# Ambo University

## SCHOOL OF GRADUATE STUDIES

## College of Natural and Computational Science

# Characterization and Cost Estimation of Erosion in Abay basin:

## Case study on Meja watershed

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science

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*Ambo, Ethiopia, December, 2012*

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## LIST OF SYMBOLS AND ACRONYMS

CGIAR- Consultative Group on International Agricultural Research

CSAs- Critical Source Areas

CVM-Contingency Valuation Method

DAP-Diammonium Phosphate

D- Decade (The Ten Consecutive Sampling Days)

EARO-Ethiopia Agriculture Research Organization

EHRS-The Ethiopian Highland Reclamation Study

ETB-Ethiopian Birr

FAO Food and Agricultural Organization of the United Nations

GD-Galessa Monitoring Station During the $n^{th}$ Decade

GMS-Galessa Monitoring Station

ha- Hectare

HARC-Holeta Agriculture Research Center

ILRI- International Livestock Research Institute

IWM- Integrated Watershed Management

IWMI- International Water Management Institution

KD- Kollu Monitoring Station During the $n^{th}$ Decade

KMS-Kollu Monitoring Station

LD-Land Degradation

LULC - Land Use and Land Cover

mcf- Moisture Correction Factor

MD-Melka Monitoring Station During $n^{th}$ Decade

MMS- Melka Monitoring Station

MoWR - Ministry of Water Resources

$NO_3$-N- Nitrogen in the Form of Nitrate

NBDC-Nile Basin Development Challenge Programme

$NH_4$-N- Nitrogen in the Form of Ammonia

Pav -Available Phosphorus

PCA- Productivity Change Approach

Q-Discharge ($m^3s^{-1}$)

RCA-Replacement Cost Approach

SCRP- Soil Conservation Research Programme

SOM- Soil Organic Matter

SSC- Suspended Sediment Concentration

SY- Total Suspended Sediment Yield

SSY-Area Specific Suspended Sediment Yield

SWC-Soil and Water Conservation

TBoANRD- Tigray Bureau of Agriculture and Natural Resources Development

UNCED- United Nations Commission on Environment and Development

WHO- World Health Organization of the United Nations

WTP-Willingness to Pay

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# APPROVAL SHEET OF THE THESIS

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## STATEMENT OF THE AUTHOR

I declare that this thesis is my work and all sources of materials used for this thesis have been duly acknowledged. This thesis submitted in partial fulfillment of the requirements for MSc degree in **Environmental science** to Ambo University. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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# ABSTRACT

*In Ethiopia, soil erosion during the rainy season constitutes a sever threat to the national economy. The study site, head of the Abay basin is among the heavily affected areas, which is a peril for the crop water productivity. Most studies conducted in the country are focused on quantification of sediment and lack of specific information about temporal and spatial variability of sediment and its associated plant nutrients loss. This study was, therefore undertaken to quantify and characterize sediment and runoff water along with calculating the onsite economic cost of erosion in terms of its associated loss of plant nutrients. To estimate plant nutrient and sediment concentration, depth integrated runoff samplings were made at three monitoring stations in which two from sub catchments and one at the outlet of the watershed. The ten consecutive day samples were bulked on decade basis for each station and then both physical and chemical parameters of the sediment and runoff samples were analyzed at Ambo University. The cost of erosion in the watershed was calculated based on Productivity change approach focusing on available plant nutrients of N and P losses. The average suspended sediment concentration during the rainy season was 3.0±1.1, 2.2±1.3 and 1.4± 0.9 g $L^{-1}$ in which the area-specific sediment yield was ranges from 74 t $km^{-2}$, 248 t $km^{-2}$ and 604 t $km^{-2}$at Melka, Galesssa and Kollu monitoring stations respectively. The result revealed that both sediment and nutrient concentrations were highly variable both in space and time; in which lower concentration occurred towards the end of the rainy season than at the beginning in each station. Based on the complex interaction of multiple natural and anthropogenic factors; the Ridge of Meja River was the most critical source areas for the loss of sediment and associated plant nutrients in the watershed during the rainy period. The correlation matrix between erosion process parameters revealed that both sediment texture and discharge had strongly significant correlated with sediment and nutrient losses. Nutrients loss associated with the sediment and runoff water was a challenge for the productivity and survival of Meja watershed as depicted by an estimated cost on farmer's* ***595,*** **510** and **2475** *birr/ha from the sub catchments of Melka, Kollu and Galessa stations respectively due to the loss of major crop nutrients of Nitrogen (N) and Phosphorus (P) only in one rainy season.*

*Key words:* Blue Nile basin, catchment, Critical areas, Erosion, Nutrient loss, Runoff, Suspended sediment, watershed

# 1. INTRODUCTION

## 1.1 Background

Accelerated soil erosion, mainly caused by water, is a widespread problem affecting environmental quality, agricultural productivity and food security of the world (Lal, 2001). Although many countries of the world suffer from the problem of loss in soil fertility and/or nutrient losses together with sediment and runoff, decline in productivity and environmental degradation are more significant in developing countries. This is because of their limited capacity to replace the lost soil and plant nutrients (Woldeamlak, 2009).

In Ethiopia, soil erosion by water during rainy season is estimated as 42 Mg $ha^{-1}$ $yr^{-1}$, or 4mm of soil depth per annum with equivalent economic cost of 619.2 million birr by the year 1900 (Hurni, 1993) which constitutes a sever threat to the national economy. The Ethiopian highlands, which are the center of major agricultural and economic activities, have been the victim of soil erosion for centuries. These lead to the decline of the civilizations of Lalibela in the 14th century; that of Gondar in the 17th century and of Shewa in the subsequent periods (Hurni, 1993). Studies indicate that about half of the highland‘s land area (nearly 27 Million hectares) is significantly erode and over one-fourth (14 Million hectares) are seriously eroded. Based on the findings of (Fitsum *et al*., 1999, Bezuayehu *et al*, 2002 and EHRS,1986) it was estimated that the highlands of Ethiopia lost about 41-47 kg of nitrogen/ha from agricultural lands through erosion in runoff and in the eroded sediment. The excessive dependence of the Ethiopian rural population on natural resources, particularly land for their livelihood is the underlying cause for land and other natural resources degradation (EPA, 1998). Abay River contributes up to 62% of the Nile flow measured at Aswan, and a similar proportion of sediment in the Nile. For example more than half of the Blue Nile soil is eroded from an area of around 16% of the whole Abay basin (ranging from 15-30 t/ha sediment yield) and the total soil eroded from the Blue Nile is 91.24 Million tons which is due to poor water and land management (Seleshi *et al*, 2009, Fikadu *et al.*, 2009 and IWMI, 2009).

Referring to this massive loss of the soil resource and plant nutrients from the highlands of the country and its transport to the neighboring downstream countries, especially Egypt and the Sudan, some researchers use a cynical metaphor- '**the country's largest export**' (Markos, 1997). According to Bezuayehu *et al*, (2002), the major physical agent in environmental degradation in Oromia region is soil erosion which has contributed to the low yield of crops and livestock of the region, and the immediate causes are topography, rainfall, lack of vegetation cover, soil properties, and land use and management practices.

## 1.2 Statement of the Problem and Significant of the Study

The study site, head of the Abay River basin is heavily affected by water erosion, which threatens the land-water productivity. Water erosion induced rapid degradation of the ecosystems that contributes significant amount of sediment to the Nile. Rapid deterioration in land and water quality has reduced the already insufficient food production of the area. Despite the highly variable and erratic rainfall concentrated in one particular rainy seasons (June - August); it carry a significant sediment load and plant nutrients during the flood period, resulting increases the cost of production due to loss of most top fertile soil and plant nutrients. Though there are abundant literature on the extent of land degradation and soil erosion in the highlands of Ethiopia; watershed based quantification and characterization of runoff, sediment and associated plant nutrients is still scarce. Because most of the studies carried out in the basin were focused on quantification of soil loss either at runoff plot level or in basin scale than investigating the economic effect of nutrient losses associated with sediment and runoff at watershed. Similarly as sediment transport in rivers is associated with a wide range of environmental and engineering issues, the most highly appreciated efforts on watershed management interventions usually face problems due to lack of specific information about the sediment loss, the relationship between soil erosion and nutrient depletion and water quality. However, in recent years there has been a shift towards evaluating the effect of nutrients losses on soil productivity and crop yield income.

Thus information on quantity and characteristics of runoff in terms of sediment and plant nutrients along with economic valuation in this study can therefore decisive input for beneficiaries, who are involved in planning, designing, and environmental related activities in Meja watershed and similar catchments in the basin. This is because mostly farmers sense the impact of erosion on their livelihood when it is interpreted to them in terms of any monetary value which can be help to them to estimate productivity gains due to mitigation measures or the opportunity cost of not taking measures. Therefore; to investigate the effects of erosion on the livelihood of the local people; such field oriented research in the basin at representative watershed scale like Meja watershed has practical relevance for devising strategies and polices for a prolong land and water management in the basin in general and the Meja watershed in particular. Hence; this study is one input with little effort and cost, through quantification and characterization of the suspended sediment yield and runoff water quality analysis in the watershed and then give a preliminary data on the basin.

## 1.3 Objectives of the Study

**General objective**

Physico-chemical characterization of sediment and runoff water along with economic valuation of erosion in terms of essential plant nutrients loss by runoff in the watershed

**Specific objectives**

- Quantifying suspended sediment concentration loss with runoff from the watershed
- Analyzing the spatial and temporal load–discharge variability of sediment and plant nutrient loss
- Characterizing of sediment and runoff water samples for selected physical and chemical parameters
- Estimating the economic effect of erosion due to the loss of major plant nutrients in the watershed

## 1.4 Scope of the Study

The study is limited to the major part of one rainy season (from the onset of July to offset September), in which some sediment has been lost before the measurement was started. Also only suspended sediment yield was considered without accounting for the bed loads. The economic analysis is oversimplified the system by considering only major plant nutrients of N and P and by assuming one crop that grows in a part of the watershed without giving due attention to the diversity of the cropping systems. However, this is believed to give the indication of both the physical soil and water loss and the economic cost due to the nutrients loss.

# 2.LITERATURE REVIEW

## 2.1 Watersheds and its Processes

According to Smith (1978), watershed is defined as surface drainage area above a specified point on a stream enclosed by a topographic boundary or perimeter. The common and central characteristic of all watersheds is that they hold multiple, interconnected natural resources: soil, water and vegetation that impact on one resource invariably affects the status of the others (White, 1992:1, Agenda 21 of the UNCED and the Brundtland Report- Our Common Future- of the World Commission on Environment and Development (WCED) (WCED, 1987).

Watershed processes is described in terms of processes occurring on upland areas, in small stream channels, and over entire watersheds. According to Schumm, (1977 and ASCE, 1982), the watershed processes are divided into:

**Upland Areas-**Processes considered for upland areas hydrologic processes including runoff sediment detachment, transportation and deposition and sediment yield.

**Lateral or Runoff areas-** This consists of flow to, into, and within small concentrated flow channels or rills.

**Water body areas-**They are where the waters join another water body such as a river, lake, reservoir, estuary, wetland, sea, or ocean.

## 2.2 Causes of Land Degradation

According to Mitiku *et al.* (2006) land degradation is the reduction in the capacity of the land to produce benefits from a particular land use under a specified form of land management. Soil erosion is one of the major causes of land degradation in world wide. Although soil erosion is a natural process, human “factor” can speed up erosion, and this is referred to as accelerated (human induced) soil erosion. According to Steiner (1996), soil loss can be 20 to 40 times higher than the rate of soil formation, that restoration of soils within a time span that bears any relations to human history is impossible, which implied the need for controlling soil erosion in order to ensure sustainable use of land.

### 2.2.1 Factors of Influencing Soil Erosion and Land Degradation

In general, soil erosion varies according to land-use and agro-climatic zones. According to Mitiku *et al*, (2006) and Foster (1982), apart from land use activities that trigger erosion processes, there are natural and anthropogenic factors that directly or indirectly influence the process of erosion and land degradation. These strongly interlinked factors include:

**Climate-**Rainfall erosivity which is a function of amount, intensity, duration, wind speed and Temperature

**Soil properties-** Erodibility which depends on texture, soil organic matter, permeability soil structure and soil depth

**Topography-** which include **s**lope angle and slope length

**Vegetation-** such as ground cover plant height, roots and organic matter

**Soil management-** includes practices like crop rotation, tillage direction, machines, timeliness of planting and fertilization

On the other hand, Douglas (1994), Steiner (1996) and Hurni (1993) explain this definition embraces not only the biophysical factors of land use but also socioeconomic aspects such as how the land is managed and the expected yield from a plot of land.

### 2.2.2 Effects of Erosion and Sedimentation

According to Bewket (2003) soil erosion particularly in the form of water erosion have tremendous environmental, social and economic negative impacts that can be summarized as on –site and off-site impacts (Figure1) and they are summarized in the following diagram (Mitiku *et al.*, 2006).

