



**AMBO UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES, DEPARTMENT OF BIOLOGY,**  
**ENVIROMENTAL SCIENCE PROGRAM**

**CHARACTERISTICS AND ONSITE COSTS OF THE SEDIMENT LOST  
BY RUNOFF FROM DAPO AND CHEKORSA WATERSHEDS, DIGGA  
DISTRICT**



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## Acronyms

AVP: Available phosphorus

BARC: Bako Agricultural Research Center

C/N: Carbon/Nitrogen

CR: Chekorsa River

CRC: Checkorsa River Catchment

d; decade

DDS: Dapo down Stream

DFA: Discriminate Function Analysis

DR: Dapo River

DRC: Dapo River Catchment

DUS: Dapo Upperstream

FAO Food and Agricultural Organization

GDP: Gross Domestic Product

gm/L: gm per liter

INM: Integrated soil nutrient management

IWMI: International Water Management Institute

kg/ ha/yr: Kg per hectare per year

L: liter

LD: Lelisa Dimtu

m.a.s.l: Meter above sea level

Mg: Mega gram

Mha: Million hectare

Mm<sup>3</sup>/d: Mega metric cube

NBDC: Nile Basin Development Challenge

NH<sub>4</sub>-N: Ammonium nitrate nitrogen

NO<sub>3</sub>-N: Nitrate nitrogen

NPK: Nitrogen, phosphorus and potassium

OC: Organic carbon

PO<sub>4</sub><sup>-3</sup>: Phosphate ion

Ppm: Parts per million

Q: discharge

SPSS: Statistical Package for Social Science

SSC: Suspended Sediment Concentration

SSL: Suspended Sediment Load

SWC: Soil and water conservation

t/ha/d: tonnes per hectare per decade

TKN: Total Kjeldal Nitrogen

tons /ha /yr: tons/hectare/year

USLE /RUSLE: Revised/Universal Soil Loss Equation

WAO: Woreda Agricultural Office

## ***Abstract***

This study conducted in two sub catchments of the Abay Basin identified the quantity and quality of sediment loss and its origin though most studies conducted in Ethiopia focus on quantification of soil loss. Also, the onsite economic cost in terms of yield reduction was estimated taking maize (*Zea mays*) as representative crop. For this purpose, two monitoring stations were selected at the outlet of the two watersheds. Depth integrated runoff samples were collected during the rainy season in 2011 while discharge of the Rivers was estimated from staff gauge-discharge relationship. Daily runoff samples were bulked for ten consecutive days and filtered to separate the sediment from the water. The water and sediment were subsampled for oven dry to determine sediment concentration and for chemical analysis to determine the Nitrogen and Phosphorus content at Ambo University laboratory. The difference in sediment concentration between the two Rivers was statistically significant. Regression analysis between that suspended sediment concentration is related to discharge for Dapo River ( $R^2=0.7$ ) but this relation was very weak for Chekorsa River ( $R^2=0.286$ ). The concentration of the plant nutrients considered was greater in the sediment delivered to the outlet than that of the original surface soil. The concentration of available P in the sediment was 2.7 to 9 times its concentration in surface soil from Dapo river catchment and Chekorsa river catchment, respectively. The soil nutrients in the sediment and surface soil of the lower and upper catchment were used to identify sediment source areas using a quantitative composite sediment fingerprinting method with 87% of source type correctly classified. The contribution of the upper stream part to the sediment load of River Dapo was greater than its downstream part, with values ranging from 37% to 67% using Total Kjeldal Nitrogen, and 44% and 56% using organic carbon to nitrogen ratio but in average 56% to 63%. Mean lost of available nitrogen and phosphorus was  $1.6\pm 0.14$  and  $0.4\pm 0.06$ , and  $1.5\pm 0.17$  and  $1.1\pm 0.13$  in Kg per decade from Chekorsa and Dapo River, respectively. As a result, the estimated onsite cost to farmers due to the total loss of nitrogen and phosphorus throughout the study period was about 3321 and 4975 Birr ha<sup>-1</sup> for Dapo, and 3545 and 2324 Birr ha<sup>-1</sup> for Chekorsa catchments in that order. The study therefore helps to understand the processes and cause of nutrient loss at a micro watershed level and to implement targeted management interventions.

**Keywords:** Soil loss, sediment fingerprinting, soil nutrient depletion, Blue Nile Basin

# 1. Introduction

## 1.1. Background and Justification

Environmental problems have become major global concerns. Soil erosion by water is among the severe environmental and agricultural production problem across the world. Erosion causes significant loss of soil fertility and productivity (Mequanint Tenaw and Seleshi Bekele, 2009). Soil erosion is among the common threats to agricultural production in Ethiopia (Lakew Desta, 2000, Sileshi Bekele and Holden, 1998). In the Ethiopian highlands, soil loss due to water erosion is about 1493 Mt<sup>-1</sup>yr (Hurni, 1993). Nearly half of this is estimated to come from cultivated fields, which account for only about 13% of the country's total area. These losses will inevitably cause decrease in yield unless appropriate measures are taken. In the Abay basin (the Ethiopian part of the Blue Nile Basin) soil erosion by water is a major cause of soil fertility and productivity loss (Mequanint Tenaw and Seleshi Bekele, 2009).

Understanding soil loss and its process is crucial in order to select and implement integrated nutrient management options to attain sustainable agricultural production. The provision of reliable information on the provenance of suspended sediment transported by rivers is important from a number of perspectives such as to establish catchment sediment budget, validation based on physically distributed soil erosion and sediment yield model. The targeting of sediment management strategies is a key requirement in developing countries because of the limited resources available (Collins and Walling, 2002). However, most studies conducted in Africa including Ethiopia focus on quantification of soil loss using the University soil Loss Equation (USLE) or its revised version (RUSLE), erosion pins, runoff plots or remote sensing technologies. The efforts have given little attention to the original provenance or sources of sediment.

Estimation of sediment yield has important economic consequences (Gruhn *et al.*, 2000). Most current evaluations of the costs of land degradation have focused on the loss of soil from farm plots and the loss of nutrients resulting in decreased productivity or the need for increased inputs

to maintain productivity (Berry *et al.*, 2003). However, the cost of nutrient loss through rivers and streams from small catchments has not been well researched.

Soil degradation in the form of nutrient depletion, is an important factor for the declining agricultural production in Ethiopia (Sileshi Bekele and Holden, 1998). According to Getnet Dubale *et al.* (2009) soil erosion induced productivity losses are distinct in the Upper Blue Nile Basin. The cost of soil erosion to farmers is two-fold; loss of productivity due to loss of plant nutrients and economic cost of fertilizer in order to compensate the lost nutrients (Gruhn *et al.*, 2000). The physical, chemical and biological effects of soil degradation on the ecosystems and human populations have been researched to some degree, but little research has been done about the economic costs of soil degradation (Görlach *et al.*, 2004), in particular sediment and nutrient loss by rivers from small catchment.

Diga District where the two study catchments are found is located in the western Oromia, Ethiopia where low soil fertility is one of the major factors limiting maize production and productivity (Wakene Negassa, 2005). Dapo and Chekorsa streams are tributaries of Didesa River, the largest tributary of the Blue Nile River in terms of volume of water, contributing roughly a quarter of the total flow as measured at the Sudanese border (MWRE, 2010). Conducting such studies in the Blue Nile Basin benefits not only the upper stream community but helps to plan interventions that minimize the offsite costs such as siltation of dams and reduction of water quality for domestic uses.

This study was made mainly to understand the processes and cause of soil and its onsite costs to the farmers' in terms of yield lost at micro levels.

## **1.2. Statement of the problem**

Soil nutrient depletion has become a major agricultural problem in central highlands of Ethiopia due to improper land management practices. It is understood that it is impossible to achieve food security in the region without overcoming the problem of nutrient depletion (Belayneh Ayele, and Hager, 2010). In the study area, local communities are cultivating the top and bottom of the slopes, aggravating the problems of soil erosion and loss of soil fertility, which are the major challenges of the watershed (Brihanu Zemedin *et al.*, 2010). In some parts of the watersheds, all

the top soil has been lost exposing the bed rocks and tree roots. In response to the productivity declines, farmers open a new agricultural land which increases deforestation.

The quantity and quality of soil lost by water erosion and the sources of the sediment was not determined. Determining the concentration of major nutrients lost is very helpful for estimating productivity loss and corresponding economic cost. As the on- site economic impacts of sediment loss on the livelihood of the local people have not been estimated, this study attempted to generate such crucial evidence, which can be used to inform the local community and policy makers so that appropriate actions will be taken on the ground.

### **1.3. Significance of the study**

The study is an input to the Nile Basin Development Challenge Program of the Challenge Program on Water and Food being implemented in the Blue Nile Basin. Meanwhile, the Ethiopian government has launched the building of the Millennium Dam which is located at the outlet of the Abay River. This study being conducted in one of the major tributaries of Abay River is essential to design and implement suitable management practices to curtail the siltation and eutrophication risks that may affect the Dam.

The finding of the study helps the local farmers to recognize the cost of sediment lost and it may assist policymakers to know the “concealed” costs of soil-nutrient losses so as to highlight the potential impacts and benefit of soil-conservation investments on the environment and economy of the local communities.

### **1.4. Objective of the study**

The overall objective is to analyze the quantity and characteristics of soil lost by runoff and identify sediment contributory areas.

The specific objectives of the studies are:

- To estimate the sediment concentration at the outlet of Dapo and Checkorsa watersheds
- To analyze the major plant nutrients lost with the sediment
- To identify the potential subarea contributors of the sediment to Dapo River
- To estimate the crop productivity loss due to soil erosion



### **1.5. Hypothesis**

Water erosion in the study area is taking the top fertile soil and thereby delivering the major nutrients to the outlet which significantly influences the agricultural productivity of the watershed.

### **1.6. Scope of the study**

The study was based on three months of water sampling during the period characterized by high rainfall and sediment concentration in the runoff at monitoring stations. The discharges of the rivers carrying sediment from the watersheds were quantified and chemical properties of the sediment were analyzed in order to estimate the amount of nutrient lost from the catchments. The economic cost of nutrient losses from the watershed was also included in the study to create an easily understandable result for the local farmers and policy makers. The study also included information which is difficult to obtain using manual and digital monitoring techniques in combination i.e. the sources of the suspended sediment transported by rivers whether the dominant source is from the upper or the lower areas of the Dapo watershed.

## **2. Literature Review**

### **2. 1. Concept of soil erosion**

Soil erosion caused by water and wind is a widespread problem in both rural and urban areas of the world. Soil erosion is normally a natural process occurring over geological timescales; but where (and when) the natural rate has been significantly increased by anthropogenic activity accelerated soil erosion becomes a process of degradation and thus an identifiable threat to soil (Le Bas, and Kozak, 2007). About 80% of the world's agricultural land suffers moderate to severe erosion, and 10% suffers slight to moderate erosion. Croplands are the most susceptible to erosion because their soil is repeatedly tilled and left without a protective cover of vegetation (Pimentel, 1995). Most studies showed soil erosion is severe in the Ethiopian Highland. FAO (1999) indicated that Ethiopia is among the countries with high degrees of erosion with highest nutrient depletion rates.

#### **a. What is soil erosion**

Christine and Josef (2007) defined soil erosion as the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere'. Soil erosion is normally a natural process occurring over geological timescales; but where (and when) the natural rate has been significantly increased by anthropogenic activity accelerated soil erosion become a process of degradation and thus an identifiable threat to soil. Erosion occurs when soil is left exposed to rain or wind energy. Water is the main cause of erosion in the highlands of Ethiopia particularly during the concentrated rain in three to four months of summer season (Paulos Dubale, 2001). Relevance to this work as it affects the two study watersheds is soil erosion by water known as water erosion.

Water erosion depends on four factors: rainfall, soil type, slope gradient, and soil use/vegetation cover (Ballayan, 2000). Raindrops hit exposed soil with great energy and easily dislodge the soil particles from the surface in the form of runoff (Pimentel, 2006).

Soil erosion by water is a process in which the detachment of individual soil particles from the soil mass cause a breakdown of the soil aggregates. The detached soil particles would be

transported by the water known as surface runoff. Runoff mostly formed when the rainfall intensity is higher than the infiltration rate (Helmecke, 2009).

## **2.2. General overview of soil loss extent in Ethiopia**

The excessive dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is underlying cause for degradation of land and other natural resources (Drechsel *et al.*, 2004). Soil erosion by water represents among the major threats to the long-term productivity of agriculture particularly in the Ethiopian highlands. As a result, productivity is rapidly declining (Tegenu Ashagrie, 2009 and Tilaye Teklewold, 2007). All physical and economic evidence shows that loss of land resource productivity is an important problem in Ethiopia and with continued population growth the problem is likely to be even more important in the future (Berry *et al.*, 2003).

There are several studies that deal with the severity of land degradation at the national level in Ethiopia. For example, Shibru Tefera (2010) remarked the relative probability of greater impact of nutrient depletion in Ethiopia, where it is more severe than the other SSA countries. Water erosion was the most important process and that in mid 1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation (Berry *et al.*, 2003).

The total soil eroded within the landscape in the Abay Basin is estimated to be 302.8 million tons per annum out of which 101.8 tons per annum was estimated to be from cultivated land (Fistum Hagos, 2009). Berry *et al.* (2003) estimated the rate as less as  $130 \text{ t}^{-1}\text{ha}^{-1}\text{yr}$  for cropland and  $35 \text{ t}^{-1}\text{ha}^{-1} \text{ yr}$  averages for all land in the highlands, but even at the time these were regarded as high estimates. According to Getnet Dubale *et al.* (2009) soil loss in the Blue Nile Basin is above  $2.00\text{-}4.00 \text{ t /km}^2 \text{ /yr}$ . The same author estimated that about 24 Million ton per year sediment is deposited in river channels within the Upper Blue Nile. Another study by Biniam Biruk (2009) estimated loss of  $16\text{-}50 \text{ t}^{-1}\text{ha}^{-1}\text{yr}$  from the Ethiopia highlands. According to Hurni (1993) soil losses in the Ethiopian highlands may reach as high as  $200\text{-}300 \text{ t}^{-1}\text{ha}^{-1}\text{yr}$ . According to Getnet Dubale *et al.* (2009), the amount of sediment yield delivered at Ethiopia Sudanese boarder from the upper Blue Nile is estimated to be 62 Million ton per year.

The loss of nutrient-rich top soil by water leads to loss of soil quality and hence reduced crop yield. Soil erosion by water and its associated effects are therefore recognized to be severe threats to the national economy of Ethiopia. In Ethiopia, particularly on the Gumera watershed, the study by Mequanint Tenaw and Seleshi Bekele (2009) showed that about 72% of erosion potential area with an average annual sediment load ranging from 11 to 22 t/ha/yr exceeding tolerable soil loss rates of Ethiopia. The same author remarked that sheet and rill erosion are by far the most widespread kinds of accelerated water erosion and principal cause of land degradation in the country and their combined effect significantly affect agricultural production and productivity. Berry *et al.* (2003) estimated a loss of \$106 million a year or about three percent of agricultural GDP from a combination of soil and nutrient loss.

Most of the sediment in the Nile flows from the Ethiopian Highlands through the Blue Nile and Atbara River. Nearly all of the sediment (~ 90%) enter into Sudan from the Blue Nile during the flood season (July - October) (Abdalla Abdelsalam, 2008).

