SOIL LOSS ESTIMATION USING UNIVERSAL SOIL LOSS EQUATION (USLE) FOR KANO RIVER IRRIGATION PROJECT.

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M.ENG DISSERTATION

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DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of (Engr. Dr. SalisuDan'azumi) and has not been presented anywhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write-up (SafiyyahAliyu Mahmoud; SPS/13/MCE/00023) were carried out under our supervision.

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ABSTRACT

The loss of soil from farmlands may be reflected in reduced crop production potential, lower surface water quality, reduction of nutrients and organic matter, and loss of fertile top soil. This study was carried out to estimate soil loss using universal soil loss equation (USLE) for four sectors namely Yakasai, Kosawa, Chirin and Kode of the Kano River Irrigation Project. USLE comprises of the product of five factors namely; Rainfall erosivity factor (R), Soil erodibility factor (K), Slope length and gradient factor (LS), Crop cover and management factor (C), and Erosion control practice factor (P). The R-factor determined from rain gauge data of thirty years for Kano state was 143.07 (MJ mm/ha hour year), the K-factor determined from laboratory analysis of the soil samples was 0.4127 (tons hour/MJ mm) for Yakasai, 0.7581 (tons hour/MJ mm) for Kosawa, 0.3288 (tons hour/MJ mm) for Chirin and 0.3968 (tons hour/MJ mm) for Kode. LS-factor determined from survey measurements was 0.2084 for Yakasai, 0.2440 for Kosawa, 0.2246 for Chirin and 0.2296 for Kode sector, C-factor determined from literature was 0.175 & P-factor also determined from literature was 0.75. The estimated soil loss was 1.62 (tons/hectare/year) for Yakasai, 3.47 (tons/hectare/year) for Kosawa, 1.39 (tons/hectare/year) for Chirin and 1.71(tons/hectare/year) for Kode sectors. The soil loss estimated was classified as very low based on the Ministry of Agriculture, Food and Rural Affairs Ontario where any soil loss less than 6.7 (tons/ha/year) is regarded as very low. The estimated soil losses were lower than the maximum tolerable limit which is 12 tons/hectare/year. As such, the soil loss rate is within a tolerable limit. Therefore, the level of soil erosion will permit a level of crop productivity to be sustained economically and indefinitely in all four sectors. Some erosion control measures may be used to reduce and prevent potential soil loss.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Soil erosion by overland flow is a major ecological problem facing Nigeria and many parts of the world which are subject to heavy rainfall (Adewumi*et al.,* 2013). Soil erosion occurs when soil is removed through the action of wind and water at a greater rate than it is formed. It is considered the second prevalent environmental problem the world faces. Pimentel *et al*., (2009) revealed shocking figures about the erosion phenomenon, that is, most of the soil from farmlands is washed away about 10-40 times faster than it is being replaced, citing examples that United States was losing soil 10 times faster than the regular replacement rate, China and India are said to be losing soil 30-40 times faster. Soil erosion trend has increased throughout the 20th century. The land degradation in the world is about 85% which is associated with soil erosion, most of which occurred since the end of World War II, causing a 17% reduction in crop productivity (Angima*et al*., 2003).

The surface of the earth has taken millions of years to form and we must learn to respect it. Also, soil is formed at a rate of 1cm every 100 to 400 years and it takes 3000 to 12000 years to build enough soil to form a productive land (NDA, 1999). Soil is a non-renewable resource, once it is destroyed it is gone forever. Soil loss by water affects the soil quality and productivity by reducing infiltration rates, water holding capacity, nutrients, organic matter and soil depth. Land degradation is widely regarded as a global problem associated with desertification in arid, semiarid and dry sub-humid zones commonly called the dry lands (Gisladottir and Stocking, 2005).

In agricultural lands, accelerated soil erosion is responsible for loss of fertile top soil, depletion of soil fertility and subsequent decrease in crop productivity (Lal, 2003). The rate and magnitude of water erosion is controlled by rainfall and run-off, soil erodibility, slope gradient, slope length, cropping, vegetation and tillage practices. The loss of nutrient-rich topsoil from hill slopes causes severe agricultural problems for an extremely vulnerable agricultural society that depends on soil quality as a fundamental base for its livelihood (Erlangung, 2010).

Deforestation, overgrazing, intensive cultivation, soil mismanagement, cultivation of steep slopes and urbanization accelerate the soil erosion hazard and are the main causes of soil erosion. The three major causes of soil erosion are overgrazing with 35%, 30% deforestation and 28% excessive cultivation (Blanco and Lal, 2008). Farmers in developing countries depend on the food production every year and exclude conservation practices to reduce erosion risks. Nowadays, climate change can be listed to be one of the main drivers of soil erosion. Due to global warming, the amount of erosive rainstorms has increased. Soil erosion is a key element in the sector of land use change. Studies have figured out that soil erosion reduces the agricultural productivity approximately by around 10% for each 10cm of soil loss, depending on the soil texture, fertilizer etc, and even higher losses are possible (Baker*et al.,* 2004). The high rates of weathering and erosion processes prevent soils from reaching maturity. Also infiltration of water is decreased by shallow calcareous crust formations due to high evaporation rates (Jebari*et al.*, 2010) which in its turn accelerates the erosion processes. Earth landscape processes such as soil erosion and deposition have been active since the first rain fell and the first wind blew millions of years ago, playing a significant role in the formation of these landscapes (Toy *et al*, 2002). Erosion processes are driven by the potential energy generated from tectonic activities inducing the landscape cycle, raising and lowering the surface of the earth. The degradation of the landscape works through four types of external processes: rock weathering, mass movement, erosion and deposition (Toy *et al*, 2002).

According to Tukur*et al.,* (2013) in a study to examine the rate of sedimentation in the conveyance canals of Kano River Irrigation Project (Phase 1), there are deposits of fine sand fraction (76.3%)
with a small amount of clay and silt of about 12.04% and 11.66% respectively in the canals. The average canal concentration for the suspended sediment concentration was found to be 8474.4 ton per annum. They concluded that over the years, the canals at the Kano River Irrigation Project havenot received proper attention to remove the sediments from the canals. Rather, the problem of sedimentation is compounded by escalated erosion within and upstream of the irrigated plots by human and animal activities. This in turn affected the total hectares under cultivation and serious crises of irrigation water. As such, it is evident that erosion exits in the Kano River Irrigation Project.

In recent times, the evaluation of soil erosion which is multidisciplinary in nature is being achieved by the use of soil erosion models. These models assist in the understanding of a given system and therefore when used for hypothesis testing can provide a predictive tool for management. They are also useful in the design of erosion-control measures and the evaluation of land-use management practices (Szilassi*et al*., 2006). The choice of which model to use depends therefore on the objective and scale of work to be done, the availability of data and support facilities. A number of empirically and physically basedsoil erosion models have been developed.They include but are not limited to MEDRUSH(a product of the Mediterraneandesertification and land use Project), Universal Soil Loss Equation (USLE) and the Reviseduniversal soil loss equation (RUSLE),European soil erosion model (EUROSEM),Agricultural non-point source pollution model(ANGPS) and Water erosion prediction project (WEPP).

The universal soil loss equation was used to estimate the soil loss in this research. USLE was used for estimating the soil loss even though it was formulated using the environmental conditions of the eastern U.S.A. This was simply because there are no empirical models developed in Nigeria, Kano to be precise for estimating soil loss. Therefore, models developed in other countries are used for soil loss estimation in Nigeria. The USLE consist of the product of five factors namely; Rainfall erosivity factor (R), Soil erodibility factor (K), Slope length and Gradient factor (LS), Crop cover and management factor (C) and Erosion control practice factor (P). Ozcan*et al.*, (2008) pointed out some limitations of the USLE as a prediction model, because this equation predits the total soil loss of rill and inter-rill erosion without differentiating these components. Furthermore, this equation does not include soil loss as a result of gully formation and it does not estimate sediment deposition in specific areas. An additional limitation of the USLE is that it requires long-term data to develop the parameters for climate rainfall erosivity factor (R) and soil erodibility factor (K) for locations and soils outside the original data set.

1.2 PROBLEM STATEMENT

Soil erosion is one of the most serious ecological problems in the world. In agricultural lands, accelerated soil erosion is responsible for the loss of fertile top soil, depletion of soil fertility and decrease in crop productivity. Erosion act on land and inhabitants in many ways by changing the soil properties bringing economic consequences on populations. Erosion related economic hardship can be derived from physical and chemical changes in the soil properties, causing reduction in crop yields and requirements of increased efforts to maintain the agricultural productivity. These problems are related to the changes in water holding capacity, reduction in organic matter content and general soil degradation. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure or even change the texture. Textural changes can in turn affect the water holding capacity of the soil, making it more prone to extreme conditions such as drought (Jeje, 2005).

Ofomata (2012) revealed that sheet erosion is the most widespread type of erosion in the country and that every part of Nigeria is affected by one form of erosion or the other. Also, erosion in Borno, Kano, Kaduna and Sokoto is as a result of the combined effect of wind and water action, while the other parts of the country are affected by erosion due mainly to the action of running water. Soil erosion occurs in several parts of Nigeria under different geological, climatic and soil conditions. But the degree of occurrencevaries considerably from one part of the country to the other. The incidence of soil erosion in the country is not new, as it has formed a subject for serious consideration since the beginning of this century. Man needs the soil for his cultivation and has to clear the ground (bush or forest) for farming. He also burns the grass and trees and has need to graze his animals. Each of these activities leads to exposing the soil to the elements and, invariably, to accelerated soil erosion and deterioration, depending on the existence of other favourable conditions. These other factors include climate, topographic disposition and lithology, especially the nature of surface materials.

According to Isa (2002), Kano River Irrigation Project had a serious problem of siltation of canals due to the accumulation of sediment deposit and water weeds which increased the depth of the canals. This resulted to ponding of water and unnecessary overtopping of the canal embankments. The impact of siltation has reduced the discharge of the canals and therefore blocked all chances of getting adequate water supply.

The populace in the area covered by the Kano River Project do engage in tree cutting for charcoal burning, land clearing for cultivation and grazing of livestock which by far increases the rate at which the soil is lost. The authorities are less concerned in preventing unauthorized destruction of vegetation which results to soil erosion. Also, the general public are unaware of the potential problems of soil erosion due to the absence of educational efforts aimed at reducing deforestation through development of alternative energy sources.

1.3 JUSTIFICATION OF THE STUDY

This research is necessary as soil loss is one of the major forms of land degradation. From researches conducted by Isa (2002) and Tukur *et al*., (2013), it is evident that soil erosion exists in the Kano River Irrigation Project. According to the HadejiaJama'are River Basin Development Authority which is in charge of all the irrigation projects in the study area, the farmers in some of the areas have complained of soil loss from their farms. Estimating the soil loss in Yakasai, Kosawa, Chirin and Kode sectors of Kano River Irrigation Project will enable us to know the extent of the erosion, its effects on crops, cropped and uncropped lands and the suitable measures to be taken in order to prevent potential erosion. Due to the absence of current research on soil loss estimation using the universal soil loss equation in the above mentioned area, this type of research is important.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

This research is aimed at estimating the soil loss in Yakasai, Kosawa, Chirin and KodeSectors of Kano River Irrigation Project using the Universal Soil Loss Equation (USLE).

1.4.2 Objectives

i. To use rain gauge data and determine the rainfall erosivity factor (R).
ii. To collect samples of soil in the study area and determine the soil erodibility factor (K).
iii. To conduct survey measurements to determine the slope length-gradient factor (LS).
iv. To determine the crop/vegetation and management factor(C) and the erosion control practice factor (P).
v. To combine all the factors above in order to get the total soil loss.
vi. To check whether the soil loss found is within the tolerable limit or otherwise.

1.5 SCOPE AND LIMITATIONS

1.5.1 Scope

The soil loss was estimated for Yakasai, Kosawa, Chirin and Kode sectors of Kano River Irrigation Project using the universal soil loss equation which involves determining factors such as Rainfall erosivity factor (R), Soil erodibility factor (K), Slope length and gradient factor (LS), Crop cover and management(C)and erosion control factor(P).

The Study Area

The Kano River Project phase 1 consists of three local government areas notably Bunkure, Garun-Malam and Kura Local Government Areas. Kano River Project is a large scale intensive irrigation scheme designed to cover an area of 58,000 acres in Kano State. Kano State Government established the Kadawa Irrigation Scheme in 1970, and the Bagauda Lake in 1974. The project was under the authority of the HadejiaJamaare River Basin Development Authority in 1976. Kano River Project has 22,000 hectares of irrigable areas out of which only 15,000 hectares had been fully developed at cost of about N160 million between 1970 and 1984 (H.J.R.B.D.A, 2004.). The remaining 7000 hectares is being developed by present Civilian administration. The position of the project lies between 11º3'N - 12º3'N and 8º30'E - 9º40'E (Maurya, 1993). The total landmass was to cover about 60,000 hectares. It is located at a vast area over 25Km south of Kano city. The geology of the area belongs to northern Nigeria basement complex with dominant rock type of granitic gneisses and schist weathered by rivers (NEDECO, 1974).

The creation of large scale irrigation scheme in Kano State, has brought new ideas and opportunities to the people such as offering farmers improved irrigation machinery and crop varieties which have contributed to the increase in food and other raw materials to meet the needs of the growing population, and farmer's gross revenue worth billions of Naira annually. (H.J.R.B.D.A, 2004)

Kano River Project Phase 1 was carved out from three local government areas: Bunkure, Garun-Malam and Kura. In the irrigation project, water main canal splits the settlement into west and east branch regions. The economic activity of the natives is predominantlyagriculture during the dry and rainy seasons. During the dry season, farming is done through irrigation due to inadequate water/rainfall, except for some vegetable gardening, maize etc. The annual mean rainfall is between 500mm and 900mm. However, it is usual to regard mid-May to mid-October as the wet season (Leows and Ologe, 1981).

1.5.2 Limitations

The research was limited to soil loss estimation in Yakasai, Kosawa, Chirin and Kode sectors of the Kano River Irrigation Project.

1.6 CONTRIBUTION TO KNOWLEDGE

Universal Soil Loss Equation (USLE) has not been used to estimate the soil loss in Yakasai,Kosawa, Chirin, Kodeand all the other sectors of the Kano River Irrigation Project. As such, the research contributes to knowledge by providing basics for estimating the total soil loss in these sectors and other farmlands using the USLE.

CHAPTER TWO

LITERATURE REVIEW

2.1 PREAMBLE

Soil erosion is the single major process responsible for the loss of billion tons of soils worldwide. For example, Murck, *et al.*, (1996) estimated global rate of soil loss through erosion at over 25 billion tons per year for both rural and urban environments. Soil erosion is one form of land degradation along with soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization, and soil acidity problems. These other forms of land degradation, serious in themselves, usually contribute to accelerated soil erosion. Land degradation is one of the most serious ecological problems in the world. It entails two inter related, complex systems: the natural ecosystem and the human social system. Causes of land degradation are not only biophysical, but also socio-economic (marketing, income, human health, poverty), undermining food production and political stability (UNCCD, 2004; and WMO, 2006). Soil erosion is a naturally occurring process involving the mobilization and deposition of soil particles, mainly by water and air.

It is inevitable that human beings will face the fatal effects of soil erosion in the near future (Collins, 2001). However, while soil erosion is a feature of any natural ecosystem, the rate at which it is taking place has been significantly accelerated by anthropogenic influences, most notably inappropriate land use activities associated with agriculture (Inman, 2006).

Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage (Wall *et al.*, 2003). Soil erosion is often considered as a cause and an effect of desertification (Lal, 2001) and important feedbacks have been shown to exist amongerosion, biodiversity loss and climate change. An increase in rates of soil erosionbecause of climatic changes that increase aridity could result in enhanced loss of soilresources and a loss in biodiversity, which can further increase rates of soil erosion and resultin loss of vital services from dry lands, including the possible reduction in primary production (Chapin *et al.*, 1997).

Soil erosion is a serious environmental, economic, and social problem. It not only causes severe land degradation and soil productivity loss, but also threatens the stability and health of society in general and sustainable development of rural areas in particular (Jing *et al.*, 2005).

2.1.1 Soil Erosion Along the Kano River Irrigation Project

According toSalisu*et al.,* (2014), there is widening of cross section dimension of virtually most of the field in the Kano River Irrigation Project and collector drains with fewer affected by silt deposition due to channel erosion and distortion of the bed slope, transportation of eroded materials by both water and human activities in the project area. It was recommended that efforts should be made to reduce erosion in the upstream areas through tree planting at the erosion catchment area and to prevent cattle using the canals and irrigated farms as transit routes, (Isa, 2002)

2.2 SOIL EROSION BY WATER

This type of erosion is generally classified by the erosive agent inducing the process; water (Toy *et al.*, 2002). According to Kirby (2000), two third of the erosion is caused by water. Soil can be detatched by splashing or by the effect of raindrops on the soil surface. Water erosion can occur in many ways, for example coastal erosion by waves, splash erosion from the impact of precipitation and irrigation water, erosion due to overland flow (also called sheet erosion or rill/inter-rill erosion), stream channel erosion or erosion by percolating water (Strahler and Strahler, 2003). Basically the impact of water droplets and/or the sheer stress caused by water in motion detaches soil particles, followed by transport and finally deposition of the particles eroded (Strahler and Strahler, 2003).

During storm events, rainfall intensity can exceed the infiltration capacity of the soil and the excess water will form a runoff directed downslope (Toy *et al.*, 2002). The magnitude of the runoff varies due to different factors such as the initial soil moisture, the infiltration capacity and the variations in precipitation intensity (Toy *et al.*, 2002). The moving water in the runoff and sub-surface flow naturally induces erosion on the soil. The runoff will cause sheet erosion, which is more or less spatially uniform in the removal of soil, or rill erosion which occurs in small closely related channels called rills (Strahler and Strahler, 2003;). With time, rill erosion will progress to gully erosion as the channel increases in size and is defined as a gully (Toy *et al.*, 2002).

2.2.1 Factors Controlling the Rate of Water Erosion

Soil erosion is controlled by(Wall *et al.*, 2003):

i. Rainfall intensity,
ii. Soil erodibility,
iii. Slope gradient and length,
iv. Vegetation and
v. Conservative measures.

i Rainfall intensity

The greater the intensity and duration of a rainstorm, the higher the erosion potential. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter are easily removed by the raindrop splash. Both rainfall and runoff factors must be considered in assessing water erosion problem (Ritter, 2012). The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles. Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short duration, high-intensity thunder storms. Although the erosion caused by long-lasting and less intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time. Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff can be increased if infiltration is reduced due to soil compaction, crusting or freezing. Runoff from the agricultural land may be greatest during spring months when the soils are usually saturated, snow is melting and vegetative cover is minimal.

ii Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Many factors are important for the soils ability to resist erosion. The permeability is important since it defines how the precipitation will be divided in terms of soil moisture, surface runoff and infiltrated ground water (Toy *et al*, 2002). Also organic content is important; higher organic content will decrease the soil erodibility (FAO, 1996). As high organic content increases the porosity and thereby also the permeability and the water holding capacity of the soil, potential erosive runoff is reduced (Jankauskas*et al.*, 2007). High presence of coarse grain size particles also reduces the erosion significantly. For example, in Mediterranean calcareous soils like the soils of semiarid Tunisia, a 10% presence of pebbles in the surface horizon reduces the erodibility by as much as 15%, while a high content of pebbles indicates good resistance to erosion (FAO, 1996).

iii Slope Gradient and Length

Naturally the steeper the slope of a field, the greater the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Slope affects erosion and depth of soil as the greater the slope, the greater the erosion. Topography can be uniform (constant over the length), convex (increasing slope), concave (decreasing slope) or a complex of these (Toy *et al.*, 2002). Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (Wall *et al.*, 2003).

iv Vegetation

The loss of protective vegetation through overgrazing, ploughing and fire makes soil vulnerable to being swept away by wind and water. Plants provide protective cover on the land and prevents soil erosion because the plants slow down the water as it flows over the land and this allows much of the rain to soak into the ground. Plants also break the impact of a raindrop before it hits the soil, reducing the soil's ability to erode (NDA, 1999).

Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate. The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil, and which intercept all falling raindrops at and close to the surface and the most efficient in controlling soil (e.g. forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

v Conservation Measures

Certain conservation measures can reduce soil erosion. Land management practices such as tillage and cropping practices directly affects the overall erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of approaches or more extreme measures might be necessary. For example, contour plowing, strip cropping, or terracing may be considered (Ritter *et al.*, 2012).

2.2.2 Types of Soil Erosion by Water

The expression "erosion by water" has been used to describe many widely different phenomena, including the depletion of soil constituents by dissolution and leaching (El-Swaify, 1976). Soil erosion by water is the result of rain detaching and transporting vulnerable soil either directly by means of rain splash or indirectly by rill and gully erosion Early in the study of erosion, the mode of running water on the land surface was considered to take essentially three forms: sheet, rill, and gully erosion. Sheet erosion, now frequently called inter rill erosion, involves the more-or-less even removal of layers of soil from an entire segment of sloping land, and is by far the least conspicuous. It is the type of erosion that results from runoff that spreads across the soil surface during rainfall (i.e. when the infiltration rate has been exceeded).

It may take various forms and degrees. It typically occurs evenly over a uniform slope and goes unnoticed until most of the productive topsoil has been lost (Ritter *et al.*, 2012). Sheet erosion is caused by the force of raindrops impacting on bare soil and dislodging particles of earth. This force is dependent on the speed of fall (a function of the length of fall and the wind speed) and the weight (a function of the diameter of drops).

Rill erosion results when surface water runoff concentrates, forming small yet well-defined channels. Rill erosion results from the concentration in surface depressions of water that subsequently flows down slope along paths of least resistance thus forming micro channels or rills (El-Swaify, 1976). Rill erosion occurs when runoff water forms small channels as it concentrates down a slope. These rills can be up to 0.3m deep. If they become any deeper than 0.3m they are referred to as gullies.

Gully erosion is an advanced stage of rill erosion where surface channels are eroded to the point where they become a nuisance factor in normal tillage operations. Gully formations are difficult to control if corrective measures are not designed and properly constructed. Control measures must consider the cause of the increased flow of water across the landscape and be capable of directing the runoff to a proper outlet. Gully erosion results in significant amounts of land being taken out of production and creates hazardous conditions for the operators of farm machinery (Ritter, 2012). Gully erosion happens when runoff concentrates and flows strongly enough to detach and move soil particles. Splash back at the base of the gully erodes the subsoil and the gully eats its way up the slope. Gullies may develop in watercourses or other places where runoff concentrates. In cultivation or pastures, advanced rill erosion can develop into gully erosion. Gully depth is often limited by the depth of the underlying rock which means gullies are normally less than 2m deep but may reach depths of 10-15m.

Bank erosion is the wearing away of the banks of a stream or river. This is distinguished from erosion of the bed of the watercourse which is referred to as scour. The roots of trees growing by a stream are undercut by such erosion. When a stream is straightened or widened, stream bank erosion increases. Damaging or removing streamside vegetation to the point where it no longer provides for bank stability can cause a dramatic increase in bank erosion. A degrading streambed results in higher and often unstable, eroding banks. When land use changes occur in a watershed, such as clearing land for agriculture or infrastructural development, runoff increases. With this increase in runoff the stream channel will adjust to accommodate the additional flow, increasing stream bank erosion. Addressing the problem of stream bank erosion requires an understanding of both stream dynamics and the management of stream side vegetation.

2.2.3 Effects of Soil Erosion by Water

The effects of soil erosion can be felt both onsite meaning at the site of soil disruption or off-site, meaning the location where the soil deposits. When the top soil is eroded from an area, the area loses its most nutrient rich layer and therefore the soil quality is reduced. Poor soil quality means smaller crop yields and may even wash away seeds and small plants. Crop emergence, growth and yield are directly affected by the loss of natural nutrients and applied fertilizers. Seeds and plants can be disturbed or completely removed by the erosion. Organic matter from the soil, residues and any applied manure is relatively light weight and can be readily transported off the field. Pesticides may also be carried off the site with the eroded soil. Soil quality, structure, stability and texture can be affected by the loss of soil (Ritter *et al*., 2012).

The soil carried away needs to go somewhere, and this leads to off-site problems. When soil is carried away from a farmer's field by water, it carries with it contaminants, such as fertilizers and pesticides, this run-off can cause water pollution that contaminates drinking water and disrupts ecosystems of lakes and wet lands. This negatively impacts the fish and wildlife that depends on these downstream waters for food and habitat. Sediments that accumulates downslope of the erosion can obstruct the flow of water in streams and drainage canals, leading to flooding. The off-site impacts of soil erosion by water are not always as apparent as the on-site effects. Eroded soil deposited downslope, inhibits or delays the emergence of seeds, burry seedlings and necessitates replanting in the affected areas. Also sediment can accumulate on down-slope properties and contribute to road damage. Sediments that reaches streams or water courses can accelerate bank erosion, obstruct stream and drainage channels, fill in reservoirs, damage fish habitat and degrade downstream water quality (Ritter *et al*., 2012).

In a study conducted by Inman (2006),the effects of soil erosion can be sub-divided into on-farm and off-farm impacts On-farm impacts are predominantly borne by the farmer and are essentially related to loss of production capacity. As soil erosion takes place, the ability for cereal crops and grass to flourish is reduced which, in turn, has a direct impact on the productivity of the land. The upper soil horizon or 'top soil' is the most productive component of any soil series and it can take up to 150 years for 1cm of topsoil to develop (Inman, 2006).

Off-farm impacts of soil erosion are largely inflicted on wider society and take a number of forms such as flooding, declining water quality and pollution of air; involving emissions of greenhouse gases such as carbon dioxide, methane and nitrous oxides. Soil eroded from agricultural land will often find its way into a main river channel from where it can be transported downstream as far as the sea. In order to illustrate the off farm impacts of water induced soil erosion in a logical manner, it is helpful to visualize a hypothetical ton of soil as it moves from land situated in the headwaters of a catchment progressively downstream into the marine environment. By tracking the pathway of soil erosion in this way, it is possible to identify some of the main impacts of eroded soil at each stage of the journey. These impacts are briefly outlined below:

i. Damage to roads and footpaths - When significant quantities of soil are eroded from agricultural land, roads and footpaths can become blocked which has a negative impact on motorists and walkers. Soil deposition on roads can induce traffic accidents due to the creation of slippery surfaces and can also increase localized flooding when drains become blocked by excessive sediment loads.

ii. Impacts on strategic reservoirs - Sediment entering reservoirs can reduce storage capacity and can also create infrastructural difficulties e.g. blocking outlet valves. Management solutions take many forms from the creation of up-stream silt traps ('ponds') through to dredging, all of which have cost implications. The process of transporting and disposing of silt can be particularly costly.

iii. Nutrient enrichment of freshwater water bodies - Soil particles often have phosphate attached to them due to a chemical bond between phosphates and clay fractions within the soil. If phosphate levels in water bodies become too high, excessive nutrient loadings can occur resulting in eutrophication taking place and a corresponding depletion in oxygen levels. This can have fatal effects on macrophytes, fish and other freshwater flora and fauna. Certain forms of algae are toxic to humans which means their proliferation due to nutrient enriched waters is less than desirable on human health grounds.

iv. Contamination of drinking water - Soil erosion has a significant effect on the quality of potable drinking water supplies. Not only do suspended sediments affect the taste of water but the associated phosphate loads also have to be removed by water companies to provide drinking water fit for human consumption.

v. Siltation of waterways impeds navigation - Soil emanating from agricultural land will often end up in estuaries or harbors. When the level of soil deposition reaches a certain threshold, navigation by ships and boats becomes impossible and it is necessary to dredge impacted areas. This is a costly and difficult process

vi. Nutrient enrichment of marine water bodies - The phosphate loadings associated with soil erosion do not just impact freshwater water bodies as discussed above. Phosphate also reaches marine waters which are increasingly suffering from high levels of nutrient enrichment, much of which emanates from agricultural land. It is unfortunate to note that much of the sediment dredged from estuaries and harbors are dumped in the sea, thereby contributing to nutrient enrichment in marine waters

2.3 SOIL EROSION CONTROL

Toy *et al*., (2002) described some basic concepts for erosion-control principles. Some important conservation practices are listed below;

i. Maintain vegetation/ground cover. Erosion is reduced by the ground cover providing canopy that intercepts the rainfall and thereby reduces its erosivity. Ground cover from plant litter also contributes and root networks improves soil fixation. Plant litter is preferably maintained for the period of highest rainfall erosivity (if not possible for the whole year).

ii. Add support practices such as banquettes, terraces, vegetation strips, strings of rock and armored waterways to reduce erosion in steep slopes. Ridging or contouring perpendicular to the runoff is also a good measure.

iii. Modify the topography to avoid convexity at the end of slopes. Flat and concave segments at the end of a slope are preferred to induce deposition.

iv. Incorporate biomass (manure, sewage sludge, paper mill waste) into the soil; as mentioned in 2.2.1 soil erodibility, the erodibility is reduced with increased organic matter content in the soil. Also the litter of last year's crop will contribute to higher organic matter content.

2.3.1 Other Erosion Control Methods

As compiled by Sutton and Williams (2015), other erosion control methods are:

i. Erosion Control Blanket

Erosion control blankets are usually woven from a chosen material and are meant to slow down the speed at which water moves across the surface. The material chosen is usually something with lots of ridges and obstructions for the water to slow down on. There are many different types of erosion control blankets, some that are synthetic and some that are natural. There are even a few that are both synthetic and natural. These blankets can be made out of straw, coconut fiber, aspen fiber, jute, and polypropylene (plastic). Most of these blankets can be bought in many sizes. Common ones are 80 to 100 square yards. Most of these are rolled up and cut into widths ranging from 3 to 8 feet wide.

The erosion control blankets are relatively easy to install. The largest concern is making sure the water moves over the top of the blankets. To do this one needs to key it into the slope by digging a small trench on the top of the slope. In this trench the top end of the material is laid into the trench to line it. To line it the edge is folded underneath itself and then it is secured using staples. The trench is then filled up to the previous soil level. The edge of the blanket that is upwind needs to be overlapped underneath the blanket next to it.

ii Fiber Rolls

Fiber rolls are the other type of erosion control device. These are usually made of the same materials used in erosion control blankets but are rolled into large diameter "logs." These logs can be made to just about any diameter and are usually incased in some kind of netting sewing into the desired shape. The purpose of these logs is to pool up and slow down water long enough for any sediment that is in the water to settle out. The three major materials used in fiber rolls are coconut fiber, rice wattle and wheat wattle. The concept behind the fiber roll is the same regardless of the material.

