# SEDIMENT DELIVERY INTO THE KUBANNI RESERVOIR, AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

**BY**

**Yakubu Obadaki YUSUF**

**B.Sc. (ABU, 1999);M.Sc. (ABU, 2006)**

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# DECLARATION

I declare that the work in the dissertation entitled "Sediment Delivery into the Kubanni Reservoir, Ahmadu Bello University, Zaria, Nigeria" has been performed by me in the Department of Geography under the supervision of Prof. E.O. Iguisi, Dr. A.L. Bello. and Prof. O.F. Ati.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

| Yakubu Obadaki YUSUF | | February 20, 2013 |
|---|---|---|
| Name of Student | Signature | Date |

# CERTIFICATION

This dissertation entitled "Sediment Delivery into the Kubanni Reservoir, Ahmadu Bello University, Zaria, Nigeria", by Yakubu Obadaki YUSUF meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

---------- ----------

**Prof. E.O. Iguisi**
Chairman, Supervisory Committee Date

---------- ----------

**Dr. A.L. Bello**
Member, Supervisory Committee Date

---------- ----------

**Prof. O.F. Ati**
Member, Supervisory Committee Date

---------- ----------

**Dr. I.J. Musa**
Head of Department Date

---------- ----------

**Prof. A.A. Joshua**
Dean, Postgraduate School Date

# DEDICATION

This project is dedicated to the Glory of Allah (sw), my parents, Alh. Ahmed Yusuf and Haj. Maryam Yusuf, my wife, Mrs. Kabirat Omowumi Yakubu, and children, Abdullahi, Abdurrahman and Maryam As-siddiqah.

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# ABSTRACT

In an attempt to assess the sediment delivery into the Kubanni reservoir, a continuous monitoring of the four tributaries contributing sediments into the Kubanni reservoir, Ahmadu Bello University, Zaria from 2011 to 2012 was carried out. The monitoring was done by measuring their discharges using the $120^0$ and $90^0$ v-notch weirs for the Malmo and Tukurwa streams and the velocity-cross-sectional area method for Maigamo and Goruba streams. Water samples were collected for onward analysis in the laboratory to derive the suspended and dissolved sediment concentrations. Products of the sediment concentrations and discharges gave the sediment loads and a rating relation between sediment loads and discharges was used to determine the sediment yield of the contributory tributaries. A February 2009 NIGERIASAT imagery was used for the classification and characterization of the Land use/Land cover of each sub-basin by supervised classification with maximum likelihood algorithm taking advantage of spectral signatures using ILWIS 3.7 software.

The summary statistics including the channel suspended sediment yields of the four tributaries is increasing progressively with the Malmo stream having the least (248.29 tons/yr) and the Goruba stream having the highest (12880.55 tons/yr). The situation is not much dissimilar in the derived dissolved loads where the Malmo stream has the least value of 89.99 tons/yr and the Goruba stream has the highest value of 8654.77 tons/yr. The research revealed that the suspended sediment yield of the Malmo tributary has reduced almost by half tribute to the efforts of the University administration in their afforestation and reduction of farming activities within the sub-basin. There is a

significant difference between the suspended sediment yields of the four tributaries. There is also a significant difference between their respective dissolved sediment yields and comparing the suspended and dissolved loads of each of the tributaries also revealed a significant difference except for the Goruba stream. It was concluded that there exists significant relationship between land use and sediment yields of the tributaries with the scattered cultivation, apart from increasing progressively, making up the significant part of the LULC subsets for each of the sub-basins.

The implication of this is that apart from the Malmo sub-basin, farming is prevalent, and is therefore the major contributor to their sediment yields. This signifies the overwhelming importance of LULC in determining sediment yield of rivers as inferred by previous works. This conclusion is further corroborated with the anomaly observed in the Maigamo sub-basin having the highest Specific Sediment Yield (SSY) as a result of man's influence farming very close to its gauging station thereby affecting the consecutive increase in the SSY of the sub-basins.

Based on the findings, recommendations were made to the Ahmadu Bello University administration among which are enforcement of the ban on farming, grazing and mining strengthened with a legal backing, acquisition of more lands, encouraging annual tree planting, building low check-dams, mounting sediment traps at strategic locations, long term monitoring of the tributaries and dredging of the reservoir.

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the Study

Water is essential to life and its distribution and availability are closely associated with the development of human society. Apart from air, water is the most important resource to man. He can survive longer without food than without water. So, without it, life is impossible. Indeed it is a foundation for human prosperity and adequate quality water supply provides basis for its development (Ward, 1975; Young, 2006). The demand for water doubles every 20 years which is more than twice the rate of the world's population growth (USAID, 2003). New water sources are becoming scarcer and to treat and remediate existing sources more expensive (Clothier *et al.*, 2008).

Inevitably, modern man needs water for various purposes: agriculture, industry, domestic and municipal use and he depends largely on the rivers, lakes and aquifers to meet his water needs. Its inadequacy in supply to households and its contamination can cause offensive odour and thereby precipitate severe health problems like water related illness, such as typhoid fever, cholera, diarrhea etc which are prevalent sometimes to an epidemic scale and food shortages become critical (Handidu, 1990; Ogbonna, 1997; Meinzein-Dick, 1998; Anil-kumar, 2004; Ariyo and Jerome, 2004; Hinman *et al*, 2006; McCully, 2006).

Just as the world's population is unevenly distributed by region, so is the annual supply of water. In the same vein, water shortages will not come all at once in every part of the

world. Rainfall is determined by uneven weather patterns and as a result, some area of the world gets more precipitation than others. As a result of extreme fluctuations in river discharges in some climatic regions, dams are constructed across rivers to create water reservoirs for power generation, irrigation, flood control, recreation and domestic water supply (Spencer, 2003).

When a dam is constructed across a river, the resultant reservoir receives water and sediments from the catchment area of the river network. Sediments reaching the reservoir come from the inflow drainage area and are taken mainly through the major fluvial channels network (Carvalho *et al*, 2000). Eroded sediments are transported and deposited into the reservoir and this becomes worrisome if the dam is not designed to flush out such sediments as they will continue to settle at the bottom of the lake and overtime increase in thickness. This tendency ultimately reduces the actual depth of the lake, and the volume of water that can be retained in the reservoir (Leopold *et.al.*, 1964; Maddock, 1969; McPherson, 1975; Vanoni, 1975; Painter, 1976; Rodda, 1976; Koi *et al.*, 2006; Strahler and Strahler, 2006).

Mineral materials of many different shapes and particle sizes erode and contribute to the overall stream load. The materials carried by rivers are termed sediment load. Sediment load is composed of eroded materials of different shapes and sizes, determining their mode of transportation downstream. Sediment load are broadly classified into bedload, suspended load, and solution or solute load. Bedload is the load that remains in contact with the channel bed moving by a combination of rolling, sliding and skipping. These include the largest and heaviest materials in the stream, ranging from sand and gravel to

cobbles and boulders and it is important in scouring the channel (Smith and Stopp, 1978; Knighton, 1998; Thomas *et al*., 2004).

Solute load is chemical material carried in dissolved form which can result from mineral alteration from chemical erosion or may even be the result of ground water seepage into the stream. Materials comprising the dissolved load have the smallest particle size of the three load types. The quantity of the dissolved solids in the stream is referred to as the Total Dissolved Solids (TDS) and it is important in the assessment of water quality and pollution (Ward, 1975; Degens *et.al.*, 1991; Knighton, 1998).

The suspended sediment loads are those materials carried by rivers and transported in suspension. Stream flow keeps these suspended materials, such as clay and silt, from settling on the stream surface bordering the channel as well as erosion of the channel itself. These materials are too large to be dissolved, but too small to lie on the bed of the stream. It is usually much greater in volume than the bedload and, from the point of view of reservoir sedimentation, it is of crucial importance (Ayoade, 1988; Mangelsdorf, 1990; Hudson, 1993; Spencer, 2003; Thomas *et al*., 2004; Koi *et al.*, 2006; Ritter, 2006).

Sediment yield is the total amount of sediments that are generated within the catchment area of the river and subsequently moved from a drainage basin through a cross-section during a specified period of time to be deposited on flood plains, in storage reservoirs, or carried off to the seas. Sediment yield in drainage basins is a function of many variables including the nature of the geology and soil, relief characteristics, vegetation cover,

drainage characteristics, climate, time and land use pattern and intensity within the drainage basin (Gregory and Walling, 1973; Oyebande and Martins, 1978; McCalla *et al*., 1984; Phillip, 1990; Brooks *et al*., 1997; Iguisi and Abubakar, 1998; Linse *et al*., 2001; Oyegun and Ede, 2005).

Sediment yield has been identified as the major cause of reservoir sedimentation. Glymph (1973) for instance, reported that some small reservoirs in the United States incure up to 25% storage loss annually as a result of sediment deposited in them. Dasma *et al*. (1973) identified a similar phenomenon for reservoirs downstream of mining areas while Platt (1971) reported similar occurrence in reservoirs downstream of logged areas. In Nigeria, Imevore *et al.* (1988) for example reported that some dams in Nigeria which include the one near Ile-Ife at Oke Odo had become totally silted up and turned into weed-infested marshes due to rapid urban development and farming activities at the headwaters of the lake. Another example is that of Effon Alaye reservoir in Ondo State, which would have completely silted up, but for perennial dredging. Adedeji and Jeje (2004) have also observed significant channel erosion of the Opa basin in southwestern Nigeria. The situation in northern Nigeria where there is marked seasonality in rainfall is even worse (Ologe, 1973a).

## 1.2 Statement of the Research Problem

The problem of reduction in the installation capacity of dams, especially in the northern part of the country, as a result of rainfall seasonality and sediment load cannot be

overemphasized. The Kubanni dam, on which the entire community of the Ahmadu Bello University and immediate environs depend, is not an exception.

Prior to 1973, Ahmadu Bello University (ABU) water demand had always been met, though inadequate and irregularly, by the Zaria water treatment plant, located some 25 km south-east of the institution. The desire to achieve equilibrium between water supply and demand led the ABU authority, in 1973, to start the construction of a small earth dam across River Kubanni in order to retain water that would meet the community's present and future needs. At the completion of the dam, in 1974, it had a storage capacity of 2.6 x $10^6$ $m^3$ with maximum depth of about 8.5m, a catchment area of 57$km^2$, a lake surface area of 83.4 ha and supply capacity of 13.64 million litres per day to cater for about 50,000 people (Committee on Water Resources and Supply, 2004).

The dam was designed to have a hollow spillway, such that excess water over the storage capacity of the lake spills into this hollow and is evacuated through pipes under the embankment. However, the facility for flushing out sediments was not provided. It has, therefore, had its fair share of the sediment yield problem over the years. Although efforts have been made by the authorities concerned to nip the problem in the bud, it seems to persist.

Iguisi (1997), in his study of the extent of sedimentation in the dam recorded a maximum reservoir depth of 5.2m as against the initial 8.5m which indicate a loss of about 3.3m (i.e. about 30% loss in storage capacity in 23 years) and an average annual loss of depth

of about 14.3cm. This is the result of eroded materials transported and deposited into the reservoir.

In 2008, the report of the ABU Committee on Protection of the Kubanni dam surmised that from the year 2023, rationing of water will start; first during dry season, later in both seasons. From the year 2039, there will be no more water in the reservoir during dry season. In year 2059, the reservoir, completely silted up, will disappear from maps (Committee on the Protection of Kubanni Dam, 2008).

Otun and Adeogun (2010) in their study of the analysis of fluvial sediment discharges into the Kubanni reservoir estimated a total sediment load of 20,387,000 kg/year. By simple comparative analysis, the reservoir had lost about 48% of its initial volume to sedimentation implying that the reservoir had experienced severe stacking of sediments over the past years.

Thus, sediment production within the basin is very high, confirming Ologe's (1973b) remarks before the construction of the dam that unless precautions are taken, the Kubanni reservoir is likely silted like the Daudawa dam in Katsina state, where dredging has been carried out in an attempt to restore storage capacity. It also confirms the statement of Ogunrombi (1979) that high rates of sediment supply to the reservoir by sheet erosion and from gullies, which are widespread in the river catchment, should normally be expected.

The studies of Iguisi (1997), ABU Committee on Protection of the Kubanni dam (2008) and Otun and Adeogun (2010) were mainly concerned with the net accumulation of

sediments in the reservoir. It is however, important to find out the sources of sediment and their nature for the purpose of designing measures for controlling sediment delivery into the dam.

The accumulated sediment in the reservoir comes from the catchment area of the river network composed of four major tributaries including the Malmo (northernmost), Tukurwa, Maigamo and Goruba streams (fig.1). It is not likely that these tributaries produce equal amounts of sediments into the lake.

Yusuf (2006), assessed the magnitude of the suspended sediment produced by the Malmo tributary of the Kubanni River. A Channel Sediment Yield (CSY) value of 482 tons/yr and a Specific Sediment Yield (SSY) value of 92 tons/km$^2$/yr were derived for the catchment area of the tributary and part of his recommendations was that future studies should look into the spatial distribution of sediment contribution into the reservoir by all the in-flowing streams so as to determine which inflow is the most problematic in terms of reservoir sedimentation.

Yusuf (2009) went further to attempt a comparative analysis of the suspended and dissolved sediment yields of the same tributary. The results showed that the dissolved sediment yield was a bit higher than the suspended sediment yield. However, there is no statistically significant difference between them. This implies that estimating sediment yield by considering only suspended sediment yield is an underestimation and this further complicates the already established siltation problem of the Ahmadu Bello University

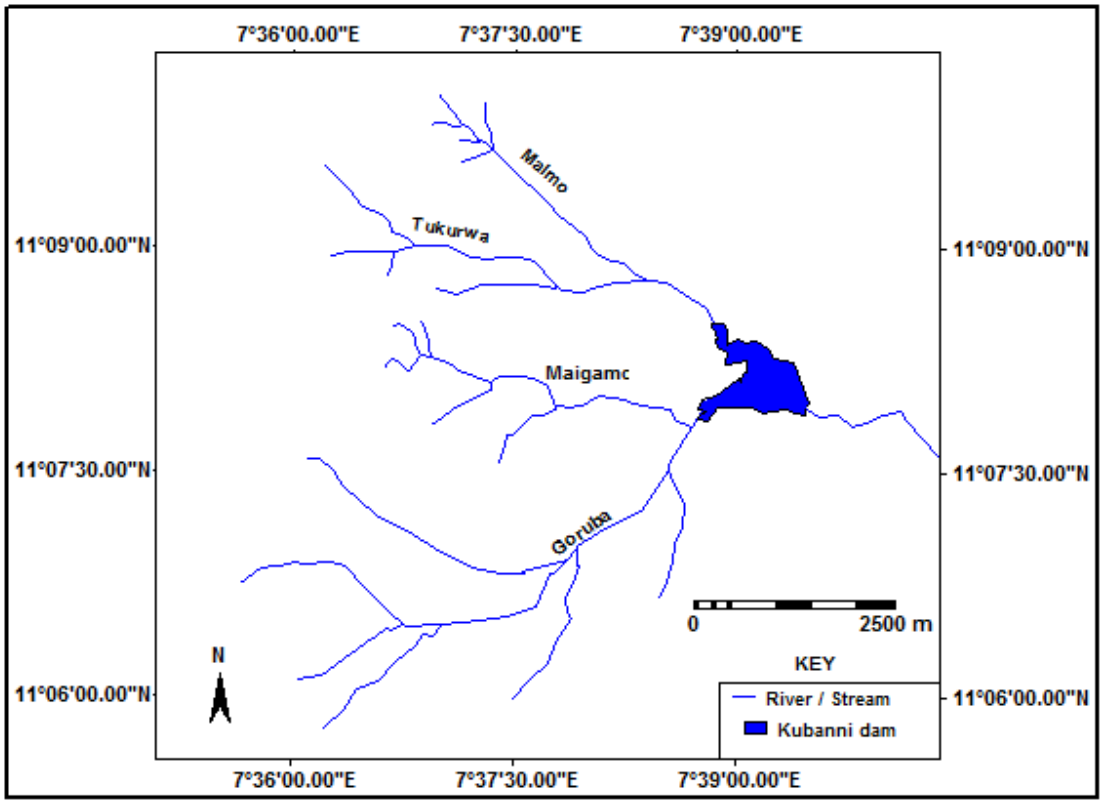



**Fig.1 The Kubanni Reservoir and the Four Tributaries Contributing Sediments to it**
**Source: Adapted and Modified from Zaria SW Topographic Map**

reservoir as it influences the water quality. These high sediment yields of the Malmo tributary cannot however be said to be representative of the other tributaries contributing sediments into the reservoir as they differ in their individual characteristics. The research questions therefore include:

1. What is the characteristics of the sediment deposited into the reservoir?
2. How much sediment does each tributary contribute?
3. What is relationship between and among the sediment contributed by the tributaries?
4. What are the causes of the sediment delivered into the reservoir?

5. What are the control measures of sediment delivery into the reservoir?

## 1.3 Research Aim and Objectives

The aim of this study is to assess the sediment delivery into the Kubanni reservoir of Ahmadu Bello University, Zaria, Kaduna State. The specific objectives are to:

i) Characterize and classify the sediment delivery into the reservoir;

ii) Determine the sediment yield of the contributory stream tributaries;

iii) Compare between and among the sediment yield of the contributory stream tributaries

iv) Examine the causes of the sediment delivered into the reservoir;

v) Recommend measures towards controlling sediment delivery into the reservoir.

## 1.4 Hypotheses

Deriving from the above objectives are the null hypotheses that:

i) There is no significant difference in the suspended sediment yields of the tributaries.

ii) There is no significant difference in the dissolved sediment yields of the tributaries.

iii) There is no significant difference in the suspended and dissolved sediment yields of the tributaries.

## 1.5 Scope of the Study

This study focuses on the impounding reservoir of the Ahmadu Bello University, Zaria and the four major tributaries contributing sediment into it. It is mainly an exploratory study aimed at examining the relative contribution of suspended and dissolved sediment yields into the Kubanni reservoir. Emphasis is also laid on their land use-land cover (LULC) characteristics in order to find out its relationship with the sediment yields produced by them. This is because previous studies have proven its significant effect on the magnitude of sediment yield through its influence on the degree of protection afforded by vegetation cover, the physical characteristics of the soil and the potential for surface runoff generation (Douglas, 1967; Walling and Gregory, 1970; Goudie, 1981; Osterkamp *et al*., 1991; Knighton, 1998).

Bedload is not considered in this study because while dissolved and suspended load are important components of the total sediment load; in most river systems, the bed load is what influences the channel morphology and stability (Knighton, 1998; Kondolf *et al.*, 2002). The gentle undulating terrain of the study area also reduces the component of the bedload in sediment delivery as most would have been deposited along stream channels before reaching the reservoir. .

It is worth mentioning here that utilizing data of more than a year would have been laudable but for the absence of continuous monitoring of the tributaries, there is no available data that can be utilized. Data on sediment concentration and stream discharge

were collected from May 2011 to February, 2012 which marked the flow period of the tributaries delivering sediments into the reservoir..

## 1.6 Justification of the Study

Water is one of those things that people usually take for granted until it is either gone or unsuitable to drink. Water is a limited resource and the demands for which are fast increasing. Populations in some cities, like Zaria and in Ahmadu Bello University in particular, for instance, are expanding at an astronomic rate, but instead of the water supply situation to improve, it is worsening day by day. The problem is further compounded by reduction in the installed capacity of reservoirs, especially in the northern part of the country, as a result of rainfall seasonality and siltation due to sediment delivery into the reservoirs. Knowledge of the sources and magnitude of these sediments is also lacking. This is why there is the need of close monitoring and examination of the dams' reservoirs and the sediments deposited into them from their catchment areas for the purpose of effective management.

### 1.7 Organization of the Study

This study is in six chapters. Chapter one introduces the study and presents the research problem, aim and objectives, research hypotheses, scope and justification of the study. Chapter two, deals with the review of relevant literatures. A description of the study area makes up chapter three. Methods for data collection and analysis are presented in chapter four. The results obtained from field and laboratory works are presented, described and

discussed in chapter five while chapter six is the conclusion, implication and recommendations of the study.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.0 Introduction

The Hortonian overland flow model of 1945 succintly describes the hillslope hydrological processes prevailing in the study area. The study area is part of the seasonally humid tropical region characterized by strong seasonality in rainfall with marked dry and wet seasons. At the onset of the rainy season, the vegetation cover is sparse, decimated by the long dry season (6 months) with abundant bare surfaces.

As the rainy season commences, high intensity rainfall impacts on the bare surfaces, detaching and eroding substantial amount of sediments from the topsoil and transporting them downslope. These sediments ultimately are washed into rivers and finally into the reservoirs. This process continues unabated for a considerable period during the first half of the rainy season before vegetation covers the soil surface.

In addition, Knighton (1998) explained that rivers usually have well defined spatial boundaries and can usefully be regarded as open systems in which energy and matter are exchanged with an external environment. The character and behaviour of the fluvial system at any particular location reflect the integrated effect of a set of upstream controls, notably climate, geology, basin physiography and land use, which together determine the hydrologic regime and the quantity and type of sediment supplied.

## 2.1 The Concept of Sediment Yield

Disintegration of the earth's crust by several physical and chemical processes provides the majority of materials that may become fluvial sediment. From these materials, soils are formed.

Erosion of soils by water can be separated into sheet and channel erosion, but no distinct division exists. Sheet erosion occurs when fine-grained silts and clays are removed from a surface in a sheet of relatively uniform thickness, by raindrop splash and sheet flow. Because of irregularities on the land surface, sheet flow quickly concentrates into small rills or channels, which grow in size as they join. Within these channels the water erodes the banks and bed materials. Virtually all the sediments contained in streamflow are derived from sheet wash and channel erosion upstream. Owing to gravity however, many forms of mass wasting take place, ranging from slow creep to very rapid landsides.

The rate of sediment movement and its distribution within a river is a function of sediment characteristics, mainly grain size and density, and of flow characteristics, mainly velocity and temperature (Guy, 1964; Painter, 1976; Knighton, 1998).

Sediment entering the stream from the catchment area is carried downstream by the transporting medium, namely water. During the movement of water, the potential energy is transformed into kinetic energy and part of the latter is consumed for transporting the sediment. Moving sediment, which in turn, invariably reduces the sediment-transporting

capacity. The upper limit of transporting capacity is governed by this circumstance (Bogardi, 1974).

In general, sediment load carried by natural streams can be separated into three components:

(a) The dissolved load, consisting of all organic and inorganic materials carried in solution by moving water,

(b) The suspended or wash load, consisting of organic and inorganic particulate matter that is suspended in and carried by moving water.

(c) The bed load, consisting of coarse materials such as gravels, stones, and boulders that move along the bottom of the channel. These materials move by skipping, rolling and sliding or saltation (Ward, 1975; Ayoade, 1988; Knighton, 1998).

This distinction is somewhat arbitrary because there is an interchange of particles between the two later modes of transport as some bed load materials can be carried in suspension by turbulent mixing process. With regards to catchment denudation, the dissolved and suspended loads are the main components. But from a geomorphological standpoint, the bed load is the principal concern because of its influence on the adjustment of river channel form. Of the three components of load, however, it contributes least to the total (Knighton, 1998).

Ayoade (1988) emphasized that solute (dissolved) load is important in the assessment of water quality and pollution but from the point of view of reservoir sedimentation, it is the

sediment load that is of crucial importance. Walling and Kleo (1979), added that information on the magnitude of the suspended sediment loads of rivers has many practical applications ranging from geomorphological studies of denudation rates and patterns of landform development to problems of upstream soil loss and downstream channel and reservoir sedimentation.

Several workers have given their own definition of sediment yield. Gregory and Walling (1973) have defined sediment yield of a drainage basin as the resultant of the processes of erosion, transportation and deposition operating in that basin with a basic unit of tons/km$^2$/yr and its magnitude reflects the sediment delivery ratio. Schumm (1977) defined sediment yield as the total amount of sediment moved from a drainage basin. He added that it is usually calculated from measurement of the sediment concentration in a stream of water, which does not include bed load, or from the amount of sediment deposited in a reservoir, which is a measure of total sediment load. Also, Knighton (1998) defined sediment yield as the total sediment outflow from a basin over a specified time period, with sediment in suspension as the dominant component.

However, for the purpose of this study, which is related to upstream soil loss and sedimentation of the Ahmadu Bello University reservoir, sediment yield of the tributaries of the Kubanni river is the total suspended and dissolved sediment outflow from them over a year with a basic unit of tons/yr or tons/km$^2$/yr. Where tons/yr represents channel sediment yield and tons/km$^2$/yr represents specific sediment yield as

adopted by Adedeji and Jeje (2004). Bedload is not considered because while dissolved and suspended load are important components of the total sediment load; in most river systems, the bed load is what influences the channel morphology and stability (Knighton, 1998; Kondolf *et al.*, 2002). The gentle undulating terrain of the study area also reduces the component of the bedload in sediment delivery as most would have been deposited along stream channels before reaching the reservoir. .

## 2.2 Factors affecting Sediment Yield

Whatever sediment is produced and transported depends on the magnitude of the various active and passive forces operating within the catchment. Over areas of continental and subcontinent scale, the major determinants of sediment yield of rivers are climate and relief (Fournier, 1960; Douglas, 1967; Wilson, 1973, Syvitski *et al*., 2003). In local areas, additional and often important controls include geology (Hadley and Schumm, 1961; Mclennan, 1993), soil types (Wischmeier and Smith, 1978; Bartholic, 2004), vegetation (Langbein and Schumm, 1958; Jansen and Painter, 1974), drainage characteristics (Morisawa, 1967; Pinet and Souriau, 1988); Milliman and Syvitski, 1992), time (Gregory and Walling, 1973; Schumm, 1977) and land use pattern within the drainage basin (Onodera, 1957; Guy, 1965; Ursic and Dendy, 1965; Morris and Fan, 1998; Verstraeten and Poesen, 2001).

### 2.2.1 Rainfall and Temperature

Climate has been regarded as of fundamental significance by many workers and this arises from the receipt of radiation and precipitation which gives rise to a particular

pattern of climate and to a particular assemblage of geomorphological processes in a specific area (Peltier 1950; Budel, 1969; Tricart and Cailleux, 1972; Jansen and Painter, 1974).

The existence of strong climatic control on the erosion process was demonstrated by Corbel (1964) who examined sediment yields in four temperature zones, using the rainfall and two relief classes, and found that erosion rates vary inversely with temperature being lowest in the tropics. Fournier (1960) however suggested that the effect of climate is inverted, with the greatest erosion occurring in the seasonally humid tropics and declining progressively through the equatorial regions to the temperate and cold regions. Much of this divergence of opinion must be due to the lack of adequate data with which to resolve the complex multivariate controls on erosion (Painter, 1976).

The overall effect of climate is commonly defined by curves that relate sediment yield to mean annual precipitation or mean annual runoff. The rate of surface runoff, which plays a significant role in the erosional process and magnitude of sediment yield is influenced by precipitation. Langbein and Schumm (1958) defined the relation between annual sediment yield and annual precipitation for drainage basins averaging about 3500 $km^2$ in the conterminous United States for an annual mean temperature of $10^oC$ (fig 2.1A).

Although precipitation is the dominant climatic factor influencing sediment yield, the effect of temperature needs to be considered, because more precipitation is required to produce a given amount of runoff in a warm climate than in a cool climate (Schumm,

1977). The curve of fig.2.1A, therefore, is the relationship between sediment yield and precipitation adjusted to an annual warm temperature of 10$^{o}$C, the Langbein and Schumm (1958) curve reaches a peak at an effective precipitation of about 300mm (i.e. semiarid conditions), trailing off at lower values because of lower runoff totals and at higher ones because an increasingly abundant vegetation cover affords better protection against erosion. However, this interpretation is limited in a number of respects, not least because the curve is based on group-averaged United States data in which tropical areas are not represented, and because sediment yield may again begin to increase for precipitation amounts over 1000 mm.

A much more comprehensive analysis by Walling and Kleo (1979) revealed not only considerable variability in annual sediment yields (Fig 2.1Bi) but also a more complex average relationship with three peaks (fig 2.1Bii). Because of the scale of variability, Walling and Kleo questioned the justification for ascribing the three peaks to specific climate conditions, but tentatively suggested what they represented respectively; Continental semi-arid conditions (2450mm); high rainfall Mediterranean climates (1250-300mm); and tropical monsoon conditions (>2500mm). The first corresponds approximately with the Langbein and Schumm (1958) peak (fig. 2.1A), while the other two may indicate the effects of seasonal precipitation regimes (Knighton, 1998).

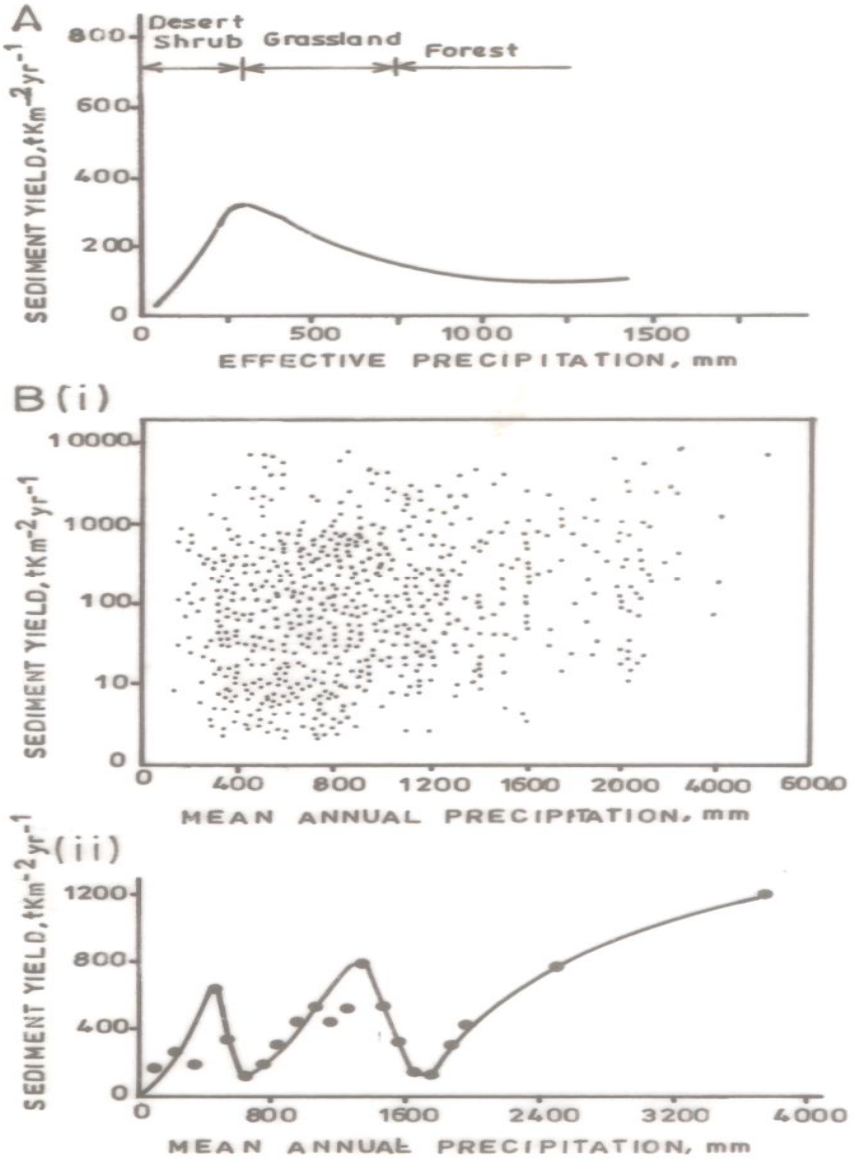



**Fig. 2.1 Relationship of Sediment Yield to: (A) Effective Precipitation. (B) Mean Annual Precipitation- (i) Raw Data; (ii) Group-averaged Data**
**Sources: (A) Langbein and Schumm, 1958 (B) Walling and Kleo, 1979**

Sediment discharge is related to basin relief, basin area and temperature by the relation:

$Qs = aR^{3/2}A^{1/2}e^{kT}$ ..... (2.1)

where Qs is the long-term sediment load (kg/s), R is relief defined as the highest point of elevation (m) minus the elevation of discharge station (m), A is basin area ($km^2$), T is mean surface temperature of the drainage basin and k and a are constants ($2*10^{-5}$ and 0.1331 respectively) (Syvitski, 2002). Syvitski *et al*. (2003) divided the known global river data into different climatic zones, polar, temperate and tropical based on the above formulation. Calculations based on this model indicate that the polar rivers with sub-zero temperatures show the lowest values in sediment yield (120 $t/km^2/yr$), whereas tropical rivers with temperatures of more than 30°C have extreme sediment yields (3648 $t/km^2/yr$).

### 2.2.2 Relief and Slope

The magnitude of the component of gravitational force acting along slopes and channels and the potential energy of the drainage basin, is determined by the initial relief which is dependent on the magnitude of uplift, and the relief at any time during the erosional development of the drainage basin. Relief and slope therefore influence the rate at which denudational processes operate (Gregory and Walling, 1973).

The work of Fournier (1960) also indicate that erosion varies directly with relief, but that this effect is less in the tropics than in the temperate regions, Schumm (1963) demonstrated the direct relationship with relief and further concluded that annual sediment yield is directly proportional to main channel slope.

Mcpherson (1975) examined the relationship between sediment yields between geomorphic and hydrologic variables on the one hand and sediment yield on the other

using regression analysis. He discovered that mean land slope and unit mean discharge were the variables which gave the highest correlation coefficients.

Recent studies have also underlined the importance of relief. In assessing the relative influence of a wide range of factors on global soil loss, Phillips (1990) found that slope gradient ( the relief variable) accounted for roughly 70 percent of the variation, with runoff production per unit of precipitation and rainfall erosivity ( the climate variable) controlling approximately 15 and 14 percent respectively. Milliman and Syvitski (1992) analyzed the data from 280 rivers which together account for > $62*10^6$ km or about two-thirds of the land surface draining into the oceans and concluded that basin elevation (expressed via maximum headwater elevation) is a major control of sediment yield, other factors such as climate and runoff of the basin are of only secondary significance.

Although the form and relative significance of the relief variable varies between the two studies above, they both identify the overall importance of relief in accounting for the variation of sediment yield at the global scale. In addition, many studies have pointed to the significant influence of basin elevation and morphology on river sediment fluxes, but only a few mathematical relationships are available. Pinet and Souriau (1988) found river sediment fluxes to be linearly correlated with mean basin elevation. Looking mainly at river sediment yields of large world rivers, they proposed the following two equations to describe mechanical denudation globally:

$Ds = 419*10^{-6}Elev - 0.245$ (regions related to orogenesis < 250 Ma) ..... (2.2)

$Ds = 61*10^{-6}$ Elev (regions related to orogenesis > 250 Ma), ..... (2.3)

where Ds is the denudation rate in m kgyr$^{-1}$ and Elev is the mean basin elevation in metres. From the equations above, Ludwig and Probst (1998) estimated that 5.2 billion tons yr$^{-1}$ originated from old continental crust (73% of the total area), while 11 billion tons yr$^{-1}$ originated from young continental crust (27% area). However, the high denudation rate in the young continental crust is also associated with high sedimentation rates as observed by the considerable intercept in the equation obtained for regions related to orogenies < 250 Ma. The high erosion rates in young continental crust is due to the relatively easy weatherability compared to the highly resistant old continental crust, and low relief and slope factors.

Relief is a major factor as it induces greater mechanical erosion (Montgomery and Brandon, 2002). Although factors such as lithology, climate, run-off and vegetation influence erosion rates, mean local relief is a primary control on erosion rates. Based on the studies of rivers categorized on the basis of elevations, mountainous rivers showed greater loads and yields (Chakrapani, 2005).

At smaller spatial scales where differences in climate and relief are more subdued, other factors assume greater significance, particularly in so far as they influence runoff production (Knighton, 1998).

### 2.2.3 Geology

The type of rock underlying the basin determines the nature and extent of groundwater storage and also the type of material that is available for erosion and transport within the

drainage basin. Geology includes the lithologic character of rocks, as well as structure, the influence of fractures (joints and faults), and other deformational features and their distribution.

The role of geology in mechanical erosion is less understood. However, the influence of lithology on mechanical erosion rates is probably high with respect to channel erosion, but less important with respect to hill slope erosion because the outcropping lithologies are normally covered with soils. Rivers flowing over crystalline terrains erode with difficulty, whereas unconsolidated sedimentary rocks yield greater sediment loads to rivers. Also, basins underlain by shales and siltstones erode rapidly and those underlain by sandstone and conglomerates erode slowly. Kattan *et al*. (1987) estimated that in the Senegal river, 20% of the total river transport is derived from channel erosion.

Another variable is infiltration capacity; weak rocks that produce sandy soils with a high infiltration capacity produce less runoff and therefore little sediments (Table 2.1.).

A negative correlation between sediment yield and weathering history, as measured by the Chemical Index of Alteration (CIA) of the suspended sediments, is observed for many of the world's major rivers. CIA is represented as the molar ratios of $[Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O]*100$ as measured in sediments. Values of about 45–55 indicate virtually no weathering, whereas values of 100 indicate intense weathering with complete removal of the alkali and alkaline earth elements (Kattan *et al*., 1987).

**Table 2.1 Lithologic Units, Cheyenne River Basin**

| Stratigraphy units | Mean Infiltration (mm/hr) | Sediment yield (tons/km$^2$/yr) | Drainage density (km/km$^2$) |
|---|---|---|---|
| Wasatch formation | 233.68 | 0.33 | 3.35 |
| Lance formation | 127 | 1.28 | 4.4 |
| Fort Union formation | 33.02 | 3.33 | 7.07 |
| Pierre Shale | 25.4 | 3.58 | 9.98 |
| White River group | 4.57 | 4.61 | 160 |

Source: Hadley and Schumm, 1961

By assigning CIA values representative of unweathered (50) and extremely weathered (100) sources to extreme denudation values, a relationship was constructed between weathering and denudation:

Sediment yield (t/km$^2$/yr) = $(2.25*10^5)(10^{-0.04335(CIA)})$..... (2.4)

The global river data were thus divided into three groups. Many of the high-yield areas correspond to the negative sediment yield–weathering relationship and are consistent with weathering intensity, providing a first-order control on sediment yield. These areas are considered to have a sediment discharge that approaches an equilibrium with prevailing weathering conditions termed equilibrium denudation regions, whereas most of the other areas have sediment yield much lower than that predicted from the relationship; four areas (Huang He, Mekong, New Zealand, rivers of Oceanic Islands) are

considered to have higher sediment yield, termed non-equilibrium denudation regions. The denudation of areas that deviate substantially from this relationship primarily can be understood in terms of natural and anthropogenic processes that accelerate or moderate erosion rates and provenance from easily eroded glacial debris that has not experienced a normal weathering history (Mclennan, 1993).

### 2.2.4 Soil and Mantle

Soil as a factor affecting sediment yield, is genetically tied to the geology of the bedrock from and upon which it develops. Although overland flow may occur when the infiltration rate has not been exceeded by rate of precipitation, overland flow occurs when the precipitation rate exceeds the infiltration rate of the ground's surface and the infiltration rate is different for different surfaces (Dunne and Leopold, 1978).

The erodibility of soils, their susceptibility to erosion and transportability, depends upon many factors, most of which are highly interrelated. The soil erodibility factor, K, in the Universal Soil Loss Equation (USLE), considers soil properties that influence both detachment and transport of soil materials. These include soil texture, organic matter content, structure, size, shape, stability of aggregates, permeability of the soil to water, the level of compaction of the soil, and water content (Lal, 1988).

Coarse textured soils (sands) have large pores, which allow water to drain more easily than fine textured soils (Clay). These coarse soils allow water to infiltrate more quickly. Soil erodibility tends to increase with greater silt content and decrease with greater sand

and clay contents. Organic matter binds individual particles together thus increasing aggregate strength, hence the resistance to detachment. Soil structure, in terms of its size, shape and aggregate stability, influences the infiltration rate. Erosion will not occur if the infiltration rate is greater than the rainfall rate. Permeability of the soil to water affects erosion because rainfall must enter and move through the soil if runoff is to be minimal (Wischmeier and Smith, 1958).

Compaction increases risk of erosion and can reduce crop yields by up to 60%. Clay soils and soils low in organic matter content are particularly prone to compaction (Dumanski et.al.,1986). Also, since cohesion is reduced by lack of moisture, soils are generally more erodible when dry than when moist. Erosion, both fluvial and aeolian (wind) is therefore generally greatest in arid and semi-arid regions, where soil is poorly developed with low moisture content and vegetation provides relatively little protection.

Soil erosion and sediment yield are therefore affected by properties such as texture of the soils and sediment. The texture of the eroded materials is associated with the sources of erosion. Coarse materials are usually produced by stream-bank and gully erosion, while the fine materials are often from sheet and rill erosion (Bartholic, 2004).

### 2.2.5 Vegetation

Vegetation type and density, depending on the geology, soil and climate influences the volumes of runoff and sediment that are eventually discharged from a catchment area of a river basin (Schumm, 1977). With increase in precipitation, there will be increase in

vegetation cover, Langbein and Schumm (1958) showed erosion to be a maximum at an annual rainfall of 250-350mm in the United States. Below this, although concentrations of sediment may be higher owing to the tendency for areas of low rainfall to have high intensity storms, total sediment yield decreases. Above 250-350mm, vegetal cover becomes increasingly complete and less erosion and lower sediment yields result (as in Fig 2.1A). Once vegetation is complete, further increase in rainfall may give higher yields, as encountered in many upland peat areas in the United Kingdom (Anon. 1972).

Vegetation is known to protect soil from raindrop impact, reduce surface runoff rate, hold soil in place, improve soil structure and increase transpiration rate. Leaves and branches that do not directly contact the soil have little affect on amount and velocity of runoff from prolonged rains, but they reduce the affective rainfall energy by intercepting falling raindrops. Water drops falling from the canopy may regain appreciable velocity but usually less than the terminal velocities of free- falling raindrops. The amount by which energy expended at the soil surface is reduced depends on the height and density of the canopy. Also, soil aggregates may be very unstable under tree- shaded surfaces; hence erosion may be quite effective on such surfaces. However, close growing vegetation intercept falling raindrops so near the surface that the drops regain no fall velocity, and they also obstruct runoff flow and thereby reduce its velocity and transport capacity (Wischmeier and Smith, 1978).

Generally, in the humid tropics, as a result of a high infiltration rate, surface wash is minimal in forests. Thus suspended sediment yield varies from 60-100 tons/km$^2$/yr on

lowlands, rising to 200 tons /km$^2$/ yr on highlands. The drier savannas, characterized by tufted grasses growing as individual clumps, leave wide expanses of bare surfaces especially during the dry season. Thus grasslands are liable to severe rain splash and wash erosion especially at the onset of the rains. Protection from erosion is least where the ground is covered by thorn scrubs, as in the Sahel of West Africa, which constitutes one of the zones of most severe fluvial erosion in the world, with denudation rate of between 1000 and 2000 tons/km$^2$/yr (Fournier, 1960).

From above, it is evident that vegetated surface allow more water to infiltrate than bare surfaces. A simple illustration of this is shown in Fig. 2.2.