### **2.3. Suspended sediment**

River suspended-sediment concentrations provide insights to the erosion and transport of materials from a landscape, and changes in concentrations with time may result from landscape processes or human disturbance. The behavior of suspended sediment in watercourses is often a function of energy conditions, i.e. sediment is stored at low flow and transported under high discharge conditions. However sediment transport rates are also a function of sediment availability (Baca, 2002).

Traditionally, these dynamics are characterized by empirical relationships between suspended sediment concentration and discharge. These relationships are normally not homogenous in time, neither within nor between events (Baca, 2002). Experimental data has shown that there are three common shapes of the hysteresis loops encompassing (i) clockwise, (ii) counter clockwise and (iii) , though it is possible to obtain loops which are (iv) single valued or (v) single valued plus a loop (Sander *et al.*, 2011).

## 2.4. Nutrient depletion

Soil nutrient availability changes over time. Soil fertility is one of the key factors in determining agricultural output, and soil fertility depletion is seen as the most important process in the land degradation equation and a primary constraint to improving food security in developing countries (Drechsel *et al.*, 2004).

Of the global cultivated area for the crops in the year 2000, 56% was affected by N deficit at an average rate of  $17.4 \text{ kg}^{-1} \text{ ha}^{-1} \text{ yr}$ , 80% by P deficit at that of  $5.0 \text{ kg}^{-1} \text{ ha}^{-1} \text{ yr}$  and 56% by K deficit at that of  $38.7 \text{ kg}^{-1} \text{ ha}^{-1} \text{ yr}$  (Tan *et al.*, 2005). The same author also remarked that at the global scale, a shortage of N, P, and K was observed in developing and least developed countries. Developed countries were still deficit in N and P in an area of 108 Mha (52%) for N and 151 Mha (73%) for P despite being less serious than in other countries.

Table 1: Global nutrient loss rate classes ( $\text{kg}^{-1} \text{ ha}^{-1} \text{ year}$ )

Class	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Low	<10	<4	<10
Moderate	10-20	4-7	10-20
High	21-40	8-15	21-40
Very high	>40	>15	>40

Source FAO (1999)

The above nutrient deficits were due to the considerable nutrient depletion from cultivated land. About 86 percent of the countries in Africa lose more than  $30 \text{ kg}^{-1} \text{ ha}^{-1} \text{ yr}$  of NPK (Henao and Baanante, 1999). Likewise, Gruhn, *et al.* (2000) indicated that in Sub-Saharan Africa net annual nutrient depletion was estimated at  $22 \text{ kg}^{-1} \text{ ha}$  of nitrogen,  $2.5 \text{ kg}^{-1} \text{ ha}$  of phosphorus, and  $15 \text{ kg}^{-1} \text{ ha}$  of potassium during 1982-84. And according to the report of World Bank (1999) the estimate is much greater in Sub-Saharan Africa reaching a net loss of about  $700 \text{ kg}^{-1} \text{ ha}$  of nitrogen,  $100 \text{ kg}^{-1} \text{ ha}$  of phosphorus, and  $450 \text{ kg}^{-1} \text{ ha}$  of potassium in about 100 Mha of cultivated land over the last 30 years. In addition, Henao and Baanante (1999) suggest that nutrient mining may be accelerating. It is well researched that erosion plays a major role in nutrient removal from cultivated land.

## **2.5. Transportation of nutrient to water body**

Runoff carries some inorganic nitrogen, primarily as nitrate and ammonium, at concentrations that are commonly 3 ppm or less (Castro, 2004, Wortmann 2006). The same authors indicated Nitrate-N is generally leached into the soil and ammonium nitrogen becomes attached to soil particles with precipitation that occurs before runoff begins. In addition to creating water deficiencies, runoff and soil erosion cause shortages of basic plant nutrients, such as nitrogen, phosphorus, potassium, and calcium, which are essential for crop production.

Pimental *et al.*, (1995) showed a ton of fertile agricultural topsoil typically contains 1 to 6 kg of nitrogen, 1 to 3 kg of phosphorus, and 2 to 30 kg of potassium, whereas a severely eroded soil may have nitrogen levels of only 0.1 to 0.5 kg per ton. They also suggested that wind and water erosion selectively remove the fine organic particles, leaving behind large particles and stones. Eroded soil typically contains about three times more nutrients than the soil left behind. Similarly, Jun *et al.* (2005) indicated that the entire nutrient in surface soil had lower values than that in sediment.

There are abundant examples which demonstrate how sediment quality has been affected in response to human activities. A well-known example is the widespread particulate phosphorus increase in many agricultural river basins in the world Philip *et al.* (2010). They also remarked that fertilizer use and accelerated soil erosion on agricultural river basin have resulted in elevated sediment inputs and phosphorus concentrations in stream and lake beds.

According to Sharpley *et al.* (2000) soil P levels are higher in the top 5 cm of the surface soil. Soil detachment and transport in surface runoff preferentially erode finer particles. This results in eroded material with higher total phosphorus (>0.45) content in the runoff compared to the soil in the source area. In addition, overland flow is efficiently removing high concentration of P, because of the largest concentration of P in the surface layers, and the greatest concentrated hydrologic energy on the soil surface than the subsurface (Zaimes, and Schultz, 2002 *et al.*, 1998 work).

The removal of soil particles, from the topsoil can have a devastating impact on overall soil organic matter levels because organic materials are concentrated in the surface layer of the soil (Van-Camp, 2004). Nitrogen is lost to surface waters and ground waters through overland flow and leaching and below-ground movement of nitrate (Wortmann, 2006). The amount of nitrogen delivered depends on the volume of drainage water and nitrate concentration in the soil solution (Wortmann, 2006). For example, it has been estimated that in Albania, water erosion washes away 60 million tons of coarse materials every year. These comprise 1.2 million tons of organic matter, 100,000 tons of nitrates, 60,000 tons of phosphates, and 16,000 tons of potassium (Van-Camp, 2004).

## 2.6. On site impact of soil erosion

The impacts of soil erosion can be on-site and off-site (Figure 1). The farmer will probably be more concerned about the former, which occur on the eroded land itself. They describe the decline in crops productivity, the reduction of the soil's water holding capacity, its nutrients and organic matter, which often revealed as a decline of productivity (Helmecke 2009).

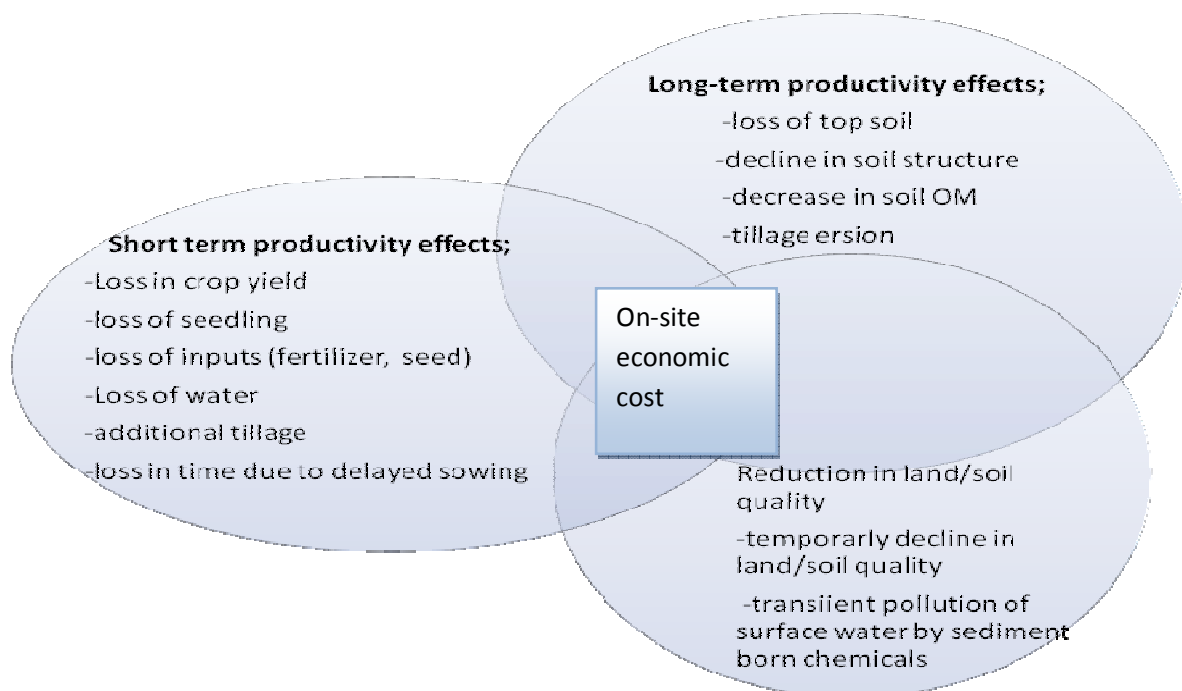


Figure 1: On site effects of soil erosion

Source (Helmecke, 2009).

### 2.6.1. Economic impacts of soil erosion

Plants need relatively large amounts of nitrogen, phosphorus, and potassium. These nutrients are referred to as macro nutrients, and they are most frequently supplied to plants as fertilizers. When insufficient, these primary nutrients are most often responsible for limiting crop growth. Their balance in soil depends on the rate which they naturally regenerate, applied in the form of fertilizers and the rate at which they are removed from the soil system by plants and soil erosion. The cumulative effect of yearly negative nutrient balances on crop yields is often seen through the impact of soil erosion on productivity (Gruhn *et al.*, 2000).

Table 2: Global estimated impact of soil erosion on crop production

Commodity	Net production (Mg 10 <sup>6</sup> )	Estimated production loss (%)	Estimated production if there were no erosion (10 <sup>6</sup> Mg)
Cereals	1896	10	2086
Soybeans	126	5	132
Pulses	56	5	59
Roots and Tubers	609	12	682
Total	2687	32	2959

Source (Helmecke 2009)

In 1995, a total production loss of 32 per cent was estimated to have resulted from soil erosion (Table 2). Some deficiency caused by erosion can be temporarily compensated by increased application of fertilizer and irrigation (Pimentel *et al.*, 1995) but to completely restore the original soil productivity it often needs long physical and biological rehabilitation periods. However, farmers often aim for short-term results and might therefore tend to increase fertilizer input as much as they can afford. Although this might help to cope with the temporary productivity loss it leads to other long term damages (Helmecke 2009). Van-Camp, (2004) suggests that more fertilizer and organic manure are needed on agricultural land on which intensive erosion occurs to counteract the losses caused by soil erosion, compared to the requirements in non-eroded areas. Soils in all major maize growing regions of the country are



depleted of nutrients, thus demanding high soil amendments with nitrogen and phosphorous (Kebede Mulatu *et al.*, 1993). Decline in soil fertility due to depletion of macro nutrients in the country is therefore eradicating production including maize production.

Loss of soil productivity leads to reduced farm income and food insecurity, particularly among the rural poor and thus continuing or worsening poverty (Shibru Tefera, 2010). In least developed countries, productivity reductions were equivalent to 27% of the average crop yield in the year 2000. And the average yield reduction from N, P, and K deficits was 35% in least developed countries, 27% in developing countries, and 11%.

Erosion can decrease rooting depth, and plant-available water reserves (Lal, 1987). Thus, the exposed soil remaining will be less productive in a physical sense. These effects may be cumulative and may not be revealed in the short term. Erosion may also affect yields by influencing the micro-climate (Eaton, 1996). Soils that suffer severe erosion may produce 15 to 30% lower corn yields than uneroded soils, and with fertilization, the yield reductions range from 13 to 19%. Similarly, once the organic matter layer is depleted, soil productivity and crop yields decline because of the degraded soil structure and depletion of nutrients. For example, the reduction of soil organic matter from 4.3 to 1.7% lowered the yield potential for corn by 25% in Michigan (Pimental *et al.*, 1995). Therefore, crop yields on severely eroded soil are lower than those on protected soils because erosion reduces soil fertility and water availability.

There is strong evidence that yield decline with erosion follows a curvilinear, negatively exponential form. In other words, there is a sharp initial decline from a status of high productivity, followed by successive stages of decreasing impact.

In Ethiopia, soil erosion in 1990 was estimated to have cost (based on 1985 prices) nearly 40 million Birr (ETB) in lost agricultural production. Thus in 1990 approximately 17% of the potential agricultural GDP was lost because of soil degradation. The permanent loss in value of the country's soil resources caused by soil erosion in 1990 was estimated at ETB 59 million. This is the amount by which the country's soil stock should be depreciated in the national accounts or which should be deducted from the country's Net National Income (Fistum Hagos, 2009).

Investment in measures to reduce degradation is expensive both in terms of improving soil (fertilizers, manure, crop residues) and structures such as terraces, grass lines and hedges that all require investments in labor. Decisions to invest therefore have to be made relative to the benefits that are both on-farm and off-farm, while the investment costs are usually borne on-farm (Berry *et al.*, 2003).

### **2.7. Valuing soil nutrient loss**

In order to plan a better environmental decision-making policy, the economic valuation of environmental problems is important. For this reason, soil erosion by water which is considered as a major environmental threat to the sustainability and productivity of agriculture (Pimentel *et al.*, 1995) is the main focus of many countries.

Soil deterioration makes itself felt in different ways, and there are different methods of classifying the economic impacts of soil degradation. Different impacts can be classified spatially into on-site and off-site effects, distinguished according to the economic values that are affected (Görlach *et al.*, 2004). Likewise he added those impacts may also be grouped according to causality as direct and indirect impacts.

The costs of loss of natural capital are borne at the level of individuals, communities and by the broader economy. But this loss of natural capital also results in changes in economic, human, social, and land capital, the value of investment in land management (Berry *et al.*, 2003). Thus, the majority of empirical estimates have centered on the impact that soil degradation has on agriculture and forestry (Görlach *et al.*, 2004), and also here the study concerns the direct, on-site economic effect.

FAO (1999) remarked that the estimates of cost could be based primarily on the measurement of two variables: production loss or replacement cost. The basic premise of the replacement-cost approach is that the costs incurred in replacing productive assets damaged by an environmental impact can be measured. These costs can be interpreted as an estimate of the benefits presumed to flow from measures taken to prevent those damages from occurring. The replacement cost is a

popular method of assessing the value of soil erosion. To value nutrients via fertilizer prices requires either a translation of the lost nutrients into marketed fertilizer types or an expression of fertilizers in nutrient units (Gruhn *et al.*, 2000). In addition, a number of studies have considered the cost of replacing lost nutrients. Replacement cost is the cost of additional inputs (basically fertilizers) used by farmers in order to maintain production levels on the degraded soils (Görlach *et al.*, 2004).

To assess by how much erosion has been causing on site economic impact, it is necessary to consider the multiple factors that influence erosion rates as well as soil component and other agro-ecological conditions prevailed in the specific area that affect productivity (Pimental *et al.*, 1995). A partly, the approach of replacement cost cannot consider this concept whereas estimating the approximate production loss is better. As a result, to estimate onsite economic cost of soil loss by runoff, production loss instead of replacement cost was the concern of this study.