The installation of the fiber logs does not change based on the material used. The basic concept of a fiber log is to lock it into place so that soil and water cannot remove it from where it is installed. A trench is dug at a depth equal to half of the diameter of the log. This is so that the fiber log can become part of the slope. Wooden stakes are used to hold them in place. They are approximately 2-3 feet apart and the type of stake is dependent on the situation. If a species that can be live staked can survive in your location, it is a good idea to use a live stake to hold the log in place and to also start vegetative establishment. Planting into the fiber log is also a good way to establish plants.

iii Alternatives

Some alternatives to erosion control blankets and coir logs are hydro mulch, temporary silt fencing or using real logs and rocks to create locations for water to settle out. Hydro mulching can be expensive and is not effective during the rainy season, but if the species that colonize the site can be established before the mulch runs off, it can be very successful. The downside is that unless you plant the species you want; invasive species can show up. Temporary silt fences are usually meant to catch any runoff from the construction of the project, but they can be used until the slope re-establishes itself enough to stop any runoff. Once this is accomplished, removal of the fences is required. Finally using the natural material to create runoff catch basins can be a very cheap process if there are available materials on site. Another benefit is that the catchment areas can appear to be natural to the untrained observer. A problem with these natural catchments is that you can only create them in areas that the water funnels to and they cannot be made on a large scale.

2.4 THE UNIVERSAL SOIL LOSS EQUATION (USLE)

The simplest mathematical model for prediction of soil loss is the Universal Soil Loss Equation (USLE) and has been frequently used over the world since it was developed by American statistician W. H. Whichmeier in the 1960's (Fistikogli and Harmancioglu,2002).USLE as a complete technology was first published in United States Department of Agriculture (USDA) handbook 282. An updated version was published in 1978 in USDA handbook 537. The model is empirical and was developed using over 10,000 statistical records of erosion, sampled over the American Great Plains (FAO 1996). The USLE is the most widely used equation in erosion modeling (Fistikogli and Harmancioglu, 2002) and also the most commonly used estimator of soil loss caused by overland erosion. The equation was based on an extensive set of more than 10,000 plot years of runoff and soil loss data from experimental centers in the eastern U.S.A. The

USLE was designated "universal" because it is free of some of the generalization and geographic and climatic restrictions inherent in earlier models. The USLE identifies the major factors affecting soil loss (Lal, 1994).

There exist several models to predict the extent of water induced erosion (Brady and Weil, 2002, 2008) such as Water Erosion Prediction Project (WEPP) (La'en*et al*., 1991) and the European Soil Erosion Model (EUROSEM) (Morgan et al., 1992). EUROSEM model have been developed to describe and quantify soil erosion processes and are particularly suitable for adaptation across arrange of scales in the landscape. The model deals with: the interception of rainfall by the plant cover; the volume and kinetic energy of the rainfall reaching the ground surface as direct through fall and leaf drainage; the volume of stream flow; the volume of surface depression storage; the detachment of soil particles by raindrop impact and by runoff; sediment deposition; and the transport capacity of the runoff (Morgan *et al*., 1992). On the other hand, WEPP is an American model based on a continuous simulation approach in which changing soil moisture conditions are modelled from daily calculations of the soil water balance. In this way, the conditions at the start of each rainstorm are predicted. The problems with continuous simulation models are that they require a large amount of input data on changing climatic and land use conditions over a year. These continuous simulation models are highly sensitive to the modelling of evapotranspiration and dynamic properties of the soils and they yield predictions for a large number of events that produce only small amounts of runoff and soil loss (Morgan *et al*., 1992).

However, the USLE has been useful in predicting the average rate of soil loss due to water erosion from agricultural lands (Wischmeier and Smith, 1978). In the early 1990s the basic USLE was updated and computerized to create an erosion prediction tool called the Revised Universal Soil Loss Equation (RUSLE) as reported by Renard*et al*.,(1997). The USLE/RUSLE soil loss prediction is dependent upon soil properties including texture, organic matter content and structure of the soil. The predicted soil loss A is estimated using the following equation:

The USLE, derived empirically is (Lal, 1994):

……………………………………………….. (2.1)

Where;

A= The average annual soil loss (tons/ha/yr)

R= Rainfall erosivity factor (MJ mm/ha hryr)

K= Soil erodibility factor (tons hr/MJ mm)

LS= Slope-length (dimensionless) and slope-gradient factor (dimensionless)

C= Cropping-management factor (dimensionless)

P= Erosion-control practice factor (dimensionless)

Each of the six factors in the USLE has been formulated by Wischmeier (1978) in such a way that it is linearly related to the soil loss. Each variable can be isolated and quantified into numbers using standard USLE plots or unit plots (Lal, 1994). When the variables of the USLE are multiplied together, the answer is the amount of soil loss. Amongst the USLE factors,soil erodibility (K) factor is applicable to most tropical soils (El-Swaify and Dangler, 1976; Roose, 1977; Angima*et al*., 2003) and was found to strongly correlate with soil loss (Tejada and Gonzalez, 2006). Soil characteristics influencing soil erodibility are infiltration capacity and structural stability (Millward and Mersey, 1999). These are largely influenced by soil texture, organic matter and soil plasticity. High infiltration capacity means that less water will be available for runoff and the surface is less likely to be ponded and more susceptible to splashing. In particular, soils which are highly permeable have high infiltration capacities (e.g. sandy soils) and are more prone to water erosion since the soil easily allows water to penetrate and therefore easily washed away (Zachar, 1982). On the other hand, stable aggregates resist the beating action of rain and thereby save soil even though runoff may occur. The factors that determine aggregate stability include bulk density, atterberg limits as well as texture and organic matter content of soils (Toy *et al*., 2002).

Moreover, soils with larger sand and silt proportions are more vulnerable to water erosion due to lack of stability of soil particles (Toy *et al*., 2002). Similarly, soils with relatively low organic matter content are very vulnerable to water erosion (Brady and Weil, 2002) since organic matter increases the stability of soil. A 36% decrease in K-factor value was observed in organic matter amended soil in respect to the control (Tejada and Gonzalez, 2006). Furthermore, the susceptibility of soil to water erosion also depends on slope length (Toy *et al*., 2002) and is most prevalent in sloping areas (Angima*et al*., 2003).

The USLE may properly be used to (Wischmeier, 1978):

i. Predict average annual soil movement from a given field slope under specified land use and management conditions;

ii. Guide the selection of conservation practices for specific sites;
iii. Estimate the reduction in soil loss that would result from a change in cropping or conservation practices;
iv. Determine how conservation practices may be applied or altered to allow more intensive cultivation;
v. Estimate soil losses from land use areas other than agricultural purposes; and
vi. Provide soil loss estimation for determining conservation needs.

2.4.1 Universal Soil Loss Equation (USLE) Parameters

i Rainfall Erosivity Factor (R)

The contribution of the erosive agent water (precipitation) is represented by the rainfall erosivity factor R. This factor may be the most important factor in the USLE compared to the other input parameters (Jebari, 2009). The kinetic energy of the rain can be considered as the potential rainfall energy available to be transformed into erosion. The erosivity of a single raindrop is naturally described as the droplet kinetic energy E; the mass of the droplet multiplied by the square of the velocity at impact divided by two; $E=mV^2/2$(Toy et al, 2002). The R-factor corresponds to this kinetic energy *E* of the rainfall, multiplied by the maximum intensity of a 30-min rain I_{30}according to the original approach by Wischmeier (FAO, 1996), however Jebari*et al*., (2008) found that using 15-min periods for the maximum rainfall intensities could be more suiting for semiarid regions. The R-factor is calculated over long term conditions (20 years) for all storm events. Then an annual average is deduced from this (FAO, 1996). According to the original approach by Wischmeier, two valid storm events must be separated by a minimum of six hours.

Erosivity is the power of a storm to erode soil. It is usually determined from the storm characteristics such as rainfall intensity and energy. At the plot surface the storm power is expended in several components:

i. Rainfall power, the product of the total amount of incident rainfall energy and intensity;
ii. The runoff power or stream power, the product of the flow rate and the flow gradient; and
iii. Seepage power, the product of the seepage gradient and seepage flow rate

The numerical value used for the R-factor in the soil loss equation must quantify the raindrop impact effect and must also provide relative information on the amount and rate of runoff likely to be associated with the rainfall regimes (Lal, 1994). The storm erosion index or Storm $EI_{30,}$ derived by Wischmeier appears to meet these requirements better than any other of the many rainfall parameters. The relationship is expressed by the equation (Lal, 1994),

$$\text{Storm } EI_{30} = \{\sum 1099 \times [1 - 0.72 \times \text{Exp}(-1.27 \times Ir)] \times Rr\} \times I_{30} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

Where;

I_{30}= maximum rainfall intensity during the storm.

Ir = rainfall intensity (inch/hour) in a particular time interval of the storm.

Rr = rainfall amount (inch) during the same time interval.

These values are inputted into equation (2.2) for each time interval of the storm. The sum of the computed values is called the storm energy or E value. The E value is multiplied by the I_{30}, which is the maximum 30-minute intensity during the storm. The product is called the Storm EI_{30}. It is expressed in foot-ton inches per acre-hour (Lal, 1994).

Previous research has indicated that storm soil losses from cultivated fields were directly proportional to a rainstorm parameter identified as the Storm EI_{30}. The sum of the storm EI_{30} values for a given period is a numerical measure of the erosive potential of the rainfall within the period. The average annual total of the storm EI_{30} values in a particular locality was the rainfall erosion index (R-factor) for that locality (Lal, 1994).

Rills and sediment deposits observed after an unusually intense storm have sometimes led to the conclusion that significant erosion was associated with only a few storms, or that it was solely a function of peak intensities. However, more than 30 years of measurements in the U.S. mainland have shown that this was not the case. The data show that a rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms, as well as the effects of the occasional severe ones (Lal, 1994).

ii The Soil Erodibility Factor (K)

The soil erodibility factor can be described as the soils tendency to erode. It is dependent on the local soil properties and can be determined in various ways; through sample analysis of the soil, from a soil map or survey of the site or through a combination of these (Jebari, 2009; Fistikogli&Harmancioglu, 2002). Two energy sources are considered to erode the soil and the erodibility factor is defined by the soil ability to resist these sources; the surface impact of the rain droplets and the shearing stress of the horizontal runoff (FAO 1996). Wischmeier determined the main attributes for the soil erodibility factor with experimental plots with both simulated and natural rain under specific conditions; 22-meter plot length, 9% plot slope, no organic matter ploughed in for three years and cultivation of the plot in the direction of slope (FAO, 1996). Wischmeier found that the main attributes of the soil for determining the K-values were organic matter content, texture, surface horizon structure and the permeability.

When determining the K-factor by sample analysis the following data is determined (Whishmeier and Smith, 1978);

i. The percentage of silt and fine sands; grain sizes 0.002 mm – 0.100 mm
ii. The percentage of sands; grain sizes 0.100 mm – 2 mm
iii. The percentage of organic matter content
iv. The soil structure class where the aggregate durability is considered; 4 classes are used
v. The soil permeability class; 6 classes are used

Soil erosion depends not only on rainfall erosivity but also on the soil's resistance to erosion, which is measured as the soil erodibility factor K. The measurement of K can be done using Universal

Soil Loss Equation (USLE) given by Wischmeier and Smith (1978) by knowing other factors of the equation using natural or simulated rainfall experimentation, but this process is costly and time consuming.

Wischmeier*et al*. (1971) gave empirical nomograph for estimating erodibility from basic soil properties. Fuzzy logic based program FUZKBAS was also given by Torri*et al*. (1997) to obtain K values.The modified version of nomographic expression given by Wischmeier*et al*. (1971) for estimating K in SI units (thr / ha MJ mm) as given by Rosewell(1993) is.

$K = 2.77\ M^{1.14}(10^{-7})(12-\alpha) + 4.28(10^{-3})(\beta-2) + 3.29(10^{-3})(\gamma-3)$………………………….. (2.3)

Where,

M = (% silt+% Very fine sand) (100-% clay),

α = Organic matter (%),

β = structure code and

γ = permeability rating.

For soils with less than 70% silt plus very fine sand, the nomograph can be expressed by the following relationship (Wischmeier*et al*., 1971;Wischmeier and Smith, 1978):

$K= [2.1 \times 10^{-4} \times (2 - OM) \times M^{1.14} + 3.25 \times (St - 2) + 2.5 \times (pt - 3)]/100$………………. (2.4)

Where;

K= Soil erodibility factor

OM= Organic matter content (%)

M=(% Silt +%fine sand) × (100-%Clay)

St= Soil structure code

Pt= permeability class

Figure 2.1 shows a nomograph that is used in determining soil erodibility factor.

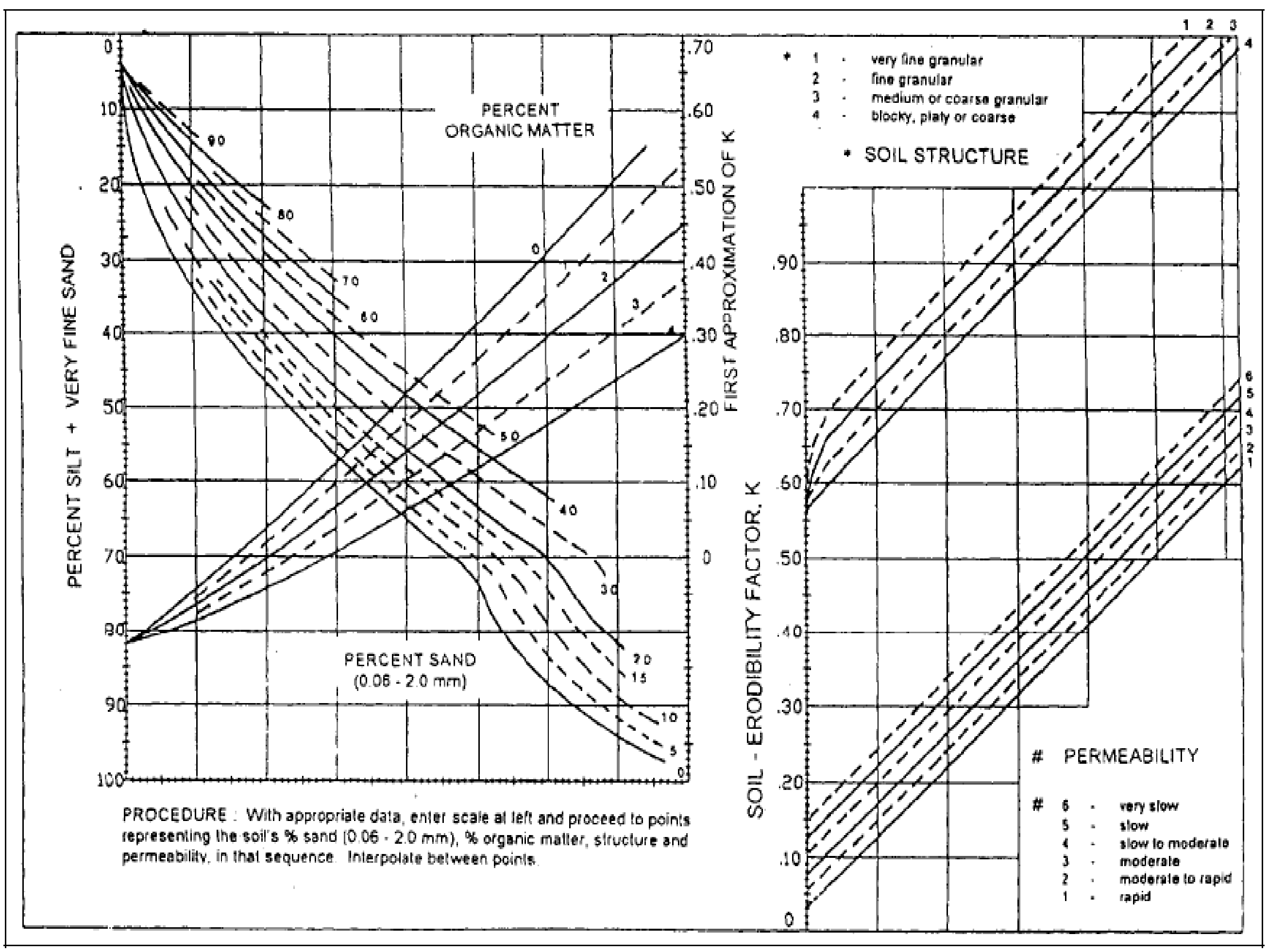

Figure 2.1**:** Nomograph for calculating soil erodibility factor (Tew, 1999)

iii Slope Length & Gradient Factor (LS)

