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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

FEDERAL MINISTRY OF WATER RESOURCES
AND RURAL DEVELOPMENT
FEDERAL REPUBLIC OF NIGERIA

THE STUDY ON THE NATIONAL WATER RESOURCES MASTER PLAN (NWRMP)

SECTOR REPORT

VOLUME TWO
PART 2

MARCH 1995

SANYU CONSULTANTS INC.
SUMIKO CONSULTANTS CO., LTD.

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COMPOSITION OF THE REPORT

The Draft Final Report on the Study on the National Water Resources Master Plan (NWRMP) for the Federal Ministry of Water Resources and Rural Development in the Federal Republic of Nigeria comprises the following volumes:

- Volume One : SUMMARY AND MAIN TEXT
- Volume Two : SECTOR REPORT

This contains 12 Chapters, each of which has been presented in an independent manner for the sub-sector designated compiling all the requirements concerned, while major findings and recommendation of each sub-sector along with inter-sub-sectoral relations and basin-wide considerations are summarized in Volume 1:

CHAPTER 1.	NWRIS and SIA	Part 1
CHAPTER 2.	Socio-Economy and Land Use	
CHAPTER 3.	Water Resources and Management	
CHAPTER 4.	Water Source Works	
CHAPTER 5.	Irrigation and Drainage	
CHAPTER 6.	Water Supply and Sanitation	
CHAPTER 7.	Gully Erosion and Flood Control	Part 2
CHAPTER 8.	Hydropower Generation	
CHAPTER 9.	Inland Navigation	
CHAPTER 10.	Inland Fisheries	
CHAPTER 11.	Environmental Management	
CHAPTER 12.	Institution and Legislationl	

- Volume Three : WATER RESOURCES INVENTORY SURVEY
- Volume Four : WATER RESOURCES DATABASE MAPS
- Volume Five : SATELLITE IMAGE ANALYSIS

This is Volume Two: SECTOR REPORT - Part 2

It may be noted that all the findings and recommendation contained in this Report are those made by the Study Team with the members of Sanyu Consultants Inc. and Sumiko Consultants Co., Ltd. and do not imply any authorization by the Japan International Cooperation Agency or the Government of Japan.

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Part 7A General Background

7A. 1 Flood and Drainage Problems

7A. 1. 1 General

In Nigeria, serious problems associated with flooding are generally limited because of the country's geomorphological characteristics comprising mainly plateaus and plains with generally gentle relief. An exceptional case that once occurred was the flash flood in the Upper Benue Basin caused by an inadvertent discharge of water from the Labgo Dam, located in the upstream reach of the Benue River in Cameroon. The international rivers such as the Niger and the Benue are vulnerable to an accidental flash flood of this type, for which the FMWRRD has initiated a comprehensive study. Therefore, the subject is excluded from the scope of Chapter 7.

Wetlands which are susceptible to seasonal flooding, are widely developed in the Lake Chad Basin, the Coastal Plain including the Niger Delta, and the flood plains along major rivers and their tributaries (Fig. 1). Their physiographic features are described in detail in para. 3B. 1.4(1). An appreciable part of the wetlands have been traditionally utilized for paddy fields during the flooded, wet season, for residual soil moisture cultivation during a period following the wet season and for irrigation farming during the flow recession of the dry season. Therefore, flooding can provide benefits to some of the inhabitants of the wetlands with their housing areas located at elevations normally higher than the maximum water level during the wet season. Never-the-less, the wetlands in the depressions or backbasins behind natural levees of major rivers in the Coastal Plain are generally susceptible to flooding due to the relatively long lasting wet season. In addition, problems associated with flooding have become more serious in recent years due to accelerated urbanization as population increases rapidly. Recent urban developments have tended to be implemented without taking account of adequate drainage systems and have given rise to adverse problems such as rainfall runoff flooding, supply and deposition of excessive sediments in river

channels, and acceleration of soil degradation in the upland areas. River courses in the coastal plains, inland basins and flood plains extremely meander and often form braided river systems developed with interconnecting tributaries across unstable sandbanks. Bank erosion and river bottom scouring, which are particularly severe at bends in river channels or at intersections of interconnecting tributaries, are further accentuated by sediment accumulation due to excessive discharge from urban areas and result in changing water courses that threaten housing areas with flooding. Bank erosion is also caused by tidal waves or waves formed by river traffic. Estuaries and tidal flats in the coastal plains become increasingly vulnerable to flooding and bank erosion by tidal waves as mangrove and tropical rain forests are lost due to progressive urbanization.

In the North-East Region, which belongs to an arid climatic zone with limited rainfall, seasonal streams (wadi) often wash away roads, bridges, abutments and other surface structures and intensify sheet erosion causing watershed deterioration. No serious flooding problems have been reported in the wetlands within the Lake Chad Basin. The problems in the Basin are mostly associated with the severe recession of the lake water due to climatic change since the late Pleistocene.

The flood and drainage problems, as above described, are inextricably linked to recent urbanization and are closely related to soil erosion, resulting watershed deterioration in the upland areas. This chapter deals with the flood and drainage problems as well as the soil erosion problems with special emphasis on watershed management.

7A. 1. 2 The Niger Delta

The shape of the Niger Delta is the characteristic delta formed by the distributaries and ramifications of the original Niger River when it approaches the Gulf of Guinea. Along the river, the range between the average low and high water levels increases when going downstream to a point which is called the apex of the delta, where the range starts to decrease until it reaches the tidal range of the sea into which the river discharges. It may be seen that according to this definition, an apex of the Niger Delta is situated near the village of Aboh, Delta State. Below Aboh, the aspect of the Niger River

changes: the bifurcations, ramifications and meanders begin and about 250 km downstream from Aboh, the Niger River reaches the ocean through numerous outlets, as are depicted in the Satellite Image Analysis (Vol. Five of this Report).

Some of the sediments which are transported by the Niger River are deposited on the low-lying banks of rivers and creeks of the delta, but the major part is discharged through the outlets expanding the Delta into the sea. The upper layers of the delta area may be divided into three parts:

- Sandy area, seldom flooded along the Niger's distributaries extending some 100 km downstream from the Delta apex is an extension of the floodplain as found along the Niger River, the only difference being a gradual increase of the silt and clay content resulting in a more erosion-resistant bank material. With somewhat braided river-bed, at the downstream from Aboh, the river changes into an undivided channel with a strongly meandering course until a few km below Samabri, the Niger River forks into the Nun and Forcados Rivers, each of which in turn bifurcates again and again into meandering river branches and enters the tidal swamp area.
- The mangrove swamp area covers about 10.4×10^3 sq.km along 400 km of the coastline. The semi-diurnal tide with an average range of 1 m in the western part and increasing to 2 m in the eastern part of the Delta enters the swamp area through some 20 entrances. The creeks which intersect this mangrove-covered muddy and hardly inhabited area seem to have an average depth of 10 m and the tidal discharge to affect their respective widths. As a whole, these creeks are navigable except for some sharp bends and shallowings where the tides meet.
- The strip of sandy ridges separating the mangrove area from the sea varies in width from less than 30 m to 20 km. these ridges may be slightly eroded from the landward-side by the creeks of swamp area, and their size and shape are mainly controlled by the erosion and accretion forces of the littoral drift.

With the exception of the mangrove swamps where trees grow only along the borders of creeks, an entire area of the Niger Delta is generally covered with a dense vegetation while the annual rainfall increases when moving from the apex toward the Delta coast. It may be observed that the Nun River, formerly a navigable river has suffered deteriorating shipping

conditions due to a disproportionately large sediment transport from the Niger River. As the Forcados River receives more water, and this river offers the best navigable conditions.

The Niger Delta like any other delta has been built up by the deposition of sediment due to the decrease of flow velocity as the inflowing rivers enter the Gulf of Guinea, a larger and calmer water body. The resultant topography is of very poor slopes leading to numerous crisscrossing distributaries and estuaries with pronounced meanders. This vast riverine area is rich in agricultural potential with large annual rainfall, gentle wind and fertile soil. The delta is also rich in forest and marine resources as well as containing the bulk of Nigeria's reserves of crude oil and natural gas. The main topographic feature of this area is the levees of rivers as the highest land sloping gradually away from the river banks to lowlands called "backswamps". Such backswamps are usually filled during the floods as the level of water rises in the river channels, leaving only a narrow stretch of unsubmerged land between the river, banks and backswamps. It is on such relatively flood-free stretches of land that the inhabitants have settled and built their houses. In the lower Delta and coastal areas, however, large expanses of land are inundated during the months from August to October, while at other times, such areas are periodically inundated only during the high tides.

Some reports indicate that over 700×10^3 ha of arable land in the Niger Delta particularly in the Nun and Forcados River areas are rendered useless due to annual floods which occur during the high water level season lasting 4 to 5 months. During this period, the river level rises up to 10 m thereby overflowing their banks and submerging thousands of hectares of valuable agricultural land including towns and villages for nearly half of the year each year. By the effect of annual floods, most of the towns and villages along the Nun and Forcados Rivers lose an average of 5 to 10 m of land yearly along their shores while others are forced to move to new sites. When the flood water level recedes, it creates the attendant problem of soil erosion. There is the erosion caused by the seepage of rain water and large collections of stagnant water behind the towns which seep through underneath the towns and dissolve the alluvial soil and cause severe erosion even during the dry season. In addition, there is the erosion caused by the torrential rains over the Niger Delta which wash away the surface soil.

The Niger Delta Development Board (NDDB), the predecessor of the present Niger Delta Basin Development Authority (NDBDA) was created in 1961 to pay special attention to and solve the peculiar problems of the Niger Delta including the challenging problems of flood and erosion. In addition, the River State University of Science and Technology was established to meet the challenges of environmental protection and development. While the Niger Delta has contributed a greater part of the FGN total revenue through its crude oil resources, the FGN and the Rivers State have not yet shown any physical evidence of the completion of any substantial flood and erosion protection works in the Niger Delta. It is quite apparent that no significant development could be carried out in the areas of the Niger Delta affected by annual flooding and erosion in terms of agriculture, social infrastructures, industrialization and so forth, unless the problems of floods and erosion are mitigated and controlled. The combination of flooding and erosion which affect the Niger Delta is unique and will require unique solutions for its control.

