APPLICATION OF EXISTING MODELS FOR THE PREDICTION OF GULLY GROWTH
(A CASE STUDY OF EFON–ALAAYE ACTIVE GULLY EROSION)

BY

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CERTIFICATION

I hereby certify that this work was carried out by Engr. Joseph Okpone Adam in the department of Civil Engineering, Federal University of Technology, Akure and to the best of my knowledge, it has not been submitted elsewhere for the award of degree.

11/10/05

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DEDICATION

This work is dedicated to my ever loving and supportive wife Regina, my children Juliet, Paul, Samuel and Nathaniel and above all to the Almighty God Jehovah who is the epitome and personification of wisdom, knowledge and understanding.

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ABSTRACT

The erosion problem at Efon–Alaaye in Ekiti State, Nigeria, was investigated with a view to determining the type(s) of gullies and major factors responsible for accelerated erosion in the area. During the reconnaissance, 8 major gullies were identified, 4 of this, which were observed to be most active were selected for the study.

The rainfall data of the area over the past 10 years was obtained. The drainage area for each of the gullies was surveyed with a view to determining the area, length of the gully head to water shed divide and the slope. Similarly, a total of 12 samples of soils with 3 samples each from the eroding layer of each of gully were collected and analyzed in order to determine the strength, physical and chemical properties of the soils.

The width of each of the gullies was measured at 0.5m vertically and 2.0m horizontally at the end of years 2000, 2001, 2002 rainy seasons respectively in order to determine the magnitude of growth for each of the gullies. Using Beer & Johnson's and Thompson equations of growth and head advancement, the annual growth of each of the gullies was predicted.

The results obtained show that Sheet wash, Rill and Gully types of erosion are plaguing the area with gully erosion being the most severe. It was also observed that the area experiences large amounts of rainfall with the average annual rainfall being as high as 1471 mm and intensities of 80mm/hr for 30 minutes duration for a return period of 2 years being recorded. The results also showed the slope of the area to be generally steep with slope varying between 9% and 22%. The soils were observed to be generally sandy and loose with clay and organic carbon contents varying between 1% and 6 % and 0.2 % and 0.6 % respectively. The stability of the gully sides show factors of safety varying between 0.53 and 1.67 with the lowest value being observed at Igbo-Egun. Simple prediction models were established for both annual surface growth and head advancement for the area. The models reveal an average value of the coefficient of surface growth K_a and head advancement K_h of 0.559 and $8x10^{-5}$ respectively.

TABLE OF CONTENT

List of Tables

List of Figures

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATION

$C\mu$ = Apparent cohesion

$\varnothing$ = Angle of internal friction

G_A = Area of Gully Growth

G_H = Length Gully head advancement

H_C = Critical Height of Gully

H_A = Excess length over critical height

γ = Unit weight of Soil

D.E.M = Digital Elevation Model

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Erosion has been defined as the process whereby the surface of the earth crust or land is attacked, eaten into, sculturied into gullies, vallies, hills and cliffs and is completely washed away into the rivers and seas eventually (Fubara, 1986).

Soil erosion is a serious ecological menace. In fact, it is capable of endangering the health of the ecosystem. This is evident from what Lowdermilk (1939) called the eleventh commandment, which was quoted by Fubara (1986). He says: -'Thou shall inherit the earth as a faithful steward, conserve its resources and productivity from generation to generation. Thou shall safeguard thy fields from erosion. If thou shall fail in thy stewardship of the land, thy fruitful fields shall be sterile, become stony grounds or Wasting Gullies. And thy descendants shall decrease and live in poverty or perish from the face of the earth'

Lowdermilk's statement shows that man's existence is also predicated on his ability to save the earth from the grip of erosion.

1.2 Agents of Erosion

The various factors causing erosion are primarily connected with: climate e.g. rainfall, wind, temperature etc. earth materials e.g. geotechnical properties and landform such as, shape, length and slope of the catchments and those associated with human activities (Egboka & Okpoko, 1984).However wind induced erosion has been observed in the Northern part of Nigeria (Ologe, 1971),while erosion in the Southern part is mainly fluvial or rain induced.

When rain falls, each drop of the rain possesses a kinetic energy that depends on the size of raindrop, the angle at which it strikes the ground, its terminal velocity and the intensity of rainfall. Thus when the raindrop strikes the ground, it loosens or detaches soil particles from the ground. These particles are eventually entrained and subsequently transported into rivers and stream hence starting off the process of erosion.

Run-off from rainfall also contributes to the erosion process. Run-off may either be concentrated or un-concentrated. While concentrated run-off is generally responsible for the development of gullies, non-concentrated run-off lead primarily to sheet wash and the direct consequence of this phenomenon includes erosion of pavements, exposure of foundation bases, etc. Apart from climate and geomorphorlogical factors, man-made or human factors also contribute tremendously to soil erosion. These are factors generally connected with man's use of the land for purposes such as agriculture, mining, and construction, etc. (Ofamata 1979, Floyd 1965). It has been observed that nature slowly wears away land surfaces thus inducing erosion. However human activities such as construction, mining and agriculture, increase the rate of erosion some 200 or even 2000 times that amount since they usually involve excavation, disturbance of the earth surface and removal of top soil leading to erosion. For example, it is reported that road and home building in Oakland hills above Lake Ternescal resulted in erosion that filled the lake to such an extent that it had to be dredged in 1979 at a public cost of $750,000. The situation is further aggravated when such developments are highly concentrated. For instance, the Apartheid in South Africa which compelled about 42% of the people to live on 13% of the land resulted in overcrowding leading to serious land degradation and excessive erosion. (Http//www.search.gov.ca 2003)

Some efforts have been made to identify the causes of erosion in the study area with a view to finding solution. In 1990, the Benin-Owena River Basin Authority (BORBDA) set up a technical committee to identify erosion and flood prone areas of the former Ondo State. Their report shows that the erosion in the area like most other parts of southern Nigeria is primarily fluvial. They also reported that three main types of erosion are prominent in the area namely Sheet, Rill and Gully.

Both the Federal and State governments including some spirited individuals have constructed some erosion control works, in form of concrete drain channels, revetments, etc. in the area all of which are aimed at controlling the gully growth and reduce the effect of surface wash. These have however proved inadequate as poor planning, improper location of urban centres and other anthropological factors are further aggravating the situation.

1.3 Objectives of the Study

The main objectives of this study are to: -

i Determine the main types of erosion in the study area.

ii Determine the various causes of erosion particularly the gully growth in the area.

iii Measure the annual rate of surface growth and head advancements of the gully.

iv Develop simple models for prediction of surface growth rate and head advancement for the area.

1.4 Justification of Work

Erosion can be described among the top league of ecological disasters ravaging the country today. For example, available records show that not less than 155 persons lost their lives over a period of 5 years in erosion related disasters and properties destroyed during such incidents run into billions of Naira nation-wide (Aikhoimu, 19 91).

Three reasons may be responsible for these fatal and costly incidents:

i Absence of control measures.

ii Poorly constructed control measures.

iii Absence of prediction models which would serve to warn the people ahead of time.

The third reason obviously stands out as the most important. This work is therefore aimed at addressing the issue of the absence of prediction model.

CHAPTER TWO

LITERATURE REVIEW

2.1 Preamble

Mennard (1974) while quoting from Thorp's Geography of the soils in China says. "Civilization is running down and that man is gradually but surely destroying the means by which he can exist; but there are means at hand by which this decadence may be indefinitely checked". If we control population increase, adopt a means of checking soil erosion, and improve our transportation system facilities, it is possible for us to indefinitely postpone the day when the world will no longer support a larger human population".

Thorp's statement not only shows the significance of the control of soil erosion to the survival of the ecosystem but also the general well being of man. It is therefore very evident that soil erosion is an important factor in the assessment of the health of the ecosystem. The truthfulness of the above assertion is evidenced by the fact that estimates of soil erosion (soil loss) are usually considered in relation to issues involving the management of Land and Water as it affects sediment transport and storage in low lands, reservoirs, estuaries and irrigation and hydropower systems (Osterkamp, et al., 1991). Erosion has been observed to affect the level of pollution of the air as is usually the case with wind erosion (Oyebande, 1988) as well as the stability of Civil- Engineering structures such as Highways (Jegede & Oguntuase, 2000) buildings, dams, tunnels retaining walls etc.

Soil erosion is a very complex natural process but strongly modified by human activities such as land clearance, agriculture, landscaping, construction, mining activities and urbanization. Natural erosion process most often results in normal erosion. This generally poses little ecological problem since the normal process of weathering replenishes the amount of soil due to this process of erosion (Holy, 1980). However human activities have been observed to be the strongest factor responsible for accelerated erosion since it is capable of increasing the rate of erosion 200 or even 2000 times over increasing the rate of erosion 200 even 2000 times over leading to accelerated or abnormal erosion that is the main source of threat to the ecosystem.

For example, it is reported that human activities alone have degraded some 15% (2000 million ha) of the earth's land surface between latitudes 72^0 N and 57^0 S, 50% of this amount being water induced, over 30% being due to wind erosion while the greater part of the remainder is due to chemical erosion (Osterkamp, et al., 1991). This has not only contributed to the pollution of the air as is the case with wind erosion (Oyebande, 1988) but has also affected the quality of water, silted water courses and has reduced the stability of most slopes (Ologe, 1985).

Soil erosion is however a global problem and it is assuming an alarming dimension with every passing day. Foster and Lane (1982) reported that the rate of soil erosion in the United States of America is about

17 times the rate of formation while the rate is about 34 times in Asia, Africa and South America. Food and Agricultural organization (F.A.O) an agent of the United Nations Organization (U.N.O) estimates that about 140 million ha of high quality soil mostly in Africa and Asia will be degraded by the year 2010 unless better land management policies are adopted. Supporting this finding Alayande and Bamigboye (1994) observed that the total annual rates of erosion in continents such as Asia, Europe and Africa whose areas are $44.89 \times 10^6 km^2$, $9.67 \times 10^6 km^2$ and $29.81 \times 10^6 km^2$ are as high 208, 75 and 72 $tonnes/km^2$ respectively. In the same vein, while highlighting the rate of abnormal erosion on bare soils in some selected countries, Ingold and Thompson (1990) observed those countries such as United State of America, China and Nigeria experience as much as 90, 360 and 150 tonnes/Ha/Year on the average. This situation no doubt can be described as worrisome.

There is no part of Nigeria that is not affected by accelerated erosion in one form or another with its attendant consequences. It is little wonder therefore that it has attracted the attention of several researchers in different parts of the country. Carter (1958), Nwajide (1979), Egboka & Okpoko (1984), Ogbukagu (1987), are some of the researchers that have worked extensively on the erosion problem in Eastern Nigeria. They observed in their various studies that the geologic formation of this area is primarily sand and because of its friable and loose nature coupled with high intensity rainfall, the propensity for erosion is high. Mortimore (1965), Ologe (1971) and Mustapha (1977),. examined the forms and causes of erosion in Northern Nigeria. They opined that wind erosion is more prominent in this area particularly in the areas lying within the Sudan Sahel region. They attributed this to the high winds prevalent in the area.

In their study of erosion problem in parts of South Western Nigeria. Jeje, (1986), Lal (1987), BORBDA (1991), Jegede and Oguntuase (2000), showed that erosion in this part of the country is primarily fluvial aided by high intensity rainfall and steep slopes resulting in high run-offs. Abam (1984) reporting on erosion problem in the Niger Delta area observed that it is mostly bank or coastal and is not unconnected with the high density of rivers in the area.

2.2 Forms of Erosion

Holy (1980) classified erosion into three different forms viz:

Sheet Or Surface Wash: This involves the removal of soil particles from the surface due to raindrops striking the earth with certain energy and at certain angle. The soil so detached is then transported to streams and river by means of over land flow.

Rills And Gullies: these occur when there is differential soil removal from the earth surface, resulting in the formation of shallow and narrow channels called rills. These channels begin to receive concentrated flows resulting in increase in width and depth and with the passage of time develop into gullies.

Bank Or Stream: This is the type of erosion observed at the banks of streams, rivers and oceans. It involves the eating away of the riverbanks. With the exception of bank erosion the study area is plagued by Sheet, Rill and Gully erosion, (BORBDA, 1990). This observation is confirmed by the presence of eroded highway pavements, exposed foundation bases and gullies of different magnitudes in different parts of the town.

2.3. Soil Erosion Processes

Wall et al (2003) observed that soil erosion is initiated and controlled by the action of the following factors:

(a) Climate of the area

(b) Geology including soil nature

(c) Vegetative cover

(d) Slope gradient and length

(e) Human etc.

2.3.1. Climate

The two most important climatic factors that effect erosion are Wind and Rain. Wind erosion generally involves the selective removal of certain particle sizes of soils, particularly fines from an area due to the effect of wind. This occurs mostly in areas susceptible to high winds and where dry land farming is practiced. Because of the effect wind erosion has on the quality of air, water etc most countries are already putting in place legislation regulating the minimum air quality standard permissible. (Saxton, 1983).

The main components of rainfall that determine its erosivity are :- Intensity, Duration, Total amount and frequency, diameter and velocity of raindrops. The falling rain generates erosion either through the detaching effect of raindrops resulting from the kinetic energy possessed by each rain drop which usually depends on its size and terminal velocity or through the force developed by the flowing water in the form of concentrated or non - concentrated run off depending on the slope, vegetation and soil nature or the combined action of all (Bolanjo, 1998). Rainfall in the tropical region is generally of very high intensity and long duration sometime reaching about 300mm/hr. This is traceable to the high temperatures in this region. This results in raindrops of large sizes of up to 4.0mm and large volumes of run off (Lal, 1987).

2.3.2 Geology

Both soft (sedimentary) and hard (Basement Complex) rocks are subject to degradation through fluvial erosion. However; soft rocks are generally more susceptible to degradation than hard rocks. While the extent and effectiveness of degradation of soft rocks is predicated on the degree of consolidation and /or cementation, soil erosion in areas underlain by rocks of the basement complex including younger and older granites such as the study area, usually occur along modern and ancient water channels due to fluvial action orchestrated by slopes resulting in the development of gullies. (Ogbukagu, 1976).

2.3.3 Soils

Soil would respond differently to agents of erosion. Olson and Wischmeier (1963) observed that if all other things are equal, difference in the magnitude of erosion can vary up to 30 fold due to differences *in soil* properties only. Bryan (1976) showed that Physical and Hydrologic, Chemical and Mineralogy, Biological and Biochemical and profile characteristics are the main properties of soil that affect its erodibility. Some of the physical properties of soil that are used to measure its erodibility are Texture, structure, strength (shear and unconfined compressive).

Three texture related indices used for this purpose include:-

(i) Dispersion Ratio (Middleton, 1930)

$$D.R = \frac{\text{Silt + Clay in Undisturbed sample}}{\text{Silt + Clay in disturbed sample}} \quad \text{---------------} \; (2.1)$$

(ii) Erosion Ratio (Middleton, 1930)

$$E.R = \frac{\text{Dispersion Ratio}}{\text{Colloid Content/Moisture Equivalent}} \quad \text{---------------} (2.2)$$

(iii) Clay or Mechanical Ratio (Bouyoucos, 1935)

$$C.R = \text{Sand/Silt + Clay} \quad \text{---------------} (2.3)$$

Lal (1987) observed that soils with low clay content are easily dispersed and hence are easily eroded. On the other hand, soils of large particle sizes require greater fluid force to detach with the particle size primary or secondary observed to be more easily eroded being 0.1mm. Wang and Lin (1965) observed that even in hilly lands i.e. lands with steep slopes, the least erodible soils are those that have high aggregate stability properties while those with high dispersion ration have high propensity for erosion. Wischmeier and Mannering (1969) showed that soils which are sandy or silty or have restricted clay contents are generally erodible. Although the erodible materials in temperate countries show a preponderance of silt and clay (fine materials), the converse is the case with tropical soils.

Strength indices are also commonly used for the measurement of soil erodibility. Apart from the fact that they can be easily and rapidly obtained, strength indices can be easily related to other soil parameters such as dry unit weight, water content etc that also affect erodibility. Hanson (1996) while advancing reasons for the use of strength index for measuring a soil's resistance to erosion opined that since erosion is a function of the forces applied by fluvial action and resistance to this action is produced by the bonding forces between soil particles and other materials in the soil matrix which is an indication of the soil strength, it is reasonable that resistance to erosion can be characterized by the measurement of soil strength. However Franti et al (1985), Nearing and West (1988), Elliot (1990), observed that although soil strength indices are functionally appealing for measuring soil erodibility, success is limited where flow is highly concentrated. This view was corroborated by Parker et al (1995) who argued that desirable though the use of strength parameters are for the assessment of erodibility because of its many advantages, its success in assessing erodibility is limited particularly in concentrated flows. Singer et al (1978) observed a correlation between soil erosion and actual shear stress and opined that the critical shear stress may be used to predict soil erodibility. Highlighting the relationship between shear strength and erosion, Lal (1975) observed that soils with strength ranging between 0 – 2kg/cm^2 are highly erodible, at 2.3kg/cm^2 are fairly erodible while those greater than 9.0kg/cm^2 are less erodible. However shear strength obtained both insitu using cone Penetrometre, Pocket Penetrometre etc and that obtained from Laboratory test using triaxial compression test or unconfined compression test have been used for assessing soil erodibility. Ayers and Perpal, (1982). Apart from the physical properties of soil, its chemical properties are also used to assess its susceptibility to erosion. Although there are several chemical properties that are relevant in the assessment of soil erodibility, many researchers have agreed that organic matter content and the amount and nature of clay mineral in the soil are most significant. Since the degree of binding possessed by any soil is generally a function of its organic content, clay and sesquixiode content, the more firmly bound a sample soil is, the higher its resistance to erosion because of its improved stability. Esiola (1966), Ghatol and Malewar (1978) all reported favourable influence on the permeability, bulk density, structural stability and hence soil erodibility with increased organic carbon content. Luk (1979) showed that there is a relationship between the organic carbon content and the percentage of water stable aggregates (WSA) present in a soil mass. He described this relationship by means of a non linear second degree polynomial equation.

$$W.S.A = 24.83 + 3.87C - 0.254C^2 \quad \text{-------------(2.4)}$$

Where C = Percentage of organic Carbon Content

However desirable though organic matter is to improving soils resistance to erosion, Krammes and Osborn (1969) and Meewig (1971) observed that high organic matter content may increase the erodibility of water –repellent soils because of mutual electrostatic repulsion developed between aggregates. Apart from the organic carbon content Grissinger 1965 noted that the clay type and amount present in a soil also affect soil erodibility.

The responses of soil to water movement within the soil mass and its behaviour as a soil water solution are important factors that also affect the erodibility of the soil. Bonett et al (1981), acknowledged that the antecedent moisture content plays a very significant role in the determination of the infiltration of soil and hence its permeability. While soils with very low permeability experience greater runoff and hence are more prone to rill and gully erosions, very high infiltration results in slumping. Similarly soil consistency, which is generally a measure of the resistance to deformation, also affects the process governing erosion. Two consistency limits have been identified to affect erosion. These are cohesion and plastic. While cohesion limit has been found to have significant effect on a soil's susceptibility to wind erosion, plastic limit of a soil can indicate the vulnerability of a soil to tunnel erosion. It has been observed that highly plastic soils such as high activity clay crack when they shrunk thus creating crevices for water passage resulting in tunnel erosion. (Yair, et al., 1980.)

2.3.4 Soil Profile

Olson (1949), showed that the profile of a soil within a watershed can affect its susceptibility to erosion in two ways:

i.) When a layer of highly cohesive soil underlies a layer of cohesionless soil, the top layer of cohesionless soil stands the risk of accelerated erosion.

ii.) When a soil with a very shallow horizon is underlain by a bedrock.

2.4 Vegetative Cover

Wall (2003) observed that soil erosion potential is increased if the soil has no or very little vegetative cover of plants and crop residues. He showed that plant and residue cover protects the soil from raindrops impact and splash. It also slows down the movement of surface run-off and allows excess surface water to infiltrate. Similarly the growth of vegetation along gullies also reduce the rate of growth as they help to reinforce the sides of gullies, reduce the velocity of flow and hence reduce its energy.

2.5 Slope Gradient and Length

The slope of catchments is another factor that can have very significant effect on the intensity of erosion. Three main slope components have been found to affect erosion intensity. These are Gradient, Length and Shape of the catchments. Zingg (1940) showed that these components of slope affect the velocity and tangential stress developed by the run off. Duely and Hays (1932) reported that run-off under a 25mm/hr. rainfall increased from 69% of rainfall at a 5% slope to 86% of rainfall at a slope of 20% on a silty clay loam. Similarly, Poesen (1984) reported a 15% greater run-off on a 26% slope than on a 3% slope. Van Liew and Saxton (1983), also showed that increase in slope steepness increased the overall erosion rates. Liattanzi et al (1974) observed that as the slope increased from 20% to 30%, interill erosion of a silty loam soil slightly more than doubled. Singer and Blackard (1982) acknowledge that there is a relationship between slope and soil properties as they affect the erosion potential of any watershed.

2.6 Human Factor

Although nature slowly wears away land leading to erosion, human activities such as agriculture, construction and mining have been observed to accelerate the rate resulting in abnormal erosion. Research has shown that construction increases the rate of erosion 200 or even 2000 times that amount. Such anthropogenic actions, which involve the removal of vegetation, or other object, that hold soil in place tend to expose it to the action of wind or water thus increasing its chances of eroding. For example it is reported that in the pre-aparthed policies in South Africa land holding polices which ensured that 42% of the people lived on 13% of the land.

resulted in overcrowding leading to the land degradation due to intensive agriculture and overgrazing culminating in severe erosion of the area (Collins, 2004). Corroborating this fact, Sidorchuk (1998) observed that the rate of gully growth induced by anthropogenic action in western Siberia is as much as 20-200m/year. The high density nature of the development will no doubt contribute to the high rate of gully erosion in the area.

2.7 Gully Erosion

Gullies or ravines are rills large enough to restrict vehicular movement. They are channels that develop due to improper management of concentrated high velocity run-off from built-up areas, roads, construction sites and footpaths, e.t.c. This run-off remove vast amount of soil from open areas resulting in one or more of the following: Loss of large volume of soil, severe limitation of land use, off site deposition of soil causing water quality decline in streams and rivers, sedimentation of dams and rivers, disruption of normal farm process and destruction of highways and create instability for buildings (Hughes, et al., 2001).

Gully erosion is a very serious problem worldwide and as a result has become a parameter in the assessment of the magnitude of erosion in any nation. Sidorchark (1995) reported that the volume of the gullies on the Russian plain is about 4% of the volume of erosion since 1700 A.D. Wassson et al (1996) observed that about 40% of the total volume of erosion in Western Europe is attributed to gullies. The situation is not different in

Africa in general and Nigeria in particular. Prest et al (1973) noted that the problem of gully erosion is very serious in China and the alluvian soils of Indian and south and eastern Nigeria. Serious though this situation is. Stott et al (2001) observed that there are not as many models for the prediction of gully growth when compared to those available for the prediction of rill and sheet erosion.