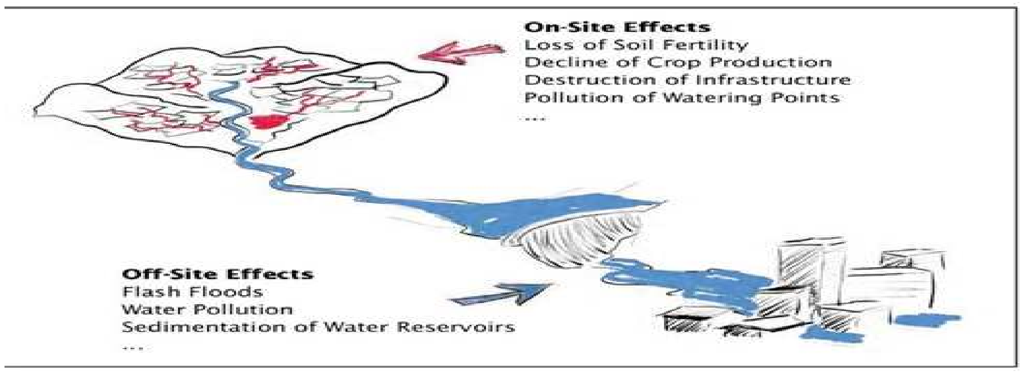
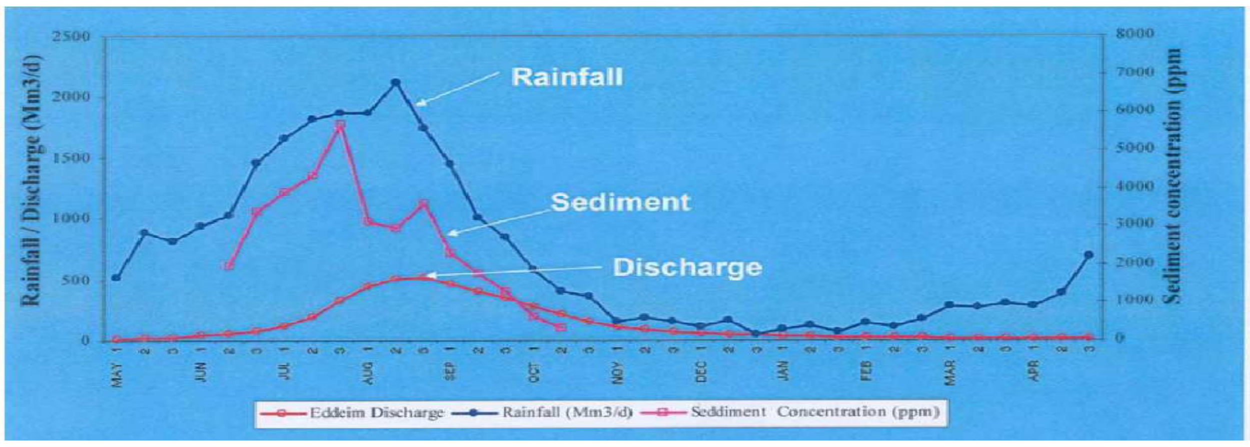


Figure 1 Effects and problems of erosion

## 2.3 Soil Erosion and Sedimentation in Blue Nile Basin

The Blue Nile River also called Abbay River cuts a deep gorge towards the western part of Ethiopia starting from its source, Lake Tana. According to MoWR (1999), most of the sediment in the Nile flows from the Ethiopian Highlands through the Blue Nile and Atbara River. About 95% of the sediment in the Nile comes from the Blue Nile and Atbara rivers during the flood season (July-October). Different scholars indicated that, currently Abay is one of the least planned and managed sub-basins of the Nile. For example Ahmed (2008) indicated that this basin discharge contributes high sediment load to the down streams.



Source - Ahmed, 2008 International Hydrological Programme, Sediment in the Nile River System

Figure 2 Comparisons of Rainfall, Discharge and Sediment Yield in the Blue Nile

About two thirds of the area of this densely populated basin fall in the highlands and hence receive fairly high rainfall of 800 to 2,200 mm per year. However, the rainfall is erratic in terms of both spatial and temporal distribution, with dry spells that significantly reduce crop yields and sometimes lead to total crop failure (Teklu, 2009).

According to Aster and Seleshi (2009), there are four main areas of high erosion hazards in the Abay Basin. These include:

1. The steep slopes around Mount Choke in East and West Gojam, mainly due to high rainfall and poor physical soil conservation structures
2. In the Lake Tana Basin, where the steep slopes around mounts Guna are cultivated (South Gonder) and Molle (South Wello)
3. In South Wello on the high hills north and west of Debre Birhan
4. The upper and middle steep and cultivated slopes of the Middle Abay Gorge in East Wellega

Based on the report by Seleshi B. (2009), the total soil eroded within the landscape in the Abay Basin is estimated to be 302.8 million tons per annum and from that cultivated land is estimated to be 101.8 million tons per annum. Thus, a total of about 2.03 million hectares (Mha) of cultivated land have unsustainable soil loss rates from the basin.

### 2.3.1 Erosion and Sedimentation in Ethiopia

Many environmentalists, policy makers and researchers agree that soil erosion by water is one of the most important chronic land degradation processes in Ethiopia. The northern Ethiopian highlands are among the most seriously affected regions in the country (TBoANRD, 2000; Nyssen *et al.*, 2004). EHRS estimated that the average annual soil loss from arable land was 100 tons/ha and the average productivity loss on cropland was 1.8 % (Constable, 1985). As a consequence of land degradation, the productive capacity of the soils in the highlands is reducing at a rate of 2-3% annually (Hurni, 1993). A study by FAO (1986) estimated a higher rate of soil loss: 2 billion Mg $yr^{-1}$ in the country as a whole and around 100 Mg $ha^{-1}yr^{-1}$ from cultivated fields. According to Woldeamlak (2003), some 50% of the highlands was already significantly eroded', and erosion was causing declines in land productivity at the rate of 2.2% per annum. This can lead to severe land degradation in the catchments and eutrophication of downstream reservoirs (Conley *et al*., 2009).

According to the research findings; most of the land in Ethiopia is exposed to water erosion and the top soil has disappeared at alarming rate. For example more than one billion tons soil is eroded in the Ethiopian highlands annually (Wakeel and Astatke, 1996). Bojö and Cassells (1995) also insist that in Ethiopia soil fertility decrease is a more important phenomenon than soil loss by erosion. Verstraeten and Poesen, (2000) indicated however that soil fertility decline due to the loss of sediment-fixed nutrient is often forgotten. For example Smaling (1990) reported an average N-P-K export through soil loss by erosion of 60 kg $ha^{-1}$ $a^{-1}$ for the whole Ethiopia which is very high compared to the 20 kg $ha^{-1}$ $a^{-1}$ which is taken up by crops. This nutrient loss is among the highest depletion rates in sub-Saharan Africa. Haregeweyn *et al.,* (2008a) also assessed the nutrient export of 13 small catchments in Tigray and found an average sediment nutrient content of 0.15 % ± 0.04 % for N, 8.13 ± 2.75 mg $kg^{-1}$ for $P_{av}$ and 429 ± 164 mg $kg^{-1}$ for K.

### 2.3.2 Erosion and Sedimentation in the Highlands of Ethiopia

Resource degradation has been recognized to be a serious problem in the highlands of Ethiopia since the early 1970s, subsequent to the disastrous drought and famine in the country. Mainly soil erosion, nutrient depletion, drought and deforestation are common environmental problems in the highlands. Consequently, a large area of cropland is subject to "unsustainable" rates of soil erosion (12.5 t $ha^{-1}$ $yr^{-1}$) in the Amhara, Benishangul Gumuz and Oromiya regions (Table 1). The major physical agent in environmental degradation in the settled highlands of the watershed is erosion (Bizuayehu *et al.*, 2002). Therefore better land and water management are critical to improvement of human well being in the drought-prone Ethiopian highlands which is again requires a better understanding of the hydrological characteristics of different watersheds in the headwaters of the Nile River is of considerable importance because of the international interest in the utilization of its water resources, the need to improve and augment development and management activities of these resources, and the potential for negative impacts of climate change in the future (MoWR,2008).

Table 1 Erosion rates in the highlands of Ethiopia estimated by scholars

| **Source** | **Calculation** | **Land use** | **Erosion rate t/ha/yr** | | | **Net loss (%)** |
|---|---|---|---|---|---|---|
| | | | Low | High | average | |
| **EHRS** | Estimated | cultivated | | | | 10 |
| **Grunder 1986** | Measured | Grass | Near zero | - | 72 | |
| | | Tef | - | 282 | | |
| **Solomon Abate 1994** | Measured | cultivated | | 139 | | |
| **Hurni 1983b** | USLE estimate | cultivated | | 120 | | 17 |
| **Hurni 1988** | USLE estimate | | | | 42 | 2 |
| **Belay Tegene** | | Bare soil | 293 | - | - | |
| | | Dom cult | - | - | 75 | |
| **Gebre Michael 1989** | Measured | cultivated | 78 | 218 | 152.5 | |
| **Bojo & Cassells1994** | Estimated | | | | 20 | |
| **Tolcha 1991** | Mean annual net loss 83 t/ha/yr | | | | | |

Source: - Characterization and Atlas of the Blue Nile Basin and its Sub basins IWMI (Aster D and Seleshi B (2009).

### 2.3.3 Erosion and Land Degradation in Meja Watershed

Land degradation in the study watershed is taking place at an alarming rate because of rugged topography and erratic rainfall and aggravated by anthropogenic activities such as deforestation, continuous cultivation, and overgrazing. For example based on the field visit hydrology reconnaissance survey conducted by IWMI from August 4th – August 13th 2010; most communities live on the ridge tops but cultivate the steep valley sides and Slopes of up to 80° are being cultivated; where slopes are too steep for tilling by oxen people use hoes and the area has been also heavily deforested in the last 10-20 years.

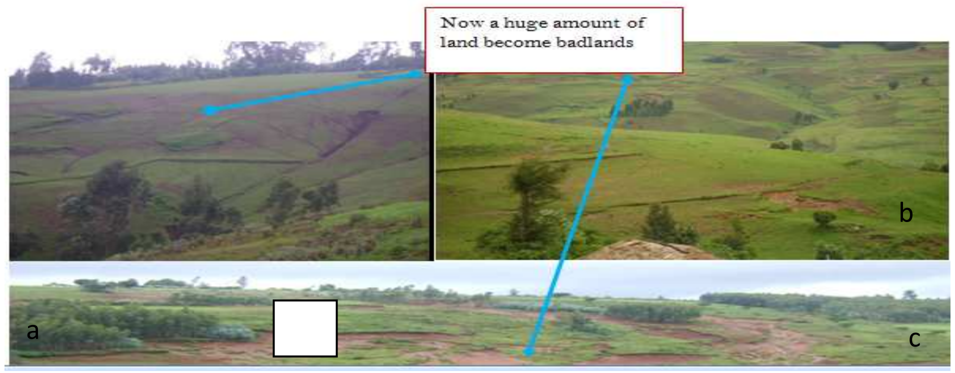


Photo was taken during the cropping season but still almost bare since farmers lost hope to undertake farming activity because the land is severely degraded which adds another stress on their livelihood and food security; phen ally now they become wound an external aid though they have sufficient land size.

Figure 3 Extent of land degradation in Meja watershed photo taken at Serti(a), Galessa(b) and Kolu(c) kebele sub catchments

Birhanu A. (2011) is also found that 100% of the respondents reported that there was soil erosion and/or sedimentation problem in their farm lands so that land degradation is threat to their production like reduction on the land productivity potential of the land and increase cost of production. These can all reduce crop yields and are compounded by the inability of the typical subsistence farmer to provide the inputs necessary to restore soil quality like inorganic fertilizers. As a result, the region is considered one of the most degraded and degrading regions in Ethiopia (Figure 3).

b

Erosion is also one of the most serious environmental and economical problems in Meja watershed through increases natural level of sedimentation of reservoirs (Figure 4) and irrigation canals by reducing their storage capacity as well as life span.

As per field observation the Dam was constructed on Meja River a year ago now crammed with sediment.

Figure 4 Sedimentation problems at Tulu Gurji kebele dam project at Mekja River

## Major Causes of Erosion and Land Degradation on the Watershed

### Physiographic Nature

The topography of the region is very rugged and sensitive to erosion, and also difficult for effective utilization and management; which speeds up the transport of sediment and runoff through erosion in the catchment into rivers while giving less chance for deposition and getting retention time in the watershed. Based on the field survey during this work, most of the communities of the watershed live on the ridge tops but cultivate the steep valley sides i.e. slopes of up to $80^{o}$ are being cultivated (Figure 5) as a result erosion in the form of slope slumping and gulleying is a major threat of the area.

A slope up to 70-80% is cultivated in the study watershed.

Increasingly mountainous and steeper slopes are cultivated, in many cases without or almost there is no any soil and water conservation or protective measures against land erosion and degradation; now most of fertile lands being changed in to marginal lands.

Figure 5 Gullying and cultivation of hilly slope challenges in Meja watershed

### Population Pressure and Socio Economic Situations

According to the Jeldu district bureau of agriculture and rural development report on watershed management (2010), some society members are still landless due to land shortage and poor land use policy such as inequitability of land sharing in the area. These processes in turn go ahead to expansion of agricultural and grazing activities into marginal and steep slopes, which exacerbate environmental degradation in the watershed.

For example Birhanu A. (2011) indicated that there was dense natural forest before 20-30 years in the area where as per the observation during this field work (Figure 6); almost there were no any natural forests which can be seen in the watershed due to intensive deforestation for the purpose of expanding agricultural activities.

Figure 6 Agricultural Extensifcations in Meja watershed through deforestation

Another challenge for sustainable land management in Meja watershed is low income nature of the poor rural farmers. As rooted in the data from a parallel study (part of this project) by other researcher survey on soil water interventions on their land showed that the poor farmers in general were less interested in soil and water conservation investments due to its long-term impact on their livelihood.

In other instance, the researcher was also try to understand the farmers indigenous knowledge becomes worthless due to the fact that emphasis were given for short term development so that traditional ecological principles, no longer play a decisive role. Like an intensive user of chemicals instead of organic and natural soil fertility enhancement mechanisms.

As per some discussion with the local farmer on their general perception about the land degradation; most of the people believe that land degradation and climate change is because of the ***wrath of GOD*** even though they are responsible what happened on their environment and instead of endeavor to rehabilitate the environmental degradation of the watershed.

### Land Management

According to informants from data stated by a parallel study which is part of this project and also the local farmers, in the watershed there is almost no soil and water conservation activities; only some remains done during the Derge regime. On the other hand; intensive tillage in the watershed i.e. the land was ploughed 2–4 times with ox-drawn ploughs before sowing enhances the temporary fine soil structure as sediment transport through runoff (section 4.2). As a result, the watershed is considered as one of the most degraded and hot spot area in the highlands of the country.

The researcher also tries to observe some of the ineffective indigenous and traditional practices result in further land degradation in the watershed. For example when their land productivity is decline most of the community loss their hope to rehabilitate the productivity of the land rather planting of eucalyptus tree on their lands and in the area fallowing particularly in Galessa and Seriti kebeles is also very common practices so as to improve the fertility of their land. On the other hand different scholars indicated that eucalyptus trees have a negative ecological effect due to its water use potential as inveterate by the observation experience (FAO, 1988).

## 2.4 Estimated Economic Impacts of Soil Erosion

Hurni, 1993 indicated that the economic impact of land degradation is extremely severe in densely populated South Asia and Sub-Saharan Africa. Yield reductions of 20 to 40% have been measured for row crops in Ohio (Mitiku *et al.,* 2006). Nutrient depletion as a form of land degradation has a severe economic impact at the global scale especially in sub-Saharan Africa. Smaling (1998) has estimated nutrient balances for several countries in sub-Sahara Africa, annual depletion rates of soil fertility were estimated at 22 kg N, 3 kg P, and 15 kg K per ha. This paper briefly discusses the some of the techniques that can be used to value soil nutrients loss due to soil erosion as suggested by different authors, which include:

- The Replacement Cost Approach (RCA): Valuing Input Costs
- The Productivity Change Approach: Valuing Production Change
- Willingness to Pay: Inference when Prices are not Available
- Hedonic Pricing: Placing a Value on Resource Characteristics

All the approaches have different merits and demerits and can be applied under different situations. Bishop and Allen (1989) suggested the consideration of the following issues and questions that can help guide in choosing a workable approach in economic analysis of erosion:

- **The objective(s) and the user(s):** who needs the assessment and why?
- **Evaluation criteria**: Is the set of evaluation criteria produce results that are credible and relevant?
- **Method sensitivity**: Can the evaluation method produce results that are objective and consistent?
- **Cost-effectiveness**: What (amount of) data does the method require? Are these data assessable at what cost?
- **Scope**: Given budget, time, human resource and data availability constraints, what is the appropriate scope and level of detail and the tolerable error?