Crop yields on severely eroded soil are lower than those on protected soils because erosion reduces soil fertility and water availability. For example in some parts of India corn yield on some severely eroded soils have been reduced by up to 24% and 65% in the Southern Piedmont of Georgia (Pimental *et al.*, 1995).

Production loss is the reduced productivity of the soil as a consequence of degradation, which could be expressed as a percentage of production from the undegraded soil (FAO, 1999).

Soil erosion can reduce crop production up to 30% (Louis, 2011).

Many of these studies are agronomic, focusing on agricultural yield losses associated with soil degradation. FAO (1999) reported that for erosion and soil fertility decline, the assumptions are: a 5-10% production loss for a "light" degree of degradation, 20% for "moderate" and 75% for "strong" degradation.

When erosion by water and wind occurs at a rate of 17 tons  $^{-1}\text{ha}^{-1}$  year, about 75 mm of water and 462 kg of nutrients are lost per hectare. As a result, an additional \$100 /ha would be required for fertilizers to replace the lost nutrients. In some part of the world, where irrigation is not

possible or fertilizers are too costly, the price of erosion is paid in reduced food production (Pimental *et al.*, 1995). However, previous research has put much emphasis on the importance of N and P lost by the Rivers for plant nutrition. For examples, Kogbe and Adediran (2003) and Alley (2009) remarked that N is without doubt the most significant nutrient for high maize yields and its deficiency limits production more than any other nutrients and P deficiency also has drastic effects on the maize yields.

## **2.8. Sediment fingerprinting**

The targeting of sediment management strategies is a key requirement in developing countries because of the limited resources available. Such targeting is, however, hampered by the lack of reliable information on catchment sediment sources. There is an increasing need for reliable information concerning the source of the suspended sediment transported by rivers. Such information is required both to design effective sediment and non-point pollution control strategies and to provide an improved understanding of erosion and suspended sediment transport within a basin which is an essential precursor to establishing sediment budgets, developing distributed sediment yield models, and interpreting sediment yields in terms of landscape evolution (Walling, 1993). Sediment fingerprinting has been developed by researchers over the past three decades for watershed sediment transport research. Sediment fingerprinting is founded on the premise that spatial and temporal variations in sediment properties directly reflect spatial and temporal variations in the relative contributions of sediment from distinguishable sources (Collins *et al.*, 2001).

This technique makes use of chemical and physical properties of the sediment to trace its source. It involves, firstly, the selection of a physical or chemical property which clearly differentiates potential source materials, and, secondly, comparison of measurements of the same property obtained from suspended sediment with the equivalent values for the potential sources, to establish the likely source of the sediment (Figure 2) (Walling, 1993 and Collins, 2001). Sediment fingerprinting is a method to identify sediment sources in a watershed and allocate the amount of sediment contributed by each source through the use of natural tracer technology with a combination of field data collection, laboratory analyses of sediments, and statistical modeling techniques. This method utilizes one or more unique physical or biogeochemical properties known as natural tracers (Davis and Fox, 2009).

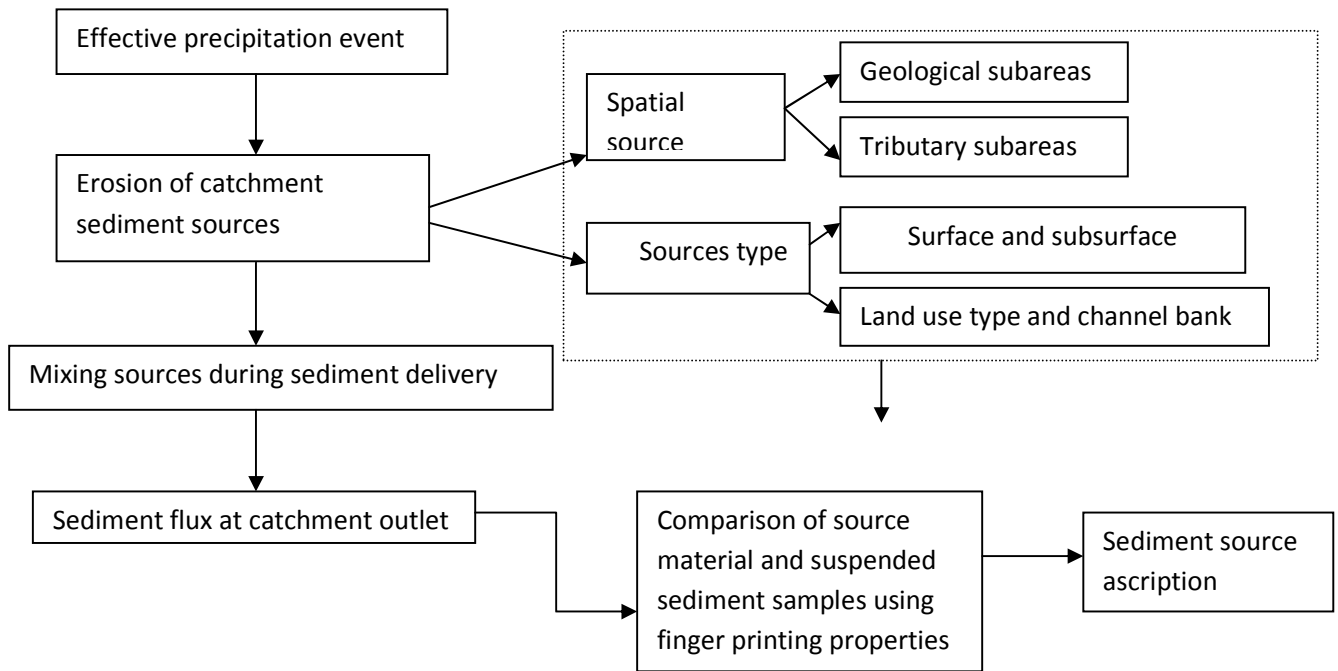


Figure 2: A conceptual model of sediment fingerprinting

Source: Collins and Walling (2002)

### 3. Materials and Methods

#### 3.1. Description of the study area

##### 3.1.1. Diga area

The study was carried out at Diga district, East Wollega Zone of Oromia Regional State. It is located at about 346 km from Addis Ababa and 15km from Nekemte town to the West (Figure 3). The total area of the District is estimated at 40,788 hectares.

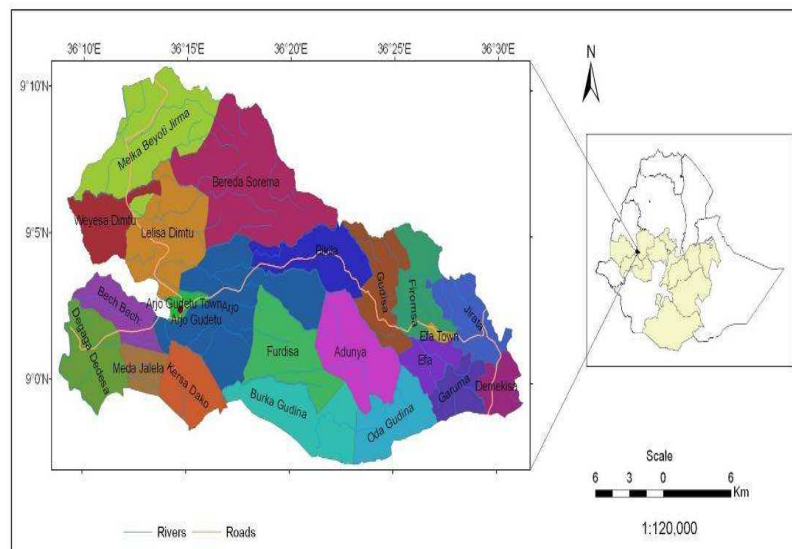


Figure 3: Map of Diga District

Source WAO, 2011

According to Joshua, *et al.* (2010), the District is stratified into two agro-climatic regions; the middle altitude to high altitude which ranges in between 2100-2342m.a.s.l and the low land which range in between 1200-2100 m asl. According to the District Agricultural Office report in 2010, middle to high altitude and the low lands covers 42% and 58% of the district, respectively. The report also shows topography of the district where the study area found is characterized as flat, gentle slope, steep slope, very steep slope and hill.

The mixed cropping system is common in the district. In the lowlands maize is the dominant field crop followed by sorghum (*sorghum bicolor*), millet (*Eleusine coracana*) and sesame (*Sesamum indicum* L) while perennial crops such as coffee (*coffea arabica*) and mango

(*Mangifera indica*) are also prevalent. In the midland, tef, millet and maize are important in that order. Livestock keeping is common all over (Brihanu Zemedin *et al.*, 2010). And according to Diga District Water Resource Office (2010), the land use of the area is divided into arable land, grazing land, forest land, bushes and shrubs, construction and others which are yet to be classified.

The high land areas of Diga District receive rainfall varying from 1376- 2037mm, and the annual mean temperature varies from 14.6<sup>0</sup> to 30.4<sup>0</sup> C (Joshua *et al.*, 2010). Regarding water resources, the district has 26 perennial and unprotected rivers and 167 streams out of which 75 are annual while 29 are protected for drinking and other uses and 138 are unprotected. There is only one unprotected reservoir (Diga District Water Resource Office, 2010). The watersheds are generally located at the high altitude and receive high rainfall during rainy season, which begins in late April, and ends in early September.

### 3.1.2. Characteristics of Dapo and Chekorsa watersheds

#### a. Size and location

Dapo and Chekorsa rivers are among the 26 perennial rivers found in the District. The catchment area of Dapo and Chekorsa are 16.2 Km<sup>2</sup> and 5.60Km<sup>2</sup> and their altitude ranges between 1,347 – 2011 and 1266 – 1430m asl, respectively. Sampling locations of the two rivers is for Dapo River at bridge on the Digga to Arjo Gudatu road at 09°03.141' N, 36°17.650'E (Figure 8) whereas for Chekorsa at bridge on the Lelisa Dimtu old State farm at 09°03.410'N; 36°13.978'E.

#### b. Physiography



Figure 4: (a) Dapo watershed outlet and (b) land use and land cover condition around the outlet

Photo credit: (Brihanu Zemedin, 2011)

Both Dapo and Chekorsa rivers are tributaries of Didesa River the largest tributary to the Blue Nile River in terms of water volume (MWRE, 2010). The watersheds are adjacent and these rivers drain separate in the same direction. Both Rivers has numerous first and second order streams flowing directly to the Rivers. Similar to CRC, the physiographic, land use and land cover condition in the downstream of DRC, around the water level gauging site, consists of mango trees and sparsely populated natural vegetation cover, lowland maize fields and, flat grazing areas in the downstream side of the bridge (Figure 4) (Brihanu Zemedin, 2011). Different to Checkorsa River, Dapo River has well established natural riparian zone Figure 15.

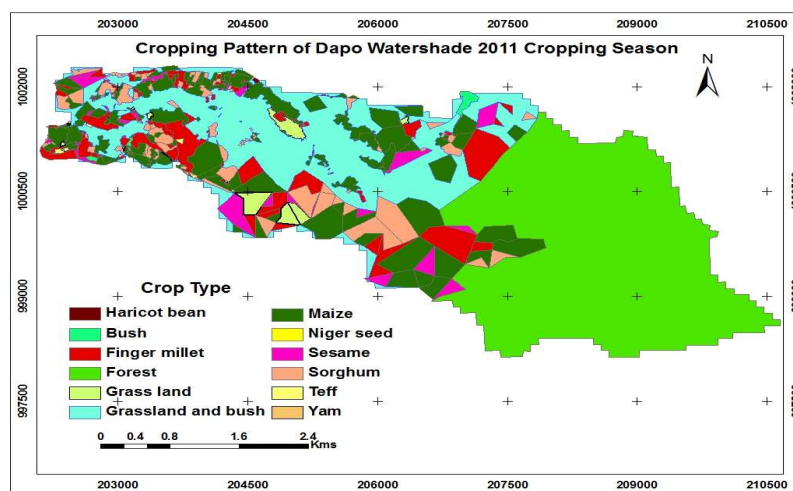


Figure 5: Land use land cover of Dapo watershed,

Source: IWMI (2012)

The dominant crop types of DRC were maize, sesame, and finger millet and about one third of the watershed area is covered by forest located at the most upper part of the watershed (Figure 5). But, in the CRC no dense forest is found. All parts of the watersheds have been used for agricultural activities. Soil textural class of DRC is clay loam whereas silt clay loam for CRC (Joshua, 2011).



## 3.2. Methods

### 3.2.1. Data gathering

Both primary and secondary data were collected for this study to estimate of several parameters illustrated conceptual framework of Figure 10. Hydrological measurements was conducted at the two monitoring stations to generate the following information: discharge (Q) of the rivers, suspended sediment concentration (SSC), suspended sediment load (SSL), its chemical analysis, and fertilizer yield response data for the study area were obtained from different research results under similar agro-ecological conditions.

### 3.2.2. Selection of runoff sampling site

Expert from the International Water Management Institute (IWMI) have identified the bridge on the main highway that goes from Diga to Ghimbi for DRC and the bridge from Arjo Gudatu to Lalisa Dimtu for CRC are ideal locations for establishing flow monitoring stations. The bridges are wide and all flows were contained inside the culvert of the bridges.

### 3.2.3. The study period

The study was from the onset (July) to the offset rainfall (September) 2011 which makes a three months period. Each month was divided into three decades (d) 10 consecutive days.

### 3.2.4. Runoff sampling

Based on the concept of Gierke (2002) the flow rate of the river at the outlet was determined using current meter (Model 0012B Surface Display Unit and Model 002 Flow Meter (Figure 7: A and B respectively) as well as, measured depth of the rivers using 1.5m wading rod (Figure 7: E). There were 9 points with 0.5m intervals for the Dapo River (DR) (Figure 6) and 5 points with 0.75m intervals for Chekorsa River (CR) across the rivers at which flow rates and depths (h) were measured simultaneously. Using these depth records, cross sectional areas (Figure 6) was calculated. The cross sectional areas were multiplied with the average flow rates at each point (Equation 1a) and then the volume (Q) of the runoff passing the outlet of the watersheds were calculated using equation 1b.

$$q_i = v_i * a_i \quad (a) \quad Q = \sum_{i=0}^n q_i \quad (b) \dots \dots \dots \text{Equation 1}$$

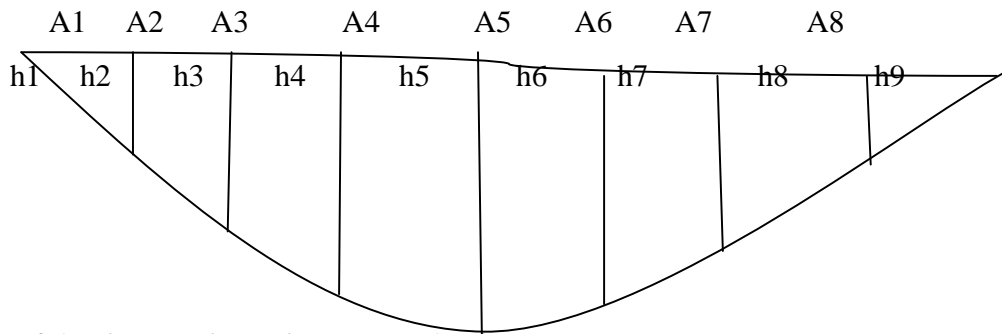
where:

$q_i$ = discharge at each cross sectional area ( $m^3sec^{-1}$ )

$v_i$ =flow velocity at each cross sectional area ( $msec^{-1}$ )

$a_i$ = cross sectional area at each point ( $m^2$ )

$Q$ = Total discharge ( $m^3sec^{-1}$ )



$h$ : Depth of the river at nine points across the river (m)

Figure 6: River cross-section shown and sub-cross sectional areas where flow velocities were measured

$$Q = c (h + a)^b \dots\dots\dots Equation 2$$

Where:  $Q$  = discharge ( $m^3sec^{-1}$ )

$h$  = measured water level (m)

$a$  = water level (m) corresponding to  $Q = 0$

$c_i$  = coefficients derived for the relationship corresponding to the station characteristics

$b$ = coefficient derived for the power relation the station characteristics

Finally, discharge rating curve were developed by fitting the relationship of measured gauge to discharge into power curve (Equation 2) for the two Rivers. And having water levels measured throughout the study period by the installed staff gauge (Figure 7: E), the discharge for each was calculated from the equations of the curves.