2.7.1 Factors Affecting Gully Growth

Young and Wersma (1973) observed that the depth of flow in channels is about 50 times that of overland and the velocity of flow is about 10 times greater hence the shear stress exerted by such concentrated flow causes greater soil detachment. These properties of running water in gullies have the capacity to lead to both lateral growth – a situation which results from the scouring effect of run – off water concentrated in the rills which is observed mostly in gently undulating landscapes and head ward growth (head advancement) which involves the gully extending upstream. Head advancement often results from waterfall undercutting and gravitational slumping of the gully head. The rate of head ward growth is faster in steeper landscapes (Milton, 1971). Corroborating this, Ashis, et al (2000) opined that the initial shape is an important parameter for the formation and development of gully head cut. Head cut convex in up-stream side is a necessary condition to develop gully while head cut concave in up-stream side is disadvantageous to gully development process. Higher convexity especially around the gully head makes the gully development process faster. Three factors that have been observed to influence channel development are:

i.) Flow Properties i.e. run-off

ii.) Topography and Soil Properties and

iii.) Gully Properties

Lettanzi et al (1973) observed that topography factors influence run - off depth and velocity and that the amount, depth and velocity of run off differ for different slope length, steepness, shape and aspect. Cohesive soils have been observed to require more energy to detach than non-cohesive soils (Bobenzer and Jones, 1971). Most researchers agree that the most commonly detached and moved material is fine to medium sand with the size fraction ranging between 0.06mm and 1.0mm, (Milton, 1971). For example Terwindt et al (1968), puts the size at 0.105mm and 0.210mm. De-Ploey (1972), puts it as 0.1mm while Farmer (1973), puts the range at between 0.24mm and 1.04mm. Bryan (1976) observed that soils with massive structure i.e soils with higher clay content are usually more stable and hence less erodible than coarse and friable soils.

Apart from the cutting effect of running water which usually lead to the detachment of soil particles and hence the gradual growth of gullies. Caeser et al (1983) and Morgestern and Price (1965) noted that there are two other factors associated with the gully properties that contribute to the abnormal or accelerated growth of gullies. These are:

i.) Changes in the channel geometry such as bends, drops and dimensions. These tend to encourage eddies and turbulent flow which increases the scouring power of the flowing water.

ii.) The Height of gully sides.

Bishop and Mongestern (1960) showed that the critical height (H_c) of a slope within which gully sides may be stable depend on undrained shear strength of the soil, the unit weight of the soil and the distance from the base of gully to a bedrock. He noted that as soon as the critical height 'H_c' is exceeded, the slopes of the gully sides become unstable thus reducing the factor of safety. This increases the risk of slope failure as the excess soil stands the risk of breaking off and crashing into the floor of the gully. This situation is usually further worsened by the fact that the shear strength of soils is generally reduced by seepage thus reducing the critical height and increasing the excess height. It therefore means that soils with low shear strength will have higher propensity to grow.

Generally, the stability of slopes such as those encountered in gullies depend on the height and gradient of the slope and the shear strength of the soils. There are several methods of calculating the factors of safety of slopes, (Whitflow, 1996); However the Taylor's stability number method was used in this work.

2.8 Prediction Of Erosion Potential

The magnitude of erosion expected in any water shed is usually measured by the amount of soil loss per annum. Although direct field measurement may be used to determine this, time constraint, cost, and the problem of adaptability have minimized the use of this approach. Mathematical models have therefore been developed that can be applied to every situation. Attempts at evolving mathematical models for the prediction of erosion potential began in the early 1930's with Baver (1933) proposing an empirical equation for this purpose.

$$E = \frac{KD}{AP} \quad P^{1}_{i} \qquad \text{--------------------(2.6)}$$

Where E = Soil erosion

K = Constant of proportionality

D = Ease of dispersion

A = Absorption or Soil permeability

P = Size Particle

In 1947, Musgrave proposed a parametric equation that comprised most of the factors affecting soil erosion.

$$A = 0.00527\, KCS^{1.35}\ L^{0.35}\, I_{30}^{\ 1.75} \qquad \text{--------------(2.6)}$$

Where A = Soil erosion (mm/year)

K = Inherent soil erodibility at 10% slope on a slope 22m long in mm/year

C = Vegetation cover factor

S = Slope percentage

L = Slope length

I_{30} = Maximum 30min. rainfall with 2 year frequency.

However, because Musgrave's equation is only applicable to long term average soil loss for broad area, further research had to be done and this led to the development of the universal soil loss equation (USLE) which was later revised and known as the Revised Universal Soil Loss Equation (RUSLE) by the Agricultural Research Service of the United States of America. This equation takes into account the total rainfall energy for a specific catchment's area rather than rainfall amount.

$$A = RKLSCP \qquad \text{-------------------(2.7)}$$

Where A = Amount of soil loss per year

R = Erosivity of Rainfall

K = Soil erodibility

L = Slope length

S = Slope gradient

C = Cropping factor

P = Conservation practice

While some of the elements of the RUSLE may be determined mathematically using standard equation in each case, others have been comprehensively researched and tables and charts have been prepared for use. One such factor that may have to be determined mathematically is the rainfall erosivity R. This is generally determined from the equation

$$R = EI_{30} \qquad \text{-------------------(2.8)}$$

Where E = Total rainfall energy (J)

I_{30} = Intensity of rainfall at 30mins interval mm/hr

Wischmerer & Smith (1987) gave rainfall energy for the tropics as

$$E = 12.1 + 8.9 \log I \qquad \text{------------------(2.9)}$$

Lal (1987) showed that rainfall energy for south western Nigeria is obtained as:-

$$E = 24R_a + 27.6 \text{ or} \qquad \text{------------------(2.10)}$$

Where R_a = total annual rainfall (mm)

$$E = 18.08\, I_{30} + 18.2 \qquad \text{---------------------------(2.11)}$$

However Kinnel et al (1994) showed that in Nigeria, $EI_{7.5}$ is more appropriate because of the frequent rainfalls of high intensities within very short time interval. Because of the difficulties sometimes encountered in obtaining all the rainfall parameters for the determination of the kinetic energy of rainfall, some researchers have developed mathematical equations that relate kinetic energy with rainfall amount

2.8.1 Models for Predicting Gully Growth and Head Advancement

Although there is a strong desire among researchers to develop models that can be used to predict the growth of gullies as accurately as possible this has not met with remarkable success because of some unpredictable situations that arise from time to time during measurement. These include:-

a) The growth of weeds along the gully between periods of measurements and

b) The presence of and change in the position of obstructions along the gully bed and constant change in the depth of gully.

Two of the models that are in use and may be modified to suit any study area are: Gulterm model developed by Stott et al (2001) which is preferably used to predict gully growth at its initial stage and that developed by Beer and Johnson (1963). For gully head cut or head advancement, the model by Thompson (1964) is used.

Gulterm's Model:

$$\frac{dQs}{dX} + \frac{d\,AC}{d\;t} = C_w\,q_w + M_u\,W + UD - C_v \qquad \text{------------(2.12)}$$

$$(1\text{-}E)\,\frac{d\;\;z}{d\;\;t} = C_v - Mt \qquad \text{------------(2.13)}$$

Where X = longitudinal coordinate (m)

T = time in seconds

C = mean volumetric sediment concentration

A = flow cross section area (m2)

C_w = sediment concentration of lateral input

Q_w = specific lateral discharge

M_u = upward sediment flux (m/s)

M_b = sediment flux from the channel banks (m/s)

Z = gully bed elevation (m)

W = flow width (m)

Vf = soils aggregate fall capacity in the turbulent flow (m/s)

E = porosity of the gully bed.

The first term on the left of equation (2.12) defines the sediment budget in the channel, the second term in the sediment storage in the flow. The right part of the equation defines the sediment flux: the first term is lateral flux, the second is upward flux, the third is sediment flux from the bank and the fourth is downward flux.

2.9 Erosion Control: -

The primary objective of any erosion control system is to limit the soil loss to an acceptable level. The various methods of erosion control may be classified into three main categories depending on the location where it is applied (i.e. Urban, Cultivated or Pasture) as Agronomic, Soil Management and Mechanical. The choice and design of erosion control measures is generally governed by the desire to harmonize the control measure adopted with the requirements placed by agricultural production, industrial management, water management, transportation, industrial development, fund and the requirements of other areas of the nations economy. It is to be noted that badly planned erosion control measures can have very damaging impact on the environment (Weidelt, et al., 1976).

In the selection of a suitable erosion control method, its primary objective should be considered i.e. whether it is to protect the bare soil, slow down the rampaging velocity of runoffor diversion of water course as is usually the case practice in urban sites. Ingold and Thompson (1990) observed that the Engineered agronomic method is begining to gain popularity because of the present development in the use of synthetic materials and improved chemical binders which are very suitable for use as root reinforcing mats, synthetic mulches, organic mulches etc. They observed that this process increases the shear strength of the soil and reduces erodibility. This view is corroborated by Collotta et al (1990,] and Kollios (1992) who also observed in their work that the engineered agronomic method of erosion control can be very effective when used on high cut slopes and soils of the types of marls. However for reasons of convenience and aesthetic, the integrated engineering-approach (mechanical) which involves primarily the use of civil engineering works such as Bench Terraces, water spreaders, check dams, retaining walls, drain channels, revetment are most often used particularly in the case of gully erosion. Okagbue (1986) however noted that the success of any method of erosion control adopted depends on the local geologic setting, geotechnical properties of the soil and their response to varying hydrological conditions, intensity of precipitation and run off in the locality and the rate of erosion.

CHAPTER THREE

MATERIALS AND METHODS

The parameters required for the research work were obtained from relevant government agencies, fieldwork and laboratory experiments.

3.1 Data Collection

Apart from the rainfall data that were obtained from Ekiti State Ministry of Agriculture, other data that were collected from both the field and laboratory include the following:

(i) Location, dimensions, annual change in dimension, and side slope of the gullies.

(ii) Drainage area and slope of each of gully.

(iii) Soil properties of eroding layer of each gully.

3.2 Location of study area and gullies

Efon-Alaaye the study area falls within latitudes 7^0 30' and 7^0 46' N and longitudes 4^0 55' and 5^0 0' E of the equator. **(Figs 3.1 & 3.2)** About 60% of the total land area is low land surrounded by high lands whose height range from about 2250 to 2280m above mean sea level.

The study involved identification of the main types of erosion and gully sites, collection of rainfall data and soil samples from eroding layers of the gully sites for laboratory analysis. Social factors enhancing the generation of erosion and existing control measures were also reviewed.

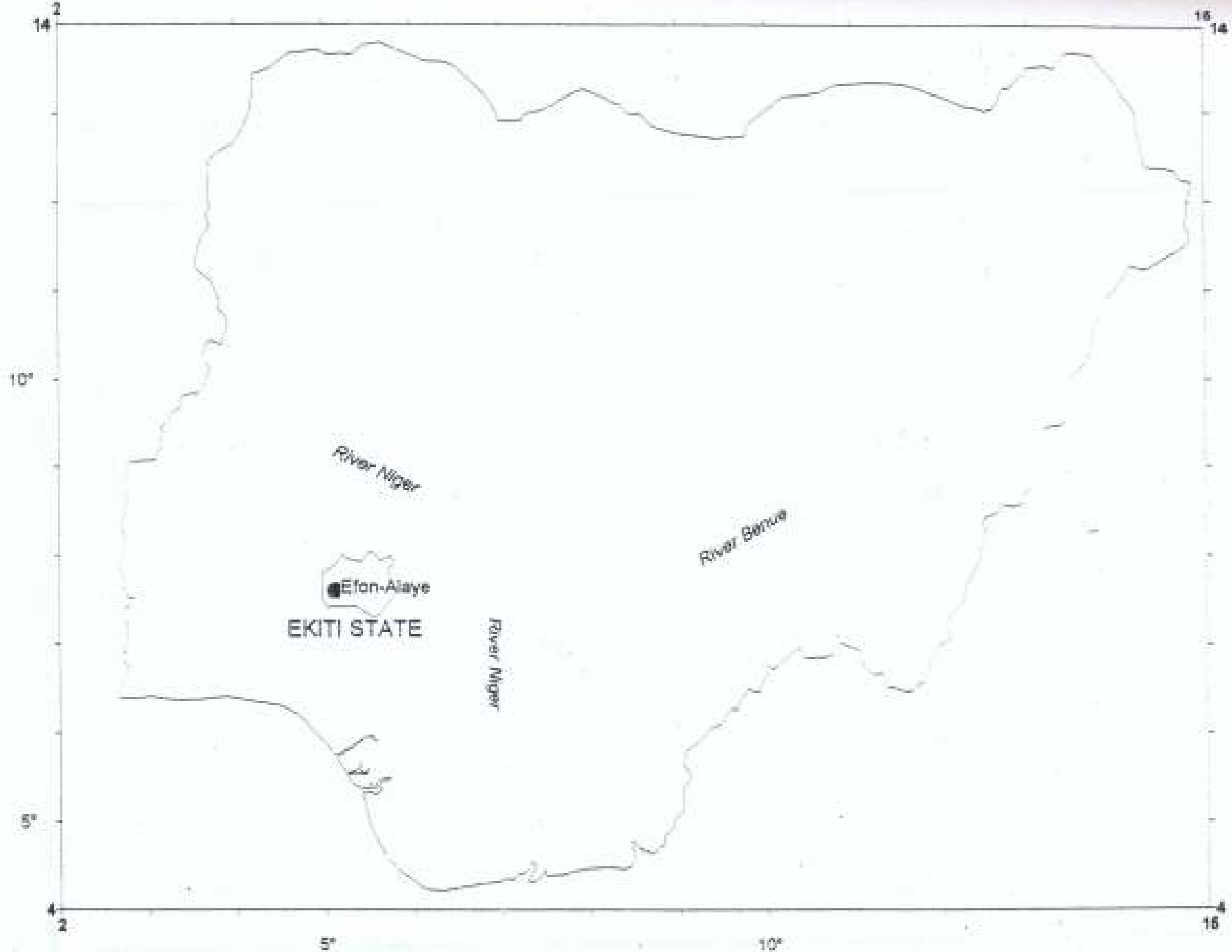


Fig.3·1 :Map showing study area (Efon-Alaye in Ekiti)

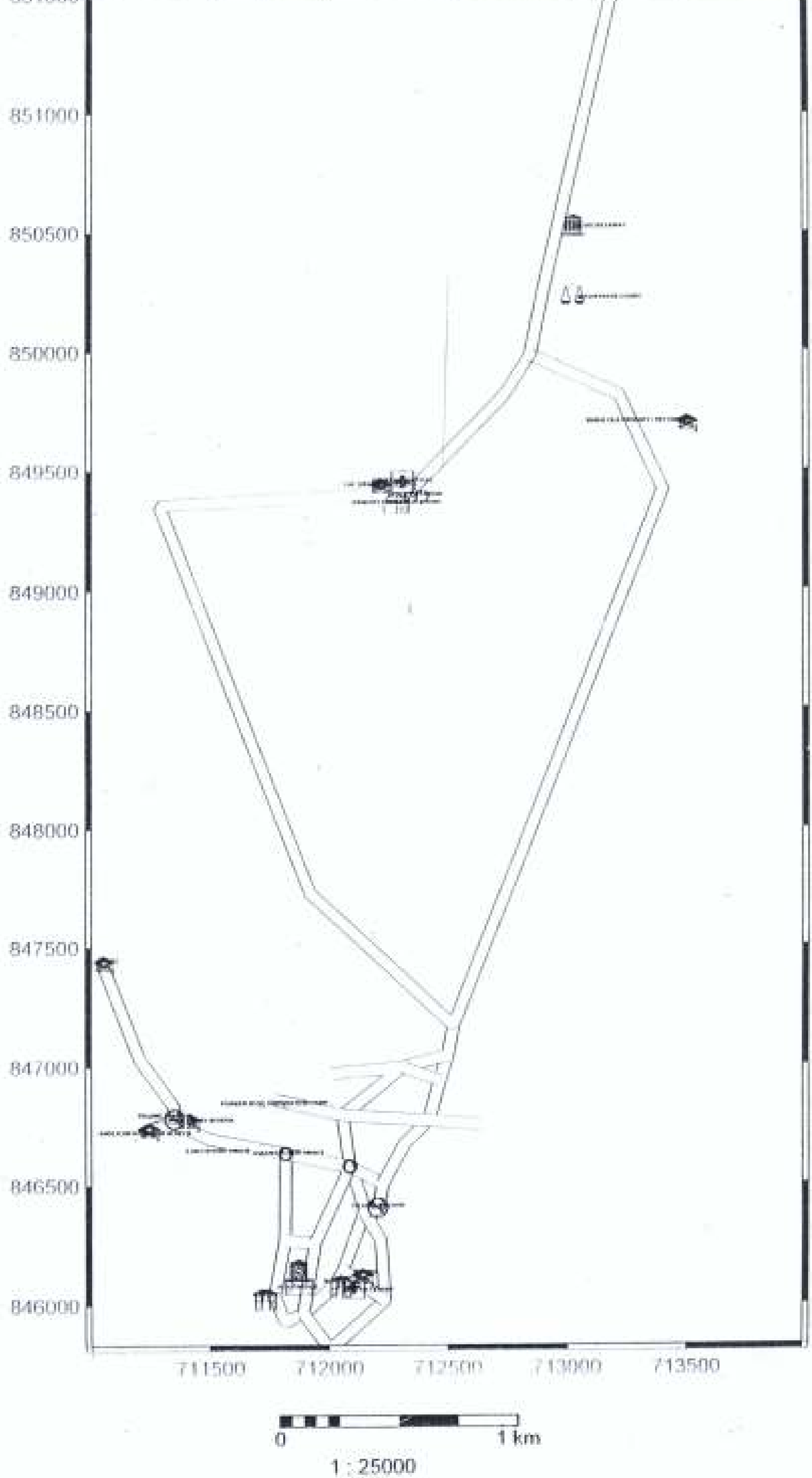


Fig.3-2: Map of Efon Alaye Township

3.2.1b Ibete

Although having a total length of 105m, only about 36m is exposed to erosion with the remaining being overgrown by weeds before joining the upstream end

of River Oni. The width of the gully varies from 0.6m to 2.5m at the base and between 3.1m at its head to a maximum of 8.0m at the top. Its depth varies from2.0m to a maximum of 3.5m.

3.2.1c Igbo-Egun

This gully has a total length of about 200m with only about 34m of this length experiencing abnormal growth. Its width varies from 1.8m to about 3m at the base and between 7.5m at the head to a maximum of 10.5 mid-length. Its depth vary from 8.0m to a little over 10.5m within the area experiencing growth.

The remainder of the gully is located in thicket with no human activity around the area. This has resulted in the gully side being overgrown with vegetation thus slowing down its rate of growth.

3.2.1d Isaja

Although there are two gullies located within this area i.e. Isaja 1&2. Isaja 2 is chosen for the research since Isaja1although larger in all respects. has become completely vegetated possibly because of the complete absence of human activity around the gully and has stopped growing. Isaja 2 measures 60m in length, its base width varying between 0.3m and 1.5m while its top width varies between 1.5 and 3.2m. Its depth varies between 0.9m and 2.8m (See Fig. 3.3 and Plates 1 & 2).

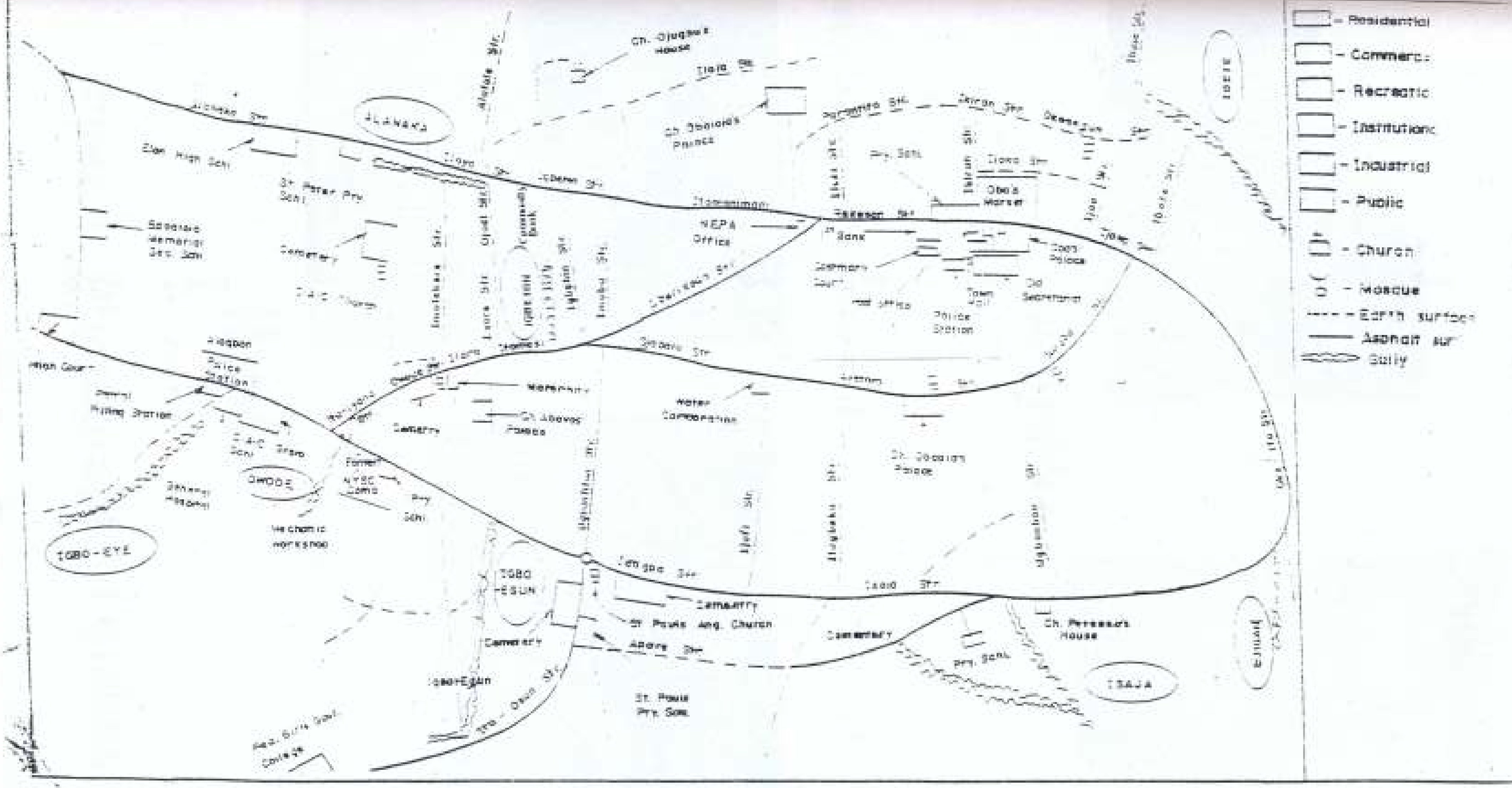


Fig. 3.3 MAP SHOWING EFON-ALAAYE WITH GULLY LOCATIONS

Alanaka

Ibete

Plate 1: Photograph of gullies

Igbo-Egun

Isaja

Plate 2: Photograph of gullies

3.2.2 Determination of Area of Surface Growth and Head Advancement of Gullies

In order to determine the magnitude of growth and head advancement per year the dimensions of length, breadth and depth of each of the gullies were taken at 0.5m intervals vertically downward (in the direction of depth) except for upper Igbo-Egun, which was taken at 1.0 interval, and at 2.0m intervals horizontally along the length of the gully. These measurements were taken at the end 2000, 2001 and 2002 rainy seasons respectively. The change in with over the entire depth was then used as ordinates for calculating the total area for each year (Appendix B). Similarly the distance over which the head of the gully advanced each year was measured over successive years.