### 2.4.1 The Replacement Cost Approach: Valuing Input Costs

Barbier (1998) explains that in developing countries, the most common methodology for the economic assessment of soil nutrients is the replacement cost. The Replacement Cost Approach (RCA) is primarily used to assign monetary values to depleted soil nutrients as the cost of purchasing a quantity of chemical fertilizer with a nutrient content equivalent to the quantity lost. Drechse *et al.,* (2004), indicates the key advantage in using the RCA is that market prices are usually available for at least some common nutrients, making assessments simple once the nutrient database is obtained. The RCA suffers from some inherent limitations. For example, on the one hand, not all fertilizer applied is used by plants-a certain amount will be lost again. On the other hand Bojö (1996), a significant portion of lost nutrients might themselves not have been plant-available so there is no justification for putting a cost on their replacement.

### 2.4.2 The Productivity Change Approach: Valuing Production Change

Based on the concept of Enters (1998) the basic principle behind Productivity Change Approach (PCA) method assumes that the value of productivity change is equal to the difference in crop yields with and without that change, multiplied by the unit price of the crop which is or might be grown, potentially adjusted to reflect any differences in the costs of production. The main advantage of the approach is that it is logical, straightforward to apply (as long as relevant data such as crop yield changes over time are available) and relatively easy to comprehend even for non-specialists (Barbier, 1998). While the PCA has many advantages, it also suffers from a number of inherent problems such as the difficulty in linking yield with nutrient loss as described earlier (Lal 1995 and Enters 1992). This is complicated, since farmers can be expected to adapt their farming systems in the face of soil fertility decline and other changes.

### 2.4.3 Willingness to Pay: Inference When Prices are Not Available

According to Lal (1995), the fundamental basis behind the two valuation methods described above is that nutrient inputs (RCA) or agricultural outputs (PCA) are, or can be, priced in the market. However, even when explicit markets or prices do not exist, soil nutrients still have value. The Willingness-to-Pay (WTP) approach is one methodology that attempts to value soil nutrients by discovering their implicit value to farmers or others. WTP often use the Contingent Valuation Method (CVM), a technique used to assess the valuation of goods or services which are not traded and, therefore, have no explicit price. The approach is referred to as "contingent", because participants are asked about their valuations of goods, such as plant nutrients, contingent on some hypothetical scenario (Mitchell and Carson, 1989).

# 3 MATERIALS AND METHODS

## 3.1 Description of the Study Area

### Location and Physiographic Features

The study was conducted at Meja micro watershed in Jeldu district, in the southern part of upper Blue Nile Basin, Central Ethiopia (9° 02' 47" to 9° 15' 00" N and 38° 05' 00" to 38° 12' 16" E). The watershed has an undulating terrain nature and with altitude ranging from 2400-3200 meters above sea level (Figure 7). The study watershed has an area of 9260 ha. It is located at 114kms and 70kms away from Addis Ababa and Ambo, respectively. There is one town namely Gojo or Jeldu which is some part and in the Easter boarder of the watershed.

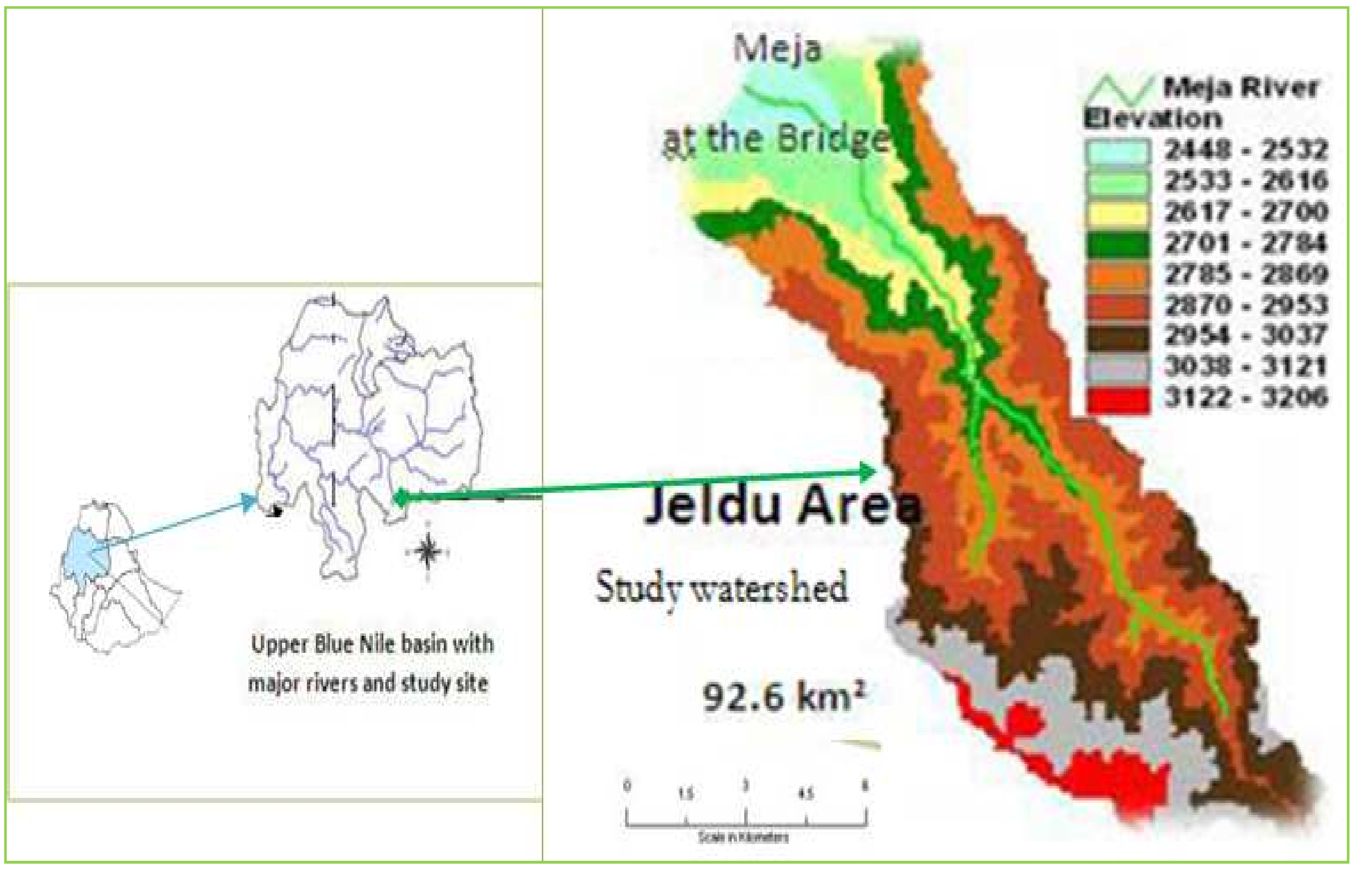


Figure 7 Location of the study watershed

### Geology and Soil

The geology of central high lands of the country is characterized by late tertiary rock that covers the Pre- Cambrian rocks that underlie all other rocks in Ethiopia The dominate soil of the study watershed is Haplic Luvisols which is dominated by red loam in upper part and clay loam in the lower parts (Birhanu A. , 2011).

### Vegetation

Eucalyptus (*Eucalyptus globules)* is the main tree planted in the area while there is almost no natural forest except some remnants of very few scattered trees of forest in the crop land and scattered vegetation around the steep slopes and gorge of Meja River. According to Birhanu A. (2011), 20-30 years go the area was fully covered by natural forest. *Hagenia abyssinica*, *Dombeya torrida*, *Buddleja polystachya* and *Chamaecytisus palmensis* (tree Lucerne) are among the fodder trees and shrubs species that are considered important contributors to grazing animal nutrition in the highlands of Galessa and Jeldu areas.

### Climate and Hydrology

The mean annual minimum and maximum temperature ranges from 17 to 22 $C^0$. The mean annual rainfall varies from 900 mm in the lower parts of the area (Melka) to 1,350 mm at higher altitudes (Galessa). Apart from some fluctuations in recent years, generally, the watershed has a bi-modal rainfall pattern whereby it receives the short '*Belg'* rains between March and April which helps land preparation; while the main rainy season starts from June and continues up to offset of September when the main cropping is done. The major river is the Meja River, a tributary of the Nile River which joins the Gora River that flows into the Guder River. The Meja River originates at high altitude just outside Jeldu district in the Dendi district. The headwaters are in a flat wide valley, which is a wetland heavily utilized for livestock grazing in Galessa. It then drops steeply and flows through a relatively narrow deeply incised valley. Numerous tributaries drain into the Meja from both the east and west sides (IWMI, 2009).

### Land Use and Socio-economic Pattern

The total population of the District is 202,655 (out of which 102,796 are female and 99,859 are males). The average household size is 7 persons in the District. From this, the Watershed has total area of 9260 ha, with variable agro ecology of high lands (80%), midlands (15%) and lowlands (5%). According to the Bureau of agriculture and rural development of the district, the average land holding in the Watershed is 2 ha per household. In the watershed, agriculture is the major livelihood of the people followed by livestock production and tree planting, mainly eucalyptus. The most common land-use systems in the study areas are mixed crop–livestock systems. Barley (*Hordeum vulgar)* is the dominant crop, followed by Potato (*Solanum tuberosum*), Wheat (*Triticum vulgare*) and Enset (*Ensete ventricosum*). Fallowing is very common in order to enhance the fertility of soil since some part of the watershed land is already degraded particularly in the upper and along with the middle part of the watershed of Seriti and Galessa kebeles. Cattle, sheep and horses are the dominant livestock species.

Table 2 Land use land covers classification of the study watershed

| Land use land cover types | Area (ha) | Proportion (%) |
|---|---|---|
| Arable land | 6,009.5 | 64.8 |
| Grazing land | 328.00 | 3.5 |
| Forest land ( mainly eucalyptus plantation) | 2,233.6 | 24.05 |
| Others (barren degraded lands, buildings, grave yards, roads, etc) | 710 | 7.65 |
| Total | 9260 | 100 |

Source – Jeldu district bureau of agriculture and rural development, 2011

## *3.2* Methods

### 3.2.1 Field Work

#### 3.2.1.1 Selection of Sampling and Monitoring Sites

The fieldwork involved the collection of runoff samples at the outlet and from the tributary sub catchments. The latter was undertaken to permit the characterization of suspended sediment originating from the different sub-catchments represented by the tributaries. The sampling sites or monitoring stations were selected based on the consideration of two major parameters. The one is where the discharge measurement gages are located which was installed by international water management institute (IWMI) of NBDC2 and the second most important factor was the land use land cover (LULC) of the micro watersheds i.e. agricultural, grazing and plantation are of the most important factors considered for this particular research since they are the dominate LULC in the watershed. Then by integrating of these factors and their accessibility condition; three monitoring stations were selected during the reconnaissance survey within the watershed during the study period for monitoring runoff, sediment and nutrient losses and they are summarized in Figure 4 and Table 3.

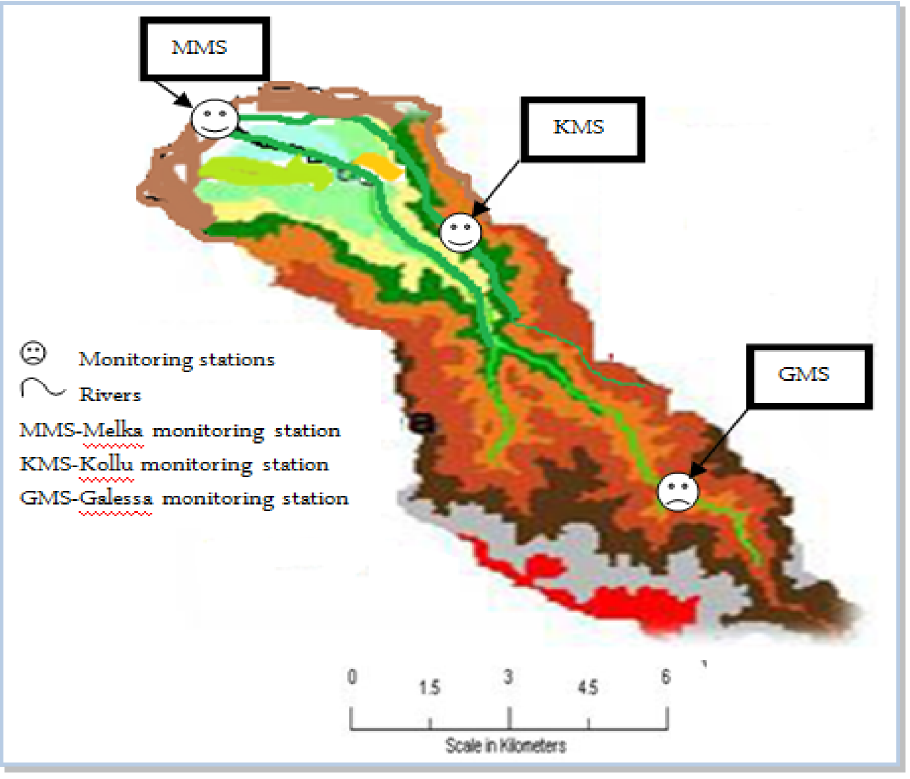


Figure 8 Location of monitoring stations

As shown in Figure Galessa station is located at the upper inlet part of the watershed which was dominantly grazing land. Kollu is located at Lega Jeba River which drains sub catchments that are dominantly covered by cultivated lands and tree plantation. On the other hand Melka monitoring station was located at the out let of the watershed (at bridge of Melka to Chobi road) in Meja River (Main River in the study watershed.