Figure 7: Current Meter model used for measuring river flow and staff gauge (E) at DR monitoring station

Photo Credit: Brihanu Zemedin (2011)

### 3.2.5. Water sampling and storage

Depth integrated runoff water were collected manually from catchments at the monitoring stations using one liter plastic bottle three times per day to represent the daily runoff. The daily samples were mixed and two liters were subsampled and bulked in a 20 liter Jerry Can for 10 consecutive days. The bulked sample was kept in the nearby soil laboratory.

The bulked water sample were labeled properly and kept in the refrigerator at 4°C in order to minimize further chemical and physical changes of both the sediment and the water (Annex 8).

### 3.2.6. Estimation of sediment load

The sediment in the collected water was allowed to settle down before the top 18L were decanted laboratory beakers and the remaining two liters which contain most of the sediment were filtered using watman filter paper (Annex 8).

$$S = M_s / V_w \text{ and } SSL = S \times Q \dots \dots \dots \text{Equation (3)}$$

Where;

S: suspended sediment per liter (gm/L)

Ms: mass of suspended sediment left on Watman filter paper (gm)

Vw: volume of water collected per decade (L)

SSL: suspended sediment load per decade (Kg/d)

Q: mean discharge of the rivers per decade (L/d)

The sediment remained on the filter paper were weighted using digital weight balance for each decade separately. Then, the amount of soil loss per decade was calculated from the estimated mean discharge of water passing the gauged sites for each decade using Equation 3.

### 3.2.7. Chemical analysis

Table 3: Methods and procedure used for the chemical analysis sediment and water

Sample	Parameter	Method	Reference
	OM	Wet oxidation/ Walkley-Black	Jackson, 1967
	TKN	Modified Kjeldahl digestion	Dalal <i>et al.</i> 1984
Soil	NO <sub>3</sub> -N	Magnesium Oxide-Devrda's alloy	Maiti, 2004
	NH <sub>4</sub> -N	Magnesium Oxide-Devrda's alloy	Maiti, 2004
	P <sub>2</sub> O <sub>5</sub>	Alkaline Extraction of Olsen Method	Olsen and co-worker ( 1954)
	Texture	Hydrometer	Bouyoucos 1962
	Dissolved ammonia	Phenate method using Spectrophotometer; Modele Eleco SL-160 Double beam UV	Patnaik (2010)
Water	Dissolved nitrate & phosphorus	Spectrophotometer; Modele Eleco SL-160 Double beam UV	Patnaik (2010)

After decantation and filtration process, chemical analysis had been conducted both on the soil and the water at Ambo University. On the air dried soil, the concentrations of OC, total nitrogen, available phosphorous, NH<sub>4</sub>-N, NO<sub>3</sub>-N were determined using standard procedures (Table3). Water quality analyses were also conducted for the dissolved PO<sub>4</sub><sup>-3</sup>, NH<sub>4</sub>-N and NO<sub>3</sub>-N (Table3).

### 3.2.8. Suspended sediment fingerprinting

Some part of the watershed surface soil was chemically analyzed by Joshua *et al.* (2010) representing subareas of Dapo Watershed i.e. transect one representing the lower part of near the out let and transect two and three representing the middle to upper part). Transect for DDS is found between 1353 -1499 and US transect located between 1500 and 1645 (Figure 8). Tracers properties of transect two and three were pooled as showed on Figure 17 and 18, and represented as the upper part of the watershed were agricultural activities practiced excluding the uppermost natural forest ( Figure 5 and Annex 2).

Then comparison between the sediment and surface soil properties was done following the conceptual model of Collins and Walling *et al.* (2001) (Figure 9). The relative contribution from the two transects are done using the assumption of Collins and Walling *et al.* (2001). Since fingerprinting properties of any suspended sediment samples are dependent upon the corresponding properties in the source materials, the relative proportion of the source materials from downstream (DS) and (US) was estimated using the Mixing model (Equation 4).

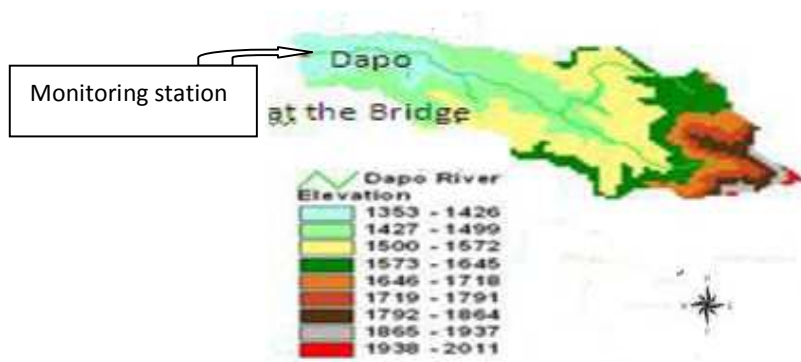


Figure 8: Points where the surface soil samples were taken in the DRC

Source: Brihanu Zemadin *et al.*, 2010

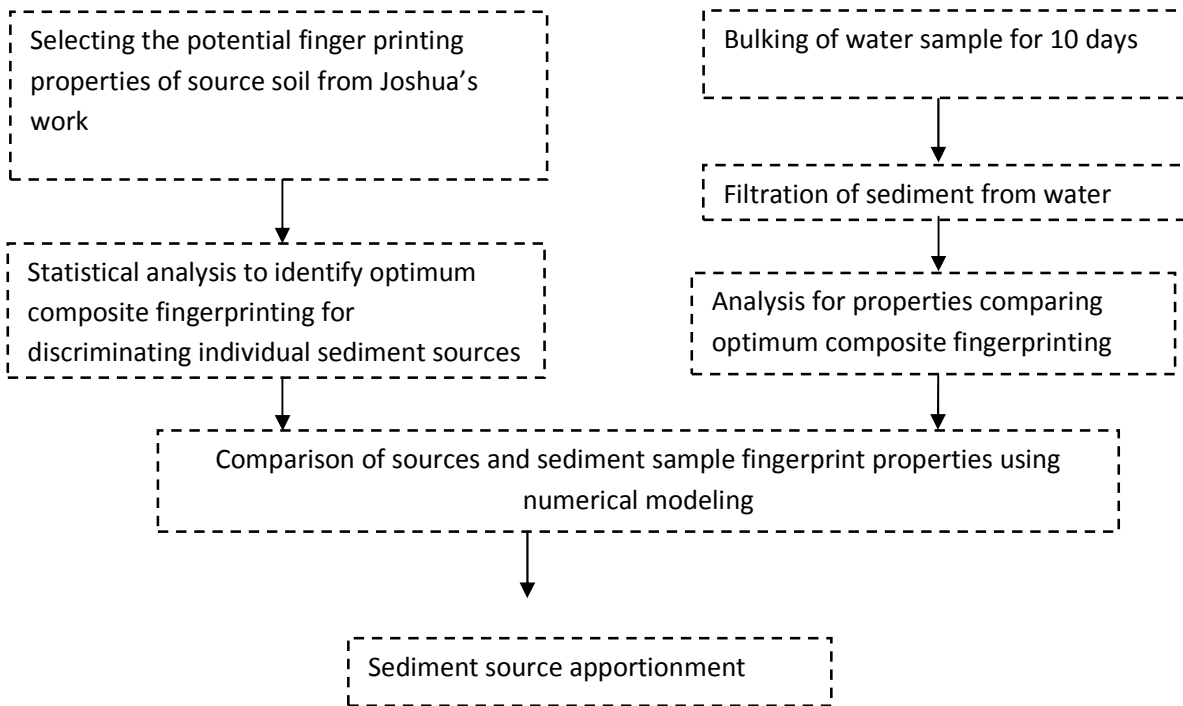


Figure 9: Summary of fingerprinting procedure of Walling and Collins (2002)

$$C_i = P_{su} \cdot S_{ug} \cdot Z_u \cdot O_u + P_{sd} \cdot S_{id} \cdot Z_{sd} \cdot O_{sd} \quad \dots \dots \dots \text{Equation 4}$$

$$0 < P < 1 \dots \dots \dots \text{Equation 5}$$

$$\sum_i^n P = 1 \dots \dots \dots \text{Equation 6}$$

$$R = \sum_{i=1}^n \left\{ \left[ C_i - (P_{su} S_{su} Z_u O_u + P_{sd} S_{sd} Z_{sd} O_{sd}) \right] / C_i \right\}^2 W_i \dots \dots \dots \text{Equation 7}$$

Where:

$C_i$  = concentration of fingerprint property  $i$  in each sediment sample collected from the catchment outlet

$P_s$  = relative contribution of each individual source type to the sediment sample ( $u$  = upstream transect and  $d$  = downstream transect)

$S_i$  = mean concentration of tracer property  $i$  for each individual source type

$Z$  = particle size correction factor (ratio of the specific surface area of the sediment sample to the mean specific surface area of each source type)

$O$  = organic matter content correction factor (ratio of the organic carbon content of the sediment sample to the mean organic carbon content of each source type)

$W_i$  = tracer-specific weighting reflecting the analytical precision.

### 3.2.9. Effects of Nutrient Loss

The amounts of N and P delivered to the outlet of the watershed with water and suspended sediment were estimated using Equation 8 and 9, respectively. The total N and P lost was estimated by adding the amount lost with water and that with suspended sediments (Equation 10). This was converted to financial loss, using the production loss technique of FAO (1999).

$$N_{wi} = N_{cwi} \times q_i(a), \text{ and } TN_w = \sum_{i=1}^9 N_{Li}(b) \dots \dots \dots \text{Equation 8}$$

$$N_{si} = N_{csi} \times SSL(a), \text{ and } TN_s = \sum_{i=1}^9 N_{si}(b) \dots \dots \dots \text{Equation 9}$$

$$GTN = (TN_w + TN_s) / A \dots \dots \dots \text{Equation 10}$$

Where;

$N_w$ : nutrient loss with water per decade (gm/d) (nitrogen/phosphorus)

$N_s$ : Nutrient loss with suspended sediment per decade (gm/d) (nitrogen/phosphorus)

$N_{cw}$ : nutrient concentration in water (gm/L) ((nitrogen/phosphorus)

$N_{cs}$ : nutrient concentration in suspended sediment (gm/Kg) (nitrogen/phosphorus)

$SSL$ : suspended sediment loss (Kg)

$q$ : discharge of the rivers per decade (L/d)

$A$ : area of the catchments (ha)

$i$ : decades

$TN$ : total nutrient loss (Kg) (nitrogen/phosphorus)

Grand total nutrient loss (Kg/ha) (nitrogen/phosphorus)

Since maize is among the major crop type in the watersheds, secondary data of maize grain yield response to N and P under similar agro-ecological condition were used to develop a yield response curve. Then, fertilizer yield response curve was developed by fitting the data into

quadratic relation (Equation 11) and then yield loss due to loss of available N and P were estimated using response equation.

$$Y=ax^2+bx+c.....\text{Equation 11}$$

Finally, local market price of maize was used to convert the loss in grain yield to finance loss incurred due to the loss N and P.

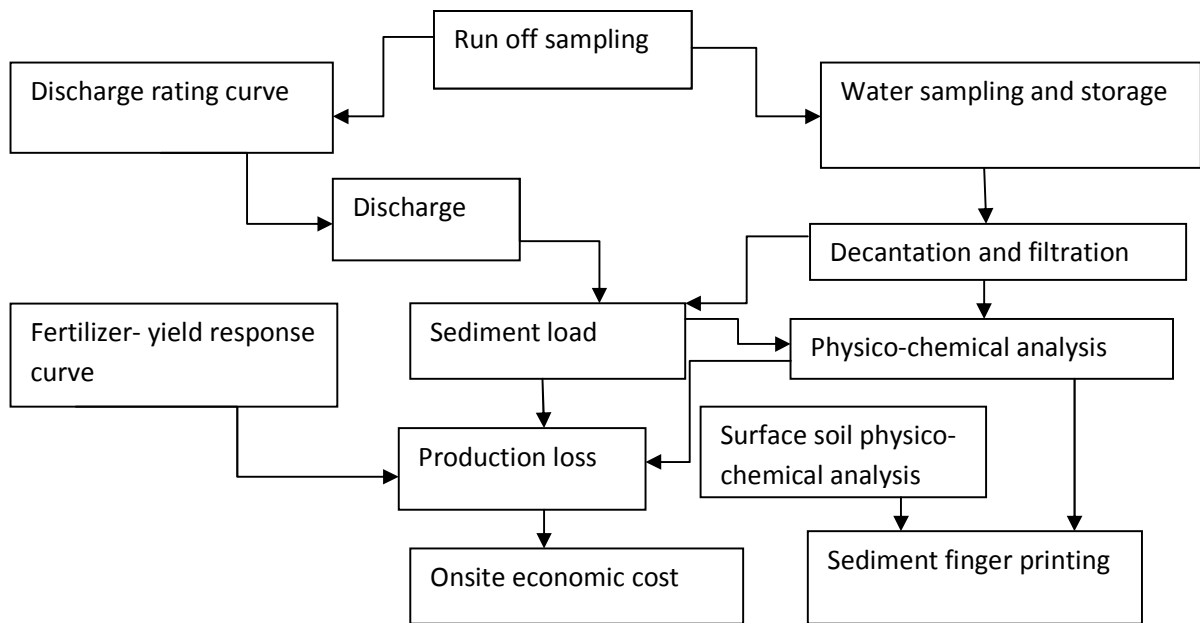


Figure 10: Schematic illustration of summary of overall methodology/procedure followed

### 3.3. Data analysis

Statistical comparisons were performed using both parametric and Non-parametric methods. Regression analysis between and within the two Rivers for SSL, Q and SSC were done. Significance of differences in sediment load, between the two watersheds at the gauging sites was determined by t- test at 95% confidence limit. The potential fingerprint properties were done using Kruskal–Wallis H-test for the two transects representing the lower and the upper stream of Dapo watershed and then multi-variate function analysis in particular Discriminate Function Analysis was done to discriminate or identify composite fingerprinting properties (TKN, P<sub>2</sub>O<sub>5</sub>, and N:C ratio) using step by step Wilk’s Lambda minimization. The data for these and various purposes were analyzed using SPSS and presented using Sigma-plot version 10 software.