Although slope has a powerful influence on erosion, the presence of erosion and heavy run-off on gentle slopes indicates that this phenomenon can occur without any need for gentle slope. Slope intervenes in erosion in terms of its form, gradient, length and position. As the gradient increases, the kinetic energy of rainfall remains constant but transport accelerates toward the foot as the kinetic energy of the run-off increases and outweighs the kinetic energy of the rainfall when the slope exceeds 15%. Zhang (2007) showed that soil loss increases exponentially with the slope gradient. In the United States, the exponent is 1.4. Hudson and Jackson (2000) emphasized that in Central Africa, aggressiveness of the climate increases the effect of slope over what is found in the United States, so that they obtained exponents averaging about 1.63 on complete rotations (including grassland and fallow periods), and up to 2.02 on clayey soil and 2.17 on sandy soil under extensive maize cropping. An exponent in the region of 2 would seem more likely under African conditions. In theory, the longer the slope, the more run-off will accumulate gathering speed and gaining its own energy, causing rill erosion and more serious gullying. The influence of slope on run-off is still less clear, being sometimes positive, sometimes negative, sometimes nil, depending on the prior moisture and condition of the soil surface (Wischmeier and Smith, 1978). There are two effects that topography has on erosion. Obviously, steeper slopes favor greater erosion but the length of a slope also plays an important role. In general, the longer the slope, the greater the erosion, because longer slopes favor higher water velocities. To counteract the effects of topography on erosion, farmers are encouraged to employ soil conservation measures such as contour ploughing and strip cropping.

The slope length and steepness factor (LS-factor) describes the combined effects of slope length and slope gradient. It represents the ratio of soil loss per unit area on a site to the corresponding loss from a 22.1m (72.6ft) long experimental plot with 9% slope. Slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for disposition to occur or to the point where run-off enters a defined channel (wet or dry). The slope steepness is the segment or site slope, usually expressed as a percentage. Although the LS factor has traditionally been expressed as two parameters in the USLE, it is universally computed as a combined term. Slope length and slope steepness strongly influence the transport of soil particles once the soil particles are dislodged by raindrop impact or run-off.

Because the LS factor can be defined to be substantially greater than unity, it can have a considerable effect on the predicted erosion (Whischmier& Smith, 1978).

Slope length and slope gradient are normally combined into one single factor. Different empirical relations are used to determine this factor and many recent studies (Jebari, 2009) use the equation recommended by Morgan and Davidson (1991). The equation recommended by Morgan and Davidson is expressed as:

$LS = \sqrt{(L/22)}\ [(0.065 + 0.045\ S) + (0.0065 S^2)$……………………………………….(2.5)

Where;

L = Slope length (m)

S = Slope steepness (%)

Another equation used to determine the LS factor by Goldman et al, (1986) is mathematically expressed as:

$S_{fact=}\ [65.41(S^2_{slope}/a^2) + 4.56\ (S_{slope}/a) + 0.065]\ (4.53 \times 10^{-4} L_{slope})^{mLS}$…………………… (2.6)

$a = (S^2_{slope+}\ 10000)^{0.5}$ ……………………………………………………………… (2.7)

Where;

S_{slope} = Slope gradient in percent

a = a factor in the LS factor equation (unitless)

L_{slope}= slope length (cm)

m_{LS} = exponent in the LS factor equation (unitless)

The exponent $m_{LS}$is equal to: 0.2 for S_{slope}< 1%; 0.3 for 1% S_{slope}3%; 0.4 for 3.5% S_{slope} 4.5%; 0.5 for slope 5%. Equations (5) and (6) have been expressed as a figure by a number of authors such as Wischmeier and Smith (1978) and Robert and Hillborn, (2012).

iv Crop Cover and Management Factor

The C factor is used within both the USLE and the RUSLE to reflect the effect of cropping and management practices on erosion rates, and is the factor used most often to compare the relative impacts of management options on conservation plans. The C factor indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations, or other management schemes (Renard*et al*., 1997). The C factor reflects the effect of cropping and management practices on the soil erosion rate. The C factor indicates how conservation plans will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations, or other management schemes (Van der Kniff*et al*., 2000). Vegetation cover protects the soil by dissipating the raindrop energy before reaching the soil surface. As such, soil erosion can be effectively limited with proper management of vegetation, plant residue, and tillage (Lee, 2004). In both USLE and RUSLE, the C factor is computed using empirical equations that contain field measurements of ground cover (Wischmeier and Smith, 1978; Renard*et al*., 1997). The C-factor describes the relation between the erosion on bare soil and the erosion on cropped conditions. It is also called the 'plant cover factor' (FAO, 1996). In theory it will adopt a value of 1 for completely unprotected, bare soil (which means no influence on gross erosion estimation) and for more erosion reducing plant cover the value decreases, giving a lower estimation on gross erosion (FAO, 1996). For example, an area with light forest vegetation will be assigned a value of 0.10.

v Erosion Control Practice Factor (P)

The P factor accounts for control practices that reduce the erosion potential of run-off by their influence on drainage patterns, run-off concentration, run-off velocity and hydraulic forces exerted by run-off on the soil surface. It is an expression of the overall effects of supporting conservation practices such as contour farming, strip cropping, terracing and sub-surface drainage on soil loss at a particular site as those practices principally affect water erosion by modifying the flow pattern, grade or direction of surface run-off and by reducing the volume and rate of run-off. The value of P-factor decreases by adopting these supporting conservation practices as they reduce run-off volume, velocity and encourage the deposition of sediment on hill slope surfaces. The lower the P-factor value, the better the practice is for controlling erosion.

CHAPTER THREE

METHODOLOGY

3.1 SOIL LOSS ESTIMATION

The soil loss was estimated using the universal soil loss equation (USLE). USLE is one of the standard equations used in estimating soil loss from agricultural lands. It comprises the product of rainfall erosivity factor (R), soil erodibility factor (K), slope length and gradient factor (LS), crop cover and management factor (C), and the erosion control practice factor (P) as suggested by Lal (1994).

………………………………………… (3.1)

Where;

A= Average annual soil loss (tons/ha/year)

R= Rainfall erosivity factor (MJ mm/ hahour year)

K= Soil erodibility factor (tons hour/MJ mm)

LS= Slope-length (dimensionless) and slope-gradient factor (dimensionless)

C= Crop cover and management factor (dimensionless)

P= Erosion control practice factor (dimensionless)

3.2 DETERMINATION OF RAINFALL EROSIVITY FACTOR (R)

Rainfall data was obtained from the weather station of MallamAminu Kano International airport and was used to calculate the erosive power of rainfall in the area. The rainfall data was taken for each day at an interval of thirty minutes. The rainfall for each 30 minutes was summed for each day, and the daily rainfall amount was summed to obtain the monthly rainfall amount. The rainfall for each month was summed to obtain the annual rainfall amount. The monthly and annual rainfall amounts were inserted in the equation below to calculate the Rainfall erosivity factor (R). The relationship below was developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980).

□=*112* *1.735* ×*10*1.5 log10Pi2p−*0.08188*………………………… (3.2)

Where;

R = Rainfall Erosivity(MJ mm/ hahour year)

Pi = Monthly Rainfall (mm)

P = Annual Rainfall (mm)

3.3 DETERMINATION OF SOIL ERODIBILITY FACTOR (K)

The soil erodibility factor was determined using the modified version of nomographic expression in equation 3.3 and 3.4, given by Wischmeier*et al*.,(1971) for estimating K. A nomograph can also be used as shown in Figure 2.1. Soil samples were collected from Yakasai and Kosawa areas, Kura L.G.A and also Chirin and Kode of Bunkure LGA of the Kano River Irrigation Project. Ten samples were taken, three from Yakasai, two from Kosawa, three from Chirin and two from Kode, and five from Bunkure which were stored in polythene bags. These soil samples were collected mainly for the determination of soil erodibility factor (K) where sieve analysis, hydrometer analysis and organic matter of the soil samples were determined in the laboratory.

For soils with more than 70% silt plus very fine sand.

$$K = 2.77\, M^{1.14}(10^{-7})(12-\alpha) + 4.28(10^{-3})(\beta-2) + 3.29(10^{-3})(\gamma-3) \quad \text{.........(3.3)}$$

Where,

M = (% silt+% Very fine sand) × (100-% clay),

α = Organic matter (%),

β = structure code

γ = permeability rating.

For soils with less than 70% silt.

The nomograph expressed by the following relationship (Wischmeier*et al*., 1971; Wischmeier and Smith, 1978) was used.

$$K= [2.1 \times 10^{-4} \times (12 - OM) \times M^{1.14} + 3.25 \times (St - 2) + 2.5 \times (Pt - 3)]/100 \quad \text{.............. (3.4)}$$

Where;

OM= Organic matter content (%)

M = (%Silt + fine sand) × (100- Clay)

St= Soil structure code

Pt= permeability class

3.3.1 Particle Size Analysis by Simple Dry SievingBS 1377: Part 2:1990

Simple dry sieving was used to determine the particle sizes with negligible amounts of particles of silt or clay sizes. This method was used because less than 10% of the material passes through 63µm sieve in some of the samples. The sieves used were selected to adequately cover the range of aperture sizes for the soil sample. The sieve used were selected to suit the size of the sample and type of material.

Apparatus

i. British standard test sieves as 6.3mm, 5mm,3.35mm, 2mm, 1.18mm,0.6mm, 0.425mm, 0.3mm, 0.212mm, 0.150mm, 0.075mm
ii. Weigh balance
iii. A thermostatically control drying oven
iv. At least six metal trays
v. Scoop
vi. Mechanical sieve shaker

Sample Preparation

The sample to be used for the test was obtained from the original sample by riffling. The appropriate minimum quantity of material depends upon the maximum size of the particles present. The soil sample was placed on a tray and allowed to dry overnight. After drying to a constant weight, it was then weighed to an accuracy within 0.1% or less of its total mass.

Test Procedure

i. The dried soil sample was placed in the topmost sieve and was shaken long enough that all the particles smaller than each aperture size can pass through. This was achieved by using a mechanical sieve shaker.
ii. The whole nest of sieves with receiving pan was placed in the shaker, the dried soil was placed in the top sieve, which was then fitted with the lid, and the sieves were securely fastened down in the machine.
iii. Agitation in the shaker was done for about 10 minutes. The maximum mass of the sample which can be sieved in one cycle depends on the used and the particle size of the sample.

iv. The material retained on each sieve was transferred to a weighed container. All particles lodged in the apertures of the sieves were carefully removed with a sieve brush, the sieve being first placed upside-down on a tray. These particles were added to those retained on the sieve.

v. Weighing of each size fraction was done to an accuracy of at least 0.1% of the total initial test sample mass.

vi. The mass of soil retained by each sieve was weighed and recorded against the sieve aperture size on the particle size test work sheet.

vii. The percentage soil retained by each sieve was determined by:

Weight retained by each sieveTotal weight ×100....………. (3.5)

viii. The percentage retained by each sieve was used to determine the percentages of the particles.

ix. The procedure was repeated for the other samples.

3.3.2 Determination of Clay and Silt Particle Sizes Using Hydrometer Analysis

The hydrometer analysis is a widely used method to obtain the distribution of particles sizes in the silt range (63-2µm), and the percentage of clay particles < 2µm. The test is performed if more than 10% of the material passes through the 63µm sieve.

Apparatus

i. Soil hydrometer
ii. 1000 ml glass measuring cylinders with rubber stops
iii. Thermometer
iv. High speed stirrer
v. Sieves diameter; 63µm,212µm, 600µm, 2mm and a receiver
vi. Drying oven, 105-110°C
vii. Stop watch readable to 1s.
viii. Weigh balance
ix. Steel rule
x. Evaporating dish
xi. 1000ml beaker
xii. Two measuring cylinder, 100ml and 50ml

xiii. Wash bottle and distilled water
xiv. Constant temperature bath
xv. Glass rod: 12mm diameter, 400mm long
xvi. Standard dispersant solution: that is 33g sodium hexametaphosphate and 7g of sodium carbonate in distilled water to make 1 litre solution

Sample Preparation for Hydrometer Analysis

The sample was dried in an oven at 60-65°C. 50g of the soil sample was weighed and placed in a 1000ml beaker. The organic matter content of the soil samples was removed as follows:

i. 150ml of hydrogen peroxide was added and stirred gently on a low heat gas flame.
ii. It was covered with a cover glass and allowed to stand overnight.
iii. The next morning, the flask was heated and stirred gently on a low heat gas flame. It was agitated frequently by shaking with a rotary motion and frothing over was avoided. More hydrogen peroxide was added, about 100ml until oxidation was complete.
iv. As soon as frothing stopped, the volume of liquid was reduced to about 50ml by boiling which decomposed the excess hydrogen peroxide.
v. The contents of the conical flask were transferred to a funnel with a Whatman No 50 filter paper, and washed thoroughly with distilled water.
vi. The residue was transferred from the filter paper to a container using a fine jet of distilled water from a wash bottle and dried at 60-65°C.
vii. The weight was measured, weight after pre-treatment.

Hydrometer Analysis Test Procedure

Dispersion

i. 100ml of the standard dispersing solution was added to the soil.
ii. The mixture was shaken thoroughly until all the soil is in suspension.
iii. The soil was transferred to the cup of the high-speed stirrer with some distilled water and was stirred for about 1 hour.
iv. The suspension was transferred to the 63µm sieve placed on a receiver.
v. The soil in the sieve was washed with about 500ml of distilled water.
vi. The suspension in the receiver was transferred to a 1000ml sedimentation cylinder.

vii. The material retained on the 63µm sieve was transferred to an evaporating dish and dried in an over at 105-110°C.

viii. When cooled, the material was sieved on 2mm, 600µm, 212µm and 63µm sieves.

ix. The material retained on each sieve was dried and weighed.

x. The material passing 63µm sieve was added to the sedimentation cylinder.