#### 3.2.1.2 Discharge Measurements

The rivers discharge was measured directly by **Area - velocity** method (Graf and Altinakar (1998)) using staff gages that were installed across the flow cross sections of the monitoring rivers. Then the discharges of each monitoring stations was calculated (equ. 3-1):

$$\mathbf{Q\ (m^3/se) = A\ (m^2)\ x\ V\ (m/se)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 3-1}$$

Where **Q**=the total discharge, **A**= the cross sectional area of the river and **V**=is the average velocity of the runoff

But since the analysis was for bulked over ten days sample, the consecutive days' discharge was summed to get the total volume of water losses in each station for each decade.

##### a) Cross sectional Area Measurement

The cross-sectional areas of the three monitoring stations were calculated from the water column made perpendicular to the flow direction and the total width of each river. For the purpose of cross sectional area measurements, the rivers were divided in to sub sections so that the total discharge was calculated from the summations of each section (Figure 9).

##### b) Flow Velocity Measurement

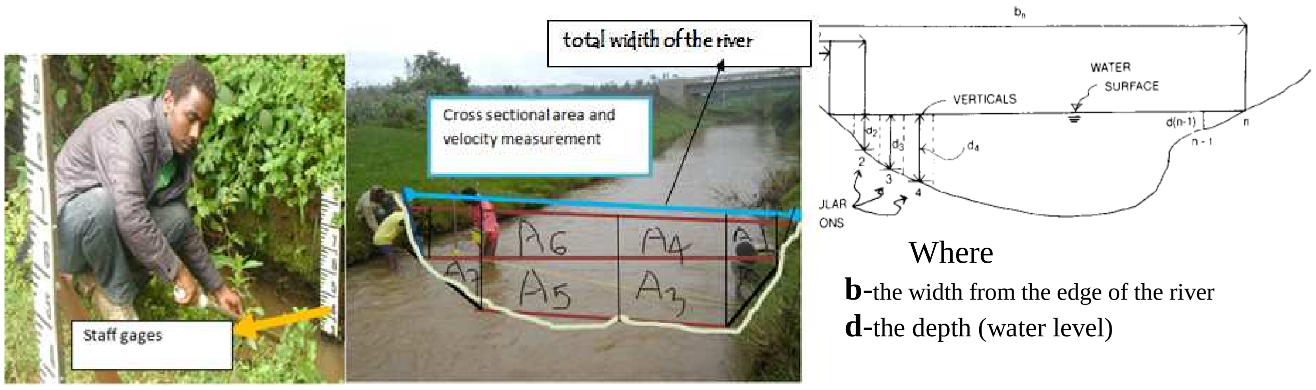
The velocity of water lost by runoff at Melka and Kollu stations was measured using current meter in different cross section of the rivers channel and the average values was calculated (Figure 9) whereas at Galessa it was measured using floating method since the current meter was taken in to other project site. Each float velocity measurement was repeated three times over a distance of 10 m (5 m upstream and 5 m downstream of the cross sectional measurement points) and the average was taken.

The surface velocity was converted to the average velocity using Prony's empirical equation (equ. 3-2) (Graf and Altinakar, 1998):

$\mathbf{V=0.8v_S}$-------------------------------------------------Equation 3-2

Where  V = average velocity (m s $^{-1}$), $v_S$ = surface velocity (m s $^{-1}$)

Since the mean velocity in a vertical profile is approximated by the velocity at 0.4 depth of the current meter, we use the measured velocity as an average velocity at that vertical for the case of current meter measurement and equation 3-2 for the case of floating method.



Where

**b**-the width from the edge of the river

**d**-the depth (water level)

Figure 9 Field area and velocity measurements and diagrammatic area calculations

#### 3.2.1.3 Stage-Discharge Curves

Since there was no full run off velocity data in each monitoring stations because the current meter was not available throughout the season and also due to difficulty of measuring during flooding; **Q-d** rating curves was developed for each sites. These rating curves were used to estimate the continuous discharge from recorded continuous depth for whole study period. At each rivers flow monitoring stations, the enamel painted staff gauges (gauge posts) were erected at different levels so that each respective water depth was recorded at the time of runoff sampling to make it flow proportional sampling (Figure 9).

Thus, a curve is drawn by plotting 'stream discharge 'Q vs. gauge height h' (Appendix 1) using power function of Graf and Altinakar (1998) (equ. 3-3).

$Q = K(H + Ho)^n$ ………………………………………………………Equation 3-3

Where $Q$ is the discharge in m$^3$, $Ho$ is the height of zero measurement and H is the observed depth of water in m. $K$ and $n$ are parameters that are constant and vary depending on stream characteristics.

From the rating curve, the stream discharge corresponding to staff gauge readings data was taken throughout the rainy season (Appendix 3).

#### 3.2.1.4 Sediment and Runoff Sampling Techniques

Runoff sampling and discharge measurement was limited to a major part of the summer rainy season (from onset of July to the offset of September) since sediment and nutrient loss is closely associated with rainfall-runoff events. Therefore the fieldwork was focused on the collection of representative runoff samples using 1liter plastic bottles from each monitoring stations. The amount of sample was based on the probability of flooding and soil erosion of the watershed i.e. at least once a day in July – August 15 and twice a day from August in order to get sufficient sediment for laboratory analysis. Samples were collected at the same time of the manual runoff discharge measurements.

Depth-integrated sampling was applied in the rivers vertically from the streambed direction to the water surface nearly at a constant speed to overcome the effect of velocity gradient.

The sampling was done at the same location along the cross section to avoid the influence of proximity of the riverbanks or the pier and the velocity gradient on suspended sediment concentration.

NB- All the composite samples were coded as follows:

- First the abbreviation of the station M, K and G (indicating for Melka, Kollu and Galessa stations),
- Followed by D (indicating the ten consecutive sampling days (decade)), and then
- Followed by 1, 2, 3, 4, 5, 6, 7, 8, 9(indicates first, second, third …, ninth decades)

*For example, $MD_1$ indicted that sample from Melka station in the first decades (ten consecutive days)*

Table 3 Detail description of monitoring stations and sampling periods

| Monitoring stations | Code | Starting date (D1) | End date (D8 and/or 9) | Location | Catchment area(km2) |
|---|---|---|---|---|---|
| **Melka** | MD* | July 02/2011 | Sep 28/2011 | E=038º01′49″.9<br>N =09º17′29″.1 | 92.8 |
| **Kollu** | KD* | July 02/2011 | Sep 28/2011 | E=038º03′27″.1<br>N=09º18′03″.3 | 2.6 |
| **Galessa** | GD* | July 02/2011 | Oct 06/2011 | E=038º09′03″.7<br>N=09º09′03″.7 | 1.6 |

#### 3.2.1.5 Sample Handling

To minimize cost and also to get sufficient soil sample for analysis, the 10 consecutive day’s samples were bulked in to one container as decade. Then, a composite sub-sample of one litter was taken from bulked samples for analysis. Here; each daily collected samples was put with sample preservation technique by storing at $4c^0$ temperature until laboratory analyses undertaken to minimize farther biological and other chemical degradations particularly for plant nutrients.

### 3.2.2 Laboratory Analysis

For quantification and physcio-chemical characterization of the sediment and runoff water lost from the watershed; samples were brought to Ambo university laboratory to analysis those parameters that were assumed to be indicator of the watershed degradation. The parameters that were analyzed were briefly described as follows:

#### 3.2.2.1 Suspended Sediment Load Estimation

To determine the suspended sediment concentration (SSC), the runoff samples were filtered using a pre weighted Whatman cellulose filter paper N0 42. Thus SSC of the bulked samples was determined using equ 3-4:

**SSC = M-mf / V** ------------------------------------------------------------------Equation 3-4

Where; SSC = the suspended sediment concentration (g $L^{-1}$); M = mass (g) of sediment and filter paper, mf = mass of empty filter paper; and V = is the volume of the water sample (L) which was constantly 10 and 20 L form July – mid August and August 15 - end of September, respectively.

The total sediment that was lost from the watershed was determined by measuring instantaneous discharge, Q ($m^3$ $s^{-1}$) and instantaneous suspended sediment concentration, SSC (g/L) for the bulked samples of each decades (equ. 3-5)

**Total suspended sediment lost (SY) (g) = SSC x $Q_t$**----------------------------------Equation 3-5

Where; SSC is the suspended sediment concentration (g $L^{-1}$) and $Q_t$ ($m^3$/s) is the total discharge for the 10 consecutive days of each monitoring sites.

But to get the dry sediment concentration some pre-weighted filtered soil was dried in the oven for 24 hours at 105 °C in the laboratory, and then reweighted again and the moisture content was calculated and used as correction factor (mcf). Then the filtered suspended sediment was air-dried, labeled and packed in aluminum foil after weighted with digital balance and kept for further analysis.

#### 3.2.2.2 Physical and Chemical Analysis

The texture of the sediment was determined using hydrometer method (Table 4) after pre-treatment with hydrogen peroxide to remove the organic fraction and chemical dispersion with sodium hexametaphosphate. Grain-size analysis of all suspended sediment samples was impossible, as many of the samples in a given station did not contain enough soil for all physico chemical analysis. The samples were, therefore, grouped according to their date, station and suspended sediment concentration for grain size analysis.

Figure 10 Sediment grain size analysis using Hydrometer

The chemical analysis was done for both the sediment and water samples focusing on essential plant nutrients including total N(TN), $NH_4$-N, $NO_3$-N, plant available P and organic carbon for the sediment and dissolved nitrate, ammonia and phosphate for the water (Appendix 2). Standard methods were used for each parameter (Table 4).

Table 4 Methods used for the physico-chemical parameters analysis

| Parameter | | Methods used | Reference |
|---|---|---|---|
| For sediment | SSC | Gravimetric(filtration) | |
| | Texture | Hydrometer | Bouyoucos 1962 |
| | SOM | Walkley and Black | Jackson, 1967 |
| | Total nitrogen | Modified Kjeldahl digestion | Dalal *et al.* 1984 |
| | Nitrate(NO3-N) | Magnesium oxide-Devarda's alloy | Maiti, 2004 |
| | Ammonium(NH4-N) | Magnisum oxide-Devarda's alloy | Maiti, 2004 |
| | Available phosphorous | Olsen's | R. Olsen and co-worker ( 1954) |
| For runoff water | Dissolved nitrate | UV-Spectrophotometer | Patnaik (2010) |
| | Dissolved ammonia | Phenate | Patnaik (2010) |
| | Dissolved phosphorus | UV-Spectrophotometer | Patnaik (2010) |

### 3.2.3 Estimating Cost of Erosion

The economic valuation was done by considering the sediment and essential plant nutrients lost associated with the sediments and runoff as consequence of erosion. **Productivity change approach (PCA)** was applied to estimate this cost due to its advantage of the approach; it is logical, straightforward to apply (as long as relevant data such as crop yield changes over time are available) and relatively easy to comprehend even for non-specialists (Barbier, 1998).

The economic loss due to the lost nutrient was estimated based on yield response curve developed from secondary generated data by researchers on the major crops grown in the watershed and the current market price of these crops.

The computation of nutrient value of both in the sediments and runoff water was based on the commonly used sources of nutrients by the local farmer's i.e. chemical fertilizers. Based on the data got from the bureau of agriculture and rural development, the chemical fertilizers commonly used by the local farmers were urea and diammonium phosphate (DAP) for supplying nitrogen (N) and phosphorus ($P_2O_5$) nutrients respectively for growing crops. Thus for the purpose of calculating the onsite economic cost of erosion, only inorganic form of available nitrogen ($NH_4$-N and $NO_3$-N) as a source of nitrogen fertilizer and $P_2O_5$ as phosphorous fertilizer both in the sediment and dissolved in runoff water were considered based on the stchiometric principles.

The general procedures used for the valuation is given as the following diagram-

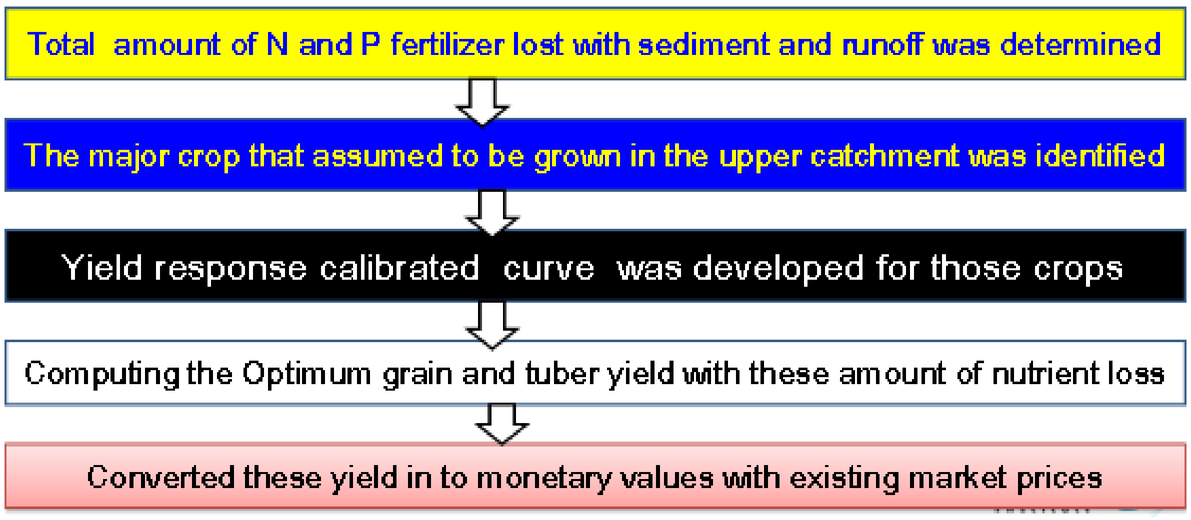


Figure 11 General procedures followed for cost calculation of nutrient loss

of erosion

### 3.2.4 Statistical Analysis

The data was analyzed using SPSS version 16.0 Software and presented using Sigma plot 10. Different statistical analyses including Pearson's Correlation between eroded parameters to discriminate those influencing variables in the process of erosion was conducted. Regression was also conducting to determine spatial and temporal variability of SSC and nutrient losses between locations of each monitoring stations and periods when samples were undertaken. Statistical significance of the changes in sediment characteristics as well as the differences in runoff water quality between the monitoring stations was also determined.