3.2.3 Determination of Catchments Properties (Landform)

In order to determine the drainage area above the gully head, the slope of the approach channel, the distance from the gully head to the watershed divide, the drainage area of each of the gullies was surveyed using a global positioning system (GPS) equipment. The data obtained are presented as contour maps in the form of digital elevation models (D.E.M.)

3.2.4 Experimental Procedure (Determination of Soil Properties)

A total of 12 samples of soil with 3 from each of the eroding layer of the gullies were obtained both in the disturbed and undisturbed states.

The laboratory experiments carried out on the samples include:

i. Natural moisture content

ii. Particle size analysis (Sieve & Hydrometer)

iii. Consistency limits

iv. Permeability

v. Triaxial Compression

vi. Organic content

All the laboratory test were conducted according to B.S. 1377 (1987), Method of Testing Soil for Engineering Purposes.

3.3 Data Analysis

The various data gathered were analysed and in some cases, equations were used.

3.3.1 Determination of Area of Growth

With the average change in width measured at 0.5m intervals vertically along the direction of the depth as ordinate, the total area of growth was calculated using the trapezoidal rule:

$$A = h[0.5(y_1 + y_n) + (y_2 + y_3 + \dots y_{n-1})] \text{-------------} (3.1)$$

Where A = Area of strip (m^2)

h = Distance between successive ordinates (2m)

y = Height of ordinate(m) i.e. average change in width at 0.5m interval measured vertically downward.

3.3.2 Determination of Stability Characteristics

To assess the stability of the slopes of the sides of the gullies and its possible contribution to their growth, the height in excess (He) of the critical height (Hc) and the factor of safety of each of the gullies were determined using Taylor's stability number method. In order to achieve this, the depth of the gullies and the slope of their sides were measured.

$$H_c = \frac{C_u N_s}{\gamma} \qquad \text{--------------(3.2)}$$

$$H_e = H_{av} - H_c$$

where H_c = critical height (m)

C_u = Cohesion of soil (kN/m^2)

H_{av} = average ht of gully(m)

N = Stability factor taken as 5.2 since depth of bedrock is unknown but reasonable.

H_e = height in excess of H_c (m)

Using Taylor's stability number method the average factor of safety for each of the gullies was determined as follows.

$$F = \frac{Cu}{NH\gamma} \qquad \text{----------(3.3)}$$

Where Cu = Apparent cohesion (KN/m^2)

N = Stability number related to side slope (angle of shearing resistance, details in appendix A)

γ = Unit weight of soil (KN/m^3)

H = Vertical height of slope (m)

3.3.3 Surface Growth

Using Beer & Johnson's model of growth as a basis, the coefficient of surface growth for the study area may be obtained as follows.

$$G_A = KR^{0.0982} \quad L_g^{0.7954} \quad L_w^{-0.2473} \, e^{-0.0014p} \quad \text{------------(3.4)}$$

Where G_A = Total Surface Growth (m^2)

K_a = Coefficient of annual surface growth which generally depends on local conditions.

L_g = Length of Gully (m)

L_w = Distance from Gully head to water shed divide (m)

e = Base of natural log

P = Deviation of precipitation from normal which may be taken as Average Precipitation in 'm' (Chow 1964).

3.3.4 Head Advancement

Using Thompson's model of head advancement as a basis, the coefficient of annual head advancement for their study area is developed as follows.

$$G_h = KA^{0.99} S^{0.14} R^{0.74} CL \quad \text{----------------(3.5)}$$

Where G_h = Gully head advancement per year (m)

K_h = Coefficient of head advancement which depends on local condition.

A = Area of catchments above gully head advancement (m^2)

S = Slope of approach channels in degrees

R = Sum of total rainfall equal to or exceeding 12.7mm for the period under consideration. (m)

CL = Clay content of eroding profile in %

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Rainfall

The rainfall record in the area over the past 10 years (1993 to 2002) shows an annual value ranging from 970.1mm to 1743.8mm with the minimum occurring in 1994 and the maximum occurring in 1996 (Table 4.1). The actual values of rainfall for years 2001 and 2002, that were used for the study work are 1183.1mm and 1479.6mm respectively. The rainfall intensity obtained from the duration-frequency curve shows intensities of 240mm/hr and 80mm/hr for 7.5 min. and 30 min. duration respectively considering a return period of 2 years (Fig. 4.1)

The mean annual rainfall of 1481.1mm for the past ten years and intensity of 270mm/hr are considered. Rainfall of this magnitude and intensity possess very large drop diameter (up to 4mm), high drop density (i.e. number/m^2/s) and high drop terminal velocity. Generally, rainfall possessing these characteristics are very erosive since they are known to have very high kinetic energy and hence dislodgement and entrainment capacity of soil particles. They also have very high shearing stresses and thus are capable of creating rills and gullies speedily.

It is little wonder therefore, that the study area experiences the three main types of gullies caused by rainfall possessing these properties i.e. surface wash, which is evidenced by failed highways and exposed foundation bases.

rills criss-crossing almost every open space and gullies that are growing every day. Also noticed was the regular siltation of culverts and watercourses in the study area, which evidently is the result of settling and the transporting of dislodged soil particles into them.

Table 4.1 Summary of Rainfall Data

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total Rainfall (mm)	1258	970.1	1441.3	1743.8	1420.4	1378.6	1427.4	1183.1	1384.3	1258.5
Average annual rainfall (P)mm									1356.22	1340.45
Sum of total rainfall									1017	1001
Rainfall index (R)									1190.5	1082.3

(Ekiti State Environmental Protection Agency's Ecological Report on Efon Alaaye, 2002)

Note: Average annual rainfall, sum of total rainfall and rainfall index(R) are not required for 1993 –2000, since the study period covers 2001and 2002

4.2 Gully And Catchments Properties

The total lengths of the gullies vary from a minimum of 60m for Isaja to a maximum of 350m for Igbo Egun. The maximum top widths of the gullies vary from a minimum of 6.0m for Isaja to a maximum of 10.5m at Igbo-Egun upper.

Similarly the maximum depth of 10.5m was observed at upper Igbo-Egun with the depth of other gullies ranging between 1.5m and 5.0m. The drainage areas of the gullies vary from a minimum of 7.5 ha for Ibete to a maximum of 83.2 ha for Isaja.

Also the distance from watershed divide to gully head vary from 75m for Igbo-Egun upper to a maximum of 150m for Isaja. The gullies are located within the densely built up area of the town and as a result most of the precipitation end up as runoff into the gullies. Noteworthy is the fact that the town is not only surrounded by high lands but the area draining into the gullies are relatively steep varying from a minimum of 9.6% for Alanaka to a maximum of 17.1% for Igbo-egun. (Table 4.2 & Fig 4.2 to 4.5). This situation no doubt may not only reduce the permeability potential of the soil but also increase the velocity of the runoff and hence increase its shearing stress. It is also pertinent to note that the gullies are of considerable depth with the height in excess of the critical height varying from a value of 0.24m for Ibete to a maximum of 5.75m for Igbo Egun and the side slopes vary from a minimum of 55° for Isaja to 83° for Igbo-egun. (Fig. 4.6 & 4.9).

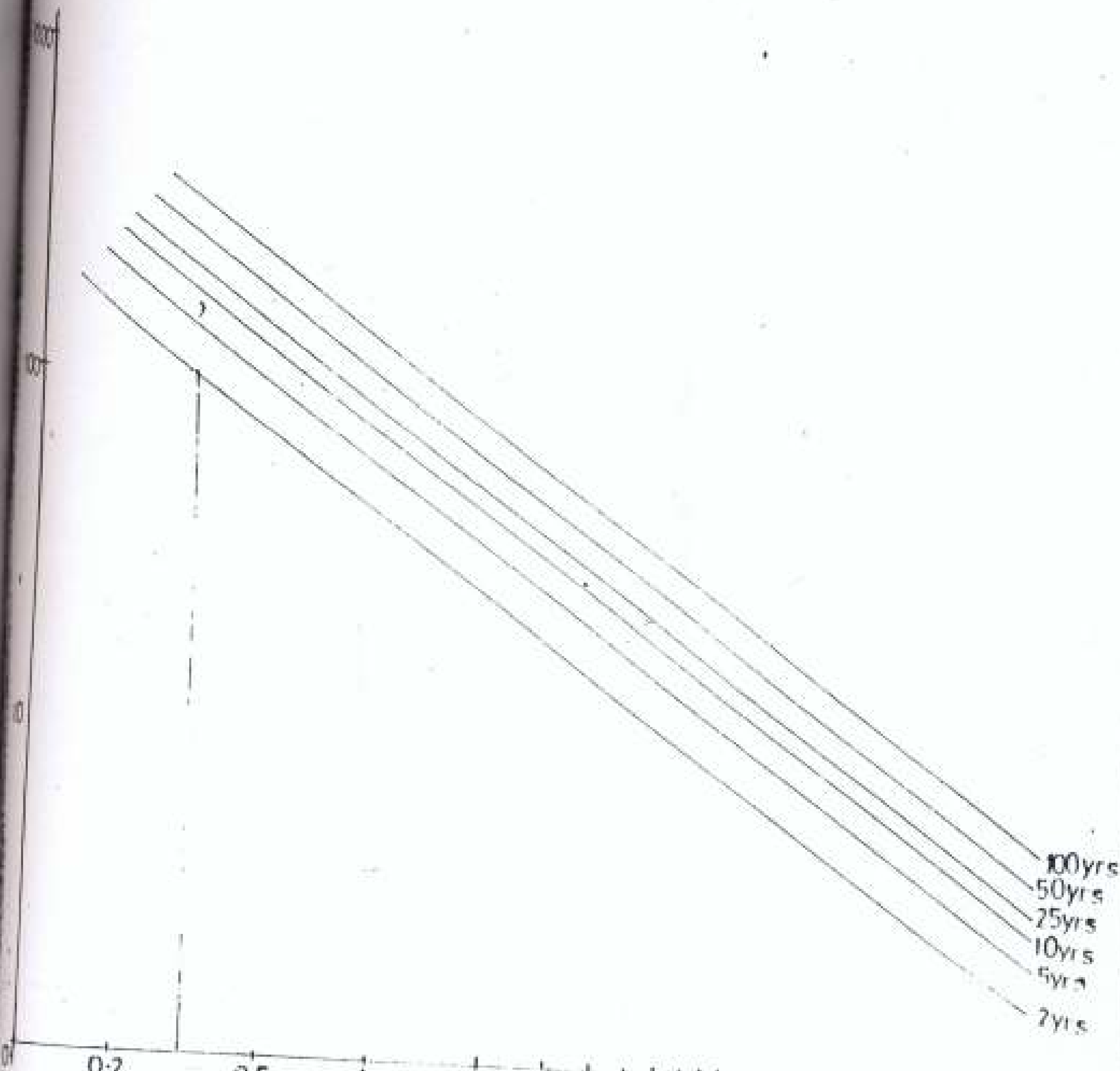


Fig.4·1·RAINFALL INTENSITY DURATION FREQUENCY CURVES FOR EFON-ALAYE.

The likely consequence of these is that the gullies are relatively unstable. This is confirmed by the low factor of safety observed for the gullies with maximum being 1.67 for Ibete and the minimum of 0.53 being recorded at Igbo-egun (Table 4.2).

Table 4.2: Summary of Landform and Stability Characteristics of Gullies

Year	2000/2001				2001/2002			
Gully	Alanaka	Ibete	Igbo-Egun	Isaja	Alanaka	Ibete	Igbo-Egun	Isaja
Length (m)	151.4	36.0	34	60	150.52	36.38	60.0	60.0
Length from gully head to water shed divide (m)	462.5	226.7	1150	316.5	462	226.7	454.2	249.69
Length of Head Advancement	0.52	0.28	0.61	0.22	0.32	0.21	0.45	0.26
Width of catchments (m)	400	283.3	450	267	400	283	450	267
Area of catchments (m^2)	186,200	75556.1	315000	832,105.5	186,199.25	75555.72	314,977.865	832,105.25
Slope of catchments %	9.6	13.6	17.2	15	9	13.6	17.1	5
Area of gully growth (m^2)	10.8742	2.866	5.488	3.67825	8.27605	2.2305	6.747	3.19045

Gully	Alanaka	Ibete	Igbo-Egun	Isaja
Critical height H_c (m)	2.48	3.51	2.75	1.44
H_{AV}	2.86	3.26	8.50	2.7
H_e	0.38	-.35	5.75	1.23
Av F.S	1.22	1.67	0.53	1.31