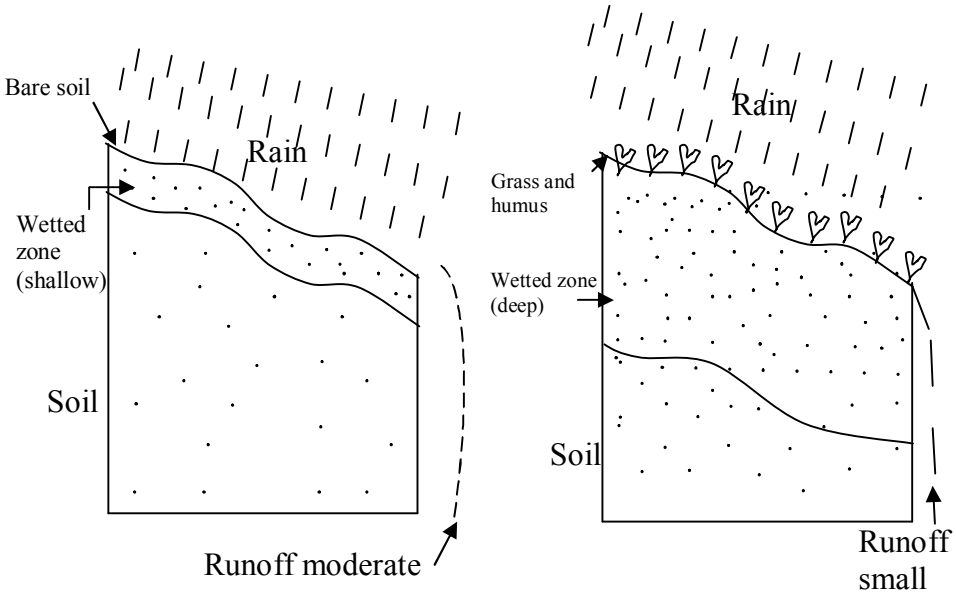



**Fig. 2.2 A Diagrammatic Representation of Infiltration Rate on Bare and Vegetated Surfaces.**

### 2.2.6 Drainage Basin Area

Basin area alone is not a determining factor of sediment yield. Smaller basins generally exhibit steeper slopes and steeper stream gradients than large basins and thus aid in large sediment yields, whereas large basins show low slopes and low stream gradients, and hence result in low sediment output. Basin area integrates several factors such as gradient, storage capacity, etc. which influence sediment yields. Because of these variables controls, rivers draining only 10% of the world's drainage basins account for more than 60% of the sediment discharge to the oceans (Milliman, 1991).

In undisturbed drainage basins from the western Southern Alps in New Zealand, high sediment yields, more than ten times the world average are reported (Griffiths, 1979), caused mainly due to steep catchments and rise in elevation from sea level to over 3000m. Locally, the influence of certain rivers can have a great influence on the regional budget, as in the Ganga/Brahmaputra into the Indian Ocean, which show extremely high mechanical denudation rates compared to chemical denudation rates or the Huang He and Chanjiang rivers into the Pacific Ocean (Ludwig and Probst, 1998).

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Drainage basin area is in many respects the easiest basin characteristic to relate to drainage basin processes but because it is in turn correlated with other characteristics such as relief, in that the highest relief ratios tend to occur in the smaller basins, its significance may not be easy to interpret. For many years however a simple relation between an index of stream flow (Q) and catchments area (A) has been used as a guide to

discharges of a particular value. Such relations have usually taken the form $Q = aA^b$ and have been used particularly for predicting flood events.

Due to the nature of basin characteristics and to the restricted areal occurrence of intense precipitation of large amount, storm discharge per unit area, expressed as mean annual flood for example, may be inversely proportional to catchments area. This inverse relation arises partly from the storage potential of the basin, including storage in channels as well as in lakes because small catchments may be dominated by erosion whereas deposition may figure more prominently in larger catchments. Thus in many areas sediment yield per unit area has been observed to decrease as catchments area increases and according to measurements in the United States it appears that, on average, watersheds less than $25km^2$ produce seven times as much sediment per unit area as watersheds greater than $2500km^2$ (Table 2.2) (Gregory and Walling, 1973).

**Table 2.2 Average sediment production for groups of drainage area in the United States**

| Watershed size range | Arithmetic Average annual sediment production | Number of measurements |
|---|---|---|
| Less than 26 $km^2$ | 1810$m^3/km^2$ | 650 |
| 26 - 260 $km^2$ | 762 $m^3/km^2$ | 205 |
| 260 - 2600 $km^2$ | 481 $m^3/km^2$ | 123 |
| More than 2600 $km^2$ | 238 $m^3/km^2$ | 118 |

Source: Gottschalk, 1964

Other indices of size of basin have been employed in relationship with drainage basin process. Use of length of longest stream, or total channel length, is sometimes quicker, and sometimes more relevant than use of basin area, but both are closely related to area. Length of longest stream (L) in a relation with mean annual discharge (Q) was utilized by Morisawa (1967) where the relation took the form $Q = aL^B$.

Finally, the spacing of the drainage channels with the drainage basin expressed as drainage density is an index of the efficiency of the basin in disposing of water and sediment. The effect of relief has already been made clear and the effect of density can be illustrated by an example from the cornfield Wash drainage basin in northern New Mexico. Within this area of similar geology, land use, and climate, runoff and sediment yield data were collected for several years for small drainage basins. Of particular interest is the fact that channel networks in the drainage basins are not fully developed. That is, many of the valley networks do not contain fully integrated, well-defined channel network. For example, in one basin the drainage density is 0.6 and in another it is 5.6. Therefore, the effect of drainage density on runoff and sediment yield can be isolated, and both mean annual runoff and sediment yield are found to be significantly greater from drainage basins with high drainage densities but similar relief/length ratios (Table 2.3).

**Table 2.3 Hydrologic and Geomorphic Data from Paired Watersheds of similar Relief/Length Ratios, Cornfield Wash, New Mexico**

| | Drainage Area ($km^2$) | Relief/ length | Drainage density | Mean annual Sediment Yield ($tons/km^2/yr$) | Mean annual runoff (mm) |
|---|---|---|---|---|---|
| a | 3.02 | 0.023 | 0.6 | 1.54 | 41.63 |
| a' | 2.23 | 0.026 | 2.1 | 4.35 | 56.58 |
| b | 0.84 | 0.043 | 3.1 | 9.47 | 113.92 |
| b' | 0.74 | 0.046 | 5.6 | 17.41 | 162.3 |
| c | 2.66 | 0.035 | 1.3 | 2.3 | 52.48 |
| c' | 0.64 | 0.036 | 3.0 | 5.63 | 94.21 |

where a and a' stand for paired watersheds. Source: Schumm, 1969

### 2.2.7 Time

In landform development, the distinction between cause and effect is a function not only of spatial distribution but also of time. Thus the distinction between cause and effect in the shaping of landforms depends upon the size of the system in space and upon the length of time being considered (Schumm and Lichty, 1965). Therefore, "time" here refers to the period since the inception of the erosional process and in itself has no effect on the landscape; rather it records the accomplishments of the system. Three time spans, designated cyclic, graded and steady time, can be distinguished and although these do not correspond to specific absolute values, they are significantly different in duration (Gregory and Walling, 1973).

Depending on the time span considered, time may be either an extremely important independent variable or of relatively little significance in considerations of the fluvial system. For example, during a short period of steady time, there may be continuous sedimentation, with no variation in the type of sediment deposited. During graded time, however, there is a larger variation in the quantity and type of sediment transport in response to both hydrologic and other variables. During cyclic time, a progressive decrease in size and quantity of sediment is likely. Therefore, it is possible to consider all three zones of the fluvial system with regard to different spans of time (Fig. 2.3).

For the earth scientist, cyclic and graded time have the most significance. Steady time is of concern to the hydraulic engineer and sediment transport specialist, but for any real consideration of fluvial systems an awareness of the significance of all three is necessary (Schumm, 1977)

### 2.2.8 Land Use

Erosion, the producer of sediments, is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (ploughing, irrigation, grazing), forestry, construction, surface mining and urbanization. It is estimated that human activities have degraded some 15% (2000 million $km^2$) of the earth's land surface between latitudes $72^oN$ and $57^oS$ (Osterkamp *et.al.*, 1991). The study by Douglas (1967) on soil erosion in small catchments in eastern Australia (which had few effects of man), compared to the study by Fournier (1960) of a

large, world-wide data base of small catchments erosion data, indicate that anthropogenic effects increase soil erosion by about two orders of magnitude.

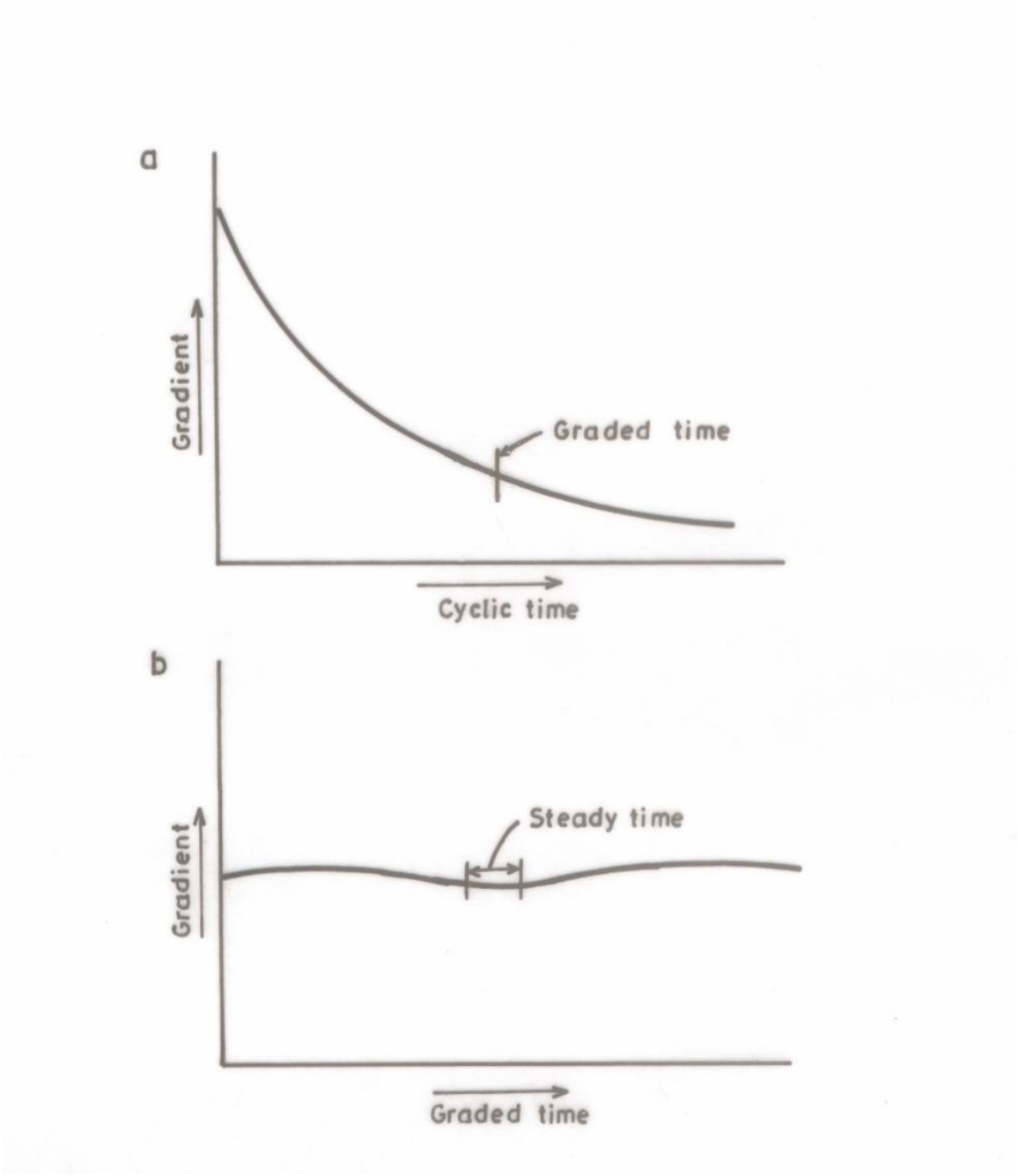



**Fig. 2.3 (a) Progressive Reduction of Channel Gradient during Cyclic Time**
**(b)Fluctuations of Gradient Above and Below a Mean during Graded Time**
**Source: Schumm and Lichty, 1965**

Landuse can significantly affect the magnitude of sediment yield through its influence on the degree of protection afforded by vegetation cover, the physical characteristics of the soil and the potential for surface runoff generation (Knighton, 1998). For example urban development is the most dramatic change of landuse and the accompanying construction can greatly increase sediment yield (Wolman and Schick, 1967).

Also, Walling and Gregory (1970) demonstrated that the annual sediment yield of some 200 tons/$km^2$ from a small agricultural catchment was increased by a factor of four after urbanization.

In showing the influence of the removal of forest in accelerating erosion, Onodera (1957) reports a hundred fold increases in sediment yield following total deforestation. Management practices, notably logging and the attendant road construction in forests can greatly increase sediment loads and Magehen (1972) quotes increases of 750 times for areas in the USA. Also, the increasing practice of opencast strip mining also presents problems and Collier and co-workers (1964) reported that mining in area of over less than 1% of a catchment increased the sediment yield resulting from sheet erosion by 83%.

Ursic and Dendy (1965) assessed sediment yields from small drainage basins under various land uses and two precipitation rates. The corresponding outcome is shown in table 4 with croplands recording highest amount of sediment yield and woodlands the least.

**Table 2.4. Sediment Yield (tons/km$^2$/ year) vs. Land–use and Precipitation Rate (1000 and 1750 mm/year) on Small Drainage Basins (0.04 – 0.12 km$^2$)**

| LANDUSE | SEDIMENT YIELD | |
|---|---|---|
| | 1000 mm/year | 1750 mm/year |
| WOODLANDS | 2 | 5 |
| ABANDONED FIELDS | 9 | 80 |
| PASTURE | 250 | 500 |
| CROPLANDS | 2000 | 9000 |

Source: Ursic and Dendy, 1965

Over much of the earth's surface, the most significant determinant for land degradation is human activity and among all the categories of human influences that alter sediment loads in rivers, none exerts as much influence as the reservoirs. Together with land-use changes, deforestation and soil conservation practices, the natural sedimentary cycle has been greatly altered. River impoundments provide important benefits to society through flood control, power generation, water storage and release for agriculture, industry and domestic supplies. The adverse environmental effects include dislocation of human populations, silting of reservoirs, reduced sediment flux to the oceans, downstream scouring of channels, life cycle and habitat of aquatic organisms, eutrophication, anoxia and toxic conditions (Morris and Fan, 1998; Chakrapani, 2005).

From the foregoing descriptions of the relationships that exist between sediment yield and influencing factors, it can be observed that these factors are in most cases interrelated and act concertedly to slow or accelerate the rate of sediment yield.

## 2.3 Previous Studies on Sediment Yield in Nigeria

A large number of studies have been carried out on sediment yield in many parts of the world. In Nigeria, a number of studies on this matter are also evident. Ologe (1986) for example, applied four general models out of existing models, relating sediment yield to mean annual rainfall, mean temperature and relief within the context of the Nigerian environment.

### 2.3.1 Louis Peltier's Model of estimating Sediment Yield

The first generally known attempt to relate sediment yield as a dependent variable to gross climatic elements as a set of independent variables was made by Louis Peltier (1950). His model is reproduced here as Fig. 2.4A and a number of rainfall stations in Nigeria (Table 5) have been plotted onto it. The map shows the following characteristics:

(a) Stations with mean annual rainfall less than about 762mm but greater than about 508mm fall within Peltier's zone of "moderate" fluvial erosion as do stations (not represented here) falling between about 1524mm and about 1778mm.

(b) Stations having more than about 1778mm per annum lie within the belt of "minimum" fluvial erosion as do stations (not represented here) with less than about 508mm.

(c) Stations with rainfall between about 762mm and about 1524mm lie within the zone of "maximum" fluvial erosion. This includes most of Nigeria, as Fig. 2.4B, which is an attempt to present the relevant part of Fig. 2.4A on a map of the country, clearly shows.

Peltier's hypothetical concept is relevant because it takes into account two principles which feature prominently in the analyses of later workers. The first is that the rate of erosion increases with increasing rainfall. This increase is not indefinite however, and the second principle is that as rainfall increases vegetation cover also increases and progressively protects the soil from erosion. Thus, fluvial erosion is expected to be at a maximum where rainfall is high enough to give rise to significant runoff but not so high as to result in forest vegetation. In Nigeria, such areas will include the Derived Savanna, Southern Guinea Savanna, Northern Guinea Savanna and Sudan Savanna zones. It should be noted however, that these ecological belts differ considerably in terms of vegetation bulk per unit area and of rainfall seasonality, which should lead to considerable spatial variation in erosion rates. Also, in very humid areas without vegetation, accelerated erosion will be experienced. Peltier's model is not sufficiently refined to bring this out.

### 2.3.2 Lee Wilson's Model of estimating Sediment Yield

In 1958, Langbein, and Schumm analysed records from sediment-measuring stations and from surveys of sediment trapped in reservoirs in the U.S.A and attempted a tentative quantitative statement of the relationship between gross climate and sediment yield. They concluded that sediment yield in the U.S.A. is at a maximum where mean annual precipitation is about 381mm, decreasing to zero with zero precipitation and to an asymptotic level with higher precipitation.

Lee Wilson, another American worker, has produced a model along the same lines as Peltier but based it on the conclusion of Langbein and Schumm (Wilson, 1969). Fig. 2.4C

shows Wilson's scheme on which rainfall stations in Nigeria has been plotted. The scheme suggests rather different patterns of world distribution of rates of fluvial erosion from those of Peltier. It suggests that the whole of the savanna belt in Nigeria falls within the zone of maximum fluvial erosion (fig. 2.4D).

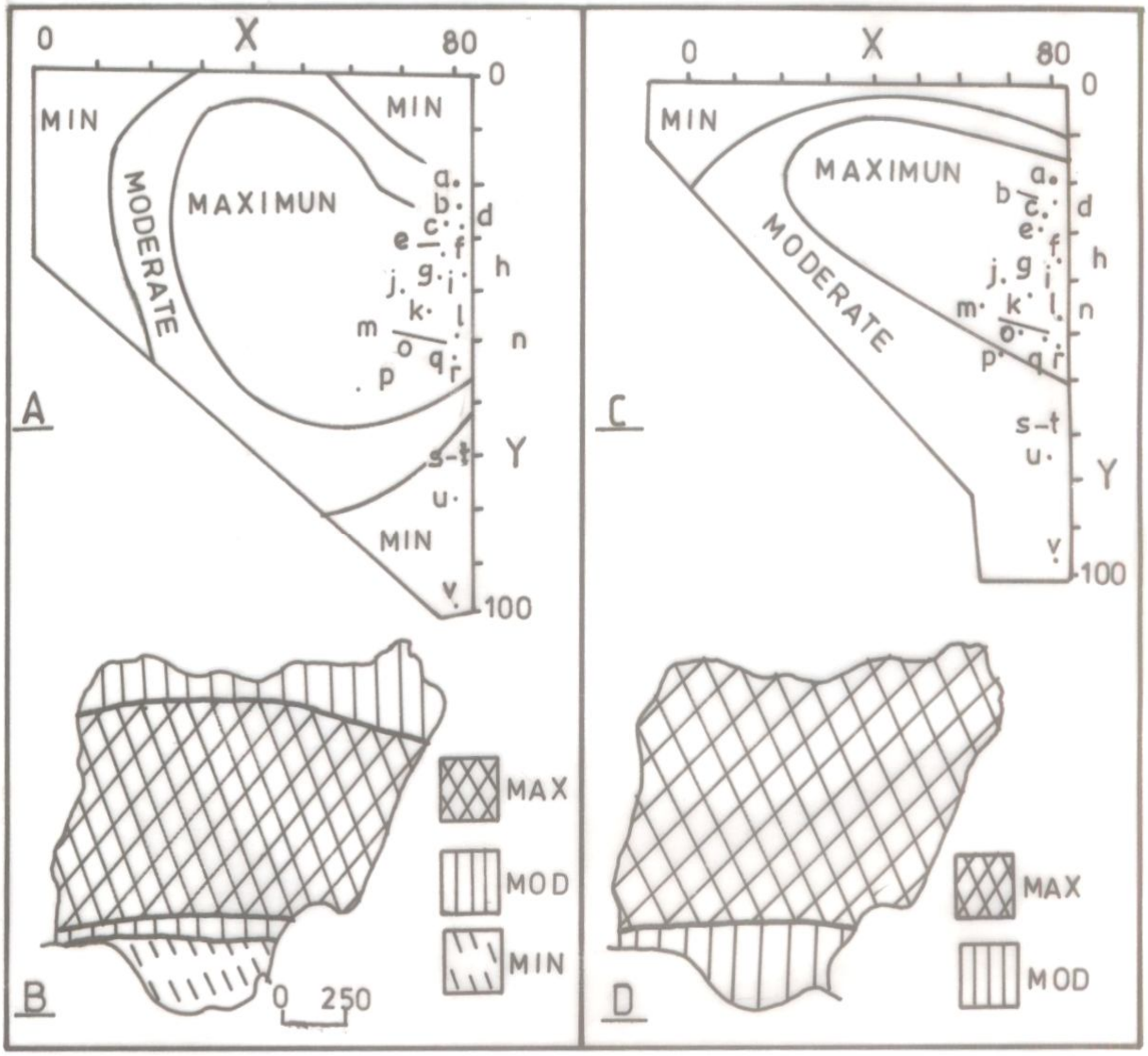



**Fig. 2.4 Models Relating Sediment Yield to Mean Annual Rainfall (Y) and Mean Annual Temperature (X). A and B After Louis Peltier (1950). C and D after Lee Wilson (1973). a,b,c,…… Rainfall Stations in Nigeria (see Table 2.5)**
**Source: Ologe, 1986**

**Table 2.5 Rainfall Stations Shown in Fig. 2.4**

| S/N | Alphabet | Station |
|---|---|---|
| 1 | a | Nguru |
| 2 | b | Maiduguri |
| 3 | c | Katsina |
| 4 | d | Sokoto |
| 5 | E | Potiskum |
| 6 | F | Kano |
| 7 | G | Gusau |
| 8 | H | Yelwa |
| 9 | I | Yola |
| 10 | J | Bauchi |
| 11 | K | Samaru |
| 12 | L | Ibadan |
| 13 | M | Ilorin |
| 14 | N | Bida |
| 15 | O | Kaduna |
| 16 | P | Jos |
| 17 | Q | Minna |
| 18 | R | Makurdi |
| 19 | S | Enugu |
| 20 | T | Ikeja |
| 21 | U | Benin |
| 22 | V | Port-Harcourt |

Source: Ologe, 1986

### 2.3.3 S.A. Schumm's Model of estimating Sediment Yield

In 1965, S.A. Schumm returned to the theme of the relationship between climate and sediment yield with a more refined kind of analysis. He summarized the relationship with a series of curves in which:

(a) the form of each curve is more or less identical with that of every other curve and is a function of mean annual rainfall and vegetation bulk;

(b) the position of each curve on the horizontal axis is controlled by mean annual temperature.

Fig. 2.5a shows Schumm's family of curves for mean annual temperatures of $4.4^0$C, $10^0$C, $15.6^0$C, and $21^0$C. As he was writing about the U.S.A where mean annual temperatures are everywhere or nearly everywhere below $27^0$C. Schumm did not include curves for $27^0$C and higher mean annual temperatures.

It seems reasonable to assume that such curves would have had a form similar to the ones produced by Schumm but would have been located farther and farther away from zero mean annual rainfall. On this basis, and assuming a mean annual temperature of $27^0$C for Nigeria, the curve for this value is sketched in on Fig. 2.5a. This is an attempt to see how, given Schumm's thesis; sediment yield may be expected to vary with mean annual rainfall in Nigeria.

The curve suggests that the highest rates of erosion in Nigeria of over 600 tons/mi$^2$/yr (1553 tons/km$^2$/yr) are to be found within curved east west belt of country embracing the northern part of the Northern Guinea Savanna zone and the southern part of the Sudan Savanna zone, an area receiving 762-1016mm of rain per year (Fig.2.5b). It suggests further that sediment yield may be expected to be at a peak of about 830 tons/mi$^2$/yr (2148 tons/km$^2$/yr) where mean annual rainfall is 838-864mm, decreasing rapidly with lower rainfall and rather rapidly with increasing asymptotic level where rainfall is higher than about 1651mm.

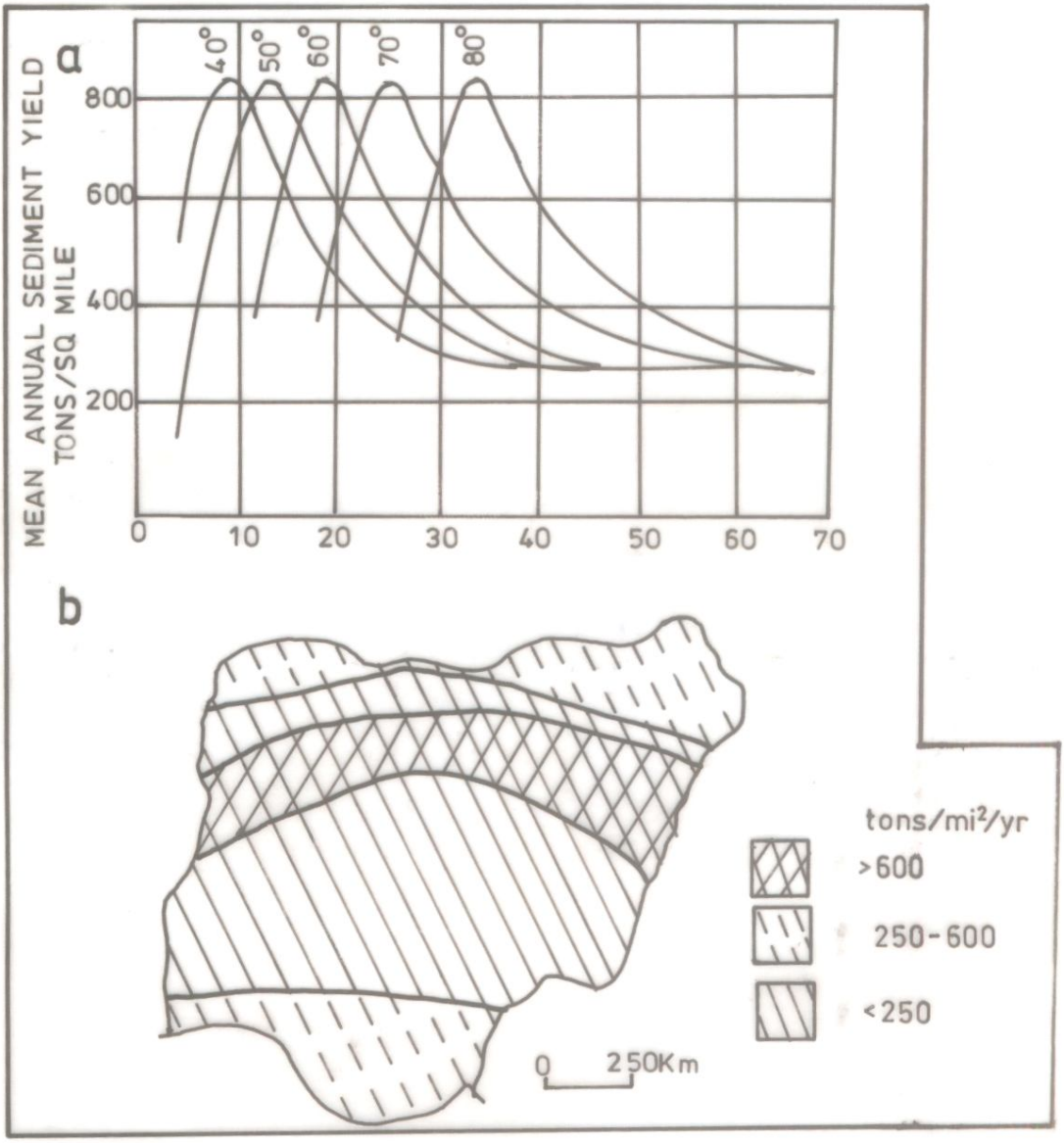



**Fig. 2.5 (a) Effect of Temperature in the Relationship between Sediment Yield and Precipitation (From Schumm, 1965)**
**(b) Expected sediment yield in Nigeria as derived from the curve for 80°F (27°C)**
**Source: Ologe, 1986**

### 2.3.4. Fournier's Model of estimating Sediment Yield

Soil erosion is a function of other factors besides mean annual rainfall and mean annual temperature. These include rainfall seasonality, relief, soil characteristics and land use. Fournier (1960) has developed empirical equations incorporating the first two of these other factors for predicting sediment yield on a world-wide basis. He found highly significant correlations between sediment yield data (from 78 drainage basins varying in area from 2460 to 1,060,000km$^2$) on the one hand and rainfall seasonality (defined as a ratio of the square of the maximum mean monthly precipitation to the annual precipitation) and relief (mean height and mean slope) on the other. On this basis, he produced a map of world distribution of erosion. He subsequently produced a map showing the distribution of erosional hazard in Africa (Fournier, 1962). Fig. 2.6 has been extracted from this second map.

Based on Fournier's model, the highest rates of erosion in Nigeria are to be expected in the extreme North West; in the extreme north around Nguru; on and around the Jos Plateau and in the southern part of the highlands of southern Sardauna province. Most of the rest of Nigeria north of the Niger and the Benue has a very high erosional hazard. The lowest rates of erosion are to be expected in southern, particularly south-western Nigeria. In general, the map can be interpreted partly in terms of rainfall seasonality and partly in terms of relief.

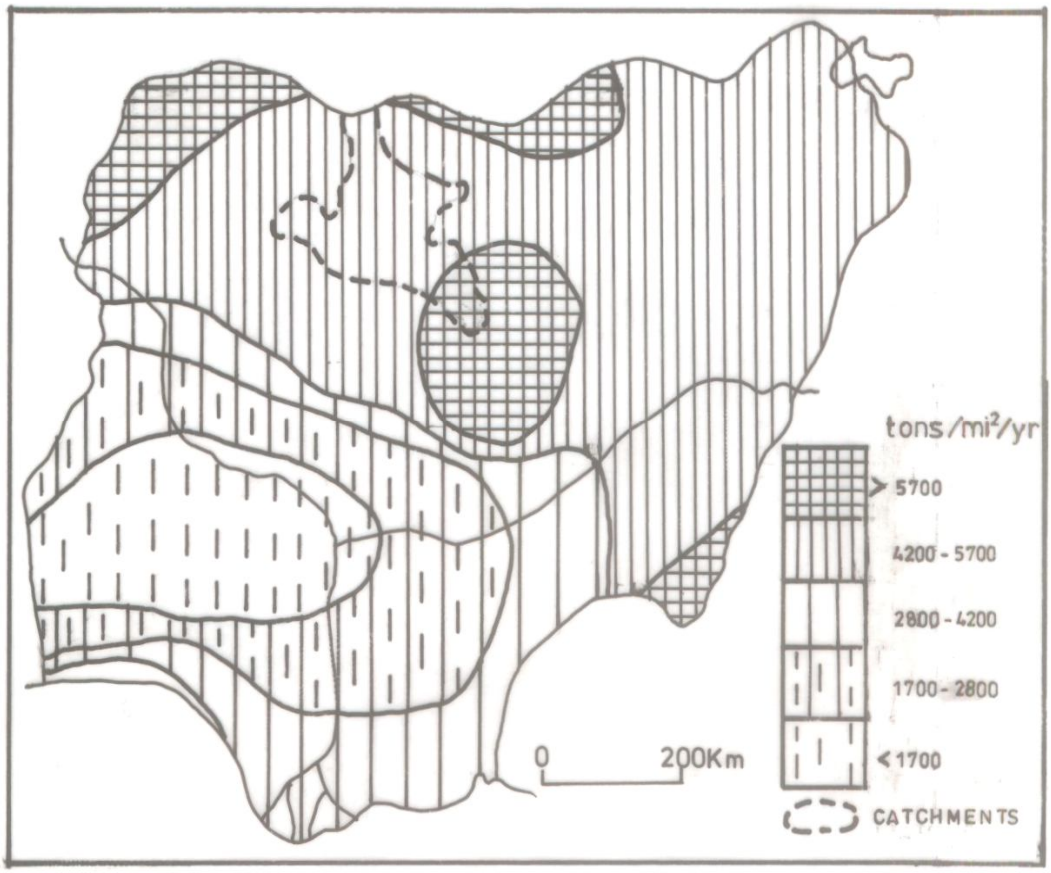



**Fig. 2.6 Erosional Hazard in Nigeria according to Fournier (1962)**
**Source: Ologe, 1986**

### 2.3.5. Comparison of the Various Models for estimating Sediment Yield

While differing in details, the first two models agree in suggesting that most of the savanna belt in Nigeria (and this means most of the country's surface area) belongs to the world's zone of highest rates of fluvial erosion under natural conditions. The southern boundary of the zone of maximum erosion on fig. 2.4B and 2.4D coincide remarkably well and is located somewhere south of the northern boundary of tropical Rain forest. The two maps differ as to the northern boundary of this zone: Peltier's model puts it well within Nigeria while Wilson's puts it north of Nigeria's northern frontier.

The model derived from Schumm and Fournier's model produce results which are not comparable either in terms of the magnitudes of erosion predicted for various parts of the country which are several or many times higher on fig.2.6 than on fig. 2.5b, or in terms of the spatial distribution of erosional hazard, as a comparison of these two maps readily shows.

### 2.3.6. The Models and Measured Data

Testing the validity, and therefore the value, of the above models calls for comparisons with actual field data, which are, unfortunately, still generally lacking. Short-term data are available for four major rivers within the Chad basin (U.S. Department of the Interior, Bureau of Reclamation, 1968) and two within the Sokoto basin. These are presented in Table 2.6. This table shows mean annual sediment yields for the six catchments, which are more or less contiguous (see fig 2.6). Rainfall and vegetation conditions are also shown and an attempt has been made to indicate sediment yield based on Schumm's model and Fournier (1962).

Based on Schumm's model the absolute range of sediment yield to be expected from the area is 400 – 830 tons/$mi^2$/yr (1035-2148 tons/$km^2$/yr). It is very interesting that in four of the catchments (Bunsuru, Gagere, Sokoto and Kano) recorded sediment yields lie within this range, two of them lying in the upper and two in the lower part of the range, in the case of the Zamfara, actual sediment yield is much higher than maximum predicated by Schumm's model while in the case of the Chalawa it is very much higher (in fact nearly five times as high).

**Table 2.6 Recorded and Expected Sediment Yield in Six Catchments in Northern Nigeria**

| Hydrological Station | River | Catctment Area ($mi^2$) | Mean Annual Rainfall (ins) | Percentage of Catchment within: | | Sediment Yield-tons/$mi^2$/yr ($tons/km^2/yr$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Northern Guinea | Sudan Savanna | Recorded | Expected After Schumm | Expected After Fournier |
| Zurmi | Bunsuru | 2640 (6832 $km^2$) | 30-40 (762-1016 mm) | 100 | 0 | 512 (1325) | 600-830 (1553-2148) | 4200-5700 (10870-14752) |
| Kaura Namoda | Gagere | 2387 (6178 $km^2$) | 30-40 (762-1016 mm) | 16 | 84 | 710 (1837) | 600-830 (1553-2148) | 4200-5700 (10870-14752) |
| Gusau | Sokoto | 1026 (2656 $km^2$) | 30-45 (762-1143 mm) | 62 | 38 | 808 (2091) | 470-830 (1216-2148) | 4200-5700 (10870-14752) |
| Anka | Zamfara | 1596 (4130 $km^2$) | 30-40 (762-1016 mm) | 20 | 80 | 1100 (2847) | 600-830 (1553-2148) | 4200-5700 (10870-14752) |
| Railway Bridge | Chalawa | 2625 (6794 $km^2$) | 30-45 (762-1143 mm) | 15 | 85 | 4062 (10512) | 470-830 (1216-2148) | 4200-5700 (10870-14752) |
| Chiromawa | Kano | 1510 (3908 $km^2$) | 35-50 (889-1270 mm) | 57 | 43 | 566 (1465) | 400-830 (1035-2148) | > 5700 > (14752) |

Source: Modified from Ologe, 1986

Fournier's model predicts sediment yield rates of 4,200 to 5,700 tons/mi$^2$/yr (10,870 to 14,752 tons/km$^2$/yr) for the same area. In five of the catchments, the predication is from 8 to 11 (perhaps even more) time higher than the measured rates. In the sixth catchment (the Chalawa) the measured rates is fairly close to the lower limit of the range prediction. Thus, although it is empirically based, Fournier's prediction of sediment yield for this part of Nigeria is unrealistically high (Ologe, 1986).

Ologe's work has been followed by several field studies in different parts of the country. In the northern part of Nigeria, Iguisi (1997) attempted an assessment of the level of sedimentation of the Kubanni reservoir in ABU, Zaria, where he observed that the reservoir recorded a maximum depth of 5.2m as against the initial 8.5m which indicate that the reservoir has an average annual loss of about 3.3m (i.e about 30% loss in storage capacity) in 23 years. This was attributed to the erodible materials transported and deposited in the reservoir floor.

In Port Harcourt, Oyegun and Ede (2005) also attempted assessment of the amount of sediment yield under five land-use types over a twelve month period with the aid of sediment traps. It was discovered that sediment yield on bare surfaces was greatest. They showed that land-use exerts a statistically significant influence on sediment yield with the magnitude of sediment yield differing considerably between land-use types. The exception to this trend is that between built-up areas and farmland land-use, there was no statistically significant difference in the magnitude of sediment yield.

Yusuf (2006) attempted an assessment of the magnitude of sediment produced by the northern tributary of the river, a 3rd order basin covering 5.25 $km^2$ flowing into the Ahmadu Bello University (ABU) reservoir, constructed to provide water for the university community. The study area was monitored for one year with data on sediment concentration and stream discharge collected from the gauging station made up of a 120° V-notch control stucture (weir), and a stage used to estimate the discharges. Suspended sediment samples, were collected at the gauging station using the USDH 48 sampler for onward analysis in the laboratory to determine the suspended sediment concentration. A rating curve was used to allow a reasonable estimate of suspended sediment yield for the study area. The coefficients of determination ($r^2$) measuring the strength of the linear correlation between the variables were found to be statistically significant at the 0.05 level using the F-ratio (ANOVA) test. A Channel Sediment Yield (CSY) value of 482 tons/yr and a Specific Sediment Yield (SSY) value of 92 tons/$km^2$/yr were derived for the catchment area. This value is high and the information thus provided presents a basis for comparison with other basins or basins of similar characteristics and the need for immediate measures to control sediment yield into the ABU reservoir.

This study was followed by a comparative analysis of the suspended and dissolved sediment yields of the same tributary in 2009. The suspended sediment yield has been acquired in the previous study. From the samples of the filtered river water (i.e. aliquot) from which the dissolved concentration (i.e. total dissolved solids) was derived and the discharge records which have been carefully kept, the dissolved sediment discharges provide the basis for estimating the dissolved sediment yield. The results showed that the

dissolved sediment yield is higher than the suspended sediment yield of the tributary. However, there is no statistically significant difference between them.

Yusuf and Audu (2010) attempted an assessment of the current level of siltation of the Galma reservoir in Zaria, Kaduna state. The level of sedimentation of the lake was determined by measuring the depth of the lake from its surface to its bed during the dry season at intersects between grid lines designated as sampling points. In all, there were 48 sampling points over the lake area for the purpose of collecting data on depth of lake. Results obtained shows that from its initial depth of 14m, the lake has lost about 5.2m depth to sedimentation representing about 37.1% storage loss in 35 years. This implies that the storage capacity of the lake has reduced considerably and has serious implications for future water supply to the Zaria Community.

Similar study was carried out by Yusuf (2011) on the Jibia reservoir in Jibia, Katsina state. The results obtained show that Jibia reservoir is rapidly silting up with the initial depth of 21m reduced to 13.43m indicating that 7.57m has been lost to sediment accumulation. The reservoir is being silted at the rate of 0.379m annually. The useful life of the reservoir is threatened because 36% of the storage capacity is already lost leaving 65.95% storage capacity and by the year 2046, the dam will be completely silted up. This implies that there are serious implications for future water supply in Jibia town and its surrounding villages and conscious efforts have to be made to reduce the siltation rate in order to prolong the useful life of the reservoir.

Yusuf and Igbinigie (2010) examined the relationships amongst discharge, suspended and dissolved sediment discharges of the Samaru stream in Zaria, a 1st order basin with a total stream length of 1.05km, basin area of 2.28km$^2$, drainage density of 0.46km/km$^2$ and a relative relief of 30.48m. The stream was monitored for six months by collecting data on sediment concentration and stream. The data provided the basis of a suspended sediment discharge (Qs) – discharge (Q) rating curve which revealed the considerable scatter about the straight line relationship, with a coefficient of correlation (r) of 0.666 and coefficient of determination ($r^2$) of 0.443 indicating that the stream discharge has a great influence on the level of suspended sediment discharge. It further provided the basis of a dissolved sediment discharge (Qd) – discharge (Q) rating curve revealing a considerable scatter about the straight line relationship with a very high coefficient of correlation (r) of 0.901 and correspondingly high coefficient of determination ($r^2$) of 0.812 indicating that stream discharge has a strong influence on dissolved sediment discharge (Qd). Furthermore, the suspended sediment discharge (Qs) and dissolved sediment discharge (Qd) values for the catchment area were correlated for which they had a positive and moderately strong correlation value of 0.408 which was significant even at 0.01 level of significance indicating that there is no significant difference between both variables.

Otun and Adeogun (2010) in their study of the analysis of fluvial sediment discharges into the Kubanni reservoir estimated a total sediment load of 20,387,000 kg/year. By simple comparative analysis, the reservoir had lost about 48% of its initial volume to sedimentation implying that the reservoir had experienced severe stacking of sediments over the past years.

Tukur (2011) examined the causes, extent and effects of sedimentation in five systematically selected water conveyance canals of Kano River irrigation project (Phase I), Kano state, Nigeria. Canal widths were measured using measuring depth while depths (to the surface of the accumulated sediments and of the accumulated sediments) were measured and the t-test was used to determine if there was a significant difference between the designed and present depth of the canals. The total volume of sediment deposit was found to be 32609.37$m^3$. The result of the test showed a significant difference between the designed and present depth of the canals which had significantly reduced from 5.05m (100%) to 1.33m (23%). Many factors are believed to have contributed to the increase of sediments in the canals which include movement of cattle across the canals, frequent deforestation of vegetation along Tiga dam which increases the rate of erosion and deposition of sediment in the dam.

Abu *et al*. (2011) also attempted an assessment of the effect of land use/land cover changes on the rate of sedimentation in the Galma reservoir, Zaria. The results reveal that cultivated area increased from 2476.25$km^2$ to 3241.36$km^2$; built-up area from 4.06$km^2$ to 13.67$km^2$ from 1970s to 2000s respectively while forest and water body show a reduction of 1085.35$km^2$ to 313.52$km^2$ and 7.12$km^2$ to 5.81$km^2$ from 1970s to 2000s respectively. Area statistics of 203.25km2 was uniform for rock outcrop throughout the decades of 1970-2000. Hydrographic survey of the reservoir was conducted by carrying out depth measurements from the surface to its bed and the results obtained shows that the dam has lost 7.6m depth to sedimentation; indicating 51% loss in installed storage capacity. This study, in relation to Yusuf and Audu (2010) asserts that unwholesome practices by man

have significant implications for future water supply to the residence of Zaria which therefore makes this study imperative.

## 2.4 Methods of Measuring Sediment Yield of a River

Several methods are available for assessing the sediment yield of a river. There are however, three main methods used in estimating sediment yield and these include reservoir/lake sedimentation studies or surveys, fraction collectors or source area measurements of erosion and direct measurements of suspended sediment concentration at basin outlet or sediment sampling (Gregory and Walling, 1973; Hudson, 1993; and Knighton, 1998).

### 2.4.1 Reservoir Sedimentation Studies

Reservoirs and artificial stock ponds can provide a very valuable source of data on sediment yield, because measurements of the rate of accretion of repositioned sediment, suitably corrected for the trap efficiency of the water body, directly reflect the sediment yield of the tributary watershed (Glymph, 1954). Trap efficiency is the proportion of sediment caught and it depends on:

A. The size of the trap compared with the amount of inflow, that is the proportion of the flow which is caught in the reservoir, and

B. The spread of flow through the reservoir, which, combined with the particle size of suspended material, determines how much time there is for sediment to settle out in the reservoir. Trap efficiency may be estimated from Fig. 2.7 (Brune, 1953).