## Conceptual Frame Work of the Research Method

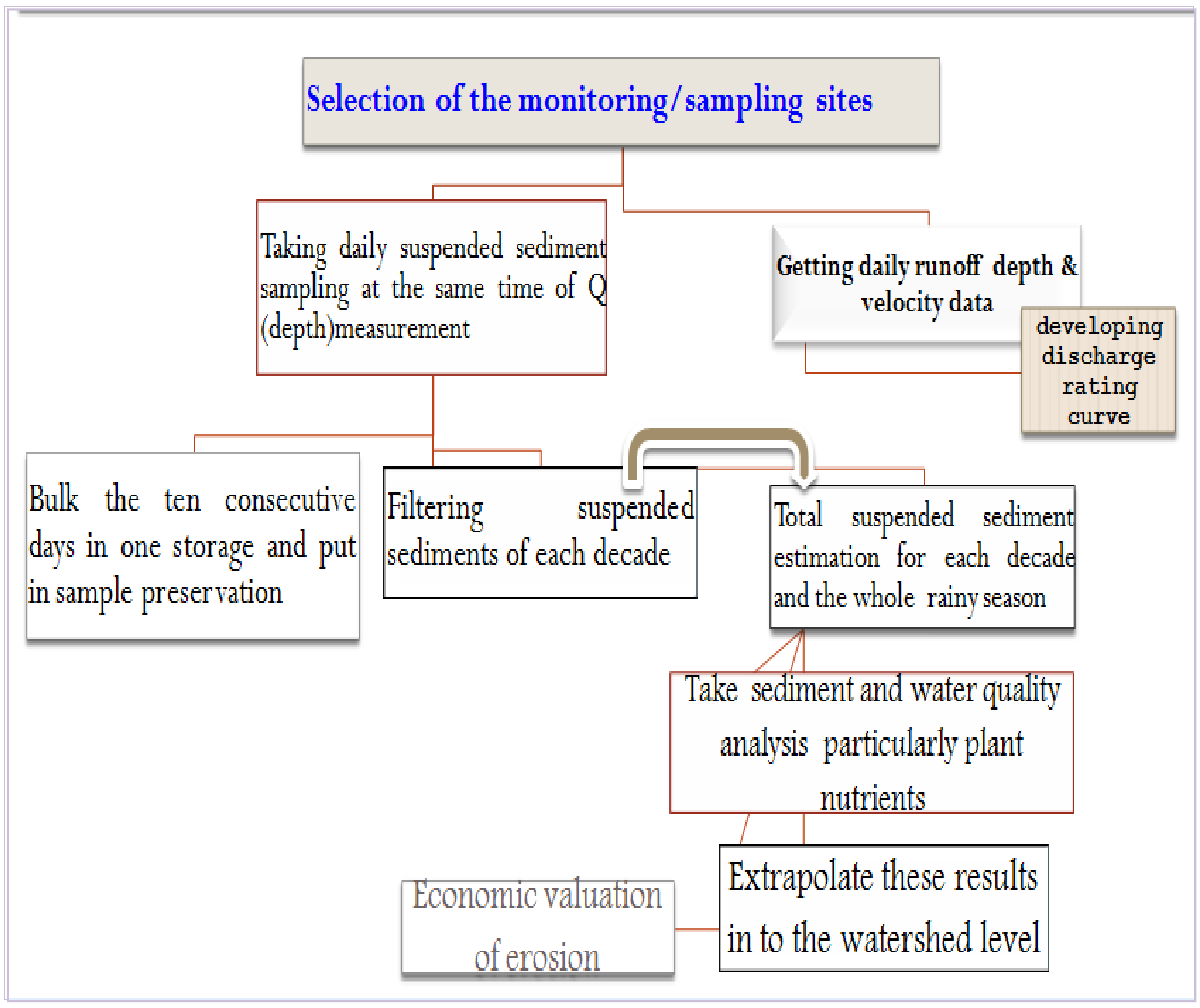


Figure 12 General conceptual frame work of the research

# 4 RESULTS AND DISCUSSION

## 4.1 Suspended Sediment Analysis

### 4.1.1 Suspended Sediment Load Estimation

After the bulked runoff samples from each station were filtered (Figure 12); then both the suspended sediment concentration (SSC) and total sediment yield (SY) data was obtained for all stations of each decade which is presented in the following table (Table 5). The mean average SSC during the rainy season was 3.0±1.1 g $L^{-1}$ from the watershed (at Melka) while 1.4±0.9 and 2.2±1.3 g $L^{-1}$ at Galesssa and Kollu sub catchment monitoring stations respectively (Table 5). The mean total suspended sediment lost from the watershed during the rainy season (in three month only) was 6812, 1570 and 398 tons from the watershed (**Melka**), **Kollu** and **Galessa** monitoring stations respectively (Table 5**).**

In part, as the study was limited to three months it is difficult to compare with erosion rate in other parts of the country. However, since the majority of the soil erosion in Ethiopia takes place during these months, the magnitude may be close to the annual soil loss which implies that still erosion in the study watershed was one of the challenges for sustainable crop-water productivity both in terms of its sediment and runoff water quality.

### 4.1.1 Temporal and Spatial Variability of Suspended Sediment

All the sediment data analysis shows that there was a significant variation both in time and space. For example the average SSC at Melka in the first decade (from July 02-11) was by far higher than that of decade 8 and 9 (after September 20). Within the same decade it also varied between stations. The statistical analysis also revealed that both the SSC and SY significantly vary between decades and monitoring stations. For example parametric test between SSC and monitoring station shows that there is difference between the Melka with that of Kollu and Galessa stations is statistically significant at $p<=0.05$.

So that in order to take into account the influence of period and location effects on sediment transport for any management interventions; this research efforts to answer when and where problems are sever and hot spots or actions shall be taken.

Table 5 Suspended sediment concentration of runoff samples

| Station | Sample Code | SSC (gm/L) | Average discharge of the decade ($m^3/s$) | Total volume water lost $m^3$ $(10^3)$/decade | Total suspended sediment load for the 10 days(kg)$(10^3)$ |
|---|---|---|---|---|---|
| **Melka** | MD1 | 4.5 | 5 | 435 | 1960 |
| | MD2 | 4.8 | 3.6 | 315 | 1510 |
| | MD3 | 2.4 | 3.4 | 290 | 696 |
| | MD4 | 2.9 | 4.6 | 398 | 1154 |
| | MD5+6 | 2 | 3.4 | 291 | 582 |
| | MD7 | 2.7 | 3 | 259 | 700 |
| | MD8+9 | 1.7 | 1.4 | 124 | 210 |
| | Mean | 3.0±1.1 | 3.5±1.1 | 301.7±93.3 | 973.2±558.3 |
| | Total | | | 2112 | 6812 |
| **Kollu** | KD1 | 4.3 | 0.6 | 218 | 937 |
| | KD2 | 3.4 | 0.5 | 78 | 265 |
| | KD3 | 2.2 | 0.3 | 65 | 143 |
| | KD4 | 1.9 | 0.4 | 96 | 182 |
| | KD5+6 | 1.5 | 0.2 | 16 | 24 |
| | KD7 | 1.1 | 0.1 | 10 | 11 |
| | KD8+9 | 1 | 0.1 | 7 | 7 |
| | Mean | 2.2±1.3 | 0.3±0.2 | 74.3±64.2 | 329.4±224.2 |
| | Total | | | 490 | 1570 |
| **Galessa** | GD1 | 2.8 | 1.2 | 86 | 241 |
| | GD2 | 2.6 | 0.9 | 37 | 96 |
| | GD3 | 1.1 | 0.7 | 12 | 13 |
| | GD4 | 0.9 | 0.4 | 8 | 7 |
| | GD5 | 0.6 | 0.2 | 18 | 10 |
| | GD6+7 | 1.2 | 0.4 | 21 | 25 |
| | GD8+9 | 0.8 | 0.1 | 6 | 5 |
| | **Mean** | **1.4±0.9** | **0.6±0.4** | **28.1±22.1** | **87.3±56.7** |
| | **Total** | | | **188** | **398** |

Where- *MD, KD and GD is Melka, Kollu and Galessa station at the $D^{th}$ decade respectively, Wt is weight, SS is suspended sediment and SSC refers to suspended sediment concentration*

#### 4.1.1.1 Temporal Variability of Sediment Concentration

The analyzed data's revealed that both the SSC and SY were significantly varied between decades. While from the regression analysis between both SC and SY and sampling time (decade) indicated that it was strong relation in each station with ($R^2$=-0.71, -0.90 and -0.64 at Melka, Kollu and Galessa) (Figure 13). This may due to an intensive tillage in the watershed i.e. the land was ploughed 2–4 times with ox-drawn ploughs before sowing (at the beginning of sampling) enhances the temporary fine soil structure as sediment transport through runoff.

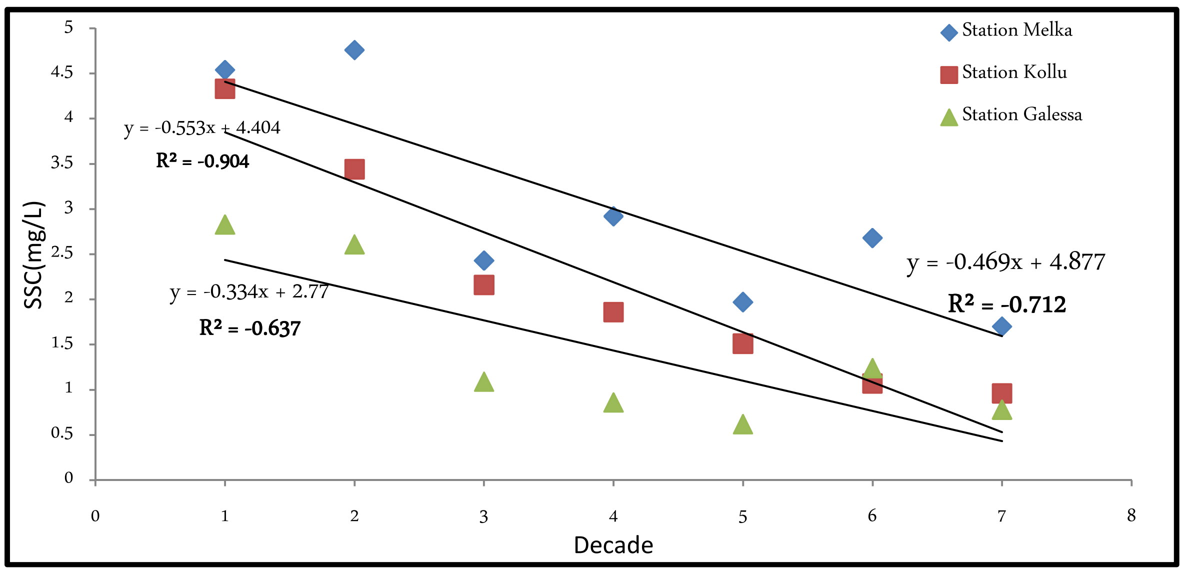


Figure 13 Regression lines between suspended sediment and period

While from the general trends of the mean SCC from the three sites (Figure 14) confirms that sediment concentrations were higher at the start of the rainy season and decreased towards the end, although much depends on the land use type and rainy events.

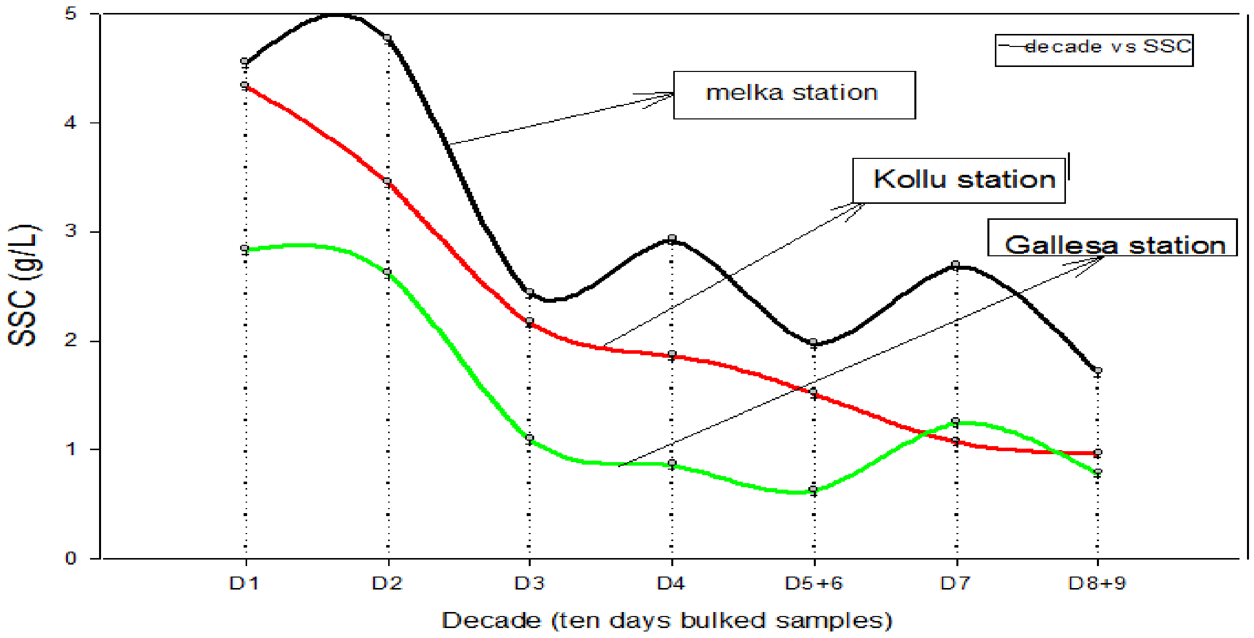


Figure 14 Temporal trends of SSC in the three monitoring stations

This is may be related to the tillage and sowing operation that was started at the beginning of the rainy season.  This confirms the soil conservation research programme (SCRP) data that indicates soil loss rate –maximizes during ploughing and the first month after planting of the crops (EHRS, 1986).

Form the data retrieved by other researcher in the watershed; Potato was the major crop in the upper part of the watershed (Galessa kebele) which was grown at the earlier rainy season so that the probability of erosion was reduced since the land was under medium (30 - 60%) and high (60% and

70%) cover results less damage the land with erosion at the time of sample collection. Another reason for such differences was due to the particle size of the sediment; i.e. the textural analysis of the sediment indicated that very fine at the beginning of the rainy season and which consent with the correlation (Table 8) of particle size and SSC, higher SSC was yielded in sediments of very fine. While in case of Galessa and Melka monitoring sites this trend was not true; sediment concentration was increased from $D_4$ and $D_5$ (end of August) towards $D_6$ and $D_7$ (mid of September), (Figure 14) since there was tillage operations at the upper part of the catchments. For example in Galessa fallowing is very common practice so that farmers were take tillage operation during the beginning of September to prepare the land for the coming year production. Whereas in case of Melka; there was irrigation in the dry season so that the land was under tillage operation in the ridge of Meja river for intercropping production particularly Teff during September which increases the probability of sedimentation in the rivers. Accordingly the field was bare and offer less resistance to splash and runoff erosion during this time. Another factor that hampered the probability of sediment next to the LULC was the discharge of the rivers of the upper sub catchments the stations (Figure 15). This is because the correlation matrix between SCC and Q also indicated that it has a positively significant relation at $R^2$=0.59 (Table 9).