Sedimentation

i. The sedimentation cylinder was filled with distilled water to the 1 L graduation mark.

ii. The sedimentation cylinder was placed in the constant temperature bath, set on 25°C.

iii. The second cylinder containing 100ml of the dispersant solution and distilled water was placed to exactly 1 L in the constant temperature bath: this is for calibration readings of the dispersant solution and for storage of the hydrometer between the readings.

iv. The cylinders were allowed to stand in the bath until they have reached the bath temperature (about 1 hour).

v. The cylinder was closed and shaked vigorously to obtain a uniform suspension. A glass rod was used to stir so that all the materials go into suspension. The cylinder was inverted for a few seconds, and then stood in the constant temperature bath. Without delay as soon as it was in the upright position, the stop watch was started (zero time).

vi. The hydrometer was inserted steadily and allowed to float freely.

vii. Readings of the hydrometer were taken at the top of the meniscus level from 0, 0.5, 1, 2, 4 minutes.

viii. The hydrometer was removed slowly, rinsed in distilled water, and placed in the separate cylinder of distilled water in the constant temperature bath.

ix. The top of the meniscus reading was observed and recorded, R□.

x. The hydrometer was inserted for further readings at the following times from zero: 8, 30min; 2, 8, 24 hours and twice during the following day.

xi. The temperature of the bath was observed and recorded after every recording.

3.3.3 Determination of Organic Matter Content of the Soil Samples (Walkey-Black Method)

Apparatus

i. Burette 50ml
ii. Erlenmeyer flask 500ml
iii. Pipette
iv. Pipette filler
v. Measuring cylinder
vi. Reagent dropper
vii. Weigh balance

Reagents

i. Potassium dichromate ($K_2Cr_2O_7$) 1N – dissolve 49.04g of $K_2Cr_2O_7$ in distilled water and dilute to 1 liter.
ii. H_2SO_4 conc. If chloride (Cl) is present in the soil add Ag_2SO_4 to the acid at the rate of 15g per liter.
iii. O-phosphoric acid (H_3PO_4) Conc.
iv. O-phenanthroline ferrous complex 0.025M (ferroin). When ferroin indicator is not available, it can be prepared as follows- dissolve 14.85g of O-phenanthroline monohydrate and 6.95g of $FeSO_47H_2O$ in water dilute to 1 liter.
v. Barium diphenylamine sulfonate (0.16%) optional. Can be used in place of O-phenanthroline ferrous complex.
i. Ferrous sulphate (0.5N) dissolve 140g of $FeSO_2$ $7H_2O$ in water; add 15ml conc. H_2SO_4. Cool and dilute to 1 liter. Standardize this reagent daily or each time before using for organic C determination by titrating against 10ml $1NK_2Cr_2O_7$.

Procedure

i. The soil sample was taken and grinded to pass through 2mm sieve.
ii. The samples were weighed and transferred into a 500ml Erlenmeyer flask. (1.00g was used)
iii. 5ml of 1N $K_2Cr_2O_7$ solution was pipette into each flask and swirled gently to disperse the soil.
iv. Concentrated H_2SO_4 was added rapidly using an automatic pipette, directing the stream into the suspension. The flask was swirled gently until soil and reagents are mixed and

was swirled more vigorously for one minute. The beaker was rotated again and the flask was allowed to stand undisturbed for thirty minutes.

v. 100ml of distilled water was added after standing for thirty minutes.

vi. 3 drops of indicator were added and titrated with 0.5N ferrous sulfate solution. As the end point was approached, the solution took on a greenish cast and then changes to dark green. At this point, the ferrous sulfate was added drop by drop until the color changed sharply from green to maroon in reflected light against a white background.

vii. A blank titration was made in the same manner but without soil (steps3, 4, 5, and 6) to standardize the dichromate.

viii. The result was calculated using the formula;

(Blank titre value−actual titre value)×0.3×F×Mg of air dry soil…………………… (3.6)

Where;

F= Correction factor= 1.33

M= Conc of $FeSO_4$= 0.5

Organic matter (%OM) = % Organic Carbon × 1.729…………………................(3.7)

3.3.4 Determination of Soil Structure Code

The soil structure code was determined using Figure 3.2 which shows the soil textural classification triangle, (Ontario Center for Soil Resource Evaluation,1993). Percentage clay and sand in the samples were used to determine the soil structure codes for each sample. i.e. (very fine granular = 1, fine granular = 2, coarse granular = 3, blocky, platy or massive = 4).

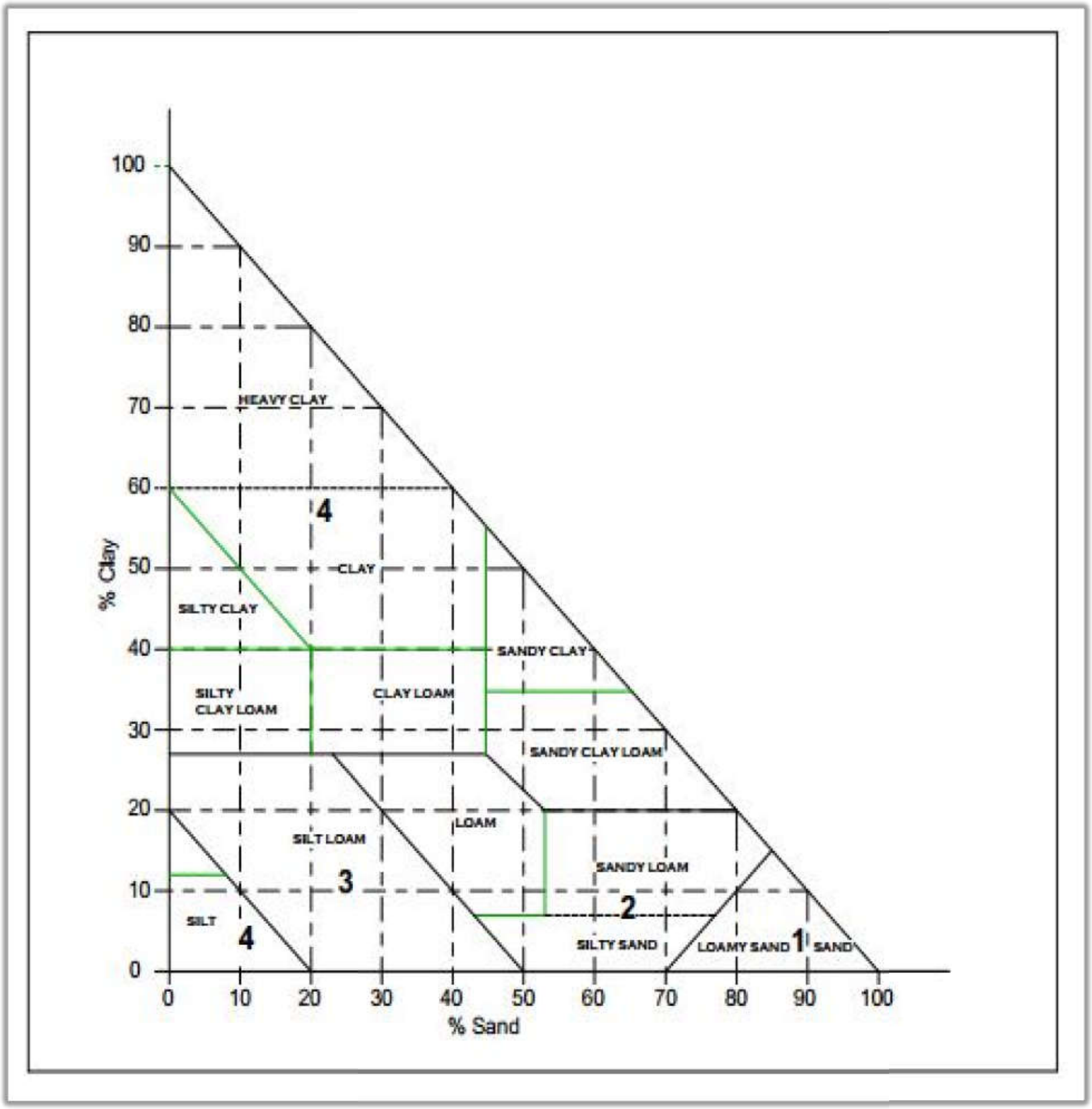

Figure 3.1: Soil textural classification triangle (Ontario Center for Soil Resource Evaluation, 1993).

3.3.5 Determination of Permeability Class of Each Soil Sample

The permeability class was chosen from a table in the national soil handbook (USDA, 1983) which gives different soil textures and their permeability class. Table 3.1 shows the permeability class of different types of soils and a class was chosen based on the type of soil for each sample.

Table 3.1; Soil permeability code based on textural class (National soil handbook USDA, 1983)

Soil Type	Permeability Code
Heavy clay, Clay	6
Silty clay loam, Sandy loam	5
Sandy clay loam, clay loam	4
Loam, Silt loam, Silty sand	3
Loamy sand, Sandy loam	2
Sand	1

Where 1 = Rapid, 2 = Moderate to rapid, 3 = Moderate, 4 = Slow to moderate, 5= Slow and 6 = very slow

3.4 DETERMINATION OF SLOPE LENGTH & GRADIENT FACTOR (LS)

A survey of the area of study was conducted using a handheld Global Positioning System (GPS) model (Garmin e Trex 10). For each corner point, the device was used to obtain the geographical co-ordinates and elevations of Yakasai, Kosawa, Chirin and Kode sectors of the Kano River Irrigation Project. The co-ordinates and elevations were downloaded from the GPS into the computer using Map source program. The downloaded co-ordinates and elevations were transferred to excel text file and saved as CSV (comma delimited). From excel, the co-ordinates were used to plot using AutoCAD program which was further used to calculate the horizontal distances and the slope, calculated using the formula;

Height difference metersHorizontal distance $\times 100$……………………………………… (3.8)

After calculating the slope and horizontal distance, the values were inserted in the equation for calculating LS given by theMinistry of Agriculture, Food and Rural Affairs Ontario;

$LS= [0.065+0.0456(S) + 0.006541(S)^2] (L \div 22.1)^{NN}$…………………………….. (3.9)

Where; S= Slope steepness (%)

L= Slope length (m)

NN= Constant

Table 3.2; NN values

S	<1	$1 \leq S < 3$	$3 \leq S < 5$	≥ 5
NN	0.2	0.3	0.4	0.5

Ministry of Agriculture, Food and Rural Affairs Ontario (2012)

3.5 DETERMINATION OF CROP COVER AND MANAGEMENT FACTOR (C)

The crop cover and management factor was obtained from literature. Different types of crops have different C factor values. A table was provided by the Ministry of Agriculture, Food and Rural Affairs Ontario (2012), where different crop types were listed and their corresponding factors. Similarly, different tillage methods were listed and their factors. An appropriate C value was determined by selecting the crop type and tillage method that corresponds to the field and then multiplied together.

Table 3.3; Crop type factor (CTF)

Crop Type	Factor
Grain corn	0.40
Silage corn, beans & canola	0.50
Cereals	0.35
Seasonal horticultural crops	0.50
Fruit trees	0.10
Hay and pasture	0.02

Table 3.4*;* Tillage method factor (TMF)

Tillage Method	Factor
Fall plow	1.0
Spring plow	0.90
Mulch tillage	0.60
Ridge tillage	0.35
Zone tillage	0.25

The C-factor is given by Equation 3.10.

C-Factor = Crop Type Factor (CTF) × Tillage Method Factor (TMF)………………… (3.10)

3.6 DETERMINATION OF EROSION CONTROL PRACTICE FACTOR (P)

The erosion control practice factor was also obtained from literature. The Ministry of Agriculture, Food and Rural Affairs Ontario (2012) provided a table that showed the P factor values for different erosion control practices (Table 3.5) and the corresponding P factor value was chosen for the erosion control practiced in the study area.

Table 3.5; Erosion control practice factor

Erosion control practice	P- Factor
Up & down slope	1.0
Cross slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

3.7 DETERMINATION OF THE SOIL LOSS TOLERANCE RATE

When the soil loss is calculated, it is necessary to classify the type of erosion based on the soil loss determined in order to prevent any potential soil loss. Table 3.6 shows the classification of the soil erosion class and their potential soil loss in tons/ha/year, Ministry of Agriculture, Food and Rural Affairs Ontario (2012).

Table 3.6; Soil Loss Tolerance Rates

Soil Erosion Class	Potential soil loss tons/ha/year
Very low (Tolerable)	<6.7
Low	6.7 – 11.2
Moderate	11.2 – 22.4
High	22.4 – 33.6
Severe	>33.16

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RAINFALL EROSIVITY FACTOR (R)

Table 4.1 shows the rainfall erosivity factors for each year which was further averaged to obtain the annual rainfall erosivity factor (R). The summary of the rainfall data used for determination of rainfall erosivity factor is shown in appendix A.

Table 4.1; Monthly and annual rainfall erosivity factor for thirty yearsrain gauge data ofKano State (1985-2014).

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	R-Factor
1985	0	0	-5.37	0	0.11	40.64	41.35	40.31	31.55	0	0	0	148.59
1986	0	0	0	-58.58	-23.75	35.80	50.28	41.43	30.03	4.2	0	0	79.41
1987	0	0	0	27.88	23.89	43.56	34.48	22.74	-10.88	0	0	0	141.67
1988	0	-32.89	0	-1.28	-17.50	32.97	41.08	59.78	33.70	0	0	0	115.86
1989	0	0	0	0	-22.53	5.54	36.63	58.94	24.7	10.74	0	0	114.02
1990	0	0	0	0	12	19.06	51.79	50.65	-3.72	0	0	0	129.78
1991	0	0	-63.54	18.12	32.69	14.19	47.70	36.56	25.98	0	0	0	111.7
1992	0	0	0	4.83	31.55	9.06	41.73	53.69	43.34	0	-85.11	0	99.09
1993	0	0	0	0	8.2	48.62	35.03	56.42	23.40	0	0	0	171.67
1994	0	0	0	-12.54	-35.54	27.61	36.28	53.91	37.38	4.03	0	0	111.13
1995	0	0	0	-30.22	-1.90	38.55	43.08	37.04	41.10	-47.14	0	0	80.51
1996	0	0	0	0	0.83	31.28	44.23	55.49	42.54	6.11	0	0	180.48
1997	0	0	0	-4.83	21.94	32.61	42.78	55.81	42.54	1.01	0	0	191.86
1998	0	0	0	-26.76	9.43	29.91	56.98	56.94	51.22	-12.58	0	0	165.14
1999	0	0	0	0	2.57	18.18	58.72	55.70	40.69	-18.27	0	0	157.59
2000	0	0	0	0	22.75	30.03	52.35	50.29	35.71	-1.25	0	0	189.88
2001	0	0	0	-2.07	32.05	36.95	58.70	55.34	34.32	0	0	0	215.29
2002	0	0	-56.59	-79.87	29.10	47.09	54.21	39.89	10.35	0	0	0	44.18
2003	0	0	0	-31.48	11.45	41.03	51.59	55.30	39.65	-25.55	0	0	141.99

2004	0	0	0	34.59	36.33	53.53	44.90	40.58	0	0	0	0	209.93
2005	0	0	0	-68.60	25.11	35.27	51.38	54.63	36.71	0.11	0	0	134.61
2006	0	0	0	0	30.72	24.70	51.38	48.85	48.95	0	0	0	204.6
2007	0	0	0	3.99	21.41	50.48	37.87	55.44	1.37	0	0	0	170.56
2008	0	0	0	0	-25.63	36.49	56.80	47.29	32.92	-62	0	0	85.87
2009	0	0	0	0	-6.55	-3.76	96.95	51.08	38.32	-61.58	0	0	114.46
2010	0	0	0	14.09	4.79	27.86	45.67	47.74	44.48	11	0	0	195.63
2011	0	0	0	2.11	25.37	36.69	43.66	52.46	40.82	3.38	0	0	204.49
2012	0	0	0	0	11.96	52.72	54.22	54.15	24.19	-17.42	0	0	179.82
2013	0	0	0	-0.73	4.75	19.73	35.70	58.96	49.35	-25.92	0	0	141.84
2014	0	0	0	-11.9	17.82	18.17	-55.79	57.66	35.66	-1.12	0	0	60.5

From the result above, it can be seen that the rainfall in most of the years began in April and ended in October with little amounts. This is the normal duration of rainfall in Northern Nigeria and Kano to be precise. It was observed that the higher the rainfall amount, the higher the rainfall erosivity factor which is the power of rainfall to detach soil particles and vice versa. Rainfall amount was highest in 2001 with an erosive factor of 215.29 MJ mm/ha hour year and lowest in 2002 with a value of 44.1MJ mm/ha hour year. In northern Nigeria, rainfall is usually at maximum in July and August where its intensity and frequency increases much compared to the rest of the months.The rainfall erosivity factor calculated for this research is 143.07MJ mm/ha hr year and was calculated for a period of thirty years. This is the erosive impact of rainfall on the soil. Rainfall erosivity factor is usually calculated with as many rain gauge data as available as such, thirty years rain gauge data was used for the determination of rainfall erosivity factor for Yakasai, Kosawa, Chirin and Kode of Kano River Irrigation Project.