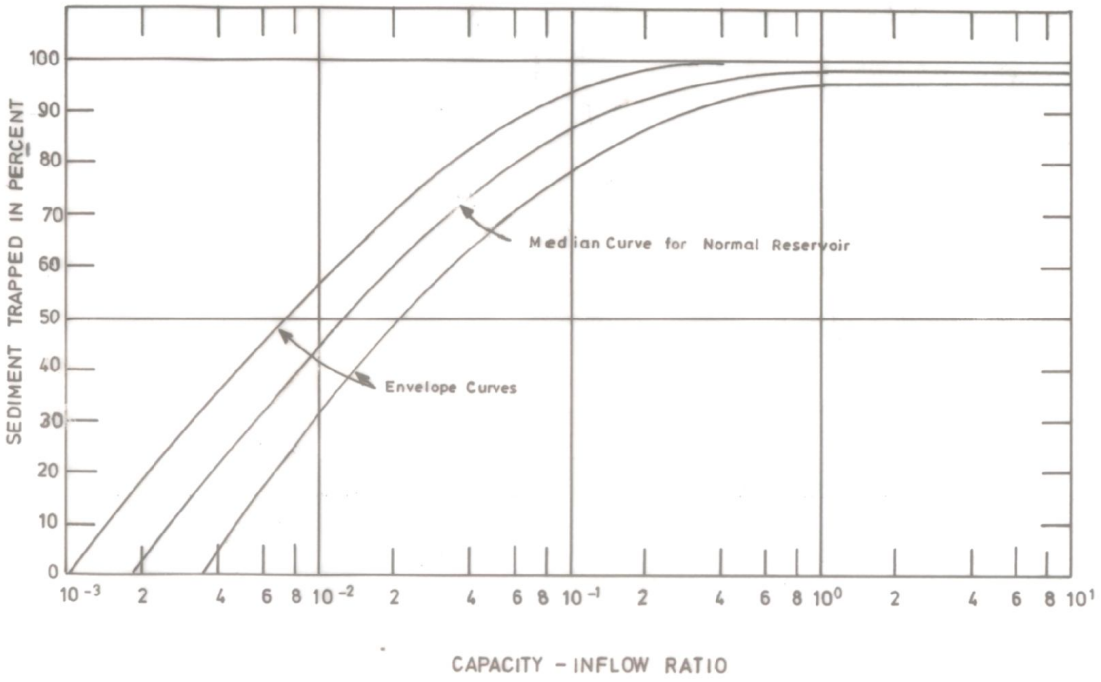



**Fig. 2.7 Trap Efficiency of Reservoirs**
**Source: Brune, 1953**

Accurate surveys of the reservoir or pond basin are required at intervals so that the accumulation can be calculated. If a reservoir is partly flooded, the survey must be carried out from boats, and the level of the sediment may be determined either by a probe or an echo-sounder and bathymetry from valeports using state of the art sensors to generate precision (Shepherdson, 1965; Castle, 1965; Heregeweyn *et al*., 2006). It is also necessary to take sample and determine the density of the sediment in order to calculate the weight from the measurement by volume (Mchenry, 1964; Hudson, 1993).

The ideal situation is to carry out a survey after the reservoir is completed and before it starts to fill, but existing reservoir can be used by comparing successive surveys over a

period of time. In all cases it is most important to establish a permanent basin in successive surveys.

Recently, hydrographic surveying has experienced a conceptual change in depth measurement technology and methodology. Multibeam echo sounders (MBES) and airborne laser sounding systems (ALS) now provide almost total seafloor coverage and depth measurement. The high data density and high acquisition rates have led to huge bathymetric data sets and much ancillary data.

However, reservoir data on sediment yield does not distinguish between the suspended load and bedload component of the total yield and the results are essentially long term (Gregory and Walling, 1973).

### 2.4.2 Fraction Collectors

Where a reservoir is not available for a sediment accretion survey or when more detailed and short term data is required, alternative techniques of assessing sediment yield must be employed. The most direct is an approximation of the reservoir principle and involves collecting the total sediment load transported by a stream (Gregory and Walling, 1973). It is a method avoiding separate estimate of suspended load and bedload and it involves mixing up all the moving sediment and then taking a single sample of the mixture.

A turbulence flume is a purpose built structure with obstructions in the streambed to create as much turbulence as possible before the flow passes over a point where samples

can be taken. The same effect may be found out at a rock bar or perhaps where the stream flows through a restricted opening such as a bridge or to culvert, large bed load material will settle to the bottom again so the sample has to be taken quickly by scooping a bucket full of the mixture. However, this technique is only applicable to small catchments and experimental erosion plots (Gregory and Walling, 1973; Loughran, 1989; Hudson, 1993; and Knighton, 1998).

Larger stream or rivers may be sampled at a turbulence flume using a slot sample (Barnes and Frevert, 1954; Barnes and Johnson, 1956). An application of this method is further described by Brown et.al. (1970). The sampling slot is narrow with sharp edges, and the water and sediment drop through into a hollow pipe or channel leading to a container. The slot must not be too small to avoid being blocked by trash. A slot width of 5mm set in a weir of 5m width will take a $1000^{th}$ sample of the flow. If this is still too large to handle comfortably, further subdivisions may be used, either another slot splitter or a sampling wheel (Parsons, 1955). Some of the difficulties associated with this method are:

(a) The splitter may affect the flow at entry into the slot

(b) The slot may be blocked by floating trash

(c) The concentration of sediment may not be equal across the width of the weir

(d) Coarse bedload may not be evenly mixed or not caught (Hudson, 1993).

An alternative to plot measurements is to estimate erosion using a soil erosion model such as the widely applied Universal Soil Loss Equation (Wischmeier and Smith, 1978) or the more recent WEPP (Water Erosion Prediction project) model (Lane et al, 1992).

They have their own limitations and data requirements. Assuming that reasonable estimates of gross erosion (E) in the catchment can be made, the final but not inconsiderable step is to multiply these estimates by a sediment delivery ratio (Dr) in order to obtain the sediment yield (Sy = E.Dr).

The sediment delivery ratio (Dr) is the ratio of the amount of sediment, which leaves a water shed to the gross amount of sediment that was originally eroded or detached from the soil mass in the drainage basin. It is however a highly variable quantity, being influenced by a wide range of geomorphological and environmental factors whose absolute and relative significance are difficult to establish (Walling, 1983; and Richards, 1993).

### 2.4.3 Sediment Sampling Procedures

Fraction collectors are specialized installations suitable only for small catchments. An alternative method of assessing sediment yield, and one suited also for large drainage basins, involves sediment sampling techniques. If frequent measurements of suspended load and bedload discharge are made at a stream flow gauging station in order to define the variations through time, estimates of sediment yield can be computed on a daily or longer time basis (Gregory and Walling, 1973).

The estimation of suspended load by sampling is relatively simple, but taking a representative sample of bedload is difficult (Hudson, 1993). Apparatus for continuous monitoring of suspended load, including photo-electric devices and radioisotope gauges

(Fleming, 1969), could be used to overcome the necessity for very frequent spot measurements, especially during periods of rapidly changing stream stages, and automatic pumping devices could also prove extremely valuable. Indeed, in a small catchment a pumping sampler or a continuous monitoring apparatus may be essential if the variations in sediment transport through time are to be recorded accurately. However, cost, and a couple of other constraints, limits the application of these devices (Gregory and Walling, 1973).

In the absence of frequent samples other samplers such as grab samples, point integrating samples or depth integrating samples, are used and a resort is usually made to the sediment rating curve technique of calculating sediment yields (Campbell and Bauder, 1940; Oyebande, 1981; Ayoade, 1988; and Knighton, 1998). This technique is primarily applicable to the suspended load and involves deriving a generalized relationship between sediment discharge or concentration and stream flow, which can be used to predict the variations in sediment transport from a continuous record of stream discharge. The relationship or rating curve is usually presented as a straight line graph plot on logarithmic coordinates (see fig. 2.8).

Several types of rating curve can be derived and these include instantaneous rating curves which relate sampled suspended sediment concentrations to the discharge at the time of sampling, daily rating curves which relate daily mean discharge to daily mean concentration and rating curves for particular sediment sizes (Colby, 1956). Sediment sampling is therefore required only to derive and check the rating curves and it is possible

to tentatively extend the relationship to period when no sampling was carried out, but for which discharge records are available. The exact method of computing the estimate of sediment yield may involve streamflow duration curves and manual data processing (Miller, 1951) or a detailed digitised streamflow record and computer processing (Walling, 1971).

Care is required if error in the estimated yields are to be avoided, and Walling (1971) has shown that the use of daily mean discharge value instead of hourly point values, with an instantaneous rating curve, can lead to underestimation by as much as 50 percent. Because suspended load is not a capacity load, the graphical relationship between sediment transport and discharge (fig. 2.8) often exhibits considerable scatter (Colby, 1956), and in some cases their scatter may be so marked as to render the technique of little value. Seasonal effects on the relationship can be overcome to some extent by constructing individual rating curves for different seasons (Miller, 1951; Hall, 1967; Walling and Gregory, 1970; and Brown, 1972).

Bedload is not explicitly considered, although it is generally a minor component of the total (usually < 15 per cent). In addition, the calculated value applies to the basin as a whole and is therefore not directly related to conditions within the drainage basin. With these problems however, this method is still arguably the most reliable method (Knighton, 1998), and this is why it is adopted in this study.

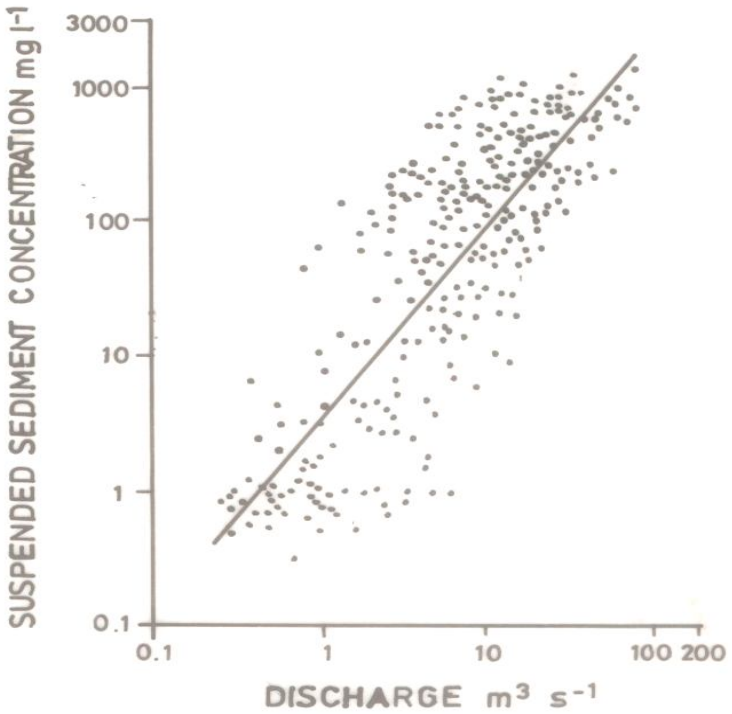



**Fig. 2.8 A Sediment Concentration-Discharge Relationship**
**Source: Walling and Webb, 1992**

# CHAPTER THREE

# THE STUDY AREA

## 3.1 Location, Position and Size

The study area is in Zaria, Kaduna State, Nigeria (Fig. 3.1). Zaria is one of the provinces that make up the Central high plains of Northern Nigeria and it is approximately 670m above mean sea level. It is located about 950km away from the coast. Zaria is the second largest city in Kaduna State, covering a total land mass of about 61km$^2$ making it a nodal point in terms of road and rail transport because of locational factors (Jatau, 1999; Arowolo, 2000).

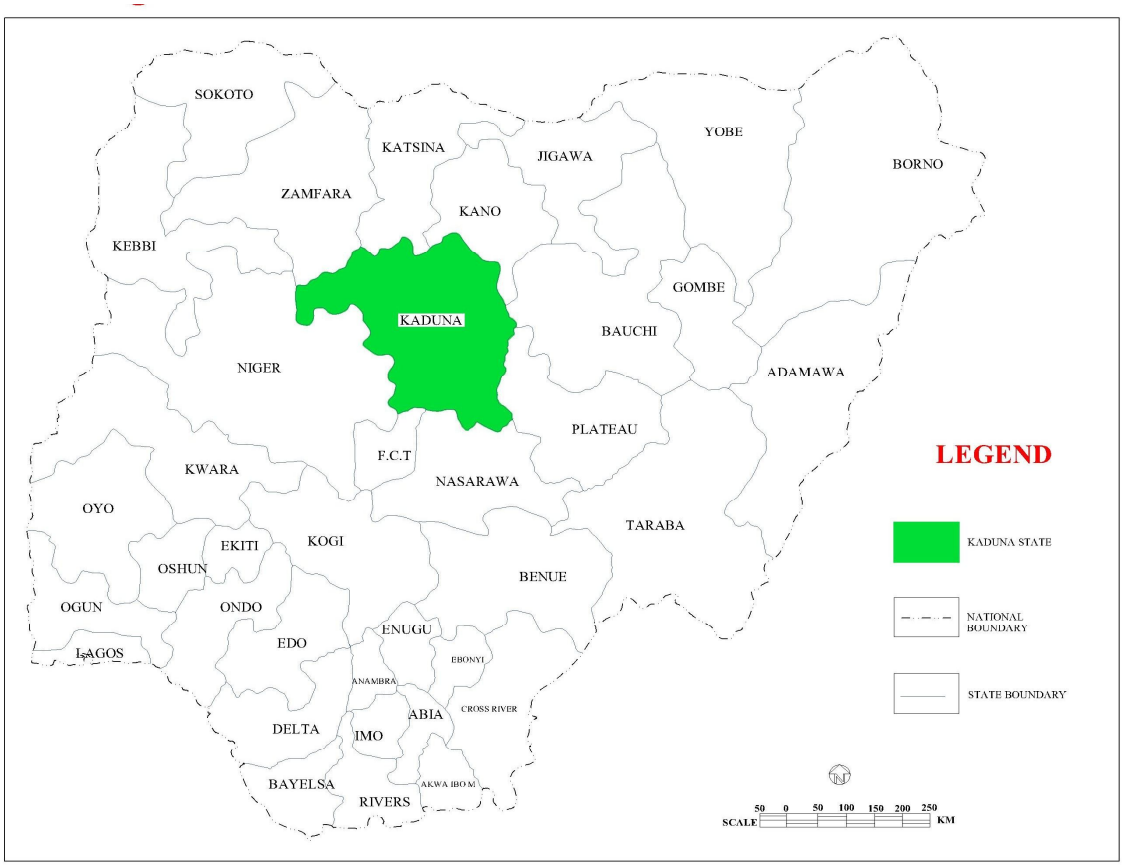



**Fig. 3.1: Nigeria showing Kaduna State**
**Source: Kaduna State Urban and Regional Planning**

The study sites are located in the upper Kubanni drainage basin, in Zaria $11^{0}05^{/}50^{//}$ $11^{0}10^{/}25^{//}$ N and $7^{0}35^{/}40^{//}$- $7^{0}38^{/}50^{//}$ (Federal Survey Topographical Sheet 102, Zaria S.W). The Kubanni River takes its source from the Kampagi Hill, in Shika, near Zaria. It flows in a southeast direction through Ahmadu Bello University main campus, Samaru. It has four major tributaries upstream of the Kubanni reservoir. The tributaries of the river were used for this study (fig.3.2a and 3.2b).

## 3.2 Climate

The study area belongs to the tropical continental type of climate corresponding to Koppen's tropical savannah or tropical wet and dry climate zone (Aw), characterized by strong seasonality in rainfall and temperature distributions (Oladipo, 1985). It has two distinct seasons: the dry or harmattan season (October to March) and wet season (April to September). The seasons generally coincide with the southward and northward movement of the surface transition known as Inter-Tropical Discontinuity (ITD) between the hot, moist tropical maritime air-mass (mTs) of Atlantic ocean origin to the south and the cold, drier tropical continental air-mass (cTs) blown by the northeast trades from the Sahara Desert.

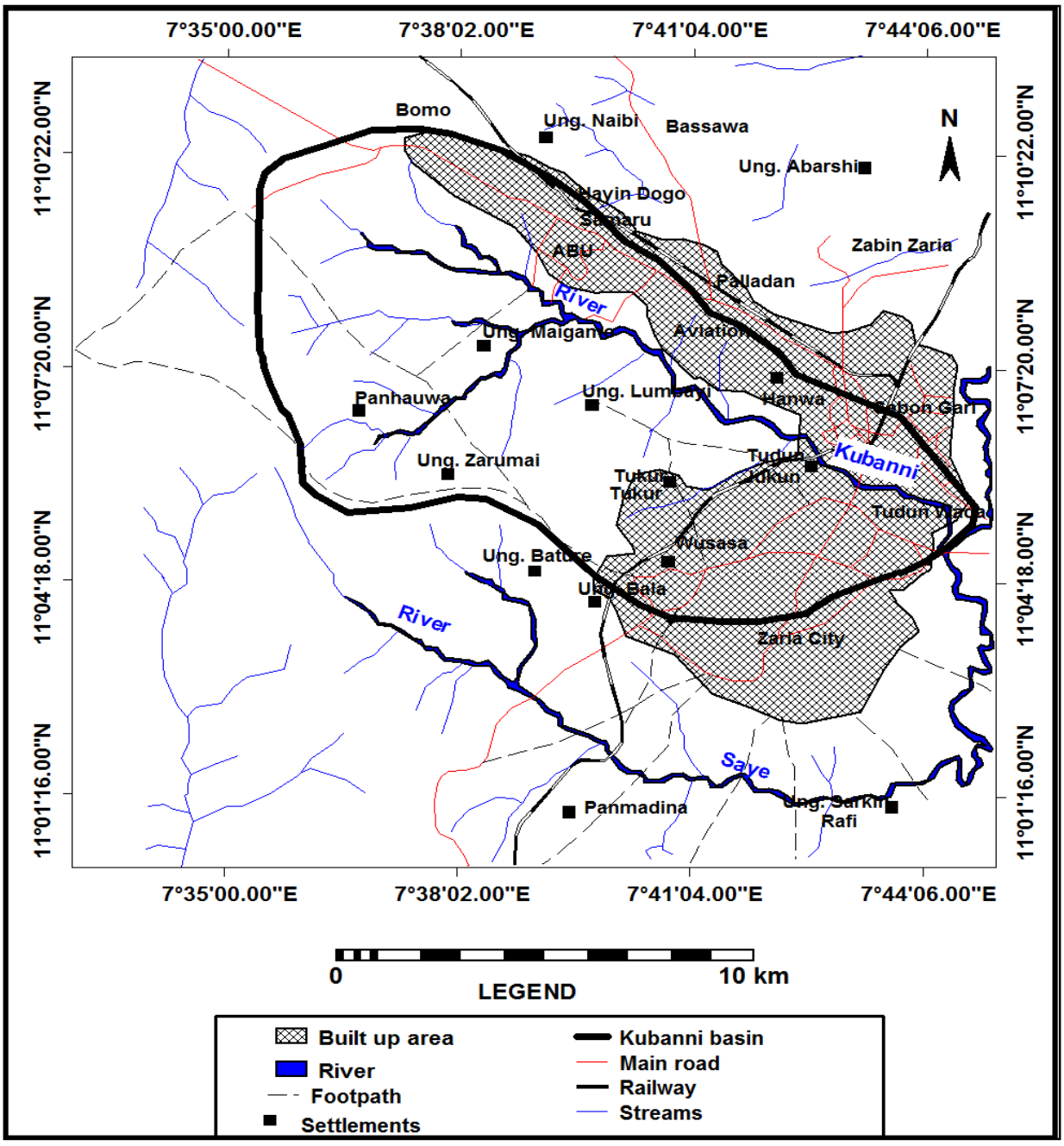



**Fig. 3.2a The Kubanni Basin**
**Source: Adapted and Modified from Zaria SW Topographic Map**

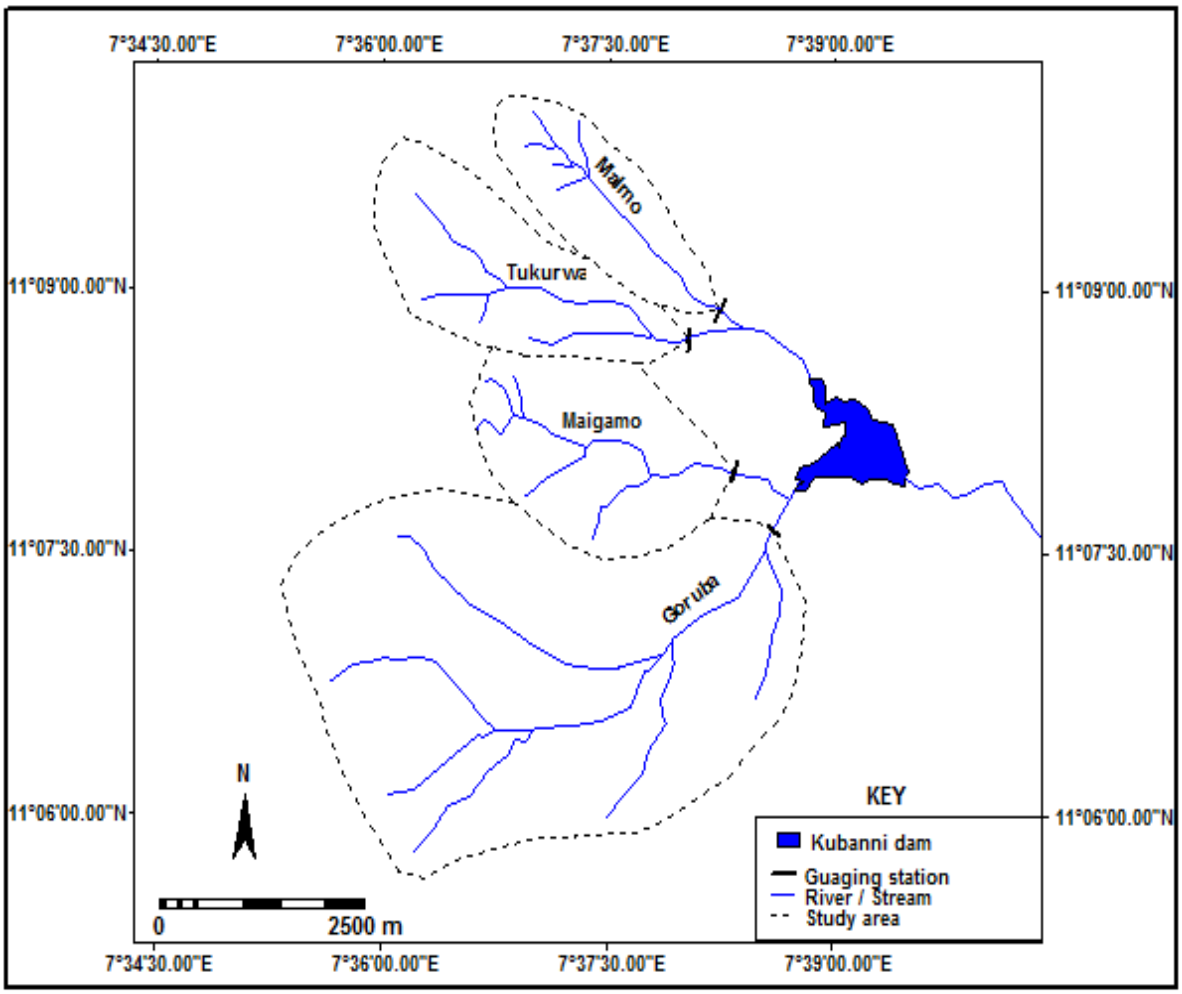



**Fig. 3.2b The Kubanni Reservoir and the Study Gauging Stations Upstream**
**Source: Adapted and Modified from Zaria SW Topographic Map**

In general, when the ITD is located south of Zaria, there is little or no cloud formation and no precipitation occurs. Conversely, when the ITD is located north of the study area, rainfall occurs (see fig. 3.3a and 3.3b).

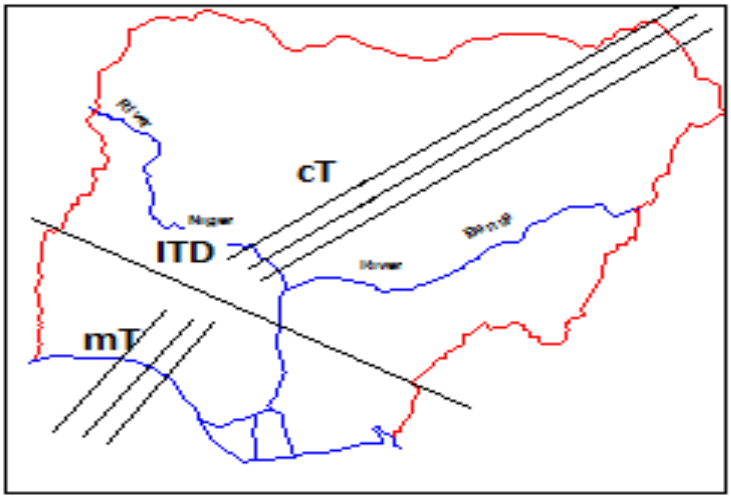



**Fig 3.3a Position of the ITD Across Nigeria in January.**

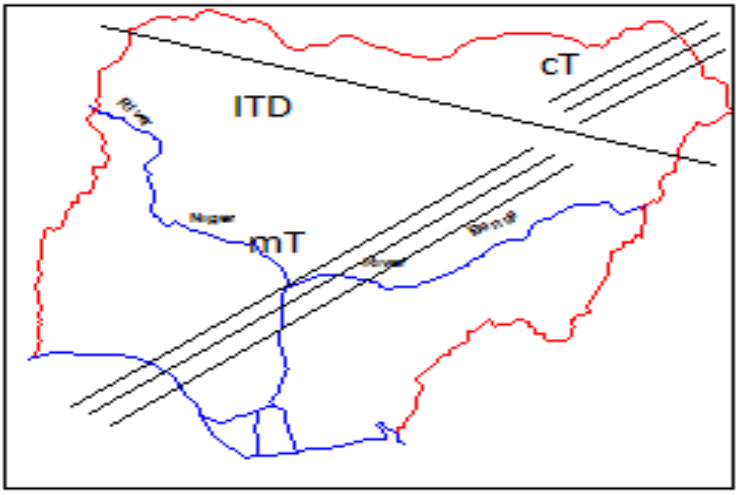



**Fig 3.3b Position of the ITD Across Nigeria in October.**

Onset of the rainy season is highly variable and unpredictable; although long-term average appears to be first week of May (see Table 3.1).

**Table 3.1 Onset of Rainy Season in Zaria**

| Mean Onset Date | Extremes: Early start Date (year) | Extremes: Late start Date (year) | Number of years of record | Source |
|---|---|---|---|---|
| 18th March | 9th Jan. (1928) | 1st May (1977) | 55 (1928 -1982) | Owonubi & Olorunju(1985) |
| 3rd May | 18th April (?) | 18th May (?) | 41 (1943 -1983) | Akintola(1986) |
| 13th May | -- | -- | -- | Kowal and Adeoye (1973); Kowal and Kassam(1973) |

Variability in the cessation date of the rainy season has also been observed. Akintola (1986), for example, reports that the expected mean cessation date of the rainy season is October 8th with an upper limit of October 23rd and a lower limit of September 23rd.

Several researchers have however reported September 23rd as the mean cessation date of the rainy season (Kowal and Kassam, 1973; Kowal and Adeoye, 1973), using a regression equation of latitude position on cessation date of rainy season in Northern Nigeria.

Due to variability in the onset and cessation of the rainy season, number of rain days in a year also varies considerably. Akintola (1986), using rainfall records of 1943 – 1983 reported a mean of 81 days. Hocking and Thomson (1979) reported a long-term average of 92 days while Kowal and Adeoye (1973) and Kowal and Kassam (1973) obtained 35

days, using a regression equation of latitude position on number of rain days in a year in Northern Nigeria.

Mean annual rainfall is also highly variable due to the considerable variability in the onset, cessation and number of rain days of the rainy season (see Table 3.2).

**Table 3.2 Mean Annual Rainfall Amount in Zaria**

| Mean Annual Rainfall (mm) | Extremes Low (mm) | (year) | High (mm) | (year) | No. of Years of record | Source |
|---|---|---|---|---|---|---|
| 1078 | 764 | (1982) | 1482 | (1954) | 54 (1928-1982) | Owonubi and Olorunju (1985) |
| 1046 | 585 | (1983) | 1963 | (1950) | 41 (1943 -1983) | Akintola (1986) |
| 1066 | ------ | | ------ | | ------ | Kwabe (1987) |
| 1060 | ------ | | ------ | | ------ | Kowal and Knabe (1972) |
| 975 | ------ | | ------ | | ------ | Kowal and Adeoye (1973) Kowal and Kassam (1973) |

Long- term average appears to be about 1,000mm while drought years can be as low as 500mm and wet years as high as 2,000mm. However, the mean annual rainfall of Samaru is 800mm and a paramount feature of the rainfall in Zaria is its convective nature and the characteristic occurrence of associated thunderstorms with heavy winds (Ojo, 1982; Oladipo, 1985; and Ayoade, 1988).

Rainfall intensity in Zaria has been observed to vary from as low as 20mm/hr to as high as 300mm/hr (Kowal and Knabe, 1972). Table 3.3 summarizes the characteristic rainfall intensity for Zaria.

**Table 3.3. Frequency Distribution of Rainfall Intensity in Zaria**

| Rainfall Intensity (mm/hr) | Frequency % | Contribution to Annual Rainfall (%) | Cumulative Frequency |
|---|---|---|---|
| <25 | 14.4 | 3 | 3 |
| 26-50 | 19.6 | 12 | 15 |
| 51-75 | 16.0 | 15 | 30 |
| 76-100 | 10.0 | 18 | 48 |
| 101-125 | 24.0 | 14 | 62 |
| ≥126 | 16 | 38 | 100 |

Source: Kowal and Knabe, 1972

The onset of harmattan is normally marked by sudden drop of both relative humidity and vapour pressure (Ojo, 1982; Ati 1990).

Mean monthly temperature is about $27^0$C but it is highest between the months of March and May, which represent the hot dry period. It is lowest in December/January reaching about $22^0$C with the humidity dropping to less than 15%. However, the mean minimum and maximum vary greatly from year to year. Figures of $17^0$C for mean minimum and up to $31^0$C for mean maximum monthly temperature were recorded in 1985 (Kwabe, 1987; abu.edu.ng, 2012).

## 3.3 Geology

The Zaria region is primarily underlain by the Basement Complex Rocks. The region is an area within the Zaria plain, a dissected part of the Zaria – Kano portions, an extensive peneplain, which had developed on crystalline metamorphic rock, and believed to be overlain by wind drift sediments.

Wright and McCurry (1970), presented a fairly detailed description of the geology of Zaria region by classifying the basement complex rocks of Zaria into three principal groups:

(i) Younger metasediments found in a north-south trending belt. These younger metasediments include Quatzites (forming ridges), Schists and Phylites.

(ii) A re-mobilized older crystalline Basement Complex made up of Gneisses, Migmatites and ancient metasediments.

(iii) Granites and Granodiorites of late pre-cambrian to lower palaezoic age, which includes groups one and two above.

The geologic materials of the study area are composed mainly of fine-grained biotite gneiss and migmatites, with some coarse-grained granitic outcrops in a few places. The gneisses are moderately to weakly foliated, principally made up of quartz and oligoclase (Du preez and Barber, 1965).

Superficial deposits include young and old laterites, as well as young and old alluvium. Thorough and deep chemical weathering has developed thick lateritic regolith of varying

degrees of induration. The laterites are different in morphological character and occur at different levels of the valley sideslope profiles. The massive and hardened laterites form older laterites (vermicular and vesicular types) and occur at high levels on the upland and close to the interfluves as mesas and buttes. As the older laterites are destroyed by erosion, the rubble is transferred to gentle sloping surface at lower levels where it undergoes re-concretion to form what has been described as younger laterites (Pullan, 1970; Ologe, 1972; Wright and McCurry, 1970; and Bello, 1973).

The older alluvium is made up of brown to brownish red, fine to medium-grained, fairly indurated sands, clay and gravels. Thorp (1970) described sites of older alluvium located within the study area where gullies are incised into them. The younger alluvium which are mostly unconsolidated, are made up of grey-brown sands, silts and clay. Ololobou (1982), observed an excellent site, which occurs about 0.5km upstream from the bridge along Zaria by-pass. Within the Kubanni basin, the presence of younger laterite with recent alluvial deposits along the river are prominent, there exists a crust belt occurring across the Kubanni basin with recent alluvial deposits along the dam impoundment.

## 3.4 Topography

Zaria is situated on a plain which is part of the extensive gentle rolling peneplain which extends from Sokoto to Lake Chad, and northwards from south of Kaduna to Tigueddi Scarp near Agades (Niger Republic). This embraces most of the northern Nigeria and has been correlated with the mid-tertiary African planation surfaces, recognized in other parts of the continent (King, 1962). The plain, which is generally undulating, varies in altitude

from about 550m to 740m above the sea level and is dotted with outcrops of rocky inselbergs, with the Kufena hill attaining a height of 820m and flat top lateritic ironstone capped residuals. The study area is between the Kufena Hill and one of such residuals, the Kampagi Hill, about 708m above sea level (Iguisi, 1996).

Valley side slopes exhibit a convex-concave form with few rectilinear elements (Ameh, 1966; Ojenya, 1989). Slope angles of the valley sides are generally low between $0.5^0$ and $4^0$; although relatively steeper slopes have been observed especially adjacent to isolated residuals and erosional scarps (Abubakar, 1966; Bello, 1973). The characteristic slope angle of the valley side slopes is however $1^0$ –$2^0$ (Ibrahim, 1986; Ojenya, 1989).

The drainage systems of Zaria focus mainly on River Galma. Except for Galma river, all streams in the area are seasonal, flowing only during and after rains, although the larger ones have surface water along stretches for much of the year. A very good example is the Kubanni river along Samaru (Mortimore and Wilson, 1965).

Du preez and Barber (1965) remarked that the geology of the area gave rise to its characteristic dendritic drainage pattern in the south eastern portion, trellis in the northern portion, where, the tributaries of Kubanni, enter the main river at right angle.

The Kubanni river is a $5^{th}$ order basin with total stream length of 127.1 km, basin area of 117 $km^2$, drainage density of 1.09 $km/km^2$, and a relative relief of 200m (Ololobou, 1982). The catchment area of the A.B.U Dam is 57 $km^2$ out of which the northern tributary, a $3^{rd}$ order basin with total stream length of 12.5 km, accounts for a basin area

of 5.25 $km^2$. The drainage density of the tributary is 2.38 $km/km^2$ and its relative relief is 40m.

Due to poor conservation and landuse practices like extensive vegetation clearance for agricultural and urban development purposes, intensive grazing, livestock tracks and human footpaths criss-crossing the area, overland flow, rilling and gullying have become the dominant modes of rainwater disposal from the landscape (Ologe, 1971; 1972; Bello, 1973; Ogunrombi, 1979; Iguisi, 1996). Gully density in the study area was observed to be about $41km/km^2$ in 1963 and has sharply risen to 112 $km/km^2$ in 1989 (Ahmed, 1989). This represents an increase of about 22% in about 25 years. Gully growth takes place through recurrent undermining and collapse of gullyside walls and headscarp recession due to increased energy of concentrated runoff resulting in the development of micropediments, mounds and hillocks (Bello, 1973).

The gullying effect is pronounced mainly in the upper stream, characterized by high stream frequency and wide sandy channels (Ologe, (1971). Iguisi and Abubakar (1998) have reported that those gullies have contributed to sedimentation of the A.B.U. Lake. The main stream, which is Kubanni, flows from northeast to south of the tributaries and gullies along the channel are found to go dry in the dry season and are composed of alluvial soils.

## 3.5 Soils

The soil type is highly leached ferruginous tropical soils, developed on weathered regolith overlain by a thin deposit of windblown silt from the Sahara desert during many decades of the propagation of the tropical continental air mass into the area (Wright and McCurry, 1970; Kowal and Omolokun, 1971; and Tokarski, 1972).

The soil pattern of Zaria have been described by Klinkenberg (1970) according to the geological units identified by Wright and McCurry (1970) as:

(i) Fadama Soils: These are soils that occur in the bottoms of extensive wide valley systems. They are generally classified as hydromorphic (Ipinmidun, 1972). Fadama soils are mostly dark grey clays with poor to very poor drainage, most of which have been formed in alluvial material. They occur widely in the Galma, Shika and Kubanni Basins.

(ii) Soils developed on Metasediments (Schists and Quartzites): As a result of the wide spread elongated quartzite ridges to the west of Zaria, soils are shallow and stony in the interfluve crests. However on the middle and lower slopes, soil profiles are deeper, become reddish-grey in colour, exhibit signs of clay accumulation, and hard iron concretions (Laterites) are found.

(iii) Soils developed on Granites: The soils close to the granitic outcrops appear deep and consist mainly of weathered material and do not show distinct profile development. They contain many unweathered fragments of quartz and feldspar. The clay and iron accumulation are not yet apparent. Further away from the granite hills, very deep red clayey soils occur. On the lower slopes

and in poorly drained areas, soils are mottled and generally of grey colour. They also contain fragment of quartz and feldspar.

Most of the soils have a sandy loam texture (Kowal and Knabe, 1972; Kwabe, 1987). Leaching of clay minerals and ions down the profile is the major soil development process. The soil exhibits a marked horizon differentiation with Iron oxides deposits in the clay-rich B-horizon, underlying the A-horizon, in form of mottles, concretions or as ferruginous hard pans called duricrusts. The topsoil is rather coarse due to elluviation of the fines of the A-horizon (Nyagba, 1986).

Kowal and Kassam (1978) and Jaiyeoba (1986) have observed that the organic matter and nitrogen contents of the soil are very low (1-2%) resulting from frequent bush burning, overgrazing, continuous cultivation and rapid oxidation decomposition of humified organic matter of the soil. The low activity of the clay particles has resulted in low cation exchange capacity (CEC) and exchangeable bases. The soils have an average pH of 7.1 and are generally neutral in reaction with profiles usually less than 150cm deep, below which occurs partially weathered rocks of the parent material.

Man's activities which include grazing and cultivation, has exposed the soil of this area to erosion and the depletion of its nutrient status and as a result of the high clay content of the soil and the overlain drift, a shallow surface capping readily forms after high intensity rainfall and this tends to inhibit infiltration, favour overland flow and consequently increases sediment yield.

## 3.6 Vegetation

The relatively deep tropical ferruginous soils and climate condition of Zaria are suitable for and sustain a good cover of savanna woodland (Northern Guinea Savanna) with a variety of grasses, woody shrubs and short trees. Even though the study area lies within the Guinea savanna zone, the fact remains that there is little natural or climatic vegetation and the area has become a derived savanna type which is characterized by shrubs, stems, and trees along with some tuft cover and some clusters of trees along river courses. The characteristic vegetation cover is hardly preserved due to urbanization and poor management practices, like fuelwood harvesting, annual bush burning, cultivation and intensive grazing (Rains, 1963; Ologe, 1971; abu.edu.ng, 2012).

The land management practices have resulted in the evolution of thorny shrub interspersed with short annual grasses. Also, trees have developed some adaptive features such as thick cuticle and thick young twigs to enable them survive the high evapotranspiration and the annual bush burning.

The dominant shrub around the area is *Isoberlinia doka* with an average height of 50 cm. Other less frequent shrub species include *Butyrispernum spp., Pilliostigma spp.,* and *Terminalea avicenniodes.*

The common grass communities in the study area are mostly *Andropogon spp.* (Kwabe, 1987), which are almost completely absent during the long dry season. However, the

grasses sprout during the raining season, shrubs grow very rapidly, but no sooner than the raining season ceased than they become dry. Grazing also contribute to their absence.

Trees here include *Magnifera indica* dotting everywhere, *Parkia clappertoniana, Tamarinda indiana* and several others, which are found to be useful to man. Yearly the trees are left standing while the area is being cultivated. During the raining season, the vegetation is thick and greenish, but are dry and brownish during the dry season with little of these plants retaining their leaves.

## 3.7 Land Use

Except for the Malmo tributary which is dominated by urbanization in the northern margin, intensive farming activities, mining and grazing are prominent within the study area, especially around the southern boundary.

Two types of lands are found around the study area; Gona or upland fields which support crops such as maize, millet, sorghum and groundnut, during the wet season and fadama or lowland fields which supports crops such as sugarcane, onion, tomatoes, pepper, spinach and other garden vegetables throughout the year. There is a relative soil buffering by the addition of organic manure and fertilizer application (Norman, 1970; Jaiyeoba, 1995; Yusuf, 1999).

The farms are usually worked by manual labour, using crude and simple implement such as hoes and cutlasses. This method of farm preparation leaves the farm with some dried

logs on the ground, and those that cannot be moved by manual labour are left standing. The dry logs are usually cut into smaller bits and are used for the purpose of firewood, which has been one of the most effective fuel type in the homes and also serves as the main source of energy, especially for farmers and restaurant operators.

Sand mining is also conspicuous with their leftovers as holes, pit, gullies etc. used as material for molding bricks and building of mud houses, for both residential and animal shelter and in road construction. Minor fishing activities usually take place especially during the dry season both on commercial and consumption scales. Within the basin are mechanic workshops, whose refuse and wastes find their ways into the Kubanni river especially at the upper course.

Settlement pattern in the Kubanni basin is highly concentrated from the northeastern parts to the northwestern parts. The remaining settlements are scattered randomly within the basin. Urban areas, which include part of the university campus environment, the administrative, academic and staff residential areas are located within the catchment area of the Malmo tributary of the basin.

In the year 2000, the University authority placed embargo on farming practices in the staff residential area which still persisted for some years but presently, evidence of farming activities can only be found on crossing the Malmo tributary. This farming activity has a serious implication for sediment generation and delivery into the reservoir.

# CHAPTER FOUR

# METHODOLOGY

## 4.1 Types and Sources of Data

In order to achieve the aim and objectives of this study, both Primary and Secondary data were used. The Primary data include data on sediment concentration and stream discharge that were collected from the gauging stations indicated in Fig.3.2b during the flow periods of the tributaries from May 2011 to February, 2012 and onward analysis in the laboratory. A 2009 satellite imagery with resolution of 32m obtained from the National Centre for Remote Sensing (NCRS) was utilized for the landuse/landcover characterization and classification in order to look at its relationship with sediment delivery into the reservoir. Related materials obtained from maps form the secondary data.

## 4.2 Methods and Procedures

### 4.2.1 Stream Discharge

The measurement of stream discharge usually involves consideration of both stage and velocity. Stream discharge is defined as the volume of water passing through a given cross-section of the river during a given period of time. Units used are those of volume/time, and values are generally reported in cubic metres per second ($m^3/s$) or in litres per second (l/s).

There are a number of ways in which river discharge can be measured. These include velocity-area technique, dilution gauging, volumetric gauging, the slope area technique,

weirs and flumes (control structure method) and the rated section. The velocity-area (AV) technique is the most widely used for spot measurements of discharge while the control structure, specifically the weir, involves a similar theoretical basis to the velocity-area technique (Gregory and Walling, 1973). The velocity-area and weir techniques were used because of the size of the rivers, the accuracy required and the equipment available.

Gauging stations made up of calibrated control structures (weirs), were used to estimate the discharges for the Malmo and Tukurwa tributaries so that a simple stage measurement will be sufficient to provide a value of discharge.

Stage-calibrated $120^{o}$ and $90^{o}$ V-Notches sharp-crested weirs were used for the Malmo and Tukurwa tributaries respectively (Plate 4.1). The $120^{0}$ V-Notch is already installed for the Malmo tributary by Yusuf (2006) with discharge formula of:

$$Q = 2.47H^{2.5} \text{ ---------- (4.1)}$$

while the $90^{0}$ V-Notch was fabricated at Centre for Automotive Design (CAD) and Metallurgical Engineering Department, A.B.U., Zaria, with discharge formula of:

$$Q = 1.38H^{2.5} \text{ ---------- (4.2)}$$

Where Q = Discharge in $m^3/s$

H = Head of water in metres (stage).

The difference in the discharge formulae for the two streams is as a result of their shapes and sizes.

The measurements of the water head, also referred to as water depth, above the weir crest (H) is supposed to be carried out with a staff gauge at a distance two to three times the maximum head behind the crest, in order to avoid the effects of drawdown. However, to reduce the risk of vandalization, an addition of 0.01m was consistently added to the calibration value of the weir to take care of the drawdown effect. This was the difference as established by Yusuf (2006). Measurements were observed after rainfall events and twice a day; in the morning (around 7.00am) and in the evening (around 6.00pm) everyday, which represent instantaneous and regular interval monitoring after Ogunkoya (2000). Subsequently, the daily average readings were inserted into the discharge formula in order to obtain the stream discharge.