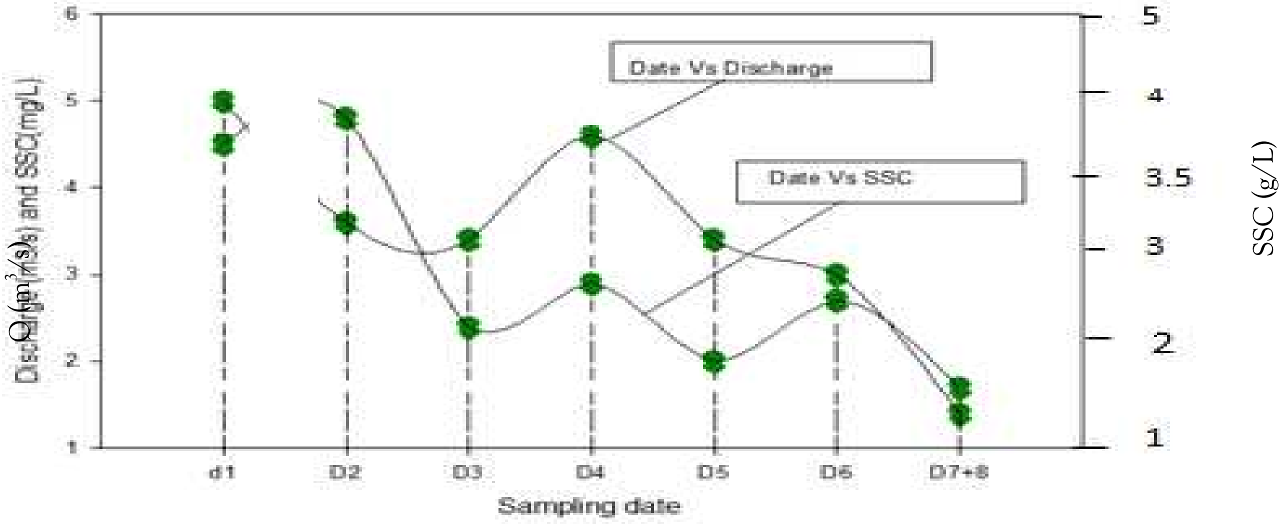


Figure 15 Temporal variability of Sediment concentration with respect to discharge effects

### SSC and Discharge or Hysteresis Effect

In theory SSC should increase with discharge because the associated increase in turbulence enhances the capacity of the water to carry suspended sediment (Amanuel, 2009). In this particular study, the relationship between sediment concentration and discharge were scattered correlation which reflects periods of the year when sediment may be more readily available than at other times, which is related to land use land cover effects. As a result the correlation strength between SSC and discharge was weak in all stations ($R^2$=0.35, 0.56 and 0.53 at Melka, Kollu and Galessa station) having very scattered Q-SSC rating graph though it has positively related in all the three stations.

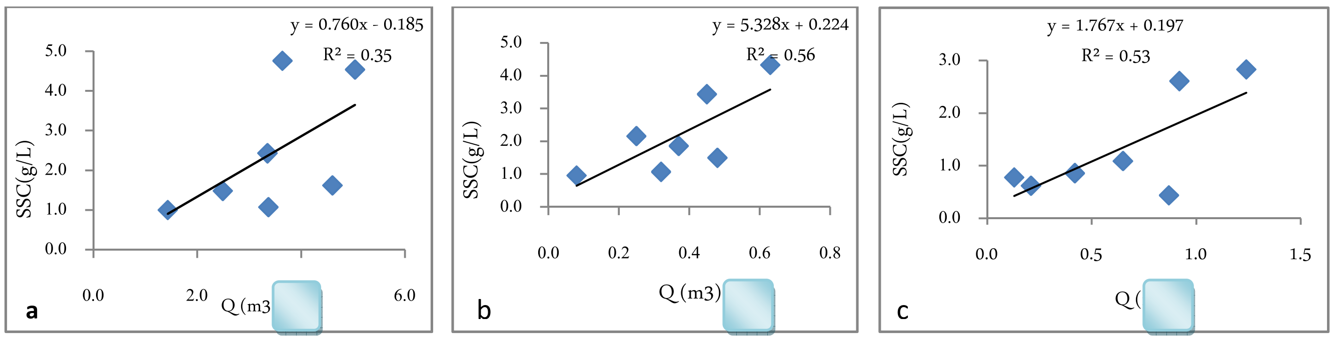


Figure 16 Q-SSC rating curve (a) for Melka, (b) for Kollu and (c) Galessa monitoring stations

Thus based on the general trend observed from the graphs, it is possible to conclude for all stations: ***'for a given runoff discharge, lower SSC-values occur towards the end of the rainy season than at the beginning'.***

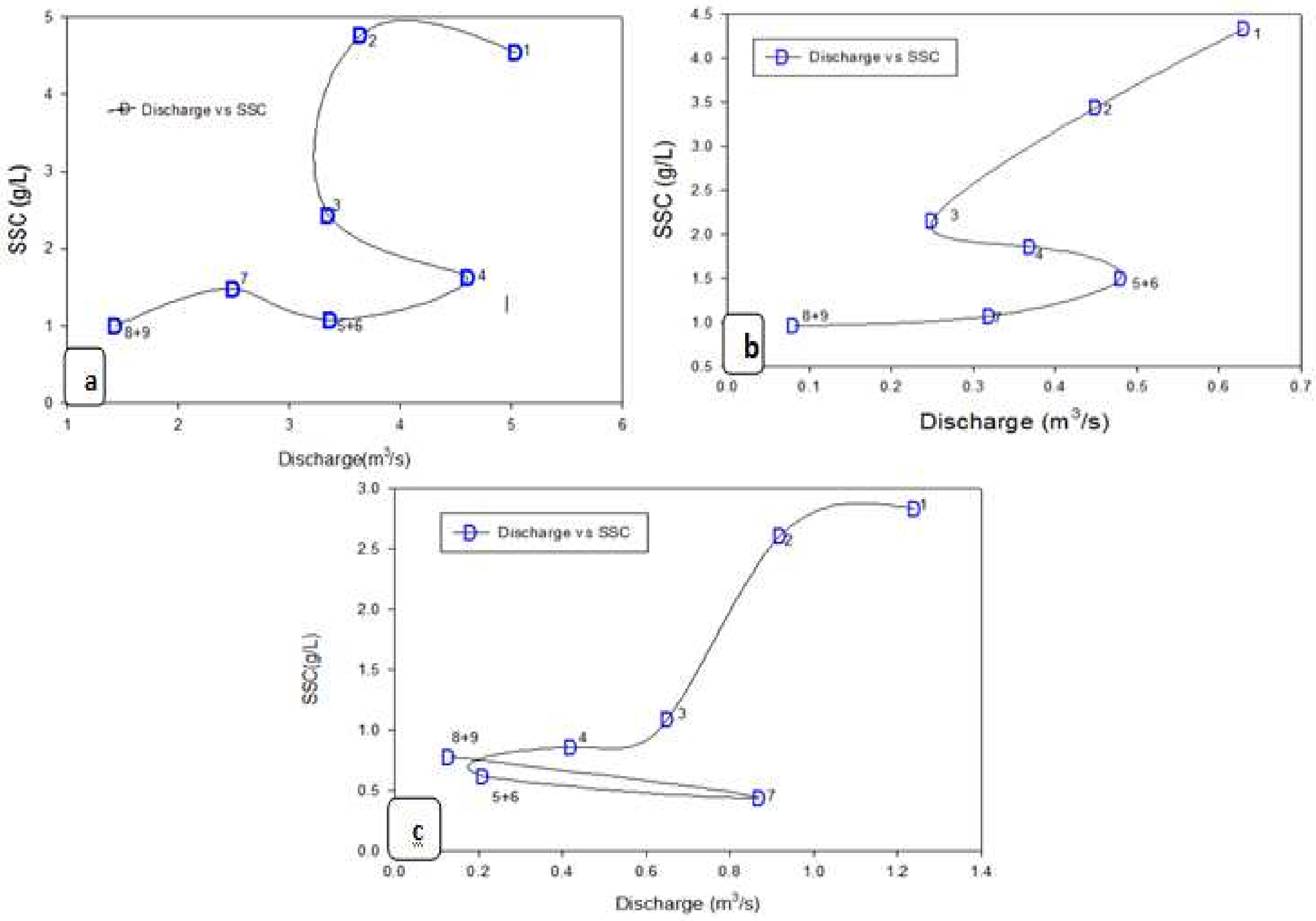


Figure 17 Q-SSC temporal rating curve (a) for Melka, (b) for Kollu and (c) Galessa monitoring stations

This is because based on the data rooted from a parallel study (part of this project); this is again due to an increase in vegetation (crop) cover decreased the sediment sources as per end of rainy season though discharge has positive correlation to SSC to all stations. For instance Potato was the major crop in the upper part of the watershed (Galessa kebele) which was grown at the earlier rainy season so that the probability of erosion was reduced since the land was under medium (30 - 60%) and high (60% and 70%) covered results less damage the land with erosion at the time of sample collection. whereas the average land cover(mainly referring to the crop cover) at the middle and along the lower part of the watershed was between 10-20% which was another factor to increased sediment probability. This is because Walling, 1977 indicates that scatter SSC–Q relationship is typical of 'supply-limited' or sediment sources conditions in its upper catchments which can be explained by hysteresis effects of sediment transport systems.

#### 4.1.1.2 Spatial Variability of Sediment Concentration

Based on the quantification of sediment in each monitoring sites; there was a significant difference both in amount and type of sediment lost among stations (Figure 19). The mean SSC (g $L^{-1}$) ranges from 3.0±1.1 in Melkal to 2.2±1.3 in Kollu and 1.4±0.9 in Galessa (Table 5).

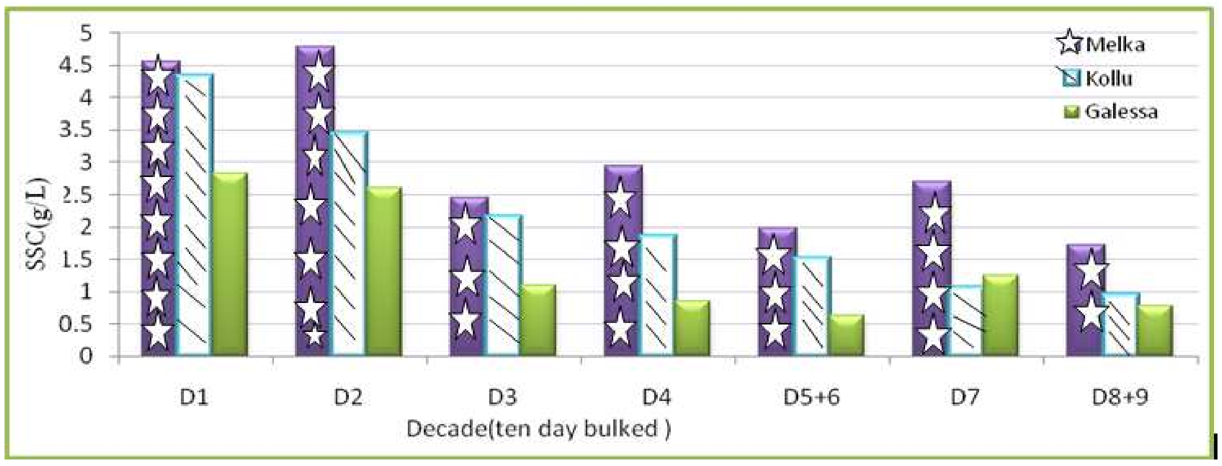


Figure 18 Spatial variability of SSC among the three monitoring sites

While the statistical significant test at (p-value <=0.005) among stations also shows that there was high variation in suspended sediment concentration. Moreover, the high standard deviations and covariance in SSC also indicate that there is variation in SSC within each station due to the variation in the catchment characteristics and socio-economic or land use factors in which it needs farther investigation on the major factors for such difference (Table 5).

Table 6 Sediment variability among stations

| Sampling station | Average SSC (gm/L) | Average discharge ($m^3/s$) | Total suspended sediment load loss (kg)($10^3$) | SSC SD among stations | SSC CV(%) among stations |
|---|---|---|---|---|---|
| **Melka** | 3 | 3.5 | 24611 | 1.2 | 120 |
| **kollu** | 2.2 | 0.3 | 2753 | 1.3 | 90 |
| **Galessa** | 1.4 | 0.6 | 683 | 0.9 | 80 |

Though it needs detail research about this difference is due to the human activities and/or LULC of the upper sub catchments of erosion contributing areas of the monitoring stations. For example based on the Land Use map of the watershed (Figure 19); SSC in Galessa is relatively low since the upper contributing or source areas was dominantly grazing land which reduce the probability of sediment. Whereas the higher sediment lost at Melka station is may due to in consequence of an intensive agricultural activity on the ridge of the Meja River which makes the land very susceptible to soil erosion. It is the fact that agricultural tiles are another sediment source and the increased runoff rates from sheet and rill flow, gully development, and enlargement of drainage ditches aggravating the process of erosion and sediment yield from agricultural lands. This is because SCRP research data indicates that erosion losses as highest from cropped land, highest (80% annual loss) on crop land than other land use types on account of ploughing and planting nature of the sector (EHRS, 1984).

While Still in Kollu was also relatively higher than Galessa which may be due an intensive agricultural activities on the upper part of the Lega Jeba river contributories but still lower than that of Melka since some part of the upper catchment was covered with planting trees particularly eucalyptus and settlement which reduces the probability of soil erosion.