## 4. Results and Discussions

### 4.1. Discharge

Water levels across the width of the Rivers and corresponding flows of water at different intervals were indicated in annex 4 and resulted power curves (Figure 11). According to Braca (2008) continuous measurement of flow past a river section is usually time consuming, impractical during flood event and prohibitively expensive. Using these stage-discharge relationship curve, it was estimated that the average flow discharge of DR were 0.64 and 0.24  $Mm^3d^{-1}$ (Table 4).

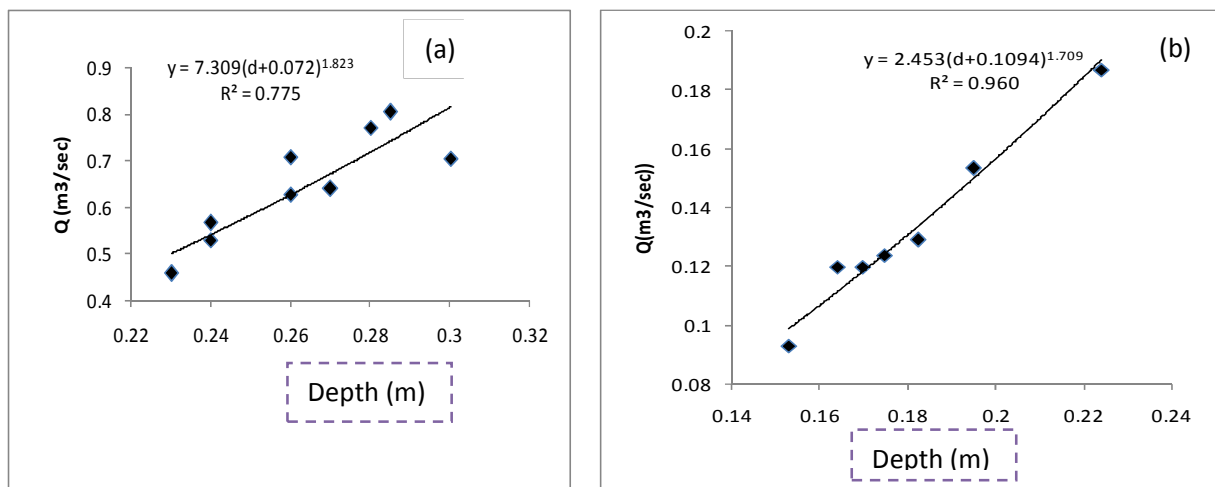


Figure 11: Discharge rating curve for DR (a) and CR (b)

Since water levels using staff gauge were measured throughout the study period, using this stage-discharge rating curve, total discharge for each decade of each month were estimated and presented under annex 5 and 6.

#### 4.1.1. Suspended sediment and its interaction with discharge

The timing of sediment transported and the differences in behavior between the two rivers have not been examined in detail previously. But, the study showed, the load maxima occurred during d7 following discharge maxima for Dapo River. Figure (12) and (13) showed a deficit in sediment concentration during high discharge decades which might be due to the effect of riparian zone (figure 15) or the uneasily erodibility of soil in the DRC compared to CRC. The regression analysis in table (4) of sediment concentration and discharge also shows the same result. Regarding Chekorsa River, sediment maxima coincide considerably with discharge

maxima. All of the SS maxima are associated with increases in discharge. As such, increase in discharge is very strongly related to TSS for CR than for DR.

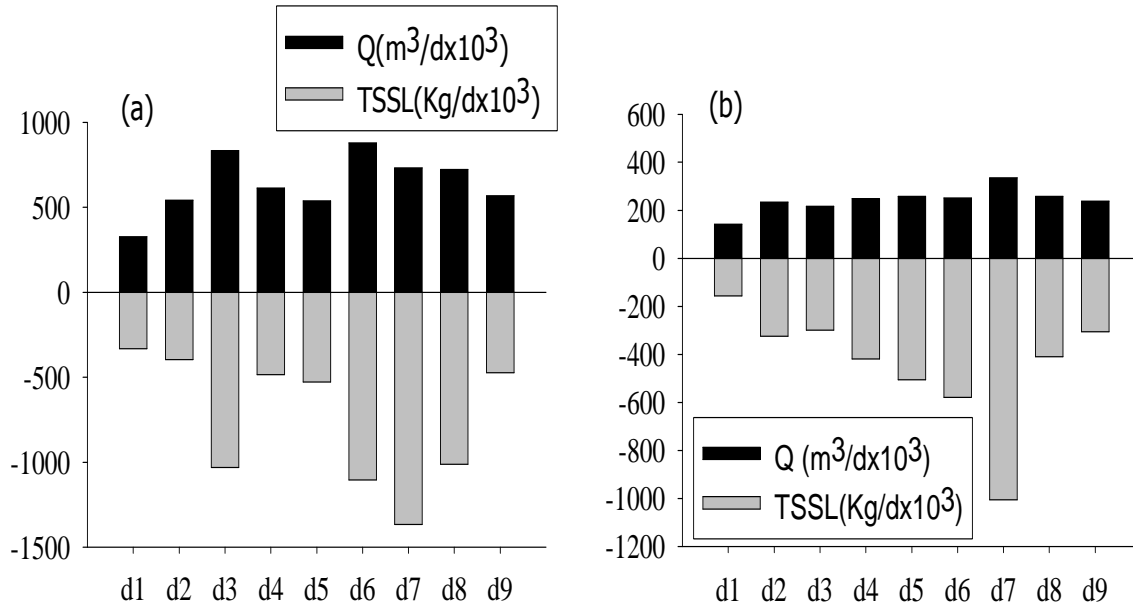


Figure 12: Trends of total suspended sediment change with discharge of DR (a) and CR (b).

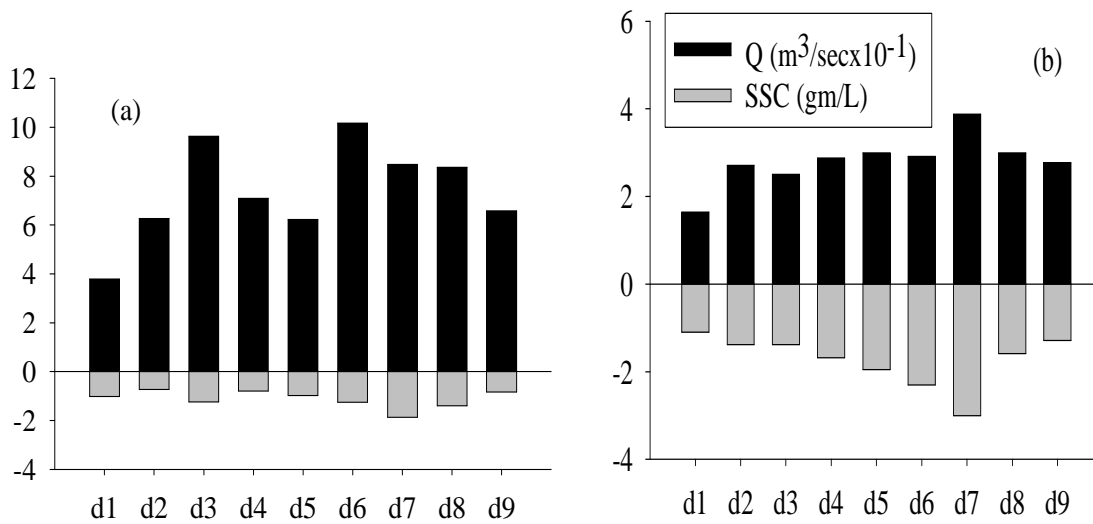


Figure 13: Changes of suspended sediment concentration with decade average discharge of Dapo (a) and Chekorsa Rivers (b)

Extreme short-term variations in sediment concentration and load (Figure 12 and 13). Some possible causes of these variations are soil erodibility, turbulent fluctuations of stream velocity, local dredging, and effect of the riparian zones and vegetation cover, size of the catchments, land use type and population density. So, further research is essential to investigate the effects of all these variables on soil erosion.

Comparing the two rivers, SSL of Chekorsa river is strongly related to discharge with a coefficient of determination ( $R^2$ ) 0.85, as compared to 0.7 for Dapo river. And from Figure 12 (a) we can easily observe that peak SSL occurred after the peak discharge. It might occur due to the availability of easily erodible sediment following the peak discharge during decade 6. It indicates that sediment became ready to be eroded after the peak discharge. Peter (2002) also stated that sediment transport rates are a function of sediment availability in addition to energy conditions.

T test between total discharge of each decade shows that there is significant difference between the two rivers. However, similar test for total sediment loss between the two rivers showed no significant difference in total sediment loss at  $P < 0.05$ . Almost equal amount of SSL was lost by the two rivers, though the total discharge for DR is much greater than that of CR. In addition, regression analysis between total discharges with SSC of each decade showed that CR has stronger relation ( $R^2 = 0.73$ ) than DR ( $R^2 = 0.29$ ). CR is taking away sediment in almost equal amount not due to its discharge but owing to its higher sediment concentration.

Table 4: Comparison of DR and CR with Statistical analysis

	Dapo River				Chekorsa River				t	
	Mean	SD	CV	R <sup>2</sup>	Mean	SD	CV	R <sup>2</sup>	value	p-value
Discharge										
(Mm <sup>3</sup> /d)	0.64	0.17	26.7	1	0.24	0.043	18.09	1	6.83	0
TSS (Tons/td)*	747.86	379	50.7	0.7	434	217	49.82	0.85	2.16	0.05
SSC(gm/L)	1.12	0.36	32	0.3	1.74	0.597	34.29	0.73	2.66	0.02
Soil loss(t/ha/d)	0.42	0.21	50.7	0.7	0.75	0.335	44.82	0.79	2.52	0.023

\*TSS: total suspended sediment loss per total decades (td)/study period

#### 4.2 Temporal variability of suspended sediment with discharge

Figure (14a) shows from decade 1 to decade 2, suspended sediment concentrations decreased considerably with the increased discharge. However, during d2 to d3 and d5 to d6 SSC increased with discharge. The trend of SSC showed in Figure 14b indicated that decade1 starts from the high point. It clearly depicts that the sediment concentration were high during land preparation though the study began after seed have emerged i.e. the sediment became available for transport before the event of d1. Several studies (for example Peter, 2002) had showed that the sediment availability is highest when soil surface is not protected by vegetation and during land preparation. As discharge decreased, SSC increased from d6 to d7 whereas from d7 through d9 SSC decreased. However, the sudden increase of the discharge to the highest level during the d6 resulted in high sediment availability during d7 from distant areas of the watershed. However, Figure (14a) indicates there is a steep increase in sediment concentrations with increasing discharge and substantial decrease in SSC with discharge. The figure also shows increase in SSC though discharge at d7 and most of d5 decreased but vise versa at d2.

With respect to substantial differences in discharge and sediment transport between decades, two types of Q-SSC hysteretic loops were identified for DR and CR differently (Figure 14a and Figure 16a). Ongley (1995) also found that sediment concentration relation is highly variable on an event-to-event scale. Relationship Q-SSC is characterized dominantly by anti-clockwise hysteresis two times though it is not clear clockwise hysteretic loops and clockwise hysteresis for CR. However, since short-term dynamics of storm events are important in sediment loading (Eder *et al.*, 2010), single event SSC hysteresis must be done to support this interpretation.

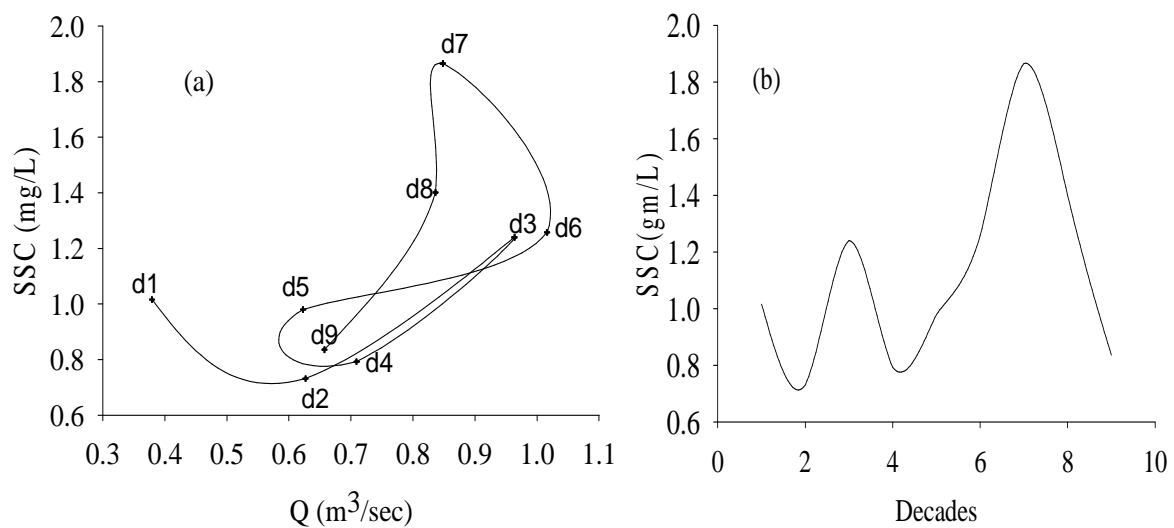


Figure 14: Relationship of SSC with Q (a) and Change in SSC with decade (b) of DR

The counter clockwise hysteresis and/or the variation in sediment concentration for the Dapo watershed can be interpreted in a number of ways. Firstly, it might be due to substantial cut down of rainfall then decrease in discharge up to d5. Secondly, due to the tabulated shift in sowing time of the major crop types (Annex 1) in the upstream to the major crop types of the downstream. These shapes of SSC and discharge were occurred with respect to the reasoning proposed by several authors. For example, Ongley (1996) remarked that during prolonged rainstorms, discharge and turbulence may remain high but there is usually a progressive decline in the quantity of suspended material in the water. Thirdly, it might be due to the source of eroded sediment is distributed uniformly over the entire catchment, and when the sediment supply is not easily eroded (Sander *et al.* 2011).

Fourthly, the sediment washed away from cultivated field (Figure15a) had been trapped to its maximum or over accumulated in the riparian zone (Figure 15b) and then washed away after the peak discharge event when the supply of sediment is not easily eroded. Lastly, Dapo watershed is larger in size; as such sediment could not be delivered promptly to the stream with the peak discharge. The studies on SSC hysteresis effect in Slovakia by (Peter, 2012) also indicate the same result



Figure 15: Photos showing accumulated sediment at the edge of cultivated field with teff (*Eragrostis tef*) and vegetation along the Dapo Stream serving as riparian zone.