**Plate 4.1: A $90^0$ V-Notch installed at Gauging Station of Tukurwa Stream**

For the Maigamo and Goruba streams however, the velocity-area technique of measuring stream discharge was used because of their larger sizes. This is based on the fact that discharge, Q, is a direct function of average stream velocity, V, and the cross-sectional area of the channel, A, at the point of measurement:

$$Q = AV \quad \text{---------- (4.3)}$$

The cross-sectional areas of the channels at the gauging stations were obtained by multiplying the channel width by depth. The relevant depth here is that measured from the water level to the bottom of the channel using installed staff gauges (Plate 4.2).

The stream velocity can be obtained by using one of the several methods described by Gregory and Walling (1973). In this study however, the float method was used because of its simplicity and safety. Detailed studies of the distribution of velocity in a given vertical profile are greater than the average velocity for that profile. A generally accepted conversion factor is that the mean velocity in any given vertical profile is 0.85 times the surface velocity (Smith and Stopp, 1978).



**Plate 4.2: Field Assistant observing Installed Staff Gauge Level at the Goruba Stream**

### 4.2.2 Sediment Concentration

**(a) Field Work**

Suspended sediment samples were collected at the gauging stations using the USDH 48 sediment sampler designed by the United States Federal Inter-Agency Sedimentation Project after rainfall events during discharge measurements. The depth-integrated technique was adopted to take sediment-water mixture vertically from the water surface to the riverbed at the middle of the channel.

The sampler with a simple open nozzle was lowered close to the streambed and raised to the surface at a constant rate. The depth-integrated sample is therefore collected at a velocity similar to the streamflow velocity. The concentration of the sample so taken represents the discharge weighted mean concentration for that vertical. After collection, samples were stored in clean plastic bottle, labelled and taken to the laboratory for analyses (Plate 4.3).



**Plate 4.3: Field Assistant using USDH Sediment Sampler to collect Water Sample just after a Storm**

**(b) Laboratory Analyses**

The samples collected from the field were analysed in the laboratory to determine the suspended and dissolved sediment concentrations. The suspended sediment concentration was determined using the following procedure:

(i) After shaking the water sample thoroughly, a 250ml standard quantity, of each sampled water-sediment mixture was filtered using a vacuum pump assembly through a weighed membrane filter paper (Plate 4.4).

(ii) The sediment retained together with the filter paper was oven-dried at $105^0$C for 18 hours and then cooled in a desiccator

(iii) The oven-dried, cooled filtrate with the filter paper was then re-weighed

The difference between the initial weight of the filter paper and the final weight as in (i) and (iii) above (i.e weight of the residue), constitutes the suspended sediment concentration. This weight is further multiplied by four (4) to get the Suspended Sediment Concentration in milligrams per litre (mg/l) because the filter sample had a volume of 250ml, which is a quarter of a litre, but what is imperative is the value for a litre. The obtained value in milligrams per litre (mg/l) constitutes the Suspended Sediment Concentration for the sampling point. This value was then multiplied by the corresponding river discharge to derive the suspended sediment discharge (Qs) in milligrams per second (mg/s).



**Plate 4 .4: Filtration of Water Sample in Progress using the Filtration Unit**

To determine the dissolved sediment concentration or Total Dissolved Solids (TDS) and dissolved sediment discharge in (mg/l and mg/s) respectively, the total dissolved solid (TDS) is first determined. This is done by using the aliquot obtained as filtrate from the filtration which is 250ml in volume. An empty crucible is weighed using a mechanical weighing balance and recorded as ($W_1$) and the aliquot gotten from the filtration of the filtration of the water sample (250ml), which is the filtrate, is then transferred into the already weighed empty crucible. The aliquot in the crucible is oven dried at a temperature of about $150^0$C for 24 hours to completely dry the aliquot of any moisture.

After oven drying, the crucible was allowed to cool for a while in the desiccator so as to prevent moisture from getting into the already dried sample. The crucible with the oven dried aliquot is then re-weighed using a weighing balance and recorded as $W_2$. The difference between the weight of the empty crucible and the weight of the crucible after oven drying the aliquot in it gives the value of the TDS for the water sample and recorded as ($W_3$).

This is expressed as:

$W_3 = W_2 - W_1$ ---------- (4.4)

This weight is further multiplied by four (4) to obtain the TDS value in milligrams per litre (mg/l).

Furthermore, the obtained value in milligrams per litre (mg/l) which constitute the TDS for the sampling point was multiplied by the corresponding stream (river) discharge ($m^3/s$) to derive the dissolved sediment discharge (Qd) in milligrams per second (mg/s).

## 4.3 Data Analyses

### 4.3.1 Estimation of Suspended Sediment Yield

As suspended sediment measurements are rarely continuous, temporal extrapolation is often required to enable a reasonable estimate of suspended sediment yield to be made (Gregory and Walling, 1973; Painter, 1976). This is usually achieved through the sediment rating curve which relates suspended sediment concentration, suspended sediment load to stream discharge, on the basis of a limited number of sediment

measurements (Walling, 1978; Rannie, 1978; Walling and Webb, 1988; Walling and Webb, 1992; Richards, 1993).

The rating curve is normally presented as a straight line plot on logarithmic coordinates with equation of the form:

$$Cs = aQ^b \quad \text{---------- (4.5)}$$

or

$$Qs = aQ^b \quad \text{---------- (4.6)}$$

Where Cs = Suspended Sediment Concentration in mg/l

Q = Stream Discharge in $m^3/s$

a = Intercept when Q is the unity on the logarithmic plot and

b = Slope of the line

Qs = Suspended Sediment Discharge in mg/s

A more precise form of rating curve as proposed by Bauer and Tille (1967) and Douglas (1971) was used to regress stream discharge on the suspended sediment discharge, by using their log exponents (log) as shown below:

$$\log Qs = \log a + b \log Q \quad \text{---------- (4.7)}$$

Where Qs = Suspended Sediment load in mg/s

Q = Stream Discharge in $m^3/s$

a, b = Constants representing the intercept and slope of the rating plot respectively.

The suspended sediment load (Qss) in mg/s, a product of discharge and concentration was then converted to kg/day thus:

$$Qss = \frac{QCs}{1000} * 60 * 60 * 24 \quad \text{---------- (4.8)}$$

where Qss = Suspended Sediment Load in kg/day

Q = Stream Discharge in $m^3/s$

Cs = Suspended Sediment Concentration in mg/l

A further division of the suspended sediment load derived above by 1000 will give the channel sediment yield in tons/day. Therefore, a continuous record of suspended sediment discharges, provide an estimate of sediment yield throughout the year for each of the tributaries (Oyebande, 1981; Thomas, 1983; Ferguson, 1987).

### 4.3.2 Estimation of Dissolved Sediment Yield

Dissolved sediment yield for each of the tributaries was estimated using the same methods as those of suspended sediment yield described above, except that the total dissolved solids and dissolved sediment load will be represented as TDS and Qds respectively.

### 4.3.3 Classification and Characterization of Land Use-Land Cover

Classification and characterization of land use/land cover within the tributaries was carried out using remote sensing and Geographic Information System (GIS) techniques. A February 2009 NIGERIASAT-1 satellite imagery with resolution of 32m obtained

from the National Centre for Remote Sensing (NCRS) was utilized (Fig. 4). Geometric correction and enhancement was carried out on the imagery to make it interpretable.

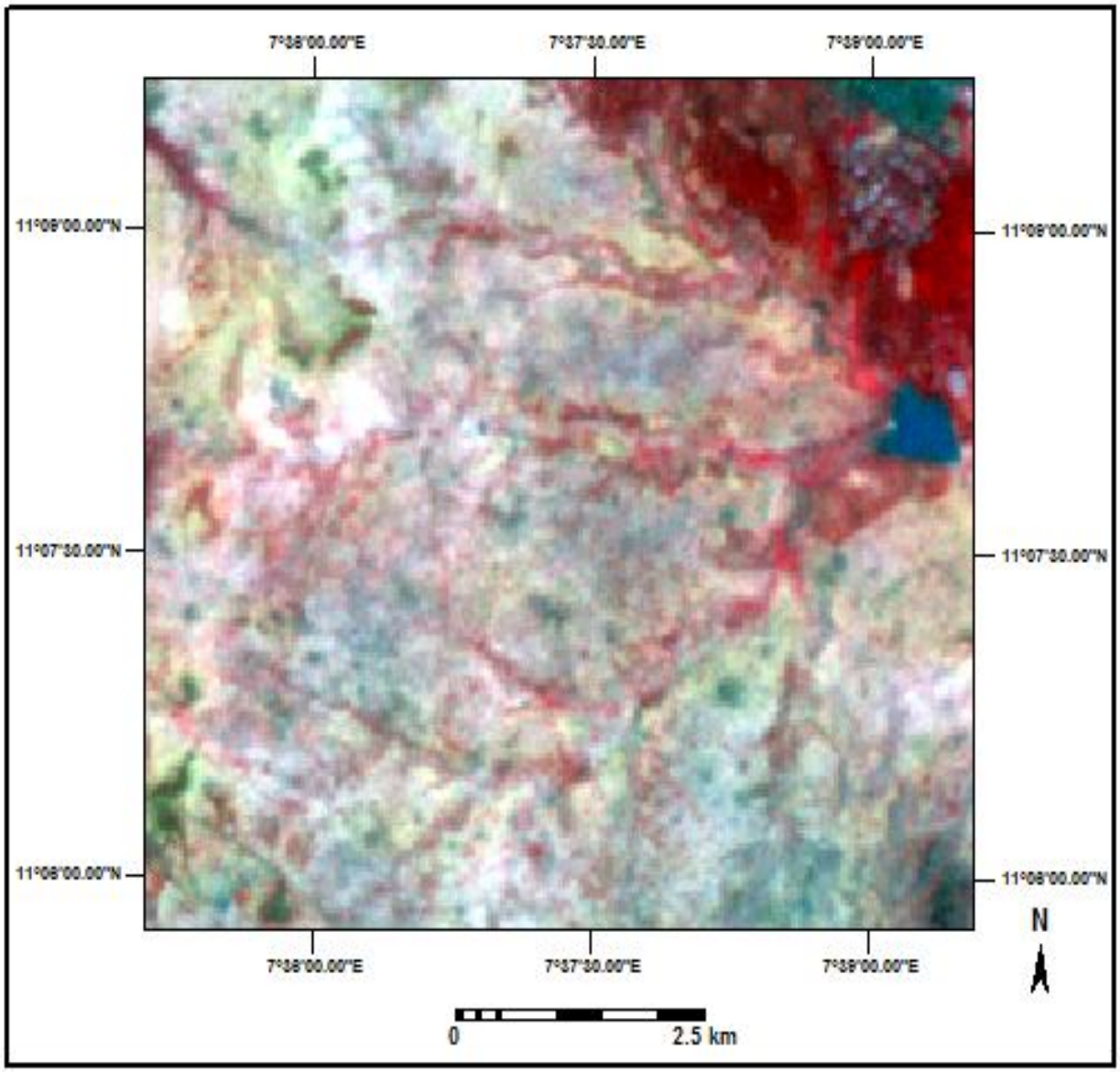



**Fig. 4: February 2009 NIGERIASAT Imagery of the Study Area**
**Source: National Centre for Remote Sensing, Jos**

The image was then classified using supervised classification with maximum likelihood algorithm taking advantage of spectral signatures. The area coverage of each of the sub-basins was then determined. All these were carried out using the ILWIS 3.7 software.

### 4.3.4 Statistical Analyses

Descriptive statistics in the form of tables and graphs and a major statistical tool; the Analysis of Variance (ANOVA), for testing differences between and amongst the various values obtained for the tributaries were utilized in this study. Furthermore, the significance and reliability of the results obtained were tested by the use of appropriate statistical measures including the correlation coefficient (r) to measure the performances of the linear correlation between variables and the ratio of explained variation to the total variation, t-ratios to check the significance of the regression coefficients, F-ratio to check the statistical significance of the correlation coefficient of determination ($r^2$). All analyses were carried out by the use of Microsoft Excel and SPSS statistical packages. The confidence level that will be used in accepting or rejecting the hypotheses is 95% corresponding to an alpha value of 0.05.

# CHAPTER FIVE

# RESULTS AND DISCUSSION

## 5.1 Discharges of Studied Streams

Observation of the discharge for the four tributaries was carried out throughout their flow period starting from 13th May 2011 using the control structure (weir) method for the Malmo and Tukurwa streams and the velocity-cross-sectional area (VCSA) method for the Maigamo and Goruba streams (Appendix I). The summary of the results are presented on Table 5.1.

**Table 5.1 Summary of Discharge Statistics for the Four Tributaries**

| Statistics | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| N | 246 | 192 | 176 | 175 |
| Minimum | 0.0001 | 0.0001 | 0.0003 | 0.0004 |
| Maximum | 0.364 | 0.706 | 17.8341 | 22.2786 |
| Range | 0.3639 | 0.7059 | 17.8338 | 22.2782 |
| Mean | 0.0216 | 0.0564 | 1.184 | 1.4744 |
| Std. Error of Mean | 0.0034 | 0.0086 | 0.2116 | 0.2842 |
| Std. Deviation | 0.0537 | 0.1195 | 2.8067 | 3.7592 |
| Variance | 0.003 | 0.014 | 7.878 | 14.131 |
| Sum | 5.3087 | 10.837 | 208.38 | 258.01 |

Table 5.1 shows that the Malmo stream has the longest flow period of 246 days and is the only one that extends into February year 2012. This is actually earlier than the case in Yusuf (2006) where it extended to April but the two situations confirm contribution to surface flow by subsurface flow during the dry season (Gregory and Walling, 1973; Knighton, 1998; Rawat, 2011).

The measured daily mean instantaneous discharge values in $m^3/s$ throughout the study period recorded the lowest values of 0.0001 $m^3/s$ on 3rd February, 2012 and 9th December, 2011 in the Malmo and Tukurwa tributaries while the lowest values of 0.0003 $m^3/s$ and 0.0004 $m^3/s$ were recorded for the Maigamo and Goruba tributaries on 28th and 27th November, 2011 respectively. The highest value of 22.2786 $m^3/s$ was recorded for the Goruba stream on 8th August, 2011. It is worth noting here that the smaller sub-basins; Malmo and Tukurwa are the ones with least discharges while the largest has the highest (see Fig. 4.1). This trend is also reflected in the range, mean, standard deviation and variance of the discharge measurements culminating into the highest total discharge value of 258.01 $m^3/s$ for the Goruba stream and lowest value of 5.3087 $m^3/s$ for the Malmo stream in the study period.

A careful observation of the regime diagrams (Fig. 5.1a to 5.1d) for the four tributaries reveal that September is the month with highest discharge except for the Tukurwa tributary where August is the month with the highest discharge corresponding with the known month of highest rainfall in the study area. An interesting observation is the fact that the discharge regime is noticed clearly as from May to October with a single maxima which correlates with the rainfall period in the study area and relegates the significance of the contribution to discharge by subsurface flow during the dry season.

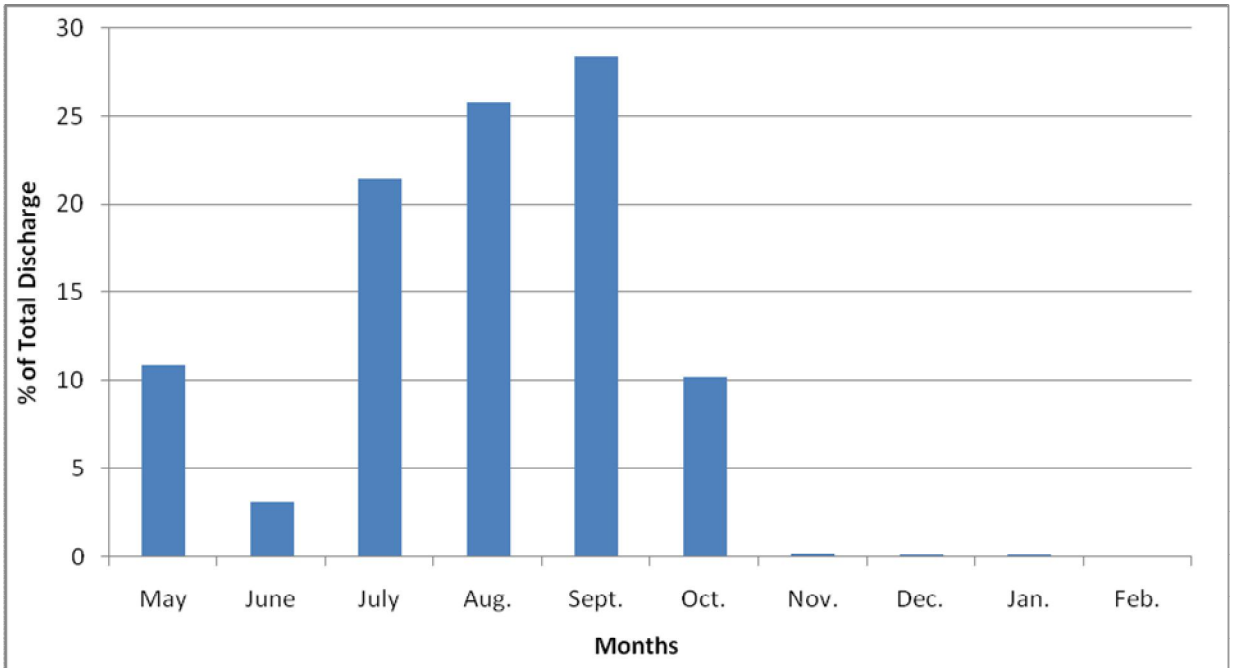



Fig. 5.1a Discharge Regime Diagram for Malmo Stream

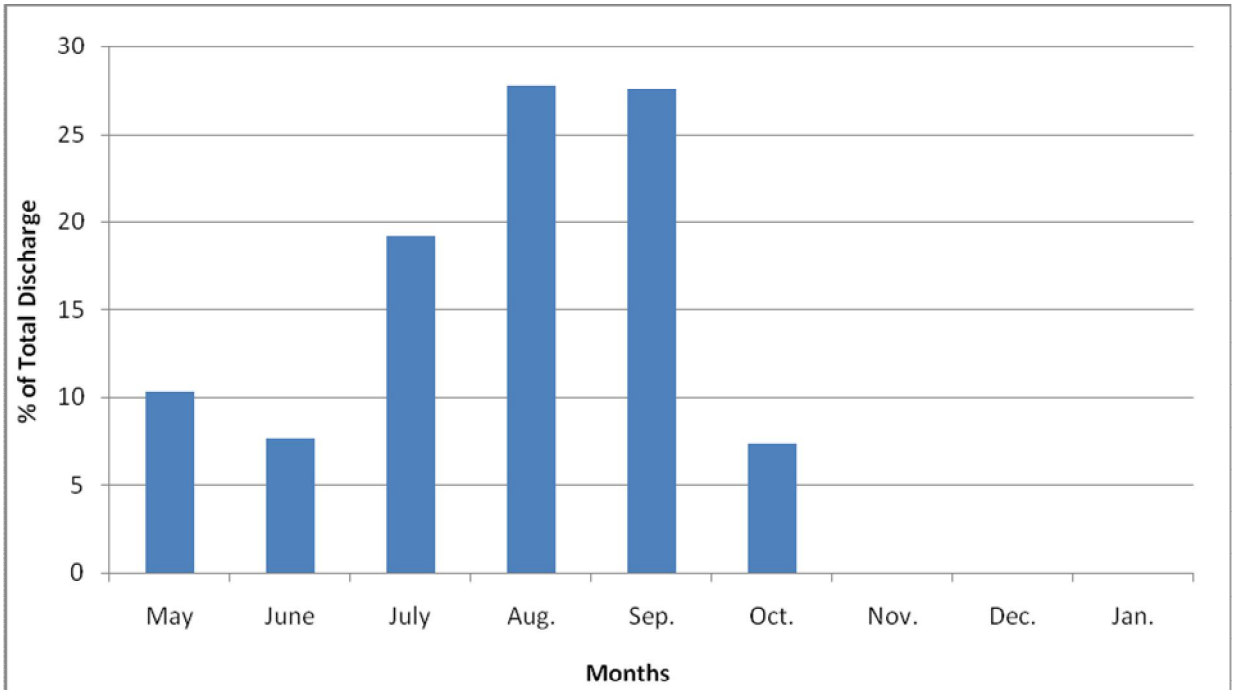



Fig. 5.1b Discharge Regime Diagram for Tukurwa Stream

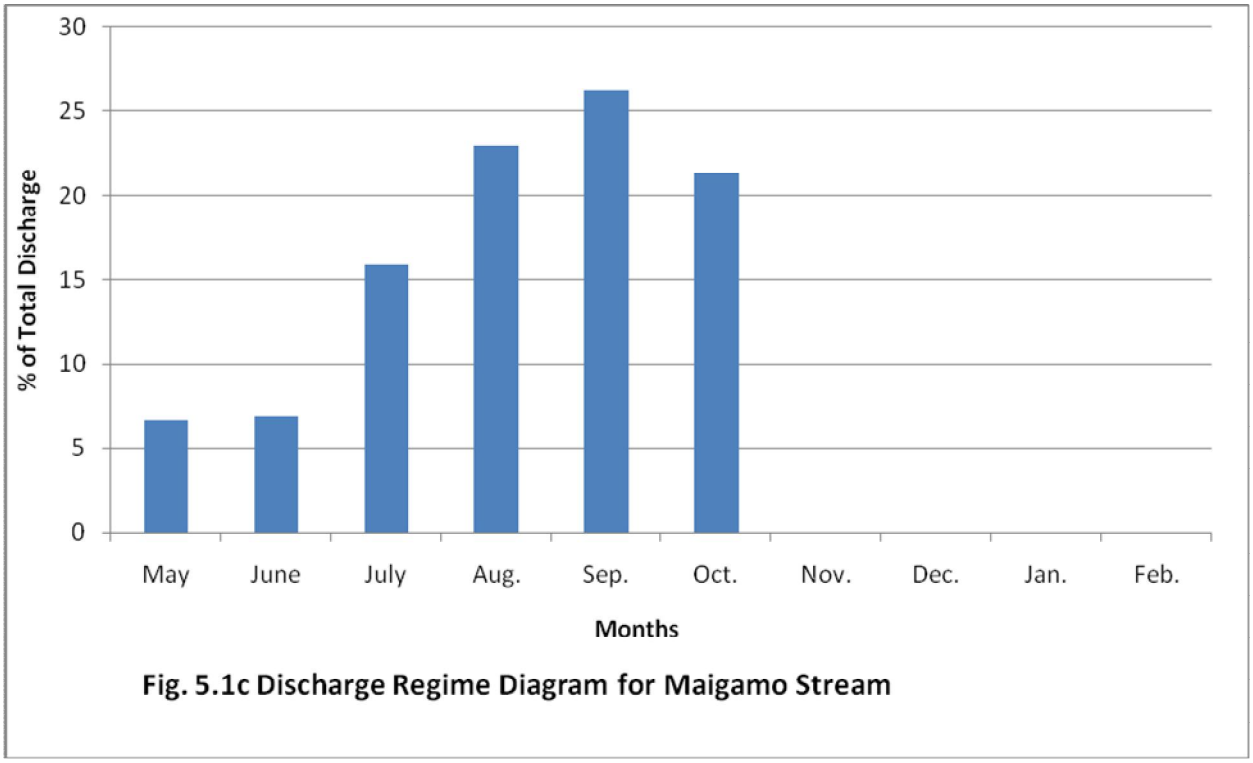



**Fig. 5.1c Discharge Regime Diagram for Maigamo Stream**

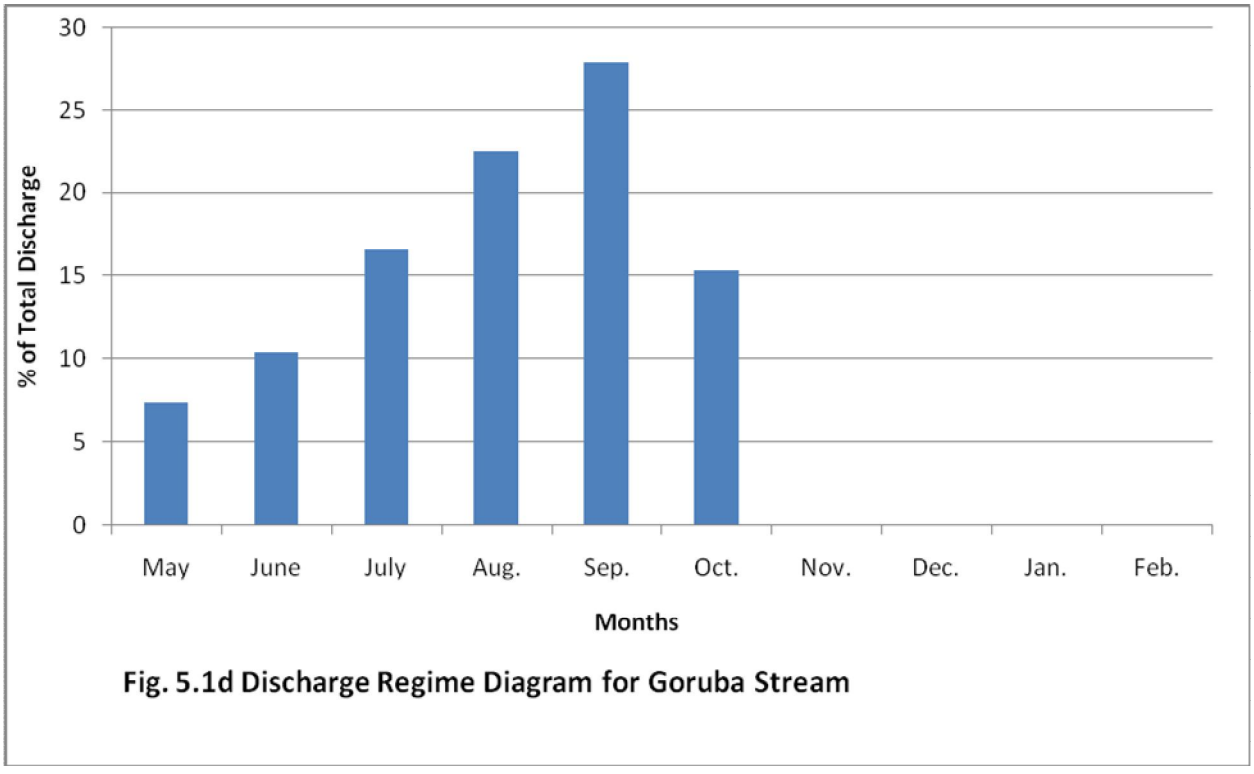



**Fig. 5.1d Discharge Regime Diagram for Goruba Stream**

## 5.2 Suspended and Dissolved Sediment Load

The instantaneous suspended and dissolved sediment concentrations/loads for the four tributaries are presented in Appendices II and III. Tables 5.2a and b present the summary statistics for the instantaneous suspended and dissolved sediment loads which are products of suspended sediment concentration and discharge on one hand and total dissolved solids and discharge on the other. The suspended sediment concentration and total dissolved solids were derived in the laboratory from the water samples collected at the gauging stations of the four tributaries during instantaneous discharge monitoring.

A careful observation of the summary statistics for the instantaneous suspended and dissolved sediment load shows a consecutive increase with increase in the sizes of the sub-basins which may cannot be disassociated from the increasing trend of discharge observed earlier.

**5.2a Summary Statistics for Instantaneous Suspended Sediment Load (Qss) for the Four Tributaries**

| Statistics | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| N | 25 | 25 | 26 | 26 |
| Minimum | 3.79 | 0.02 | 75.99 | 13.32 |
| Maximum | 607.18 | 441.84 | 33100 | 97800 |
| Mean | 106.79 | 158.15 | 5339.4 | 8270.9 |
| Std. Error of Mean | 25.36 | 22.4249 | 1470.87 | 3727 |
| Std. Deviation | 126.801 | 112.124 | 7500.02 | 19004 |
| Variance | 16080 | 12570 | 56250000 | 361200000 |
| Sum | 2669.76 | 3953.8 | 139000 | 215000 |

**5.2b Summary Statistics for Instantaneous Dissolved Load (Qds) for the Four Tributaries**

| Statistics | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| N | 25 | 25 | 26 | 26 |
| Minimum | 1.44 | 0.04 | 16.38 | 0.96 |
| Maximum | 109.6 | 264.8 | 5285 | 16900 |
| Mean | 30.1 | 91.496 | 1188.1 | 3557.3 |
| Std. Error of Mean | 4.457 | 14.6672 | 231.94 | 876.166 |
| Std. Deviation | 22.2849 | 73.336 | 1182.67 | 4467.59 |
| Variance | 496.616 | 5378 | 1399000 | 19960000 |
| Sum | 753.68 | 2287.4 | 30900 | 92500 |

## 5.3 Suspended and Dissolved Sediment Load-Discharge Relationship

In order to derive the complete suspended sediment loads, the instantaneous suspended sediment loads were regressed on the discharge using their log exponents as in equation 4.7. The coefficients and model summary of their relationship are presented in tables 5.3a and b respectively.

**5.3a Coefficients of Qss-Q Relation for the Four Studied Sub-Basins**

| Basin | Factor | Coefficients | Std. Error | T | Sig. |
|---|---|---|---|---|---|
| Malmo | Constant1 | 2.865 | 0.158 | 18.137 | 0.000 |
| | LOGQ1 | 1.137 | 0.162 | 7.014 | 0.000 |
| Tukurwa | Constant2 | 2.729 | 0.101 | 27.091 | 0.000 |
| | LOGQ2 | 1.063 | 0.098 | 10.841 | 0.000 |
| Maigamo | Constant3 | 2.881 | 0.124 | 23.281 | 0.000 |
| | LOGQ3 | 0.926 | 0.17 | 5.439 | 0.000 |
| Goruba | Constant4 | 2.847 | 0.114 | 24.931 | 0.000 |
| | LOGQ4 | 0.895 | 0.119 | 7.552 | 0.000 |

**5.3b Model Summary for Qss-Q Relation for the Four Sub-Basins**

| | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| r | 0.825 | 0.915 | 0.743 | 0.839 |
| $r^2$ | 0.681 | 0.836 | 0.552 | 0.704 |
| Std. Error of the Estimate | 0.26502 | 0.35224 | 0.43209 | 0.46018 |
| F | 49.199 | 117.534 | 29.531 | 57.034 |
| Sig. | 0.000 | 0.000 | 0.000 | 0.000 |

The coefficients of the Qss-Q relationship in table 5.3a indicate that there is a direct relationship between suspended sediment load and discharge for the four tributaries as exhibited in figures 5.2a to d. In order to check the significance of the regression coefficients, a and b (i.e intercept and slope), the t-ratio test was conducted and in all cases, it was observed that $t_a$ and $t_b$ were statistically significant at 0.05 level of significance. Therefore, we can say that there is a strong relationship between the regression coefficients.

The coefficient of correlation (r) and coefficient of determination ($r^2$) in all cases were high. Although the values are high, inference on these values cannot be made without checking the statistical significance of the $r^2$ computed, as their high values do not conclude that the independent variable (Q) is a good determinant of the dependent variable (Qss). In all cases, using the F-ratio (ANOVA) test, the regression coefficient of determination ($r^2$) was found to be statistically significant at the 0.05 level of significance, indicating that discharge (Q) is a good determinant of the suspended sediment discharge (Qs) as illustrated in table 5.3b. The strongest relationship between

suspended sediment load and discharge was experienced in the Tukurwa stream which is exhibited in the lowest degree of scatter of the points in fig. 5.2b. On the other hand, the weakest relationship between suspended sediment load and discharge was experienced in the Maigamo stream which is exhibited in the highest degree of scatter of the points in fig. 5.2c. Possible reasons for this will be explained later after the LULC classification of the sub-basins.

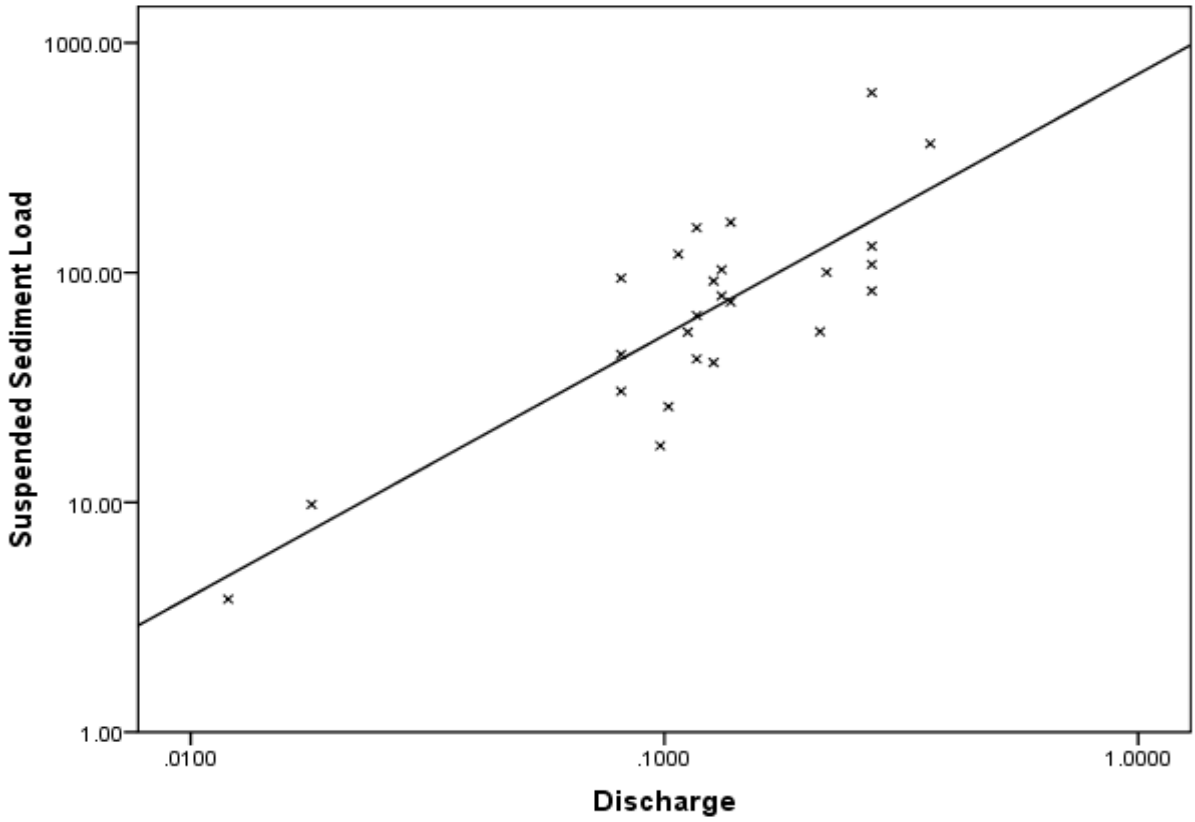



**Fig. 5.2a Qss-Q Relation for Malmo Stream**

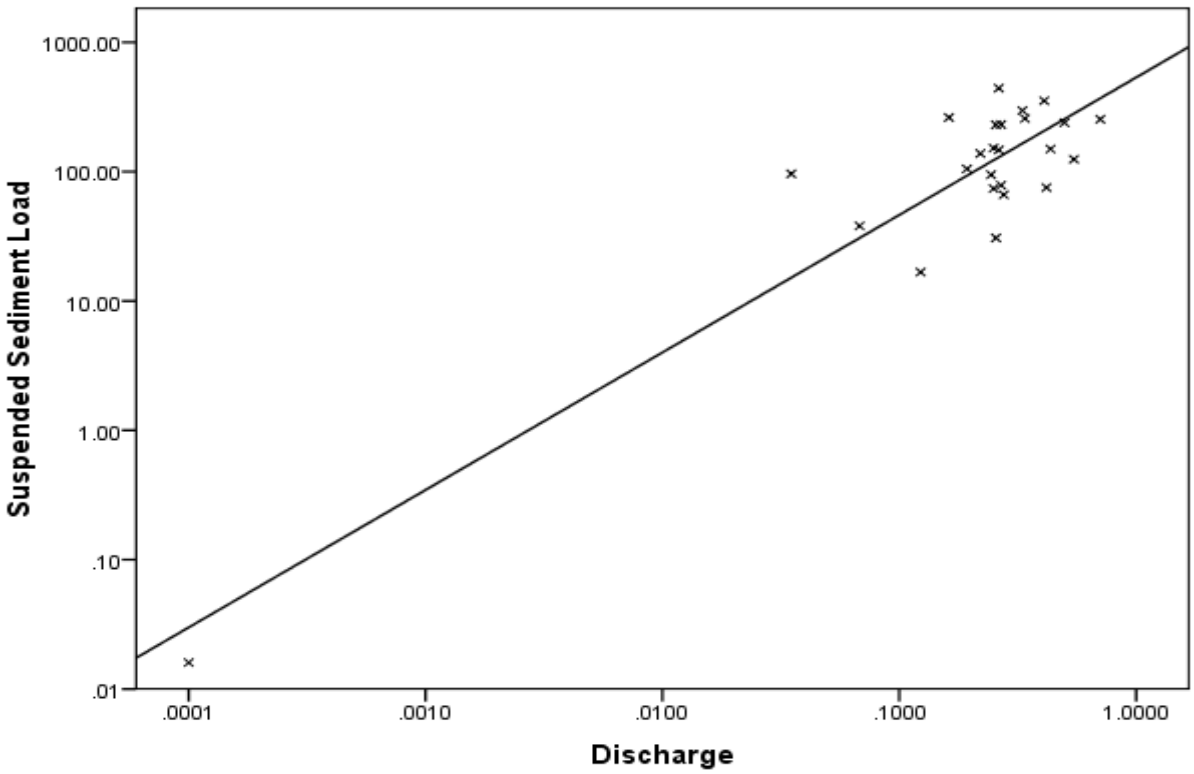



**Fig. 5.2b Qss-Q Relation for Tukurwa Stream**

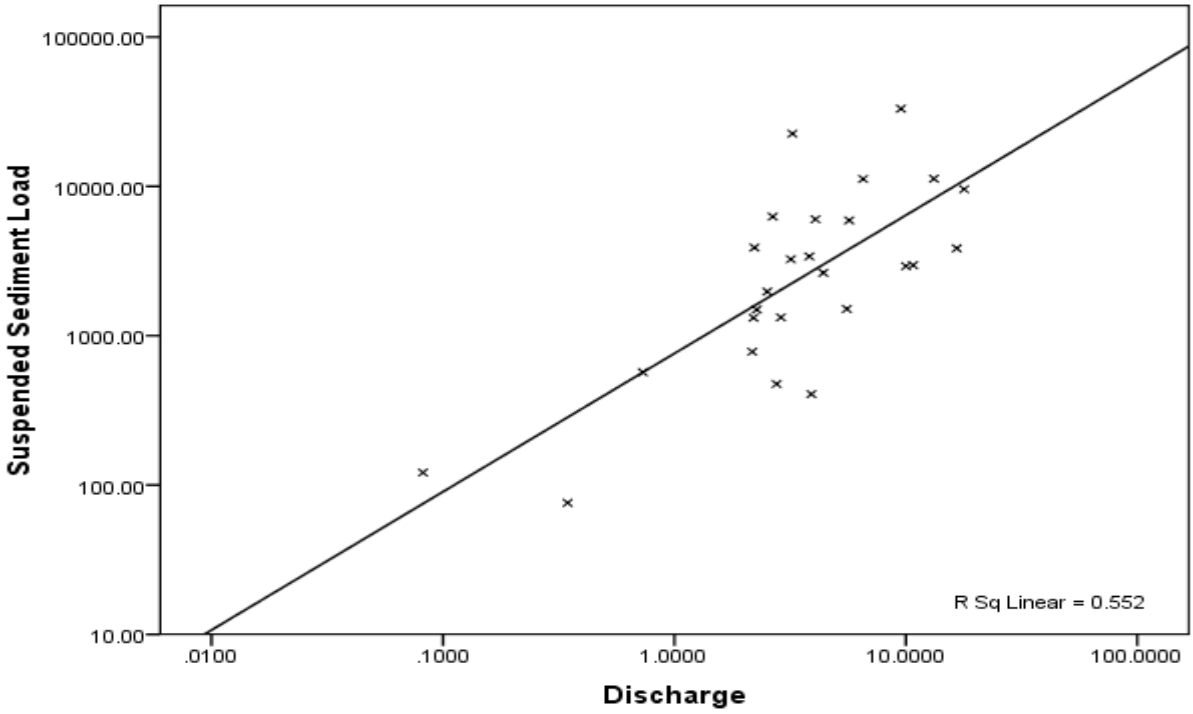



**Fig. 5.2c Qss-Q Relation for Maigamo Stream**

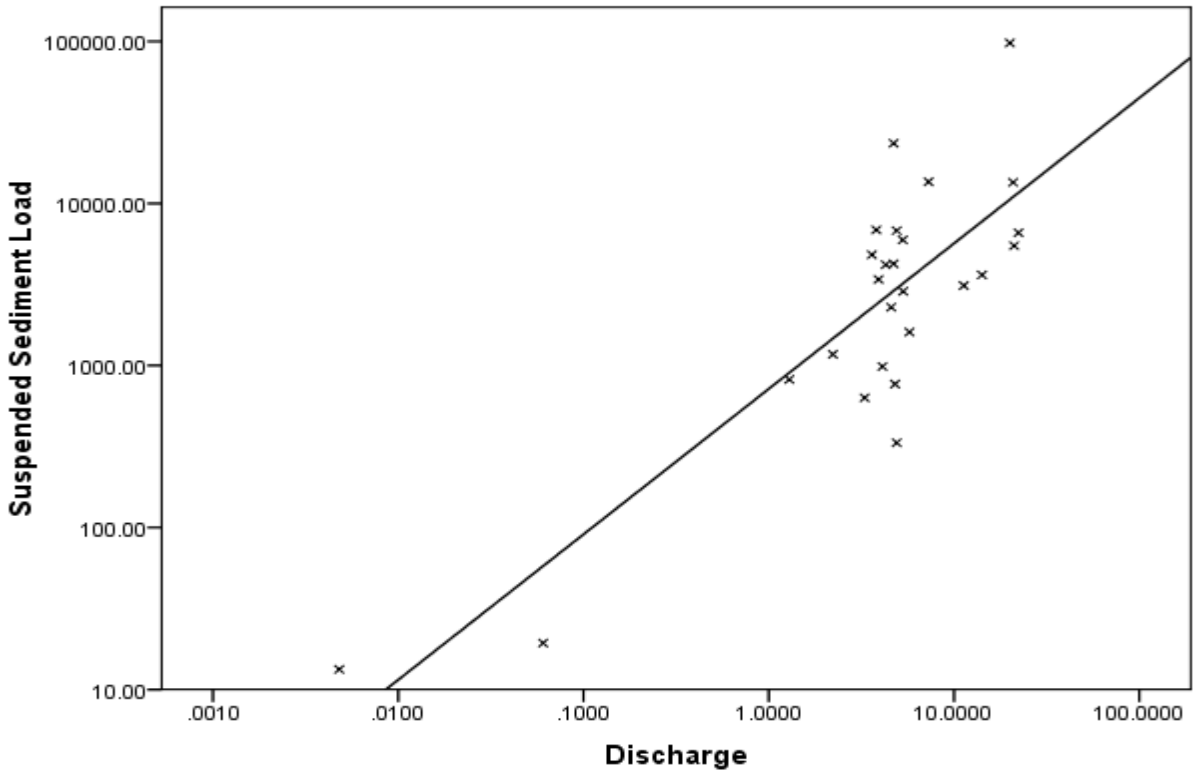



**Fig. 5.2d Qss-Q Relation for Goruba Stream**

Also, in order to derive the complete dissolved sediment loads, the instantaneous dissolved sediment loads were regressed on the discharge using their log exponents as in equation 7. The coefficients and model summary of their relationship are presented in tables 5.3c and d respectively.