4.2 SOIL ERODIBILITY FACTOR (K)

4.2.1 Sieve Analysis and Hydrometer Analysis Result

Figure 4.1 and 4.2 show the results of the sieve analysis and hydrometer analysis conducted for Yakasai, Kosawa, Chirin and Kode sectors. The tables of the sieve analysis and hydrometer analysis results are presented in appendix B and C.

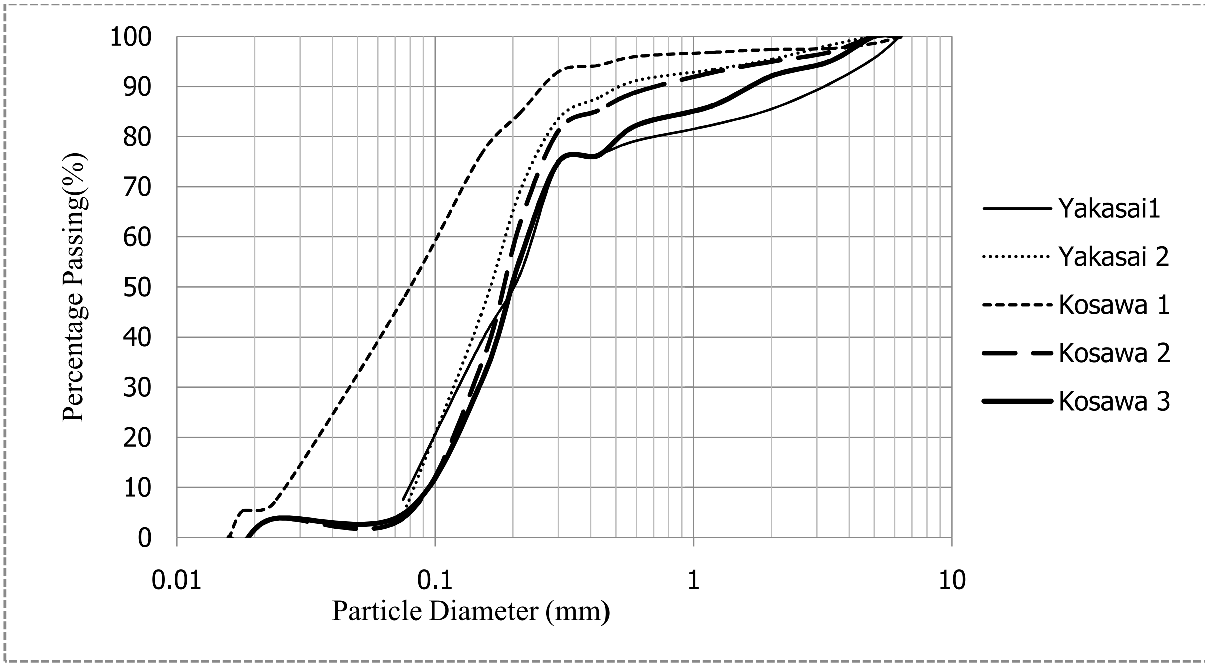

Figure 4.1; Sieve analysis and hydrometer analysis for Yakasai and Kosawa

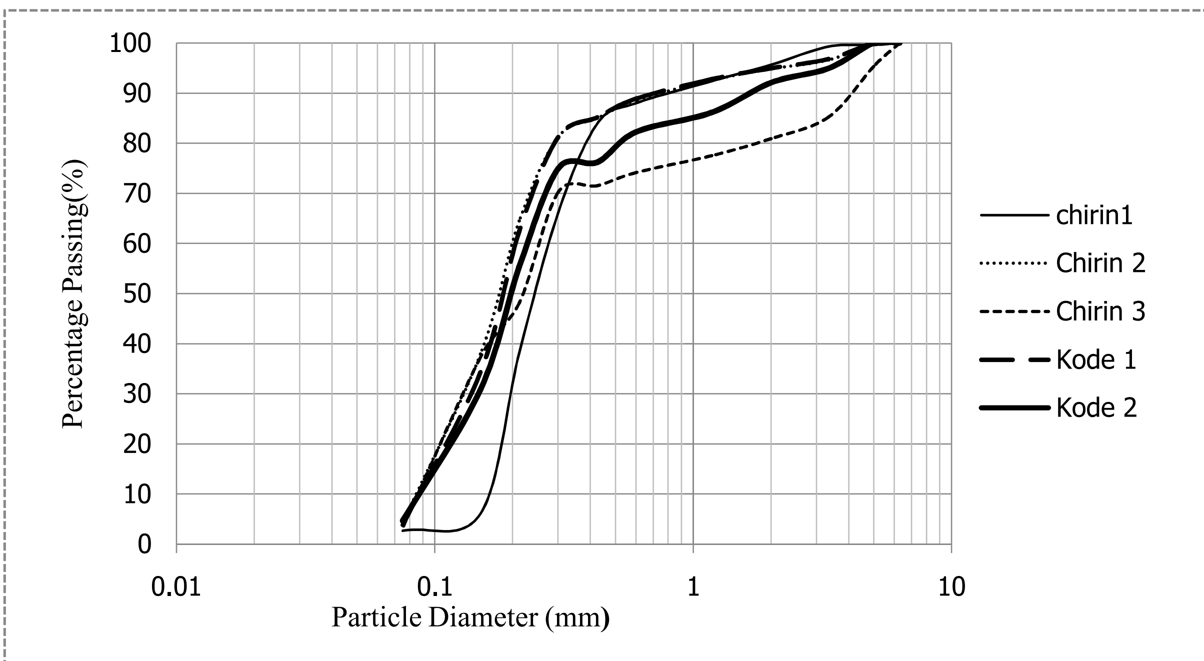

Figure 4.2; Sieve analysis for Chirin and Kode

From the result of the sieve analysis conducted for the first five samples for Yakasai and Kosawa, it can be seen that the first two samples (Yakasai 1 and 2) did not require hydrometer analysis, this is simply because less than 10% of the material passed through 63µm sieve. But as shown in the results of samples 3, 4, and 5 (Kosawa 1, 2, 3) more than 10% of the material passed through the 63µm sieve and a lot of material was retained in the receiver as such, hydrometer analysis is required to determine the particle diameter of the finer particles i.e. silt and clay which were retained in the receiver. After conducting the hydrometer analysis, the sizes of the particles that passed through 63µm sieve were determined. The values were later merged with that of the sieve analysis to obtain the complete curve including all the particle sizes. From the graphs, the percentages of clay, silt, sand and gravel were determined for each sample as shown in Table 4.2.

From the result of the sieve analysis conducted for Chirin and Kode shown in Figure 4.2, it can be observed that all the samples did not require hydrometer analysis. This is simply because less than 10% of the samples pass through the 63µm sieve i.e. small amount of soil was retained in the reciever. The percentages of the particle sizes for all the 10 samples are shown in table 4.2.

Table 4.2; Percentage gravel, sand, silt & clay for Kosawa, Yakasai, Chirin and Kode

Sample no.	Sample label	Fine Gravel (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
1	Yakasai 1	13.8	8.2	29.9	44.8	3.3	0
2	Yakasai 2	1.8	4.8	24.5	64.4	4.5	0
3	Kosawa 1	2.4	0.8	12.2	37	47.6	0
4	Kosawa 2	0	0.2	6.2	45.2	47.4	0
5	Kosawa 3	0.6	0.2	9	49.6	40.6	0
6	Chirin 1	0.7	6.9	54.28	35.45	2.7	0
7	Chirin 2	3.4	4.02	28.06	60.24	4.28	0
8	Chirin 3	14.24	7.74	29.42	44.82	3.28	0
9	Kode 1	3.2	4	30.42	58.56	3.82	0
10	Kode 2	5.06	8.78	30.82	50.66	4.68	0

4.2.2 Organic Matter Determination

The result of the titration performed on the five samples for Yakasai and Kosawa sectors is shown in Table 4.3 and Table 4.4 shows that of Chirin and Kode.

Table 4.3**;** Titration result for determination of organic carbon for Yakasai and Kosawa

Sample no.	Sample label	Initial titer value (cm^3)	Final titer value (cm^3)	Actual titer value (cm^3)
1	Yakasai 1	9	16.1	7.1
2	Yakasai 2	16.1	24.6	8.5
3	Kosawa 1	24.6	31.4	6.5
4	Kosawa 2	31.4	38.4	7
5	Kosawa 3	38.4	45.8	7.4
	Blank	0	9.0	9.0

Table 4.4 Titration result for determination of organic carbon for Chirin and Kode sectors

Sample no.	Sample label	Initial titer value (cm^3)	Final titer value (cm^3)	Actual titer value (cm^3)
6	Chirin 1	0	8.5	8.5
7	Chirin 2	0	9.0	9.0
8	Chirin 3	0	8.3	8.3
9	Kode 1	0	7.8	7.8
10	Kode 2	0	9.4	9.4
	Blank	0	10	10

The values of the blank and actual titer values, correction factor, Conc of $FeSO_4$ (M) and g of air dry soil were inserted in equation 3.6 and percentage organic carbon and organic matter was determined.

Table 4.5; Percentage organic carbon, organic matter content and average organic matter content for Yakasai and Kosawa Sectors

Sample no.	Sample label	% Organic Carbon	% Organic Matter (OM)	Average (OM)
1	Yakasai 1	0.3791	0.6555	0.4140
2	Yakasai 2	0.0998	0.1725	
3	Kosawa 1	0.4389	0.7589	0.6669
4	Kosawa 2	0.3990	0.6899	
5	Kosawa 3	0.3192	0.5519	

Table 4.6**;** Percentage organic carbon, organic matter content and average organic matter content for Chirin and Kode

Sample no.	Sample label	% Organic Carbon	% Organic Matter (OM)	Average (OM)
6	Chirin 1	0.2993	0.5174	0.4829
7	Chirin 2	0.1195	0.3449	
8	Chirin 3	0.3392	0.5864	
9	Kode 1	0.4389	0.7589	0.4830
10	Kode 2	0.1197	0.2070	

4.2.3 Soil Structure Code

Soil structure codes for each of the samples sites were determined using the soil textural classification triangle (Figure 3.1). From the triangle, the soil textural class and structure code for the samples were determined. The result shown in Table 4

Table 4.7; Soil structure codes for each soil sample

Sample no	Sample label	Textural Class	Soil structure code
1	Yakasai 1	Loamy sand	1
2	Yakasai 2	Sand	1
3	Kosawa 1	Silty sand	2
4	Kosawa 2	Silty sand	2
5	Kosawa 3	Silty sand	2
6	Chirin 1	Sand	1
7	Chirin 2	Sand	1
8	Chirin 3	Loamy sand	1
9	Kode 1	Sand	1
10	Kode 2	Sand	1

4.2.4 Soil Permeability Class

The soil permeability class was also chosen from table provided by the United State Department of Agricultural (USDA) National soil handbook (1983). The corresponding permeability class for each sample is shown in Table 4.8.

Table 4.8;Permeability class for the soil samples

Sample no.	Sample Label	Soil permeability class
1	Yakasai 1	2
2	Yakasai 2	1
3	Kosawa 1	3
4	Kosawa 2	3
5	Kosawa 3	3
6	Chirin 1	1
7	Chirin 2	1
8	Chirin 3	2
9	Kode 1	1
10	Kode 2	1

Table 4.9; M values for the soil samples

Sample no.	Sample Label	M Values
1	Yakasai 1	4810
2	Yakasai 2	6890
3	Kosawa 1	8460
4	Kosawa 2	9260
5	Kosawa 3	9020
6	Chirin 1	3815
7	Chirin 2	6452
8	Chirin 3	4810
9	Kode 1	6238
10	Kode 2	5534

M=(%Silt + %Fine sand) × (100-%Clay)

4.2.5 Soil Erodibiliy Determination

Table 4.10 shows the results of soil erodibility factor determined using Equation 3.4 which is the nomographic expression by Wischmeier and Smith (1978).

Table 4.10; Soil erodibility factor (K)

Sample no	Sample label	Soil Erodibility factor (K)	Average K value
1	Yakasai 1	0.3180	0.4127
2	Yakasai 2	0.5073	
3	Kosawa 1	0.7083	0.7581
4	Kosawa 2	0.7900	
5	Kosawa 3	0.7760	
6	Chirin 1	0.2094	0.3288
7	Chirin 2	0.4567	
8	Chirin 3	0.3203	
9	Kode 1	0.4180	0.3968
10	Kode 2	0.3755	

From the result of the particle size analysis conducted in the laboratory for Yakasai and Kosawa of Kura LGA, the soil samples were classified as loamy sand for sample 1, sand for sample 2 and silty sand for samples 3, 4, and 5 obtained from Figure 3.1. There are no clay particles present in the soil which have water logging capacity to hold nutrients and water. The soil is dry, nutrient deficient and fast draining. This explains the low organic matter content in the soil with an average of 0.4140% for Yakasai and 0.6669% for Kosawa. Water logged soils tend to accumulate organic matter because the microbial processes in particular decomposition and mineralization were slowed down which isn't the same with the other types of soils.

For Chirin and Kode of Bunkure LGA, samples 6, 7, 9 10 were classified as sand and sample 8 was classified as loamy sand also from Figure 3.1. The samples from this area did not contain clay particles and also have low organic matter content with an average of 0.4829 for Chirin and

0.4830 for Kode. The fact that clay particles are not present and also low organic matter content, soil erodibility was high as the particles are loose and prone to erosion.