It should be noted that the deltas all over the world have been thoroughly developed for their wealth of resources for centuries. The technology of flood control embankments initially in primitive and indigenous mode and subsequently improved and upgraded has been extensively utilized in other large deltas of the world such as the Mekong, the Irrawaddy and the Mississippi. But unlike many other deltas, the Niger Delta is about the least utilized with regard to its potential for large-scale agricultural development. The factors militating against such development may include the difficulty of access being mainly by water and the non-availability of large tracts of flood-free land. In addition, it may be mentioned that there might have been the sociological and cultural restrictions on what may appear to be feasible solutions based upon purely technical considerations.

7A. 2 Soil Erosion Problems

7A. 2. 1 Introduction

Soil erosion has affected human life in various ways such as (1) watershed deterioration threatening the nation's water resources, (2) damages to and losses of farming lands, residences and urban infrastructure enforcing resettlement of residents and relocation of surface structures and (3) excessive sediment accumulation causing floods, bank erosion, scouring and interference to river navigation. There has been a long-standing search for remedies to soil erosion in Nigeria. It is reported that initially these efforts were half-hearted but lately have been feverish. The search formally began in the early 1920s, and it has led to a wide range of measures conceived and executed by an assortment of agencies. With all the efforts, however, the results have been generally unsatisfactory mainly due to lack of adequate legislative provisions against erosion-inducing activities such as disorderly natural resources exploitation, and regional and urban development in erosion-sensitive areas.

Nigeria is situated mostly in the climatic zones of tropical rain forest and savanna with mean daily temperatures and annual rainfalls ranging between 20°C and 32°C and between 2,000 mm and 3,000 mm respectively, and belongs to one of the regions considerably susceptible to erosion in the world with estimated annual soil losses ranging between 1,000 and 2,000 tons per square kilometer (Fig. 2). The climatic zonation of Nigeria is illustrated in Fig.3, together with the distribution of erosion by types and intensity. The country can be divided into seven climatic zones mainly according to annual rainfall; the six east-west trending belts, from the north to the south, (1) semiarid, (2) dry-subhumid, (3) subhumid, (4) humid, (5) very humid and (6) ultrahumid zones and the one centrally located (7) plateau zone. The characteristics of these climatic zones are summarized in the table below.

Characteristics of Climatic Zones

(Quoted from FAO-World Bank Report 89/91 CP NR 45 SR, with modification)

Climatic Zone	Range of Annual Rainfall (1) (mm)	Wet Season		Mean Monthly Temperature		
		Month (2)	Length (days)	Max (3) (0°C)	Normal (4) (0°C)	Min. (5) (0°C)
Semiarid	200 - 400	Au	90	40	32 - 22	13
Dry-subhumid	400 - 800	Jl, Au	90	39	31 - 21	12
Subhumid	400 - 1200	Jn, Jl, Au, Sp	150	37	30 - 23	14
Humid	1200 - 1600	Jn, Jl, Au, Sp, Oc	200	37	30 - 26	18
Very Humid	1600 - 2000	Ap, My, Jn, Jl, Au, SP, Oc	250	33	28 - 24	21
Ultrahumid	2000 - 2200	Mr. Ap, My, Jn, Jl, Au, Sp, Oc, NV	300	32	28 - 25	23
Plateau	1200 - 1500	Jn, Jl, Au, Sp	200	31	24 - 20	14

Note: (1) Based on Map 6 (Isohytal) in NWRMP Data-Base Maps.
(2) Months in which rainfall exceeds potential evapo-transpiration
(3) The highest monthly mean of maximum daily temperature
(4) The highest and lowest monthly mean of mean daily temperature
(5) The lowest monthly mean of minimum daily temperature

The semiarid and dry zones in the northern part are characterized by severe wind erosion, while the humid zones in the southern part are dominated by notable sheet and gully erosion as well as coastal erosion along the coast facing the Gulf of Guinea. In the climatic zones in between, erosion appears to be relatively modest with generally localized slight to moderate wind, sheet and gully erosion except for limited areas of severe sheet erosion in the eastern part. Areas affected by erosion of various types and intensity are estimated for each HA based on Fig. 3 and summarized in Table 1.

Wind erosion, in its nature, is not as damaging as sheet or gully erosion in terms of soil losses, but is extensively developed in the northern states (HAs I and VIII) with considerable intensity. It must be noted that rainfall concentrates in three to four months in a year with maximum monthly rainfalls exceeding 250 mm (ref. Table 3, NWRMP Water Resources Inventory Survey). Numerous seasonal streams (wadis) form in the wet season, which enhance rainfall runoff erosion and cause damage to surface structures.

Sheet erosion which slowly removes thin surface soil layers by rainfall runoff down slopes, often seriously affects cropping because the erosion predominantly removes largely fine particles which effectively hold water and nutrients in soils. In addition, the integrated soil losses by sheet erosion must be tremendous because of its widespread distribution in Nigeria. To make the situation worse, the recent accelerated land development, urban or agricultural, has transformed a significant areas of vegetated lands into bare ground highly susceptible to sheet erosion.

While sheet erosion is most widespread but least perceived because of its slow progress, gully erosion is, in contrast, very limited in its areal distribution but disastrous because of its rapid progress. Catastrophic occurrences of gully erosion are observed in the States of Anambra and Imo where the combination of sandy soils, widespread deforestation and high rainfall runoff accelerates progress of gully erosion. On a perfectly innocent-looking and benign terrain in these areas, a gully can start off without warning in heavy over-night rain and, within only a few months, grows into a monumental gash some 100 m long, over 20 m wide and 15 m deep. Although gully erosion occurs in all the HAs as indicated in Table 1, severe gully erosion is confined to south-central states in HAs V and VII. As of September 1989, the Federal Ministry of Works and Housing had identified 550 active gully erosion sites in the States of Anambra and Imo.

At the present time, the natural environment of Nigeria is in a state of a vicious cycle of forestry degradation due to soil erosion and of soil erosion due to forestry degradation. The JICA Study on this occasion indicates that the forested area has decreased from 16.4×10^6 ha in 1980 according to the FAO-UNEP study to 13.7×10^6 ha, including mangrove forests, based on the records in the period between 1984 and 1991. Accordingly, about 250,000 ha of forests, or at an annual rate of 1.8 percent, have been lost every year by logging activities and various types of erosion. The present area of bare ground, being 7.9×10^6 ha or 8.5 percent of the country, will reach 14.8×10^6 ha or account for 16 percent of the entire land due to loss of 6.9×10^6 ha of forest at this rate by the year 2020. In the South-East Region where gully erosion is extremely active, forested land occupies 2.8×10^6 ha or 25 percent of the region at the present time. However loss of 1.2×10^6 ha of the forested land is anticipated by the year 2020 if the present rate of forest destruction continues, and will result in an increase of bare ground to 2.5×10^6 ha or 22 percent of the entire land.

This NWRMP has paid special attention to gully erosion control measures in view of conservation of the nation's water resources within a series of water resources management issues. As a matter of fact, the Federal Department of Soil Erosion and Flood Control, which used to be the Water Resources Sector of the FMWRRD but has been transferred to the FEPA since March 1993, deals with gully erosion control in terms of civil engineering works as one of the important policies in environmental protection, while the Federal Department of Agricultural Land Resources and Forestry is concerned with land resources management including soil conservation operations particularly in agronomic terms.

7A. 2. 2 Definition

Soil degradation is defined by FAO as "phenomena which result from processes reducing the capability of soils to produce or to create useful materials or services". the processes are classified into two categories; a) loss of soils and b) change in quality of soil components. Soils comprise clastic materials covering the land surface and are unstable on slopes tending to move from higher to lower positions. Types of soil movement can be divided into surface erosion and mass-movement; the former is scraping of surface soils by wind, water and ice and the latter is movement of massive soils by gravity. The surface erosion is further classified into wind, sheet, gully, coastal and glacial erosion. The mass-movement includes landslide and debris flow caused by infiltration of water into ground and/or rises of groundwater levels. Steep slope such as gully walls formed by surface erosion are susceptible to mass-movement. The term 'soil erosion' in this report includes all the types of surface erosion excluding glacial erosion and mass-movement.

Soil erosion occurs under natural conditions (natural erosion) but is often accelerated by destruction of vegetation or disturbance of surface soils due to urban and regional development (accelerated erosion).

Wind erosion is a phenomena in which surface clastic particles are removed by wind. This type of erosion is dominant in the northern dry-semiarid zones of Nigeria during the dry season as aforementioned. Sheet erosion remove a large area of soils by water runoff and occurs over the entire country, but with considerable intensity in the southern highly humid zones.

Gully erosion carves ground deeply by washing out surface soils and forms outstanding erosional features in the south-central part of Nigeria.

A gully at an early stage of erosion is called a 'rill' which in general, is scales of less than 45 cm and 25 cm in width and depth respectively. Soil erosion is initiated with minor wash-out of surface soils. As the area of wash-out is expanded, uneven surfaces with a number of minor depressions are developed and rills are formed with concentration of surface water in these depressions. The rills grow to gullies with progressive concentration of surface waters. A number of rills extensively developed on gentle slopes of bare ground are often observed in the North and Central Regions. These rills, without growing to gullies, gradually erode extensive areas of the slopes. This process is one of the mechanisms developing sheet erosion.

Gully erosion does not appear to be correctly recognized in Nigeria and is often described as landslide in lists of erosion sites or other documents prepared by RBDAs or local governments. As aforementioned, gully erosion is a phenomenon in which particles of surface soils are washed out by surface water. On the other hand, landslide is massmovement in which land destruction under gravity forces is triggered by reduction of particle cohesion of soils due to a rise of groundwater levels resulting from infiltration of surface water. Soils washed out by gully erosion are stirred and transported downstream, while masses of soil are often moved by landslide, more or less keeping their original shape. Prevention or protection measures are also different for gully erosion and for landslide. Therefore, these two types of soil movement should be strictly distinguished.

7A. 3 JICA-NWRIS, SIA and Database

7A 3. 1 Flood Control

The table on the following page indicates the number of flood/sediment problem sites together with that of existing and proposed flood control/river training projects recorded by JICA-NWRIS. However, the records are in many cases scarce and are inconsistent depending on LBAs, RBDAs or other agencies responsible for local river management, because each agency has its own standards for recognition of problem sites or specification of flood control and river training works.