Land use land cover patterns of Meja watershed

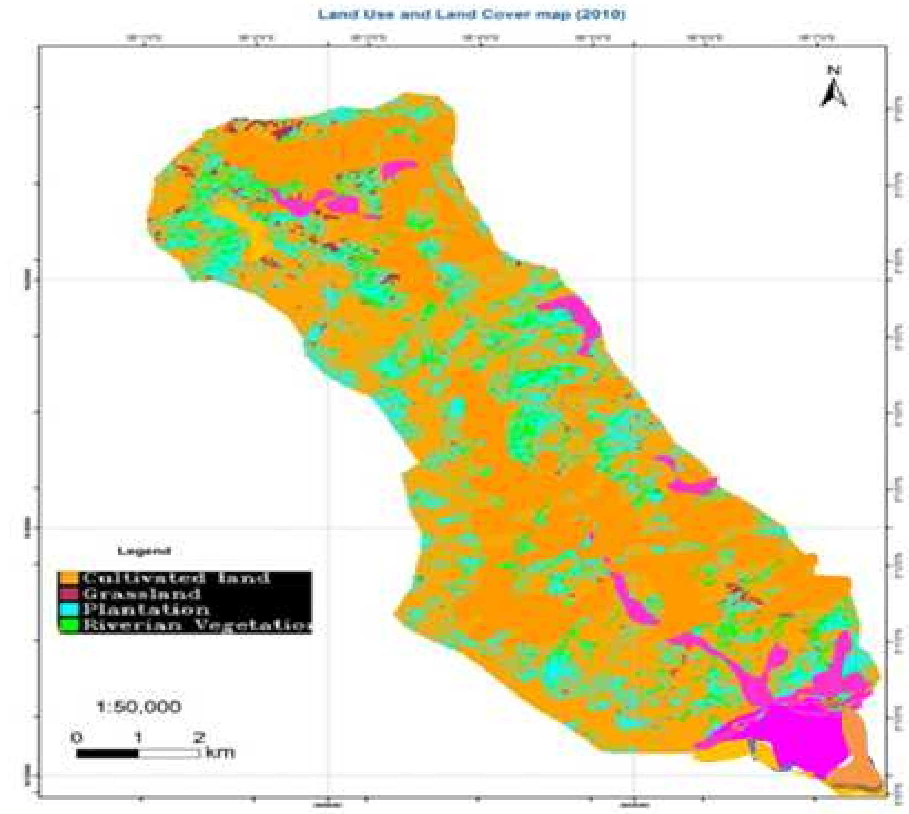


Figure 19 Land use land cover map of the study watershed

Source – Birhanu Ayana research paper on sustainable rain water harvesting management practice in Meja watershed (2011)

Another major factor for the variation of sediment losses between the three stations were due to the surface soil texture of the sub catchments contributing areas. This is because based on the **Pearson's pair-wise correlation** (Table 9) SSC were highly correlated to the particle size of the soil. If so, it is possible to identify the most critical sources areas that play a great role in the process of erosion in the watershed since the texture of sediment is a reflection of the sources of erosion (FAO, 1988). Thus from the mean soil type as presented in the following soil map of Jeldu woreda, it is easily to identify the most critical and play a great role in the process of erosion during the study period (Figure 20).

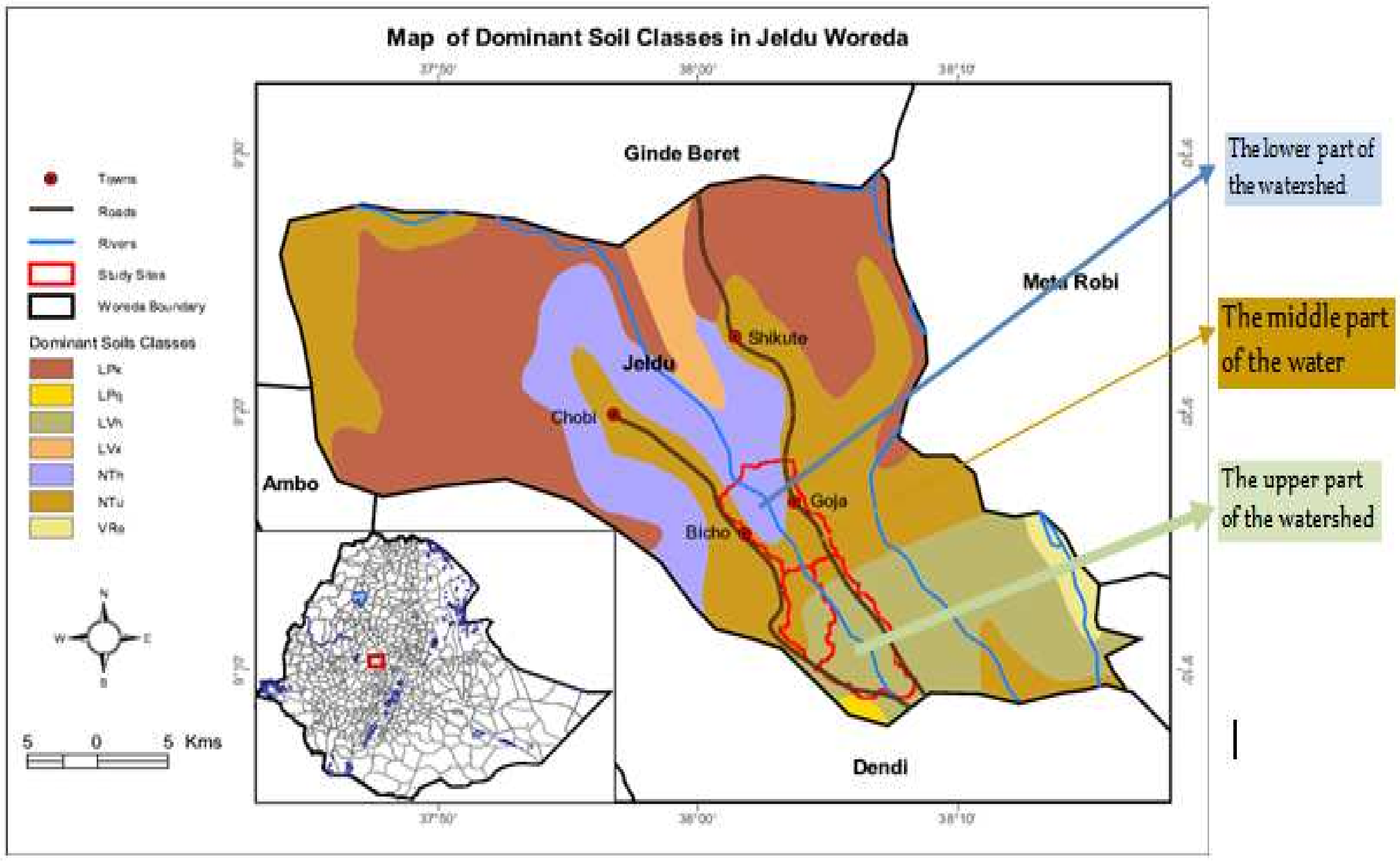


Figure 20 soil map of Jeldu district including the study watershed (source- IRLI, 2009)

From the map, the lower part of the watershed sub catchments are dominantly haplic Nitosoil (NTh). On the other had according to FAO (1988) this soil is characterized by relatively high content of clay and silt and surface soils may contain several percent of organic matter, revealed highly susceptible to erosion as compared to humic nitisols (NTu) and haplic luvisols (LVh) of the middle and upper part of the dominant soil type of the watershed. Similarly, the mean particle sizes of the collected sediment in the out let of the watershed was dominantly clay and silt (Table 7). Thus, by ignoring other factors in the process of erosion at Meja watershed; this confirms the higher percentage of sediments and associated nutrients was come from the lower part of the watershed since nutrients are strongly adsorbed to the finer soil fractions due to have high specific surface areas (Haregeweyn *et al.* 2008).

Yet, besides soil type and land use activities; the physiographic feature of the sub catchments was also the key factor that playing in the loss of sediment. Based on the digital elevation model of the watershed done by Birhanu Z.*et al.*, (2012), the runoff at the out let of the watershed was collected from the upper steppy part of Meja river gorge system while for Galessa was from flat areas of the upper catchments. Therefore the Ridge of Meja River was the most critical source areas (at Meja station) for the loss of sediment in the watershed as compared to Kollu and Galessa stations.

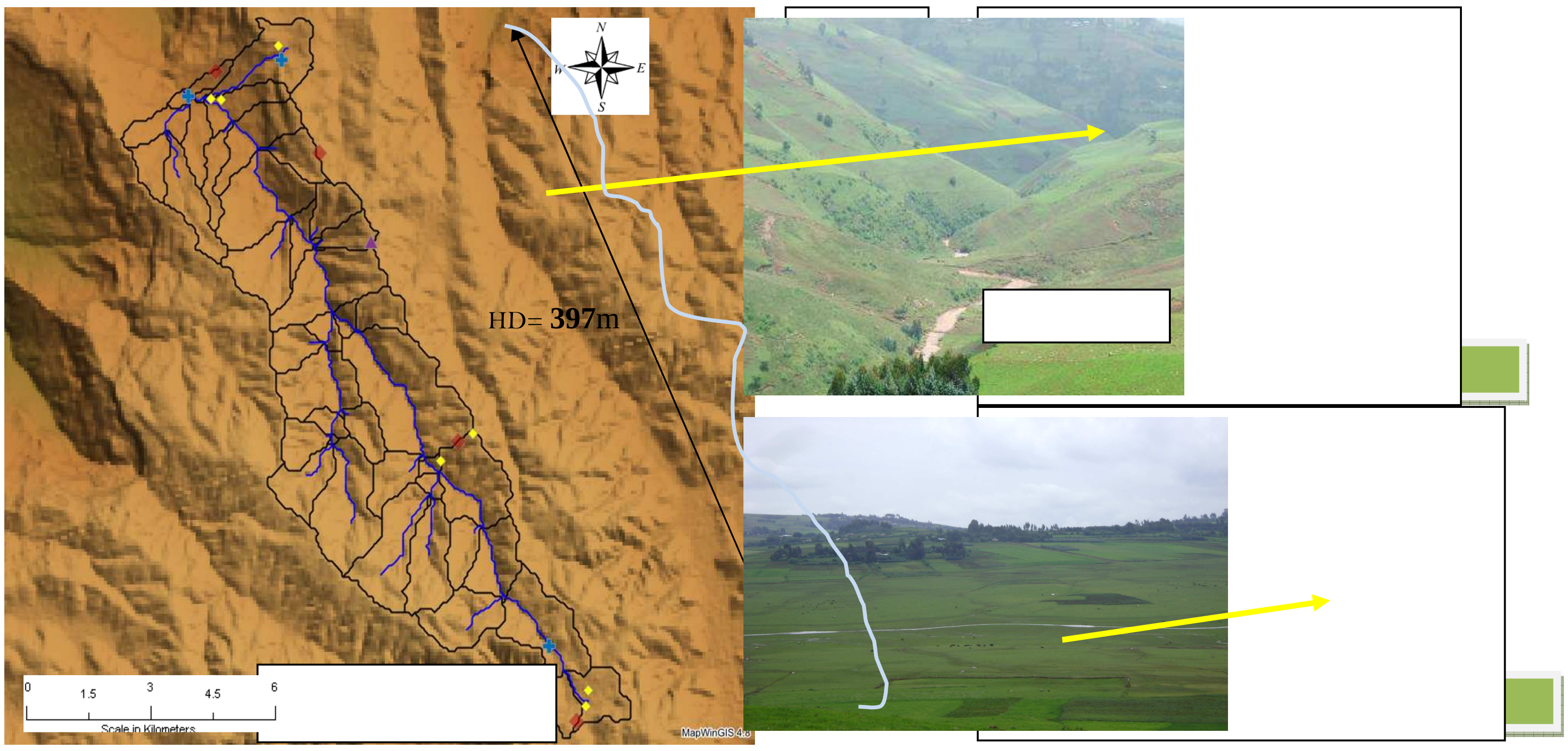


Figure 21 phsiographic featurres of Meja watershed (a) high erosion hazard areas due to steep slope at the middle and lower part of the watershed and (b) less erosion due to flat grazing land at upper part of Meja watershed.

Source(map) -Establishing Hydrological and Meteorological Monitoring Networks in Jeldu, Diga and Fogera Districts of the Blue Nile Basin, Ethiopia, B. Zemadim *et al* .(2012)

### 4.1.2 Area Specific Suspended Sediment Yield

Specific sediment yield (SSY) refers to the mass of sediment per unit area of a catchment that enters in to monitoring stations. Comparison of the sediment yield between the three monitoring sites is only possible after adjusting for the specific size of land that contributes the sediment. The SSY ranges from 448 ton km$^{-2}$ at Galessa, 604 ton km$^{-2}$ at Kollu and 74 ton km$^{-2}$ at Melka. The higher SSY values particularly in the sub catchments(Kollu and Galessa stations) might be explained by the smaller size of the sub catchment area in this study and hence may because of less probability for sediment deposition within the catchment (mainly at Kollu) and related factors may lead to exaggerated figures.

The magnitude and range of SSY values in this study area was high as compared to global and regional datasets. Nyssen (2005) reported that African and world mean SSY are 299 and 252 t $km^{-2}$ $y^{-1}$, respectively. While based on the study in northern Ethiopian highlands by Haregeweyn et al, (2008) showed that SSY of small catchment (189 - 1860 ton $km^{-2}$), the SSY of this study is in agreement with this range though it ranged at the maximum rate. Yet; the researcher still believes that it needs further researches for such differences among the monitoring stations upper catchment characteristics and other socio-economic factors that controls sediment lost.

## 4.2 Texture of the Sediment

The effect of sediment loss in degradation is highly related to the particle size of sediment. This is because the active fraction of sediment is usually cited as that portion which is smaller than 63µ m (in silt + clay) (Lal, 1998). The average texture of the sediment revealed that clay in Melka and clay loam both in Kollu and Galesssa stations (Table 7). While the mean comparison test between the texture of the sediment in all stations indicated that there was no significant at $P<= 0.05$ which implies that fine soil particles was play great role in the process of erosion in the watershed.

From the mean correlation test analysis of sediment texture with those eroded parameters (Table 9), it has a significant strongly correlated at 0.05 level of significant with all nutrients and sediment loss in all stations at 0.01 level of significant (having $R^2=0.83$ and -0.89 with % of clay and sand respectively (Table 9). The average texture of the catchment soil is silt clay (IWMI, 2011). Yet, as per the texture analysis of sediment it was more of clay; which implies that the suspended sediment collected that moved along with run-off came from fine-grained fertile and productive soils. Therefore the texture of the sediments reflects the rate and severity of erosion in the study watershed during the rainy season was a challenge for the livelihood of the poor farmers. This is because nutrients are strongly adsorbed to the finer soil fractions, which are preferentially transported by the sedimentation processes because of their high specific surface areas (Haregeweyn et al. 2008).