**5.3c Coefficients of Qds-Q Relation for the Four Sub-Basins**

| Basin | Factor | Coefficients | Std. Error | T | Sig. |
|---|---|---|---|---|---|
| Malmo | Constant1 | 2.114 | 0.166 | 12.739 | 0.000 |
| | LOGQ1 | 0.831 | 0.17 | 4.877 | 0.000 |
| Tukurwa | Constant2 | 2.383 | 0.098 | 24.399 | 0.000 |
| | LOGQ2 | 0.971 | 0.095 | 10.212 | 0.000 |
| Maigamo | Constant3 | 2.4 | 0.092 | 26.128 | 0.000 |
| | LOGQ3 | 0.852 | 0.126 | 6.748 | 0.000 |
| Goruba | Constant4 | 2.488 | 0.051 | 48.763 | 0.000 |
| | LOGQ4 | 1.115 | 0.053 | 21.042 | 0.000 |

**5.3d Model Summary for Qds-Q Relation for the Sub-Four Basins**

| | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| r | 0.713 | 0.905 | 0.809 | 0.974 |
| $r^2$ | 0.508 | 0.819 | 0.655 | 0.949 |
| Std. Error of the Estimate | 0.27847 | 0.34164 | 0.32064 | 0.20561 |
| F | 23.788 | 104.293 | 45.536 | 442.775 |
| Sig. | 0.000 | 0.000 | 0.000 | 0.000 |

The coefficients of the Qds-Q relationship in table 4.3c indicate that there is a direct relationship between dissolved sediment load and discharge for the four tributaries as exhibited in figures 5.3a to d. In order to check the significance of the regression coefficients, a and b (i.e intercept and slope), the t-ratio test was conducted and in all cases, it was observed that $t_a$ and $t_b$ were statistically significant at 0.05 level of significance. Therefore, we can say that there is a strong relationship between the regression coefficients.

The coefficient of correlation (r) and coefficient of determination ($r^2$) in all cases were high. Although the values are high, inference on these values cannot be made without checking the statistical significance of the $r^2$ computed, as their high values do not conclude that the independent variable (Q) is a good determinant of the dependent variable (Qds). In all cases, using the F-ratio (ANOVA) test, the regression coefficient of determination ($r^2$) was found to be statistically significant at the 0.05 level of significance, indicating that discharge (Q) is a good determinant of the dissolved sediment discharge (Qs) as illustrated in table 5.3d. The strongest relationship between

dissolved sediment load and discharge was experienced in the Goruba stream which is exhibited in the lowest degree of scatter of the points in fig. 5.3d. On the other hand, the weakest relationship between dissolved sediment load and discharge was experienced in the Malmo stream which is exhibited in the highest degree of scatter of the points in fig. 5.3a. This can expressly be related to their sizes as the former is the largest with highest discharge while the later is the smallest with the lowest discharge.

Following this conclusion, it will be expected that, since the sub-basins increase in size progressively, the strength of the dissolved sediment load and discharge relationship should follow suit. This was the case except for the Maigamo stream which altered the increasing trend. The possible reason for this will also be explained later after the LULC classification of the sub-basins.

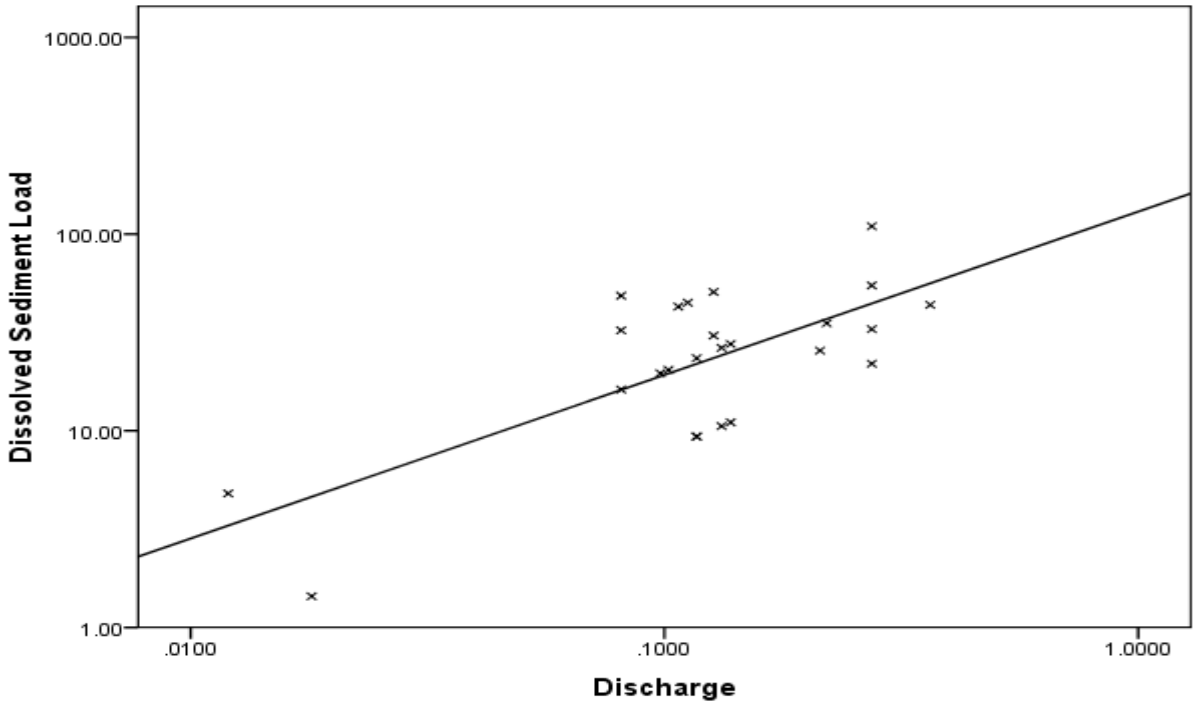



**Fig. 5.3a Qds-Q Relation for Malmo Stream**

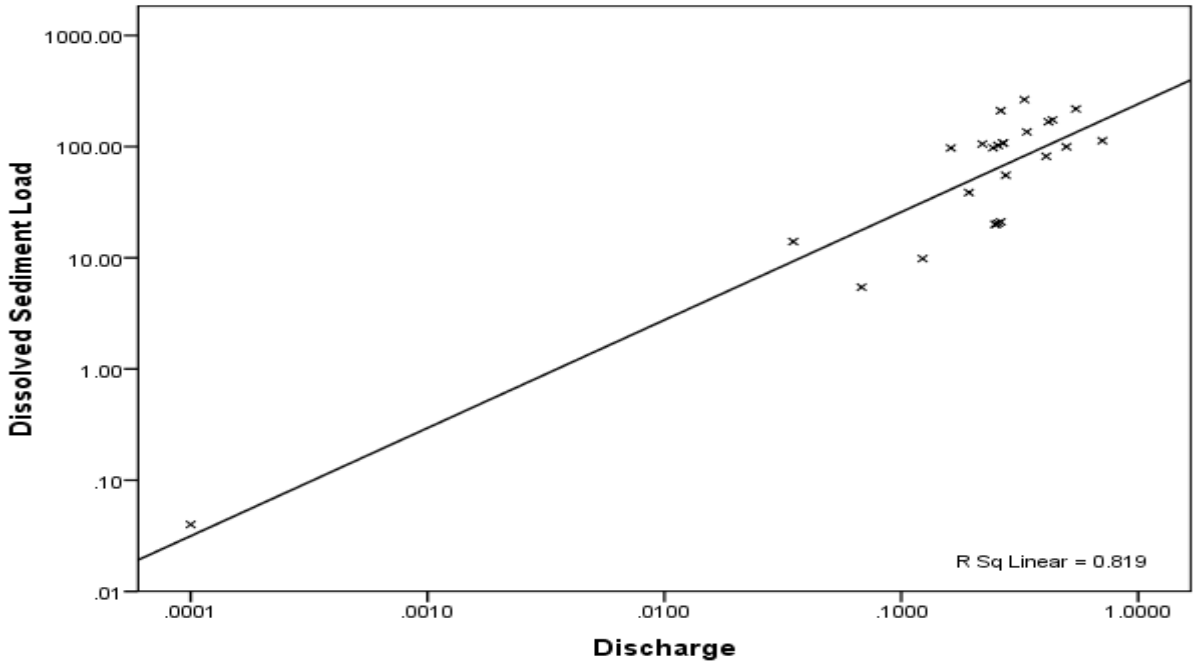



**Fig. 5.3b Qds-Q Relation for Tukurwa Stream**

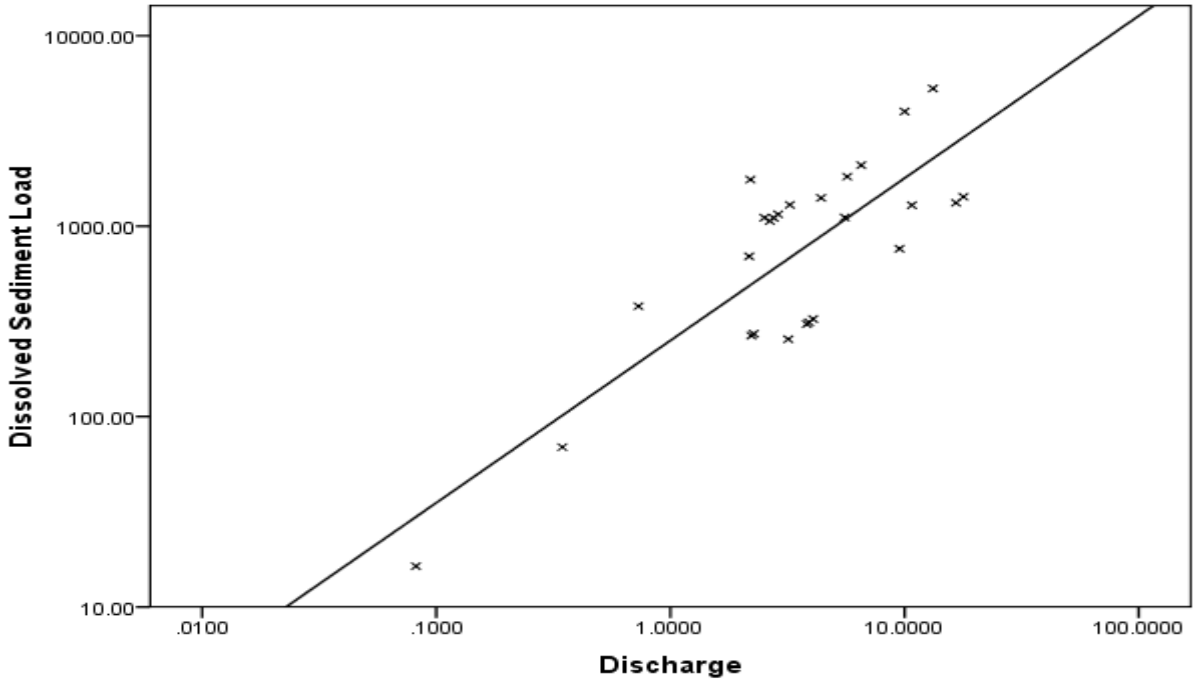



**Fig. 5.3c Qds-Q Relation for Maigamo Stream**

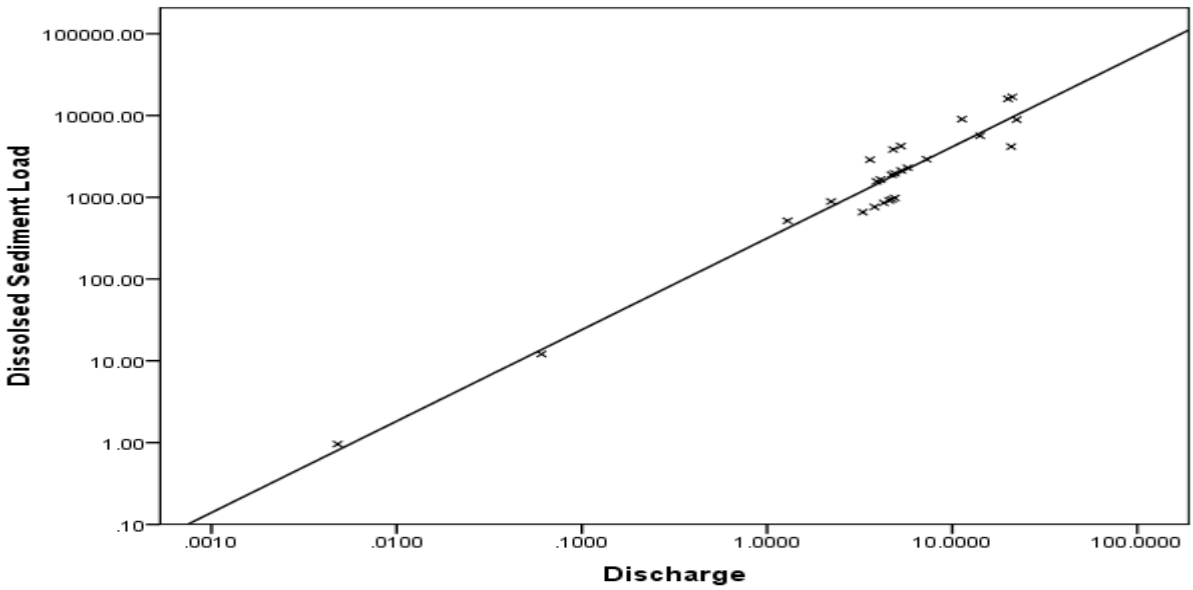



**Fig. 5.3d Qds-Q Relation for Goruba Stream**

## 5.4 Suspended and Dissolved Sediment Yields

Consequently, using the regression coefficients, tables 5.4a and b present the summary statistics for the continuous suspended and dissolved sediment loads for the four tributaries including their sediment yields in kg/yr derived using equation 8 and tons/yr after dividing by 1000.

**5.4a Summary Statistics for Derived Suspended Sediment Load for the Four Tributaries**

| Statistics | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| N | 246 | 192 | 176 | 175 |
| Minimum | 0.02 | 0.03 | 0.42 | 0.64 |
| Maximum | 232.26 | 370.07 | 10956.17 | 11307.32 |
| Mean | 11.6819 | 27.6023 | 801.5771 | 851.8846 |
| Std. Error of Mean | 2.0551 | 4.3705 | 134.2515 | 149.2601 |
| Std. Deviation | 32.2324 | 60.5593 | 1781.047 | 1974.5261 |
| Variance | 1038.927 | 3667.426 | 3172128 | 3898753.3 |
| Sum | 2873.75 | 5299.63 | 141077.6 | 149080.4 |
| Sediment Yield | 248292 | 457888 | 12189105 | 12880547 |
| Channel Sed. Yield | 248.292 | 457.888 | 12189.11 | 12880.547 |

**5.4b Summary Statistics for Derived Dissolved Load for the Four Tributaries**

| Statistics | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| N | 246 | 192 | 176 | 175 |
| Minimum | 0.06 | 0.03 | 0.25 | 0.05 |
| Maximum | 56.14 | 172.26 | 2924.6 | 9792.53 |
| Mean | 4.2339 | 14.2386 | 237.8589 | 572.4079 |
| Std. Error of Mean | 0.5757 | 2.1368 | 37.1002 | 120.9585 |
| Std. Deviation | 9.0292 | 29.6089 | 492.1895 | 1600.1308 |
| Variance | 81.566 | 876.686 | 242250.48 | 2560418.56 |
| Sum | 1041.55 | 2733.8 | 41864.4 | 100171.1 |
| Sediment Yield | 89990 | 236200 | 3617084 | 8654774 |
| Channel Sed. Yield | 89.99 | 236.2 | 3617.084 | 8654.774 |

The summary statistics for the derived suspended sediment load for the four tributaries in table 5.4a indicates that, although the number of days of continuous flow is reducing with the size of the sub-basins, the statistics including the channel suspended sediment yields

of the four tributaries is increasing progressively with the Malmo stream having the least (248.292 tons/yr) and the Goruba stream having the highest (12880.547 tons/yr). The situation is not much dissimilar in table 5.4b where the Malmo stream has the least value of 89.99 tons/yr and the Goruba stream has the highest value of 8654.774 tons/yr.

In an attempt to examine the temporal variation in suspended sediment load, figures 5.4a to 5.4d present the regime diagrams for the suspended sediment load of the four tributaries.

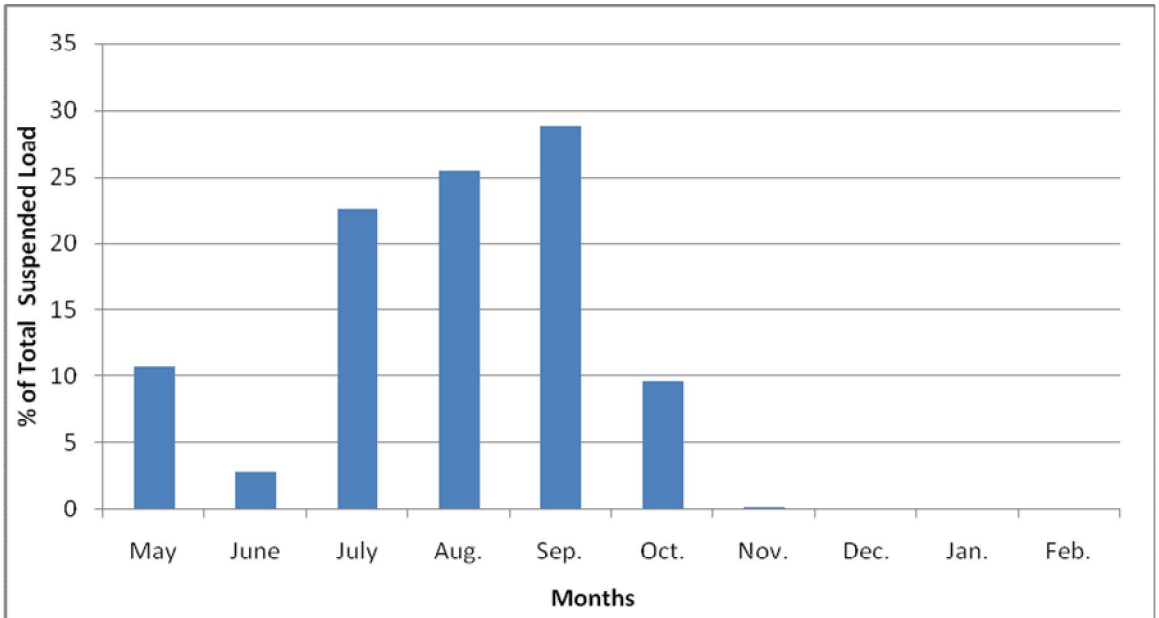



**Fig. 5.4a Suspended Sediment Load Regime Diagram for Malmo Stream**

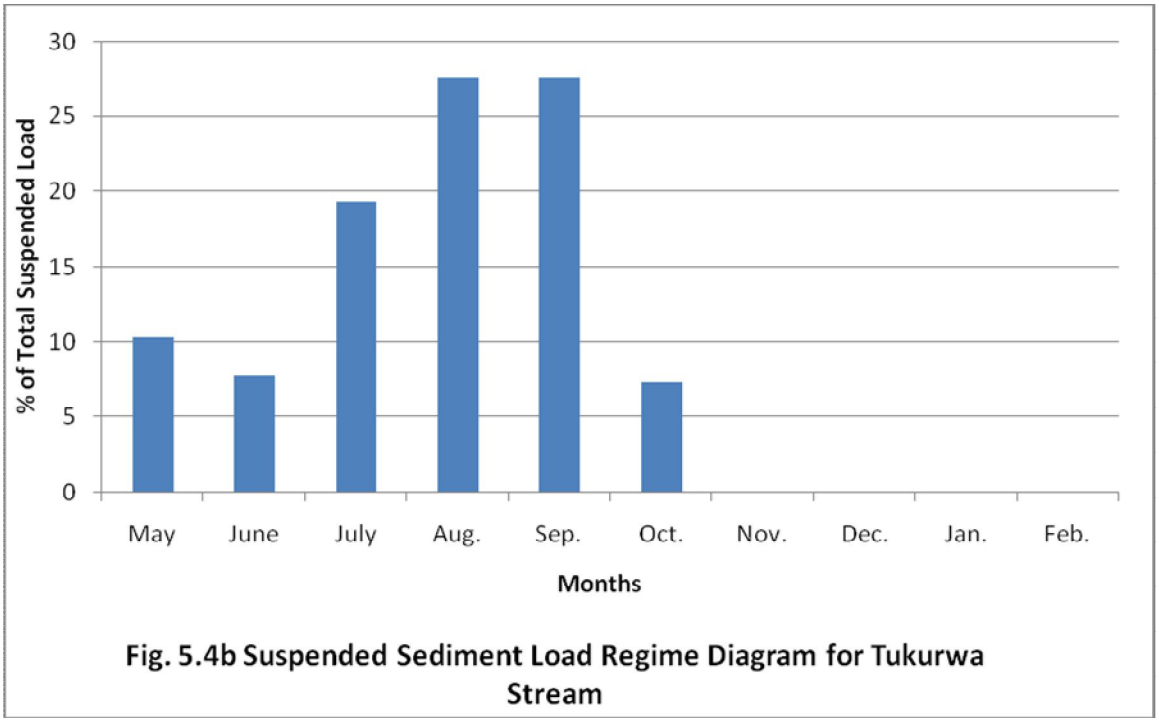



**Fig. 5.4b Suspended Sediment Load Regime Diagram for Tukurwa Stream**

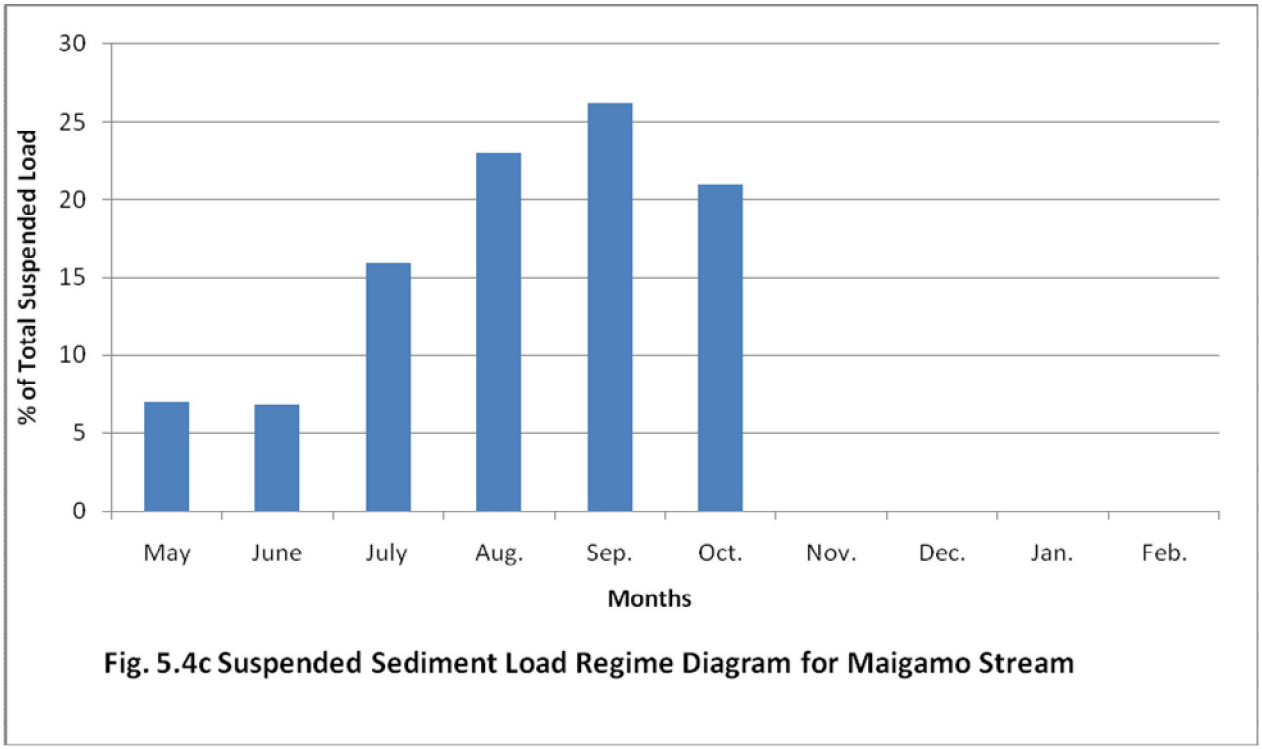



**Fig. 5.4c Suspended Sediment Load Regime Diagram for Maigamo Stream**

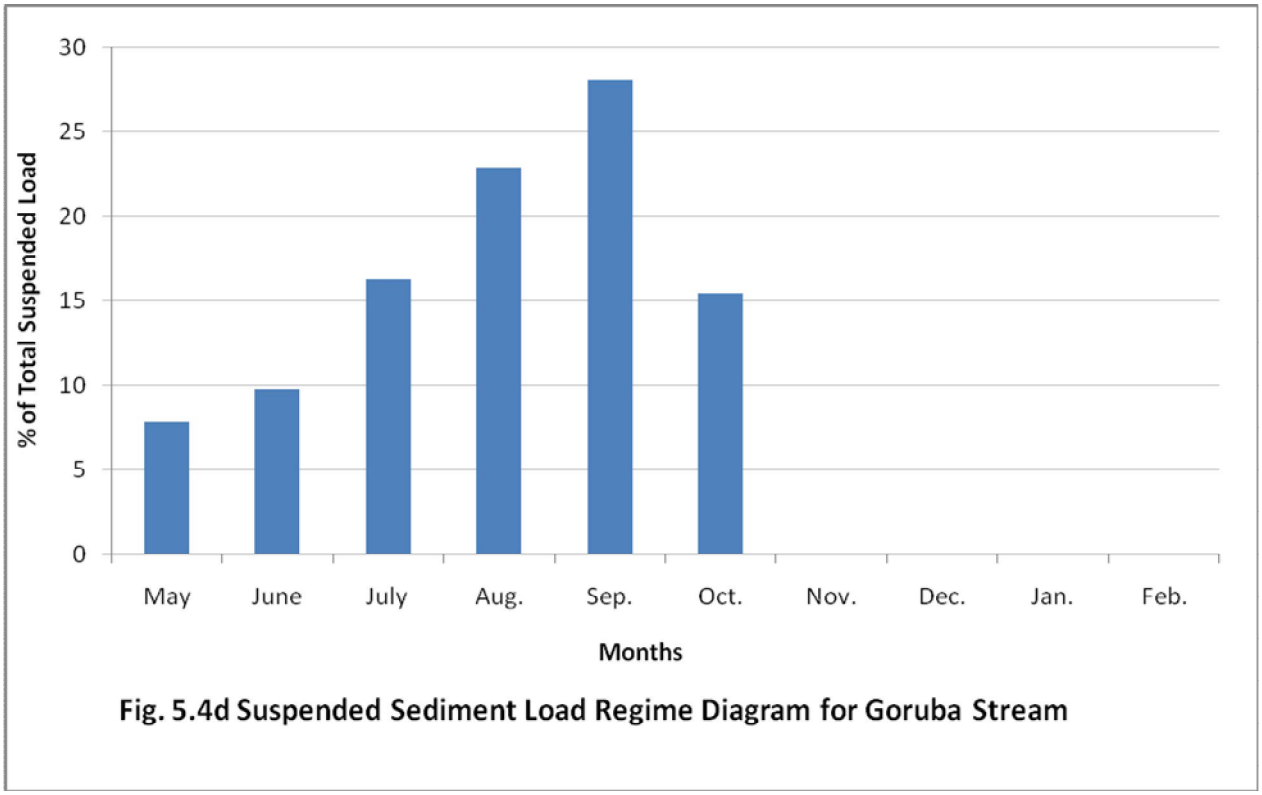



**Fig. 5.4d Suspended Sediment Load Regime Diagram for Goruba Stream**

The suspended sediment load regime diagrams above reveal that the month of September, which is the month with highest discharge, has the highest suspended sediment load followed by August and July while the months of November, October, June and May have the least values for the Malmo, Tukurwa, Maigamo and Goruba streams respectively.

Also, in an attempt to examine the temporal variation in dissolved sediment load, figures 5.5a to 5.5d present the regime diagrams for the dissolved sediment load of the four tributaries.

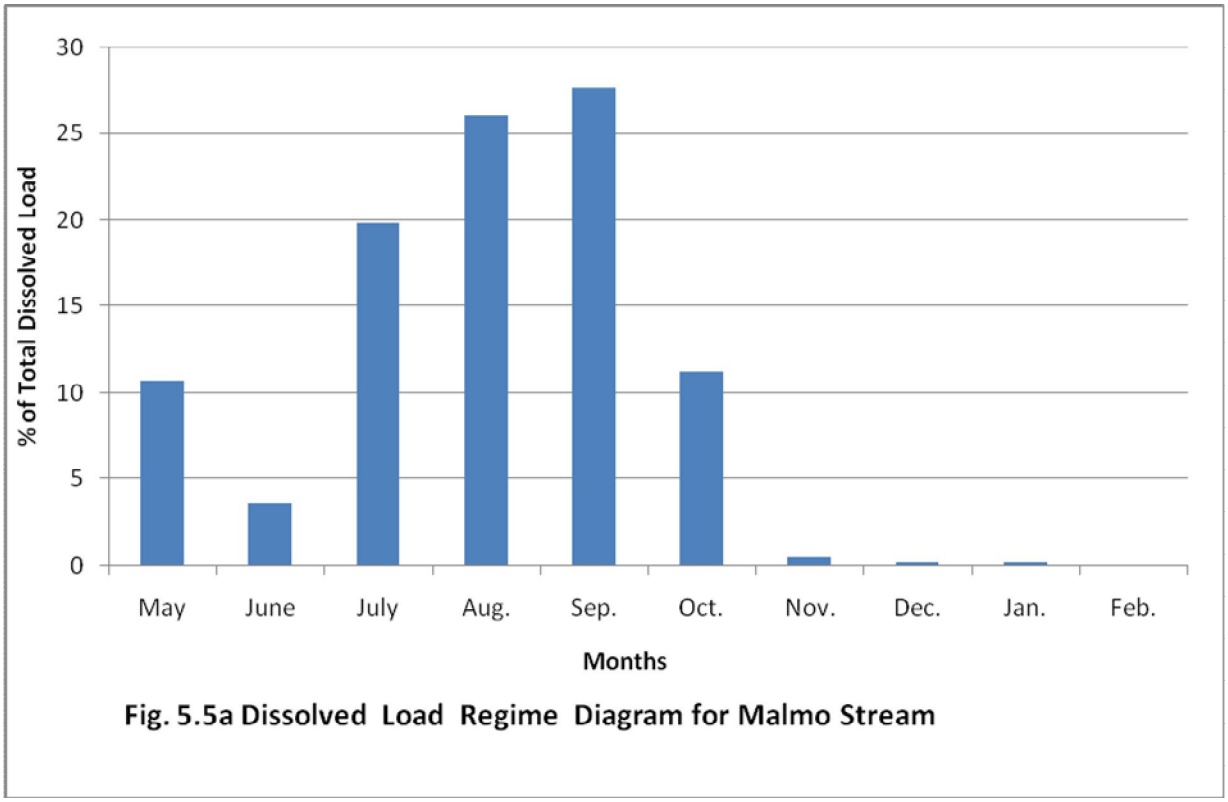



**Fig. 5.5a Dissolved Load Regime Diagram for Malmo Stream**

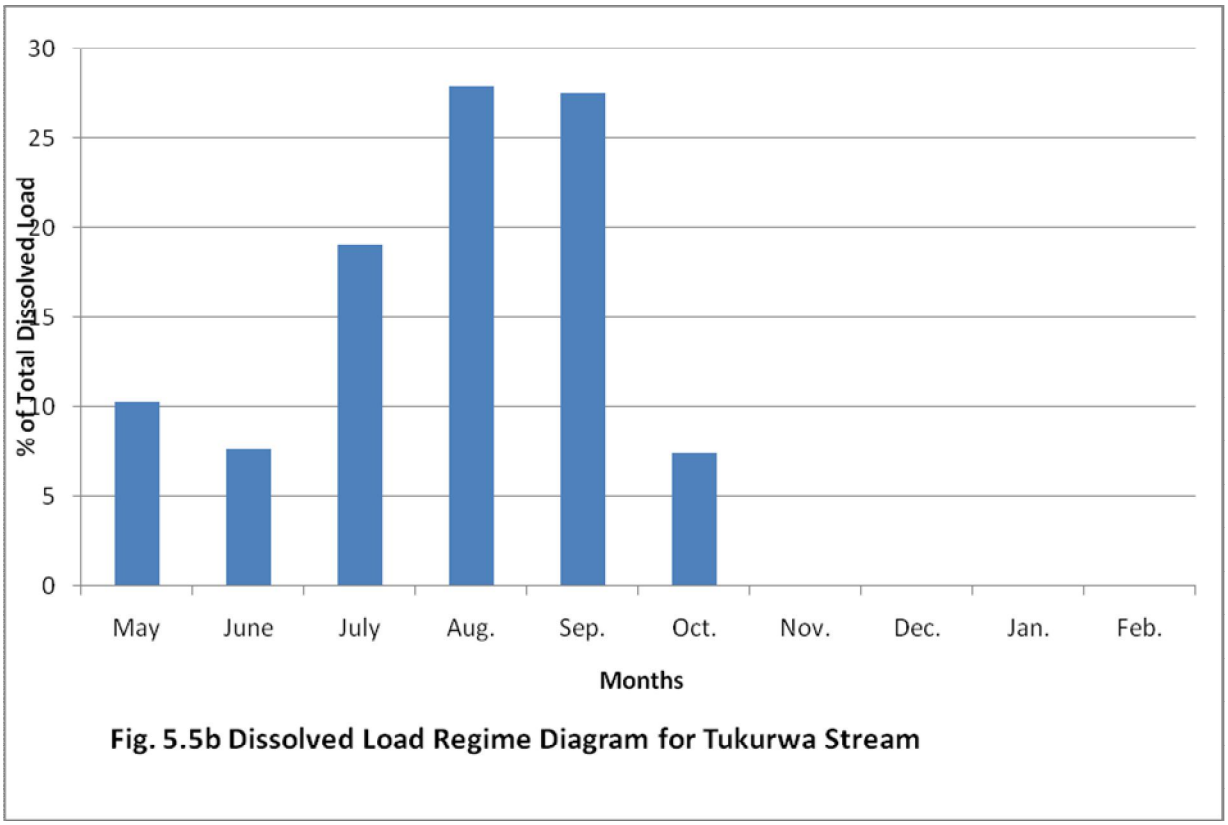



**Fig. 5.5b Dissolved Load Regime Diagram for Tukurwa Stream**

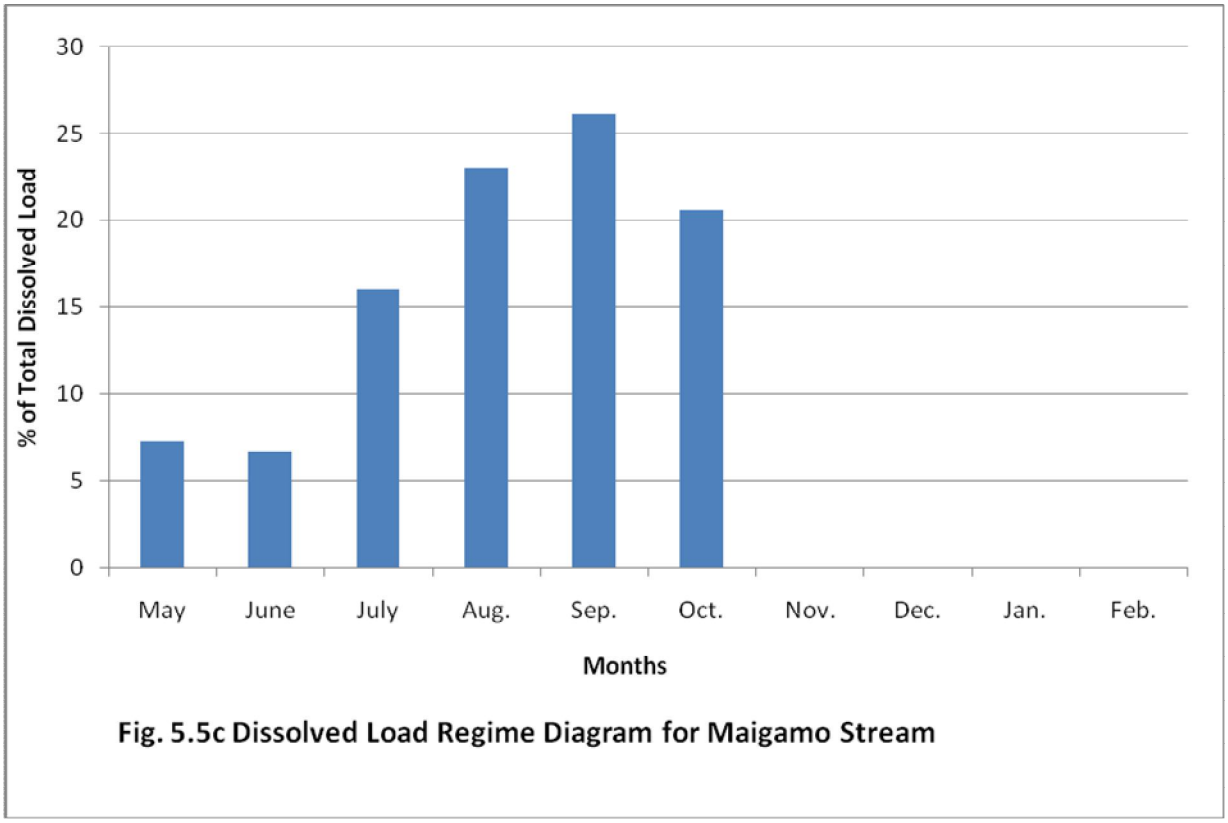



**Fig. 5.5c Dissolved Load Regime Diagram for Maigamo Stream**

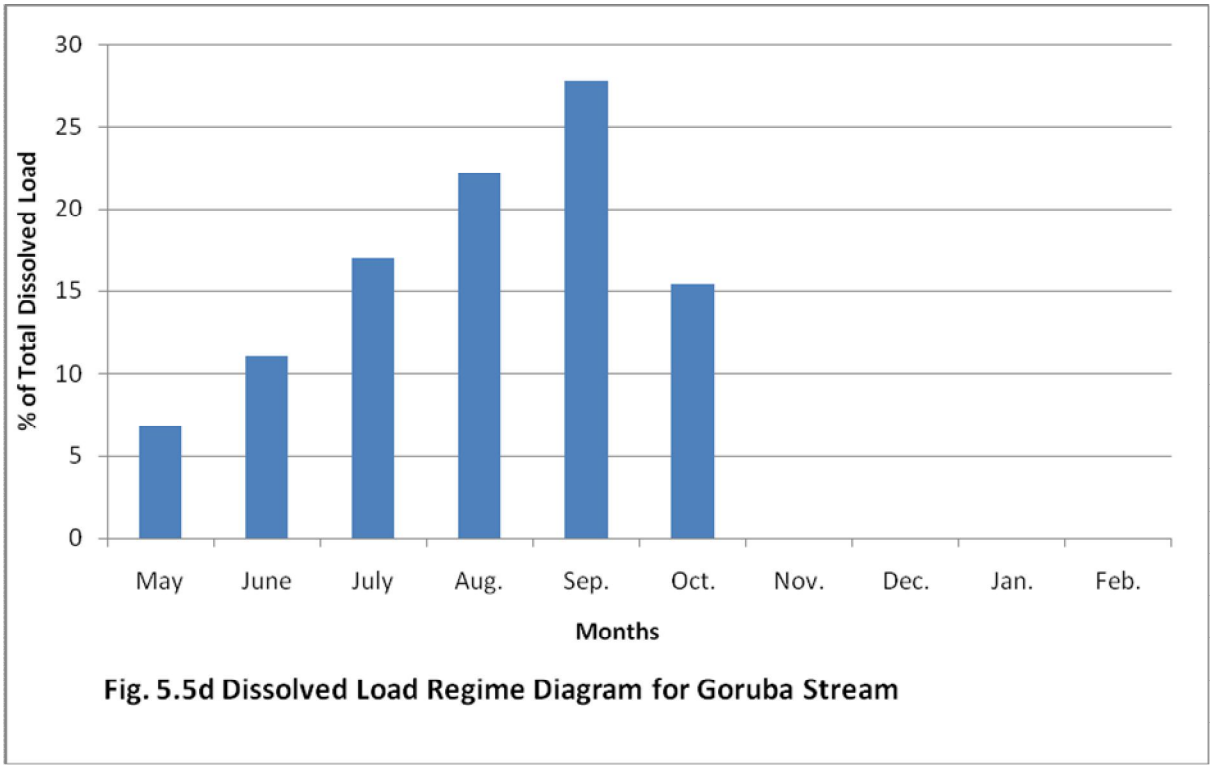



**Fig. 5.5d Dissolved Load Regime Diagram for Goruba Stream**

The dissolved sediment load regime diagrams above reveal that the month of September, which is the month with highest discharge, has the highest suspended sediment load followed by August and July, except for the Tukurwa stream where the month with highest dissolved load is August which is actually its month of highest discharge (see fig. 5.1b) while the months of January, October, June and May have the least values for the Malmo, Tukurwa, Maigamo and Goruba streams respectively.

## 5.5 Sediment Yields Hypotheses Testing

### 5.5.1 Suspended Sediment Yield

In order to test whether there is no significant difference in the suspended yields of the tributaries, the Analysis of Variance (ANOVA) was used and the result is presented in table 5.5a below showing that there is a significant difference in the suspended sediment yields of the four tributaries.

**Table 5.5a ANOVA for the Suspended Sediment Yields of the Four Tributaries**

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 127460599.4 | 3 | 42486866.45 | 27.01763 | 0 |
| Within Groups | 1234460473 | 785 | 1572561.113 | | |
| Total | 1361921073 | 788 | | | |

### 5.5.2 Dissolved Sediment Yield

To test whether there is no significant difference in the dissolved sediment yields of the tributaries, the Analysis of Variance (ANOVA) was also used and the result is presented in table 5.5b below showing that there is a significant difference in the dissolved sediment yields of the four tributaries.

**Table 5.5b ANOVA for the Dissolved Sediment Yields of the Four Tributaries**

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 40393586.2 | 3 | 13464528.73 | 21.65495 | 0 |
| Within Groups | 488094084.8 | 785 | 621775.9042 | | |
| Total | 528487671 | 788 | | | |

### 5.5.3 Suspended and Dissolved Sediment Yields

Also, in order to test whether there is no significant difference in the suspended and dissolved sediment yields of the tributaries, the Analysis of Variance (ANOVA) was used and the result is presented in table 5.5c below showing that there is a significant difference in the suspended and dissolved sediment yields of the four tributaries except for the Goruba stream. This can be attributed to its being the largest sub-basin with the highest discharge which increases the dissolved load produced within.

**Table 5.5c ANOVA for the Suspended and Dissolved Sediment Loads for the Four Tributaries**

| Statistic | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| df | 491 | 383 | 351 | 349 |
| F | 12.1792 | 7.5458 | 16.3804 | 2.1162 |
| Sig. | 0.01 | 0.06 | 0 | 0.147 |

Comparatively, the results above confirm that the suspended sediment yield for the Malmo stream, apart from being lower when compared to that of Yusuf (2006) is actually greater than the dissolved sediment yield and there is a significant difference between them which correlates with the geology of the study area that is predominantly basement complex. The lower suspended sediment yield is attributed to the better conservation methods by the Ahmadu Bello University while possible sources of error in the dissolved

sediment yield may include the long waiting period of the samples, laboratory procedures and the accuracy level of the weighing balance.

## 5.6 Land Use-Land Cover (LULC) Classification and Characterization

The result of the LULC for the four sub-basins is presented in figures 5.6a to 5.6d while table 5.6 summarizes their LULC characterization in square kilometers represented in fig. 5.7.