In general, the wetlands as shown in Fig. 1 are more or less susceptible to flooding and have rivers with sediment problems. In particular, large parts of the Niger Delta and other coastal plains in the lowermost reach of major rivers such as the Niger and the Cross are subject to seasonal inundation during the wet season. Although there are no records of flooding/sediment problem sites for states such as Delta, Rivers and Akwa Ibom, a considerable part of these states are inundated during the wet season. In addition to the annual flooding, unusually heavy flooding has been recorded in Rivers State at intervals of about three years for the last decade. More than 200 villages were inundated on occasions of such high flood waters which lasted for two to three weeks with water levels rising at a rate of 5 to 7 cm a day.

The rivers in the southern states meander forming braided river systems and many accompanying ox-bow lakes in their flood plains. Problems of sediment accretion as well as bank erosion and scouring are considerable in braided river systems particularly at sharp bends or at confluences of rivers.

Flood/Sediment Problem Sites and Existing/Proposed Projects

	Number of Problem Sites		Number of Project			
			Existing		Proposed	
	Flood	Sediment	FC (1)	RT (2)	FC (1)	RT (2)
Kebbi	NR (3)		1	0	0	0
Sokoto	NR		1	2	0	0
Katsina	NR		0	0	0	0
Niger	NR		3	0	2	1
Kwara	NR		0	2	1	0
Kaduna	NR		1	0	1	1
Kano	NR		0	0	2	0
Jigawa	NR		0	0		
Yobo	3	3	0	0	0	0
Borno	NR		1	0	0	0
Oyo	2	1	0	0	1	0
Osun	6	1	3	0	5	0
Ogun	1	1	0	0	0	0
Lagos	NR		NR	NR	NR	NR
Ondo	NR		0	0	0	0
Edo	NR		0	0	0	0
Delta	NR		0	0	0	0
Abuja FCT	NR		NR	NR	NR	NR
Kogi	NR		0	0	0	0
numbra	1		1	0	0	0
Imo	13		3	0	0	0
Rivers	NR		0	0	0	0
Enugu	NR		0	0	0	0
Abia	17		4	0	0	0
Akwa Ibom	NR		0	0	0	0
Cross River	13		0	18	0	12
Plateau	5	0	1	0	1	0
Benue	3	0	1	0	0	0
Bauch						
Taraba	0	1	0	0	1	0
Adamawa			1	0	1	0
Total	21	44 7	25	22	15	13

Note: (1) FC: Flood Control
(2) RT: River Training
(3) NR: No Record

The Hadejia and Jama'are Rivers in the Lake Chad Basin in the Northeast Region (HA-VIII) also form vast flood plains, in which they meander and comprise a number of branch streams with unstable water courses. Seasonal flood problems exist but are limited within a few months of the wet season. Sediment accretion and scouring problems have been also reported in association with flood problem sites.

The flood plains along the Niger River upstream of Lokoja (the confluence between the Niger and the Benue Rivers) and along its major tributaries such as the Sokoto, Kaduna and Rima rivers (the Northwest Region) are also susceptible to annual flooding and are included in the River Training Program being carried out by FMWRRD (Para. 3B.5.3.(4)).

Development of flood plains is relatively limited along the Benue river upstream of Lokoja, and flooding and sediment accretion problems appear to be minimal. The upstream section from Numan to the international border with Cameroon is being studied in the above mentioned program.

It must be noted that problems of flooding and sediment accretion as well as associated bank erosion and scouring are considerably enhanced or, in some cases, directly caused by infrastructure development in urban and rural areas without proper plan, design and construction works.

7A. 3. 2 Gully Erosion

(1) Distribution

A map showing present distribution of gully erosion on SSHA basis is prepared using the following documents and is included in the Water Resources Data-Base Maps (Map 25, Present Distribution of Gully Erosion).

The documents used are;

a. Bareland ratio for each SSHA estimated on the basis of the Land Cover Data Set in SIA Report (Fig. 4, Bareland Distribution).
b. Areas and/or numbers of gully erosion sites recorded in JICA-NWRIS (Table 3, Land Degradation Status on State Basis).

c. Erosion Distribution and Climatic Zones (Fig. 3) prepared by modifying Soil Erosion and Land Resources in FAO-World Bank Report 89/91 CP NR 45 ST.

d. Various data acquired in the course of site investigation by JICA Team.

It was initially intended to prepare a gully erosion distribution map based only on the JICA-NWRIS record (Table 3). The records are, however, often incomplete or inconsistent depending on RBDAs, LGAs or other agencies, each of which has its own standards for recognition of gully erosion sites in size, number and intensity. In addition, some data collected by JICA-NWRIS are too old to represent the present status of gully erosion.

In practice, therefore, the following procedure was adopted to assess the present status of gully erosion for each SHA or SSHA where subdivided.

1. For SHAs or SSHAs within HAs I, II, III, VIII and the northern half of HA-IV in which sheet and wind erosion is dominant, degrees of gully erosion are judged;

1-1 Very slight where no records of gully erosion are cited in JICA-NWRIS and bareland ratios are less than 5%.

1-2 Slight or medium-slight, depending on bareland ratios, where gully erosion areas are recorded in JICA-NWRIS or are outlined in Fig. 3, and bareland ratios are 5% or higher. However, those SHAs or SSHAs which are located within zones of serious wind or sheet erosion in Fig. 3, are ranked as very slight for gully erosion.

2. For SHAs or SSHAs within HAs V, VI VII and southern part of HA VI which are extensively subjected to various types of erosion, degrees of gully erosion are judged;

2-1 Medium-serious or serious, depending on bareland ratios, where gully erosion areas are recorded in JICA-NWRIS or are outlined in Fig.3, and bareland ratios are 5% higher.

2-2 Very serious, where a number of serious gully erosion sites are located. SHAs or SSHAs of this rank are mostly situated in the states of Anambra and Imo.

2-3 Slight or medium-slight, where no areas of gully erosion are recorded in JICA-NWRIS or are outlined in Fig. 3.

The categorization of gully erosion status as above described is still very arbitrary due to insufficient information available at the present time, and should be revised based on more reliable data acquired by thorough investigation with uniform standards for recognition of gully erosion status.

(2) Occurrence

Occurrences of gully erosion are extensively observed in Nigeria and are particularly notable in the southern half of the country. As shown in NWRMP Data-Base Map No.25, gullies ranked as medium-serious or higher are mostly distributed in the southern half of HA III, and in an extensive zone encompassing the Central Highland, the eastern end of HA VI and nearly the entire extent of HAs V and VII. These areas belong to the tropical rain forest climatic zone with annual rainfall exceeding 1,200 mm and is supposed to be largely covered by dense forest. In reality, however, the present bareland ratios of these areas are very high, exceeding 13% in HAs III, V and VII, and are almost comparable to that of HA VIII which belongs to the semi-arid zone under threat of desertification. In these areas, the States of Anambra and Imo in the South-East Region are well recognized for a number of gigantic gully occurrences exceeding several kilometers in length and several tens of meters in depth and width.

The Central Highland, including Abuja FCT, is relatively resistant to erosion under natural conditions because the terrain comprises Precambrian basement rocks and Jurassic granite and is moderately covered by guinea savanna. However, gully erosion has been initiated and is now growing at several open-cast mining sites abandoned without reclamation, or in association with recent urban development to accommodate increasing population. Large gullies exceeding one kilometer in length are not uncommon in the Plateau State according to JICA-NWRIS. It is also reported that gullies have developed in the vicinity of Abuja FCT and are growing at a considerable pace, due to excessive burn-off of vegetation for increasing crop yields or constructing highways.

Occurrences of gully erosion ranked as medium-serious or serious are reported in the states of Bauchi, Adamawa and Benue. Many gullies are attributed to natural causes such as high declivity exceeding 10% or soft soils

comprising medium grained particles. However, some occurrences are associated with abandoned open-cast mining sites or caused by human activities (not specified) according to JICA-NWRIS.

In the North-West Region, gully erosion was very uncommon in the past because of low rainfall and gentle relief, though the terrain, comprising Cretaceous and Tertiary sedimentary rocks, is susceptible to wind or sheet erosion. In recent years, however, gullies are developed in places with concentration of rainfall runoff into a limited number of water courses due to development of residential areas and urban infrastructure without appropriate drainage systems. In the area neighboring Kainji Dam, gully erosion together with sheet erosion has developed in places where geomorphology indicates a large elevation difference. The town of Sokoto, being located on a highland, has recently expanded over slopes of higher elevations. Gullies have been formed on these slopes and have started affecting the town. These gullies, though small in scale, bring about serious damage to residents.

(3) Damage

There are available only a very few documents, in which damage by gully erosion is recorded on the basis of proper assessment, although a number of State Governments, LGAs, RBDAs and other agencies responsible for soil conservation have recognized serious damage by gully erosion. Areas affected by individual gullies are well documented in the land degradation lists (Form R 6-1-(1), JICA-NWRIS) provided by Governments of Anambra, Enugu, Imo, Abia, Akwa Ibom and Cross River States, all of which suffer serious damage by gully erosion. Types of damage caused by gully erosion may be summarized as follows;

a. Destruction of Forest
b. Destruction of Grass Land
c. Destruction of Farming Area
d. Damage to Socio-Economic Infrastructure and settlement Areas
e. Collapse of Roads
f. Damage to Water Supply and Drainage Facilities
g. Effect on River Management by Eroded Sediment
h. Damage to Reservoirs and Hydraulic Structures by Eroded Sediment

Gully erosion progresses at a much higher pace than wind or sheet erosion. Therefore, immediate action must be taken to prevent the progress or to protect surface structures against the erosion. The pace of the progress varies depending on climatic, physiographical, geological and other conditions. It is reported that a gully in the pronounced Agulu/Nanka Erosion complex in the Anambra State is expanding at a pace of 4 to 6 m in width every year.

Destruction of forest, grass land and farming land increases bareland, which is, if left without restoration, very susceptible to gully erosion. Accordingly, land degradation is further accelerated as gully erosion progresses.

A historical tragedy caused by gully erosion is the complete destruction of the entire hamlet of Isiamigbo in the Agulu/Nanka Erosion Complex in 1925. Gully erosion control works have been completed or are in progress at various localities for protecting government houses, schools and other public institutions. However, still many additional places require protection against gully erosion.