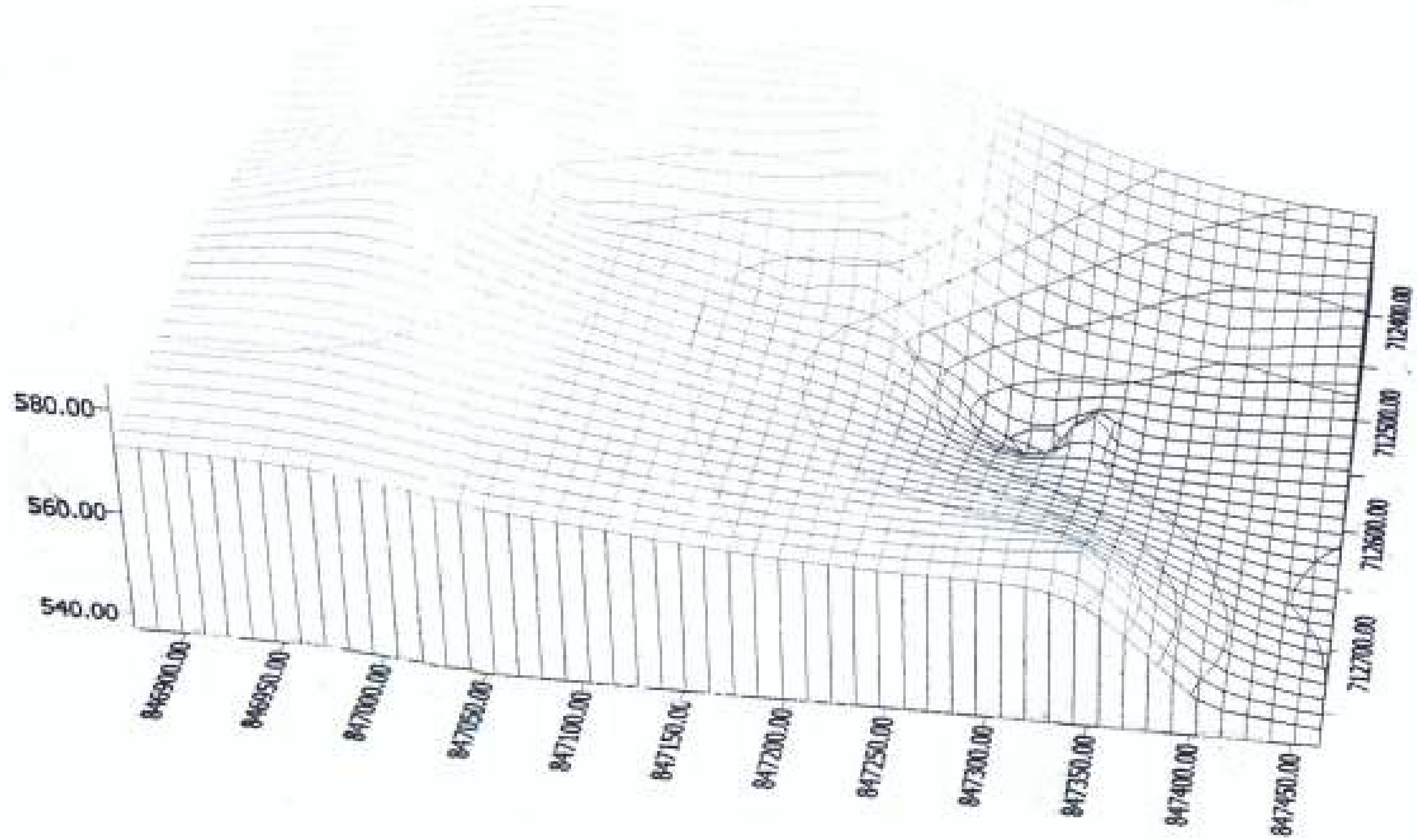


Fig. 4-2: Digital Elevation Model (DEM) of Alanaka area

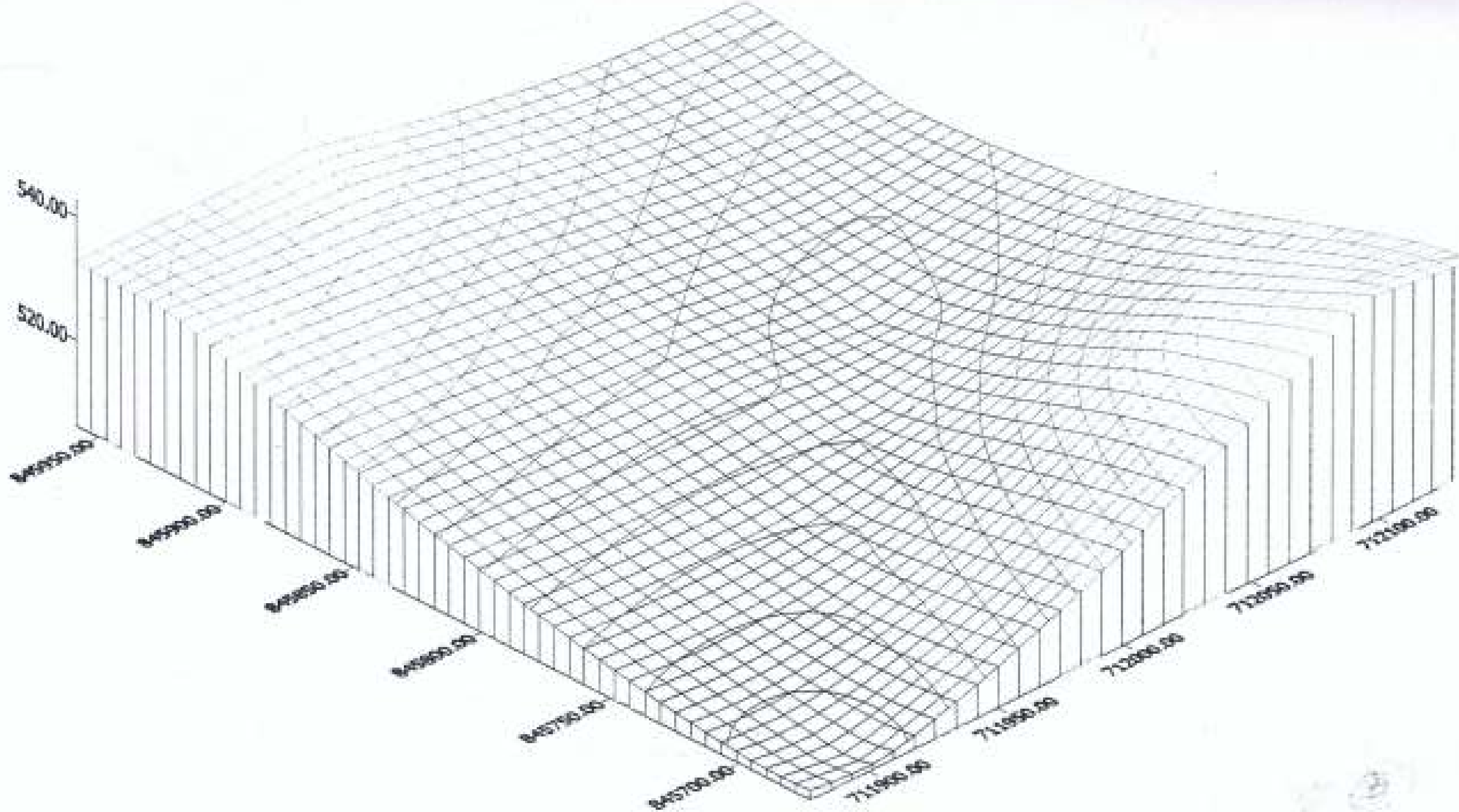


Fig. 4·3: Digital Elevation Model (DEM) of Ibete area

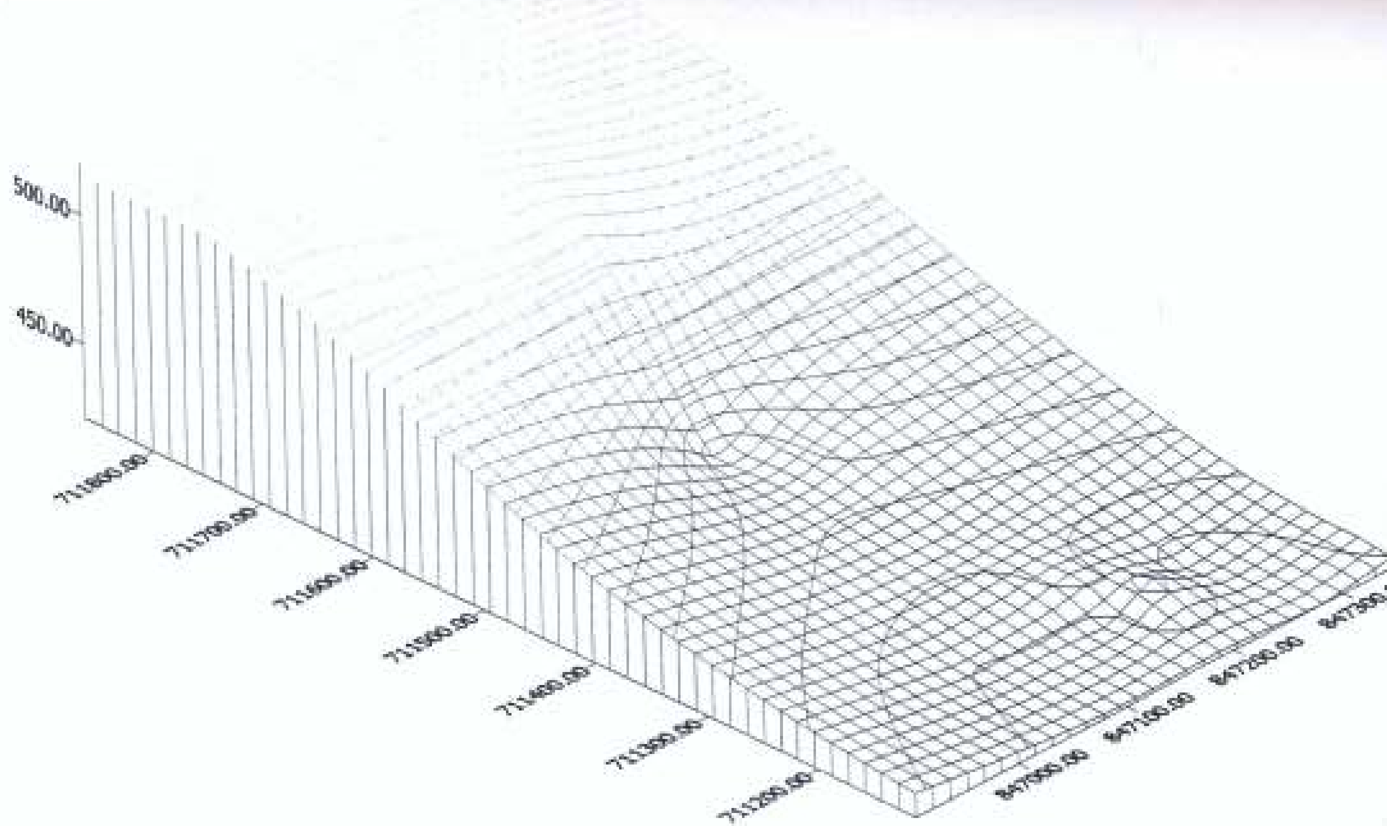


Fig. 4·4; Digital Elevation Model (DEM) of Igbo-Egun area

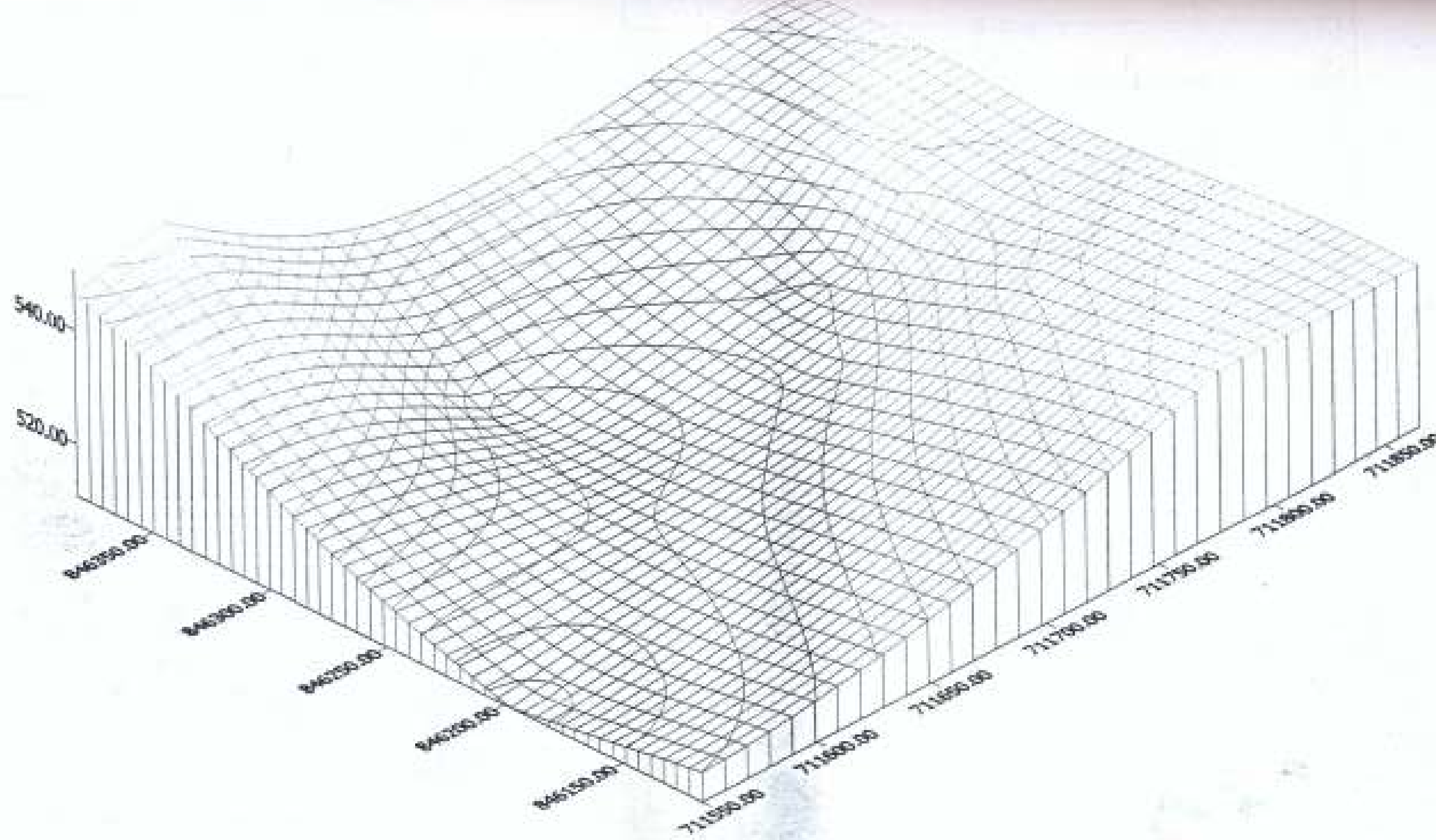


Fig. 4.5. Digital Elevation Model (DEM) of Isaja area

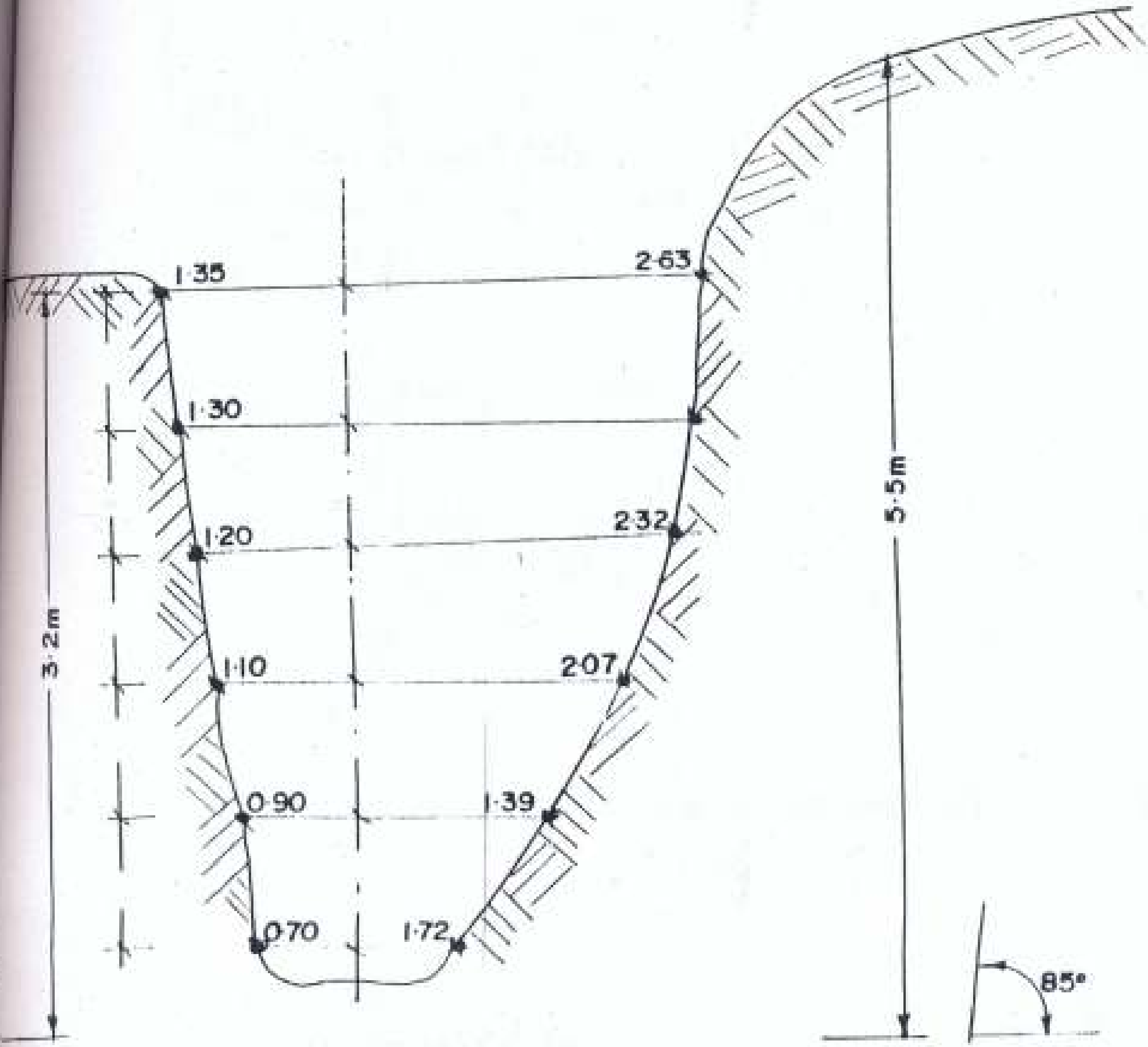


Fig.4·6: TYPICAL SECTION OF ALANAKA GULLY
Scale :- 1:50

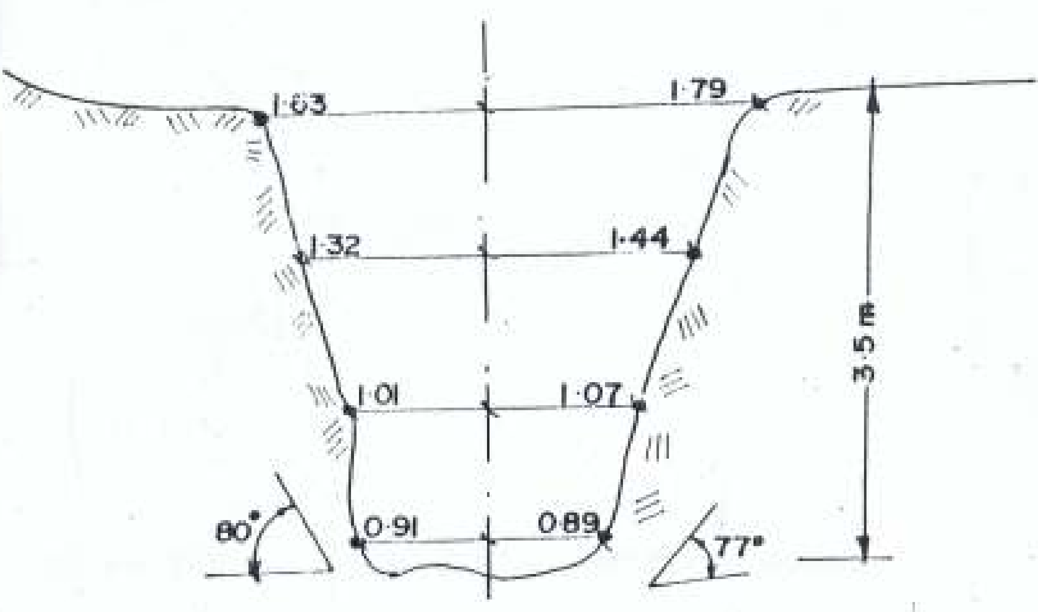


Fig 4·7: TYPICAL SECTION OF IBETE GULLY

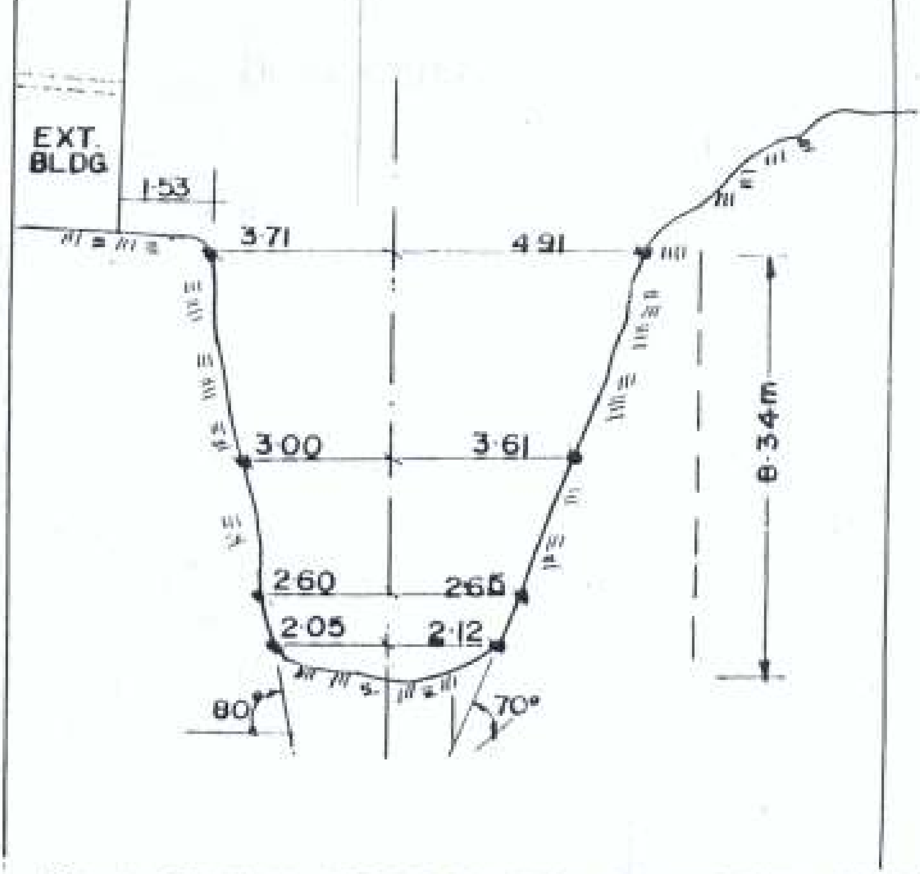


Fig. 4·8: TYPICAL CROSS SECTION OF IGBO EGUN GULLY

Scale :- 1 : 100

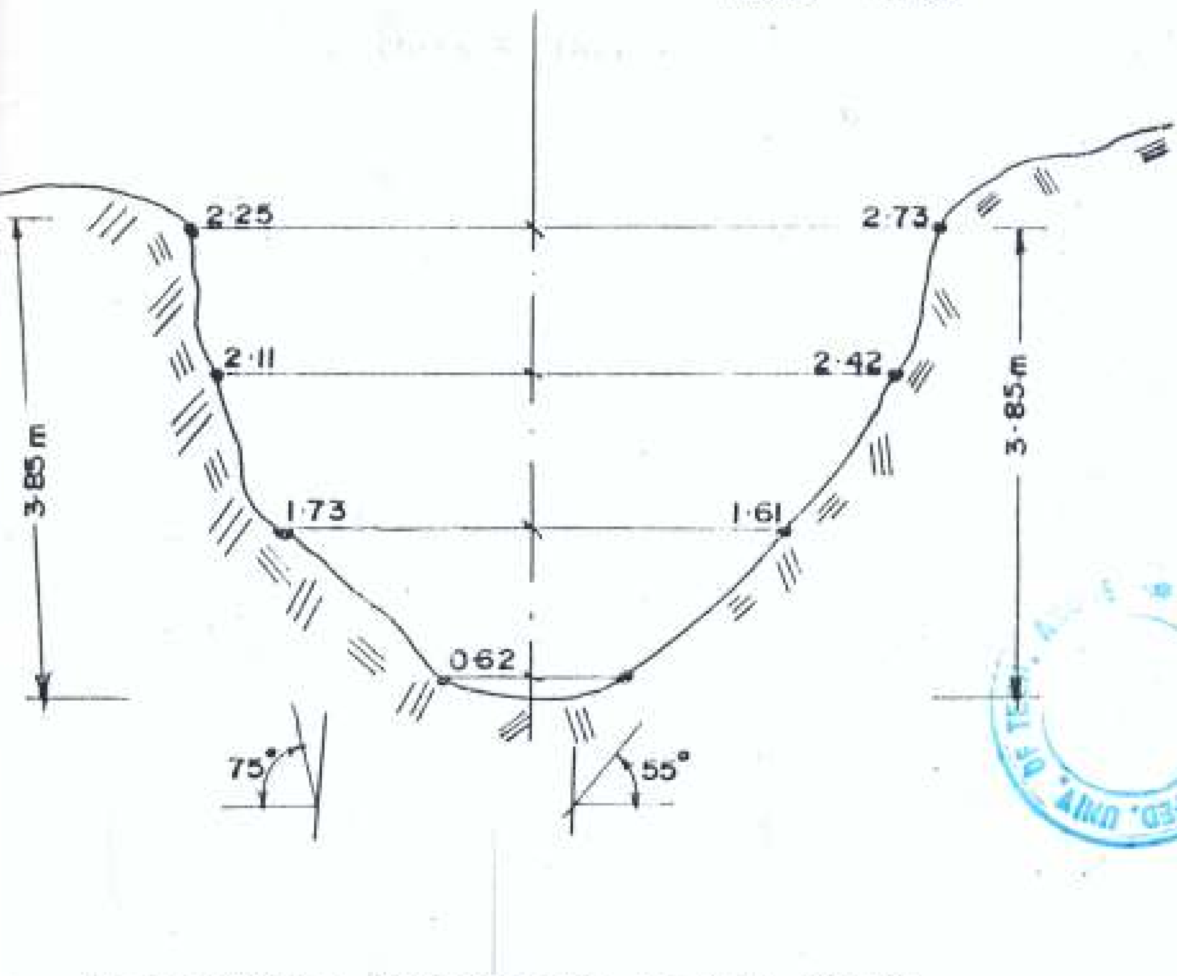


Fig. 4·9: TYPICAL CROSS SECTION OF ISAJA GULLY

Scale :- 1 : 50

4.2.1 Soil Properties

The soils of the study area show very high sand content with the percentage of sand varying from a minimum of 64 at Ibete to a maximum of 78 at Igbo-egun. It could also be observed that a very large quantity of the sample fall within 0.06mm - 1.0mm range of particle size considered being most erodible. The results also show that the soils have very low clay and organic carbon content with maximum clay content of 6.4% being recorded at Ibete and the minimum value of 2.9% at Igbo-egun. On the other hand, all the soils showed a relatively uniform value of organic carbon content, falling within 0.3% (Table 4.3, see Appendix C:).

The low values of clay and organic carbon content of the soils in the area may have contributed to high erodibility of the soils in the area as the near absence of these two properties result in the soils lacking cohesion and hence are loose making then easy to dislodge and entrain. This assertion is further confirmed by the low value of the cohesion of the soils with the minimum value of $6KN/m^2$ for Isaja and a maximum of $12KN/m^2$ for Ibete (Appendix C). Worthy of note too, is the low plasticity index of the soil as revealed by the results of the consistency limits (Table 4.3 and AppendixC). All of these confirm the low clay content of the soils. Although this has the potential to increase the permeability coefficient of the soils and hence increase its infiltration capacity, the steep slopes, coupled with near absence of these cohesive properties have made the soils more erodible.

4.3 Stability Characteristics of Gullies

All the gullies showed relatively low values of stability with the average stability factor ranging from a minimum of 0.53 for Igbo-Egun to a maximum of 1.67 for Ibete. The very low stability factor 'F' of Igbo-Egun gully makes it the most unstable gully. This is evidenced by its higher excess height. It is little wonder and relatively high rate of growth.

4.4 Development of Model for Gully Growth

The average values of the coefficient of growth K obtained for most of the gullies ranged between 0.4 and 0.7 except Igbo-Egun, which gave a value as high as 2.5. This is to be expected because of the considerable depth of the gully and its steep slope resulting in run-off of high velocity into the gully. This value not withstanding, it may still be relatively safe to adopt an average K_a value of 0.5592. The model for the area based on equation 18 becomes:

$$G_A = 0.5592R^{0.0982} L_g^{0.7981} L_w^{0.2473} e^{-0.0114p} \quad \text{-----------------(4.1)}$$

However in the case of the model for the head advancement, the study showed that apart from gully 4 (Isaja) whose average K_h value was at variance with the rest, all others fell within reasonable limits that would permit the use of an average value.

$$G_h = 8.00 \times 10^{-5} A^{0.99} S^{0.14} R^{0.74} CI \quad \text{-----------------------------(4.2)}$$

4.5 Simple Method Of Control

Although the use of civil engineering works would be preferable to arrest the abnormal growth of the Gullies particularly the ones at Alanaka and Igbo-Egun, the cost of such civil engineering works is such that it would be too much for the state government alone to bear.

In order to minimize the rate of growth and its attendant damage, the sides of the gullies should be vegetated as a temporary measure until funds are available for actual and lasting control measures.

Similarly deep reinforced concrete ground beams with boulders placed to a distance of about 5 meters beyond the heads of each of the gullies would serve to check current problem of head advancement.

4.6 Models Application

Using Alanka and Isaja as case studies for surface growth and Ibete and Igbo-Egun for head advancement the validity of the two are verified below:

(a) Surface Growth

$$G_A = 0.5592R^{0.0982} L_g^{0.7981} L_w^{0.2473} e^{-0.0111}p \quad \text{-----------------(4.1)}$$

(i) Alanaka

<u>Data</u>

K=0.559

R=1.1905

L_g=150

L_w=469.5

P=1.3562

$G_A = 0.559 \times 1.1905^{0.0982} \times 150^{0.7994} \times 462^{-0.2473} \times e^{-0.0014} \times 1.3562 = 7.623m^2$

(ii) Isaja

<u>Data</u>

$K_A = 0.559$

$R = 1.0825$

$L_E = 60.22$

$L_{SC} = 315.28$

$P = 1.3405$

$G_A = 0.559 \times 60.22^{0.7994} \times 315^{-0.2473} \times e^{-0.0014} \times 1.3405 = 4.73m^2$

(b) Head advancement

$G_h = 8.00 \times 10^{-5} A^{0.99} S^{0.11} R^{0.71} CL$ ---------------------(4.2)

Ibete

$K_H = 8 \times 10^{-5}$

$A = 75556.1m^2$

$S = 13.6\%$

$R = 1.017m$

$CL = 6.3\%$

$G_H = 8 \times 10^{-5} \times 75556.1^{0.99} \times 0.136^{0.11} X 1.017^{0.71} \times 0.063 = 0.26m$

Igbo-Egun

$K_H = 8 \times 10^{-5}$

$A = 31500m^2$

$S = 17.1\%$

$R = 1.017m$

$CL = 2.9\%$

$$G_H = 8 \times 10^{-5} \times 31500^{0.99} \times 0.171^{0.14} \times 1.017^{0.74} \times 0.29 = 0.51m$$

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Soil erosion problem at Efon Alaaye was examined. The study showed that three main types of erosion are prevalent in the area:-these are, Sheet wash, Rill and Gully with gully erosion being the most precarious.