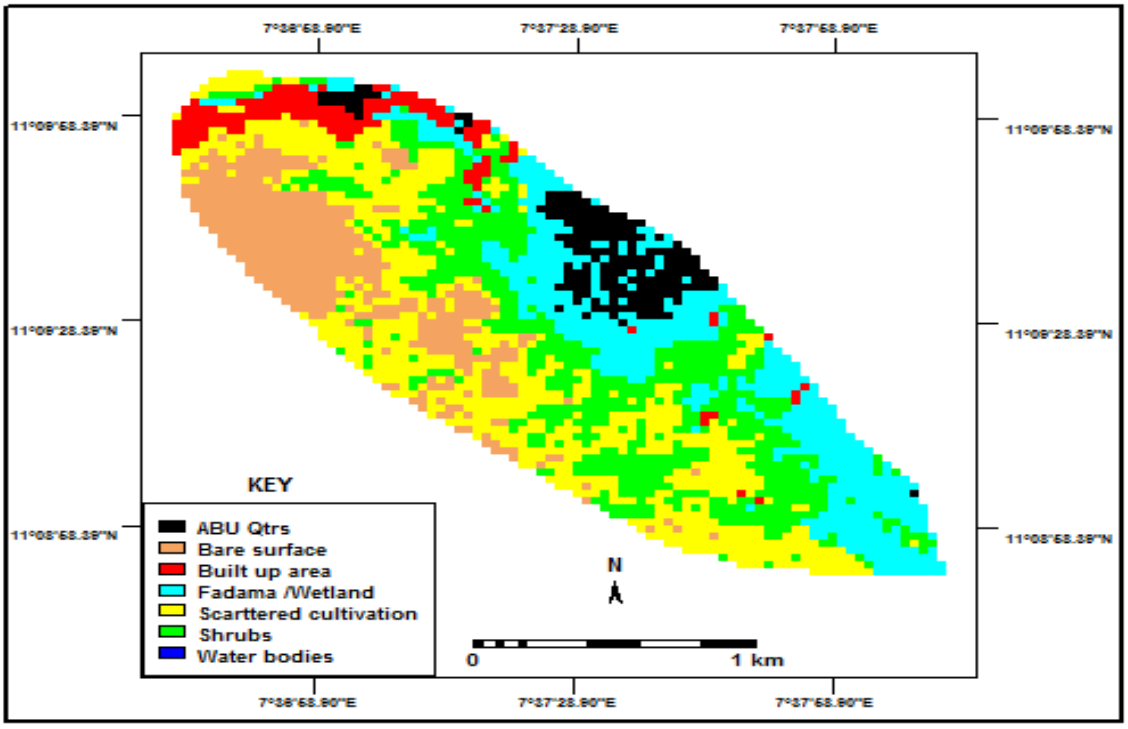



**Fig. 5.6a Classified Subset of Malmo Sub-Basin**
**Source: Laboratory Analysis, 2011**

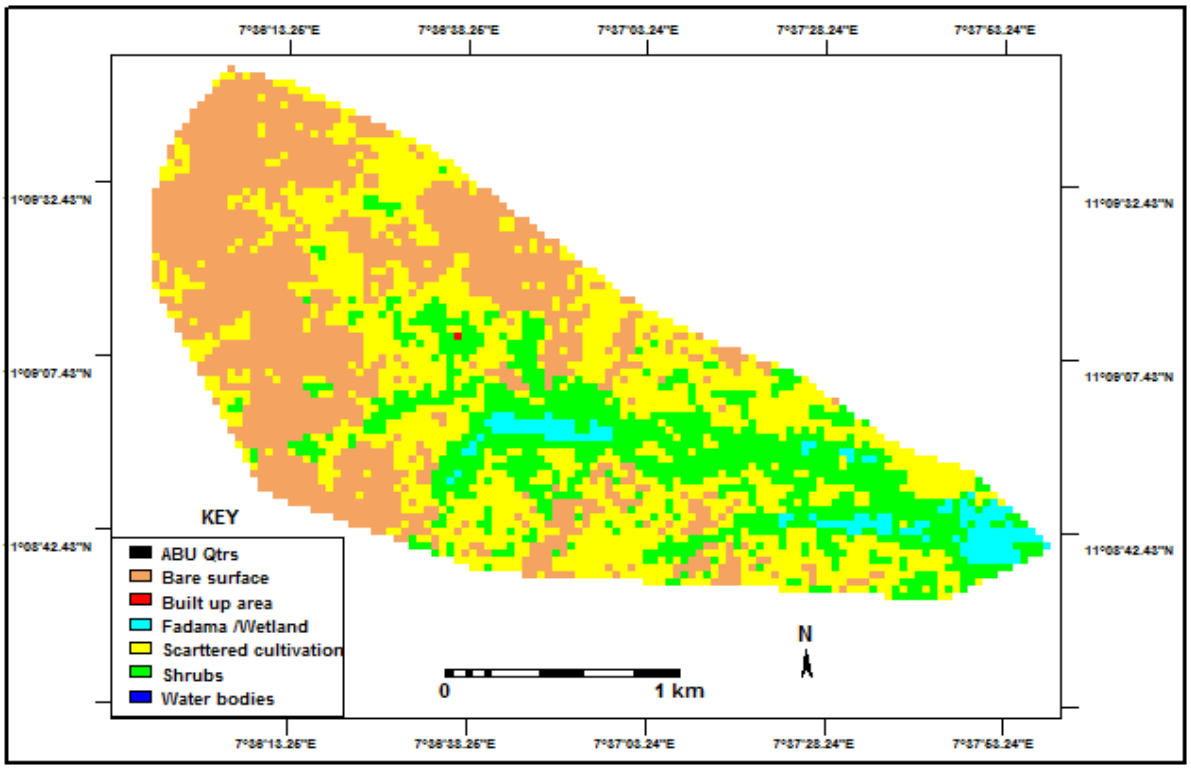



**Fig. 5.6b Classified Subset of Tukurwa Sub-Basin**
**Source: Laboratory Analysis, 2011**

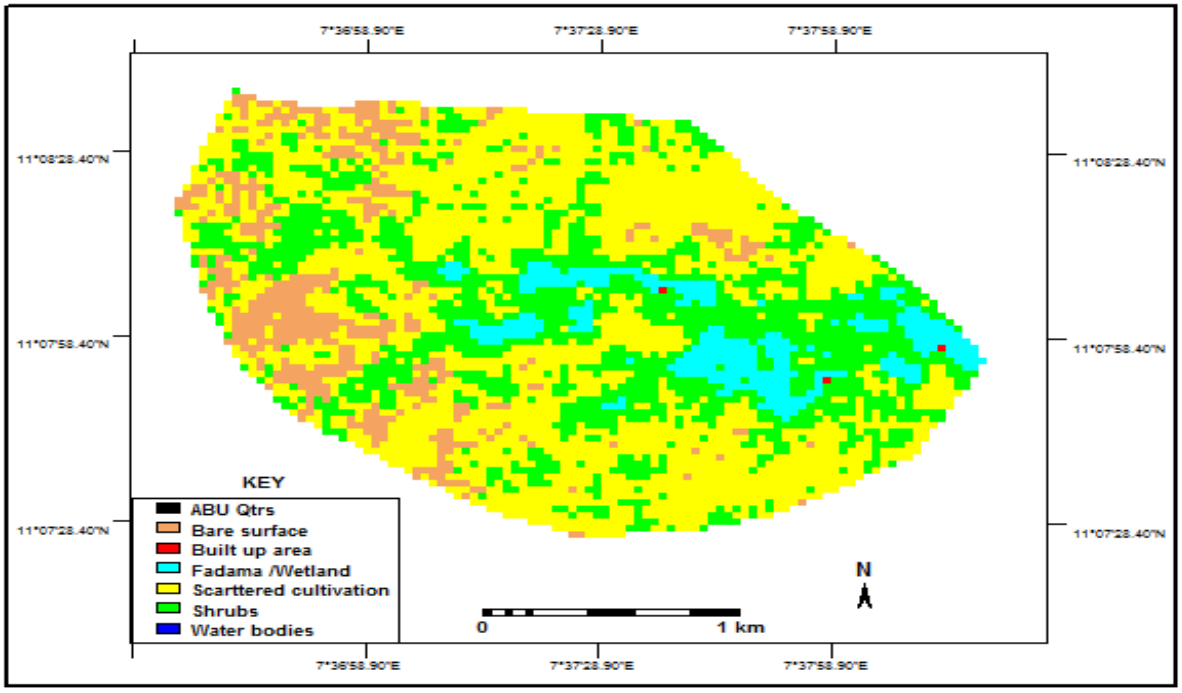



**Fig. 5.6c Classified Subset of Maigamo Sub-Basin**
**Source: Laboratory Analysis, 2011**

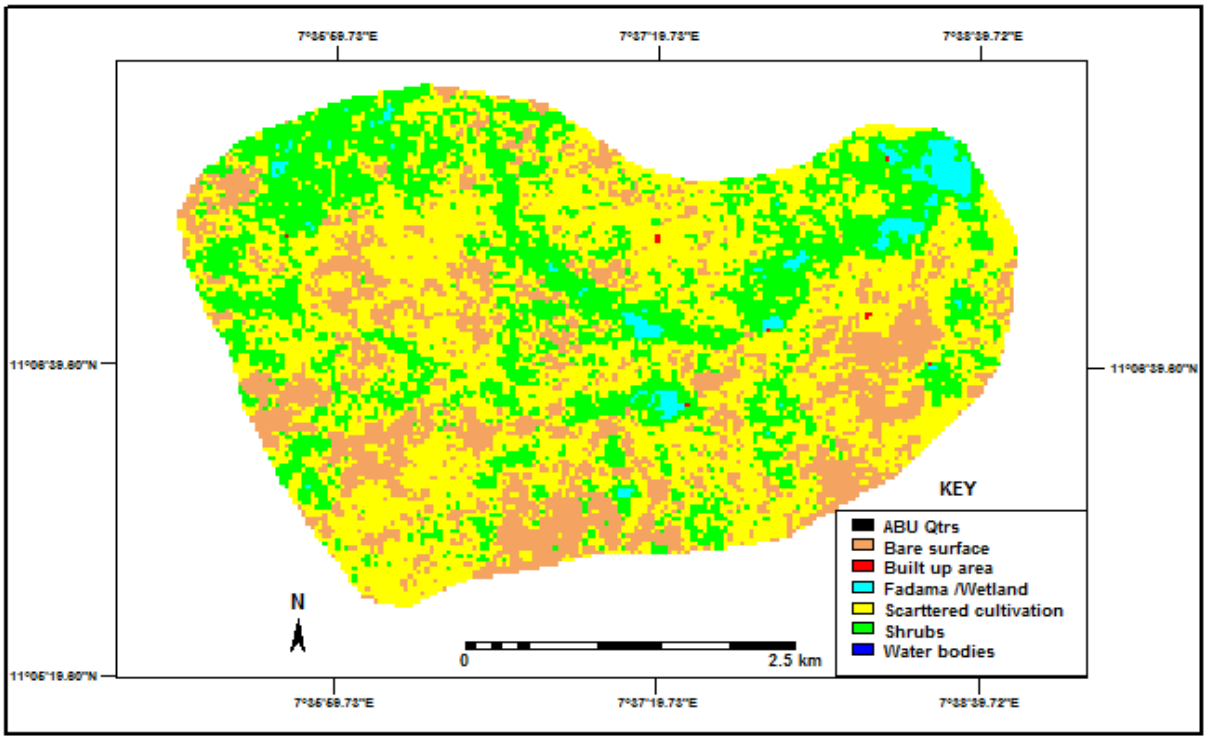



**Fig. 5.6d Classified Subset of Goruba Sub-Basin**
**Source: Laboratory Analysis, 2011**

**Table 5.6 LULC Characterization of the Four Sub-basins in km$^2$**

| LULC | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|
| ABU quarters | 0.2 | 0 | 0 | 0 |
| Bare surface | 0.47 | 1.72 | 0.53 | 3.92 |
| Built up areas | 0.15 | 0 | 0 | 0.01 |
| Fadama / Wetland | 0.59 | 0.15 | 0.34 | 0.36 |
| Scattered cultivation | 0.82 | 1.74 | 2.5 | 8.86 |
| Shrubs | 0.72 | 1 | 1.5 | 5.18 |
| Water bodies | 0 | 0 | 0 | 0 |
| **Total** | **2.95** | **4.61** | **4.87** | **18.33** |

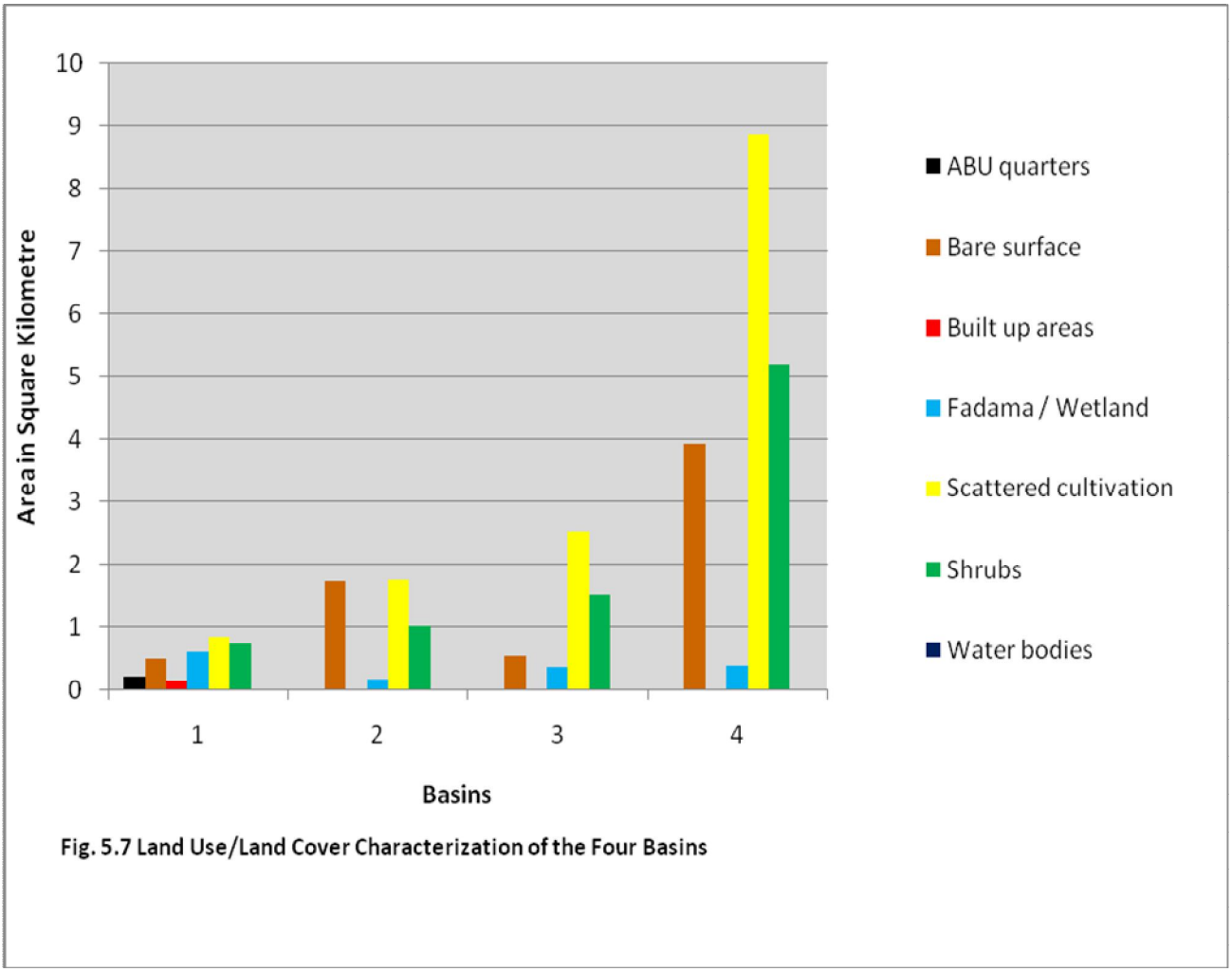



Fig. 5.7 Land Use/Land Cover Characterization of the Four Basins

The LULC classification as characterized in table 5.6 has markedly revealed the sizes of the four sub-basins increasing progressively. The subsets of the classification numbered up to seven with the Malmo having six including ABU quarters and built-up areas. Of course the ABU quarters are also built-up areas but due to the spectral signature problem of confusing the ABU quarters with forested area due to the landscaping within, they had to be separated for the Malmo sub-basin that houses the developed part of the university. The Goruba sub-basin is next with five sub-sets including small portion of built-up area occupied by some staff of ABU and farmers trespassing the ABU land. The Tukurwa and

Maigamo sub-basins between have equal LULC subsets of four only as presented in table 4.6 and represented in fig. 5.7.

The water body subset included in the classification is apparently absent in the four sub-basins because the imagery used for the analysis was captured during the dry season when there was no streamflow. However, such areas were represented by the Fadama/wetland classification.

## 5.7 LULC-Sediment Yield Relationship

A careful observation of table 5.6 and fig. 5.7 indicates that scattered cultivation, apart from increasing progressively, makes up the significant part of the LULC subsets for each of the sub-basins. The implication of this is that in most of the sub-basins, farming is prevalent, and is therefore the major contributor to their sediment yields. This implication is further aggravated with the fact that most of the farmers plant and harvest twice within the rainy season (Plate 5.1a and b). Rawat (2011) asserted that agricultural land generates about 2.4 times higher sheetwash erosion sediment than that of the relatively less disturbed barren land.

It is worth mentioning here that the LULC classification for the Malmo stream shows a slight difference between the scattered cultivation and shrubs which is an indicator that the efforts of the university administration in afforestation through their annual tree planting campaign and reduction of cultivation is yielding results and is quite commendable. This inference can be better understood when the suspended sediment

yield estimated now (248 tons/yr) is compared with that of Yusuf (2006); 482 tons/yr, indicating that the sediment yield has been reduced almost by half.



**Plate 5.1a Harvested Maize cultivated at the beginning of the Rainy Season**



**Plate 5.1b Cultivated Sorghum waiting for Harvest in the same Season**

Comparatively, the LULC classification for the Goruba stream which is the largest and furthest away from the campus shows the greatest difference between the scattered cultivation and shrubs which easily explains why it has the highest sediment yield (Tamene *et al.*, 2006; Rawat, 2011). This can be attributed to the intensive cultivation being carried out in the sub-basin (Plate 5.2a and b).



**Plate 5.2a Intensive Cultivation going on in the Goruba Sub-basin**



**Plate 5.2b Growing Crops in the Goruba Sub-basin**

The Qss and discharge correlation highest in the Tukurwa stream in table 5.3b can be attributed to the almost equal contribution of the bare surface and scattered cultivation to the LULC characterization as shown in fig. 5.7 (Tamene *et al.*, 2006). On the other hand, the weakest relationship between Qss and discharge exhibited in the highest degree of scatter of points in fig. 5.2c and the reduction in the strength of relationship between Qds and discharge for the Maigamo stream in table 5.3d can be attributed to man's additional influence of farming very close to the gauging station (Plate 5.3) which can cause "noise" in the sediment yield contribution especially during the land preparation and harvesting period. All efforts to prevent the continuation of the cultivation proved abortive.

The issue was further complicated with the farmer's claim of ownership to the land contradicting that of the University that they have been adequately compensated. The matter is presently unresolved and is being heard in the court.



**Plate 5.3 Farming Close to the Gauging Station of Maigamo Stream with Field Assistant confirming Maximum Depth of Staff Gauge**

The LULC classification as characterized in table 5.6 summarizes the sizes of each sub-basin and therefore facilitates the calculation of their Specific Sediment Yields (SSY) in tons/km$^2$/yr derived by dividing the Channel Sediment Yields (CSY) by the areas as presented in table 5.7 vary significantly, as in the study of Nigussie *et al* (2005) in Tigray – Northern Ethiopia, from 84.167 tons/km$^2$/yr to 2502.897 tons/km$^2$/yr for the suspended sediment with an average of 838 tons/km$^2$/yr which is lesser than the African average of 1000 tons/km$^2$/yr. Infact, of all the sub-basins, it is only the Maigamo sub-basin that has SSY value that is even higher than the Global average of 1500 tons/km$^2$/yr (Lawrence and Dickinson, 1995). On the other hand, the dissolved load SSY also vary significantly from 30.505 tons/km$^2$/yr to 742.728 tons/km$^2$/yr with an average of 324 tons/km$^2$/yr.

The results above confirm the fact that dissolved loads of world rivers do not vary as greatly as suspended sediment yields as concluded by Gregory and Walling (1973) while the anomaly of the Maigamo stream having highest values can be attributed to man's additional influence of farming very close to the gauging station (Plate 5.3 above) which increases astronomically, the sediment yield contribution and goes a long way to emphasize the significance of land use in determining sediment yield (Gregory and Walling, 1973; Goudie, 1981; Naden and Cooper, 1999; Restrepo and Syvitski, 2006).

**Table 5.7 Specific Sediment Yields of the Sub-basins**

| Sediment Yield | Statistics | Malmo | Tukurwa | Maigamo | Goruba |
|---|---|---|---|---|---|
| | Size ($km^2$) | **2.95** | **4.61** | **4.87** | **18.33** |
| Suspended | CSY (tons/yr) | 248.292 | 457.888 | 12189.105 | 12880.55 |
| | SSY (tons/$km^2$/yr) | 84.167 | 99.325 | 2502.897 | 702.703 |
| Dissolved | CSY (tons/yr) | 89.99 | 236.2 | 3617.084 | 8654.774 |
| | SSY (tons/$km^2$/yr) | 30.505 | 51.236 | 742.728 | 472.164 |

## 5.8 Implications of the Study for Reservoir Management

Most reservoirs store from about 1% to 20% of the annual inflow but entrap from 45% to 80% or more of the incoming sediment. This rapid sedimentation reduces the useful life of the reservoir, as well as its water supply potential (Walling and Kleo, 1979; Singh and Durgunoglu, 1989; Singh and Durgunoglu, 1990; Knighton, 1998).

Solute load is material carried in true chemical solution and is important in the assessment of water quality and pollution while suspended sediment loads are those materials carried by rivers and transported in suspension which, from the point of view of reservoir sedimentation, is of crucial importance (Bogardi, 1974; McPherson, 1975; Vanoni, 1975; Ayoade, 1988; Yusuf, 2009).

The sedimentation of the Ahmadu Bello University (ABU) reservoir which provides water for the University community is the result of eroded materials transported and deposited into the reservoir which consequently affects the water holding capacity of the reservoir. This was earlier reported by Iguisi (1997), to have an average annual loss of depth of about 14.3cm and corroborated by the ABU committee on the protection of

the reservoir that if nothing is done to reduce the spate of sedimentation, the reservoir will disappear from the maps by 2059.

The information thus provided on the magnitude of the suspended and dissolved sediment loads of the upstream tributaries of River Kubanni has many practical implications ranging from geomorphological studies of denudation rates and pattern of landform development to problems of upstream soil loss and downstream channel and reservoir sedimentation. Also, it has implication on the quality and quantity of the communal water supply of Ahmadu Bello University, where one of the gravest problems is the removal of suspended sediment particles and in the process of its purification.

# CHAPTER SIX

# SUMMARY, CONCLUSION AND RECOMMENDATIONS

## 6.1 Summary

This study attempts an assessment of the sediment delivery into the Kubanni reservoir, Ahmadu Bello University, Zaria, Nigeria, constructed to provide water for the university community. The four tributaries contributing water and sediment into the reservoir were monitored for one year with data on sediment concentration and stream discharge collected from their gauging stations made up of a $120^0$ and $90^0$ V-notch control stuctures (weirs), and a stage used to estimate the discharges. Suspended sediment samples, were collected at the gauging stations using the USDH 48 sampler for onward analysis in the laboratory to determine the suspended sediment concentrations. Rating curves were used to allow a reasonable estimate of suspended sediment yield for the four tributaries. The Total Dissolved Solids (TDS) derived from the samples of the filtered river water (i.e. aliquot) and the discharge records gave the dissolved sediment loads which provide the basis for estimating the dissolved sediment yields.

Although the flow periods of the tributaries reduced with increase in the sizes of the sub-basins, their discharges increased consecutively with the highest total discharge value of 258.01 $m^3/s$ for the Goruba stream and lowest value of 5.31 $m^3/s$ for the Malmo stream in the study period. From the regime diagrams, September is the month with highest discharge except for the Tukurwa tributary where August is the month with the highest discharge corresponding with the known month of highest rainfall in the study area. An interesting observation is the fact that the discharge regime is noticed clearly as from

May to October with a single maxima which correlates with the rainfall period in the study area.

The coefficients of the relationships indicate that there is a direct relationship between suspended/dissolved sediment load and discharge for the four tributaries. In order to check the significance of the regression coefficients, a and b (i.e intercept and slope), the t-ratio test was conducted and in all cases, it was observed that $t_a$ and $t_b$ were statistically significant at 0.05 level of significance. Therefore, we can say that there is a strong relationship between the regression coefficients. The coefficients of correlation (r) and coefficients of determination ($r^2$) in all cases were high. Using the F-ratio (ANOVA) test, the regression coefficients of determination ($r^2$) were found to be statistically significant at the 0.05 level of significance, indicating that discharge (Q) is a good determinant of the suspended and dissolved sediment load.

The summary statistics for the derived suspended sediment load for the four tributaries indicates that, although the number of days of continuous flow is reducing with the size of the sub-basins, the statistics including the channel suspended sediment yields of the four tributaries is increasing progressively with the Malmo stream having the least (248.29 tons/yr) and the Goruba stream having the highest (12880.55 tons/yr). The situation is not much dissimilar in the derived dissolved loads where the Malmo stream has the least value of 89.99 tons/yr and the Goruba stream has the highest value of 8654.77 tons/yr.

In order to test whether there is no significant difference in the suspended and dissolved yields of the tributaries, the Analysis of Variance (ANOVA) was used and the results indicate that there is a significant difference in the yields of the four tributaries. Comparing the suspended and dissolved loads of each of the tributaries also revealed a significant difference except for the Goruba stream which is attributed to its being the largest sub-basin with the highest discharge which increases the dissolved load produced within.

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Classification and characterization of land use/land cover (LULC) within the tributaries was carried out on a 2009 NIGERIASAT-1 satellite imagery using the ILWIS 3.7 software indicating that scattered cultivation, apart from increasing progressively, makes up the significant part of the LULC subsets for each of the sub-basins. The implication of this is that in most of the sub-basins, farming is prevalent, and is therefore the major contributor to their sediment yields. This implication is further aggravated with the fact that most of the farmers plant and harvest twice within the rainy season.

The LULC classification for the Malmo stream shows a slight difference between the scattered cultivation and shrubs which is an indicator that the efforts of the university administration through afforestation by annual tree planting campaign and reduction of cultivation is yielding results and is quite commendable. The suspended sediment yield estimated now (248 tons/yr) when compared with that of Yusuf (2006); 482 tons/yr, indicates that the sediment yield has been reduced almost by half.

The LULC classification as characterized summarized the sizes of each sub-basin and facilitated the calculation of their Specific Sediment Yields (SSY) in tons/km$^2$/yr which vary significantly from 84.167 tons/km$^2$/yr to 2502.897 tons/km$^2$/yr for the suspended sediment with an average of 838 tons/km$^2$/yr which is lesser than the African average of 1000 tons/km$^2$/yr. Of all the sub-basins, it is only the Maigamo sub-basin that has SSY value that is even higher than the Global average of 1500 tons/km$^2$/yr. On the other hand, the dissolved load SSY also vary significantly from 30.505 tons/km$^2$/yr to 742.728 tons/km$^2$/yr with an average of 324 tons/km$^2$/yr.

## 6.2 Conclusion

The results summarized above confirm the fact that dissolved loads of world rivers do not vary as greatly as suspended sediment yields as concluded by Gregory and Walling (1973) while the anomaly of the Maigamo stream having highest values can be attributed to man's additional influence of farming very close to the gauging station which increases astronomically, the sediment yield contribution and goes a long way to emphasize the significance of land use in determining sediment yield (Gregory and Walling, 1973; Goudie, 1981; Naden and Cooper, 1999; Restrepo and Syvitski, 2006).

The results confirm that the suspended sediment yield for the Malmo stream, apart from being lower when compared to that of Yusuf (2006) is actually greater than the dissolved sediment yield, when compared to Yusuf (2009), and there is a significant difference between them which correlates with the geology of the study area that is predominantly basement complex. The lower suspended sediment yield is attributed to the better

conservation methods by the Ahmadu Bello University while possible sources of error in the dissolved sediment yield may include the long waiting period of the samples, laboratory procedures and the accuracy level of the weighing balance.

The information thus provided on the magnitude of the suspended and dissolved sediment loads of the upstream tributaries of River Kubanni has many practical implications ranging from geomorphological studies of denudation rates and pattern of landform development to problems of upstream soil loss and downstream channel and reservoir sedimentation. Also, it has implication on the communal water supply of Ahmadu Bello University, where one of the gravest problems is the removal of suspended sediment particles and in the process of purification.

## 6.3 Recommendations

Although the ABU authority has banned farming around the Kubanni basin, it was observed that people are still farming and this contributes significantly to the sediment yield of the basin. There is therefore the need to enforce the ban, which should also be extended to the prevention of grazing by animals and soil mining for construction. This enforcement should be strengthened with a legal backing according to best legal practices to ensure compliance as interaction with some of the farmers revealed their claim that they have not been compensated for their relocation. A stance that is strongly refuted by the Ahmadu Bello University administration.

After getting the legal backing for the present land mass, prevention of cultivation, grazing by animals and soil mining therein for construction should be enforced and the University should try to acquire more lands especially in the Goruba and Maigamo sub-basins where the Channel and Specific Sediment Yield is highest. On acquisition of this land, judicious use should be made as intrusion will be encouraged if the land is left unutilized. There is no doubt that land acquisition requires a substantial amount of money and this is where international and federal agencies and stakeholders have to come to the aid of the University to achieve this noble aim.

Furthermore, the annual tree planting exercise should be encouraged as the present study has confirmed the reduction in the magnitude of sediment yield significantly as a result of the noble exercise. Infact, the tree planting should extend to the lands in dispute immediately after resolving the crisis between the inhabitants and the Ahmadu Bello University.

Since the reservoir is purposely for domestic water supply, the University administration should consider building low check-dams or submerged weirs, especially across the Maigamo and Goruba tributaries, that will act as sediment traps at strategic locations as this will go a long way to reduce sediment yield delivery into the Kubanni reservoir because 30% to 70% of the coarse sediment entering the reservoir will be trapped (Roveri, 1981). These sediments can be removed economically every 2 to 3 years during low flows or dry periods by crawler tractors or scrapers and can be used to raise the nearby lands. The experience with the weirs installed; although their installation was not

meant for that purpose, have confirmed the effectiveness of sediment traps in reducing sediment yield. On collection of the sediments, grasses that can serve as filtering agents end up growing. This observation was made at a post data collection monitoring of the study area (Plate 6.1).

A comprehensive watershed management is the best way to reduce the yield of sediment and its entry into a reservoir. Therefore, a long term monitoring of the flow measurements and sediment load of the tributaries and the reservoir on a regular basis is ideal to ascertain the level of siltation.



**Plate 6.1 Sediment Collection at the Installed V-notch Weir**

Finally, the Ahmadu Bello University administration should make fervent efforts towards dredging the reservoir in order to increase its retention capacity and empty it of the accumulated sediments over the years as all the aforementioned suggestions will only reduce subsequent rate of siltation of the reservoir. Excavation, combined with comprehensive watershed management, will extend the useful life of the Kubanni impounding reservoir.

# REFERENCES


Abu, R.D, Iguisi, E.O., and Bello, A.L. (2011) An Assessment of the Effect of Land use/Landcover Change on the rate of sedimentation on an Earth Dam, Zaria Northern Nigeria. **Journal of Geography, Planning and Environment**, 7,2, pp. 95-100

abu.edu.ng (2012) Zaria at a Glance. http://www.abu.edu.ng/info/zaria.php (Assessed September, 2012)

Abubakar, B. (1966) "The Morphology of the Kubanni Drainage Basin" **Unpublished B.A. Dissertation**, Department of Geography, A.B.U., Zaria.

Adedeji, A. Jeje, L.K. (2004) Channel erosion in the Opa basin, Southwestern Nigeria. **Journal of Environmental Hydrology**. 12, 10. pp. 1-11.

Ahmed, M.I. (1989) "Assessment of Gully Density in relation to Landuse in Upper Kubanni Drainage Basin, Zaria" **Unpublished B.Sc. Dissertation**, Department of Geography, A.B.U., Zaria.

Akintola, J.O. (1986) **Rainfall Distribution in Nigeria (1982 – 1988)**. Ibadan: Impact Publishers.

Ameh, P.I. (1966) "Slope Analysis of Kubanni River Drainage Basin" **Unpublished B.A. Dissertation**, Department of Geography, A.B.U., Zaria.

Anil-Kumar, M (2004) Plan for augmentation of capacities for water supply system in GIS (Study Area MCH). **B. Planning Thesis**, Department of Urban and Regional Planning, School of Planning and Architecture, Jawahariel Nehru Technological University, Nyderabab.

Anon. (1972) Human interference with the north Derbyshire blanket peat. **East Midland Geographer**, 12, pp.245-251.

Ariyo, A and Jerome, A (2004). Utility Privatization and the Poor Nigeria in Focus, **Global Issue Papers**, Heinrich Boll foundation, Berlin.

Arowolo, O.T. (2000) "An Assessment of Sediment Yield of River Saye and River Kubanni" **Unpublished B.Sc. Dissertation**, Department of Geography, A.B.U., Zaria.

Ati, O.F. (1990) "Normalization of Rainfall Series in Nigeria" **Unpublished B.A. Dissertation**, Department of Geography, A.B.U. Zaria.

Ayoade, J.O. (1988) **Tropical Hydrology and Water Resources**. London: Macmillan Publishers Ltd.. pp. 275.

Barnes, K.K. and Frevert, R.K. (1954) A runoff sampler for large watershed, **Agricultural Engineering**, 35, pp. 84-90

Barnes, K.K. and Johnson, H.P. (1956) A runoff sampler for large watershed. **Agricultural Engineering**, 37, pp. 813 -815, 824.

Bartholic, J. O. (2004) Predicting Sediment Delivery Ratio in Saaginaw Bay Watershed. Institute of Water Research, Mcchigan State University, East Lansing, M I

Bauer, L. and Tille, W. (1967) Regional differentiations of the suspended sediment transport in Thuringia and their relation to soil erosion, In: Gregory, K.J. and Walling, D.E. (1973) **Drainage Basin Form and Processes: A Geomorphological Approach**. London: Edward Arnold Publishers Ltd. pp. 204-205.

Bello, A.L. (1973) "The morphology of an erosional scarp, south of the Ahmadu Bello University, Zaria" **Unpublished B.A. Dissertation**, Department of Geography, A.B.U. Zaria.

Bogardi, J. (1974) **Sediment Transport in Alluvial Streams**. Akademiai Kindo, Budapest, Hungary, pp. 826.

Brooks, K.N., Ffolliott, P.F., Gergerson, H.M., and DeBano, L.F. (1997) **Hydrology and the Management of Watersheds**. Iowa: Iowa State University Press.

Brown, J.A.H. (1972) Hydrologic effects of a bushfire in a catchment in south-eastern New South Wales. **Journal of Hydrology**, 15, pp. 77-96.

Brown, H. E, Hansen, E.A. and Champagne, N.E. (1970) A system for measuring total sediment yield from small watersheds, **Water Resources Research**, 6, pp. 818-26

Brune, G.M. (1953) Trap efficiency of erosion, **Transactions of American Geophysical Union**, 22, pp. 649 – 55

Budel, J. (1969) Das system der klima-genetischen geomorphologie. **Erkunde**, 23, pp. 165-82

Campbell, F.B. and Bender, H.A. (1940) A rating curve method for determining silt-discharge of streams. **Transactions of American Geophysical Union**, 21, pp. 603-7

Carvalho, O., Junior, N.P.F., Santos, P.M.S. and Lima, J.E.F.W. (2000) **Reservoir Sedimentation Assessment Guideline.** Brasilia.

Castle, G.H. (1965) Determination of reservoir deposits by reconnaissance methods. **Proceedings of the Federal Inter-Agency Sedimentation Conference, U.S.D.A Misc. Pub.**,970, pp. 857-867

Chakrapani, G. J. (2005) Factors controlling variations in river sediment loads. **Current Science,** 88(4), pp. 569-575

Clothier, B. E., Green, S. R. & Deurer, M., 2008. Preferential flow and transport in soil: progress and prognosis. **European Journal of Soil Science** 59, pp. 2 – 13.

Colby, B.R. (1956) Relationship of sediment discharge to streamflow, **U.S. Geology Survey Open File Report**. 170pp

Collier, C.R, Whetstone, G.W. and Musser, J.S. (1964) Influences of strip mining on the hydrological environments of parts of Beaver Creek basin, **U.S. Geological Survey Professional Paper**, 427-B, B1 –B83.

Committee on the Protection of Kubanni Dam (2008) "Preliminary Report on the Remaining Storage of Kubanni Impounding Reservoir". Unpublished Report prepared for the Vice Chancellor, Ahmadu Bello University, Zaria.

Committee on Water Resources and Supply (2004) "Report of the Committee on Water Resources and Supply in Ahmadu Bello University, Samaru Campus, Zaria". Unpublished Report prepared for the Vice Chancellor, Ahmadu Bello University, Zaria.

Corbel, J. (1964) L'erosion terrestre, etude quantitative, **Annales de Geographie**, 73, pp. 385-412.

Dasma, R.F., Mitan, J.P. and Freeman, P.H.(1973) **Ecological Principles of Economic Development.** John Wiley and Sons, London.

Degens, E.T., Kempe, S and Richey, J.E. (1991). **Biogeochemistry of Major World Rivers.** London: John Wiley and Sons.

Douglas, I. (1967) Man, vegetation and the sediment yield of rivers, **Nature**, 215, pp. 925-928

Douglas, I. (1968) The efficiency of humid tropical denudation systems, **Transactions of the Institute of Geography**, 46, pp. 1 -16

Douglas, I. (1971) Comments on the determination of fluvial sediment discharge, **Australian Geographical Studies.** 9, pp. 172-176.

Du preez, J.W. and Barber (1965) The distribution and chemical quality of groundwater in northern Nigeria, **Bulletin of Geolological Survey Department of Nigeria**, No. 36.

Dumanski, J., Coote, D.R. Luciak, G. and Lok, C. (1986) Soil conservation in Canada, **Journal of Soil and Water Conservation**, 41, pp. 204-10

Dunne, T. and Leopold, L.B. (1978) **Water in Environmental Planning**. San Fransisco: W.H. Freeman.

Ferguson, R. I. (1987) Hydraulic and sedimentary controls of channel pattern. In: Richard, K.S. (ed)., **River Channels; Environment and Process.** Oxford: Blackwell, pp 129-58.

Fleming, G. (1969) Suspended solids monitoring: A comparison between the instruments. **Water and Water engineering**, pp. 377-82.

Fournier, F. (1960) Climat et erosion: Ia elation entre I' erosion du so I par L' ean at less precipitations atmospherique. In Ologe, K.O. (1986) A general and hypothetical note on sediment yield in Nigeria. Department of Geography, ABU, Zaria.

Fournier, F. (1962) Carte du danger d'erosion en Afrique au sud du Sahara foude sur L'agressivite climatique at la topographie. In Ologe, K.O. (1986) A general and hypothetical note on sediment yield in Nigeria. Department of Geography, ABU, Zaria.

Glymph, L. M. (1954) Studies of sediment yields from watershed, **International Association of Hydrology Publication**, 36, pp. 178-91

Glymph, L.M. (1973) Sedimentation of reservoir, In: Achermann, W. C. et al (eds) Man-made lakes: Their problems and environmental effect. **Geophysical Monograph**. 17, American Geophysical Union, Washington D.C. pp. 4342-4348

Graffiths, G.A. (1979) High Sediment Yield from major rocks of the western southern Alps, New Zealand. **Nature**, 282, pp. 61-63

Gottschalk, L.C. (1964) Reservoir sedimentation, In: Gregory, K. J. and Walling, D. E. (1973) **Drainage Basin Form and Processes: A Geomorphological Approach**. London: Edward Arnold Publishers Ltd.

Goudie, A. (1981) **The Human Impact: Man's Role in Environmental Change**. Oxford: Basil Blackwell Publisher Ltd. Pg. 316.

Gregory, K.J. and Walling, D.E. (1973**) Drainage Basin Form and Processes: A Geomorphological Approach**. London: Edward Arnold Publishers Ltd. 456 pp.

Guy, H.P. (1964) An analysis of some storm-period variables affecting stream sediment transport, **U.S. Geol. Survey Professional Paper,** 462E.

Hadley, R.F. and Schumm, S.A. (1961) Sediment sources and drainage characteristics in Upper Cheyenne river basin, **U.S. Geol Survey Water Supply Paper**, 1531-B, pp. 137-96.

Hall, D.G. (1967) The pattern of sediment movement in the River Tyne. **International Association of Hydrology Publication**, 75, pp. 117 -42.

Handidu, I.A. (1990) National growth, water demand and supply strategies in Nigeria in the 1960's. **Journal of the Nigerian Association of Hydrologists**, 2(1), pp. 7-13.

Haregeweyn, N., Poesen, J., Nyssen, J., Verstraeten, G., De Vente, J., Govers, G., Deckers, S. and Moeyersons, J. (2005) Specific sediment yield in Tigray – Northern Ethiopia: Assessment and semi-quantitative modeling. **Geomorphology**, 69. pp. 315-331.

Heregeweyn, N., Poesen, J., Nyssen, J, De wit, J., Haile, M., Govers, G. and Deckers, J. (2006) Reservoir in Tigray, characteristics of sediment deposition problems. **Land Degradation and Development**, 17, pp. 211-230.

Hinman, S.E., Blackburn, J.S. and Curtis, A. (2006) Spatial and temporal structure of typhoid outbreaks in Washington D.C, 1906-1909 Evaluating local clustering with G statistics. **International Journal of Health Geographics**, 13, pp. 23-27.

Hocking, J.A and Thomson, N.R. (1979) **Land and water Resources of West Africa.** Moray House College of Education, Edinburgh.

Horton, R.E. (1945) Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. **Bulletin of the Geological Society of America**, 56. pp. 275-370.

Hudson, N.W. (1993) Field measurement of soil erosion and runoff, **Food and Agriculture Organization Soils Bulletin**, 68, Silsoe Associates, United kingdom, 139 pp.

Ibrahim, A. R. (1986) "Relationship between Slope and Geology" **Unpublished B.Sc. Dissertation**, Department of Geography, A.B.U., Zaria.

Iguisi, E. O. (1996) "Variations of Soil Loss in two Sub-basins near Zaria, Nigeria." **Unpublished Ph.D. Thesis**, Department of Geography, A.B.U., Zaria.

Iguisi, E. O. (1997) An assessment of the current level of sedimentation of the Kubanni dam. **Savanna**, 18(1), pp. 17-28.

Iguisi, E.O. and Abubakar, S.M. (1998) "The effect of Landuse on Dam Siltation." Paper Presented at Annual Conference of Nigerian Geographical Association, University of Uyo.

Imevore, A. M., Ogunkoya, O. O. and Sagua, V. O. (1988) Effects of Soil Erosion on Aquatic Ecosystem in Nigeria, In Sagua, V. O. et al (eds) **Ecological Disasters in Nigeria: Soil Erosion**. Federal Ministry of Science and Technology, Lagos.

Ipinmidun, W.B. (1972) A preliminary survey of the agricultural potentials of some valleys around Zaria, Nigeria, **Nigerian Agricultural Journal**, 8(1), p.85.

Jaiyeoba, I.A. (1986) "Analysis of the Relationship between Soil Properties and Soil forming Factors in the Nigerian Savanna." **Unpublished Ph.D Thesis**, Department of Geography, A.B.U., Zaria.

Jaiyeoba, I.A. (1995) Change in soil properties relation to different landuses in part of the Nigerian semi-arid savannah, **Soil Use and Management**, 11, pp. 84-89.

Jansen, J.M.L. and Painter, R.B. (1974) Predicting sediment yield from climate and topography, **Journal of Hydrology**, 21, pp. 371-380.

Jatau, F. (1999) 'Nature and Problems of Fadama Farming in Zaria Local Government, Kaduna State, Nigeria.' Unpublished B.Sc. Project. Department of Geography, Ahmadu Bello University, Zaria.

Kattan, Z. Gac, J.Y. and Protest, J.L. (1987) Suspended sediment load and mechanical erosion in the Senegal basin-estimation of the surface run-off concentration and relative contribution of channel and slope erosion. **Journal of Hydrology**, 92, pp. 59-76

King, L. C. (1962) **Morphology of the Earth: A Study and Synthesis of World Scenery**. Oliver and Boyd, Edinburgh, 699 pp.

Klinkenberg. K. (1970) Soils, In: Mortimore, M. J. (eds), Zaria and its Region, **Occasional Paper**, 4, Department of Geography, A.B.U., Zaria, pp. 55-60.

Knighton, D. (1998) **Fluvial Forms and Processes: A New Perspective**. London: Arnold.