Damage to roads, drainage systems or water supply facilities further enhances land degradation in many ways. It must be noted that construction of these structures may expand land liable to gully erosion. It is reported by NWRIS that the Great Enugu Water Supply Scheme is at risk of gully erosion.

Gully erosion is partly and indirectly responsible for sediment accretion in river channels by supplying materials from erosion sites. However, problems associated with sediment accretion are the subject of flood control and river training, and are excluded from those for gully erosion control.

This NWRMP is mainly concerned with the present status of and the countermeasures against gully erosion in the South-East Region where damage is most serious. Erosion control and protection works are also discussed in terms of their technology and engineering, which may be applicable to other Regions.

Part 7B Flood Control and Drainage

7B. 1 Mechanism of Problem Occurrence

7B. 1. 1 Watershed Deterioration

Watershed deterioration is progressing at an alarming rate in Nigeria due to accelerated land degradation and is threatening the nation's water resources. The recent acceleration of land degradation has been mainly caused by rapid infrastructure development in urban and rural areas to accommodate increasing population. Land degradation includes soil degradation, deforestation and desertification which are closely inter-related to each other in deteriorating global environment. Of these three processes soil degradation, the major subject of Chapter 7, has two aspects as aforementioned (7A.2.2); one is the change in soil components resulting in the loss of water and nutrient retention and the other is physical losses of soils by erosion and mass-movement.

Soil degradation in terms of soil erosion occurs all over Nigeria. In the northern part belonging to the semiarid climatic zone, wind erosion is dominant and is a direct cause of desertification. In addition, rainfall runoff during the wet season forms seasonal streams which wash out a considerable amount of surface soils and often damage roads and other surface structures.

Both sheet and gully erosion are ubiquitous in the central and southern parts which belong to the subhumid to ultra humid climatic zones. Gully erosion is more damaging than sheet erosion because of its swift progress, and is considered one of the most serious elements of soil degradation. Gully erosion sites ranked higher than medium-serious have been reported mostly from the South-East and the Central-East Regions (Para.7A.3.2 and NWRMP Data-Base Map No.25). In addition to direct damage by gully erosion, a considerable amount of soils washed out from gullies accumulate in water bodies, resulting in siltation of water, destabilization of water courses or other undesirable changes in water bodies. For example, it is reported that five percent of the surface of Agulu Lake in the Anambra State has been lost by a large amount of soils washed out from gullies nearby during the period of three wet seasons between 1991 and 1993.

In the Central-East Region including Abuja FCT, no flooding problem has been observed because residential areas are developed mainly on plateaus or terraces at elevations higher than those of river channels. Recently, however, many residential areas are at risk of flooding due to rising river beds caused by sediment accumulation in river channels as soil erosion is being accelerated in their upstream reaches. Gully erosion is another menace to watershed conservation in the Region, particularly in association with open-cast mining sites that have been abandoned without restoration.

In the North-East and the North-West Regions, productive lands are being lost by desertification due to wind erosion under dry climatic condition. During the wet season, in turn, a considerable amount of soils is washed away or roads, bridges and abutments are collapsed due to formation of seasonal streams on occasion of heavy rainfalls. The surface soils consist mainly of sandy lacustrine sediments periodically deposited during the Quaternary. Surface runoff readily permeates through the highly permeable sediments and is saturated between layers of the sediments. Sands saturated with water form slurries, mixtures of water and sands, which start moving gravitationally as a mass when their weight exceeds a certain limit. The mass of slurry grows heavier collecting surface sands as it moves and destroys roads, bridges, abutments and other surface structures in its course. New wadis are also developed as bare lands expand, due mainly to regional development, and destroy roads, bridges and other surface structures forming passages for masses of slurry. In an example in Yobe State, a road had been constructed on and along a buried wadi which changed its course due to sheet erosion and extended for several kilometers along the road.

Many farmers, who have lost their lands due to desertification, start migrating from the countryside to suburbs of Sokoto City and Birnin Kebbi. Their new residential areas are developed in low lands where domestic water supply is dependent mainly on surface water collected during the wet season. There may be fears that epidemics are generated in the newly developed low lands by water contamination due to flooding during the wet season and subsequently spread over the entire city areas.

7B. 1. 2 Sediment Deposition in River Channels

Encoded soils are mixed with surface water and flow into river channels. Sediment loads in river channels increase by erosion of river beds and banks. Sediment loads of rivers in Nigeria are considerable even during the dry season. High sediment loads and resultant sediment deposition in river channels bring about various problems as follows;

a. shorten lives of natural or man-made reservoirs
b. hinder navigation of inland water course
c. interfere with domestic and agricultural water supplies
d. increase the frequency of flooding due to raised river beds or disturbed normal high-low cycles of water levels
e. deteriorate quality of domestic water and accordingly increase costs of water treatment
f. degrade aqua-ecological environments.

It is reported that many water reservoirs have become useless due to sediment deposition in the states of Oyo, Ogun and Osun in the South-West Region. In the northern states, a number of irrigation reservoirs of medium to small size are observed not to be used because accumulated sediments have been left undredged.

No serious effects of sediment deposition on river traffic have been reported to date, though many sandbars and sandbanks appear in the centre of river channels during the dry season. According to FIWD, navigation in the Niger River upstream of Lokoja is becoming difficult mainly due to decreasing discharge from the Jebba Dam. However, it is anticipated that sediment accumulation may become a problem for water transportation as it progresses.

Of the various effects of siltation on domestic water, deterioration of water supply systems is most crucial. Domestic water is, in many cases, pumped from river channels directly to water purification-distribution systems without settling ponds or filtration facilities. Excessive silt in river water easily damages pumps and purification-distribution systems. This has become a daily problem in states such as Anambra, Imo and Cross River, where people

are relying on river water for domestic use because of either deep-seated groundwater levels or a significant iron content in groundwater.

No adequate information is available on the effects of siltation on aqua-ecosystems. Some species of fish appear to be able to survive in extremely silted water. However, the following effects may be imposed on aqua-ecosystems if extreme siltation of water continues for a long period;

a. Insufficient sunlight reaching the stream bed may hamper growth of weeds, mosses or other organisms which are food for fish or other aquatic creatures, resulting in disruption of the biological balance and food chain.

b. Fish eggs and bottom dwelling creatures may be buried under sediments or may die due to oxygen depletion, resulting in destruction of breeding grounds or adverse change of stream bed biota.

7B. 1. 3 Instability of River Channels

(1) Rivers in the North East Region

The Hadejia-Jama'are River system which flows through the Lake Chad Basin into Lake Chad has a relative elevation difference of only several meters between its headwater and the entrance to the Lake, distance of some 300 km, and is braided in flat alluvial plains forming a complex network of branched rivers and channels. The braided river system reduces the surface water potential due to seepage and evaporation on the way.

Rainfall in the Region concentrates mostly within three to four months of the wet season with the maximum monthly rainfall exceeding 250 mm and forms numerous seasonal streams as aforementioned (7A.2.1). In addition, bank erosion is considerable at bends or intersections of river channels of the braided river system. Accordingly, river courses are very unstable, particularly in the extremely flat part of the Basin.

(2) The Niger Delta

The Niger Delta is an extensive plain crisscrossed by a maze of meandering rivers and creeks. The banks of these water channels consist of levees which slope down into backswamps and flooded depressions. When the Niger and its tributaries are in flood, these banks are eroded especially on the outside of meander bends which are turned into vertical faces. The flooding normally lasts for three to five months in the year, and the level differences between low and flood flow are 6 to 10 m. As the flood water recedes, the river banks become unstable with the subsequent collapse of large earth masses and also the tidal movements aid bank erosion in some places. Rates of bank erosion are 2 to 5 m per year along the larger channels, and this erosion poses serious threats to towns, villages and farmland in the region.

Networks of numerous narrow streams with unstable channels are well developed and form extensive flood plains in the Niger Delta. Extensive areas of the Niger Delta are liable to flooding but are scatteredly cultivated because of the convenient supply of domestic and industrial waters as well as river transport. Asaba, which has been recently developed for an industrial area, is an example of such an area. A steel plant in the industrial area, located on the right bank of the main stream of the Niger, is now highly vulnerable to submergence due to flooding. In the Niger Delta, as well as other coastal regions, drainages of areas liable to flooding have been well controlled by natural retarding basins. However, recent rapid urbanization and increase in population appear to adversely affect the function of natural retarding basins, which may cause considerable damage due to flooding.

7B. 1. 4 Insufficient Drainage Systems of Regional and Urban Development

The South-East and the South-West Regions have developed at a considerable pace during the last half of this century as the oil and gas fields have been exploited. Accordingly, the population has increased at a pace proportional to the development and has required the introduction of various urban and regional infrastructures. The keen worldwide demand for energy resources, particularly during the period of the late 1970s and early 1980s, has accelerated the exploitation of the oil-gas fields in these regions, which has resulted in intensifying this trend. The rapid urban and regional infrastructure development within a limited time tends to be implemented

without adequate provisions for future requirements. Construction of drainage systems with adequate capacities is one of the indispensable elements to maintain infrastructures in working condition. The South-East and the South-West Regions, in particular, are situated in areas being developed with criss-cross networks of river channels and are extremely vulnerable to seasonal flooding under a tropical rain forest climatic condition. A few examples of flood problems are quoted as follows;

(1) Aba (Abia State)

The city of Aba is a centre of transportation in the South-East Region, connecting Port Harcourt, Corabar and other major cities. The Cross River RBDA constructed two culverts, a total of 3.3 km in length, together with road side drains as a drainage system for the city in 1990. The drainage system is, however, not working properly due to excessive sediment deposition caused by maintenance negligence. The maintenance is the responsibility of the Aba LGA under the present organization of river management, but has been neglected because of insufficient budgetary provision.