Four gullies i.e. Alanaka, Ibete, Igbo-Egun and Isaja that were observed to be most active were selected for the study. The gully properties i.e. dimensions, catchment's, properties and soil properties were all measured. The result of the study showed that the area is erosion prone. Erosion and development of gullies in the study area may be attributed to:

1. Rainfall of very high intensity with average annual rainfall of up to 1471mm and intensity of up to 80mm for 30min duration
2. Steep slopes resulting in large run-off.
3. Soil with large percentage of erodible particle size fractions, low organic carbon and clay content and relatively low shear strength.
4. Great depths of some of the gullies, which make them unstable and as a result have very low factor of safety.

Using Beer & Johnson's model for prediction of annual surface growth and Thompson's model for the prediction of annual head advancement as a basis, the coefficient of annual surface K_a of 0.5592 and coefficient of annual head advancement K_h of 8 x 10^{3} were obtained thus providing models for the prediction of annual surface growth and head advancement for Efon- Alaaye. The validation of the models shows that they are relatively accurate and hence can be used to predict the rate of gully growth and head advancement for the study area.

5.2 Recommendation For Further Work

This work has provided adequate information on the erosion situation in Efon-Alaaye. However, constraint of time did nor allow the study to examine the effect of situations such as: change in the position of obstacles along the gully bed; growth of vegetation at the sides of the gullies at intervals and; soil loss due to sheet wash will have on the rate of growth of the gullies. It is therefore recommended that further work should be done in this area in other to achieve a more comprehensive model.

REFERENCES

Abam, T.K.S (1984): Erosion of Ekole creek River Bank and the suitability of the remedial structure Unpublished M.Sc. Thesis. Dept. of Geology, University of Nig. Nsukka.

Aikhoimu, M (1991): Erosion Activities of Okitipupa *Township BSc* project report Fed. Uni. of Tech. Akure.

Alayande, W.A and Bamigboye, O.A (1994) Erosion Cause, Damages and prevention: Kogi and Kwara States case studies. A paper presented at the 2nd Biennial UNESCO- IHP hydrology symposium at the National Water Resources Institute, Kaduna Nigeria.

Ashis K.D. Tadanori K. and Tetsuro T. (2000) Numerical Simulation for the Development of gully head cut http://www.kfki.baw.de/conferences /ICHE/2000-seoul/pdf/1/PAP_044.PDP.

Ayer, D.D and Perumpal, J.V (1982) Moisture and Density effect on cone index Transaction of ASAE 25 (5) 1169-1172.

Baver, L.D (1933): Rainfall characteristics of Missouri in relation to erosion. Soil Sc. Soc. Am. 2, 233-236.

Beer, C.E and Johnson, H.P (1963) Factors in gully growth in the deep losse area of Western Iowa. Trans. ASAE 6:237-240.

Bishop, A and Morgestein, N (1960) "Stability coefficient for earth slopes" Geotech 10:129-150

Bobenzer, G.D and Jones, A.B (Jnr) (1971): "Size and impact velocity effects on the detachment of soil under simulated rainfall" Transactions of ASAE 14: 625-628.

Bolanjo, E.R (1998): Hydrogeological Implications of Gully Erosion in the Angulu-Nanka Lake Area of Anambra State. Unpublished MSc Thesis Nnamdi Azikiwe Univ. Awka.

Bonnet, M Gilimour, D.A and Sinclair, D.F (1981): "Soil Hydraulic Properties and Their effects on surface and subsurface water transfer in a tropic rainforest catchment", Hydrol Sciences Bulletin 26 (13) 1-18.

BORDA (1983): "The menace of erosion and flood in Ondo State" Report of Committee on Erosion and flood control unit. Benin Owena River Basin Dev. Authority.

Bouyoucos, G.J (1936): "The clay Ratio as a criterion of susceptibility of soils to erosion". J.Am so Sc 27:738-742.

Bryan, R.B (1976): Considerations on soil erosivity indices and sheet wash".

Calena 3 (1) 99-111

BS 1377 (1975): Methods of test for Soils for Civil Engineering Purposes, British Standards Institutions, London.

Ceasar, M, Steven, R and Jones, F.R (1983): " Head wall influence on scour at culvert outlets". Jour. Hydr Div ASCE Vol 1007.

Carter, J (1958): " Erosion and sedimentation from aerial photograph – a micro study".

Nigeria Jour of Geo 11: 100-106

Chow, V.T (1964): Hand Book of applied Hydrology McGraw Hill New York.

Collins J. (2004): What you can do to control erosion and protect your property. Http//www.search.gov.ca.

Collotta, T. (1990) "Composite erosion control system for an high cut slope. Jour Geot Geom and related production tech. Den Heedt ed.pp381-384.

De-Ploey, J (1972): A Quantitative comparison between rainfall erosion capacity in tropical and a middle latitude region Geogr. Pol. 23

Dictionary of Geological terms (1962): American Geological institute, Doubleday and Coy Inc, Garden city, New York.

Duley, F.L and Hays, O.E (1932): "The effects of the degree of slope on run-off and soil erosion". Jour. Agric Res. 45 (6) 349-355.

Egboka, B.C.T and Okpoko, E.I. (1984): "Gully Erosion in the Agulu Nanka region of Anambra State Nigeria" – it's challenges. Proceedings of Conference on African Hydrology and Water Resources.

Elliot, W.C, J.I Olivieri, Lafon, J.M and Kohl, K.D (1990): Predicting soil erodibility from soil strength measurements ASAE Paper No 90-2009

Esiola. R.P (1966): Stability of soil aggregates treated with distillery black strap molasses J. Agric U.P.R. 50: 174-185.

Farmer. E.E (1973): Relative detachability of soil particles by simulated rainfall. Soil Science Society. AM Proc 37. 629-633.

Floyd. B (1965): Soil erosion and deterioration in Eastern Nig. Nig Geographical Journal 8 (1) 38-43.

Foster. G.R and Lane. L.J (1987): USDA Water Erosion Prediction Project (WEPP) NISERI. Report I.I. Agric Research Services in: nation Soil Erosion Research Laboratory.

Franti. T.G and Wason. D.A (1985): Soil erodibility and critical shear index in concentrated flow. ASAE paper No 85-2033.

Fubara. M.J (1986): Flood and Erosion contribution and remedial Erosion mental policy.Public service lecture Anambra State Government Enugu..

Fubara. M.J (1988): The menace of flood and environmental disaster combat plan Proc Ecological Disaster in Nig Erosion Pg 11-23.

Ghatol. S.G and Malewar. G.U (1978): Vertical distribution of Nitrogen and Phosphorus in relation to organic carbon in profiles of main campus parbhanic.Res. Bull marathurada Agric unit 2 (3) 30-33.

Grissinger. E.H (1965): Resistance of selected clay system to erosion by water. Water Resources Res. 2:131-138.

Hanson, G.J (1966): Erosion resistance of compacted soils. TBB Transportation. Research Record No. 1369: 26-30.

Holy, M (1980): Erosion and environment Pergamon press New Wales.

Hughes, A.O., Prosser,I.P.,Stevenson,J.,Scott,A.,Lu,H.,Gallant,J.,and C. Moran. (2001): Gully erosion mapping for the national land and Water resources audit. http//www.clw.csiro.au/publication /technical2001 /tr26-01pdf>.

Ingold, T.S & Thompson, J.L (1990): A design approach for performed erosion control systems Journal of Geotextiles, Geomembranes and Related products Den Hoedt e.d pp. 375-380.

Jegede, G and Oguntuase, A.M (2000): An Investigation of erosion induced pavement failures along the F209 Highway at Itaogbolu, South Western Nigeria. FUTAJEET, Vol 2.1 pp 30-34.

Kinnel, P.I.A, Mc Gregor, K.C and Resevelt, C.J (1994): The IxE_A index as an alternative to the EI_{30} Erosivity Index. Trans of ASAE 37 (5) 1449-1456.

Kollios, A. (1992): Geotextile creep bahaviour in reinforced slopes. Bulletin of public works research centre No 3-4 (5).

Kowal, J.M & Kassim, A.H (1976): Energy load and instantaneous intensity of Rainstorms at Sumaru, Northern Nig. Tropical Agriculture 53:185-189.

Krammes, J.S. & Osbrone, J. (1969): Water repellent soils and wetting agents on factors influencing erosion. Proc Symp on water repellent soils, Univ of Calofornia. River side Pp 177-178.

Lal. R. (1987): Soil degradation in relation to climate. Paper delivered at International symposium on climate and food security 6-9 Feb 1987 New Delhi India.

Lettanzi. A (1973): Influence of straw mulch rate and slope steepness on interill detachment and transport of soils. Unpublished. Msc. Thesis Purdue Univ. W Lafayette Ind.

Liattanzi. A.R. Meyer L.D and Baumgardners. M.F (1974): Influence of mulch rate and slope steepness on interill erosion. Soil Sci. Soc. Am. Proc. 38 (6) 946-950

Luk. S.H (1979): Effect of soil properties on erosion by wash and splash. Earth surface processes 4: 241-255.

Meeuwing. R (1971): Soil stability on high elevation range land in the intermountain area. US forest services Res paper int 94.

Mennard.H.W (1974) Geology Resource and Society-An Intro to Earth Sci. W.H Freeman and Company Ltd. NY.

Middleton. P.R (1930): Properties of soil which influence soil erosion. U.S.D.A. Tech Bulletin 178.

Morgestern. N.R and Price. V.E (1965): The analysis of the stability of general slip surfaces. Geo tech 15 Pp 79-93.

Mortimore, M.J (1965): Land & people in Kano close settled zone A.B.U Dept. of Geography Occasional paper 2.

Musgrave, G.W (1947): Quantitative evaluation of factors in water erosion. A first Approximation.. Jour. of Soil and Water Conservation. 2: 133-138.

Mustapha, S. (1977): The encroachment of the desert in the centre Bilal Al Sudan but is it really Encroaching? [Unpunished] M.Sc. Thesis ABU Zaria.

Nearing M.A and West, L.T (1988): Soil Strength indices and indices and indication of consolidation. Trans of ASAE 31 (2) 471-476.

Nwajide, C.S and Hoque, M. (1979): Gulling process in South Eastern Nig. The Nig. Field 44 (2) 64-74.

Ofomata, G.E.K (1979) Man as a factor of soil erosion in South Eastern Nig. Geo. Eco. Trop (1) pp 64-74.

Ogbukagu, K.N.(1976): Soil erosion in the northern park of the Akwa Orlu uplands of Nig. Nig. Journ of Minning & Geology B: 6-19.

Okagbue, C.O (1986): Gully development and advance in a rain forest zone of Nigeria Proc 5th International Assoc. Engr Geology Buenos Aires, Argentina.

Ologe, K.D (1971): Gully development in the Zaria Area, Northern Nig. Ph.D Thesis. University of Liverpool.

Olson, O.C (1949): Relation Between soil depth and accelerated erosion on the Wasatah mountains. J. Soil Sc. 67: 417-451.

Olson, O.C & Wischeimer, W.H (1963): Soil Erodibility Evaluation for soils on the run off and erosion stations Soil Sci.Soc. Am. Proc 27 590-592.

Osterkamp, W.R et al. (1991): The vigil Network. A means of Observing landscape change in Drainage Basins Hydrological Science Journal. 36: 321- 334.

Oyebande. (1986): Effects of Erosion on water quality and sedimentation. Proceedings National Workshop on Ecological Disaster Soil Erosion pp 229-237.

Parker. D.B. Michael. Z.G and Smith, J.L (1995): Compactive water velocity effect on soil erosion in shallow flow. J..Irrigation and Drainage Eng. ASCE, 121 (2) 170-178.

Prest, R.F. Krammer. L.A and Heinemann, H.G (1975): Sediments. Yields and sources. ARS: S. 4O USDA Washington pp 130-141.

Poeson. J (1984): The influence of slope and angle on infiltration rate and Hortonian overland flow volume. Z.F Geomorph N.F.F Supp BD 49 : 117-131.

Poesen, J., K. Vandaele, and B. Van Wesemael, (1996): Contribution of gully erosion to sediment production on cultivated lands and rangelands. P.251-266. In D. Walling and B. Webb (eds.). Erosion and Sediment Yield: Global and Regional Perspectives. IAHS Publ. N236.

Saxton K.E (1995) Wind Erosion and its Impact on offsite quality in the Columbia Plateau. An Integrated research plan. Trans of Am. Soc of Eng.38 (4) 1301-1308.

Sidorexhuk, A. (1995): Erosion-sedimentation processes on the Russian Plain and the problem of aggradation in the small rivers. p. 74-83. (In Russian). *In* R.S. Chalov (ed) Water Resources Management and Problems of Fluvial Science Izd AVN., Moscow.

Sidorchuk, A. (1998): Dynamic Model of Gully Erosion p.451-460. *In* J. Boardman and D. Favis-Mortlock (eds). Modelling soil erosion by water. Springer, Berlin.

Sidorchuk, A. and Grigor E.V. (1998): Soil erosion on the Yamal Peninsula (Russian Arctic) due to gas field exploitation. Advances In GeoEcology. 31:805-811.

Singer, M.J and Blackard,J (1982): Slope angle interril soil loss relationships for slopes up to 50%. Soil Sci. Society. Am. Jour. 46 (6) Pp 1270-1277.

Singer, M.J., Ugoliri, F.C., and Zachara, J. (1978): Engineering and Pedological properties of soil as they affect soil erodibility. California water relationship for slopes up to 50%. Soil Sci Soc Am. J 46 (6): 1270-1273.

Stott D.E., Mohtar R.H. and Steinhardt G.C (2001): GULTEM – the Model to Predict Gully Thermoerosion and Erosion (Theoretical

Wischeimeier, W.H and Mannering, J.V (1969): Relation of soil properties to its erodibility. Soil Sci. Soc. of Am. Proc 33: 131-137.

Wischeimeier, W.H and Smith, D.D (1978): Predicting Rainfall Erosion Losses. A guide to conservation Planning. USDA-SEA. Agriculture Handbook Pp 537-558.

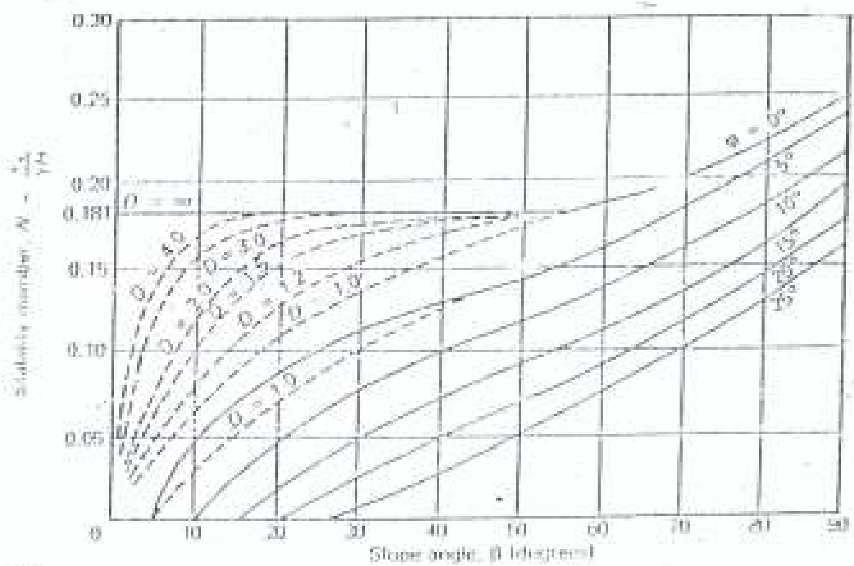
Yair,A et al (1980): Run-off and erosion processes and rates in the Zin valley Badelands Northern Negeb Israel. Earth Surface Process 5:205-255.

Young, R.A and Wiersma, J.L (1973): The role of rainfall impact in soil detachment and transport. Water Resources Res..9 (16) 1620-1636.

Zingg, (1940): Degree and length of slope as it affect soil loss in run-off. Agricultural Engineering 21 (2) 59-64.

Appendix A
Taylor's Stability Chart

Taylor's stability number method



Appendix B

Annual Gully Growth and Change in Width

Annual Gully Dimensions (Alanaka 2000)

Hor. Sec.	Vertical Dimension									
	1	2	3	4	5	6	7	8	9	10
1	1.519	1.557	1.705	1.761	1.878	1.97	2.051	2.165		
2	1.489	1.646	1.675	1.68	1.742					
3	1.387	1.606	1.717	2	2.222					
4	1.706	1.943	1.96	2.12	2.265					
5	1.624	1.876	2.141	2.317	2.136					
6	1.589	1.777	1.821	1.977	1.981	2.249	2.815			
7	1.723	1.894	2.019	2.05	2.378	2.4				
8	1.552	1.684	1.842	2.137	2.136					
9	1.652.	2	1.952	21.032	2.281					
10	1.632	1.7776	1.952	1.986	2.915	2.343				
11	1.441	1.608	1.765	1.962	2.036	2.265				
12	1.679	1.829	1.915	2.016	2.031	2.121				
13	1.421	1.586	1.557	1.662	1.768	1.805	1.841			
14	1.032	1.081	1.208	1.263	1.419	1.822	2.126			
15	0.736	1.162	1.33	1.748	2.74	2.65				
16	1.15	1.8	1.524	1.855	2.092	2.422				
17	0.951	2.252	2.405	2.724	2.82	3.143	3.148			
18	1.864	2.21	3.036	3.271	3.908	4.07				
19	1.169	1.939	2.2.2	2.858	4.015	4.566	5.273	5.872		
20	0.208	1.819	2.378	3.27	0.228	4.848	5.537	5.867		
21	1.537	2.182	2.41	3.98	4.625	5.556	6.333	6.736		
22	1.501	3	3	4.955	5.51	6.112	5.958	6.202		
23	2.151	2.674	2.228	4.777	5.683	5.507	6.393	6.605		
24	2.118	2.53	3.386	4.685	4.919	5.495	6.282	6.886		
25	1.955	2.785	4.715	5.593	6.092	6.403	6.452	7.463		
26	2.132	2.82	3.376	3.626	4.159	4.352	4.626			
27	2.136	2.857	3.424	3.649	4.155					
28	2.242	2.643	2.931	3.124	3.15					
29	2.327	2.505	2.804	3.63	3.294					
30	2.28	2.87	3.581	3.2627	3.654	3.872				
31	2.023	2.424	3.462	3.543	3.757	4.106				
32	1.922	2.338	3.006	3.189	3.427	3.692	3.859	4.169		
33	1.648	1.761	2.298	2.539	2.728	2.855	3.236	3.536		
34	1.551	1.916	2.587	2.815	3.386	3.559	3.565	3.698	3.824	

35	1.443	1.824	2.3	2.74	3.138	3.98	3.524	3.682	3.8753	4.018
36	1.312	1.682	2.151	2.442	2.748	2.761	3.055			
37	1.07	1.389	2.41	2.68	2.954	2.24				
38	1.112	1.136	1.712	2.136	2.612					
39	1.055	1.195	1.944	2.052	2.512					
40	1.036	1.405	2.253	2.348	2.362					
41	1.37	1.867	2.369	3.186	3.324	3.948				
42	2.09	2.608	2.843	3.144	3.562	3.924	4.136			
43	2.815	3.077	3.241	3.266	4.186	4.256	4.374	4.412		
44	3.051	3.143	3.354	3.624	3.828	4.056	4.136	4.524		
45	3.112	3.124	3.612							
46	1.628	2.108	2.348							
47	1.427	1.643	1.792							
48	1.442	1.476	1.536							
49	1.477	1.502	1.674							
50	1.453	1.51								

Annual Gully Dimensions (Alanaka 2001)

Hor. Sec.	Vertical Sections									
	1	2	3	4	5	6	7	8	9	10
1	1.815	1.615	1.81	1.822	1.902	2.086	2.18	2.389		
2	1.635	1.755	1.821	1.724	1.803					
3	1.499	1.749	1.846	1.768	2.487					
4	1.777	2.004	2.038	2.276	2.275					
5	1.638	1.924	2.151	2.341	2.177					
6	1.609	1.838	1.852	1.987	2.005	2.293	2.815			
7	1.743	1.938	2.043	2.05	2.473	2.461				
8	1.552	1.715	1.862	2.181	2.136					
9	1.656	1.7776	1.952	21.06	2.386					
1	1.652	1.8186	2.136	1.986	2.946	2.408				
11	1.448	1.662	2.345	1.962	2.036	2.265				
12	1.703	1.853	1.925	2.03	2.055	2.369				
13	1.421	1.606	1.581	1.682	1.792	1.863	1.841			
14	1.056	1.112	1.208	1.307	1.443	1.853	2.126			
15	0.736	1.169	1.332	1.748	2.74	2.65				
16	1.177	1.831	1.524	1.879	2.146	2.517				
17	0.971	2.272	2.429	2.724	2.84	3.167	3.148			
18	1.908	2.241	3.07	3.302	3.918	4.097				
19	1.189	1.966	0.054	2.892	4.015	4.668	5.528	6.008		
20	0.218	1.829	2.402	3.27	0.252	5.134	5.789	6		
21	1.547	2.206	2.41	4.007	4.625	5.59	6.333	6.736		
22	1.501	2.722	2.796	4.979	5.51	6.1338	5.985	6.216		
23	2.178	2.701	2.235	4.787	5.693	5.517	6.417	6.629		
24	2.135	2.55	3.406	4.733	4.943	5.495	6.282	6.886		
25	1.972	2.785	4.715	5.624	6.112	6.42	6.496	7.507		
26	2.132	2.844	3.519	3.748	4.19	4.352	4.67			
27	2.136	2.888	3.458	3.656	4.165					
28	2.252	2.667	2.9514	3.124	3.22					
29	2.337	2.529	2.865	3.661	3.294					
30	2.3	2.897	3.605	3.2827	3.668	3.937				
31	2.023	2.438	3.482	3.557	3.788	4.133				
32	1.929	2.345	3.033	3.199	3.437	3.753	3.89	4.193		
33	1.648	1.785	2.298	2.549	2.742	2.879	3.236	3.536		

34	1.582	1.936	2.597	2.815	3.386	3.579	3.589	3.78	3.824	
35	1.467	1.824	2.31	2.74	3.145	3.98	3.524	3.692	3.8853	4.14
36	1.312	1.709	2.161	2.442	2.748	2.761	3.079			
37	1.097	1.399	2.417	2.7	2.974	2.254				
38	1.117	1.136	1.715	2.136	2.612					
39	1.079	1.226	1.971	2.052	2.512					
40	1.036	1.405	2.263	2.348	2.362					
41	1.38	1.8796	2.393	3.186	3.324	3.948				
42	2.104	2.618	2.867	3.171	3.562	3.924	4.136			
43	2.885	3.104	3.255	3.395	4.213	4.256	4.374	4.412		
44	3.061	3.167	3.374	3.624	3.848	4.083	4.136	4.524		
45	3.114	3.129	3.612	0	0	0	0			
46	1.641	2.118	2.348	0	0	0	0	0		
47	1.437	1.667	1.812	0	0	0	0	0	0	
48	1.462	1.49	1.536	0	0	0	0	0	0	0
49	1.494	1.512	1.701	0	0	0	0	0	0	0
50	1.456	1.524	0	0	0	0	0	0	0	0

Annual Change in Width (Alanaka 2000/2001)