Koi, T., Norifumi, H., and Masakazu, S. (2006) Sediment yield and vegetation recovery in mounteneous region with repeated heavy precipitation, in **Disaster Mitigation of Debris Flows, Slope Failures and Landslides**. Tokyo, Japan: University Academy Press, Inc. pp. 321-329.

Kondolf, G.M., Smeltzer, M. and Kimball, L. (2002) **Freshwater Gravel Mining and Dredging Issues**. Prepared for Washington Department of Fish & Wildlife, Department of Ecology, and Department of Transportation. pp.3-4.

Kowal, J.M. and Adeoye, K.B. (1973) An assessment of aridity and the severity of the 1972 drought in northern Nigeria and neighboring countries, **Savanna**, 2 (2), pp. 145-58.

Kowal, J.M. and Kassam, A.H. (1973) An appraisal of drought in savanna areas of Nigeria, **Savanna**, 2 (2), pp 152-64

Kowal, J.M. and Kassam, A.H. (1978) **Agricultural Ecology of Savanna: A Study of West Africa**. London: Oxford University Press.

Kowal, J.M. and Knabe, D.T. (1972) **An Agroclimatological Atlas of the Northern States of Nigeria**. Zaria, Nigeria: Ahmadu Bello University Press.

Kowal, J.M. and Omolokun, A.O. (1971) The hydrology of a small catchment basin at Samaru, Nigeria. **Nigerian Agricultural Journal**, 7(1), pp. 27-40

Kwabe, S.A. (1987) "Soil wash in two Forest Reserves near Zaria, Northern Nigeria." **Unpublished M.Sc. Thesis**, Department of Geography A.B.U., Zaria.

Lal, R., ed. (1988) **Soil Erosion Research Methods**. Soil and Water Conservation Society, Ankeny, Iowa.

Lane, L.J., Nearing, M.A., Laflen, J.M., Foster, G.R. and Nichols, M.H. (1992) Description of the USDA water erosion predication project (WEPP) model, In: Parsons, A.J and Abrahams, A.D. (eds), **Overland Flow Hydraulics and Erosion Mechanics**. London: UCL Press, pp. 377-91.

Langbein, W.B. and Schumm, S.A. (1958) Yield of sediment in relation to mean annual precipitation. **Transactions of the American Geophysical Union**, 39, pp. 1076-84.

Lawrence, P. and Dickinson, A. (1995) Soil Erosion and Sediment Yield: A Review of Sediment Data From Rivers and Reservoirs (Report prepared under FAO writers' contract). Overseas Development Unit HR Wallingford Ltd., England.

Leopold, L.B. Wolman, M.G. and Miller, J.P. (1964) **Fluvial Processes in Geomorphology**. San Francisco: W.H. Freeman and Company.

Linse, S.J., Mergen, D.E., Smith, J.L., and Trlica, M.J. (2001) Upland erosion under a simulated most damaging storm. **Range Manage Journal**. 37, pp. 291-294.

Loughran, R.J. (1989) The measurement of soil erosion, **Progress in Physical Geography**, 13, pp. 216-33.

Ludwig, W. and Probst, J. L. (1998) River sediment Discharge to the oceans. Present day controls and global budgets. **American Journal of Science**, 298, pp. 265-295.

Maddock, T. (1969) Economic aspect of sedimentation, **American Society of Civil Engineers Sedimentation Manual**. HY1, pp. 191-207.

Magehan, W.F. (1972) Volume weight of reservoir sediment in forested areas, **Proceeding of American society of Civil Engineers**, 94, pp. 321-31.

Mangelsdorf, J. (1990) **River Morphology: A Guide for Geoscientists and Engineers,** Berlin: Springer-Verlag.

McCalla, G.R., Blackburn, W.H., and Merrill, L.B. (1984) Effects of livestock grazing on sediment production, Edwards Plateau of Texas. **Range Manage Journal,** 37, pp. 291-294.

McCully, P. (2006) Spreading the Water Wealth, Making water Infrastructure Work for the Poor. **International Rivers Network Report**. pp. 25.

McHenry, J.R. (964) A two-probe nuclear device for determining the density of sediments, **International Association of Hydrology Publication**, 65, pp. 189-202.

Mclennan, S, M. (1993) Weathering and global denudation. **Journal of Geology**, 101, pp. 295-303

McPherson, H. J. (1975) Sediment Yield from Intermediate Sized Basins in Southern Alberta**. Journal of Hydrology**. 25, pp. 243-257.

Meinzen-Dick, R.S. (1998) Managing competition for water resources. **Agriculture and Rural Development,** 2(98), pp. 6-9.

Miller, C.R. (1951) **Analysis of Flow Duration Sediment Rating Curve Method of Computing Sediment Yield**, U. S Bureau Reclamation, Denver, Colorado.

Milliman, J. D. (1991) Flux and fate of fluvial sediments and water in coastal areas. In **Ocean Margin Processes in Global Change** (eds. Montoura, R.F.C, Martin, J. M. and Wollast, R.) New York: John Wiley.

Milliman, J.D. and Syvitski, J.P.M. (1992) Geomorphic/tectonic control of sediment discharge to the ocean: The importance of small mountaneous rivers. **Journal of Geology**, 100, 525-544.

Montgomery, D.R. and Brandon, M.T. (2002) Topographic controls on erosion rates in tectonically active material ranges. **Earth Planet**, 201, pp. 481-489

Morisawa, M.E. (1967) Relation of discharge and stream length in eastern United States. **Proceedings of International Hydrology Symposium**. Fort Collins, Colorado, pp.173-6.

Morris, G. and Fan J. (1998) Design and management of dams, reservoirs and catchment for sustainable use. **Reservoir Sedimentation Handbook**. New York: McGraw-Hill,

Mortimore, M.J. and Wilson, J. (1965) Land and people in Kano closed settled zone, **Dept. of Geography occasional Paper**, A.B.U., Zaria, 120pp.

Naden, P. S. and Cooper, D. M. (1999) Development of a sediment delivery model for application in large river basins. **Hydrological Processes**, 13, pp. 1011–1034.

Norman, D.W (1970) Rural economy with special reference to agriculture, In: Mortimore, M. J (ed), Zaria and its region, **Occasional Paper**, 4, Department of Geography, A. B. U. Zaria

Nyagba, L. (1986) **Soils, Climate and Vegetation**. Institute of Education Press, A.B.U. Zaria

Ogbonna, D.O. (1997) Water issues in the context of resource development in the semi-arid region of Nigeria, in Daura, M.M. (Eds) **Issues in Environmental Monitoring in Nigeria,** Nigerian Geographical Association. pp 183-190.

Ogunkoya, O.O. (2000) Discrepancies in discharge records derived using the staff Gauge, staff gauge-crest stage indicator and water level recorder in S.W. Nigeria. **The Nigerian Geographical Journal**, New Series, 3 and 4, pp. 169-82.

Ogunkoya, O.O. and Jeje, L.K. (1987) Sediment Yield from Third Order Basins in the Basement Complex Rocks in Southwestern Nigeria. **CATENA**. 5, pp. 18-26.

Ogunrombi, J.A. (1979) The water quality of Kubanni reservoir, Zaria, **Savanna**, 8(2), pp. 95-99

Ojenya, S.O. (1989) "Valley side Slope Forms in the Upper Kubanni Basin." **Unpublished B.Sc. Dissertation**, Department of Geography, A.B.U., Zaria.

Ojo, O. (1982) **The Climate of West Africa**. London: HEB. pp 63-64.

Oladipo, E.O. (1985) Characteristics of thunderstorms in Zaria, Nigeria, **Weather**, 40, p. 316

Ologe, K.O (1986) A general and hypothetical note on sediment yield in Nigeria, **Journal of the West Africa Science Association**

Ologe, K.O. (1971) "Gully Development in the Zaria Area, Northern Nigeria (with particular reference to the Kubanni basin)." **Unpublished Ph.D Thesis**, University of Liverpool.

Ologe, K.O. (1972) "Some Aspects of the Problem of Modern Gully Erosion in the Northern States of Nigeria." Paper Presented at the Hydrological Technical Committee Symposium on Hydrology in Water Resources Development, Nigeria, A.B.U., Zaria.

Ologe, K.O. (1973a) "Soil Erosion, Sediment Yield and Water Resources Development in Savanna areas of Nigeria." Paper presented at the Conference on Environmental Resources Management in Nigeria, University of Ife, Ile-Ife.

Ologe, K.O. (1973b) Kubanni dam, **Savanna**, 2(1), pp. 68-74.

Ololobou, Y.P.S. (1982) "Some Aspects of River Channel Morphology in the Zaria Area of Northern Nigeria. **Unpublished Ph.D Thesis**, Dept of Geography, A.B.U Zaria.

Onodera, T. (1957) Studies of erosion in Japan, **Proceeding of the Int. Assoc. Sci Hydrol Gen. Assembly, Toronto**, 43, 1, 302-21

Osterkamp, W.R., Emmett, W.W. and Leopold, L.B. (1991) The vigil network- A means of observing landscape change in drainage basins. **Hydrological Sciences Journal**, 36, pp.331-44.

Otun, J.A. and Adeogun, B.K. (2010) Analysis of Fluvial Sediment Discharges into Kubanni Reservoir. **Nigerian Journal of Technology**. 29(2), pp. 64-75.

Owonubi, J.J. and Olorunju, S.A.S. (1985) The relationship of the of first rain and beginning of the growing season to annual rainfall at Samaru, Nigeria. **Samaru Journal of Agricultural Research**, 3(1 and 2), pp. 3-8.

Oyebande, B.L. (1981) Sediment Transport and River Basin Management in Nigeria, (Cited by Ayoade, J. O. 1988 **Tropical Hydrology and Water Resources**). London: Macmillan Publishers Ltd. pp. 198-201.

Oyebande, B.L. and Martins, O. (1978) Effects of Erosion on Water Quality and Sedimentation in Predicting Rainfall Erosion Losses: A Guide to Conservation Planning, **U.S.D.A Agricultural Handbook**. No. S37, Pg. 230.

Oyegun, C.U. and Ede, P.N. (2005) "Land-use and sediment yield in Port-Harcourt" Paper Presented at the 47th Annual Conference of the Nigerian Geographical Association, University of Port-Harcourt, Rivers State.

Painter, R.B. (1976) Sediment, In Rodda, J. C. (ed.) 1976: **Facets in Hydrology**. London: John Wiley & Sons. pp. 163-198.

Parsons, D.A. (1955) Coschocton-Type runoff samplers, **U.S. Agricultural Research Service Publication**, ARS 41-2.

Peltier, L.C. (1950) The geographic cycle in periglacial regions as it is related to climatic geomorphology. **Annals of Association of American Geographers**, 40, pp.214-36.

Phillip, J.D. (1990) Relative importance of factors influencing fluvial soil loss at the global scale. **American Journal of Science**, 290, pp.547-68.

Pinet, P and Sourau, M. (1988) Continental erosion and large-scale relief. **Tectonics**, 7, pp. 563-582

Platt, W. S. (1971) The Effects of Logging and Road Construction on the Aquatic Habit of the South Salmon River, Idaho. **Testimony of U.S. Senate Hearing on Clear Cutting Practices on Natural Timberland**. PP. 113-115.

Pullan, R.W. (1970) The soils, soil landscapes and geomorphological evolution of a metasedimentary area in northern Nigeria, **Research Paper 6**, Department of Geography, University of Liverpool.

Rains, A.B. (1963) Grassland research in northern Nigeria, 1952-62, **Samaru Miscellaneous Paper 1**, Institute of Agricultural Research, A.B.U., Zaria. pp. 5-10

Rannie, W.F.(1978) An approach to prediction of suspended sediment rating curves. In Davidson-arnott, R. and Nicking, W. (Eds.) **Research in Fluvial Systems. Geoabsracts**, Norwich, pp.

Rawat, M.S. (2011) **Environmental Geomorphology and Watershed Management.** New Delhi: Concept Publishing Company Pvt. Ltd. Pg. 287.

Restrepo, J.D. and Syvitski, J.P.M (2006) Assessing the Effect of Natural Controls and Land Use Change on Sediment Yield in a Major Andean River: The Magdalena Drainage Basin, Colombia. **Ambio,** 35 (2), pp. 65-74.

Richards, K.S (1993) Sediment delivery and the drainage network, In Beven, K. and Kirkby. M.J. (eds), **Channel Network Hydrology**, Chichester: Wiley, pp. 221-54

Ritter, M.E. (2006) **The Physical Environment: An Introduction to Physical Geography.** London: Methuen & Co. Ltd.

Rodda, J.C. (1976) **Facets of Hydrology**. London: John Wiley and Sons, Ltd. pp. 368.

Rovery, E. (1981). Reservoir's Capacity Conservation, **Wasser, Energie, left**, 73,9, pp. 199-201

Shepherdson, I. (1965) Using Raydist for sedimentation surveys on larger reservoirs. **Proceeding of Federal Inter-Agency Sedimentation Conference, U.S.D.A. Miscellaneous Publication**, 970, pp. 869-79.

Schumm, S.A. (1963) The disparity between present rates of denudation and orogeny. **U.S. Geol. Survey Professional Paper**, 454H, 13pp.

Schumm, S.A. (1965) Quaternary Palaeohydrology, In: Wright, H.E. and Frey, D. G. (eds.), **The Quaternary of the United States**. Princeton: Princeton University Press, pp. 783 -94

Schumm, S.A. (1969) A geomorphic approach to erosion control in semi-arid regions, In: Schumm, S.A. (1977) **The Fluvial System**. London: John Wiley and Sons.

Schumm, S.A. (1977) **The Fluvial System**. London: John Wiley and Sons.

Schumm, S.A. and Lichty, R.W. (1965) Time, space and casualty in geomorphology. **American Journal of Science**, 263, pp.110-19.

Singh, K. P. and Durgunoglu, A. (1989) A new method for estimating future reservoir storage capacities. **Water Resources Bulletin**, Vol. 25, No. 2, pp. 263-274.

Singh, K. P. and Durgunoglu, A. (1990) Economic reservoir design and storage conservation by reduced sedimentation. **Journal of Water Resources Planning and Management**, ASCE, Vol. 116, No. 1, pp. 85-98.

Smith, D.I. and Stopp, P. (1978) **The River Basin: An Introduction to the Study of Hydrology**. Cambridge: Cambridge University Press. pp.85-98.

Spencer, E.W. (2003) **Earth Science: Understanding Environmental Systems**. McGraw Hill Companies, New York. pp. 387-388.

Strahler, A. and Strahler, A. (2006) **Introduction to Physical Geography**, John Wiley and Sons. Boston. 794pp.

Syvitski, J.P.M. (2002) Sediment discharge variability in Arctic rivers: implications for a warmer future. **Polar Research,** 21, pp. 323 – 330.

Syvistki, J.P.M, Peckhan, S.D., Hilberman, R. and Mulder, T. (2003). Predicting the Terrestrial Flux of Sediment to the Global Ocean: Planetary Perspective. **Sedimentation Geology**, 162, pp. 5-24

Tamene, L., Park, S., Dikau, R., Vlek, P. (2006) Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia. **Geomorphology** 76, pp. 76– 91.

Thomas, J.T., Iverson, N.R., Burkart, M.R., and Kramer, L.A. (2004) Long-term growth of a valley-bottom gully, western Iowa. **Earth Surface Process Landforms.** 29, pp. 995-1009.

Thomas, R.B. (1983) Errors in estimating suspended sediment, (Cited by Li, R (ed) **Proceedings of the D. B. Simons Symposium on Erosion and Sedimentation**). Li and Associates Inc. pp. 162-177

Thorp, M.B (1970) Landforms of Zaria, In: Mortimore, M.J. (ed.) Zaria and its Region. **Occasional paper 4**, Department of Geography, A.B.U., Zaria.

Tokarski, A. (1972) Heterogonous terrace arrangement, west of Ahmadu Bello University, Zaria **Occasional Paper 4**, Department of Geography, A.B.U., Zaria.

Tricart, J. and Cailleux, A. (1972) **Introduction to Climatic Geomorphology**. London: Longman Group Ltd.

Tukur, A.I. (2011) An Assessment of Sedimentation in Water Conveyance Canals of Kano River Irrigation Project (phase 1), Kano State, Nigeria. **The Nigerian Geographical Journal**, 7(2), pp. 98-108

U.S. Department of the Interior (1968) **Annual Report.** Bureau of Reclamation.

Ursic, S.J and Dendy, F.E. (1965) Sediment yields from small watersheds under various landuses and forest covers. **Proceeding of Federal Inter-Agency Sedimentation Conference, U.S.D.A. Miscellaneous Publication**, 970, pp. 47-52

USAID (2003) USAID Investments in Drinking Water Supply and Related Activities. **US Agency for International Development Congressional Report**, 6pp.

Vanoni, V. A. (Ed.) 1975: Sedimentation Engineering, **American Society of Civil Engineers Manual on Sedimentation**, 54, pp. 481-84.

Verstraeten, G. and Poesen, J. (2001) Factors Controlling Sediment Yield from Small Intensively Cultivated Catchments in a Temperate Humid Climate. **Geomorphology**, 40, pp.123-144.

Walling, D. E. (1971) Instrumented catchments in south-east Devon. Some relationships between catchment characteristics and catchment response. In: Gregory, K.J. and Walling, D.E. (1973) **Drainage Basin Form and Processes: A Geomorphological Approach**. London: Edward Arnold Publishers Ltd.

Walling, D.E. (1978) Suspended sediment and solute response characteristics of the River Exe, Devon, England. In: Davidson-arnott, R. and Nickling, W. (eds.) **Research in Fluvial Systems. Geoabstracts**, Norwich, pp. 169-97.

Walling, D. E. (1983) The sediment delivery problem, **Journal of Hydrology**, 65, pp. 209-37

Walling, D.E. and Gregory, K.J. (1970) The measurements of the effects of building construction on drainage basin dynamics. **Journal of Hydrology**, 11, pp.129-44.

Walling, D.E. and Kleo, A.H.A. (1979) Sediment yields of rivers in areas of low precipitation: A global view. In: The hydrology of areas of low precipitation, Proceedings of the Canberra Symposium, 1979, **IAHS-AISH Publication**, 128, pp.479-93.

Walling, D.E. and Webb, B.W. (1988) The Reliability of Rating Curve Estimates of Suspended Sediment Yield: Some Further Comments IN: Sediment Budgets. **IAHS Publication** No. 174. International Association of Hydrological Sciences, Washington, DC. pp. 337-350.

Walling, D.E. and Webb, B.W. (1992) Water quality: Physical characteristics. In: Calow, P. and Petts, G.E. (eds.) **The River's Handbook: Hydrological and Ecological Principles**. Oxford: Blackwell, pp. 48-72.

Ward, R. C. (1975) **Principles of Hydrology**. London: McGraw-Hill. Pg.2.

Wilson L. (1969) Les relations entre les processus geomorphogiques et le climate moderne comme methode de paleoclimatologie. In Ologe, K.O. (1986) A general and hypothetical note on sediment yield in Nigeria. Department of Geography, ABU, Zaria.

Wilson, L. (1973). Variation in Mean Annual Sediment Yield as a Function of Mean Annual Precipitation. **American Journal of Science**, 273, pp.335-349.

Wischmeier, W.H. and Smith, D.D. (1958) Rainfall energy and its relationship to soil loss. **Transactions of American Geophysical Union**, 39, pp.285-91.

Wischmeier, W.H. and Smith, D.D. (1978) Predicting rainfall erosion losses- A guide to conservation planning. **U.S. Department of Agriculture Handbook**, 537, Washington, DC.

Wolman, M.G. and Schick, A.P. (1967) Effects of construction on fluvial sediment: Urban and sub-urban areas of Maryland. **Water Resources Research**, 3(2), pp.451-62.

Wright, J.B. and McCurry, P. (1970) Geology of Zaria. In: Mortimore, M.J. (ed), Zaria and its Regions. **Occasional Paper 4**, Department of Geography, A.B.U., Zaria.

Young, G. (2006) **World Water Development Report**. Wilfrid Laurier University, Waterloo, Ontario.

Yusuf, F. (2011) 'An Assessment of the Rate of Siltation in Jibia Dam, Jibia, Katsina State'. **Unpublished B.Sc. Project,** Department of Geography, A.B.U, Zaria..

Yusuf, Y.O. (1999) "Normality of Daily, Pentad and Decadal Rainfall Series in Samaru, Zaria, Kaduna State." **Unpublished B.Sc. Project**, Department of Geography, A. B. U. Zaria

Yusuf, Y.O. (2006) "An Analysis of the Magnitude of Suspended Sediment Production by the Northernmost Tributary of the Kubanni River, Zaria, Kaduna State". **Unpublished M.Sc Thesis**. Department of Geography, A.B.U. Zaria.

Yusuf, Y.O. (2009) A Comparative Analysis of the Suspended and Dissolved Sediment Yield of a tributary of the Kubanni River and their Implication on the ABU Dam. **Journal of Applied Scientific Research**, 5(11). pp. 1853-1859.

Yusuf, Y.O. and Audu, S.O. (2010) An Assessment of the Current Level of Siltation of the Galma Dam, Zaria, Kaduna State. In: Ogidiolu, A., Musa, S.D. and Ifatimelin. O.O. (eds.) **Contemporary Issues in Infrastructural Development and Management in Nigeria**, Department of Geography and Planning Kogi State University, Ayingba.

Yusuf, Y.O. and Igbingie, V.O. (2010) Relationship between Discharge and Sediment Load of Stream, Zaria, Nigeria. **The Nigerian Geographical Journal**, 6(1), pp.73-88

**APPENDIX I**

Table Ia: Mean Discharge Values in $m^3/s$ for 2011-2012 using the Weir Method for the Malmo Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0001 | 0.274 | 0.081 | 0.003 | 0.018 | 0.0004 | 0.0001 | 0.0001 | 0.0001 |
| 2 | | 0.012 | 0.107 | 0.018 | 0.112 | 0.012 | 0.0004 | 0.0001 | 0.0001 | 0.0001 |
| 3 | | 0.002 | 0.036 | 0.008 | 0.138 | 0.012 | 0.0004 | 0.0001 | 0.0001 | 0.0001 |
| 4 | | 0.0008 | 0.0008 | 0.008 | 0.213 | 0.011 | 0.0004 | 0.0001 | 0.0001 | |
| 5 | | 0.0006 | 0.22 | 0.008 | 0.015 | 0.01 | 0.0004 | 0.0001 | 0.0001 | |
| 6 | | 0.0004 | 0.004 | 0.004 | 0.012 | 0.274 | 0.0004 | 0.0001 | 0.0001 | |
| 7 | | 0.0004 | 0.002 | 0.117 | 0.01 | 0.036 | 0.0004 | 0.0001 | 0.0001 | |
| 8 | | 0.102 | 0.0008 | 0.047 | 0.008 | 0.023 | 0.0004 | 0.0001 | 0.0001 | |
| 9 | | 0.009 | 0.098 | 0.023 | 0.008 | 0.015 | 0.0004 | 0.0001 | 0.0001 | |
| 10 | | 0.001 | 0.044 | 0.012 | 0.008 | 0.012 | 0.0004 | 0.0001 | 0.0001 | |
| 11 | | 0.0002 | 0.01 | 0.006 | 0.008 | 0.012 | 0.0004 | 0.0001 | 0.0001 | |
| 12 | | 0.0001 | 0.001 | 0.117 | 0.008 | 0.012 | 0.0004 | 0.0001 | 0.0001 | |
| 13 | 0.081 | 0.0001 | 0.0008 | 0.102 | 0.008 | 0.01 | 0.0004 | 0.0001 | 0.0001 | |
| 14 | 0.022 | | 0.0004 | 0.044 | 0.004 | 0.01 | 0.0004 | 0.0001 | 0.0001 | |
| 15 | | | 0.0004 | 0.027 | 0.004 | 0.01 | 0.0004 | 0.0001 | 0.0001 | |
| 16 | | | 0.0004 | 0.015 | 0.213 | 0.01 | 0.0004 | 0.0001 | 0.0001 | |
| 17 | | 0.018 | 0.0004 | 0.012 | 0.023 | 0.009 | 0.0004 | 0.0001 | 0.0001 | |
| 18 | | 0.015 | 0.0004 | 0.364 | 0.012 | 0.008 | 0.0004 | 0.0001 | 0.0001 | |
| 19 | | 0.002 | 0.0001 | 0.053 | 0.274 | 0.008 | 0.0004 | 0.0001 | 0.0001 | |
| 20 | | 0.0004 | 0.274 | 0.032 | 0.025 | 0.008 | 0.0004 | 0.0001 | 0.0001 | |
| 21 | | 0.0001 | 0.036 | 0.014 | 0.015 | 0.008 | 0.0004 | 0.0001 | 0.0001 | |
| 22 | | | 0.01 | 0.01 | 0.138 | 0.003 | 0.0004 | 0.0001 | 0.0001 | |
| 23 | | | 0.003 | 0.127 | 0.036 | 0.003 | 0.0004 | 0.0001 | 0.0001 | |
| 24 | 0.081 | | 0.002 | 0.053 | 0.012 | 0.001 | 0.0002 | 0.0001 | 0.0001 | |
| 25 | 0.007 | | 0.002 | 0.023 | 0.011 | 0.001 | 0.0001 | 0.0001 | 0.0001 | |
| 26 | 0.132 | | 0.002 | 0.012 | 0.01 | 0.001 | 0.0001 | 0.0001 | 0.0001 | |
| 27 | 0.132 | | 0.002 | 0.011 | 0.01 | 0.001 | 0.0001 | 0.0001 | 0.0001 | |
| 28 | 0.117 | | 0.001 | 0.007 | 0.008 | 0.0008 | 0.0001 | 0.0001 | 0.0001 | |
| 29 | 0.003 | | 0.001 | 0.006 | 0.127 | 0.0004 | 0.0001 | 0.0001 | 0.0001 | |
| 30 | 0.0004 | | 0.001 | 0.004 | 0.036 | 0.0004 | 0.0001 | 0.0001 | 0.0001 | |
| 31 | 0.0001 | | 0.001 | 0.003 | | 0.0004 | | 0.0001 | 0.0001 | |
| **Total** | **0.5755** | **0.1642** | **1.1355** | **1.368** | **1.509** | **0.54** | **0.01** | **0.0031** | **0.0031** | **0.0003** |

Source: Fieldwork, 2011-2012

Table Ib: Mean Discharge Values in $m^3/s$ for 2011-2012 using the Weir Method for the Tukurwa Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0002 | 0.162 | 0.269 | 0.004 | 0.019 | 0.0002 | 0.0001 | | |
| 2 | | 0.068 | 0.263 | 0.052 | 0.244 | 0.012 | 0.0002 | 0.0001 | | |
| 3 | | 0.005 | 0.016 | 0.008 | 0.123 | 0.008 | 0.0002 | 0.0001 | | |
| 4 | | 0.0008 | 0.001 | 0.012 | 0.479 | 0.007 | 0.0002 | 0.0001 | | |
| 5 | | 0.0004 | 0.331 | 0.008 | 0.037 | 0.007 | 0.0002 | 0.0001 | | |
| 6 | | 0.0002 | 0.007 | 0.354 | 0.016 | 0.546 | 0.0002 | 0.0001 | | |
| 7 | | 0.215 | 0.002 | 0.263 | 0.008 | 0.08 | 0.0002 | 0.0001 | | |
| 8 | | 0.0001 | 0.0008 | 0.065 | 0.007 | 0.028 | 0.0002 | 0.0001 | | |
| 9 | | 0.018 | 0.22 | 0.035 | 0.007 | 0.018 | 0.0002 | 0.0001 | | |
| 10 | | 0.002 | 0.018 | 0.015 | 0.004 | 0.008 | 0.0002 | | | |
| 11 | | 0.0003 | 0.004 | 0.263 | 0.004 | 0.007 | 0.0002 | | | |
| 12 | | 0.0001 | 0.001 | 0.25 | 0.004 | 0.007 | 0.0002 | | | |
| 13 | 0.035 | 0.0001 | 0.0008 | 0.123 | 0.004 | 0.007 | 0.0002 | | | |
| 14 | 0.008 | | 0.0004 | 0.037 | 0.004 | 0.007 | 0.0002 | | | |
| 15 | 0.0004 | | 0.0003 | 0.019 | 0.25 | 0.006 | 0.0001 | | | |
| 16 | | | 0.0002 | 0.008 | 0.418 | 0.006 | 0.0001 | | | |
| 17 | | 0.498 | 0.0002 | 0.004 | 0.025 | 0.004 | 0.0001 | | | |
| 18 | | 0.015 | 0.0002 | 0.409 | 0.008 | 0.004 | 0.0001 | | | |
| 19 | | 0.006 | 0.0002 | 0.052 | 0.435 | 0.004 | 0.0001 | | | |
| 20 | | 0.0008 | 0.706 | 0.016 | 0.03 | 0.004 | 0.0001 | | | |
| 21 | | 0.0002 | 0.115 | 0.007 | 0.018 | 0.004 | 0.0001 | | | |
| 22 | | 0.0002 | 0.035 | 0.25 | 0.276 | 0.002 | 0.0001 | | | |
| 23 | | | 0.022 | 0.25 | 0.123 | 0.001 | 0.0001 | | | |
| 24 | 0.193 | | 0.009 | 0.158 | 0.048 | 0.0008 | 0.0001 | | | |
| 25 | 0.009 | | 0.009 | 0.045 | 0.015 | 0.0008 | 0.0001 | | | |
| 26 | 0.269 | | 0.007 | 0.015 | 0.008 | 0.0004 | 0.0001 | | | |
| 27 | 0.339 | | 0.006 | 0.01 | 0.007 | 0.0004 | 0.0001 | | | |
| 28 | 0.256 | | 0.004 | 0.008 | 0.006 | 0.0004 | 0.0001 | | | |
| 29 | 0.007 | | 0.004 | 0.004 | 0.256 | 0.0004 | 0.0001 | | | |
| 30 | 0.0008 | | 0.004 | 0.004 | 0.119 | 0.0002 | 0.0001 | | | |
| 31 | 0.0004 | | 0.131 | 0.004 | | 0.0002 | | | | |
| **Total** | **1.1176** | **0.8304** | **2.0801** | **3.017** | **2.987** | **0.7996** | **0.0044** | **0.0009** | | |

Source: Fieldwork, 2011-2012

Table Ic: Mean Discharge Values in $m^3/s$ for 2011-2012 using the Weir Method for the Maigamo Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0066 | 2.2165 | 5.5531 | 0.0024 | 1.6736 | 0.0045 | | | |
| 2 | | 0.0819 | 4.0673 | 0.4302 | 2.1686 | 0.8828 | 0.0044 | | | |
| 3 | | 0.1295 | 0.2496 | 0.2205 | 5.6878 | 0.4576 | 0.0041 | | | |
| 4 | | 0.0673 | 0.0449 | 0.1455 | 9.3806 | 0.2777 | 0.0038 | | | |
| 5 | | 0.0353 | 6.5314 | 0.0853 | 0.656 | 0.219 | 0.0017 | | | |
| 6 | | 0.0055 | 0.1154 | 0.0673 | 0.3078 | 16.575 | 0.0016 | | | |
| 7 | | 0.0052 | 0.0449 | 2.5184 | 0.149 | 4.52 | 0.0014 | | | |
| 8 | | 4.3966 | 0.0288 | 1.4565 | 0.1235 | 0.9139 | 0.0012 | | | |
| 9 | | 0.0932 | 2.1959 | 0.4689 | 0.1293 | 0.3552 | 0.0012 | | | |
| 10 | | 0.0283 | 0.4844 | 0.1812 | 0.1001 | 3.9056 | 0.001 | | | |
| 11 | | 0.0045 | 0.1553 | 0.1167 | 0.1055 | 10.617 | 0.0009 | | | |
| 12 | | | 0.0768 | 2.8844 | 0.0992 | 2.1855 | 0.0008 | | | |
| 13 | 0.7302 | | 0.0555 | 5.989 | 0.0796 | 0.7377 | 0.0007 | | | |
| 14 | 0.0889 | | 0.0271 | 1.4637 | 0.0569 | 0.3508 | 0.0006 | | | |
| 15 | | | 0.0335 | 0.4875 | 0.0414 | 0.1708 | 0.0006 | | | |
| 16 | | | 0.0209 | 0.2444 | 10.7401 | 0.1436 | 0.0006 | | | |
| 17 | | 9.5147 | 0.0223 | 0.1239 | 1.4846 | 0.0966 | 0.0006 | | | |
| 18 | | 0.0407 | 0.0191 | 17.8341 | 0.6066 | 0.1108 | 0.0006 | | | |
| 19 | | 0.0318 | 0.0145 | 1.6448 | 10.0017 | 0.0473 | 0.0005 | | | |
| 20 | | 0.0076 | 13.2125 | 0.4421 | 1.0793 | 0.0438 | 0.0005 | | | |
| 21 | | | 1.7592 | 0.1733 | 0.7359 | 0.0219 | 0.0005 | | | |
| 22 | | | 0.4775 | 0.0763 | 0.3454 | 0.0197 | 0.0005 | | | |
| 23 | | | 0.2359 | 2.2673 | 3.2151 | 0.0129 | 0.0005 | | | |
| 24 | 3.825 | | 0.199 | 2.0334 | 0.5372 | 0.0121 | 0.0005 | | | |
| 25 | 0.1766 | | 0.1631 | 0.4663 | 0.2644 | 0.0111 | 0.0004 | | | |
| 26 | 2.6573 | | 0.1583 | 0.1446 | 0.1898 | 0.0107 | 0.0004 | | | |
| 27 | 3.1839 | | 0.1284 | 0.1035 | 0.1281 | 0.0063 | 0.0004 | | | |
| 28 | 3.2343 | | 0.1096 | 0.0872 | 0.1227 | 0.0058 | 0.0003 | | | |
| 29 | 0.0772 | | 0.0999 | 0.0573 | 2.7618 | 0.0054 | | | | |
| 30 | 0.022 | | 0.07 | 0.0444 | 3.278 | 0.005 | | | | |
| 31 | 0.0081 | | 0.0555 | 0.0271 | | 0.0047 | | | | |
| **Total** | **14.0035** | **14.449** | **33.073** | **47.838** | **54.578** | **44.4** | **0.0348** | | | |

Source: Fieldwork, 2011-2012

Table Id: Mean Discharge Values in $m^3/s$ for 2011-2012 using the Weir Method for the Goruba Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0223 | 4.8981 | 3.2889 | 0.0555 | 1.8806 | 0.004 | | | |
| 2 | | 0.0048 | 7.2863 | 0.7102 | 4.1066 | 0.6113 | 0.0038 | | | |
| 3 | | 0.0032 | 0.3224 | 0.3631 | 3.6001 | 0.3111 | 0.0037 | | | |
| 4 | | 0.0028 | 0.0357 | 0.1466 | 14.813 | 0.217 | 0.0018 | | | |
| 5 | | 0.0026 | 4.2733 | 0.1269 | 1.1924 | 0.1782 | 0.0017 | | | |
| 6 | | | 0.1226 | 0.1033 | 0.3918 | 21.0885 | 0.0016 | | | |
| 7 | | | 0.0255 | 5.7397 | 0.2175 | 4.5234 | 0.0015 | | | |
| 8 | | 5.2845 | 0.0109 | 0.7815 | 0.1612 | 1.4581 | 0.0013 | | | |
| 9 | | 0.3446 | 2.2186 | 0.2706 | 0.1497 | 0.4769 | 0.0012 | | | |
| 10 | | 0.0513 | 0.5069 | 0.1607 | 0.14 | 4.9027 | 0.0012 | | | |
| 11 | | 0.0086 | 0.0636 | 0.0733 | 0.1369 | 1.8539 | 0.0011 | | | |
| 12 | | 0.0077 | 0.0221 | 0.0605 | 0.0936 | 0.7126 | 0.001 | | | |
| 13 | 1.2892 | | 0.014 | 4.519 | 0.091 | 0.3676 | 0.001 | | | |
| 14 | | | 0.0072 | 1.4072 | 0.0641 | 0.2523 | 0.0009 | | | |
| 15 | | | 0.0041 | 0.7256 | 0.0546 | 0.1896 | 0.0009 | | | |
| 16 | | | 0.0045 | 0.4889 | 14.1418 | 0.1683 | 0.0009 | | | |
| 17 | | 19.9988 | 0.0041 | 0.2085 | 1.0724 | 0.1202 | 0.0008 | | | |
| 18 | | 0.7997 | 0.0034 | 22.2786 | 0.4176 | 0.0958 | 0.0008 | | | |
| 19 | | 0.0588 | 0.0028 | 2.5573 | 11.2792 | 0.0585 | 0.0008 | | | |
| 20 | | 0.0597 | 20.8294 | 0.5939 | 0.616 | 0.0329 | 0.0007 | | | |
| 21 | | 0.0143 | 1.6475 | 0.3054 | 0.3488 | 0.0185 | 0.0007 | | | |
| 22 | | 0.0034 | 0.275 | 0.1661 | 5.3111 | 0.0162 | 0.0007 | | | |
| 23 | | | 0.0909 | 4.5758 | 1.955 | 0.0122 | 0.0007 | | | |
| 24 | 3.91 | | 0.0152 | 6.3308 | 0.7567 | 0.009 | 0.0006 | | | |
| 25 | 0.3506 | | 0.0142 | 0.9283 | 0.3112 | 0.0084 | 0.0006 | | | |
| 26 | 3.8054 | | 0.013 | 0.4102 | 0.2468 | 0.0052 | 0.0005 | | | |
| | 4.7105 | | 0.0126 | 0.2397 | 0.1779 | 0.005 | 0.0004 | | | |
| 27 | | | | | | | | | | |
| 28 | 4.7182 | | 0.011 | 0.1541 | 0.1252 | 0.0048 | | | | |
| 29 | 0.0717 | | 0.0114 | 0.1101 | 4.8009 | 0.0046 | | | | |
| 30 | 0.0283 | | 0.0098 | 0.0995 | 5.2561 | 0.0046 | | | | |
| 31 | 0.0138 | | 0.008 | 0.0481 | | 0.0041 | | | | |
| **Total** | **18.8977** | **26.6671** | **42.764** | **57.972** | **72.084** | **39.592** | **0.0349** | | | |

Source: Fieldwork, 2011-2012

APPENDIX II

Table IIa Instantaneous Suspended Sediment Concentration for Malmo Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2216 | 376 | | | | | | |
| 2 | | 316 | 1124 | | 492 | | | | | |
| 3 | | | | | 1200 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 456 | | | | | | | |
| 6 | | | | | | 396 | | | | |
| 7 | | | | 1340 | | | | | | |
| 8 | | 256 | | | | | | | | |
| 9 | | | 180 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 360 | | | | | | |
| 13 | 544 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 260 | | | | | |
| 17 | | 544 | | | | | | | | |
| 18 | | | | 1000 | | | | | | |
| 19 | | | | | 304 | | | | | |
| 20 | | | 476 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 540 | | | | | |
| 23 | | | | 724 | | | | | | |
| 24 | 1168 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 600 | | | | | | | | | |
| 27 | 780 | | | | | | | | | |
| 28 | 556 | | | | | | | | | |
| 29 | | | | | 320 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **3648** | **1116** | **4452** | **3800** | **3116** | **396** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IIb Instantaneous Total Dissolved Solids for Malmo Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 120 | 600 | | | | | | |
| 2 | | 400 | 400 | | 400 | | | | | |
| 3 | | | | | 200 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 160 | | | | | | | |
| 6 | | | | | | 200 | | | | |
| 7 | | | | 80 | | | | | | |
| 8 | | 200 | | | | | | | | |
| 9 | | | 200 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 80 | | | | | | |
| 13 | 200 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 120 | | | | | |
| 17 | | 80 | | | | | | | | |
| 18 | | | | 120 | | | | | | |
| 19 | | | | | 400 | | | | | |
| 20 | | | 80 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 80 | | | | | |
| 23 | | | | 240 | | | | | | |
| 24 | 400 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 200 | | | | | | | | | |
| 27 | 80 | | | | | | | | | |
| 28 | 200 | | | | | | | | | |
| 29 | | | | | 400 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **1080** | **680** | **960** | **1120** | **1600** | **200** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IIc Instantaneous Suspended Sediment Concentration for Tukurwa Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1620 | 292 | | | | | | |
| 2 | | 560 | 1680 | | 388 | | | | | |
| 3 | | | | | 136 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 896 | | | | | | | |
| 6 | | | | | | 228 | | | | |
| 7 | | | | 560 | | | | | | |
| 8 | | 160 | | | | | | | | |
| 9 | | | 628 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 296 | | | | | | |
| 13 | 2748 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 180 | | | | | |
| 17 | | 480 | | | | | | | | |
| 18 | | | | 864 | | | | | | |
| 19 | | | | | 344 | | | | | |
| 20 | | | 360 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 240 | | | | | |
| 23 | | | | 608 | | | | | | |
| 24 | 544 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 860 | | | | | | | | | |
| 27 | 760 | | | | | | | | | |
| 28 | 900 | | | | | | | | | |
| 29 | | | | | 120 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **5812** | **1200** | **5184** | **2620** | **1408** | **228** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IId Instantaneous Total Dissolved Solids for Tukurwa Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 600 | 400 | | | | | | |
| 2 | | 80 | 80 | | 400 | | | | | |
| 3 | | | | | 80 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 800 | | | | | | | |
| 6 | | | | | | 400 | | | | |
| 7 | | | | 800 | | | | | | |
| 8 | | 400 | | | | | | | | |
| 9 | | | 480 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 80 | | | | | | |
| 13 | 400 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 400 | | | | | |
| 17 | | 200 | | | | | | | | |
| 18 | | | | 200 | | | | | | |
| 19 | | | | | 400 | | | | | |
| 20 | | | 160 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 200 | | | | | |
| 23 | | | | 80 | | | | | | |
| 24 | 200 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 400 | | | | | | | | | |
| 27 | 400 | | | | | | | | | |
| 28 | 80 | | | | | | | | | |
| 29 | | | | | 400 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **1480** | **680** | **2120** | **1560** | **1880** | **400** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IIe Instantaneous Suspended Sediment Concentration for Maigamo Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1756 | 272 | | | | | | |
| 2 | | 1480 | 1480 | | 360 | | | | | |
| 3 | | | | | 1040 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 1716 | | | | | | | |
| 6 | | | | | | 232 | | | | |
| 7 | | | | 784 | | | | | | |
| 8 | | 600 | | | | | | | | |
| 9 | | | 600 | | | | | | | |
| 10 | | | | | | 104 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 460 | | | | | | |
| 13 | 780 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 276 | | | | | |
| 17 | | 3480 | | | | | | | | |
| 18 | | | | 536 | | | | | | |
| 19 | | | | | 292 | | | | | |
| 20 | | | 852 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 220 | | | | | |
| 23 | | | | 660 | | | | | | |
| 24 | 888 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 2360 | | | | | | | | | |
| 27 | 1020 | | | | | | | | | |
| 28 | 6964 | | | | | | | | | |
| 29 | | | | | 172 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **12012** | **5560** | **6404** | **2712** | **2360** | **336** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IIf Instantaneous Total Dissolved Solids for Maigamo Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 120 | 200 | | | | | | |
| 2 | | 200 | 80 | | 320 | | | | | |
| 3 | | | | | 320 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 320 | | | | | | | |
| 6 | | | | | | 80 | | | | |
| 7 | | | | 440 | | | | | | |
| 8 | | 320 | | | | | | | | |
| 9 | | | 800 | | | | | | | |
| 10 | | | | | | 80 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 400 | | | | | | |
| 13 | 520 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 120 | | | | | |
| 17 | | 80 | | | | | | | | |
| 18 | | | | 80 | | | | | | |
| 19 | | | | | 400 | | | | | |
| 20 | | | 400 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 200 | | | | | |
| 23 | | | | 120 | | | | | | |
| 24 | 80 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 400 | | | | | | | | | |
| 27 | 80 | | | | | | | | | |
| 28 | 400 | | | | | | | | | |
| 29 | | | | | 400 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **1480** | **600** | **1720** | **1240** | **1760** | **160** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IIg Instantaneous Suspended Sediment Concentration for Goruba Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1388 | 192 | | | | | | |
| 2 | | 2776 | 1868 | | 240 | | | | | |
| 3 | | | | | 1340 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 980 | | | | | | | |
| 6 | | | | | | 260 | | | | |
| 7 | | | | 280 | | | | | | |
| 8 | | 564 | | | | | | | | |
| 9 | | | 528 | | | | | | | |
| 10 | | | | | | 68 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 320 | | | | | | |
| 13 | 636 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 256 | | | | | |
| 17 | | 4892 | | | | | | | | |
| 18 | | | | 296 | | | | | | |
| 19 | | | | | 276 | | | | | |
| 20 | | | 648 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 540 | | | | | |
| 23 | | | | 500 | | | | | | |
| 24 | 868 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 1804 | | | | | | | | | |
| 27 | 900 | | | | | | | | | |
| 28 | 4984 | | | | | | | | | |
| 29 | | | | | 160 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **9192** | **8232** | **5412** | **1588** | **2812** | **328** | | | | |