(2) Carabar (Cross River State)

The Cross River State Government made a plan to develop the lowland around they city of Carabar in the late 1980s. The plan was implemented without taking account of any drainage systems with sufficient capacities to accommodate the considerable amount of water runoff during the wet season in this area. Since damage to roads and dwellings by flooding became apparent as the development progressed, the Cross River RBDA planned and implemented the construction of six main waterways with a number of branch channels, totalling some 40 km in length, to discharge rainfall runoff directly to the sea. The construction of the waterways, which is still continuing, was partly completed in the vicinity of the residential area in 1993. The waterway system, with identical cross-sectional dimensions (3 m wide and 2 m deep) for the entire channels, appeared to have a sufficient capacity for draining the wet seasons rainfall runoff, because no damage in the residential area was reported. However, the JICA Team observed a number of localities where soils were washed out along the channels, leaving them susceptible to collapse.

(3) Awka (Anambra State)

The city of Awka became the new capital of Anambra State in 1991 and is now developing at a considerable pace. The geology of Anambra State and its vicinity comprises mostly Cretaceous sedimentary rocks which are easily eroded unless protected by vegetation. Slush-and-burn farming and goat grazing which are popularly practiced in the State, are increasing barelands, which are particularly vulnerable to gully erosion. Although no serious flooding problems have been reported, a considerable amount of rainfall runoff during the wet season accelerates gully erosion significantly. Without proper drainage systems, gully erosion is left to progress unhindered in many places. This problem is discussed in Part 7C in more detail.

As desertification advances in the northern part of Nigeria, peoples who discarded farming are gathering in the City of Sokoto and its vicinity from the country side. The urban area which has been developed on and around the tops of hills started expanding to lower elevations liable to flooding in the wet season as population increases rapidly. Indiscriminatory settlement by migrants degrades sanitation of the urban area and creates sources of epidemic diseases particularly at an occasion of flooding. It is anticipated that influx of migrants to urban areas in the North-East and the North-West Regions will continue. Major cities such as Kano and Maiduguri in the regions may suffer similar problems in near future.

7B. 2 Current Status of Improvement Works

7B. 2. 1 Flood Control at Existing Reservoirs

(1) Dam Reservoirs

A dam has a very effective function for flood control and for prolonging the flow recession period. In the Lake Chad Basin, the Tiga and Challawa Gorge Dams in the upstream reaches of the Hadejia River have flood controlling functions. In this region the flow recession period was short and so were the periods when farming was possible but, after completion of the dams, the flow recession periods have extended and year-round farming has become possible through irrigation. The Goronyo Dam in the upstream reaches of the Sokoto River, and the Dadin Kowa and Kiri Dams on the Gongora River are used for cutting the peak flood flows, reducing the period of water shortage and providing sufficient water during the dry season. These dams were constructed primarily for irrigation but are also effective for extending the period when farming is possible in downstream areas.

Lagos is the old capital located on the shores of Lagos Lagoon at the mouth of Ogun River and is Nigeria's largest city in terms of both population and area. It used to suffer from flooding of the Ogun River and houses were damaged in the wet seasons. However, the Ogun River no longer floods since the Oyan and Ikere Gorge Dams were constructed upstream. These are the only two dams in Nigeria that were constructed for the purpose of preventing downstream flooding.

(2) Wetlands

In Nigeria, flooding allows paddy cultivation of rice in the wet season so that flooding is a benefaction of nature. The period for cultivation is prolonged as the river flow recession period extends. Generally, the systems to control flow recession periods are dams and natural or man-made retarding basins. In the Niger River drainage area in the Niger Delta, the estuary of the Cross River and the Lake Chad Basin, wetlands have a retarding function in themselves. In these areas, natural levees do not exist or are very poor and the ground gradient is very gentle, less than 1/2,000, so that overflow of rivers occurs easily and wetlands expand rapidly. Flooding areas are so vast that the

increase of water level is low compared to the volume of water flowing into the wetlands and to the amount of rainfall itself. Submergence of rice fields is therefore quite a rare occurrence. The vast size of the flood plains also endures lengthy flow recession periods even though the quantity of water flowing out of the area is relatively large. As stated above, sediment deposition in the river not only disrupts the usual flooding cycle but also increases the chance of local flash floods.

In the upstream area of the Niger River and the Chad Basin, there are many natural or man-made depressions which are used as reservoirs after the wet season. As stated above, recently these reservoirs have been affected by sediment deposition.

7B. 2. 2 Sabo Works along Hillside and River Channel

It is only since the late 1980's that the importance of 'Sabo' works have been recognized in Nigeria and the construction of check dams started about the same time. But these check dams were constructed to prevent expansion of gully erosion by covering gullies with sand. However, they had inherent structural defects and were easily damaged by water and earth pressure. There is an increasing number of check dams that prevent the influx of soil to major river channels. Their structural defects have been modified and they now work well. But because of the lack of protection of exposed slopes, erosion by rainfall occurs in the wet season, many must be expanded every year since they get filled with sands during the wet season.

The purpose of hillside works is to prevent the flow of soil from eroded hillsides and to keep a sufficient amount of soil required for vegetation. Currently no hillside works are being carried out. The only large scale hillside projects that have been attempted were model projects to test the suitability of various species for revegetation planting such as the Government House Erosion Control Project in Cross River State by C-RBDA and the Nnewi 100 Feet Road Erosion Site Control Work by AI-RBDA. Small size experiments are being conducted in Okpara Roundabout Erosion and Muritala Mohammed Erosion Sites for preventing outflow of soils. 'Sabo' works (erosion control works) conducted in Nigeria to prevent the outflow of soil are described in detail in 7C2.1.

7B. 2. 3 River Channel Improvement and Training

The river training programs have been conceived by the Water Resources Sector, FMWRRD to improve flow in the river channels downstream of major hydraulic structures and some perennial rivers. Their aim is to increase river flow rates through (1) reduction in conveyance losses by evaporation and seepage, (2) increase in flow volumes by higher driving gradients and conveyance speed and (3) increases in flow volumes by removal of obstructions along the river channels. However, the programs are still under way and only a part of the basic investigation and beacon placement on some river banks has been completed.

In Nigeria, no serious attention has been paid to the necessity of river training because flooding has never caused grave problems except for the extraordinary case in the Upper Benue Basin and has been rather beneficial for traditional cultivation of wetland, as aforementioned (Section 7A.1). However, the recent rapid urban development particularly in the Niger Delta is making use of low land areas which are liable to seasonal flooding. Besides, conveyance losses of water in braided river systems by evaporation and seepage are adversely affecting irrigation in the North Region with recent decrease of rainfall. Under the present socio-economic and climatic changes as above described, river training is becoming a significant subject for the nation's water resources and environmental conservation.

Such a major river training measure as integration of braided rivers may be desirable but requires a comprehensive study for its application because it will have a considerable impact on the ecosystem. At the present time, no shifting of major river courses has been reported, while bank erosion and scouring appear to be more critical locally. It is practical to cope with these local problems by applying simple groyne or bank protection works. The works can be carried out using locally available materials such as bamboo or wooden poles, mats, brushwoods and so forth which are aligned to form fences so as to induce deposition of sediments in controlled patterns. Such works are of a temporary nature and should be placed under continuous surveillance for repair or reconstruction whenever necessary. Application of gabions or wire sausages are preferred to concrete or block works for larger scale bank protection because they have less impact on the ecosystem and are less costly.

7B. 2. 4 Flood and Erosion Control in the Niger Delta

The flood and its attendant erosion have continued to be an annual menace to the inhabitants of the Niger Delta; thus, the people have been resigned to accepting the situation and also adjusting their agricultural and social activities. The efforts to control the flood in the Niger Delta would most certainly be a welcome relief to the inhabitants and would open up more fertile land for agricultural, industrial and urban use.

Major conventional methods of flood control in any area may include:

- Flood protection by upstream reservoirs
- Flood protection by levees
- Flood protection by channel improvement

Each of these methods may be proposed either separately or in combination to solve the flooding problems of the Niger Delta. Flood and erosion control as an aspect of environmental management should not be tackled piece-meal, and should be viewed and placed within a larger system of environmental dynamics in the Niger Delta. This is important because experience has shown in many part of the world that piece-meal development projects are spreading faster than efforts to cope with their consequences. It is essential that in executing various projects aimed at controlling floods in the Niger Delta, adequate consideration would be given at least to the hydrological consequences of flood control works so that finding a solution to the flood problems of a particular area may not create the worse problems in other parts of the Delta. It is also considered important to provide a coherent synthesis of all the dynamics inherent in the amphibian environment as an ecological system, as the basis for flood and erosion management. The major parameters of environmental dynamics in the Niger Delta include morphodynamics, hydrodynamics, pedogenesis, and the activity of the biocenoses including human.

Much has been discussed about the use of upstream reservoirs in flood control of the Niger Delta. Existing reservoirs at Kainji, Jebba and Shiroro and the proposed Lokoja and Makurdi would contribute little in reducing the Delta's floods because only very little storage, if any, is provided for flood control. For a reservoir to check floods, it should be built mainly for that

purpose. In addition, reservoirs are normally effective for the control of flooding of not too distant lands downstream of the dam.

Levees are the oldest known form of flood protection and have been used more extensively than any other forms of either flood protection or prevention. These levees along the banks of a river prevent the overbank spill of flood water at high stage thus reducing overland flooding, but at the same time they also impair the free drainage of runoff generated by local rainfall behind the embanked area. The accumulated runoff may be pumped out; however, the pumped drainage is generally cost prohibitive and has other implications such as typing up irrigation component in the scheme (to make it economically viable). Generally, the drainage is evacuated by gravity as far as possible through hydraulic structures; thus, the entire protected area is not rendered flood-free, but a reduction in depth and magnitude and related duration of flooding is achieved which benefits agricultural productivity and promotes the social activity.

Some effects of confining the flood of a river by the embankments along both banks are:

- increase in the water surface elevation of the river during the floods because water that would otherwise spread over the flood plain is confined to a leveed channel.
- increase in the flood levels upstream of the leveed section, and increase in the velocity of flow and scouring capacity of the stream because of contraction of flood channel.

The levees are usually best by a multitude of the problems which require constant attention especially where lives and properties are involved. Common among these are erosions caused by heavy rainfall, slides due to saturation with seepage water, overtopping due to either insufficient height or excessive sedimentation which eventually causes washing out of a portion of the earth embankments, burrowing animals which dig through the embankments, and so forth. All of the above require a considerable amount of maintenance and repair to avoid the failure of the levees. A honest fear to be entertained in the use of earth embankments in Nigeria would be the attitude of the Government and the people where many of the Nigeria's establishments are interested primarily in awarding contracts and not taking proper interest

in repair and maintenance once the works is completed, viz. once completed, they are allowed to deteriorate to such condition that it would warrant award of a new contract for its reconstruction. In this respect, at note of warning should be sounded that such attitude applied to a flood control and drainage scheme would prove disastrous.