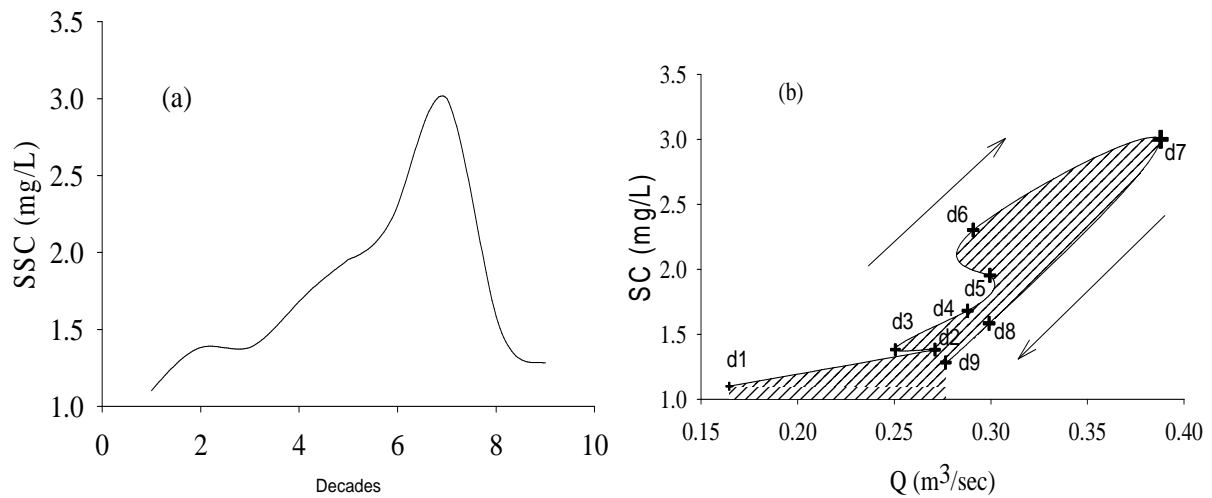


Figure 16: Change in SSC with decade (B) and relationship of SSC with Q (A) of CR

Hysteresis curves at Chekorsa showed clockwise patterns for the consecutive weekly based events (Figure16b). In this case, field evidences allow attributing the occurrence of clockwise hysteresis to the rapid displacement of sediment from source close to the stream. As it is mentioned earlier the size of chekorsa watershed is more than threefold less than that of dapo watershed. This implies that the sediment might have originated near to the river streams. Similar result were found by (Vanmaercke *et al.*, 2006) in Geba River Catchment of Northern Ethiopia and they suggested that this was probably related to sediment depletion. Clockwise loops most commonly occur when the sediment peak occurs before the water discharge peak and when there is a source of easily erodible sediment which can be rapidly depleted.

Relating the sediment concentrations to time were performed in this study during the occurrence of fully wetted and fully erodibility of all soil. As such, additional study must be conducted to find out the relation between the riparian vegetation and sediment concentration starting from the beginning to the end of rainy seasons to capture the effects of agricultural activities.

### 4.3. Plant nutrient loss from the watersheds by runoff

#### 4.3.1. Plant nutrient enrichment ratio

The concentration of OM, TKN and available P in the eroded sediment were greater than the surface soil. As shown in Table 5, the concentration of available P reaches up to greater than 2.7

and 9 time its concentration in some areas of the watershed in the DRC and CRC, respectively. This indicates that surface runoff is washing P in large amount to the water body. This is because of the largest concentration of P in the surface layers of the soil, and also the greatest concentrated hydrologic energy is on the soil surface (Zaimes and Schultz, 2002).

Table 5: Comparison of mean nutrient content of the surface, and sediment (Kg/ton) and enrichment ratio

Sub areas	surface soil (S)			Enrichment ratio (ss: s)		
	TKN	OC	P	TKN	OC	P
DDS	4.19	57.06	0.013	0.89	1.18	2.69
DUS	2.74	26.49	0.022	1.36	2.54	1.62
LD	2.58	20.47	0.002	0.95	1.5	8.99
DR (SS)	3.73	67.2	0.04			
CR (SS)	2.44	30.78	0.02			

The situation is much more severe for NO<sub>3</sub>-N and NH<sub>4</sub>-N since they are more leachable in addition to their wash away by runoff. So, if the dissolved inorganic nitrogen and phosphorus in the stream water were added to the TKN and the P<sub>2</sub>O<sub>5</sub> in sediment, the enrichment ratio (SS: S) may become even greater and much more for the other sub areas.

Correlation analysis (Anneex 11) shows there is a strong correlation between percent of clay to; phosphate (0.52), OC (0.68) and TKN (0.76). However, several investigations reported that washing away of clay particles have a great impacts on production as well as soil environment in several ways. For examples, Page, (1950) sand and silt are comparatively inert and act only as



diluents to the more active clay. Soil erosion selectively washes away soil of its fine particles clay and organic matter leaving less productive coarse sand and gravel behind. The higher the clay fraction the greater is the surface area of the soil available for sorption (Hutton *et al.*, 2008).

DRC is losing much more nutrient than CRC through greater SSC. For example, OC and P<sub>2</sub>O<sub>5</sub> concentration in SSC of DR was two times of CR (Table 5). Similarly, surface soils of DRC have greater soil fertility (Table 5). This result also support why soils with higher fertility status lose much more nutrients relative to those with a lower fertility status. Studies showed that the amount of nutrient lost was found to be strongly dependent on the nutrient status of the soil, i.e. the higher the status of a particular nutrient in the soil, the higher its loss with erosion.

Soil texture analysis shows that clay has been washed away to the streams in greatest percentage (annex 9). Therefore, if washing of clay particles continues in such a ways, it would exacerbate pressure on production, or costs of production, since it is taking nutrients since soils with higher clay content have more favorable chemical properties (Hutton *et al.*, 2008) than coarser textured soils.

#### **4.3.2. The severity of nutrient loss**

The classifications were based on FAO (1999) calcification for available nutrient loss. The result of classification signifies how much soil erosion alone is contributing for the very high nutrient loss classes reported of FAO (1999) for Ethiopia. However, the classification in the report had been based on the nutrient removal including other major means of nutrient removal such as crop residue removal, leaching evapo-transpiration, grazing etc.

Table 6: FAO (1999) severity classes of the loss available nutrients

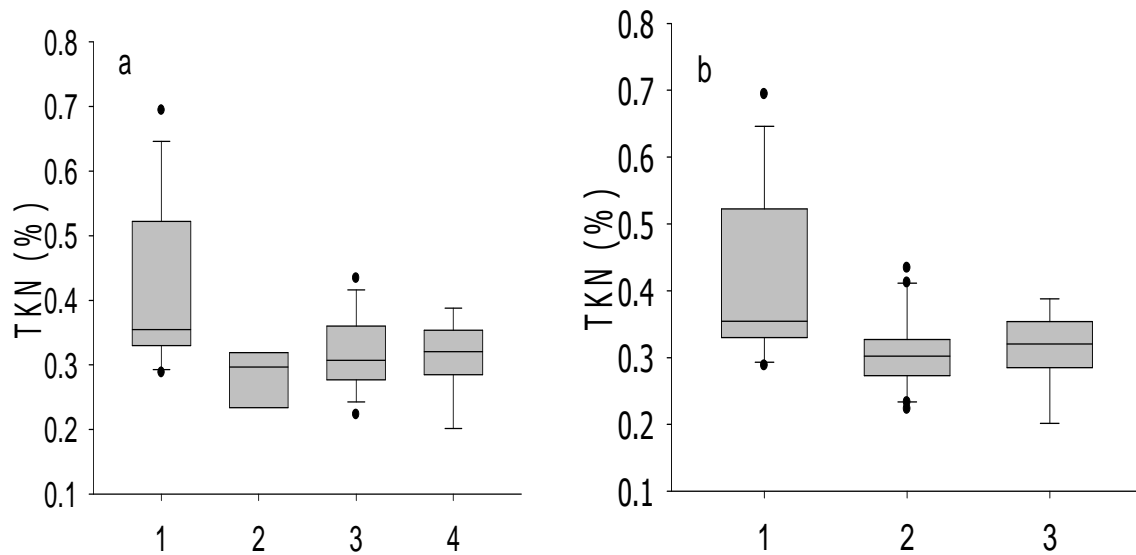
Available	Dapo catchment		Chekorsa Catchment		Loss left behind to be classified as high nutrient loss class (%)	
	Total loss	Severity class	Total loss	Severity class	DRC	CRC
N	13.58	Moderate	14.3	Moderate	35.4	30.6
P	9.31	High	4.20	Moderate	---*	47.5

Regarding nitrogen, Table 4 indicates only 35.4% and 30.6% of high nutrient loss rate class stated by FAO (1999) was left behind in DRC and CRC respectively to fall in the high nutrient loss rate class. As a result, though there are another means of soil nutrient loss, soil erosion alone had contributed about 64.6% and 69.4% high nutrient loss rate class by FAO (1999). So, Table 4 shows, According to FAO1999, if the amount of  $P_2O_5$  loss from cultivated land is between 4 and 7  $Kg^{-1}ha^{-1}yr$ , it should be classified as high nutrient loss class. Only by soil erosion  $P_2O_5$  has already attained the high soil nutrient loss rate class for Dapo (Table 6). On the other hand, in the CRC 52.53% was already attained the minimum amount  $P_2O_5$  loss to be classified as high  $P_2O_5$  loss CRC.

#### 4.4. Sediment fingerprinting

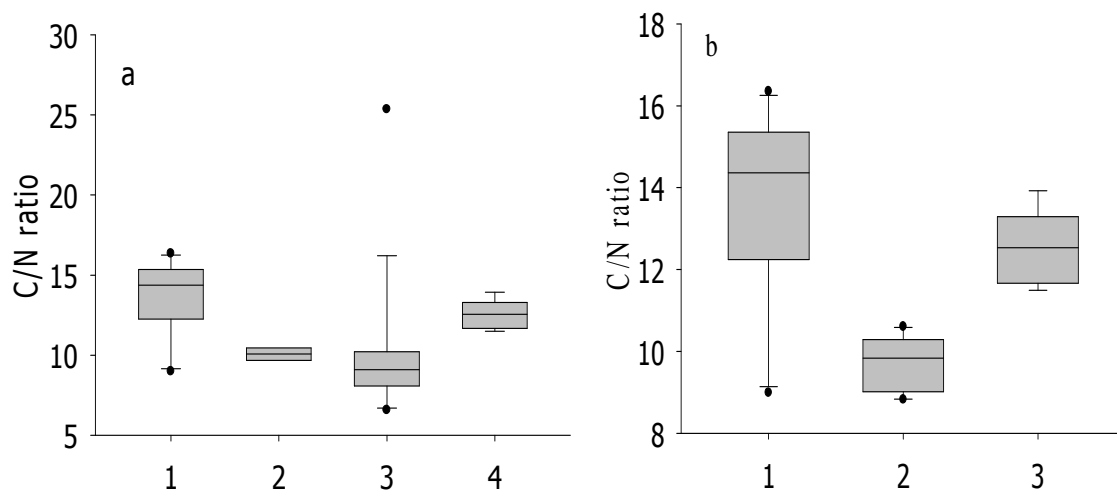
All tracers have values of H test significantly greater than 3.84. However, phosphorus couldn't accomplish the criteria of equation (5) of Collins *et al.* (1997) since  $P_i$  calculated was negative. Table (7) showed P has the greatest co-variation or standard deviation greater than mean value within each sub areas of the watershed though the difference of P between the two parts of the watersheds is significant with P value of 0.043. Figure 17a and 18a pin-point tracers' property (TKN% similar to C/N ratio) of surface soil of the upper and the middle transects have

equivalent concentration. So, sediment fingerprinting was illustrated with a better discriminations after the middle and the upper transects had been pooled figure 17b and 18b.



1, 2, and 3 represents Dapo downstream, middle transect, and upstream transect respectively, 4: Suspended sediment

Figure 17: TKN before (a) and after pooling (b) the upper two transect line respectively



1, 2 and 3 represents Dapo downstream, middle transect, and upperstream transects respectively, 4: Suspended sediment

Figure 18: Before (a) and after pooled (b) C: N ratio of surface soil and the sediment

Table 7: The result of Kruskal–Wallis  $H$  test

Tracers	Downstream			Upperstream			H- value	P- values
	Mean	Std	CV%	Mean	Std.	CV%		
OC (%)	5.708	2.257	39.549	3.111	1.753	56.346	21.49*	0.000
P(mg/Kg)	13.374	17.218	128.742	23.014	26.546	115.347	4.08*	0.043
TKN (%)	0.419	0.126	30.138	0.310	0.056	18.205	8.67*	0.003
C:N	9.890	3.585	36.26	13.545	2.350	17.34	14.36*	0.000

Critical  $H$  value = 3.84, \*significant at  $p < 0.05$

The relative percentages of sediment were calculated using equation (4, 5, and 6) and presented in Table 8. The calculated errors (R) in Table 8 indicate C: N ratio estimated the relative contribution of sediment with minimum error though R value for TKN was also low.

Table 8: The result of step wise DFA

Fingerprint properties	Wilks Lambda	Percent of source type classified correctly	Upland (%)	Lowland (%)	R*
P	0.558	50	----	----	----
TKN	0.554	68.4	63	37	0.0062
C:N	0.541	86.8	56.51	43.49	0.0025

\* Sum of square of the weighted relative error

The results of step wise DFA in Table 8 pinpoints all properties accepted by kruskal Wallis  $H$  test. The three parameters in Table 8 are therefore optimum composite fingerprint for

discriminating sediment sources type in the DRC. It comprises from the weakest to the strongest in order to distinguish the source type correctly. The optimum composite fingerprints was capable of potentially classify 86% of the source material. Consequently, the associated values of Wilks' Lambda are lower for C: N ratio. This result shows if other more fingerprint properties would be analyzed both for sediment and the source type, better composite signatures associated with Wilks' lambda values closest to zero and are capable of correctly distinguishing 100% of the source type samples for the study catchment can be obtained.

For this study only organic carbon correction factor was used assuming particle size distribution influence in the Mixing model is equal since silt to clay ratio are more or less the same i.e. 0.82 and 0.76 for the downstream and upstream respectively. Likewise, t test also showed no statistically significant difference between two transects at  $P \leq 0.05$  (P value equals 0.180) and the textural class of the two areas is also the same. In order to estimate the accuracy of the measurements of tracer properties, the tracer specific weighting ( $W_i$ ) provided by (Collins *et al.*, 1997) were used which are 0.623 and 0.459 for N and P, respectively.

Three of the four tracers, were used in the mixing model calculation. The result showed the mean values of the relative contribution of the two source areas (Table 8) indicates that the contribution of the upper sources area is greater than the downstream to the sediment load of DR, with values ranging from 37% to 67% using TKN, and 43.5% and 56.5% using OC: N ratio. However, using of C: N ratio, the relative percentage of sediment source of sediment load from the two subareas only vary in low percentage with minimum error of 0.0025 (Table 8). It might be due to the relative variation in the size of the cultivation land area from the downstream to the upstream. The land use land cover showed in Figure 6 indicates that the size of cultivated land of the low land is smaller than upper part of the catchment. However further studies need to be conducted in order to distinguish the causes of the relative sediment contribution percentage difference of the source areas from decade to decade.

Several research findings indicated decline in organic matter makes the soil more susceptible to erosion for example (Evans, 2006). The study also shows more sediment is coming from the

upper where surface soil has lesser organic matter, i.e. 5.71% and 3.05% of organic carbon for the lower and the upper stream respectively (Annex 10).

#### **4.4.1. Decade to decade variation of sediment source areas**

Furthermore, fingerprinting tasks were done in order to investigate the fluctuation of the relative contributions from individual source types. The analysis of fingerprinting showed mean contributions of each source type for each decade. Figure 19 indicates the relative contribution of suspended sediment of the upper stream was higher than the lower stream. Comparatively, during d2, d4 and d7 greater sediment contribution peaks were from lower stream though in a much lesser sediment contribution peaks of upstream d1, d3, d5, d6 d8 and d9 (Figure 19). These relative sediment contribution from the two part of Dapo catchment showed on the Figure 19 is significantly different i.e. greater contribution is from the upper stream, with  $P \leq 0.005$ .

