfr,dsh	—	—
Pedon 4		***Typic Ustifluvent (Eutric Fluvisols)***						
Behind Sheraton Hotel about *300m* away and about 200m from Ring Road.	AP 1: 0-16	I0YR 5/3	c2d(5YR 5/8)	LS	ml sbk	wposo,mvfr,ds	gs	m1rts; common mica flakes ml pores.
	Ap 2: 16-34	I0YR 4/3	c2d(7.5 YR 5/8)	LS	m2sbk	wposs,MVfr,dsh	gs	c1rts, common mica flakes ml pores.
	C1: 34-99	I0YR 5'2	m2-3d(10YR 5/6)	SL	om	wposs,mvfr,dvh	cs	vf2rts,c1rts, common mica flakes, very compact.
	2C2: 99-155	10YR 6/4	—–	SL	om	wposs,mvfrdvh	cw	c1rts,vfrts,common mica flakes.
	3C3: 155-192	!0YR 7/2	m3d(7.5YR 7/8)	FS	om	wposo,mvfrdh	cs	m1&2 pores, common mica flakes.
	4C4: !92-225	I0YR 6/3	m2d (10YR 5/6)	FS	om	wposo,mfr,ds	cs	—
	5€5: 225-280	lOYR 7/6	m2d (10YR 5/6)	FS	osg	wposo,ml,dl	—	Common mica flakes, very porous.

Remarks (9): vf-very few, f-few, c-common, m-many, I-fine, 2-medium, 3,-course, qtz- quartz, rts-roots.