Flood control by channel improvement may be divided into two categories, viz. cut-offs and dredging. Channel improvement in any form as the sole means of flood protection would be usually an expensive undertaking and only applicable to small streams. Cut-offs are not only inadequate for reducing flood heights in large streams, but they usually constitute a menace in alluvial streams unless the channel portions subject to serious erosion above and below the cut-off are stabilized by bank revetment, the bedslope above is increased by corrective dredging and the material deposited below the cut is removed by dredging.

Alternative flood control measures other than the above may be considered (1) rainwater detention polders and (2) raising some patches of land above the flood level:

- Heavy rainfall in the Niger Delta may well be responsible for a good percentage of the floods in the Delta during the months of September and October. There is the possibility of the runoff from adjacent lands reaching the water courses at the time of high tide or of arrival of the river flood crests; therefore, it may be possible to consider the construction of rainwater detention polders on the land to detain the rainwater for gradual release after the critical flood peaks pass.
- The cheapest possible way to raise some patches of land area is by dredging of sand from the rivers to fill up the selected areas to a predetermined safe level. This needs careful planning and execution to avoid undesirable consequences, because as always is the case, the lowest laying areas of the basin may be more seriously affected by any rise in river levels.

The various flood control measures and related effects as examined above would be all applicable to the Niger Delta, either separately or in combinations. The choice of alternatives, however, depends upon the prevailing local conditions. The levees or embankments are generally the

accepted method of flood protection for large streams in alluvial deposits under which classification the lower Niger, the Nun and the Forcados fall. It should be pointed out that this is the most expensive method of flood protection including the initial construction and subsequent operation and maintenance.

Reference has been made to "Report on Investigation of Possible Flood Protection Measures in the Nun and Forcados Rivers Area" (1980) prepared under the technical cooperation program by the Democratic People's Republic of Korea. It may be noted that the Seminar on Flood and Erosion Control in the Niger Delta was held at Port Harcourt in March 1981 on the basis of this Report, and the comments and observations on this Report and subsequent discussions on the Niger Delta problems are seen in its Proceedings. Taking into account all factors as mentioned above and the findings through the Korea's report, the followings are JICA's opinions for subsequent action programs:

- The topographical maps of the Niger Delta are not available. There is a strong need to undertake a systematic topographical mapping of the entire area with sufficient amount of the spot height information.
- Data collection in the Niger Delta is not systematic. In general, the available information have been derived on a piece-meal basis from the project studies which were randomly selected. There is a pressing need for a systematic collection of data that are relevant for both infrastructural development and environmental protection of the Niger Delta including river cross-sections and water levels. It is envisaged that the field data collection exercise should cover both the tidal and non-tidal zones of the Niger Delta.
- The first step to the effective control of flood and erosion is to establish a permanent program of monitoring stations throughout the Niger Delta and adjacent areas to regularly and continuously record, analyze, store and retrieve the environmental parameters describing the dynamics causing the havoc of flood and erosion. The monitoring records should include river discharge, river level variations, river bed topography, rainfall statistics and other meteorological data, topographical map data, geological structures and soil conditions, and relevant socio-economic items.
- As far as the national aspect of the Niger Delta problem is concerned, there is a need for the coordination of various efforts taken by the agencies such as the Niger Delta BDA, the Ministries of Transport and Works, the NEPA, the State Governments, the

academic institutes and others which have in their programs especially those aspects that might influence the flood and erosion situation in the Niger Delta generally and the Nun and Forcados Rivers particularly. It is suggested that the Niger Delta BDA under direction of the FMWRRD through the proposed Department of water Administration be delegated the special position of coordinating all of the activities as mentioned above in connection with proper implementation of the 1993 Water Resources decree.

- It is stressed that the question of flood protection in these areas cannot be tackled in a great haste but should be done on the basis of careful examination of the project proposals including the Korea's plan (use of the embankment from Onitsha to the heart of the Delta with internal drainage pumps) and well thought out programs of implementation in a Niger Delta Master Plan Study to be carried out some years after completion of the above recommended items.

7B. 2. 5 Urban Drainage Improvement

Drainage systems in urban areas have not been maintained properly except for those in the center of large cities and historic cities. In most cases drainage facilities are constructed after erosion and flooding has occurred. Often no action is taken unless roads and other public facilities are damaged, even if there are some problems and little is done to improve inadequate drainage works, even if the construction is not appropriate. For instance, in the 1992 survey, it was noted that traffic congestion occurred in some roads when rain water flooded the center of Onitsha due to insufficient capacity of side drains and damaged waterways, but the 1993 survey indicated that nothing has been done to improve the condition. Damage to roads in the center of Abeokuta and Ibadan has been left unattended, obstructing traffic for years.

Almost no hydrologic calculation has been conducted for the construction of drainage systems in Nigeria and most waterways have either insufficient or redundant capacities. No considerations are given to the force of water that flows into river channels, and damage is noticeable. Most drainage systems constructed in cities collect water from extensive areas and concentrate it in one or a very limited number of drains for discharge. These systems cause gully erosion. Such examples are the gully erosion in the Okpara Roundabout Erosion Site and the Muritala Mohammed Erosion Site.

Particularly, at Muritala Mohammed Erosion Site, gully erosion, 200 m wide and several kilometers long, occurred in a single night. It was caused by heavy rain that fell during construction of a drainage system just before the feeder drains were connected to the main discharge channel. Rainfall collected on one slope and scraped off the surface soil.

Little maintenance of drains and channels is done. Deposited soils in drains reduce the capacity of water flow and degrade drop and buffer blocking capacities. This causes the water to damage the drain itself. In cities, garbage often blocks open channels and hampers drainage causing floods and sanitary problems.

7B. 3 NWRMP

7B. 3. 1 Watershed Management Program

The watershed deterioration is caused mainly by soil degradation including change in quality and loss of soil by erosion, and by deforestation, both of which are attributable to expanding regional and urban development.

From an economic point of view, soil degradation is probably the most serious environmental problem, as it is a precursor to loss of soil productivity, erosion and ultimately desertification. Primary causes of the soil degradation are summarized as follows;

(1) Removal of vegetative cover
(2) Removal of topsoils
(3) Development of poor or marginal soils
(4) Poor farming practices
(5) Lack of fallow periods
(6) Overgrazing
(7) Removal of natural nutrient sources
(8) Reduced ability to support beneficial uses
(9) Reduced infiltration

In order to solve the above problems, the following approaches are necessary;

(1) Active watershed management policies and practices
(2) Revised agricultural practices (education of farmers, etc.)
(3) Standards for use suitability for all lands in Nigeria
(4) Restrictions on land clearing approval and practices
(5) Promotion of land fallow practices in agricultural cycle (education)

Gully erosion is a part of soil degradation and approaches to solving its associated problems are included in the above in general terms, but are specifically discussed in the Subchapter 7C.

Increases in population in Nigeria have resulted in increased pressures on all types of land use activities in the country, and expansion of these uses into previously unused or restricted areas. Increased pressure on resources in inhabited areas has resulted in consumption of forest resources in those areas beyond the rate of replenishment. The primary problems causing deforestation are summarized as follows;

(1) Uncontrolled development of lands for agriculture or other uses
(2) Lack of adequate controls and enforcement on timber harvesting practices
(3) Continued reliance on fuelwoods for cooking and heating
(4) Uncontrolled bushburning for land clearing

In order to solve the above problems, the following approaches are necessary;

(1) Intensify reforestation and afforestation programs
(2) Adopt and enforce sustainable harvesting policies in forest areas
(3) Promote alternatives to fuelwood, especially in urban areas
(4) Adjust fuelwood and forest products pricing to reflect real costs
(5) Enforce ban on bushburning
(6) Expand the area included in existing forest reserves, and restrict access to those areas as much as possible

7B. 3. 2 Programs Proposed for Flood Control and Drainage

(1) Flood Control

Seasonal flooding in wetlands is generally recognized as beneficial in terms of recharging shallow groundwater and permitting flood-recession agriculture. The recent rapid urban development without adequate drainage systems causes flooding on the one hand, and urban areas developed in low lands near major rivers are threatened with flooding on the other.

In order to protect the low lands against flooding, the following two measures are needed;

(1) Restriction of influx of soils and sands
(2) Protection of water pond embankment

In order to reduce influx of soils and sands, it is fundamentally necessary to legislatively enforce adequate plan, design and construction of urban infrastructures and also revegetation / afforestation in upstream areas. For protection of embankments, planting deeply rooting trees such as willow is effective. Apart from the above measures, simple groyne and bank protection works as well as gabions and wire sausages are considered effective to protect river channels against such local problems as scouring and bank erosion, as mentioned in para. 7B. 2.3.

(2) Improvement of Drainage Systems

Examples of the design and installation standards for drainage systems are shown in Appendix 7C-1. As seen in the examples, various data, such as hourly rainfall intensity for a number of years, terrain characteristics in terms of runoff coefficient, catchment areas relevant to the drainage systems and so forth are required in order to design a drainage system with an adequate drainage capacity. Therefore it is necessary, first of all, to establish the design and installation standards which are suitable for local climatic and terrain conditions. With the standards, all the existing drainage systems have to be reassessed for their adequacy in drainage capacity and to be improved accordingly. The FMWH, in cooperation with FMWRRD, should legislatively enforce the standards for construction of future drainage systems associated with urban infrastructure development. LGAs are responsible for implementation of improvement of existing drainage systems and for their maintenance.

(3) Development of the Niger Delta

The control of flood and erosion in the Niger Delta should be given high priority by the FGN through the provision of sufficient financial resources required to achieve an effective control of the problems detailed in para. 7B. 2.4. of this Sector Report. This comes from the understanding that no meaningful and significant development in terms of protection of lives and

property, socio-economic infrastructure, agriculture, fisheries, industrialization, transportation and related private activities can take place in the Niger Delta unless the threat of flood and erosion is controlled. And, further consideration has been made on the present problems that (1) the means of subsistence in the Niger Delta are below an acceptable level except for those associated with oil production, and (2) the social welfare including housing facilities, water supply and sanitation are at an unacceptably low level.