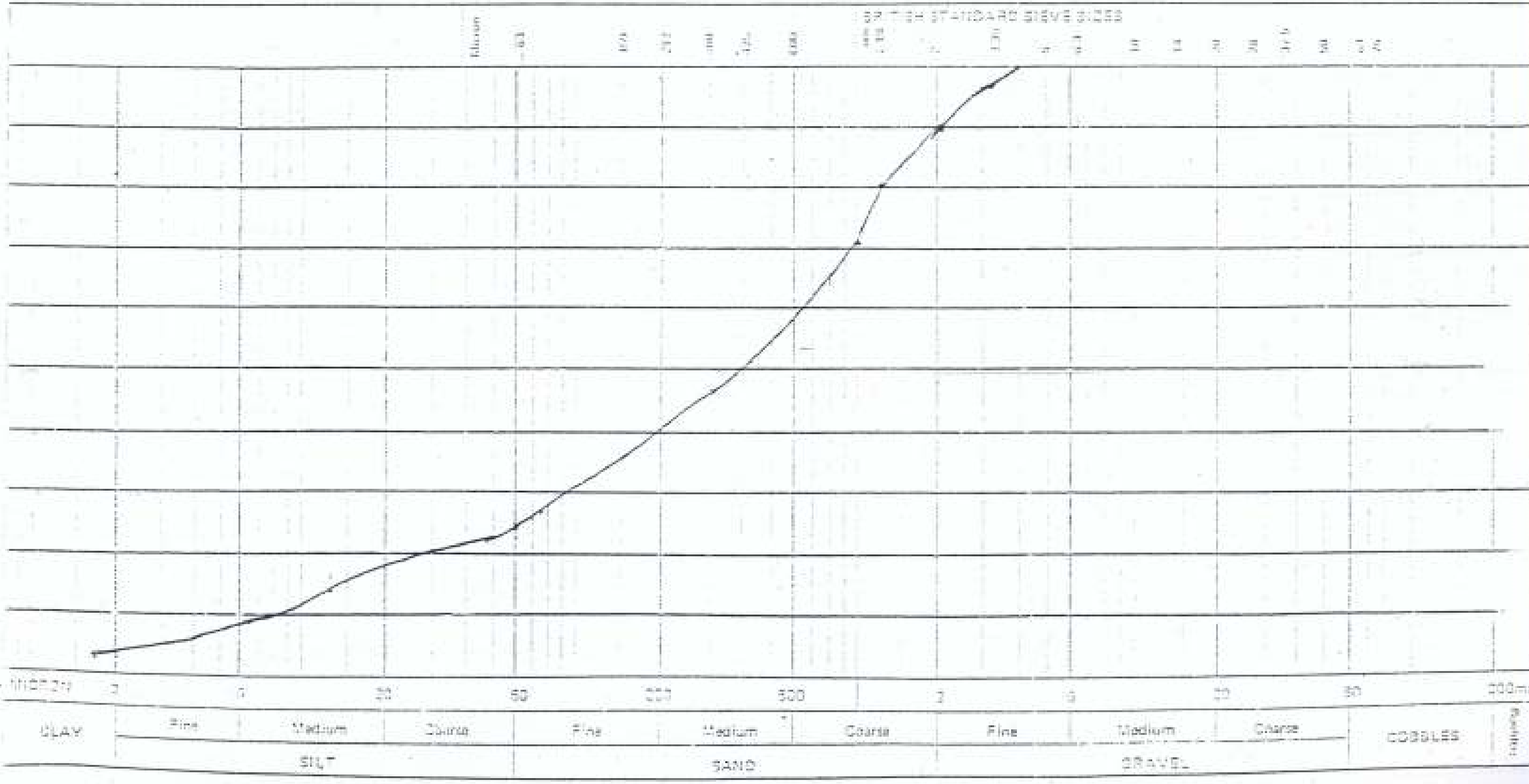
Hor. sect.	Vertical sections											
	1	2	3	4	5	6	7	8	9			
1	0.09	0.106	0.03	0.146	0.03	0.132	0.148			0.119	0.444	0.2815
2	0.16	0.026	0.09	0.078	0.122					0.141	0.194	0.1675
3	0.016	0.026	0.09	0.078	0.122					0.069	0.194	0.1315
4	0.014	0.1	0.104	0.11	0.096					0.055	0.314	0.1845
5	0.016	0.082	0.038	0.034	0.122					0.069	0.154	0.1115
6	0.006	0.008	0.01	0.062	0.006	0				0.003	0.086	0.0445
7	0.002	0.012	0.01	0.006	0.016	0.036				0.019	0.044	0.0315
8	0.014	0.016	0.142	0.07	0					0.007	0.228	0.1175
9	0.006	0.018	0.016	0.076	0.038					0.022	0.11	0.066
10	0.008	0	0.014	0.062	0.032	0				0.004	0.108	0.056
11	0.012	0.028	0.102	0.046	0.162	0.064				0.038	0.338	0.188
12	0	0.01	0.038	0.054	0.082	0.032				0.016	0.184	0.1
13	0	0.006	0.042	0.001	0.016	0.084	0			0	0.149	0.0745
14	0.01	0.026	0.024	0.07	0.082	0.032	0			0.005	0.234	0.1195
15	0	0	0.018	0.02	0.026	0.014				0.007	0.064	0.0355
16	0	0.028	0.066	0.062	0.028	0.022				0.011	0.184	0.0975
17	0.004	0.014	0.062	0.05	0.106	0.08	0			0.002	0.312	0.157
18	0	0.032	0.064	0.056	0	0.128				0.064	0.152	0.108
19	0.014	0.006	0.074	0.028	0.032	0	0.162	0.124		0.069	0.302	0.1855
20	0.022	0.028	0.022	0.032	0.006	0.086	0.104	0		0.011	0.278	0.1445
21	0.014	0.008	0	0	0.0006	0.01	0.032	0.018		0.016	0.0506	0.0333
22	0.016	0.024	0.124	0.028	0.026	0.026	0.022	0.022		0.019	0.25	0.1345
23	0.016	0.024	0.124	0.028	0.162	0.03	0.162	0.22		0.118	0.53	0.324
24	0.018	0.03	0.044	0.028	0.096	0.056	0.026	0.022		0.02	0.28	0.15
25	0.024	0.028	0.084	0.022	0.018	0.044	0.07	0.058		0.041	0.266	0.1535
26	0.014	0.054	0.07	0.062	0.11	0.122	0.076	0.0052		0.0096	0.494	0.2518
27	0.008	0.006	0.028	0	0.024	0.046	0	0		0.004	0.104	0.054
28	0.014	0.022	0.24	0.026	0.018	0.026	0.028	0.082		0.048	0.12	0.084
29	0.018	0.018	0.016	0.28	0.032	0	0.02	0.036	0	0.009	0.402	0.2055
30	0.032	0.024	0.022	0.022	0.03	0.044	0.162	0	0	0.016	0.304	0.16
31	0.016	0.022	0.026	0.016	0.144	0.024	0.062	0.022	0.018	0.017	0.316	0.1665
32	0.01	0.006	0.072	0	0.004	0.182	0.01	0.054	0.072	0.041	0.328	0.1845
33	0.032	0.012	0.004	0.012	0.016	0	0.016	0.01	0.022	0.027	0.07	0.0485

34	0.024	0.026	0.016	0.008	0.084	0.016	0	0	0.022	0.023	0.15	0.0865
35	0.012	0.016	0.028	0.026	0.036	0.006	0.016	0	0.34	0.176	0.128	0.152
36	0.008	0.014	0,.002	0.018	0.014	0.01	0.012	0.064	0.02	0.014	0.132	0.073
37	0.012	0.01	0.026	0.034	0.008	0.014	0.016	0.034	0.024	0.018	0.142	0.08
38	0.008	0.004	0.008	0.02	0.014	0.014	0.01	0.144	0.162	0.085	0.214	0.1495
39	0.004	0.022	0.03	0.034	0.032					0.018	0.086	0.052
40	0.01	0.122	0.064	0.028	0.084					0.047	0.214	0.1305
41	0.006	0.022	0.012	0.008	0.004	0.016				0.011	0.046	0.0285
42	0.016	0.012	0.006	0.006	0.014	0	0	0		0.008	0.038	0.023
43	0.014	0.024	0.086	0.122	0.144	0.162	0			0.007	0.538	0.2725
44	0.01	0.064	0	0.008	0.008	0.084	0.038	0.046		0.028	0.202	0.115
45	0.004	0.004	0.026	0	0					0.002	0.03	0.016
46	0.004	0.004	0.026	0	0					0.002	0.03	0.016
47	0.006	0.008	0	0						0.003	0.008	0.0055
48	0.004	0.016	0.014	0						0.002	0.03	0.016
49	0.012	0.004	0	0						0.006	0.004	0.005
50	0.006	0.012	0	0						0.003	0.012	0.0075
												0.1445
												5.2916
												10.872 2

PARTICLE SIZE DISTRIBUTION

LOCATION No. Alanaka BORE HOLE No. .... SAMPLE No. One PRETREATMENT DETAILS ....

DATE OF TEST .... DESCRIPTION .... LOSS ON PRETREATMENT ....



Signed ....

MATERIAL TESTING LAB, CIVIL ENGG. DEPT.

Form No. K4

PARTICLE SIZE DISTRIBUTION

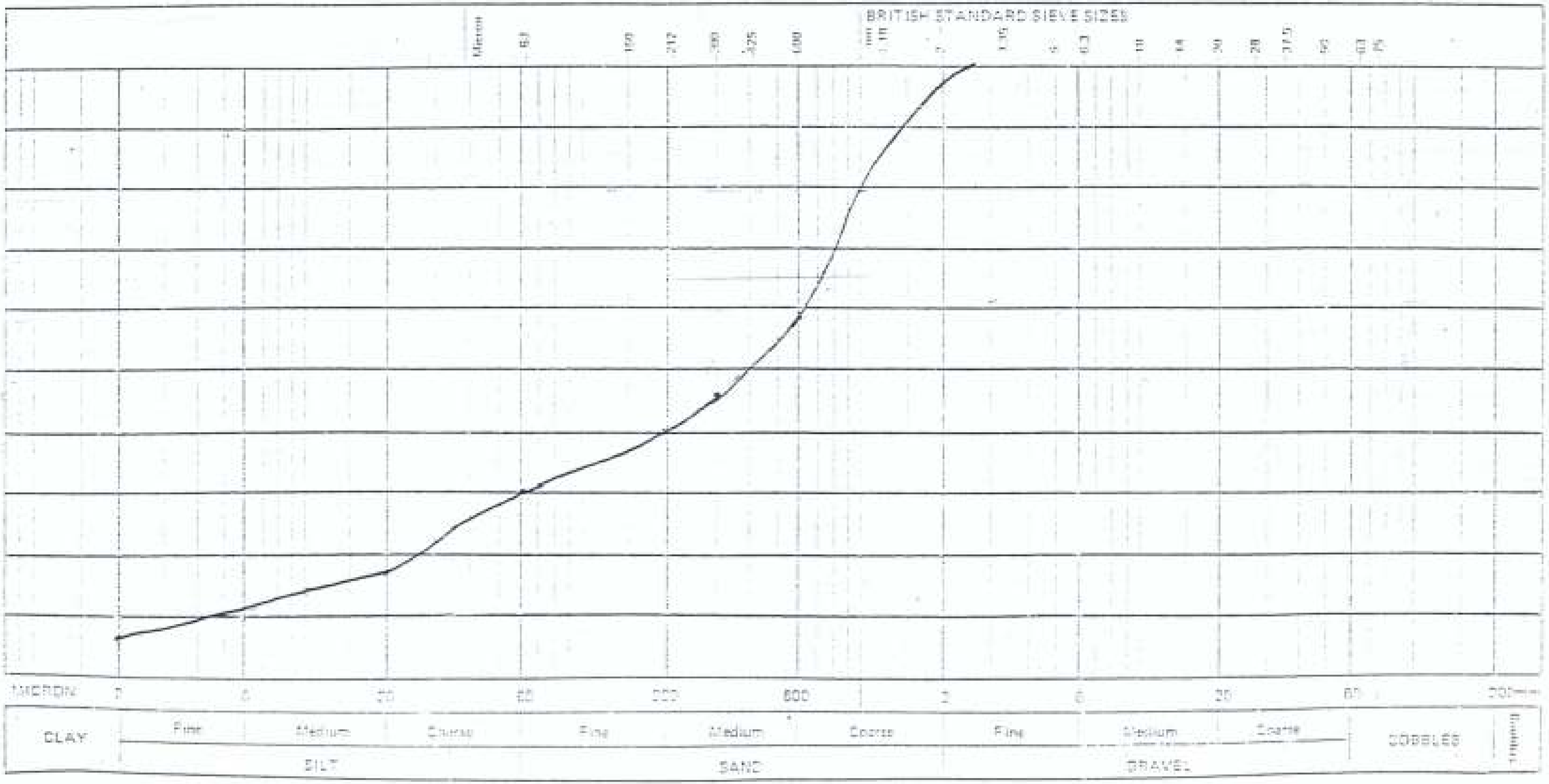
LOCATION No. Alanaka BORE HOLE No. .... SAMPLE No. Two PRETREATMENT DETAILS ....

DATE OF TEST .... DESCRIPTION .... LOSS ON PRETREATMENT ....%

PARTICLE SIZE DISTRIBUTION

LOCATION No. Bete BORE HOLE No. .... SAMPLE No. One PRETREATMENT DETAILS ....

DATE OF TEST .... DESCRIPTION .... LOSS ON PRETREATMENT ....%



Signed ....

LOCATION No. Ibe Ta   BORE HOLE No. ....   SAMPLE No. Zone
DATE OF TEST ....   DESCRIPTION ....
PRETREATMENT DETAILS ....
LOSS ON PRETREATMENT ....%

Signed ....

MATERIAL TESTING LAB, CIVIL ENGG. DEPT.

Form No. K4

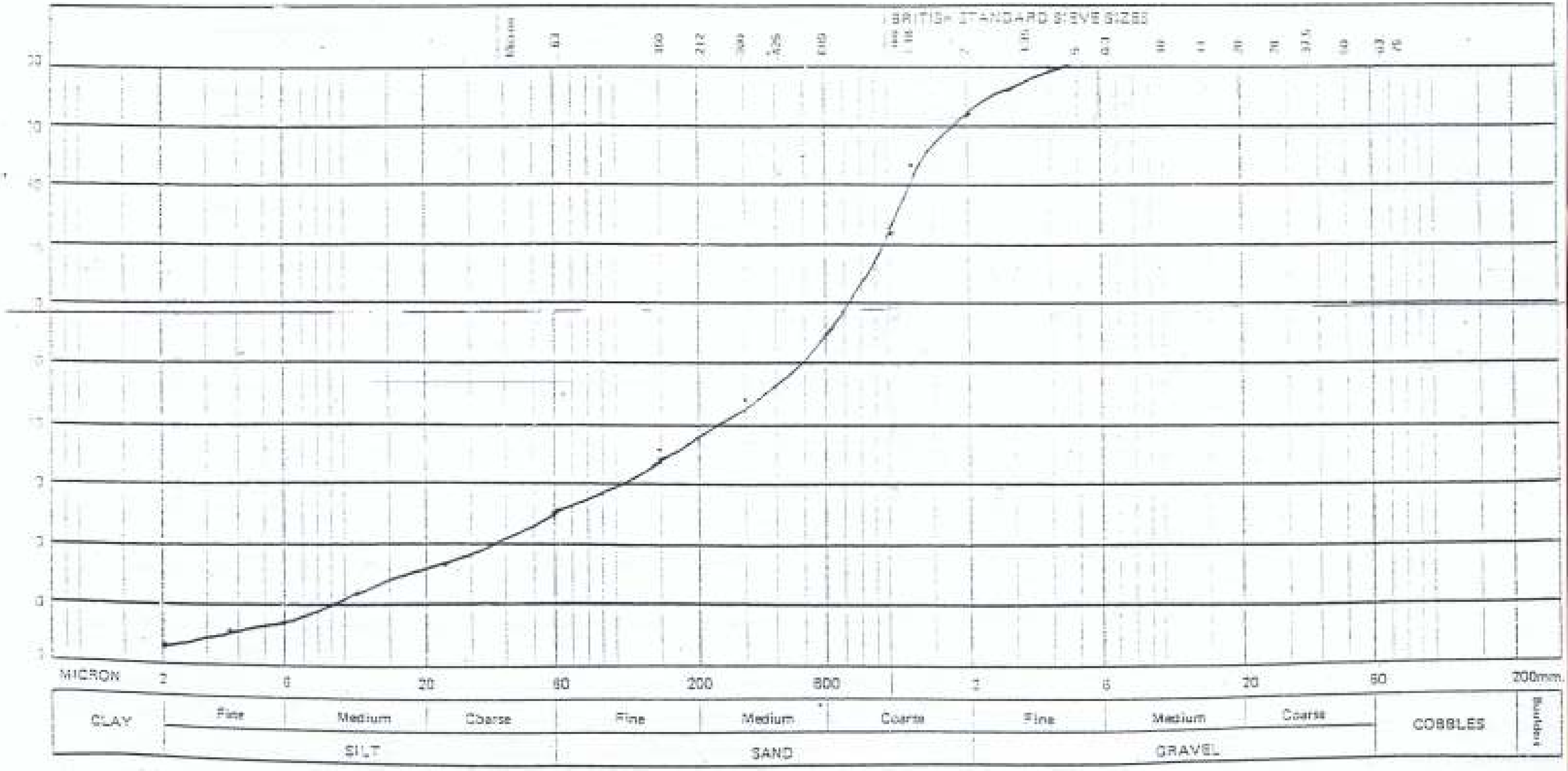
PARTICLE SIZE DISTRIBUTION

LOCATION No. Igbo-ikogun
DATE OF TEST Upper

BORE HOLE No. ....
DESCRIPTION ....

SAMPLE No. One

PRETREATMENT DETAILS ....
LOSS ON PRETREATMENT ....%



Signed ....

FEDERAL POLYTECHNIC, AUCHI

MATERIAL TESTING LAB, CIVIL ENGG. DEPT.

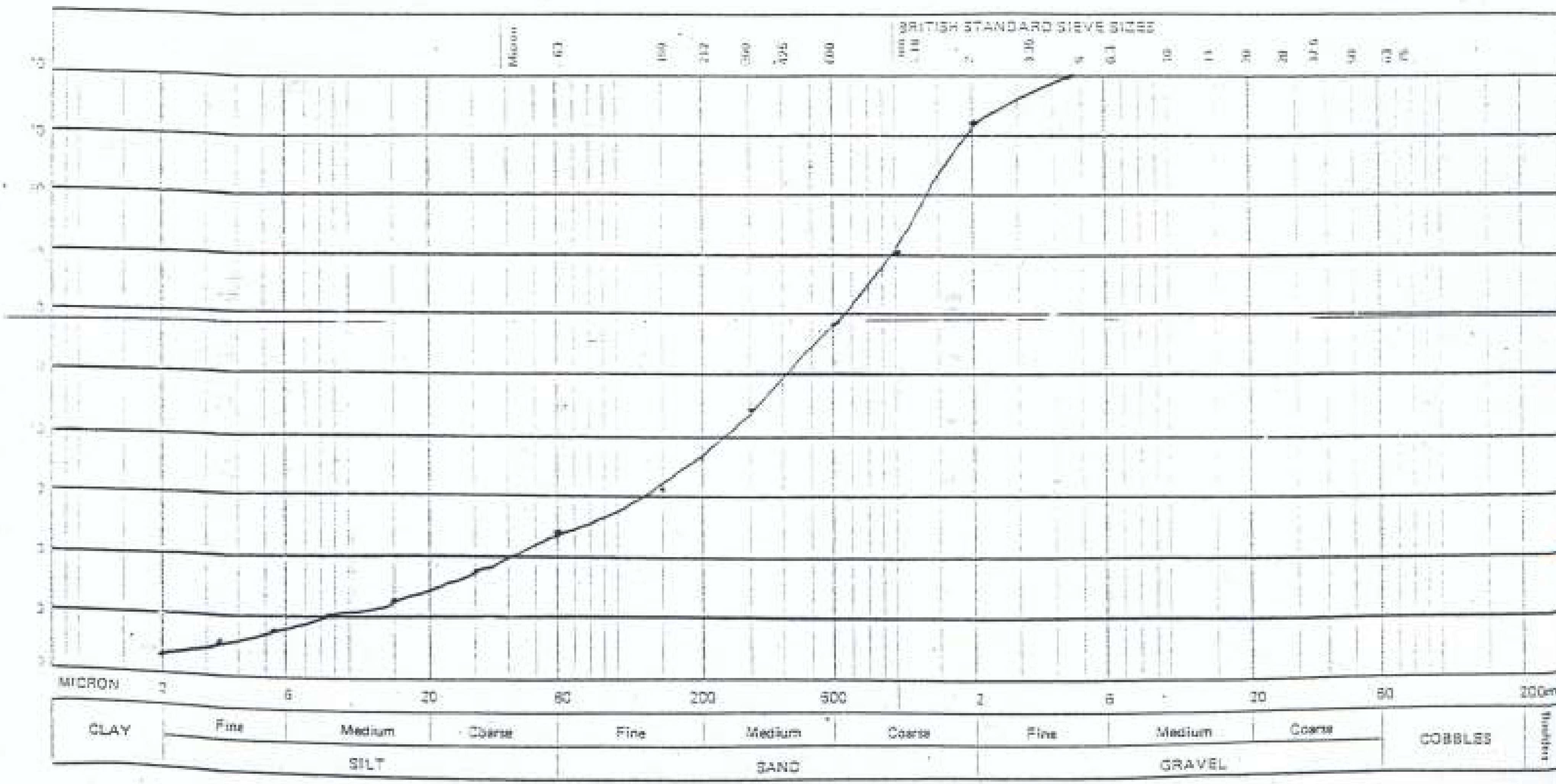
Grain size analysis

Form No. K4

PARTICLE SIZE DISTRIBUTION

LOCATION No. Igbo-Egun BORE HOLE No. .... SAMPLE No. Two PRETREATMENT DETAILS ....

DATE OF TEST. Upper DESCRIPTION .... LOSS ON PRETREATMENT .... %



Signed ....