The soil structure code determined for the soil samples of Yakasai and Kosawafrom the soil textural classification triangle using percentage clay and sand obtained from the particle size analysis is 1 (very fine granular) and 2 (fine granular). The soil texture was very fine right from sample collection at the site. The soil structure code for Chirin and Kode samples is 1 (very fine granular) for all the soil samples determined from the soil textural triangle. The permeability class for each of the samples was determined from theNational soil handbook USDA, (1983). For each of the soil samples, a permeability class was chosen. Sample 1 had a permeability rating of2 (moderate to rapid), sample 2 had a permeability rating of 1 (rapid) and samples 3, 4 and 5 have a permeability rating of 3 (moderate) for Yakasai and Kosawa. Samples 6 and 7 have a permeability rating of 1 (rapid), sample 8 had a permeability rating of 2 (moderate to rapid), 9 and 10 have a permeability rating of 1 (rapid). Water moves through the soil particles at a relatively fast rate. The soil erodibility factor calculated was 0.4127 for Yakasai, 0.7581 for Kosawa, 0.3288 for Chirin and 0.3968 for Kode. The soil erodibility factors werewithin the range of soil erodibility factors 0.02 to 0.69 (Goldman et al, 1986) except for Kosawa sector.

4.3 Slope Length-Gradient Factor LS

After survey of the areas of Yakasai, Kosawa, Chirin and Kode was conducted using a handheld GPS, the co-ordinates of the two areas were obtained as well as their elevations. This information was used to sketch the two areas for proper understanding using Auto CAD and the longest distance between two points was determined. The difference in elevations and distance was used to calculate the slopes of the two areas. Figures 4.3 to 4.6 and Table 4.11 show the four areas, their corresponding elevations, areas and horizontal distance using the survey measurements.

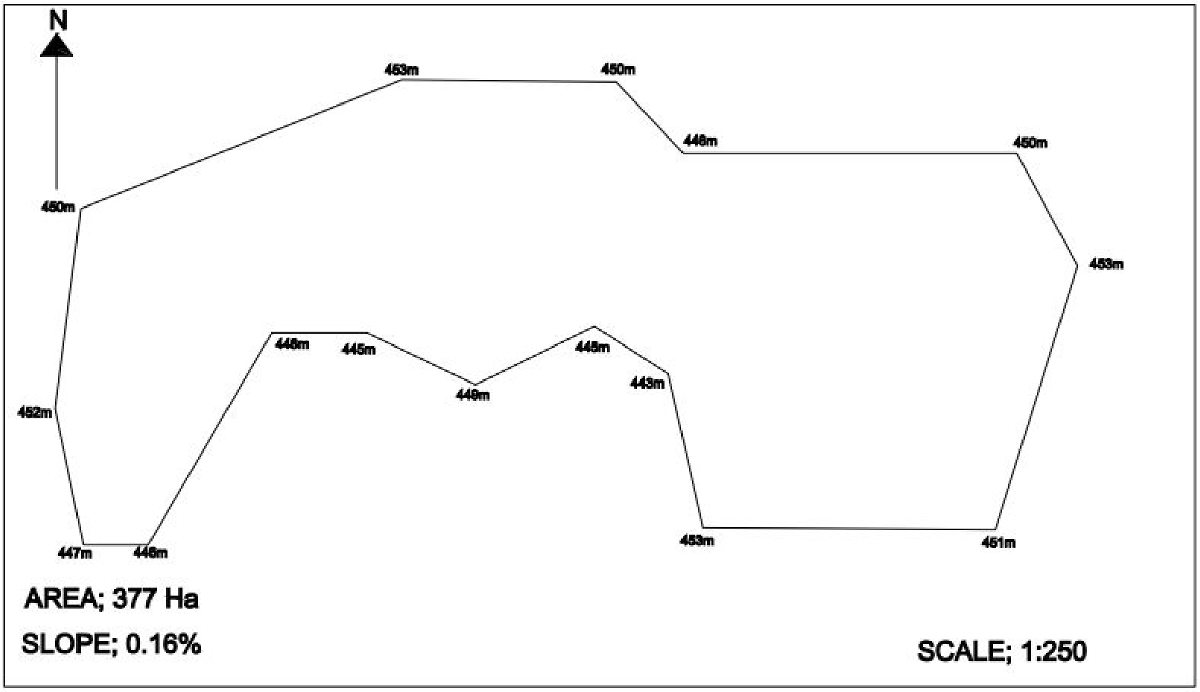

Figure 4.3; Survey measurements for Yakasai sector.

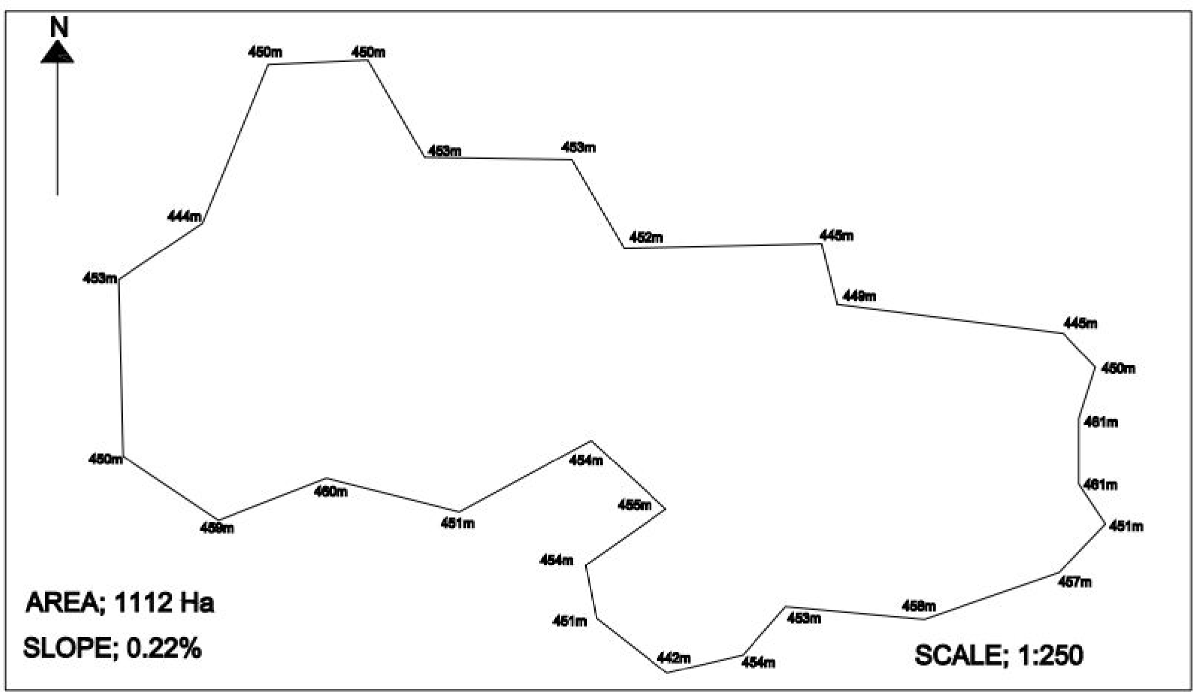

Figure4.4; Survey measurements for Kosawa sector.

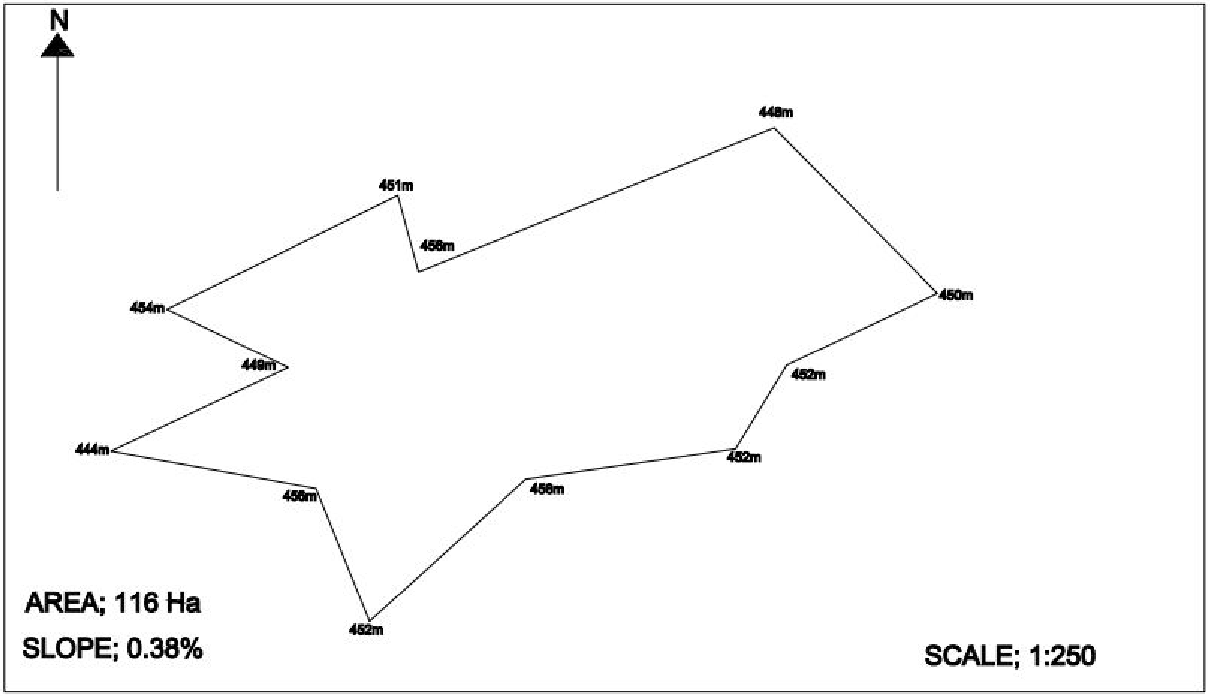

Figure 4.5; Survey measurements for Chirin sector.

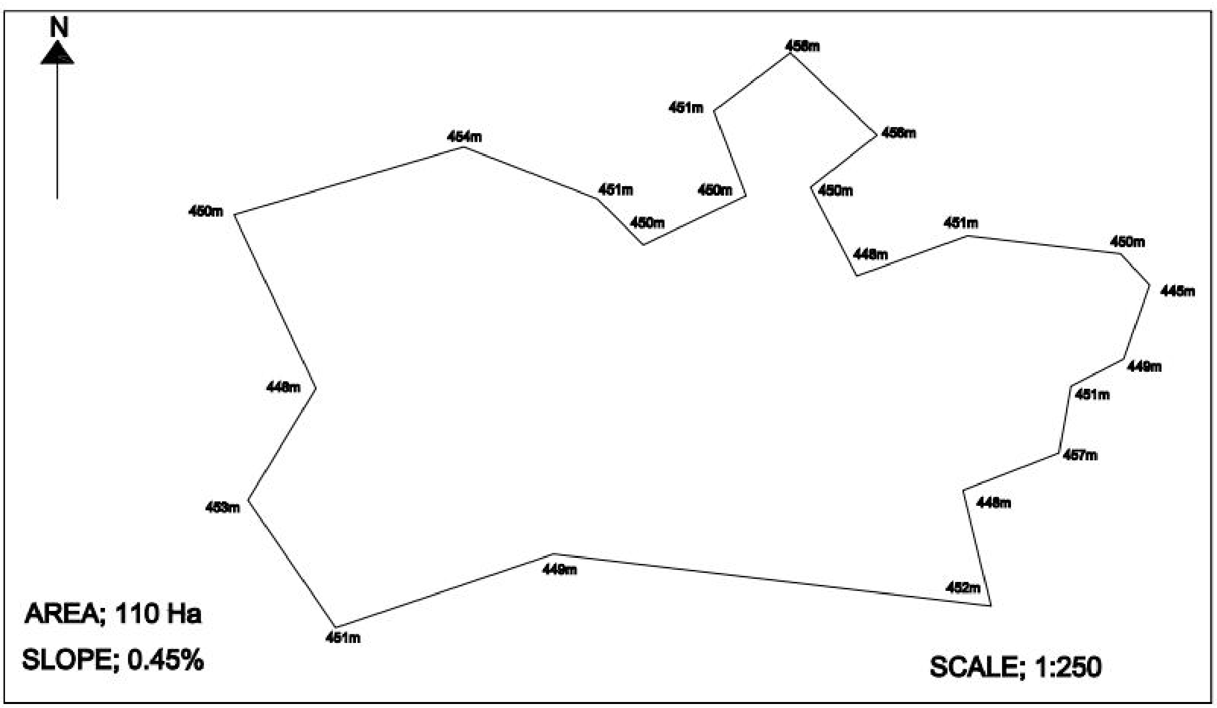

Figure 4.6; Survey measurements for Kode sector.

Table 4.11; Elevations, horizontal distances, slope % (S), and LS factors for Yakasai, Kosawa, Chirin and Kode Sectors

Sector	Highest Elevation (m)	Lowest Elevation (m)	Horizontal Distance betweenHighest and lowest elevations (m)	Slope (%)	LS-Factor
Yakasai	453	446	4380	0.16	0.2084
Kosawa	461	444	7900	0.22	0.2438
Chirin	456	444	3200	0.38	0.2246
Kode	458	445	2900	0.45	0.2296

4.4 CROP COVER AND MANAGEMENT FACTOR (C)

Table 4.12 shows the crop type factor, tillage method factor and the crop cover and management factor for the types of crops grown in the four sectors of study.

Table 4.12; Crop type factor, tillage method factor and crop cover & management factor (C)

Crop Type Factor	0.50
Tillage Method Factor	0.35
Crop Cover & Management Factor	0.175

The crop cover and management factor (C) was determined from tables provided by theMinistry of Agriculture Food and Rural Affairs Ontario (2012), where the crop type factor was chosen and the tillage method factor. The product of the two factors gave the crop cover and management factor.The types of crops grown in the area include tomato, onion, red pepper, water melon, which are classified as horticultural crops. The crop type factor for seasonal horticultural crops is

0.50 from table and the tillage method factor is ridge tillage which has a factor of 0.35 from table. The product of the two factors is 0.175 which is the crop type and management factor (C).

4.5 EROSION CONTROL PRACTICE FACTOR (P)

The farmers in the four sectors usually grow their crops on ridges. These ridges are set perpendicular to the slopes so that the furrows can hold considerable amounts of water containing suspended sandy or loamy solids. Water infiltrates into the soil reducing run-off, as such, the loss of soil is reduced. The P factor chosen for the four sectors was 0.75 from Table 3.5.

4.6 SOIL LOSS ESTIMATION

The soil loss was estimated using Equation 3.1 which is the universal soil loss equation (USLE). The result of the soil loss estimated for Yakasai, Kosawa, Chirin and Kode sectors is shown in Table 4.13.

Table 4.13; Soil Loss Estimated for Yakasai, Kosawa, Chirin and Kode Sectors.