A scenario with respect to the flood and erosion control in the Niger Delta has been presented in the final part of para. 7B. 2.4. It is expected that a Niger Delta Master Plan Study should be completed during the NWRMP period for subsequent implementation on a large and collective scale while the work for topographical mapping and establishment of systematic data collection networks should be completed within the period of the National Water Master Action Plan towards the year 2000. This proposal would have been prepared on the basis of the fact that the present FGN budgetary arrangement is in a critical situation. It is also mentioned that the small-scale flood and erosion control schemes for some of the villages in piece-meal manner as emergency measures will take place within the NWRMP period with a concept that the human displacement and relocation of the numerous communities involved would be an impossible task to implement and the people's participation in planning, construction and subsequent OM should be much appreciated. These project should be carried out in such manner as to avoid any harmful effect to the larger system of environmental dynamics in the Niger Delta. As a matter of fact, the protection works for each of the problem villages in a step-wise fashion would seem to be more realistic, and the villages saved from erosion and flood with an emphasis upon greater self-reliance, that is, increased dependence upon their own resources in seeking to achieve various objectives of the society will contribute the land for development of the area. In conclusion, it should be kept in mind that the most terrifying aspect of the flood protection program is the cost aspect.

7B. 3. 3 Inter-Governmental Coordination

The FMWRRD is fully responsible for securing the nation's water resources and, therefore, for flood control and river training. Since causes of

flooding and watershed deterioration are directly or indirectly related to regional and urban infrastructure development works as aforementioned (Section 7B. 1), cooperation of other federal departments or institutes concerned with the development is also indispensable. The FMWRRD should take the initiative of formulating a national strategy or policy for flood control and river training including watershed management, and of establishing laws and regulations which control development works in terms of environmental conservation. In line with the laws and regulation based on the national strategy, codes and standards for the development projects should be reviewed and revised or newly introduced by the federal departments or institutes concerned. Implementation of flood control or river training works are the responsibility of the State Governments or LGAs but should be placed under the strict administrative control of the FMWRRD for water resources conservation. Actual execution of the projects may be commissioned to RBDAs or contracted to private consultants or contractors for the entire or a part of the works as required.

The FEPA plays its role for flood control and river training projects related to gully erosion and should cooperate with the FMWRRD in instructing and supervising executing agencies concerned. If the projects include plantation works, the FDF is also technically involved.

7B. 3. 4 Guidelines and Criteria for Planning, Design, Construction and OM of the Proposed Programs

At the present time, bank erosion in river channels in Nigeria is becoming serious and requires bank erosion protection works to some extent. However, protection works of a simple and emergency nature, rather than large-scale construction work, are advisable for protection of the present erosion sites for the following reasons;

a. There are a number of bank erosion sites which require urgent protection works. Accordingly, it is essential to complete the protection works within a limited period with easy supplies of inexpensive construction materials.

b. It is not desirable to construct large-scale river banks which may drastically alter the present flooding systems or situations,

because agricultural activity is largely dependent on flooding during the wet season.

Examples of simple bank protection works, using sand bags or foliages, are shown in Appendix 7A-1. These examples are currently used in Asian countries and may be applicable, as they are, to some of Nigerian river channels. Application can be improved in a more suitable manner for Nigeria and better materials may be found, taking account of local conditions.

Generalization and standardization of construction methods are essential to complete the work effectively and quickly. The generalization and standardization make it possible for a State Government, a LGA or even a community of local residents to easily plan and execute appropriate erosion protection works a necessary. Also effectively eliminated by the generalization and the standardization are unsatisfactory results or accelerated erosion due to inadequate construction methods. The simple bank protection works, as shown in Appendix 7A-1, are susceptible to damage or are easily washed away at an occasion of flooding. Periodic examination and repair are necessary to maintain the protection works in good standing. Methods of examination and repair should also be standardized.

Various methods of bank protection works, other than those demonstrated in Appendix 7A-1, have been innovated in many countries and are standardized for their application. In conclusion, it is important for Nigeria to examine various simple methods for bank protection and to develop the most suitable methods, taking account of its natural and social environment.

Meanwhile, there are a few erosion sites which may require semipermanent bank protection works to preserve nearby bridges and river facilities. Even for these erosion sites, it is advisable to adopt naturally harmonizing protection works such as gabions or wire sausages. Construction standards for these types of protection works should be established by DWA.

7B. 3. 5 Plan Implementation Programs

As a basic principle it is understood that the traditional style of flood plain agriculture utilizing river flood waters for irrigation during the wet

season should continue and that any river control works should not interfere with this style of agriculture and should, if possible, increase the duration and the area of flood plain submergence. Therefore, it is advisable to use simple wooden or bamboo structures for bank protection works. In area where bank erosion is severe and where important structures exist in the river bed, protection works using gabions and wire sausages should be considered. Appropriate river protection works are described in more detail in Appendix 7A.

River training and channel improvement works in the North Region will not be carried out before the year 2020, and protection works will be undertaken only where it is necessary to protect roads, bridges or towns from the effects of flooding or erosion. In these cases only semi-natural works (using gabions and wire sausages) will be carried out. Permanent wadi control works will also not be undertaken before 2020 and any urgent works required to protect roads or bridges will be done using gabions and wire sausages.

Throughout Nigeria, there is very little hydrological information available for planning and designing river control and training works. Above all, it is essential for this country's environmental conservation management to prepare a comprehensive data base and hence detailed river maps and profiles for all major rivers and drainage basins. NWRMP recommends that information of this kind should become publicly available by the year 2020.

Watershed conservation works should include some erosion control works, detailed programs of which are presented in the Sub-Chapter 7C. There are a number of dams which are seriously damaged or are threatened with serious damage and require urgent protective action. Immediate site investigations should be carried out to prepare implementation programs for remedial and protective works for these dam sites. In other sites, long term planning for protection works should be started.

With regard to urban flooding, the RBDAs should carry out drainage improvement programs to help relieve chronic flooding and to improve sanitation as a public health measure. Drainage improvement projects should be complete by the year 2000.

Part 7C Gully Erosion Control

7C. 1 Mechanism of Gully Erosion

7C. 1. 1 Regional Distribution

(1) Precipitation (Data-Base Map No.6, Isohytal)

Notable gully erosion occurs mostly in the climatic zones with 1,200 mm or more annual precipitation (Fig. 3). Some SHAs or SSHAs in HA II, III and IV, which belong to the subhumid climatic zone with annual precipitation ranging between 800 and 1,200 mm, are ranked as medium serious or higher in the Data-Base Map No.25 (Present Distribution of Gully Erosion). No serious gully erosion is reported in the dry and semiarid climatic zones with annual precipitation of 600 mm or less.

(2) Topography

Though gully erosion occurrences have been reported in highlands of the Central Plateau and in the mountainous area adjacent to the international border with Cameroon, topographic features appear to have no distinct relation with gully erosion. However, initiation of gully erosion under natural conditions is considered to be related to development of fractures in rocks forming terrains, which may be reflected, to some extent, in topographic features as density of river courses. A river course density map is prepared on the basis of 1 to 500,000 scale satellite images (the same set as used for SIA) and is shown in Fig. 5.

The following three methods are generally accepted to obtain an index for river course density;

a. dividing the total length of rivers and valleys by the total area (Neumann)
b. dividing the total number of headwaters by the total area (Belgrand)
c. dividing the total length of rivers and valleys by the total number of confluences (Penck).

The river course density map as shown in Fig. 5, is prepared according to method a., in which lengths of all the rivers and valleys in each SHA or SSHA observed on the satellite images are measured, summed and divided by the total area of the relevant SHA or SSHA.

The river course density principally reflects terrain resistance to weathering and erosion in terms of geology and geological structure. Therefore, areas of high river course density do not necessarily include SHAs or SSHAs of serious gully erosion as seen by comparing Fig. 5 to the Data-Base Map No.25. However, SHAs or SSHAs ranked as medium serious or higher in the Data-Base Map No.25 are mostly located in areas, in which river course density is higher that 0.05 km/sq, or of the first and second orders of the density ranks. It may be implied that the river course density indicates susceptibility of terrains to initiation of gully erosion under natural conditions.

(3) Geology

The southern part of Nigeria, where gully and sheet erosion are prominent, comprises mainly sedimentary rocks of Cretaceous or younger ages. In addition, alluvial are extensively developed along the major rivers such as the Niger, the Benue and the Cross as well as their tributaries. These sedimentary rocks and alluvials are highly susceptible to all-types of erosion unless thickly covered by vegetation. The pronounced gully erosion complexes in the Anambra and the Imo States are located in terrains which comprise Cretaceous sedimentary formations gently dipping to the west and are characterized by cuestal landforms.

Apart from the terrains comprising sedimentary rocks and alluvials, notable gully erosion is also observed in the Central Plateau including Abuja FCT and in the eastern mountainous areas adjacent to the international border with Cameroon. Both of these areas consist of precambrian basement rocks which are generally resistant to erosion under natural conditions. Gullies in the Cental Plateau are mostly located near the peripheries of basement rock exposures or in the debris comprising basement rock fragments surrounding the exposures, where weathering is intense. These gullies have apparently been initiated on bare lands created mainly by open cast mining activities which have further progressed the erosion. Therefore, the geology is not a primary cause of erosion. The Precambrian rocks include granite and are also

intruded by younger granite (possibly of Jurassic). It must be noted that granite is susceptible to weathering under tropical or subtropical climatic conditions when exposed and forms incoherent soils comprising mostly medium grained particles. Rills are easily formed on terrains comprising granitic soils and grow to gullies.

Gullies in the eastern mountainous areas are not well documented but are probably of natural occurrence due to steep terrains.

(4) Vegetation

Vegetation cover is essential to protect lands against erosion. In other words, barelands are more or less susceptible to erosion. The bareland distribution map (Fig. 4) indicates that bareland ratios are relatively high in the North-West, the North-East, the Central East and the South-East Regions. The barelands in the North-West and the North-East Regions are suffering intense wind erosion under the semiarid climate conditions (Fig. 3) and are threatened with desertification at an alarming pace. Gully erosion ranked as medium serious or high spreads in the Central-East and the South-East Regions, particularly where bareland ratio exceed 10% (Fig. 4).