The fluctuation of the relative sediment contribution of the upper and lower were most probably due to the shifting in agricultural activities from the lower to the upper. The high altitude crops of the district identified under Annex 1 and Figure 6 were dominant in the upper part of the watershed. As a result, starting from June 20, land preparations, sowing were to some extent more dominant in the upper catchment (Annex 1). Teff and Niger-seed (*Guizotia abyssinica*) located in the upper part. The major crops grown in the upper part are sown between 28 July and 10 August (Annex 1). During this period more agricultural activities such as land preparation and sowing are undertaken in the upstream than the downstream.

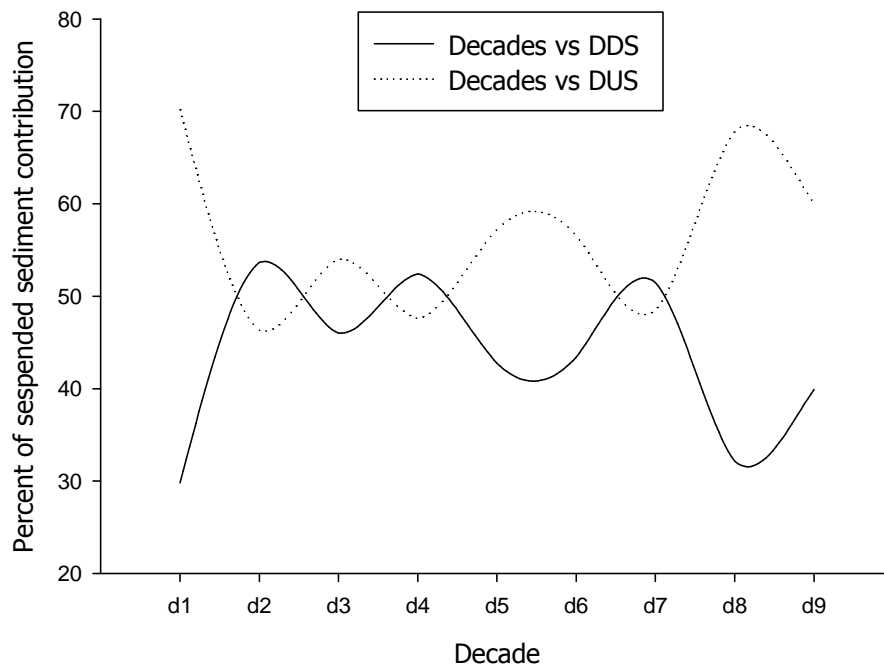


Figure 19: Sediment contribution percentage from the two source types for each subsequent decade

#### 4.5. Costs of nutrient loss

According to Gruhn *et al.* (2000), and Lakew Desta, (2000) soil fertility loss by erosion are the main ways for nutrient outflow from a watershed where as fertilizer application is the main means of nutrient inflow to a watershed. However, most farmers in the study area maintain the fertility of their soil by manuring using night corralling (Annex 3), fallowing and shifting cultivation. Yet, several natural and socioeconomic factors are involved in aggravating the decline in soil productivity by enhancing nutrient outflow. Table 9 indicates soil erosion by runoff is removing topsoil enriched in essential macro-nutrients (N and P).

Table 9: Amount of N and P loss (kg) in each decade from DR and CR during the study period

Nutrients	Site	d1	d2	d3	d4	d5	d6	d7	d8	d9	Mean	SE
N	CR	0.7	1.3	1.2	1.7	1.6	1.9	2.1	2.0	1.8	1.6	$\pm 0.14$
	DR	1.0	1.2	1.4	2.0	1.4	2.6	1.5	1.3	1.0	1.5	$\pm 0.17$
P	CR	0.3	0.5	0.2	0.5	0.7	0.6	0.6	0.3	0.3	0.4	$\pm 0.06$
	DR	0.5	1.0	0.8	1.3	0.8	1.7	1.4	1.2	0.6	1.1	$\pm 0.13$

From the measured run off and the rate of sediment losses, the macro nutrient losses with erosion per hectare were indicated on Table 9. The estimated macro nutrients in Table 9 were used as a bridge to the estimated monetary value of onsite economic cost of the lost nutrients in Table 10.

$R^2$  of graph 20 shows a wide variation of yield response to the almost equivalent amount of fertilizer rate. Wakene Negassa, *et al.* (2005) pinpointed the high variation of maize yields on control plots on farmers' fields ranges from  $<1.0 \text{ t ha}^{-1}$  at to almost  $6.0 \text{ t ha}^{-1}$  which was attributed the differences in cropping history, cropping systems, land management and variations in socio-economic circumstances of the farmers.



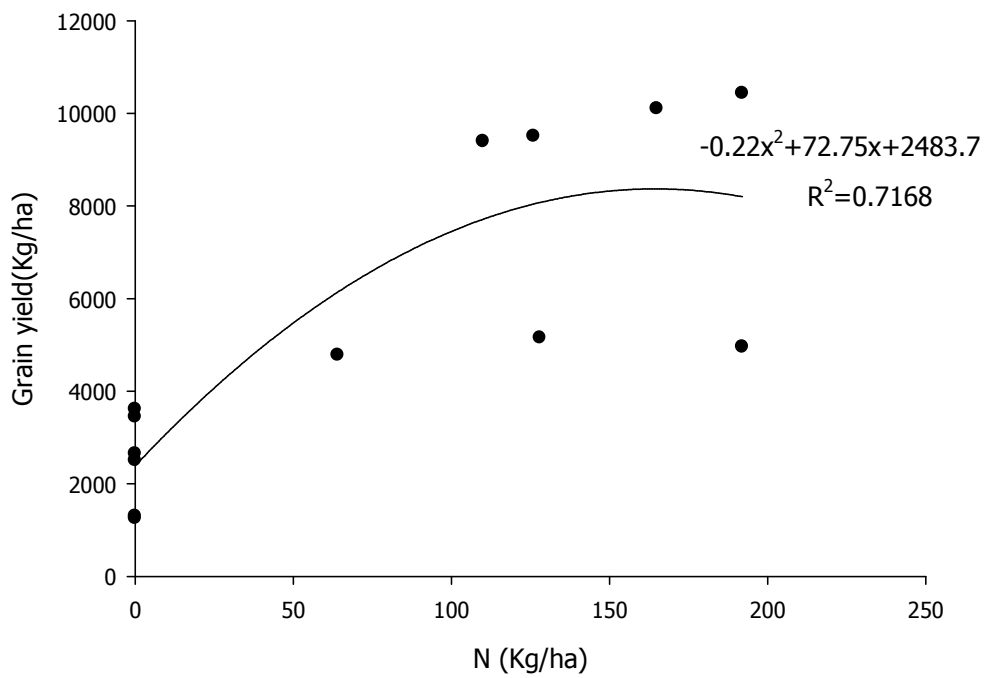


Figure 20: Response of maize grain yield to nitrogen application rate

Equations of graph 20 and 21 represents the yield response curves showing the trend of yield increment for different rates of additional N and P application.

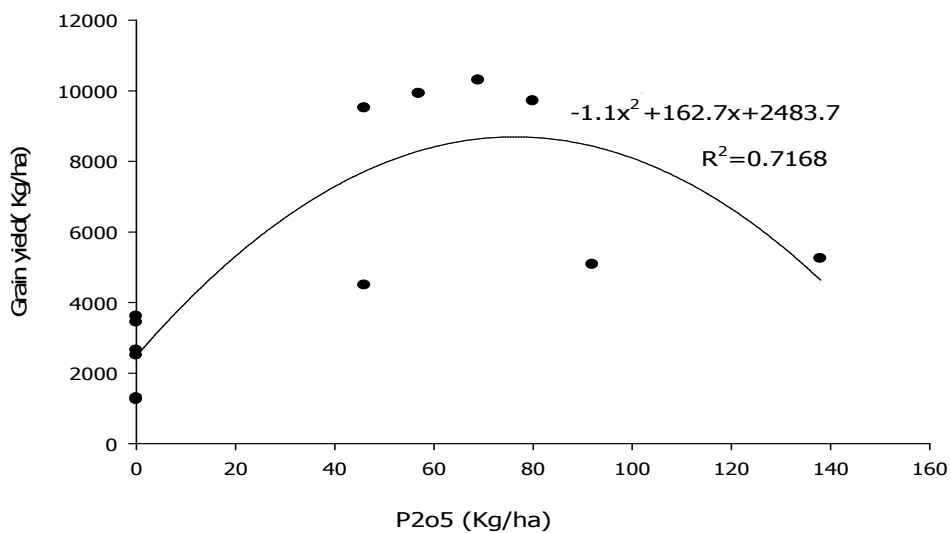


Figure 21: Grain yield response curve of maize to phosphorus rate around BARC

Mean grain yield with no N and P fertilizers were 2389.3 and 2483.7 Kg $ha^{-1}$  (Table10). Therefore, lost net maize grain yield due to the loss of available N and P $2O_5$  were about 949 and 11421kg $ha^{-1}$  from Dapo catchment whereas 1013 kg $ha^{-1}$  and 664 kg $ha^{-1}$  from Chekorsa catchment in that order (Table10). Farmers in the study area were lost about 3321 and 4975 Birr $ha^{-1}$  from Dapo catchment while 3546 and 2324 Birr $ha^{-1}$  from chekorsa catchment only owing to the loss of N and P respectively. Yield declining due to erosion follows a curvilinear, negatively exponential (FAO, 1999). So, eventually the current decline of yield will possibly reach a worst stage where there is no observation in yield decline anymore.

Table 10: Estimated monetary value of available nutrient loss by the two Rivers

Step	Estimated	Dapo catchment		Chekorsa Catchment	
		N	P	N	P
1	Total Lost/ha	13.6	9.3	14.3	4.1
2	Potential grain yield response (Kg/Ha)	3338.1	3905.1	3402.4	3147.6
3	Mean grain yield with no P and N fertilizer*	2389.3	2483.7	2389.3	2483.7
4	Net yield (Kg/ Ha)	948.8	1421.4	1013.1	663.9
5	Total price (Birr/ha)**	3320.8	4974.9	3545.9	2323.7

\* Using Figure 12 and 13 equations accordingly

\*\* Since market price of maize at Nekemte is 3.5Birr $Ha^{-1}$

However, (Wakene Negassa *et al.*, 2005) found that the relatively common practice of sole application of low rate of NP fertilizers has not sustained maize production and productivity in the region i.e. mixing with manure/compost gives a better yield. So, if OC and TKN loss were applied the potential yield estimated would be much greater than the above calculated amount. As it is depicted on Annex (12), yield declining due to erosion follows a curvilinear, negatively exponential form (FAO, 1999). As a result, it is clear that there will be a sharp decline of yield much more than the current status of productivity. Furthermore, if the loss of the essential nutrient continues in such a way, it will possibly reach a stage where there is no decline in yield.

## **5. Conclusion and Recommendations**

Results revealed that suspended sediment concentration and suspended sediment load are strongly related to the occurrence of discharge or flood events for Chekorsa River Catchment than Dapo River Catchment which might be due to the effect of the riparian zone (the natural vegetation along the side of the river) along the Dapo River. Chekorsa River is taking away sediment in almost equal amount, though the total discharge for Dapo River is about 3 times greater than Chekorsa. So, this was owing to the higher sediment concentration per liter of Chekorsa River (1.1 mg/L) than Dapo River (1.7mg/L).

So as, in Dapo River Catchment, the suspended sediment concentration was mostly controlled not only by the occurrence of intense discharge events but also by the availability of sediment in the nearby riparian zone. However, additional studies must be conducted in order to assess the capacity of the Dapo River riparian zone. Regression analysis between suspended sediment transported and discharge revealed that suspended sediment concentrations at the high discharge event scale were controlled by the dominant runoff generation process for Chekorsa River Catchment than that of Dapo River.

Fixed interval runoff samples were assessed for its discharge-suspended sediment concentration. And it produced known hysteretic discharge loops and produced an overlapped anticlockwise hysteresis for Dapo River Catchment and clockwise hysteresis relationships for Chekorsa River. In the Dapo River, there was a time when substantial amount of sediment was available to be delivered to the river. Otherwise the hysteresis relationship indicated the soil of the catchment was not easily delivered to the river which might be due to the influence of the riparian zones. But, in the Chekorsa River Catchment the relationship between suspended sediment concentration and discharge showed the soil of the catchment was being easily eroded and delivered to river. In order to understand better, similar studies must continue in the catchment including event based sediment hysteresis assessment in order to compare it with the weekly based sediment hysteresis.

Soil texture analysis showed that clay has been washed away to the streams in a greatest percentage (annex 9). Correlation analysis (Annex 11) showed that there is a strong correlation

between percentage of clay with phosphate and TKN. The result of the classification signifies the extent of soil erosion alone is contributing for the very high nutrient loss classes reported by FAO (1999) for Ethiopia.

All the four tracer properties i.e. organic carbon, nitrogen, carbon to nitrogen ratio and phosphorus, showed clear distinctions between the upland transect and the downstream transect of the Dapo watershed. The difference of the relative percentage contribution of sediment source type from the lower and the upper part of the watershed to the stream in the Dapo River Catchment is significant. The difference was attributed to the shift in agricultural activities from the lower to the upper during the study period. Therefore, application of a mixing model approach to investigate sediment sources in the catchment under different agronomic practices and with different geomorphic characteristics provides valuable information for land management planning. Soil and water management planning and nutrient management for the two sub-areas should not necessarily be the same for better efficiency. The study has incorporated the loss of productivity as a result of both dissolved and sediment-sorbed fertilizer transported in overland flow delivered to the monitoring station.

In addition, from the result of the study it is possible to conclude and recommend that;

- The rate of phosphorus loss was 9 times in the sediment than that of the surface soil.
- Further P application showed a clear decrease in grain yield than more N application rate which might be due to cultivation lands around the study area has high N deficiency than P.
- The Monetary value of the lost nutrient could ignites the local farmer if awareness creation would be conducted for sustainable nutrient management and soil conservation activities.
- The results of onsite economic cost will help farmers and local District officers to emphasize surface erosion control over other aspects of degradation and productivity improvements.
- Study is not only important to understand trends of sediment and nutrient loss but also to help in defining the type and extent of interventions required in soil and water conservation practices.

- Since yield declining due to erosion follows a curvilinear, negatively exponential, the current decline in yield will eventually reach a worst stage where there is no more yield decline.
- The results give initial information/data to warm up SWAT and NUTMON model some areas of sediment data and nutrient depletion valuation in terms of monetary value respectively
- The study helps to understand the processes and cause of nutrient loss at a micro watershed level and to implement INM (e.g., water management, organic matter enhancement, or broad improved land management) and watershed management interventions.
- Given the very diverse agro-climatic conditions, similar studies in Abay basin and limited research findings in the basin, general estimations could be made and then extended to the whole basin.