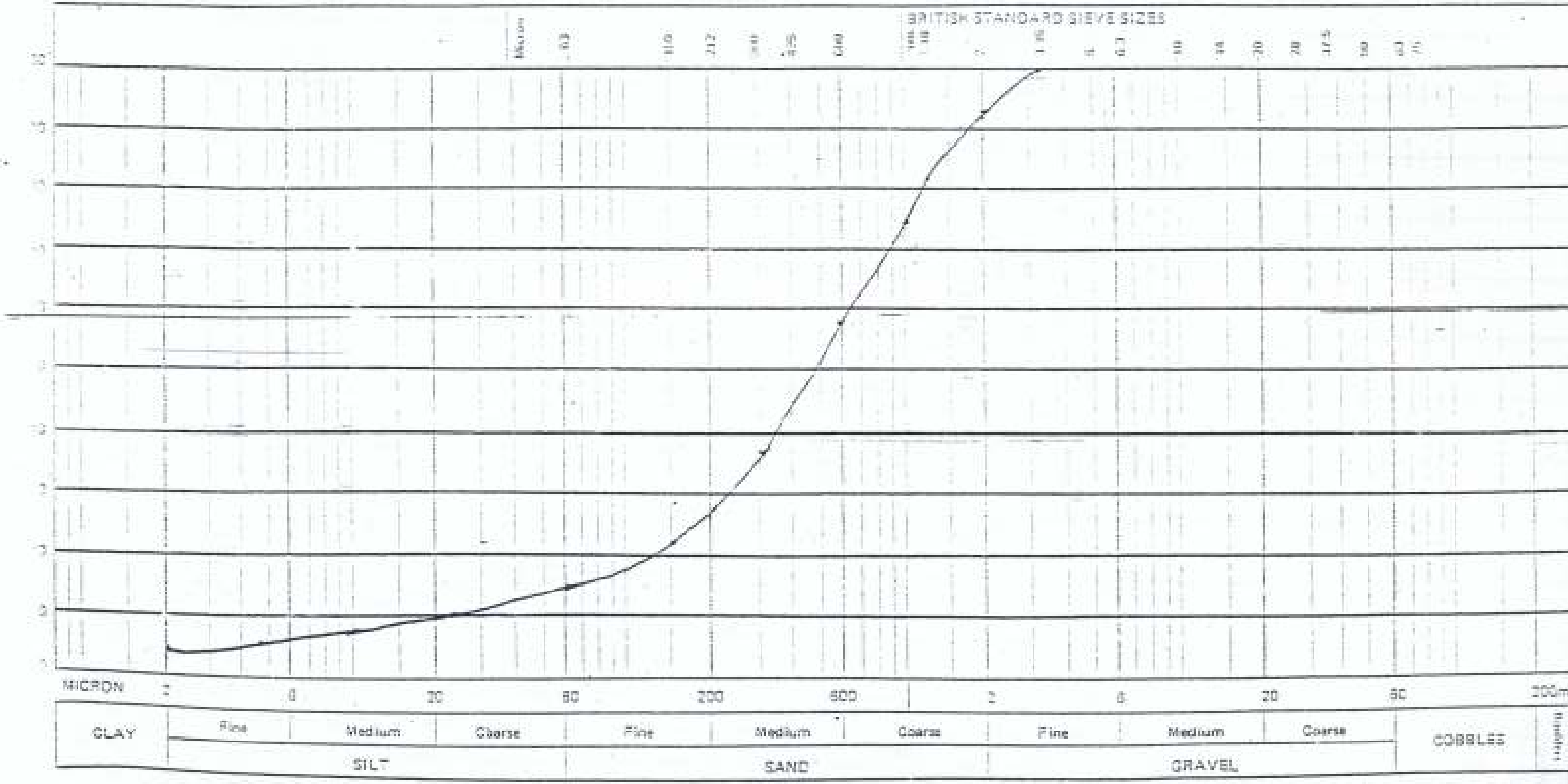
MATERIAL TESTING LAB: CIVIL ENGG. DEPT.

Form No. Kc

PARTICLE SIZE DISTRIBUTION

LOCATION No. Ispaju　　BORE HOLE No. ....　　SAMPLE No. One　　PRETREATMENT DETAILS ....

DATE OF TEST ....　　DESCRIPTION ....　　LOSS ON PRETREATMENT ....%



Signed ....

FEDERAL POLYTECHNIC, ADO EKITI

MATERIAL TESTING LAB., CIVIL ENGG. DEPT.

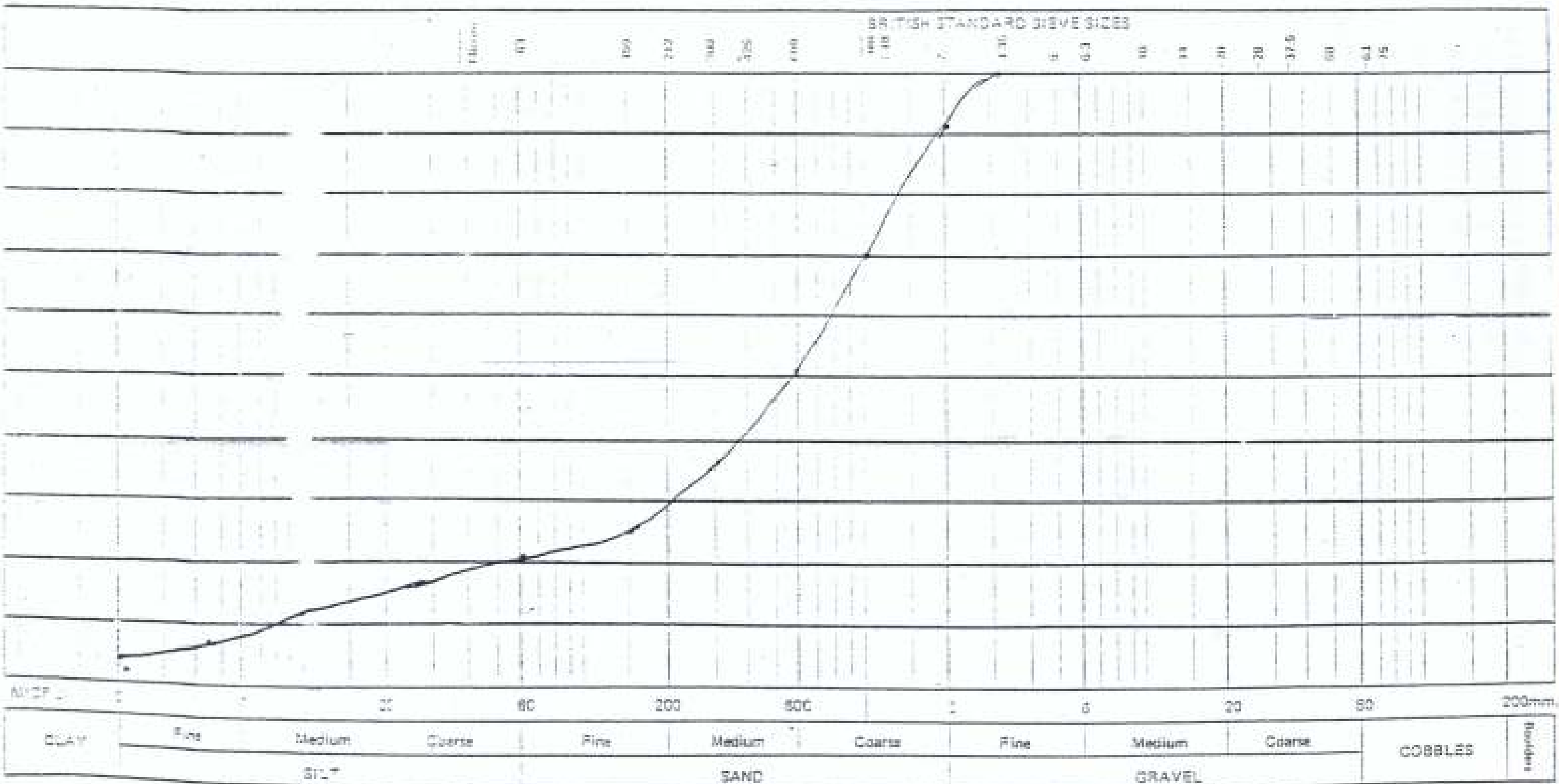
Grain size analysis sheet

Form No. K4

PARTICLE SIZE DISTRIBUTION

LOCATION No. Ilaja   BORE HOLE No. ....   SAMPLE No. Two   PRETREATMENT DETAILS ....

DATE OF TEST ....   DESCRIPTION ....   LOSS ON PRETREATMENT .... %



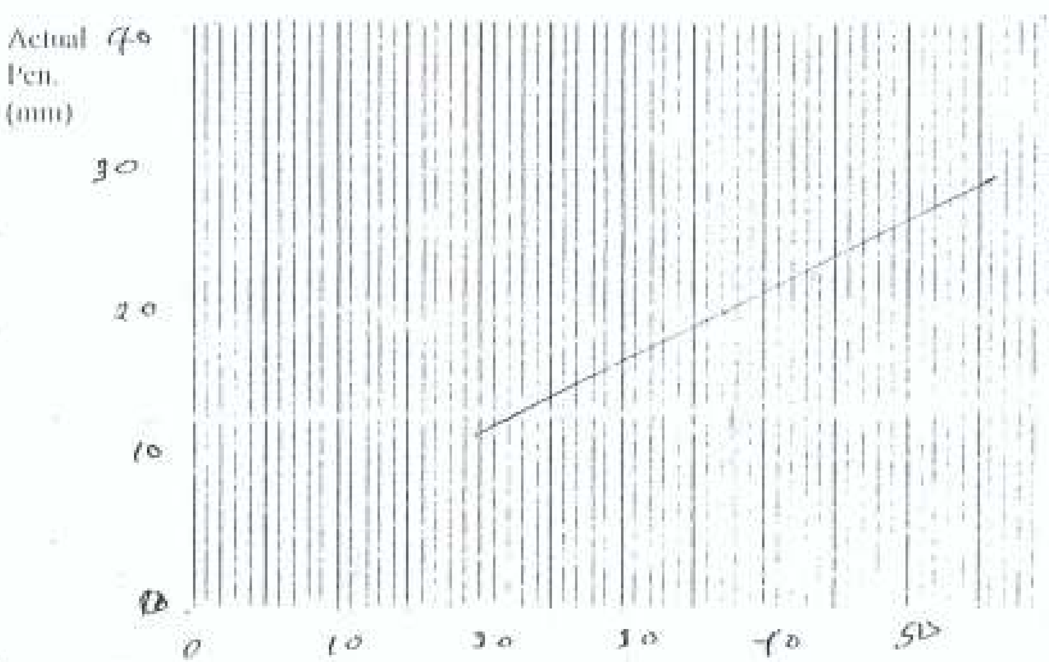
Signed ....

THE FEDERAL POLYTECHNIC ADO-EKITI (CIVIL ENG'G. DEPT)
MATERIAL TESTING LABORATORY
DATA SHEET FOR LIQUID LIMIT TEST (CONE PEN. METHOD)

Project: Location: Alanaka Borehole No: One

Description of Sample: Depth:

TEST NO.	1	2	3	4	5		
FINAL PEN (mm)							L.L% =37
INITIAL PEN (mm)							P.L.%=21
ACTUAL PEN (mm)	12	19	25.5	28		P.L	P.I%= 16
CAN NO							L.S%=
Wt Of Wet Soil + Can (W_2) gm							
Wt Of Dry Soil + Can (W_3) gm							
Wt Of Can (W_1) gm							
Wt Of Water (w) gm (W_2-W_3)							
Wt Of Dry Soil (W_d) gm (W_3-W_1)							
Moisture Content (m.c) % = w/W_d	20.5	35.1	43.5	53		21.0	



Signed............................ Moisture Content %

THE FEDERAL POLYTECHNIC ADO-EKITI (*CIVIL ENG'G. DEPT*)

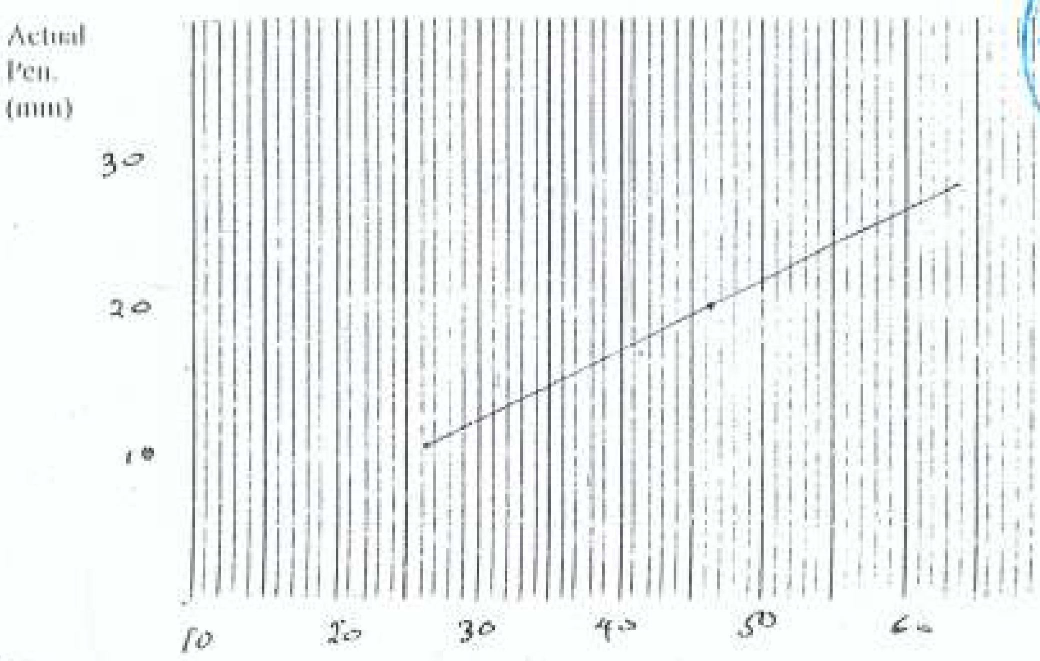
MATERIAL TESTING LABORATORY

DATA SHEET FOR LIQUID LIMIT TEST (CONE PEN. METHOD)

Project: Location: Ibete Borehole No: One

Description of Sample: Depth:

TEST NO.	1	2	3	4	5		
FINAL PEN (mm)	11	18	22.5	27.5			L.L% =46
INITIAL PEN (mm)							P.L% =27
ACTUAL PEN (mm)						P.I.	P.I% = 19
CAN NO							L.S% =
Wt Of Wet Soil + Can (W_2) gm							
Wt Of Dry Soil + Can (W_3) gm							
Wt Of Can (W_1) gm							
Wt Of Water (w) gm (W_2-W_3)							
Wt Of Dry Soil (W_d) gm (W_3-W_1)							
Moisture Content (m.c) % = w/W_d	27.2	41.5	50	63		27	



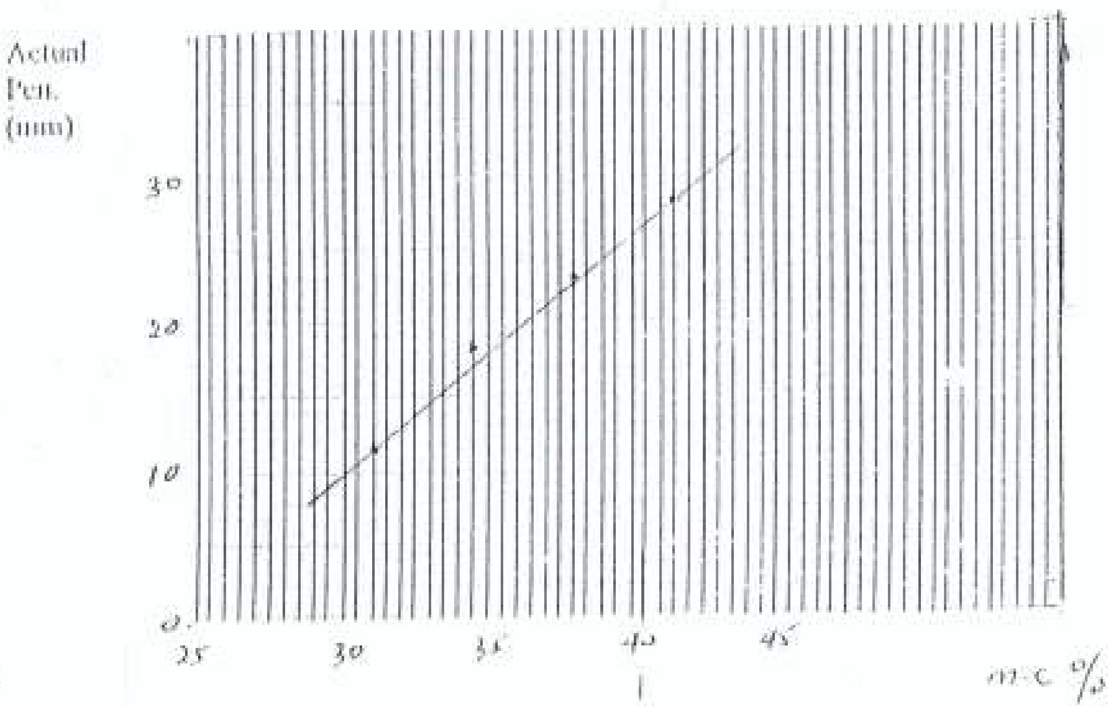
Signed.......................... Moisture Content %

THE FEDERAL POLYTECHNIC ADO EKITI (CIVIL ENG'G. DEPT)
MATERIAL TESTING LABORATORY
DATA SHEET FOR LIQUID LIMIT TEST (CONE PEN. METHOD)

Project: Location: Igbo-Egun Borehole No: Two

Description of Sample: Depth:

TEST NO.	1	2	3	4	5		
FINAL PEN (mm)							L.L% = 34
INITIAL PEN (mm)							P.L % = 23
ACTUAL PEN (mm)	12	18	23	28		P.I.	P.I% = 13
CAN NO							L.S% =
Wt Of Wet Soil + Can (W_2) gm							
Wt Of Dry Soil + Can (W_3) gm							
Wt Of Can (W_1) gm							
Wt Of Water (w) gm (W_2-W_3)							
Wt Of Dry Soil (W_d) gm (W_3-W_1)							
Moisture Content (m.c) % = w/W_d	31	34.5	38	41.5			



Signed.......................... Date ....

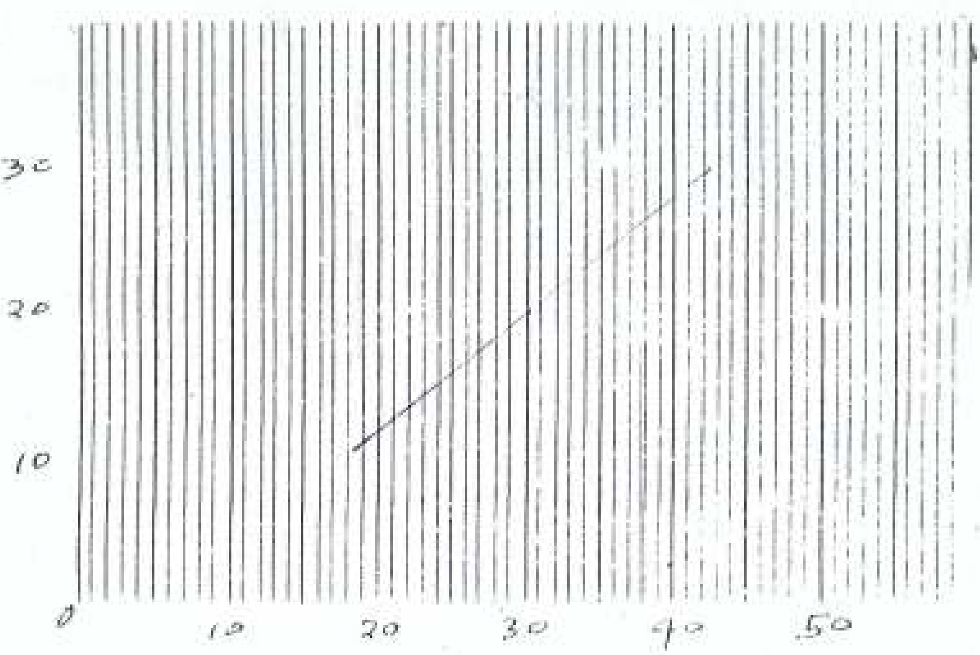
THE FEDERAL POLYTECHNIC ADO-EKITI (CIVIL ENG'G. DEPT)
MATERIAL TESTING LABORATORY
DATA SHEET FOR LIQUID LIMIT TEST (CONE PEN. METHOD)

ect: Location: Isaya Borehole No: Three

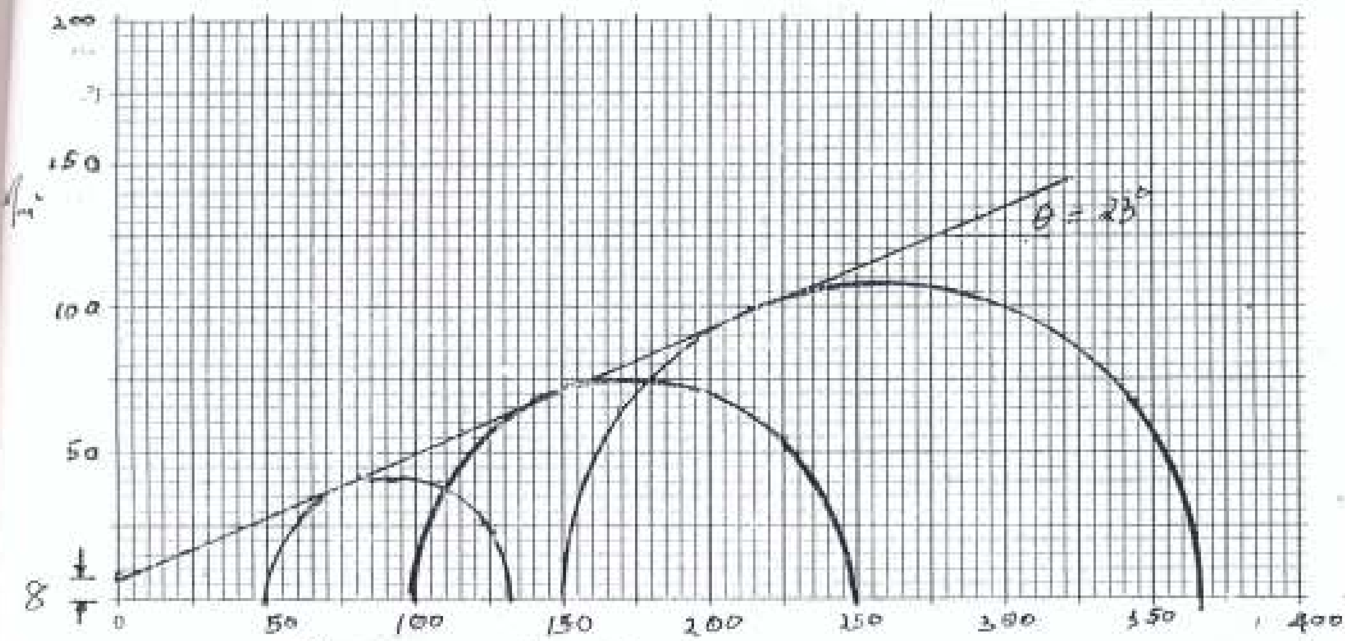
ription of Sample: Depth:

ST NO.	1	2	3	4	5		
NAL PEN (mm)							L.L% 30
TIAL PEN (mm)							P.L.% 18
TUAL PEN (mm)	12.5	16	22.5	29		P.L.	P.I% 12
N NO							L.S%
t Of Wet Soil + Can (W_2) gm							
t Of Dry Soil + Can (W_3) gm							
t Of Can (W_1) gm							
t Of Water (w) gm (W_2-W_3)							
t Of Dry Soil (W_4) gm (W_3-W_1)							
oisture Content (m.c) % = w/W_4	20	25	33	41		18	

ned
n.
m)



ned.............................. Moisture Content %



Mohr circles of Alanaka gully.