Urban development tends to expand barelands. The Anambra and the Imo States, where serious or very serious gully erosion develops, are located in a highly urbanized area (Fig. 6).

Of vegetated lands, agricultural lands are susceptible to erosion if farming practices are inappropriate, such as slash-and-burn method or cultivation without proper fallow periods. Grazing and fuel wood cutting are also substantially contributing to deforestation, and are expanding barelands at an accelerated pace. These activities are essential for Nigerian people's daily life, and are being carried out in a disorderly manner.

7C. 1. 2 Man-Made Disaster

It is believed that erosion is mostly caused by human activities and it is possible to be prevented by taking appropriate measures. The causes are

attributable to (I) improper land use. (2) improper infrastructure development and (3) inadequate erosion protection works.

All the land in Nigeria is owned by the Federal Government. People have to apply to the Federal Government for land uses. However, there are practically no restrictions on purposes and ways of land uses from an environmental conservation point of view.

Increase in food production is a National requirement to accommodate increasing population in Nigeria, resulting in expansion of farming and grazing lands in rural areas. Slash-and-burn is the traditional and the most popular farming method, particularly in the central and the southern parts of the country. This farming practice causes deforestation which leads to expansion of barelands susceptible to erosion. By the same token, overgrazing to increase livestock production is also responsible for expanding barelands.

In the northern semiarid-dry climatic zones, people are relying on shrubs for fuel. Overcutting of shrubs degrades soils, leading to desertification.

Accelerated infrastructure development in urban areas is the most conspicuous cause of land degradation and hence of erosion. Excavation of lands expands barelands and construction of paved highways increases surface with high runoff co-efficients. Infrastructure development requires careful planning and design for protection of structures and surrounding lands against destruction by water runoff, erosion, mass-movement or other natural causes. Unfortunately, however, most infrastructures in Nigeria have been constructed without taking an adequate consideration of land degradation in general or of gully erosion in particular. Improper construction works and inappropriate maintenance also cause damage to lands, leading to acceleration of erosion or induction of mass-movement. Recent urbanization is progressing at a considerable pace in Abuja FCT, and the States of Anambra, Imo, Rivers, Akwa Ibom, Abia and Cross River which have been already affected by notable gully erosion.

Since engineers in Nigeria are well aware of the seriousness of gully erosion, gully erosion control works have been exercised at various localities. However, many erosion control facilities are not functioning satisfactorily due to inadequacy of planning and design, lack of consideration for hydrologic or

hydraulic characteristics, improper construction procedures, or inappropriate maintenance. If facilities are damaged due to these faulty practices, the gully erosion situation will further deteriorate.

7C. 1. 3 Phsyical Features of Gully Erosion

(1) Water Action

Rainfall runoff is the principal agent for initiating gully erosion. At the initial stage, as aforementioned (para. 7A. 2.2), rills are formed by surface water and grow to gullies as surface water progressively concentrates into rills and shaves off surface soil. Under the tropical rain forest climatic conditions in the southern part of Nigeria, gullies grow swiftly with heavy rainfall during the wet season.

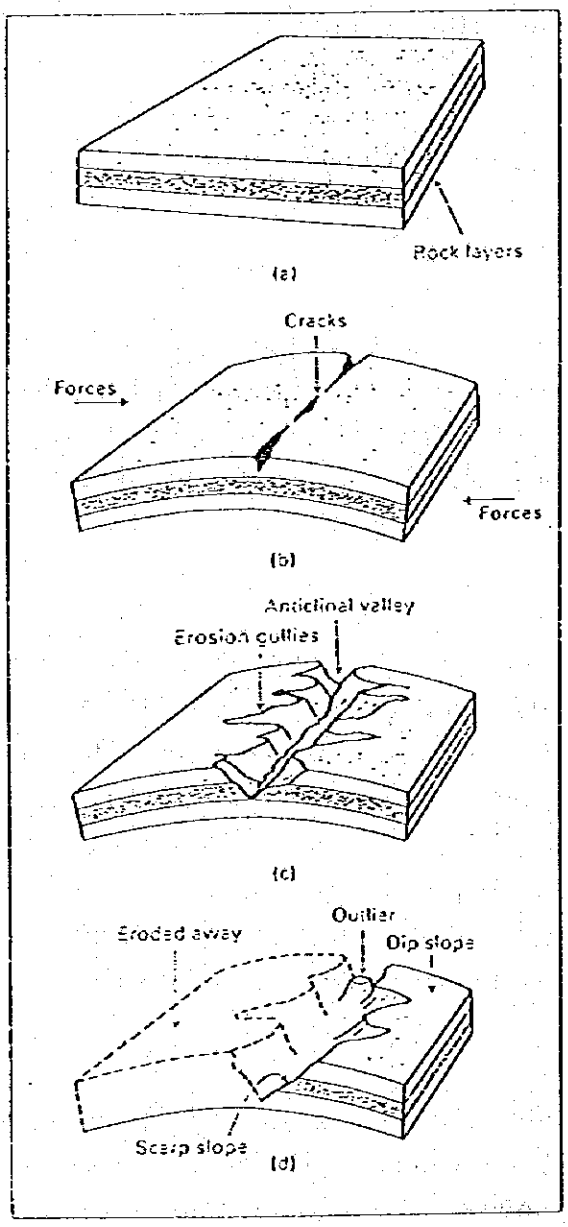
Where the ground is highly permeable to water, surface water easily infiltrates into the ground and increases subterranean water flows or lifts groundwater levels. Increased subterranean water flows due to extremely heavy rainfall during the wet season sometimes wash out a considerable amount of subsurface soils and form subsurface caves of tunnels. Grounds become unstable with increasing dimensions of the cave or tunnels and ultimately collapse, forming sizable valleys or depressions. Erosion caused by this mechanism is called 'tunnel' erosion and is sometimes classified as a type of gully erosion.

Lift of groundwater levels reduces apparent weight of land hence stability of a land mass making it liable to gravitational movement and triggers mass-movement including land-slide. Steep gully walls are at risk of mass-movement which often occurs suddenly due to heavy overnight rainfall. Mass-movement is not a direct agent forming gullies but is a dangeous element associated with gullies because of its sudden occurrence and because it enhances gully erosion.

(2) Geological Features

The most notable landform in the South-East Region, where a number of serious gully erosion sites occurs is cuesta formed over Cretaceous formations

dipping gently to the west. The following figure indicates a model of the process with which the cuesta has formed.



A Model of Cuesta Formation Process

A cuesta comprises a pair of steep and gentle slopes, called scarp and dip slopes respectively. The scarp slope is more susceptible to mass-movement than to erosion, while the dip slope is susceptible to erosion. The longer the dip slope is, the more the erosion is intensified, and the more the contribution of the rill and gully erosion becomes apparent, as shown in the following figure. Most gullies in the South-East Region have probably been initiated according to this geomorphologic process.

The Cretaceous formations comprise alternation of loosely consolidated sandstone and siltstone locally interbedded with coal measures and are generally easily decomposed by weathering. Decomposition of these rocks by weathering forms surface soils that are weakly resistant to erosion. There is a slight difference in susceptibility to weathering among these rocks. Where strata with different susceptibility are exposed side by side, lineal depressions are formed. Rainfall runoff concentrates in the depressions and initiates rills which grow to gullies.

Gullies in the Central Plateau and the eastern mountainous area are formed in the terrains comprising mainly Precambrian basement rocks, and are mostly initiated by artificial or geomorphologic factors. As previously mentioned (para. 7C. 1.1), it must be noted that granite, included in or intruding the Precambrian basement rocks, tends to be easily decomposed by weathering under the tropical or subtropical climatic conditions when exposed, forming soils comprising incoherent, medium grained particles susceptible to erosion.

(3) Soil Characteristics

The Nigerian terrain is covered by desert soils in the northern semiarid-dry climatic zone, tropical red soils in the central subhumid-humid climatic zone, forest soils in the southern very humid climatic zone, and alluvial soils in the flood plains along major rivers and in the coastal plain and deltas facing the Gulf of Guinea.

The desert soils are sandy, comprising mostly incoherent medium to fine grained particles and are liable to wind erosion during the dry season and water erosion during the wet season. Development of humic top soils is extremely poor and is generally unsuitable for vegetation except in depressions or seasonal natural water reservoirs along major rivers or near Lake Chad. Erosion proceeds evenly over the entire area and does not normally develop gullies unless disturbed by urban or regional development.

The terrain covered by forest comprises principally the tropical red soils with better development of humic top soils. The humic top soils contain sufficient nutrients to support tropical rainforest growth under the humid and warm climatic conditions. The tropical rain forest, supplying humus to the

soils, protects it from erosion. Accordingly, once deforested, the fertile top soils are easily removed by erosion and the area becomes extremely vulnerable to erosion. In fact, many gullies are developed in the terrain comprising the forest soils where deforested.

The alluvial soils are relatively fertile and suitable for cultivation, containing an appreciable amount of moisture even during the dry season and nutritious minerals and organic substances supplied by rivers. It must be noted, however, that the flood plains and the deltas are liable to seasonal or tidal flooding as well as bank erosion and scouring because braided river systems are highly developed.

The tropical red soils are classified into iron and aluminum rich laterite and iron rich red soil. These types of soils are prevailing in the high temperature and highly humid climatic zone and are characterized by (1) immature and unstratified soil profiles of considerable thickness, (2) low pH, (3) high CO_2 contents, (4) accumulation of ferric and alluminous oxides or hydro-oxides, (5) poor development of humic top soils and so forth. Weathering reaches to a considerable depth and forms a large amount of clay minerals under the tropical humid climatic conditions. As weathering progresses, increasing amount of clay minerals as well as their transformation from three-layer to two-layer structure further intensifies the weathering. Accordingly, the surface of tropical red soils terrains is continuously eroded and becomes liable to gully erosion in particular. Although the central subhumid-humid climatic zone in Nigeria is largely covered by Guinea Savanna and is protected to some extent, a slight disturbance of vegetation by human activities makes the terrains extremely vulnerable to erosion. A number of gully erosion sites are observed in this zone, particularly in HAs II, III, V and VII.