Source: Laboratory Analysis, 2011-2012

Table IIh Instantaneous Total Dissolved Solids for Goruba Stream in mg/l

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 200 | 200 | | | | | | |
| 2 | | 200 | 400 | | 400 | | | | | |
| 3 | | | | | 800 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 200 | | | | | | | |
| 6 | | | | | | 800 | | | | |
| 7 | | | | 400 | | | | | | |
| 8 | | 400 | | | | | | | | |
| 9 | | | 400 | | | | | | | |
| 10 | | | | | | 400 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 200 | | | | | | |
| 13 | 400 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 400 | | | | | |
| 17 | | 800 | | | | | | | | |
| 18 | | | | 400 | | | | | | |
| 19 | | | | | 800 | | | | | |
| 20 | | | 200 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 400 | | | | | |
| 23 | | | | 200 | | | | | | |
| 24 | 400 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 200 | | | | | | | | | |
| 27 | 400 | | | | | | | | | |
| 28 | 200 | | | | | | | | | |
| 29 | | | | | 800 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **1600** | **1400** | **1400** | **1400** | **3600** | **1200** | | | | |

Source: Laboratory Analysis, 2011-2012

APPENDIX III

Table IIIa Instantaneous Suspended Sediment Load for Malmo Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 607.184 | 30.456 | | | | | | |
| 2 | | 3.792 | 120.268 | | 55.104 | | | | | |
| 3 | | | | | 165.6 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 100.32 | | | | | | | |
| 6 | | | | | | 108.504 | | | | |
| 7 | | | | 156.78 | | | | | | |
| 8 | | 26.112 | | | | | | | | |
| 9 | | | 17.64 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 42.12 | | | | | | |
| 13 | 44.06 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 55.38 | | | | | |
| 17 | | 9.792 | | | | | | | | |
| 18 | | | | 364 | | | | | | |
| 19 | | | | | 83.296 | | | | | |
| 20 | | | 130.424 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 74.52 | | | | | |
| 23 | | | | 91.948 | | | | | | |
| 24 | 94.61 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 79.2 | | | | | | | | | |
| 27 | 102.96 | | | | | | | | | |
| 28 | 65.052 | | | | | | | | | |
| 29 | | | | | 40.64 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| Total | 385.882 | 39.696 | 975.836 | 685.304 | 474.54 | 108.504 | | | | |

Source: Data Analysis, 2011-2012

Table IIIb Instantaneous Dissolved Load for Malmo Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 32.88 | 48.6 | | | | | | |
| 2 | | 4.8 | 42.8 | | 44.8 | | | | | |
| 3 | | | | | 27.6 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 35.2 | | | | | | | |
| 6 | | | | | | 54.8 | | | | |
| 7 | | | | 9.36 | | | | | | |
| 8 | | 20.4 | | | | | | | | |
| 9 | | | 19.6 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 9.36 | | | | | | |
| 13 | 16.2 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 25.56 | | | | | |
| 17 | | 1.44 | | | | | | | | |
| 18 | | | | 43.68 | | | | | | |
| 19 | | | | | 109.6 | | | | | |
| 20 | | | 21.92 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 11.04 | | | | | |
| 23 | | | | 30.48 | | | | | | |
| 24 | 32.4 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 26.4 | | | | | | | | | |
| 27 | 10.56 | | | | | | | | | |
| 28 | 23.4 | | | | | | | | | |
| 29 | | | | | 50.8 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **108.96** | **26.64** | **152.4** | **141.48** | **269.4** | **54.8** | | | | |

Source: Data Analysis, 2011-2012

Table IIIc Instantaneous Suspended Sediment Load for Tukurwa Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 262.44 | 78.548 | | | | | | |
| 2 | | 38.08 | 441.84 | | 94.672 | | | | | |
| 3 | | | | | 16.728 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 296.576 | | | | | | | |
| 6 | | | | | | 124.488 | | | | |
| 7 | | | | 147.28 | | | | | | |
| 8 | | 0.016 | | | | | | | | |
| 9 | | | 138.16 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 74 | | | | | | |
| 13 | 96.18 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 75.24 | | | | | |
| 17 | | 239.04 | | | | | | | | |
| 18 | | | | 353.376 | | | | | | |
| 19 | | | | | 149.64 | | | | | |
| 20 | | | 254.16 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 66.24 | | | | | |
| 23 | | | | 152 | | | | | | |
| 24 | 104.99 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 231.34 | | | | | | | | | |
| 27 | 257.64 | | | | | | | | | |
| 28 | 230.4 | | | | | | | | | |
| 29 | | | | | 30.72 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **920.55** | **277.136** | **1393.176** | **805.204** | **433.24** | **124.488** | | | | |

Source: Data Analysis, 2011-2012

Table IIId Instantaneous Dissolved Load for Tukurwa Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 97.2 | 107.6 | | | | | | |
| 2 | | 5.44 | 21.04 | | 97.6 | | | | | |
| 3 | | | | | 9.84 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 264.8 | | | | | | | |
| 6 | | | | | | 218.4 | | | | |
| 7 | | | | 210.4 | | | | | | |
| 8 | | 0.04 | | | | | | | | |
| 9 | | | 105.6 | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 20 | | | | | | |
| 13 | 14 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 167.2 | | | | | |
| 17 | | 99.6 | | | | | | | | |
| 18 | | | | 81.8 | | | | | | |
| 19 | | | | | 174 | | | | | |
| 20 | | | 112.96 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 55.2 | | | | | |
| 23 | | | | 20 | | | | | | |
| 24 | 38.6 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 107.6 | | | | | | | | | |
| 27 | 135.6 | | | | | | | | | |
| 28 | 20.48 | | | | | | | | | |
| 29 | | | | | 102.4 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **316.28** | **105.08** | **601.6** | **439.8** | **606.24** | **218.4** | | | | |

Source: Data Analysis, 2011-2012

Table IIIe Instantaneous Suspended Sediment Load for Maigamo Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 3892.174 | 1510.443 | | | | | | |
| 2 | | 121.212 | 6019.604 | | 780.696 | | | | | |
| 3 | | | | | 5915.312 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 11207.88 | | | | | | | |
| 6 | | | | | | 3845.4 | | | | |
| 7 | | | | 1974.426 | | | | | | |
| 8 | | 2637.96 | | | | | | | | |
| 9 | | | 1317.54 | | | | | | | |
| 10 | | | | | | 406.182 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 1326.824 | | | | | | |
| 13 | 569.56 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 2964.268 | | | | | |
| 17 | | 33111.16 | | | | | | | | |
| 18 | | | | 9559.078 | | | | | | |
| 19 | | | | | 2920.496 | | | | | |
| 20 | | | 11257.05 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 75.988 | | | | | |
| 23 | | | | 1496.418 | | | | | | |
| 24 | 3396.6 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 6271.228 | | | | | | | | | |
| 27 | 3247.578 | | | | | | | | | |
| 28 | 22523.67 | | | | | | | | | |
| 29 | | | | | 475.03 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **36008.64** | **35870.33** | **33694.25** | **15867.188** | **13131.79** | **4251.582** | | | | |

Source: Data Analysis, 2011-2012

Table IIIf Instantaneous Dissolved Load for Maigamo Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 265.98 | 1110.62 | | | | | | |
| 2 | | 16.38 | 325.384 | | 693.952 | | | | | |
| 3 | | | | | 1820.096 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 2090.048 | | | | | | | |
| 6 | | | | | | 1326 | | | | |
| 7 | | | | 1108.096 | | | | | | |
| 8 | | 1406.912 | | | | | | | | |
| 9 | | | 1756.72 | | | | | | | |
| 10 | | | | | | 312.448 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 1153.76 | | | | | | |
| 13 | 379.7 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 1288.812 | | | | | |
| 17 | | 761.176 | | | | | | | | |
| 18 | | | | 1426.728 | | | | | | |
| 19 | | | | | 4000.68 | | | | | |
| 20 | | | 5285 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 69.08 | | | | | |
| 23 | | | | 272.076 | | | | | | |
| 24 | 306 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 1062.92 | | | | | | | | | |
| 27 | 254.712 | | | | | | | | | |
| 28 | 1293.72 | | | | | | | | | |
| 29 | | | | | 1104.72 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **3297.05** | **2184.468** | **9723.132** | **5071.28** | **8977.34** | **1638.45** | | | | |

Source: Data Analysis, 2011-2012

Table IIIg Instantaneous Suspended Sediment Load for Goruba Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 6798.563 | 631.4688 | | | | | | |
| 2 | | 13.3248 | 13610.81 | | 985.584 | | | | | |
| 3 | | | | | 4824.134 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 4187.834 | | | | | | | |
| 6 | | | | | | 5483.01 | | | | |
| 7 | | | | 1607.116 | | | | | | |
| 8 | | 5960.916 | | | | | | | | |
| 9 | | | 1171.421 | | | | | | | |
| 10 | | | | | | 333.3836 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 19.36 | | | | | | |
| 13 | 819.93 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 3620.3008 | | | | | |
| 17 | | 97834.13 | | | | | | | | |
| 18 | | | | 6594.4656 | | | | | | |
| 19 | | | | | 3113.0592 | | | | | |
| 20 | | | 13497.45 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 2867.994 | | | | | |
| 23 | | | | 2287.9 | | | | | | |
| 24 | 3393.88 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 6864.942 | | | | | | | | | |
| 27 | 4239.45 | | | | | | | | | |
| 28 | 23515.51 | | | | | | | | | |
| 29 | | | | | 768.144 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **38833.71** | **103808.4** | **39266.08** | **11140.31** | **16179.216** | **5816.394** | | | | |

Source: Data Analysis, 2011-2012

Table IIIh Instantaneous Dissolved Load for Goruba Stream in mg/s

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 979.62 | 657.78 | | | | | | |
| 2 | | 0.96 | 2914.52 | | 1642.64 | | | | | |
| 3 | | | | | 2880.08 | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | 854.66 | | | | | | | |
| 6 | | | | | | 16870.8 | | | | |
| 7 | | | | 2295.88 | | | | | | |
| 8 | | 4227.6 | | | | | | | | |
| 9 | | | 887.44 | | | | | | | |
| 10 | | | | | | 1961.08 | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | 12.1 | | | | | | |
| 13 | 515.68 | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | 5656.72 | | | | | |
| 17 | | 15999.04 | | | | | | | | |
| 18 | | | | 8911.44 | | | | | | |
| 19 | | | | | 9023.36 | | | | | |
| 20 | | | 4165.88 | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | 2124.44 | | | | | |
| 23 | | | | 915.16 | | | | | | |
| 24 | 1564 | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | 761.08 | | | | | | | | | |
| 27 | 1884.2 | | | | | | | | | |
| 28 | 943.64 | | | | | | | | | |
| 29 | | | | | 3840.72 | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| **Total** | **5668.6** | **20227.6** | **9802.12** | **12792.36** | **25167.96** | **18831.9** | | | | |

Source: Data Analysis, 2011-2012

APPENDIX IV

Table IVa Derived Daily Suspended Sediment Load for Malmo Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0138 | 171.14 | 40.087 | 0.7911 | 6.6839 | 0.0718 | 0.0138 | 0.0138 | 0.0138 |
| 2 | | 4.1239 | 55.847 | 6.6839 | 58.968 | 4.1239 | 0.0718 | 0.0138 | 0.0138 | 0.0138 |
| 3 | | 0.4881 | 15.26 | 2.5444 | 75.613 | 4.1239 | 0.0718 | 0.0138 | 0.0138 | 0.0138 |
| 4 | | 0.1639 | 0.1639 | 2.5444 | 126.79 | 3.7179 | 0.0718 | 0.0138 | 0.0138 | |
| 5 | | 0.1164 | 131.77 | 2.5444 | 5.3793 | 3.3189 | 0.0718 | 0.0138 | 0.0138 | |
| 6 | | 0.0718 | 1.1144 | 1.1144 | 4.1239 | 171.14 | 0.0718 | 0.0138 | 0.0138 | |
| 7 | | 0.0718 | 0.4881 | 62.117 | 3.3189 | 15.26 | 0.0718 | 0.0138 | 0.0138 | |
| 8 | | 52.753 | 0.1639 | 20.964 | 2.5444 | 8.9499 | 0.0718 | 0.0138 | 0.0138 | |
| 9 | | 2.9275 | 50.298 | 8.9499 | 2.5444 | 5.3793 | 0.0718 | 0.0138 | 0.0138 | |
| 10 | | 0.2138 | 19.38 | 4.1239 | 2.5444 | 4.1239 | 0.0718 | 0.0138 | 0.0138 | |
| 11 | | 0.0314 | 3.3189 | 1.8063 | 2.5444 | 4.1239 | 0.0718 | 0.0138 | 0.0138 | |
| 12 | | 0.0138 | 0.2138 | 62.117 | 2.5444 | 4.1239 | 0.0718 | 0.0138 | 0.0138 | |
| 13 | 316.39 | 0.0138 | 0.1639 | 52.753 | 2.5444 | 3.3189 | 0.0718 | 0.0138 | 0.0138 | |
| 14 | 8.4884 | | 0.0718 | 19.38 | 1.1144 | 3.3189 | 0.0718 | 0.0138 | 0.0138 | |
| 15 | | | 0.0718 | 10.833 | 1.1144 | 3.3189 | 0.0718 | 0.0138 | 0.0138 | |
| 16 | | | 0.0718 | 5.3793 | 126.79 | 3.3189 | 0.0718 | 0.0138 | 0.0138 | |
| 17 | | 6.6839 | 0.0718 | 4.1239 | 8.9499 | 2.9275 | 0.0718 | 0.0138 | 0.0138 | |
| 18 | | 5.3793 | 0.0718 | 240.03 | 4.1239 | 2.5444 | 0.0718 | 0.0138 | 0.0138 | |
| 19 | | 0.4881 | 0.0138 | 24.189 | 171.14 | 2.5444 | 0.0718 | 0.0138 | 0.0138 | |
| 20 | | 0.0718 | 171.14 | 13.263 | 9.8843 | 2.5444 | 0.0718 | 0.0138 | 0.0138 | |
| 21 | | 0.0138 | 15.26 | 4.9549 | 5.3793 | 2.5444 | 0.0718 | 0.0138 | 0.0138 | |
| 22 | | | 3.3189 | 3.3189 | 75.613 | 0.7911 | 0.0718 | 0.0138 | 0.0138 | |
| 23 | | | 0.7911 | 68.491 | 15.26 | 0.7911 | 0.0718 | 0.0138 | 0.0138 | |
| 24 | 316.39 | | 0.4881 | 24.189 | 4.1239 | 0.2138 | 0.0314 | 0.0138 | 0.0138 | |
| 25 | 2.1703 | | 0.4881 | 8.9499 | 3.7179 | 0.2138 | 0.0138 | 0.0138 | 0.0138 | |
| 26 | 71.714 | | 0.4881 | 4.1239 | 3.3189 | 0.2138 | 0.0138 | 0.0138 | 0.0138 | |
| 27 | 71.714 | | 0.4881 | 3.7179 | 3.3189 | 0.2138 | 0.0138 | 0.0138 | 0.0138 | |
| 28 | 62.117 | | 0.2138 | 2.1703 | 2.5444 | 0.1639 | 0.0138 | 0.0138 | 0.0138 | |
| 29 | 0.7911 | | 0.2138 | 1.8063 | 68.491 | 0.0718 | 0.0138 | 0.0138 | 0.0138 | |
| 30 | 0.0718 | | 0.2138 | 1.1144 | 15.26 | 0.0718 | 0.0138 | 0.0138 | 0.0138 | |
| 31 | 0.0138 | | 0.2138 | 0.7911 | | 0.0718 | | 0.0138 | 0.0138 | |
| **Total** | **849.85** | **73.639** | **643.02** | **709.18** | **810.41** | **264.27** | **1.7652** | **0.4269** | **0.4269** | **0.0413** |

Source: Data Analysis, 2011-2012

Table IVb Derived Daily Dissolved Load for Malmo Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0279 | 49.118 | 15.546 | 0.6925 | 3.7582 | 0.1034 | 0.0279 | 0.0279 | 0.0279 |
| 2 | | 2.563 | 20.218 | 3.7582 | 21.109 | 2.563 | 0.1034 | 0.0279 | 0.0279 | 0.0279 |
| 3 | | 0.4723 | 7.2302 | 1.7479 | 25.707 | 2.563 | 0.1034 | 0.0279 | 0.0279 | 0.0279 |
| 4 | | 0.1989 | 0.1989 | 1.7479 | 38.725 | 2.3609 | 0.1034 | 0.0279 | 0.0279 | |
| 5 | | 0.1516 | 39.925 | 1.7479 | 3.164 | 2.1577 | 0.1034 | 0.0279 | 0.0279 | |
| 6 | | 0.1034 | 0.9085 | 0.9085 | 2.563 | 49.118 | 0.1034 | 0.0279 | 0.0279 | |
| 7 | | 0.1034 | 0.4723 | 21.997 | 2.1577 | 7.2302 | 0.1034 | 0.0279 | 0.0279 | |
| 8 | | 19.325 | 0.1989 | 9.2995 | 1.7479 | 4.7367 | 0.1034 | 0.0279 | 0.0279 | |
| 9 | | 1.9535 | 18.609 | 4.7367 | 1.7479 | 3.164 | 0.1034 | 0.0279 | 0.0279 | |
| 10 | | 0.2455 | 8.7382 | 2.563 | 1.7479 | 2.563 | 0.1034 | 0.0279 | 0.0279 | |
| 11 | | 0.0537 | 2.1577 | 1.3322 | 1.7479 | 2.563 | 0.1034 | 0.0279 | 0.0279 | |
| 12 | | 0.0279 | 0.2455 | 21.997 | 1.7479 | 2.563 | 0.1034 | 0.0279 | 0.0279 | |
| 13 | 79.938 | 0.0279 | 0.1989 | 19.325 | 1.7479 | 2.1577 | 0.1034 | 0.0279 | 0.0279 | |
| 14 | 4.542 | | 0.1034 | 8.7382 | 0.9085 | 2.1577 | 0.1034 | 0.0279 | 0.0279 | |
| 15 | | | 0.1034 | 5.5107 | 0.9085 | 2.1577 | 0.1034 | 0.0279 | 0.0279 | |
| 16 | | | 0.1034 | 3.164 | 38.725 | 2.1577 | 0.1034 | 0.0279 | 0.0279 | |
| 17 | | 3.7582 | 0.1034 | 2.563 | 4.7367 | 1.9535 | 0.1034 | 0.0279 | 0.0279 | |
| 18 | | 3.164 | 0.1034 | 64.221 | 2.563 | 1.7479 | 0.1034 | 0.0279 | 0.0279 | |
| 19 | | 0.4723 | 0.0279 | 10.416 | 49.118 | 1.7479 | 0.1034 | 0.0279 | 0.0279 | |
| 20 | | 0.1034 | 49.118 | 6.4694 | 5.1246 | 1.7479 | 0.1034 | 0.0279 | 0.0279 | |
| 21 | | 0.0279 | 7.2302 | 2.9645 | 3.164 | 1.7479 | 0.1034 | 0.0279 | 0.0279 | |
| 22 | | | 2.1577 | 2.1577 | 25.707 | 0.6925 | 0.1034 | 0.0279 | 0.0279 | |
| 23 | | | 0.6925 | 23.768 | 7.2302 | 0.6925 | 0.1034 | 0.0279 | 0.0279 | |
| 24 | 79.938 | | 0.4723 | 10.416 | 2.563 | 0.2455 | 0.0537 | 0.0279 | 0.0279 | |
| 25 | 1.5409 | | 0.4723 | 4.7367 | 2.3609 | 0.2455 | 0.0279 | 0.0279 | 0.0279 | |
| 26 | 24.65 | | 0.4723 | 2.563 | 2.1577 | 0.2455 | 0.0279 | 0.0279 | 0.0279 | |
| 27 | 24.65 | | 0.4723 | 2.3609 | 2.1577 | 0.2455 | 0.0279 | 0.0279 | 0.0279 | |
| 28 | 21.997 | | 0.2455 | 1.5409 | 1.7479 | 0.1989 | 0.0279 | 0.0279 | 0.0279 | |
| 29 | 0.6925 | | 0.2455 | 1.3322 | 23.768 | 0.1034 | 0.0279 | 0.0279 | 0.0279 | |
| 30 | 0.1034 | | 0.2455 | 0.9085 | 7.2302 | 0.1034 | 0.0279 | 0.0279 | 0.0279 | |
| 31 | 0.0279 | | 0.2455 | 0.6925 | | 0.1034 | | 0.0279 | 0.0279 | |
| **Total** | **238.08** | **32.78** | **210.83** | **261.23** | **284.78** | **105.79** | **2.5993** | **0.8649** | **0.8649** | **0.0837** |

Source: Data Analysis, 2011-2012

Table IVc Derived Daily Suspended Sediment Load for Tukurwa Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0448 | 75.781 | 133.05 | 1.2453 | 7.0213 | 0.0448 | 0.0208 | | |
| 2 | | 28.912 | 129.76 | 21.467 | 119.4 | 4.2159 | 0.0448 | 0.0208 | | |
| 3 | | 1.5954 | 5.8019 | 2.688 | 55.821 | 2.688 | 0.0448 | 0.0208 | | |
| 4 | | 0.2087 | 0.2673 | 4.2159 | 252.45 | 2.3177 | 0.0448 | 0.0208 | | |
| 5 | | 0.0967 | 167.5 | 2.688 | 14.713 | 2.3177 | 0.0448 | 0.0208 | | |
| 6 | | 0.0448 | 2.3177 | 180.47 | 5.8019 | 291.93 | 0.0448 | 0.0208 | | |
| 7 | | 103.75 | 0.577 | 129.76 | 2.688 | 34.628 | 0.0448 | 0.0208 | | |
| 8 | | 0.0208 | 0.2087 | 27.5 | 2.3177 | 10.798 | 0.0448 | 0.0208 | | |
| 9 | | 6.6123 | 106.43 | 13.833 | 2.3177 | 6.6123 | 0.0448 | 0.0208 | | |
| 10 | | 0.577 | 6.6123 | 5.4008 | 1.2453 | 2.688 | 0.0448 | | | |
| 11 | | 0.0702 | 1.2453 | 129.76 | 1.2453 | 2.3177 | 0.0448 | | | |
| 12 | | 0.0208 | 0.2673 | 122.66 | 1.2453 | 2.3177 | 0.0448 | | | |
| 13 | 94.689 | 0.0208 | 0.2087 | 55.821 | 1.2453 | 2.3177 | 0.0448 | | | |
| 14 | 2.688 | | 0.0967 | 14.713 | 1.2453 | 2.3177 | 0.0448 | | | |
| 15 | 0.0967 | | 0.0702 | 7.0213 | 122.66 | 1.9532 | 0.0208 | | | |
| 16 | | | 0.0448 | 2.688 | 217.02 | 1.9532 | 0.0208 | | | |
| 17 | | 263.59 | 0.0448 | 1.2453 | 9.5217 | 1.2453 | 0.0208 | | | |
| 18 | | 5.4008 | 0.0448 | 211.84 | 2.688 | 1.2453 | 0.0208 | | | |
| 19 | | 1.9532 | 0.0448 | 21.467 | 226.84 | 1.2453 | 0.0208 | | | |
| 20 | | 0.2087 | 388.31 | 5.8019 | 11.658 | 1.2453 | 0.0208 | | | |
| 21 | | 0.0448 | 51.805 | 2.3177 | 6.6123 | 1.2453 | 0.0208 | | | |
| 22 | | 0.0448 | 13.833 | 122.66 | 136.9 | 0.577 | 0.0208 | | | |
| 23 | | | 8.2621 | 122.66 | 55.821 | 0.2673 | 0.0208 | | | |
| 24 | 628.85 | | 3.0634 | 73.707 | 19.642 | 0.2087 | 0.0208 | | | |
| 25 | 3.0634 | | 3.0634 | 18.284 | 5.4008 | 0.2087 | 0.0208 | | | |
| 26 | 133.05 | | 2.3177 | 5.4008 | 2.688 | 0.0967 | 0.0208 | | | |
| 27 | 172 | | 1.9532 | 3.4435 | 2.3177 | 0.0967 | 0.0208 | | | |
| 28 | 125.94 | | 1.2453 | 2.688 | 1.9532 | 0.0967 | 0.0208 | | | |
| 29 | 2.3177 | | 1.2453 | 1.2453 | 125.94 | 0.0967 | 0.0208 | | | |
| 30 | 0.2087 | | 1.2453 | 1.2453 | 53.809 | 0.0448 | 0.0208 | | | |
| 31 | 0.0967 | | 59.865 | 1.2453 | | 0.0448 | | | | |
| **Total** | **1163** | **413.22** | **1033.5** | **1449** | **1464.5** | **386.36** | **0.96** | **0.1872** | | |

Source: Data Analysis, 2011-2012

Table IVd Derived Daily Dissolved Load for Tukurwa Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0.0596 | 41.371 | 67.9 | 1.1123 | 5.0973 | 0.0596 | 0.0303 | | |
| 2 | | 17.716 | 66.42 | 13.631 | 61.728 | 3.2536 | 0.0596 | 0.0303 | | |
| 3 | | 1.3832 | 4.3095 | 2.1894 | 31.611 | 2.1894 | 0.0596 | 0.0303 | | |
| 4 | | 0.2308 | 0.2871 | 3.2536 | 119.31 | 1.9216 | 0.0596 | 0.0303 | | |
| 5 | | 0.1173 | 83.152 | 2.1894 | 9.7754 | 1.9216 | 0.0596 | 0.0303 | | |
| 6 | | 0.0596 | 1.9216 | 88.793 | 4.3095 | 135.59 | 0.0596 | 0.0303 | | |
| 7 | | 54.55 | 0.5651 | 66.42 | 2.1894 | 20.764 | 0.0596 | 0.0303 | | |
| 8 | | 0.0303 | 0.2308 | 16.952 | 1.9216 | 7.4452 | 0.0596 | 0.0303 | | |
| 9 | | 4.8351 | 55.789 | 9.2588 | 1.9216 | 4.8351 | 0.0596 | 0.0303 | | |
| 10 | | 0.5651 | 4.8351 | 4.0461 | 1.1123 | 2.1894 | 0.0596 | | | |
| 11 | | 0.0885 | 1.1123 | 66.42 | 1.1123 | 1.9216 | 0.0596 | | | |
| 12 | | 0.0303 | 0.2871 | 63.21 | 1.1123 | 1.9216 | 0.0596 | | | |
| 13 | 50.332 | 0.0303 | 0.2308 | 31.611 | 1.1123 | 1.9216 | 0.0596 | | | |
| 14 | 2.1894 | | 0.1173 | 9.7754 | 1.1123 | 1.9216 | 0.0596 | | | |
| 15 | 0.1173 | | 0.0885 | 5.0973 | 63.21 | 1.6529 | 0.0303 | | | |
| 16 | | | 0.0596 | 2.1894 | 104.45 | 1.6529 | 0.0303 | | | |
| 17 | | 123.94 | 0.0596 | 1.1123 | 6.6648 | 1.1123 | 0.0303 | | | |
| 18 | | 4.0461 | 0.0596 | 102.25 | 2.1894 | 1.1123 | 0.0303 | | | |
| 19 | | 1.6529 | 0.0596 | 13.631 | 108.59 | 1.1123 | 0.0303 | | | |
| 20 | | 0.2308 | 174.29 | 4.3095 | 7.9643 | 1.1123 | 0.0303 | | | |
| 21 | | 0.0596 | 29.601 | 1.9216 | 4.8351 | 1.1123 | 0.0303 | | | |
| 22 | | 0.0596 | 9.2588 | 63.21 | 69.626 | 0.5651 | 0.0303 | | | |
| 23 | | | 5.8823 | 63.21 | 31.611 | 0.2871 | 0.0303 | | | |
| 24 | 266.42 | | 2.4564 | 40.373 | 12.601 | 0.2308 | 0.0303 | | | |
| 25 | 2.4564 | | 2.4564 | 11.836 | 4.0461 | 0.2308 | 0.0303 | | | |
| 26 | 67.9 | | 1.9216 | 4.0461 | 2.1894 | 0.1173 | 0.0303 | | | |
| 27 | 85.115 | | 1.6529 | 2.7227 | 1.9216 | 0.1173 | 0.0303 | | | |
| 28 | 64.692 | | 1.1123 | 2.1894 | 1.6529 | 0.1173 | 0.0303 | | | |
| 29 | 1.9216 | | 1.1123 | 1.1123 | 64.692 | 0.1173 | 0.0303 | | | |
| 30 | 0.2308 | | 1.1123 | 1.1123 | 30.606 | 0.0596 | 0.0303 | | | |
| 31 | 0.1173 | | 33.618 | 1.1123 | | 0.0596 | | | | |
| **Total** | **541.49** | **209.69** | **525.43** | **767.09** | **756.29** | **203.66** | **1.3192** | **0.2727** | | |

Source: Data Analysis, 2011-2012

Table IVe Derived Daily Suspended Sediment Load for Maigamo Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 7.0794 | 1591.5 | 3742.5 | 2.7604 | 1225.2 | 4.9561 | | | |
| 2 | | 73.836 | 2800.7 | 345.9 | 1559.5 | 675.46 | 4.8535 | | | |
| 3 | | 113.12 | 208.37 | 185.66 | 3827 | 366.36 | 4.5447 | | | |
| 4 | | 61.501 | 42.193 | 126.07 | 6097.4 | 230.13 | 4.234 | | | |
| 5 | | 33.727 | 4352.8 | 76.686 | 512.32 | 184.48 | 2.0024 | | | |
| 6 | | 5.9742 | 101.61 | 61.501 | 253.27 | 10359 | 1.8925 | | | |
| 7 | | 5.6702 | 42.193 | 1792.5 | 128.9 | 3089.8 | 1.6713 | | | |
| 8 | | 3011.2 | 27.906 | 1076.6 | 108.23 | 697.58 | 1.4478 | | | |
| 9 | | 83.277 | 1577.8 | 374.78 | 112.95 | 289.4 | 1.4478 | | | |
| 10 | | 27.455 | 386.3 | 154.65 | 89.003 | 2696.9 | 1.2218 | | | |
| 11 | | 4.9561 | 133.96 | 102.67 | 93.465 | 6842.4 | 1.1076 | | | |
| 12 | | | 69.546 | 2033.8 | 88.258 | 1570.8 | 0.9926 | | | |
| 13 | 1079.3 | | 51.397 | 4015.3 | 71.904 | 571.47 | 0.8766 | | | |
| 14 | 79.694 | | 26.369 | 1081.5 | 52.603 | 286.06 | 0.7594 | | | |
| 15 | | | 32.123 | 388.6 | 39.123 | 146.37 | 0.7594 | | | |
| 16 | | | 20.704 | 204.33 | 6916.2 | 124.54 | 0.7594 | | | |
| 17 | | 6178.5 | 21.992 | 108.56 | 1095.9 | 86.102 | 0.7594 | | | |
| 18 | | 38.506 | 19.039 | 11090 | 476.3 | 97.829 | 0.7594 | | | |
| 19 | | 30.603 | 14.731 | 1205.6 | 6472.5 | 44.289 | 0.6408 | | | |
| 20 | | 8.0731 | 8387.6 | 354.8 | 814.43 | 41.23 | 0.6408 | | | |
| 21 | | | 1283.5 | 148.36 | 570.18 | 21.625 | 0.6408 | | | |
| 22 | | | 381.18 | 69.124 | 281.95 | 19.595 | 0.6408 | | | |
| 23 | | | 197.7 | 1625.5 | 2250.1 | 13.212 | 0.6408 | | | |
| 24 | 5043 | | 168.75 | 1468.8 | 425.36 | 12.447 | 0.6408 | | | |
| 25 | 150.99 | | 140.22 | 372.84 | 219.85 | 11.487 | 0.5206 | | | |
| 26 | 1884.3 | | 136.37 | 125.35 | 161.47 | 11.101 | 0.5206 | | | |
| 27 | 2229.8 | | 112.22 | 91.814 | 111.98 | 6.7793 | 0.5206 | | | |
| 28 | 2262.6 | | 96.842 | 78.275 | 107.58 | 6.277 | 0.3983 | | | |
| 29 | 69.883 | | 88.837 | 52.947 | 1953.2 | 5.873 | | | | |
| 30 | 21.717 | | 63.795 | 41.756 | 2291 | 5.4669 | | | | |
| 31 | 8.5664 | | 51.397 | 26.369 | | 5.1609 | | | | |
| **Total** | **12830** | **9683.5** | **22630** | **32623** | **37185** | **29744** | **40.851** | | | |

Source: Data Analysis, 2011-2012

Table IVf Derived Daily Dissolved Load for Maigamo Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 3.6237 | 499.78 | 1088 | 1.5383 | 393.94 | 2.6198 | | | |
| 2 | | 30.588 | 835.76 | 124.66 | 490.62 | 229.16 | 2.5704 | | | |
| 3 | | 45.091 | 78.608 | 70.773 | 1110.3 | 131.35 | 2.4212 | | | |
| 4 | | 25.902 | 18.385 | 49.767 | 1696.2 | 86.042 | 2.2703 | | | |
| 5 | | 14.996 | 1248.3 | 31.66 | 178.2 | 70.365 | 1.1487 | | | |
| 6 | | 3.1052 | 40.897 | 25.902 | 93.878 | 2747.1 | 1.0912 | | | |
| 7 | | 2.9611 | 18.385 | 556.87 | 50.78 | 913.91 | 0.9745 | | | |
| 8 | | 892.73 | 12.621 | 350.21 | 43.315 | 235.98 | 0.8552 | | | |
| 9 | | 34.127 | 495.85 | 134.09 | 45.032 | 105.99 | 0.8552 | | | |
| 10 | | 12.436 | 137.84 | 59.932 | 36.255 | 807.53 | 0.7328 | | | |
| 11 | | 2.6198 | 52.592 | 41.287 | 37.905 | 1883.8 | 0.6703 | | | |
| 12 | | | 28.967 | 624.69 | 35.979 | 493.86 | 0.6066 | | | |
| 13 | 351.02 | | 22 | 1159.9 | 29.859 | 196.83 | 0.5418 | | | |
| 14 | 32.788 | | 11.987 | 351.67 | 22.469 | 104.87 | 0.4754 | | | |
| 15 | | | 14.345 | 138.58 | 17.163 | 57.006 | 0.4754 | | | |
| 16 | | | 9.6198 | 77.219 | 1902.2 | 49.216 | 0.4754 | | | |
| 17 | | 1716.7 | 10.163 | 43.434 | 355.92 | 35.178 | 0.4754 | | | |
| 18 | | 16.917 | 8.9132 | 2922.9 | 166.77 | 39.512 | 0.4754 | | | |
| 19 | | 13.726 | 7.058 | 388.19 | 1790.9 | 19.214 | 0.4074 | | | |
| 20 | | 4.0837 | 2267.1 | 127.57 | 271.69 | 18.002 | 0.4074 | | | |
| 21 | | | 410.94 | 57.712 | 196.42 | 10.008 | 0.4074 | | | |
| 22 | | | 136.17 | 28.807 | 103.5 | 9.1498 | 0.4074 | | | |
| 23 | | | 74.937 | 509.47 | 684.85 | 6.3925 | 0.4074 | | | |
| 24 | 1427.1 | | 64.883 | 464.59 | 150.46 | 6.0551 | 0.4074 | | | |
| 25 | 58.641 | | 54.821 | 133.46 | 82.538 | 5.6285 | 0.3372 | | | |
| 26 | 582.78 | | 53.452 | 49.507 | 62.333 | 5.4562 | 0.3372 | | | |
| 27 | 679.21 | | 44.767 | 37.295 | 44.678 | 3.4837 | 0.3372 | | | |
| 28 | 688.31 | | 39.149 | 32.257 | 43.078 | 3.2481 | 0.2643 | | | |
| 29 | 29.095 | | 36.194 | 22.603 | 602.13 | 3.0573 | | | | |
| 30 | 10.047 | | 26.779 | 18.211 | 696.18 | 2.8644 | | | | |
| 31 | 4.3101 | | 22 | 11.987 | | 2.7181 | | | | |
| **Total** | **3863.3** | **2819.6** | **6783.3** | **9733.2** | **11043** | **8676.9** | **23.455** | | | |

Source: Data Analysis, 2011-2012

Table IVg Derived Daily Suspended Sediment Load for Goruba Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 23.162 | 2935.3 | 2052.6 | 52.526 | 1242.6 | 4.9505 | | | |
| 2 | | 5.8312 | 4193.1 | 518.25 | 2505.6 | 452.96 | 4.7277 | | | |
| 3 | | 4.0516 | 255 | 283.73 | 2226.2 | 246.96 | 4.6158 | | | |
| 4 | | 3.5938 | 35.342 | 125.66 | 7929.4 | 178.71 | 2.4168 | | | |
| 5 | | 3.3624 | 2596.7 | 110.39 | 825.33 | 149.73 | 2.2959 | | | |
| 6 | | | 107.02 | 91.762 | 303.79 | 10889 | 2.1742 | | | |
| 7 | | | 26.126 | 3384.4 | 179.08 | 2732.8 | 2.0518 | | | |
| 8 | | 5855.8 | 12.179 | 564.74 | 136.84 | 988.74 | 1.8044 | | | |
| 9 | | 270.71 | 1441.4 | 217.89 | 128.04 | 362.43 | 1.6792 | | | |
| 10 | | 48.942 | 382.84 | 136.46 | 120.56 | 2937.7 | 1.6792 | | | |
| 11 | | 9.8442 | 59.361 | 67.432 | 118.16 | 1226.7 | 1.553 | | | |
| 12 | | 8.9139 | 22.976 | 56.757 | 83.986 | 519.82 | 1.4256 | | | |
| 13 | 1649.6 | | 15.248 | 2730.4 | 81.888 | 286.89 | 1.4256 | | | |
| 14 | | | 8.3924 | 957.69 | 59.78 | 204.61 | 1.2969 | | | |
| 15 | | | 5.0615 | 528.33 | 51.761 | 158.31 | 1.2969 | | | |
| 16 | | | 5.5028 | 370.61 | 7605.9 | 142.24 | 1.2969 | | | |
| 17 | | 10383 | 5.0615 | 172.41 | 750.34 | 105.14 | 1.1667 | | | |
| 18 | | 576.54 | 4.2783 | 11439 | 321.69 | 85.756 | 1.1667 | | | |
| 19 | | 55.322 | 3.5938 | 1637.5 | 6207.9 | 55.069 | 1.1667 | | | |
| 20 | | 56.082 | 10769 | 441.36 | 456.08 | 32.843 | 1.0349 | | | |
| 21 | | 15.542 | 1103.3 | 242.89 | 273.67 | 19.585 | 1.0349 | | | |
| 22 | | 4.2783 | 221.07 | 140.57 | 3156.6 | 17.384 | 1.0349 | | | |
| 23 | | | 81.807 | 2761.2 | 1286.6 | 13.476 | 1.0349 | | | |
| 24 | 4467.9 | | 16.417 | 3695.8 | 548.62 | 10.254 | 0.9011 | | | |
| 25 | 274.94 | | 15.444 | 659.15 | 247.03 | 9.6384 | 0.9011 | | | |
| 26 | 2339.9 | | 14.267 | 316.57 | 200.59 | 6.2657 | 0.765 | | | |
| 27 | 2834.1 | | 13.872 | 195.41 | 149.51 | 6.0489 | 0.6261 | | | |
| 28 | 2838.3 | | 12.279 | 131.42 | 109.06 | 5.8312 | | | | |
| 29 | 66.108 | | 12.68 | 97.168 | 2882.9 | 5.6125 | | | | |
| 30 | 28.688 | | 11.069 | 88.725 | 3127.2 | 5.6125 | | | | |
| 31 | 15.053 | | 9.2252 | 46.192 | | 5.0615 | | | | |
| **Total** | **14515** | **17325** | **24395** | **34263** | **42126** | **23104** | **47.523** | | | |

Source: Data Analysis, 2011-2012

Table IVh Derived Daily Dissolved Load for Goruba Stream

| Day | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 4.3392 | 1800.7 | 1153.6 | 12.026 | 617.54 | 0.6355 | | | |
| 2 | | 0.7792 | 2807.3 | 207.9 | 1478.7 | 175.81 | 0.6001 | | | |
| 3 | | 0.4952 | 85.978 | 98.2 | 1276.3 | 82.616 | 0.5824 | | | |
| 4 | | 0.4265 | 7.3432 | 35.624 | 6205.5 | 55.228 | 0.2603 | | | |
| 5 | | 0.3926 | 1545.9 | 30.316 | 371.06 | 44.311 | 0.2441 | | | |
| 6 | | | 29.17 | 24.086 | 106.92 | 9210.5 | 0.2281 | | | |
| 7 | | | 5.0409 | 2150 | 55.371 | 1647.4 | 0.2123 | | | |
| 8 | | 4254.7 | 1.9491 | 231.36 | 39.613 | 464.64 | 0.1809 | | | |
| 9 | | 92.623 | 742.88 | 70.688 | 36.467 | 133.19 | 0.1654 | | | |
| 10 | | 11.013 | 142.6 | 39.475 | 33.835 | 1802.6 | 0.1654 | | | |
| 11 | | 1.4954 | 14.004 | 16.413 | 32.999 | 607.74 | 0.1501 | | | |
| 12 | | 1.3216 | 4.2957 | 13.244 | 21.572 | 208.68 | 0.1349 | | | |
| 13 | 878.76 | | 2.5785 | 1645.7 | 20.903 | 99.561 | 0.1349 | | | |
| 14 | | | 1.226 | 446.54 | 14.128 | 65.365 | 0.1199 | | | |
| 15 | | | 0.6533 | 212.94 | 11.808 | 47.492 | 0.1199 | | | |
| 16 | | | 0.7249 | 136.95 | 5892 | 41.568 | 0.1199 | | | |
| 17 | | 8680.1 | 0.6533 | 52.815 | 329.56 | 28.532 | 0.1051 | | | |
| 18 | | 237.4 | 0.5299 | 9793.5 | 114.82 | 22.139 | 0.1051 | | | |
| 19 | | 12.828 | 0.4265 | 870.76 | 4575.6 | 12.755 | 0.1051 | | | |
| 20 | | 13.048 | 9084.1 | 170.22 | 177.32 | 6.7023 | 0.0905 | | | |
| 21 | | 2.6404 | 532.61 | 80.925 | 93.886 | 3.5213 | 0.0905 | | | |
| 22 | | 0.5299 | 71.974 | 40.961 | 1971.3 | 3.0356 | 0.0905 | | | |
| 23 | | | 20.877 | 1668.8 | 644.91 | 2.2108 | 0.0905 | | | |
| 24 | 3038.1 | | 2.8268 | 2399 | 223.17 | 1.5734 | 0.0762 | | | |
| 25 | 94.428 | | 2.6197 | 280.46 | 82.645 | 1.4566 | 0.0762 | | | |
| 26 | 1358 | | 2.3735 | 112.5 | 63.774 | 0.8521 | 0.0622 | | | |
| 27 | 1723.8 | | 2.292 | 61.726 | 44.228 | 0.8156 | 0.0484 | | | |
| 28 | 1727 | | 1.9691 | 37.667 | 29.862 | 0.7792 | | | | |
| 29 | 16.013 | | 2.0494 | 25.865 | 1760.8 | 0.743 | | | | |
| 30 | 5.6637 | | 1.7306 | 23.098 | 1948.5 | 0.743 | | | | |
| 31 | 2.5374 | | 1.3793 | 10.248 | | 0.6533 | | | | |
| **Total** | **8844.3** | **13314** | **16921** | **22142** | **27669** | **15391** | **4.9944** | | | |

Source: Data Analysis, 2011-2012