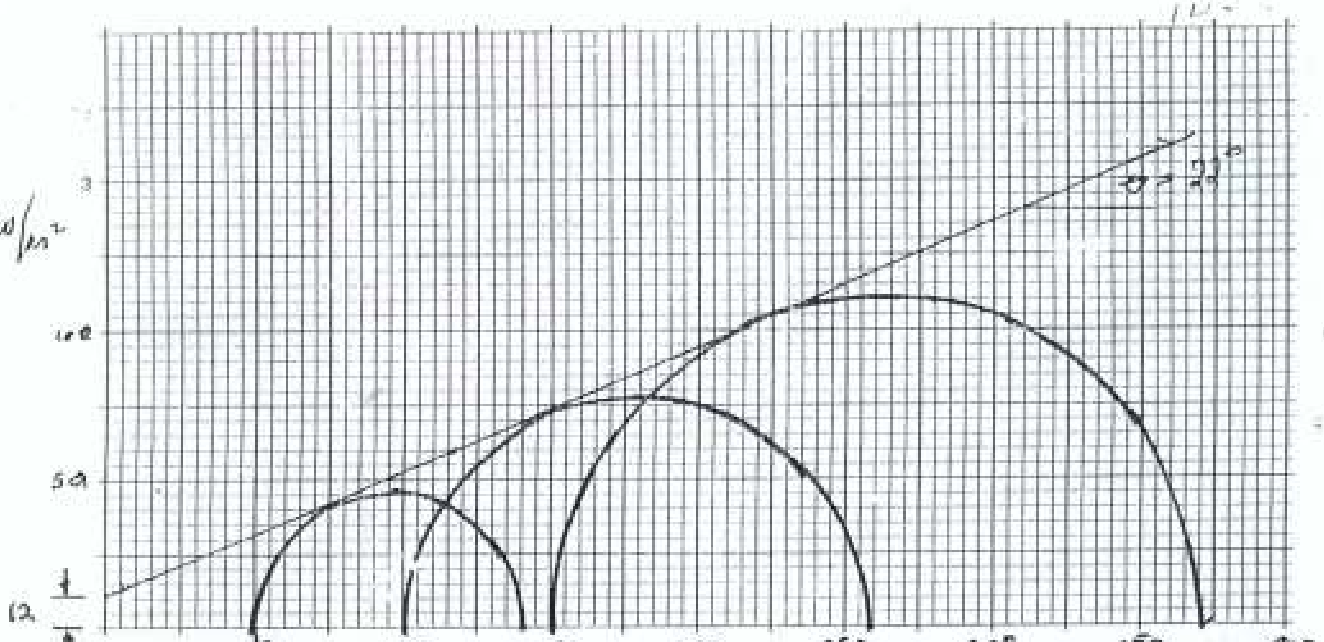
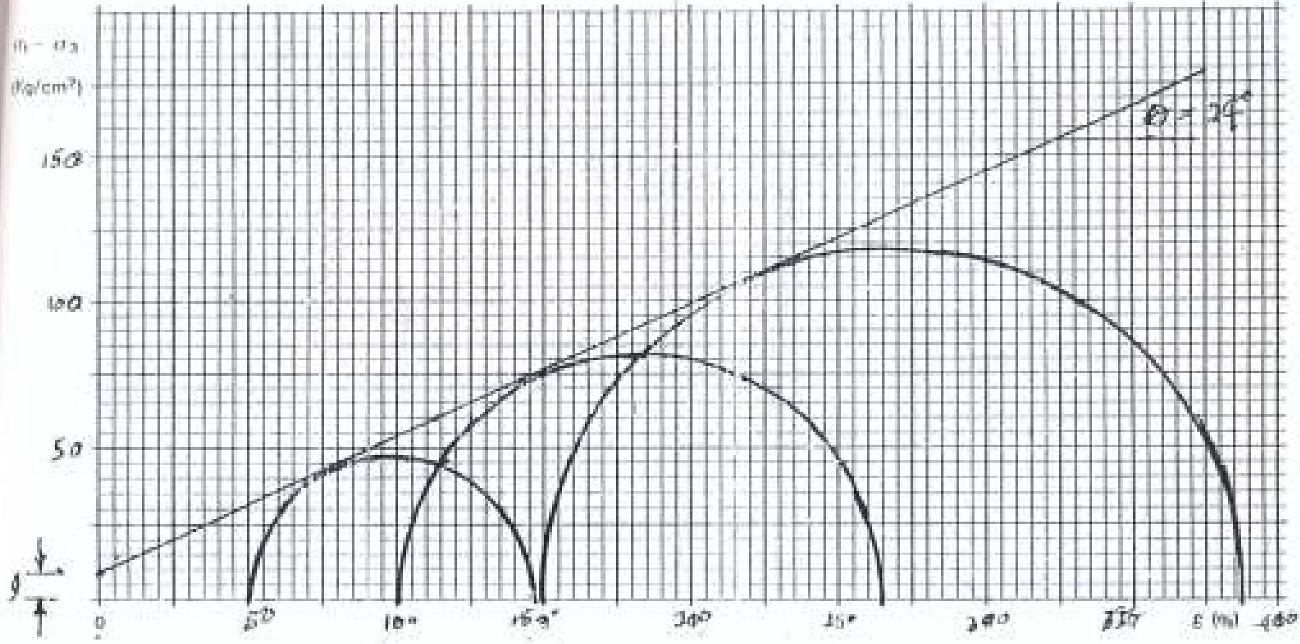


Fig Mohr Circles of Ibeta



Mohr circles of Igbo-Egun

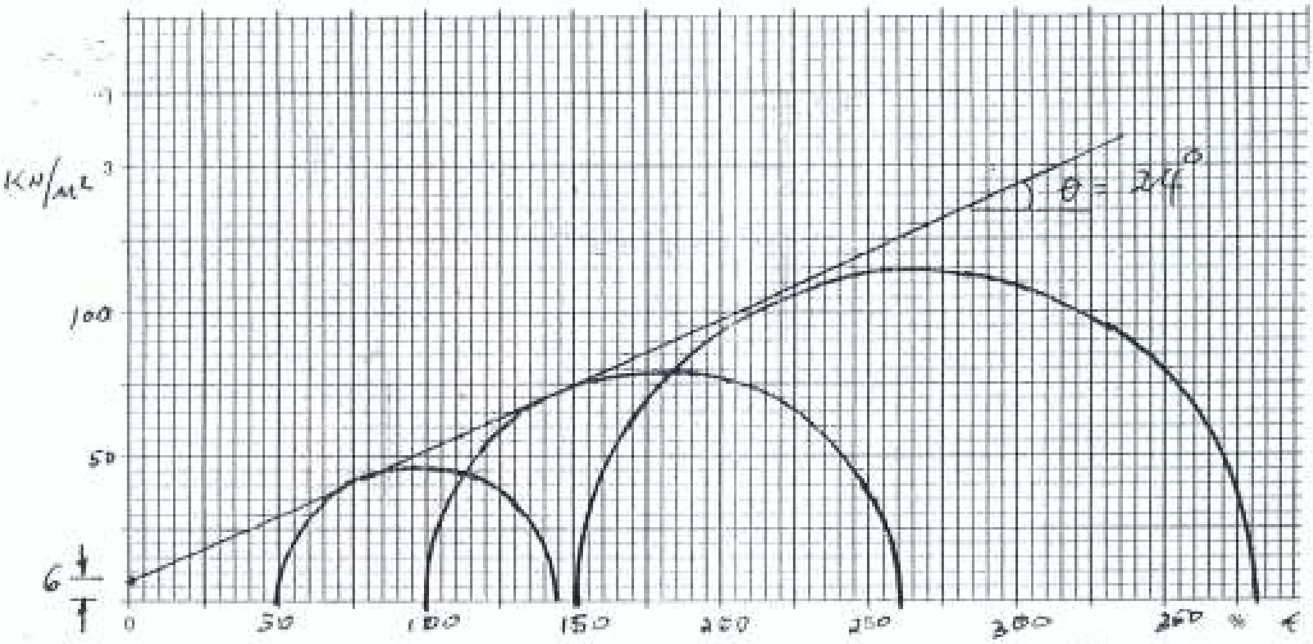


Fig Mohr Circles of Isaja gully

KN/M

CONTROL

Appendix C

Soil Investigation Data and Results

Appendix D
Computation and Data

Data and computation

Calculation of Shear Strength of Soils $\tau = C + \sigma \text{ Tan } O$

Alanaka

$C = 8$

$\gamma = 16.79 KN/M^3$

$Z = 2.86$

$O = 23^O$

$\tau = 8 + 16.79 \times 2.86 \text{ Tan } 23$

Tan22

$= 8 + 48.02 \text{ Tan } 23$

$= 28.4 KN/M^2$

Ibete

$C = 12$

$\gamma = 17.8 KN/M^3$

$Z = 3.3$

$O = 22^O$

$\tau = 12 + 17.80 \times 3.2$

$= 12 + 56.96 \text{ Tan } 22$

$= 35 KN/M^2$

Igbo-Egun

$C = 9$

$\gamma = 17.15 KN/M^3$

$Z = 8.25$

$O = 24^O$

$\tau = 9 + 17.15 \times 8.25 \text{ Tan } 24$

$= 9 + 143.4 \text{ Tan } 24$

$= 73 KN/M^2$

Isaja

$C = 6$

$\gamma = 17.8 KN/M^3$

$Z = 2.7$

$O = 24^O$

$\tau = 6 + 17.8 \times 2.7 \text{ Tan } 24$

$= 6 + 48.06 \text{ Tan } 24$

$= 27.4 KN/M^2$

Average Stability Factor for Entire Length of Gully

Alanaka

$$F = \frac{8}{0.137 \times 2.86 \times 16.79} = 1.22$$

Ibete

$$F = \frac{12}{0.13 \times 3.20 \times 17.84} = 1.67$$

Igbo – Egun

$$F = \frac{9}{0.12 \times 8.3 \times 17.15} = 0.53$$

Isaja

$$F = \frac{6}{0.095 \times 2.7 \times 17.80} = 1.31$$

Determination of Factor of Safety

i) Alanaka

LHS			RHS		
C	=	$8KN/M^2$	C	=	$8KN/M^2$
Ø	=	23^0	Ø	=	23^0
H	=	3.2m	H	=	5.5
γ	=	$16.79\ KN/M^3$	γ	=	$16.79KN/M^3$
ß	=	80^0	ß	=	85^0
N	=	0.135	N	=	0.14
F	=	$\frac{8}{0.135 \times 3.2 \times 16.79}$	F.S	=	$\frac{8}{0.14 \times 16.79 \times 5.5}$
		= 1.1			= 0.62

ii) **Ibete**

LHS

C = 12

O = 22°

H = 3.20

γ = 17.82KN/M³

B = 80°

$$F = \frac{12}{0.14 \times 3.20 \times 17.80}$$

= 1.51

RHS

C = 12

O = 22°

H = 3.51

γ = 17.80KN/M³

B = 77°

$$F = \frac{12}{0.13 \times 3.25 \times 17.80}$$

= 1.60

iii) **Igbo-Egun (Upper)**

L.H.S

C = 9.KN/M²

O = 24°

H = 10.1

γ = 17.15 KN/M³

B = 80°

N = 0.13

R.H.S

C = 9.KN/M²

O = 24°

H = 10.5

γ = 17.15 KN/M³

B = 70°

N = 0.11

(L.H.S)

$$F.S = \frac{9}{0.13 \times 10.1 \times 17.15} = 0.40$$

(R.H.S)

$$F.S = \frac{9}{0.11 \times 10.5 \times 17.15} = 0.45$$

iv) **Isaja**

L.H.S

$C = 6KN/M^2$

$\phi = 24^\circ$

$H = 2.5$

$\gamma = 17.80KN/m^3$

$B = 75^\circ$

$N = 0.12$

R.H.S

$C = 6.KN/M^2$

$\phi = 24^\circ$

$H = 2.5$

$\gamma = 17.80\ KN/m^3$

$B = 55^\circ$

$N = 0.07$

(L.H.S)

$$F = \frac{6}{0.12 \times 3.85 \times 17.80} = 0.73$$

(R.H.S)

$$F = \frac{6}{0.07 \times 3.85 \times 17.80} = 1.25$$

Surface growth

Gully 1 Alanaka

2001

$G_{A1} = 10.8722m^2$

$R_1 = 1.1905m$

$L_g = 150m$

$L_{w1} = 4635m$

$P = 1.3562$

2002

$G_{A2} = 8.28105m^2$

$R_2 = 1.0825m$

$L_g = 150.5zm$

$L_w = 462m$

$P = 1.3405$

2001

$10.8722 = K\ 1.4905^{0.0982} \times 150^{0.7994} \times 462^{-0.2473} \times e^{-0.0014} \times 1.3562$

$10.8722 = K\ 13.63447$

$\therefore K = 10.8722/13.6344$

$= 0.7974$

2002

$8.28105 = K\ 1.0825^{0.0982} \times 150.52^{0.7994} \times 462^{-0.2473} \times e^{-0.0014} \times 1.3405$

$= K1.0078 \times 55.958 \times 0.2193 \times 1 \times 1.3405$

$8.28105 = K\ 15.986$

$\therefore K = 0.5180$

$= 0.5180$

Average K value = 0.6577

Gully 2 Ibete

2001

$G_{A1} = 2.866m^2$

$R_1 = 1.1905m$

$L_g = 36m$

$L_{w1} = 266.7m$

$P = 1.3562m$

2002

$G_{A2} = 2.2305m^2$

$R_2 = 1.0825m$

$L_g = 36.28m$

$L_w = 266.42m$

$P = 1.3405m$

2001

$2.866 = K\ 1.1905^{0.0982} \times 36^{0.7994} \times 266.70^{-0.2473} \times e^{-0.0014} \times 1.3562$

$= K\ 1.0078 \times 17.543 \times 0.2512 \times 1 \times 1.3562$

$= K6.023$

iv) **Isaja**

L.H.S

$C = 6KN/M^2$

$\Theta = 24^{o}$

$H = 2.5$

$\gamma = 17.80KN/m^3$

$B = 75^{o}$

$N = 0.12$

R.H.S

$C = 6.KN/M^2$

$\Theta = 24^{o}$

$H = 2.5$

$\gamma = 17.80\ KN/m^3$

$B = 55^{o}$

$N = 0.07$

(L.H.S)

$$F = \frac{6}{0.12 \times 3.85 \times 17.80} = 0.73$$

(R.H.S)

$$F = \frac{6}{0.07 \times 3.85 \times 17.80} = 1.25$$

Surface growth

Gully 1 Alanaka

2001

$G_{A1} = 10.8722m^2$

$R_1 = 1.1905m$

$L_g = 150m$

$L_{w1} = 4635m$

$P = 1.3562$

2002

$G_{A2} = 8.28105m^2$

$R_2 = 1.0825m$

$L_g = 150.5zm$

$L_w = 462m$

$P = 1.3405$

2001

$\therefore K = 2.866/6.023$

$= 0.4758$

2002

$2.2305 = K\ 1.0825^{0.0982} \times 36.28^{0.7991} \times 266.42^{0.2473} \times e^{-0.0014} \times 1.3562$

$= K\ 1.0078 \times 17.682 \times 0.2513 \times 1 \times 1.3562$

$= K\ 6.0629$

$\therefore K = 2.2305/6.0629$

$= 0.3679$

Average K value = 0.4219

Gully 3 Igbo-Egun

2001

$G_{A1} = 8.9955m^2$

$R_1 = 1.1905m$

$L_g = 34m$

$L_{w1} = 700m$

$P = 1.3562m$

2002

$G_{A2} = 11.011m^2$

$R_2 = 1.0825m$

$L_g = 35.4m$

$L_w = 700.61m$

$P = 1.3405m$

2001

$8.9955 = K\ 1.1905^{0.0982} \times 34^{0.7991} \times 700^{-0.2473} \times e^{-0.0014} \times 1.3562$

$= K\ 1.01727 \times 16.7596 \times 0.175022408 \times 1 \times 1.3562$

$= K\ 4.0468$

$= 8.9955/4.0468$

$= 2.223$

= K1.0078 x 26.0579 x 0.24076 x 1 x 1.3405

= K 8.46905017

∴ K = 3.28875/8.4690

= 0.3883

Average K value = 0.4718

Head advancement

Gully 1 Alanaka

2000/2001

Gh1 = 0.52m2

A1 = 186,200m2

S = 9.6%

R1 = 1.017m

CL = 3.8%

2001/2002

Gh2 = 0.32m2

A2 = 186199.25m2

S = 9.6%

R2 = 1.00/m

CL = 3.8%

2001

$0.52 = K\ 186200^{0.099} \times 0.09^{0.14} \times 1.017^{0.74} \times 0.038$

$= 1649225 \times 0.7138 \times 1.01255 \times 0.038$

$= K\ 4529.562$

$K = 0.52/4529.565$

$K = 1.148 \times 10^{-4}$

2002

$0.32 = K\ 186199.25^{0.99} \times 0.09^{0.14} \times 1.001^{0.74} \times 0.038$

$K164921.8399 \times 0.7138 \times 1.0017 \times 0.038$

2002

$11.011 = K\ 1.0825^{0.0982} \times 61.4^{0.7993} \times 1150.61^{-0.2473} \times e^{0.0014} \times 1.3455$

$= K 1.0078 \times 25.962 \times 0.175 \times 1 \times 1.3405$

$K\ 4.0919$

$\therefore K = 11.011/4.0919$

2.6909

Average K value = 2.457

Gully 4 Isaja

2001

G_{A1} = $3.67825m^2$

R_1 = 1.1905m

L_g 60m

L_{w1} = 316.5m

P = 1.3562m

2002

G_{A2} = $3.28875m^2$

R_2 = 1.0825m

L_g = 60.22m

L_w = 315.28m

P = 1.3405m

2001

$3.67825 = K\ 1.1905^{0.0982} \times 60^{0.7993} \times 316.5^{-0.2473} \times e^{0.0014} \times 1.3562$

$= K\ 1.0172 \times 25.962 \times 0.2408 \times 1 \times 1.3562$

$3.67825 = K\ 6.62524$

$K = 3.67825/6.62524$

$= 0.5552$

2002

$3.28875 = K\ 1.0825^{0.0982} \times 60.22^{0.7993} \times 316.72^{-0.2473} \times e^{0.0014} \times 1.3455$

$$= K1.0078 \times 26.0579 \times 0.24076 \times 1 \times 1.3405$$

$$= K\ 8.46905017$$

$$\therefore K = 3.28875/8.4690$$

$$= 0.3883$$

Average K value = 0.4718

Head advancement

Gully 1 Alanaka

2000/2001

$Gh1 = 0.52m2$

$A1 = 186{,}200m2$

$S = 9.6\%$

$R1 = 1.017m$

$CL = 3.8\%$

2001/2002

$Gh2 = 0.32m2$

$A2 = 186199.25m2$

$S = 9.6\%$

$R2 = 1.00/m$

$CL = 3.8\%$

2001

$$0.52 = K\ 186200^{0.99} \times 0.09^{0.14} \times 1.017^{0.71} \times 0.038$$

$$= 1649225 \times 0.7138 \times 1.01255 \times 0.038$$

$$K\ 4529.562$$

$$K = 0.52/4529.565$$

$$K = 1.148 \times 10^{-4}$$

2002

$$0.32 \quad K\ 186199.25^{0.99} \times 0.09^{0.14} \times 1.001^{0.71} \times 0.038$$

$$= K164921.8399 \times 0.7138 \times 1.0017 \times 0.038$$

= K 4476.537

∴ K = 0.32/4476.537

= 7.148×10^{-5}

Average value of K = $\frac{1.148 \times 10^{-4} + 7.148 \times 10^{-5}}{2}$

= 9.314×10^{-5}

Gully 2 Ibete

2000/2001

Gh1 = 0.28m

A1 = 75556.1m2

S = 13.6%

R1 = 1.017m

CL = 6.3%

2001/2002

Gh2 = 0.21m

A2 = 75555.72m2

S = 13.6%

R2 = 1.00/m

CL = 6.38%

2001

$0.28 = K\ 75556.1^{0.99} \times 0.136^{0.14} \times 1.001^{0.71} \times 0.063$

$= 67528.459 \times 0.7563 \times 1.012 \times 0.063$

= K 2358.9

K = 0.28/3256.13

K = 8.6×10^{-5}

2002

$0.21 = K\ 75555.72^{0.99} \times 0.136^{0.14} \times 1.001^{0.71} \times 0.063$

$= K67528.12 \times 0.7563 \times 1.0017 \times 0.063$

= K 3219.332

∴ K = 21/3219.332

= 6.523×10^{-5}

Average value of K $= \frac{8.6 \times 10^{-5} + 6.523 \times 10^{-5}}{2}$

$= 7.56 \times 10^{-5}$

Gully 3 Igbo-Egun

2000/2001			**2001/2002**		
G_{h1}	=	0.61m	G_{h2}	=	0.45
A_1	=	315000m2	A_2	=	314997.865
S	=	17.1%	S	=	17.1%
R_1	=	1.017	R_2	=	1.001
CL	=	2.9%	CL	=	2.9%

2001

0.61 = K $315000^{0.99} \times 0.171^{0.14} \times 1.017^{0.74} \times 0.029$

= K277041.19 x 0.7809 x 1.012 x 0.029

= K 6361

K = 0.61/6361

K = 9.59×10^{-5}

2002

0.42 = K $314997.865^{0.99} \times 0.171^{0.14} \times 1.001^{0.74} \times 0.029$

= K277539.33 x 0.7809 x 1.0009 x 0.029

$K\ 6289.583$

$\therefore K = 0.42/6289.583$

$= 6.678 \times 10^{-5}$

Average value of K

$$= \frac{9.59 \times 10^{-5} + 6.678 \times 10^{-5}}{2}$$

$= 8.134 \times 10^{-5}$

Gully 4 Isaja

2000/2001

$G_{h1} = 0.22m$

$A_1 = 832105.5m2$

$S = 5\%$

$R_1 = 1.012m$

$CL = 3.7\%$

2001/2002

$G_{h2} = 0.26m$

$A_2 = 832105.0247$

$S = 5\%$

$R_2 = 1.001m$

$CL = 3.7\%$

2001

$0.22 = K\ 832105.5^{0.99} \times 0.05^{0.11} \times 1.017^{0.74} \times 0.037$

$= 726066.5 \times 0.426 \times 1.012 \times 0.037$

$= K\ 11581591$

$K = 0.22/11581.59$

$K = 1.9 \times 10^{-4}$

2002

$0.26 = K\ 832105.247^{0.99} \times 0.005^{0.11} \times 1.001^{0.74} \times 0.037$

$= 726\text{-}66.63 \times 0.426 \times 1.0017 \times 0.037$

K 11452.273

$\therefore K = 0.26/11452.273$

$= 2.79 \times 10^{-5}$

Average value of $K = \dfrac{1.9 \times 10^{-5} + 2.79 \times 10^{-5}}{2} = 2.345 \times 10^{-5}$