USLE Factors	Yakasai	Kosawa	Chirin	Kode
R-Factor	143.07	143.07	143.07	143.07
K-Factor	0.4127	0.7581	0.3288	0.3968
LS-Factor	0.2084	0.2440	0.2246	0.2296
C-Factor	0.175	0.175	0.175	0.175
P-Factor	0.75	0.75	0.75	0.75
Soil Loss (tons/ha/year)	1.62	3.47	1.39	1.71
Soil Erosion Class	Very low	Very low	Very low	Very low

The soil loss estimatedwas 1.62 tons/ha/year for Yakasai, 3.47tons/ha/year for Kosawa, 1.39 tons/ha/year for Chirnand 1.71 tons/ha/year for Kode as shown in Table 4.13. the soil loss for Yakasai,Kosawa,Chirin and Kode falls under the very low class of erosion from Table 3.6 provided by the Ministry of Agriculture, Food and Rural Affairs Ontario (2012). The soil loss in Kosawa sector is high because of the high soil erodibility factor value. According to

Wischmeierand Smith (1978), the maximum tolerable soil loss (12 tons/hectare/year) is defined as "the maximum level of soil erosion that will permit a level of crop productivity to be sustained economically and indefinitely". The estimated soil loss is very low and so, it does not affect crop productivity.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. The Rainfall erosivity factor (R) determined from existing rain gauge data of Kano state from year 1985-2014 is 143.07 MJ mm/ha hour year for all the four sectors.
2. Soil erodibility factor (K) determined from laboratory analysis of the soil samples was 0.4127tons hour/MJ mm for Yakasai, 0.7581tons hour/MJ mm for Kosawa, 0.3288tons hour/MJ mm for Chirin and 0.3968tons hour/MJ mm for Kode.
3. The slope length-gradient factor (LS) determined from survey measurements is 0.2084 for Yakasai, 0.2440 for Kosawa, 0.2246for Chirin and 0.2296 forKode sectors.
4. The crop cover and management factor (C) is 0.175 for all the sectors and Erosion control practice factor (P) determined is 0.75 also, for all the sectors.
5. The product of the five factors gave the estimated soil loss which is 1.62tons/hectare/year for Yakasai, 3.47tons/hectare/yea for Kosawa, 1.39tons/hectare/year for Chirin and 1.71tons/hectare/year for Kode sectors of the Kano River Irrigation Project.
6. The maximum tolerable soil loss from literature is 12tons/hectare/year which is the maximum level of soil loss that will permit a level of crop productivity to be sustained economically and indefinitely. From the result obtained, it is seen that the estimated soil loss for the four sectors is lower than the maximum tolerable soil loss and it is classified as very low. The erosion is within the tolerable limit.

5.2 RECOMMENDATIONS

1. Based on the result of this research, it is recommended that the farmers in Yakasai, Kosawa, Chirin,Kode and all the other sectors of the Kano River Irrigation Project should use soil erosion control practice to counter the soil loss in the area even though it is very low to reduce the risk of it increasing with time. Some of the erosion control practice that can be used are mulching, strip cropping and contour ridging.
2. Secondly, more rain gauging stations that will measure rainfall amounts and intensities should be installed in each local government area to tackle the problem of the scarcity of rain gauge data.

3. Further research findings should be done to determine the soil loss by wind for all the sectors. This will enable us to know the total soil loss by wind and water.
4. The populace in the areas should be advised to preserve and increase vegetation coverage to reduce the impact of rain on the soil which causes soil loss.

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APPENDIX A

Weather Data Used to Calculate Rainfall Erosivity Factor (R)

Table A1**;** Summary of rain gauge data used to calculate rainfall erosivity factor (R) from 1985-2014

RAINFALL (mm)

STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

Kano	1985	0	0	21.5	0	27.4	164.6	169.8	162.2	110.1	0	0	0
Kano	1986	0	0	0	2.1	9.8	136.6	259.2	175.2	105.8	4.2	0	0
Kano	1987	0	0	0	82.2	68.9	164.5	110.1	65.5	14.8	0	0	0
Kano	1988	0	8.1	0	32.8	16	149.2	213.6	488.5	154.1	0	0	0
Kano	1989	0	0	0	0	10.4	36	142.4	382.1	84	45.3	0	0
Kano	1990	0	0	0	0	40.1	54.8	233.1	142.4	89.2	0	0	0
Kano	1991	0	0	1.7	63	120	148.6	70	455.1	20	0	0	0
Kano	1992	0	0	0	37.4	122	45.1	191.4	324.8	205.5	0	0.7	0
Kano	1993	0	0	0	0	48.2	288.1	157.9	406.9	94.4	0.6	0	0
Kano	1994	0	0	0	17.2	6.5	101.6	149.1	325.2	156.5	35.8	0	0
Kano	1995	0	0	0	7.4	25.9	155	189.4	145	173.5	3.5	0	0
Kano	1996	0	0	0	0	37.2	143.1	253.8	417.6	235.5	47	0	0
Kano	1997	0	0	0	30.9	101	161.9	253.9	451.9	251.2	40	0	0
Kano	1998	0	0	0	14.1	69.6	173	573	571.8	444.1	26.4	0	0
Kano	1999	0	0	0	0	44.5	88.8	533.5	466.9	240.3	17.7	0	0
Kano	2000	0	0	0	0	98.3	135.7	364.2	332.4	174.4	34	0	0
Kano	2001	0	0	0	41.1	186	231.1	604.7	521.1	205.6	0	0	0
Kano	2002	0	0	2.8	1	124	274.9	376.6	199.9	54.1	0	0	0
Kano	2003	0	0	0	10	66.8	247.2	394.5	464.8	232.6	13	0	0
Kano	2004	0	0	0	176	190	406.7	277.7	229.4	0	0	0	0
Kano	2005	0	0	0	1.9	120	188.1	383.6	442.9	200.4	39.7	0	0
Kano	2006	0	0	0	0	150	114.9	374	334.4	336	0	0	0
Kano	2007	0	0	0	42.1	91	329.3	188.5	410	37.5	0	0	0
Kano	2008	0	0	0	0	11	171.7	421.7	276.8	146.6	8.1	0	0
Kano	2009	0	0	0	0	25.1	84.8	376	321.3	182.7	2.2	0	0
Kano	2010	0	0	0	65.7	43.6	121	266.1	291.5	252.4	57.4	0	0
Kano	2011	0	0	0	12.5	114.3	188.6	256.7	378.9	226.4	43.2	0	0
Kano	2012	0	0	0	0	71.9	436.4	466.4	646.9	123.5	19.6	0	0
Kano	2013	0	0	0	14.8	40	77.6	157.3	440.1	178.1	10.3	0	0
Kano	2014	0	0	0	23.5	87.5	88.9	469.4	509.6	192.7	24.4	0	0

APPENDIX B

Tables from Sieve Analysis and Hydrometer Analysis

Table B1; Sample 1 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percent Retained(%)	Percent Passing(%)
6.3	0	0	100
5	21.3	4.3	95.7
3.35	47.5	9.5	90.5

2	24.6	4.9	85.5
1.18	16.6	3.3	82.3
0.6	15.1	3	79.2
0.425	14	2.8	76.4
0.3	8	1.6	74.8
0.212	112.5	22.5	52.3
0.15	67.3	13.5	38.9
0.075	156.6	31.3	7.6
Reciever	16.5	3.3	4.3

Table B2; Sample 2 sieve analysis result

Sieve Size(mm)	Mass Retained (g)	Percent Retained (%)	Percent Passing(%)
6.3	0	0	100
5	0	0	100
3.35	8.9	1.8	98.2
2	14	2.8	95.4
1.18	10.2	2	93.4
0.6	11	2.2	91.2
0.425	17.5	3.5	87.7
0.3	20.5	4.1	83.6
0.212	73.5	14.7	68.9
0.15	122.4	24.5	44.4
0.075	199.3	39.9	4.5
Reciever	22.7	4.5	0

Table B3; Sample 3 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Passing (%)
6.3	0	0	100
5	0.7	1.4	98.6
3.35	0.5	1	97.6
2	0.1	0.2	97.4
1.18	0.3	0.6	96.8

0.6	0.4	0.8	96
0.425	0.9	1.8	94.2
0.3	0.6	1.2	93
0.212	4.2	8.4	84.6
0.15	4.1	8.2	76.4
0.075	14.4	28.8	47.6
Reciever	23.8	47.6	0

Table B4; Sample 4 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Passing(%)
6.3	0	0	100
5	0	0	100
3.35	0	0	100
2	0	0	100
1.18	0.1	0.2	99.8
0.6	0.4	0.8	99
0.425	0.4	0.8	98.2
0.3	0.6	1.2	97
0.212	1.7	3.4	93.6
0.15	3.5	7	86.6
0.075	19.4	38.8	47.8
Reciever	23.7	47.4	0.4

Table B5; Sample 5 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)
6.3	0	0	100
5	0	0	100
3.35	0.3	0.6	99.4
2	0	0	99.4

1.18	0.1	0.2	99.2
0.6	0.3	0.6	98.6
0.425	0.7	1.4	97.2
0.3	0.7	1.4	95.8
0.212	2.8	5.6	90.2
0.15	4.3	8.6	81.6
0.075	20.5	41	40.6
Reciever	20.3	40.6	0

Table B6; Sample 6 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Passing (%)
6.3	0	0	100
5	2	0.4	99.6
3.35	1.5	0.3	99.3
2	18	3.6	95.7
1.18	16.5	3.3	92.4
0.6	22	4.4	88
0.425	20.3	4.06	83.94
0.3	88.9	17.78	66.16
0.212	140.2	28.04	38.12
0.15	160.2	32.04	6.08
0.075	16.9	3.38	2.7
Reciever	13.5	2.7	0

Table B7; Sample 7 sieve analysis result

Sieve Size (mm)	Mass Retained(g)	Percent Retained(%)	Percent Passing(%)
6.3	0	0	100
5	0	0	100
3.35	17	3.4	96.6

2	8.9	1.78	94.82
1.18	11.2	2.24	92.58
0.6	20	4	88.58
0.425	17.8	3.56	85.02
0.3	19	3.8	81.22
0.212	83.5	16.7	64.52
0.15	132.9	26.58	37.94
0.075	168.3	33.66	4.28
Reciever	21.4	4.28	0

Table B8; Sample 8 sieve analysis result

Sieve Size (mm)	Mass Retained(g)	Percent Retained(%)	Percent Passing(%)
6.3	0	0	100
5	23.2	4.64	95.36
3.35	50.5	10.1	85.26
2	21.7	4.34	80.92
1.18	17	3.4	77.52
0.6	16.8	3.36	74.16
0.425	13.2	2.64	71.52
0.3	6.4	1.28	70.24
0.212	110.7	22.14	48.1
0.15	54.1	10.82	37.28
0.075	170	34	3.28
Reciever	16.4	3.28	0

Table B9;Sample 9 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Passing (%)
6.3	0	0	100
5	0	0	100

3.35	16	3.2	96.8
2	9.2	1.84	94.96
1.18	10.8	2.16	92.8
0.6	19.5	3.9	88.9
0.425	18.4	3.68	85.22
0.3	20	4	81.22
0.212	94.2	18.84	62.38
0.15	140.3	28.06	34.32
0.075	152.5	30.5	3.82
Reciever	19.1	3.82	0

Table B10; Sample 10 sieve analysis result

Sieve Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Passing (%)
6.3	0	0	100
5	0	0	100
3.35	25.3	5.06	94.94
2	14.2	2.84	92.1
1.18	29.7	5.94	86.16
0.6	19.5	3.9	82.26
0.425	30.2	6.04	76.22
0.3	6.3	1.26	74.96
0.212	98.1	19.62	55.34
0.15	122.4	24.48	30.86
0.075	130.9	26.18	4.68
Reciever	23.4	4.68	0

Table B11**;** Hydrometer analysis result for sample 3

Elapsed time (min)	Hydrometer reading (R_h)	True reading (R_h)	Effective depth (Hr) mm	Modified Reading (R_d)	Particle diameter D (μm)	Percentage finer than D, K (%)
0						

0.5	3.5	4.0	200.7	2.2	23.8	7.0
1	3.0	3.5	202.6	1.7	18.0	5.4
2	1.5	2.0	208.3	0.0	15.9	0.0
3	0.5	1.0	212.1	-0.8	11.0	-2.6
4	0.0	0.5	214.0	-1.3	8.9	-4.1
8	0.0	0.5	214.0	-1.3	5.7	-4.1
15	0.0	0.5	214.0	-1.3	6.4	-4.1
30	0.0	0.5	214.0	-1.3	5.6	-4.1
60	0.0	0.5	214.0	-1.3	5.1	-4.1
120	0.0	0.5	214.0	-1.3	4.7	-4.1
240	0.0	0.5	214.0	-1.3	4.4	-4.1
480	0.0	0.5	214.0	-1.3	4.1	-4.1
1440	0.0	0.5	214.0	-1.3	3.8	-4.1

Table B12; Hydrometer analysis result for sample 4

Elapsed time (min)	Hydrometer reading (R_h)	True reading (R_h)	Effective depth (Hr) mm	Modified Reading (R_d)	Particle diameter D (µm)	Percentage finer than D, K (%)
0						

0.5	3.0	3.5	202.6	1.7	23.8	3.8
1	1.5	2.0	208.3	0.2	18.1	-1.0
2	0.5	1.0	212.0	0.0	16.0	0.0
3	0.0	0.5	214.0	-1.3	11.0	-4.1
4	0.0	0.5	214.0	-1.3	8.9	-4.1
8	0.0	0.5	214.0	-1.3	5.7	-4.1
15	0.0	0.5	214.0	-1.3	6.4	-4.1
30	0.0	0.5	214.0	-1.3	5.6	-4.1
60	0.0	0.5	214.0	-1.3	5.1	-4.1
120	0.0	0.5	214.0	-1.3	4.7	-4.1
240	0.0	0.5	214.0	-1.3	4.4	-4.1
480	0.0	0.5	214.0	-1.3	4.1	-4.1
1440	0.0	0.5	214.0	-1.3	3.8	-4.1

Table B13; Hydrometer analysis result for sample 5

Elapsed time (min)	Hydrometer reading (R_h)	True reading (R_h)	Effective depth (Hr) mm	Modified Reading (R_d)	Particle diameter D (µm)	Percentage finer than D, K (%)
0						

0.5	2.5	3.0	204.5	1.2	23.9	3.8
1	1.0	1.5	210.2	-0.3	18.2	-1.0
2	0.0	0.5	214.0	0.0	16.1	0.0
3	0.0	0.5	214.0	-1.3	11.0	-4.1
4	0.0	0.5	214.0	-1.3	8.9	-4.1
8	0.0	0.5	214.0	-1.3	5.7	-4.1
15	0.0	0.5	214.0	-1.3	6.4	-4.1
30	0.0	0.5	214.0	-1.3	5.6	-4.1
60	0.0	0.5	214.0	-1.3	5.1	-4.1
120	0.0	0.5	214.0	-1.3	4.7	-4.1
240	0.0	0.5	214.0	-1.3	4.4	-4.1
480	0.0	0.5	214.0	-1.3	4.1	-4.1
1440	0.0	0.5	214.0	-1.3	4.0	-4.1

APPENDIX C

Parameters and Formulas used in Hydrometer Analysis Calculation

Hydrometer no = 802426/A

Test temperature = 27ºC

Meniscus Correction = C_m = + 0.5

Reading in dispersant solution 0.9967 $R_d^1 = -1.3$

Particle density Gs = 2.56

Viscosity of water = 0.7544 mPass

Initial dry mass of soil = 50g

Dry mass after pretreatment m = 50g

0.0050.00 ×100 = 0.00

Column (3) $Rh = R_h^1 + C_m = R_h^1 + 214 - 3.8$

Column (4) $H_R = R_h$

Column (5) $R_d = R_h^1 - R_o^1$

Column (6) $D = 0.005531\sqrt{\ }H_R/(Gs - 1)t = \sqrt{}H_R/t\mu m\ H_R/t\mu m$

Column (7) $K = [Gs/m(Gs - 1)] \times R_d \times 100 = R_d\%$