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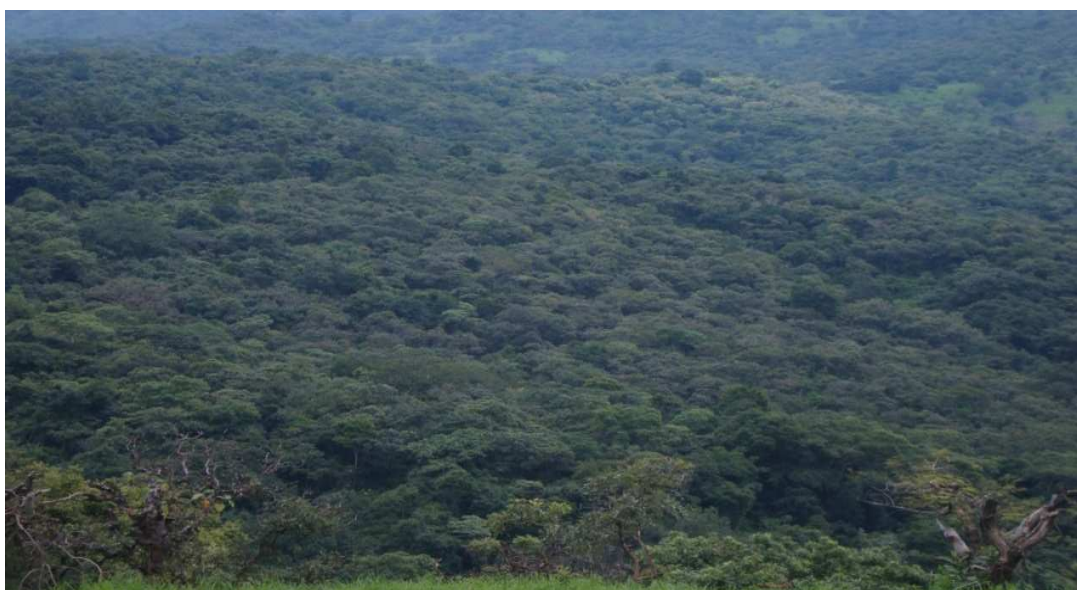
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## 7. Appendices

Annex 1: Major crop type in the upper and lower part of the watershed and their planting and harvesting date

Crops	Lower		Upper	
	Planting date	Harvesting date	Planting date	Harvesting date
Maize	3 May11	13 Oct11		
Sorghum	13 May11	30 Dec11	1May11	5 Jan 11
Sesame	25 May11	15 Nov11		
Finger millet	15July11	27 Dec 11	20 June11	30Dec11
Teff			28 July11	10 Dec 11
Niger seed			10Augst11	25Dec11

Annex 2. Natural forest coverage in the upper part of DRC



Annex 3: Cultivation of deep slope on the upper stream and corallo practice as manuring



Annex 4:Depth and cross sectional area of Dapo River

Date	Depth of water (m) at a width(m) of									Cross sectional area(m <sup>2</sup> )at a width (m) of							
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4
05/12/03	0.28	0.29	0.24	0.29	0.33	0.24	0.32	0.39	0.31	0.14	0.13	0.13	0.16	0.143	0.32	0.178	0.175
09/12/03	0.24	0.2	0.3	0.36	0.39	0.36	0.38	0.37	0.4	0.11	0.13	0.16	0.19	0.188	0.185	0.188	0.2075
10/12/03	0.31	0.33	0.37	0.37	0.32	0.31	0.32	0.39	0.35	0.16	0.18	0.19	0.17	0.158	0.158	0.178	0.185
11/12/03	0.35	0.29	0.32	0.33	0.29	0.3	0.3	0.34	0.31	0.16	0.15	0.16	0.15	0.148	0.15	0.16	0.1625
13/12/03	0.2	0.34	0.37	0.25	0.26	0.26	0.3	0.3	0.25	0.14	0.18	0.16	0.13	0.13	0.14	0.15	0.1375
14/12/03	0.32	0.3	0.29	0.32	0.3	0.25	0.25	0.25	0.25	0.16	0.15	0.15	0.16	0.138	0.125	0.125	0.125
16/12/03	0.25	0.24	0.29	0.26	0.23	0.25	0.24	0.25	0.29	0.12	0.13	0.14	0.12	0.12	0.123	0.123	0.125
18/12/03	0.25	0.3	0.19	0.25	0.29	0.25	0.27	0.2	0.22	0.11	0.1	0.1	0.13	0.133	0.118	0.113	0.1175
20/12/03	0.29	0.32	0.34	0.34	0.32	0.33	0.33	0.34	0.35	0.15	0.17	0.17	0.17	0.163	0.165	0.168	0.1725

Annex 5: Dapo hydrological data of average velocity and discharge

Date	Average water velocity (m/sec) at 0.4xdepth of water at								Average discharge (m3/sec)								Total Q	GR
	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4		
05/12/03	0.510	0.550	0.475	0.404	0.524	0.577	0.502	0.499	0.07	0.073	0.063	0.063	0.075	0.185	0.089	0.087	0.707	0.260
09/12/03	0.724	0.668	0.515	0.524	0.602	0.610	0.602	0.591	0.08	0.084	0.081	0.098	0.113	0.113	0.113	0.123	0.803	0.285
10/12/03	0.580	0.635	0.566	0.577	0.633	0.564	0.504	0.462	0.09	0.111	0.105	0.100	0.100	0.089	0.089	0.085	0.771	0.280
11/12/03	0.548	0.499	0.470	0.546	0.497	0.464	0.533	0.561	0.09	0.076	0.076	0.079	0.073	0.070	0.085	0.091	0.639	0.270
13/12/03	0.557	0.571	0.577	0.564	0.533	0.510	0.519	0.517	0.08	0.101	0.089	0.072	0.069	0.071	0.078	0.071	0.627	0.260
14/12/03	0.543	0.562	0.549	0.482	0.464	0.471	0.471	0.471	0.08	0.084	0.082	0.075	0.064	0.059	0.059	0.059	0.566	0.240
16/12/03	0.604	0.566	0.549	0.542	0.500	0.466	0.515	0.520	0.07	0.075	0.069	0.066	0.060	0.057	0.063	0.065	0.529	0.240
18/12/03	0.535	0.539	0.530	0.526	0.464	0.471	0.454	0.385	0.06	0.054	0.054	0.066	0.069	0.060	0.051	0.045	0.457	0.230
20/12/03	0.466	0.559	0.597	0.493	0.521	0.573	0.535	0.517	0.07	0.092	0.101	0.081	0.085	0.094	0.090	0.089	0.704	0.300



Annex 6: Chekorsa's collected hydrological data

Date	Water level(m) at			Cross sectional area (m2)at				Average velocity (m/sec)				Average discharge (m3/sec)				TQ	GR
	S1	M	S2	0-S1	S1-M	M-S2	S2-edge	0-S1	S1-M	M-S2	S2-edge	0-S1	S1-M	M-S2	S2-edge		
8/12/03	0.147	0.300	0.138	0.062	0.140	0.131	0.065	0.374	0.403	0.388	0.344	0.023	0.057	0.051	0.023	0.153	0.19
10/12/03	0.107	0.327	0.113	0.045	0.135	0.132	0.054	0.256	0.355	0.392	0.329	0.012	0.048	0.052	0.018	0.129	0.18
12/12/03	0.123	0.273	0.127	0.052	0.125	0.120	0.060	0.301	0.357	0.367	0.321	0.016	0.045	0.044	0.019	0.124	0.17
15/12/03	0.108	0.297	0.103	0.046	0.127	0.120	0.049	0.291	0.364	0.373	0.310	0.013	0.046	0.045	0.015	0.120	0.17
16/12/03	0.113	0.27	0.142	0.048	0.111	0.114	0.067	0.317	0.329	0.368	0.394	0.015	0.036	0.042	0.027	0.120	0.16
17/12/03	0.106	0.243	0.108	0.045	0.110	0.106	0.051	0.244	0.305	0.322	0.279	0.011	0.034	0.034	0.014	0.091	0.15
20/12/03	0.140	0.350	0.182	0.060	0.154	0.160	0.087	0.324	0.429	0.444	0.354	0.019	0.066	0.071	0.031	0.187	0.22

Annex 7: SSL and Q for dapo and Chekorsa Rivers

d	Total Q Mm3/d		Average V m3/sec		SSL Mt/d		SSC mg/L		Soil loss t/ha/d	
	DR	CR	DR	CR	DR	CR	DR	CR	DR	CR
1	0.328	0.142	0.379	0.165	332.75	190.792	1015.730	941.870	0.190	0.340
2	0.541	0.234	0.627	0.271	395.98	272.470	731.420	1163.430	0.220	0.470
3	0.832	0.216	0.964	0.250	1032.10	299.291	1239.780	1382.860	0.580	0.530
4	0.613	0.249	0.709	0.288	485.67	418.477	992.700	1681.840	0.270	0.750
5	0.538	0.259	0.623	0.300	527.15	505.541	979.640	1953.680	0.290	0.900
6	0.878	0.251	1.016	0.291	1104.29	578.812	1257.890	2302.860	0.610	1.030
7	0.733	0.350	0.848	0.350	1366.44	906.786	1865.110	3001.900	0.760	1.430
8	0.722	0.258	0.836	0.299	1012.09	409.570	1400.930	1585.000	0.560	0.730
9	0.568	0.239	0.657	0.277	474.315	306.595	835.300	1283.030	0.260	0.550

Annex 8: Readymade Water and sediment sample for chemical analysis



Annex 9: Total essential nutrient loss with sediment and discharge

Code	Essential nutrient in the TSLKg/d in sediment					Texture				Total essential nutrient kg/TQ/D		
	TKN	NO3-N	NH4-N	P2O5	OM	Sand	Silt	Clay	Class	NH3-N	NO3-N	PO4
d1	771.4	17.5	88.5	38.7	21715					141.1	784.9	1064.7
d2	1775.1	27.9	199.4	39.5	43449.5					187.4	1605.2	2075.1
d3	3140.6	65	281.8	83.5	73210.7	22	23	55	Clay	163.8	1679.1	1595
d4	1485	15.3	142.8	22.9	37696.3					150.2	2999.7	2807.9
d5	1611.8	18.5	184.5	60.5	35017.8					136	2003.9	1479.8
d6	5083.9	83.3	450	162.7	109871	22	18	60	Clay	203.6	3511.6	3292.1
d7	3216.8	38.9	318.6	93	78394.5					122.3	1957.6	2747.4
d8	2786.4	39	308.2	46.2	48124.3					180.3	1606.7	2467.9
d9	1391.9	16.7	152.4	42	35.2	25	19	56	Clay	107.9	2476.9	1088
c1	513.64	64.11	7.35	15.63	10272.8					47.97	306.41	225.08
c2	1180.34	166.7	21.28	59.76	27634.8					69.49	561.14	331.62
c3	559.11	82.44	8.32	11.31	10740.8	22	20	58	Clay	55.41	511.21	162.32
c4	633.67	136.2	13.18	70.26	22531.9					76.84	767.86	290.13
c5	839.12	145.1	24.77	65.5	31461.6					69.37	669.16	409.62
c6	1005.21	229.3	29.59	64.68	42857.4	9	30	61	Clay	68.21	779.92	418.74
c7	1555.7	207.1	18.41	36.5	31114.1					50.61	794.22	405.12
c8	574.75	111.1	13.88	54.01	17941.7					82.35	908.8	172.09
9	444.26	96.55	8.59	22.61	17708.7	11	32	57	Clay	67.75	877.47	218.89

\*code stands for D: Dapo river, the first digit: decade(10 consecutive days), the second digit:

Month(e.g D11: sample taken from Dapo River for the first decade of the first month of the study period.

Annex 10: Tracers properties for the three transects and the sediment

T. pts	Downstream				Midle				Upperstream				Sediment			
	TKN(%)	OC(%)	P(PPM)	C/N	TKN(%)	OC(%)	P(PPM)	C/N	TKN (%)	OC(%)	P(PPM)	C/N	TKN(%)	OC(%)	P(PPM)	C/N
1.00	0.35	4.94	5.40	14.23	0.30	2.87	7.14	9.66	0.25	2.44	15.26	9.85	0.27	3.79	50.83	13.92
2.00	0.29	4.71	2.40	16.35	0.30	3.18	7.40	10.45	0.28	2.50	8.04	9.04	0.36	4.11	28.18	11.49
3.00	0.35	4.63	3.00	13.07	0.32	3.22	20.96	10.08	0.30	2.69	7.44	8.96	0.34	4.11	35.32	12.27
4.00	0.40	6.11	2.60	15.40	0.33	3.36	27.64	10.24	0.30	2.91	2.40	9.70	0.39	4.50	20.61	11.62
5.00	0.36	5.22	44.40	14.69	0.23	2.06	13.00	8.82	0.22	2.38	34.80	10.68	0.31	3.85	50.10	12.60
6.00	0.34	4.23	8.00	12.62	0.26	2.79	6.30	10.60	0.31	2.79	17.80	9.08	0.32	4.02	44.78	12.54
7.00	0.35	5.03	20.80	14.49	0.23	2.30	3.24	9.83	0.28	2.67	15.04	9.63	0.35	4.10	36.60	11.71
8.00	0.47	4.39	2.90	9.29	--	--	--	--	0.31	3.18	39.44	10.35	0.20	2.76	19.92	13.69
9.00	0.69	11.21	0.90	16.15	--	--	--	--	0.29	2.93	12.14	10.07	0.30	3.84	34.57	12.89
10.00	0.31	3.49	39.80	11.12	--	--	--	--	0.36	2.73	7.58	7.49	--	--	--	--
11.00	0.51	4.59	2.60	8.99	--	--	--	--	0.32	2.13	6.92	6.56	--	--	--	--
12.00	0.56	8.32	46.80	14.89	--	--	--	--	0.41	2.86	3.88	6.96	--	--	--	--
13.00	0.60	9.17	7.00	15.34	--	--	--	--	0.41	2.77	82.64	6.72	--	--	--	--
14.00	0.30	3.87	0.64	12.98	--	--	--	--	0.43	11.00	108.84	25.35	--	--	--	--
15.00	--	--	--	--	--	--	--	--	0.36	3.10	51.44	8.69	--	--	--	--
16.00	--	--	--	--	--	--	--	--	0.32	2.72	29.98	8.64	--	--	--	--
17.00	--	--	--	--	--	--	--	--	0.27	3.79	50.83	13.92	--	--	--	--
Mean	0.42	5.71	13.37	13.54	0.28	2.82	12.24	9.96	0.32	3.27	29.09	10.10	0.31	3.90	35.66	12.53

Annex 11: R<sup>2</sup> regration analysis of nutrient with particle size distribution percentage in the sediment for CR (A) and DR (B).

	<u>TKN</u>	<u>OC</u>	<u>P</u>	<u>Sand</u>	<u>Silt</u>	<u>Clay</u>
TKN		0.485	0.621	0.074	0.997	0.672
OC			0.981	0.251	0.428	0.964
P				0.142	0.565	0.997
Sand%					0.107	0.107
Silt%						0.617

Clay%

	<u>TKN</u>	<u>OC</u>	<u>P</u>	<u>Sand%</u>	<u>Silt%</u>	<u>Clay%</u>
TKN		0.433	0.278	0.393	0.136	0.936
OC			0.989	0.1	0.339	0.539
P				0.11	0.354	0.523
Sand%					0.913	0.17
Silt%						0.016
Clay%						

Annex 12: General form of the relationship between soil loss and yields. Source (FAO, 1999)