Table 7 Sediment texture of the collected sediment

| Sample code | Clay (%) | Silt (%) | Sand (%) | Textural class |
|---|---|---|---|---|
| MD1 | 58 | 31 | 11 | Clay |
| MD2 | 53 | 34 | 13 | Clay |
| MD3+4 | 44 | 30 | 26 | clay loam |
| MD5+6 | 49 | 32 | 19 | Clay |
| MD7+8+9 | 32 | 31 | 37 | clay loam |
| Mean | 45 | 32 | 23 | Clay |
| KD1 | 42 | 43 | 15 | silt clay |
| KD2+3 | 45 | 45 | 10 | silt clay |
| KD4+5+6 | 38 | 37 | 25 | Clay loam |
| KD7+8+9 | 33 | 31 | 26 | silt clay loam |
| Mean | 35 | 37 | 28 | clay loam |
| GD1+2 | 42 | 43 | 15 | silt clay |
| GD3 | 35 | 36 | 29 | clay loam |
| GD4+5 | 32 | 27 | 41 | clay loam |
| GD6+7+8 | 28 | 24 | 48 | sandy clay loam |
| Mean | 35 | 33 | 32 | clay loam |

Where Da+b means the texture was determined by mixing the sediment of decade a and decade b

## 4.3 Plant Nutrient Losses in the Watershed

Another challenge for the productivity in the watershed is that a considerable amount of plant nutrients was lost during the time of runoff. Analysis of sediment and runoff samples from the three monitoring sites indicated that there was a significant amount of plant nutrients mainly TN, NH4-N, $NO_3$-N, Available phosphorus ($P_{av}$) and organic matter was lost associated with the sediment and runoff water.

For example the mean TN lost associated with the sediment only in three months was 2.11±1.51, 1.44±1.53 and 2.65±2.57 gkg$^{-1}$ was from Melka, Kollu and Galessa monitoring sites respectively (Table 8). The loss of P associated in sediment and runoff water samples also is a challenge for the crop water productivity in the area. From the sample analyzed an average of 0.30±0.16, 0.21±0.12 and 0.10±0.09 g kg$^{-1}$ associated with of sediment and 0.34±0.24, 0.22±0.14 and 0.20±0.17 g L$^{-1}$ of dissolved phosphate was lost in runoff only during the rainy season from the watershed (MMS), KMS and GMS (Table 8). Another challenge in the watershed is the loss of organic matter during the time of runoff which plays a great role for the process of land degradation in the watershed. The loss of organic carbon associated with the sediment was also a challenge in sustainable land management of Meja watershed. Based on the analysis the mean Organic carbon loss was 31.88±21.9, 2.3±2.0 and 10.97±8.45 g kg$^{-1}$ from Melka, Kollu and Galessa monitoring stations respectively (Table 8). This has a serious detrimental effect on soil quality and productivity in both short and long terms in which threatening the food security of the local people. This is because in the process of erosion, loss of SOC leads to depletion of soil and other nutrients (N, P, K, S, Zn) associated with the organic fraction ((Lal, 1998).

As the soil organic matter level of the sediment obtained from the watershed was low,  it can concluded that the soil fertility status of Meja watershed is poor and can gets worse if not actions are taken.  From the data retrieved by a parallel study; this is worsened by the fact that the major part of the domestically produced dungs and crop residues are used for fuel instead of soil conditioner or compost. Consequently; the productivity gets declined and now the farmers impose a threat in the production cost particularly for inorganic fertilizers which is the major peril for the livelihood of the farmers of the study watershed.

Table 8 Nutrient lost associated with sediment and runoff analysis

| **Station** | **Sample Code** | **Total lost  during the study period from  in the watershed** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **In Sediment (g/kg)** | | | | | **Dissolved in runoff water (g/L)** | | |
| | | TN | $NH_4$-N | $NO_3$-N | P-$P_2O_5$ | SOC | $NH_3$-N | $NO_3$-N | P-$PO_4$ |
| **Melka** | MD1 | 5.32 | 1.35 | 0.68 | 0.67 | 65.30 | 0.48 | 1.35 | 0.86 |
| | MD2 | 3.33 | 0.46 | 0.28 | 0.34 | 64.39 | 0.16 | 1.25 | 0.35 |
| | MD3 | 1.54 | 0.24 | 0.14 | 0.16 | 27.74 | 0.15 | 0.77 | 0.26 |
| | MD4 | 1.32 | 0.37 | 0.15 | 0.23 | 26.49 | 0.19 | 0.87 | 0.48 |
| | MD5 | 1.16 | 0.79 | 0.02 | 0.29 | 15.95 | 0.15 | 0.13 | 0.12 |
| | MD6+7 | 1.27 | 0.16 | 0.02 | 0.15 | 17.46 | 0.05 | 0.11 | 0.18 |
| | MD8+9 | 0.86 | 0.09 | 0.06 | 0.24 | 5.83 | 0.02 | 0.05 | 0.12 |
| | Mean<br>**Total** | 2.11±1.51<br>**14.80** | 0.49±0.31<br>**3.46** | 0.19±0.02<br>**1.35** | 0.30±0.16<br>**2.08** | 31.88±21.9<br>**810.23** | 0.17±0.14<br>**1.20** | 0.65±0.51<br>**4.53** | 0.34±0.24<br>**2.37** |
| **Kollu** | KD1 | 3.73 | 0.23 | 0.18 | 0.52 | 6.11 | 0.53 | 1.22 | 0.45 |
| | KD2 | 3.95 | 0.84 | 0.80 | 0.32 | 4.49 | 0.12 | 0.98 | 0.15 |
| | KD3 | 0.67 | 0.11 | 0.04 | 0.46 | 0.82 | 0.21 | 0.33 | 0.07 |
| | KD4 | 0.84 | 0.02 | 0.06 | 0.05 | 2.03 | 0.09 | 0.24 | 0.09 |
| | KD5+6 | 0.38 | 0.07 | 0.01 | 0.01 | 0.26 | 0.08 | 0.12 | 0.03 |
| | KD7 | 0.34 | 0.03 | 0.01 | 0.06 | 0.23 | 0.06 | 0.02 | 0.02 |
| | KD8+9 | 0.17 | 0.02 | 0.01 | 0.02 | 0.24 | 0.03 | 0.01 | 0.01 |
| | Mean<br>**Total** | 1.44±1.53<br>**10.08** | 0.27±0.19<br>**1.32** | 0.27±0.16<br>**0.42** | 0.21±0.12<br>**1.44** | 2.3±2.0<br>**14.18** | 0.16±0.06<br>**1.12** | 0.46±0.25<br>**2.92** | 0.22±0.14<br>**0.82** |
| **Galessa** | GD1 | 6.16 | 0.66 | 0.05 | 0.30 | 28.63 | 0.48 | 1.93 | 0.25 |
| | GD2 | 7.64 | 0.33 | 0.06 | 0.20 | 18.80 | 0.25 | 2.84 | 0.59 |
| | GD3 | 1.88 | 0.24 | 0.02 | 0.12 | 12.17 | 0.15 | 0.88 | 0.22 |
| | GD4 | 0.83 | 0.08 | 0.03 | 0.01 | 6.79 | 0.19 | 0.21 | 0.17 |
| | GD5 | 0.56 | 0.07 | 0.01 | 0.05 | 5.60 | 0.17 | 0.20 | 0.09 |
| | GD6+7 | 0.94 | 0.01 | 0.02 | 0.03 | 1.21 | 0.05 | 0.03 | 0.04 |
| | GD8+9 | 0.53 | 0.09 | 0.01 | 0.02 | 3.58 | 0.03 | 0.03 | 0.01 |
| | Mean<br>**Total** | 2.65±2.57<br>**18.54** | 0.21± 0.2<br>**1.48** | 0.03±0.02<br>**0.20** | 0.10±0.09<br>**0.73** | 10.97±8.45<br>**76.78** | 0.19±0.13<br>**1.32** | 0.87±0.56<br>**6.12** | 0.20±0.17<br>**1.37** |

The statistical significance difference test in nutrient concentration among stations at 0.05 level of significant showed that there is significant difference for $NO_3$, $NH_4$, TN and OC at Melka and Kollu with that of Galessa (p-value=0.06). This means that there was great variation in the amount and type of nutrient losses from different sub catchment of the watershed. One possible reason for the high TN and OC level at Galessa than Kollu is the addition of manure from livestock that visit the upper catchment for grazing. On the contrary the Ridge of Meja River together with the cultivation of hilly slope nature of the land aggravates the loss of sediments and fixed plant nutrients. This variation may come due to the LULC of the lower part of the watershed. For example based on the data retrieved from a parallel study (part of this project); the major crop type grown in the lower (on the Ridge of Meja River) and middle part of the watershed was wheat and Tef; on the other hand these crops by nature requires an intensive ploughing (3-4 times) and relatively high concentration of fertilizer rate than other crops grown in the watershed.

### 4.3.1 Spatial and Temporal Variability of Nutrients Loss

As shown in Table 8, there is a variation in nutrient concentration in sediment and runoff between the stations.

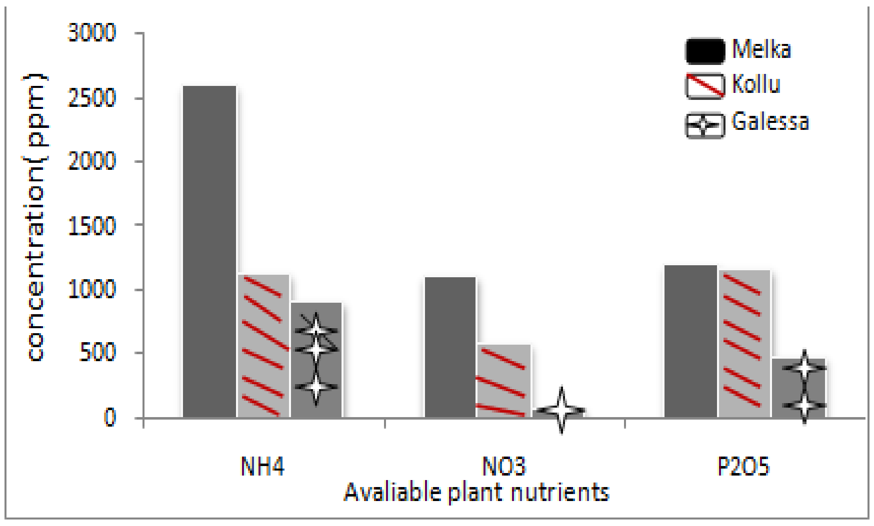
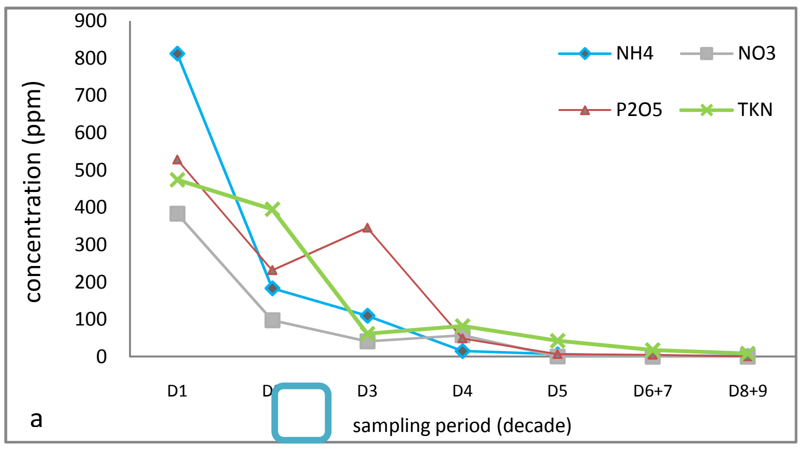


Figure 22 Spatial variability of major plant nutrient concentration

From the figure, it is possible to conclude that there was a clear difference in the concentration of nutrients across the locations. At Melka and Kollu higher than that of Galessa which can be explained by the intensive agricultural activities including application of Urea and DAP fertilizers in the upper sub catchments of these monitoring sites compared to Galessa station where the major land use was livestock grazing.

Therefore such figures revealed that their composition and magnitude varied widely within the watershed was due to several factors that needs farther and detail data to come up the major control variables for these differences among stations. So far still the mean TN, $NH_4$, $NO_{3,}$ $P_{av}$ and OC losses during the study rainy season was higher at Melka than Kollu station (Table 8) though it is no statistically significant difference (P-value=0.005).

There was also temporal variation in the nutrient concentration during the rainy season regardless of the stations. From the general trend in each station, highest concentration was at the start of the rainy season both in the sediment and runoff water (Figure 20). The mean statistical significance difference test in nutrient concentration between sampling periods at 0.01 significance level showed that there is significant difference for $NO_3$ and $NH_4$ in all the three stations (p-value=0.06) from the onset of July (D1) to the mid of August (D3). However, Pav and TN is a significant difference between sampling periods at 0.05 level of significant (P-value=0.04), and OC (P-value=0.03). This was associated with limited in supply. This is because in the watershed chemical fertilizers commonly urea and diammonium phosphate (DAP) were being intensively used to grow crops by the farmer in their agricultural fields at the time of sowing and unfortunately sampling was started the time of crop planting in the watershed.



In the figure a it is indicated that all the nutrients concentration sharply decreases from D1 to D2 except TN which started cline from $D_2$ to D3. But after the 3rd decade the concentration of all nutreints was decreased gradually which is may be related to supply limitation to wards the end of rainy season.

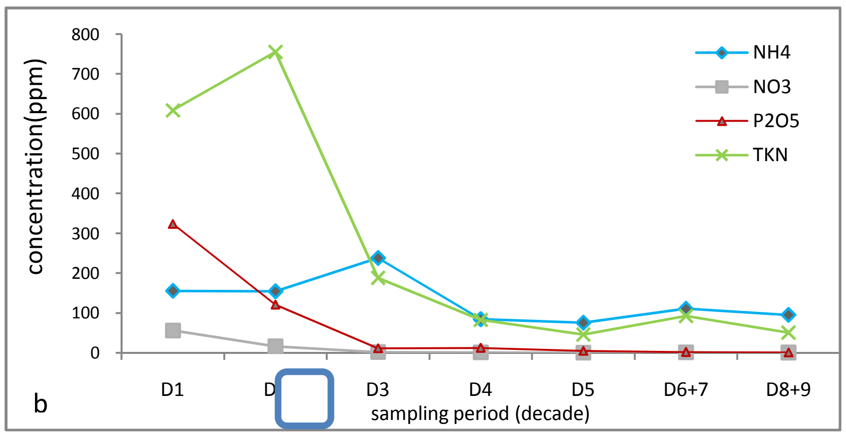


Figure 18 b shows the temporal variation of nutrient in Galessa was not yet sharp as Melka and Kollu stations and this is most probably due to less supply of this nutrients at the upper sub catchment of this monitoring site since it was dominatley grazing land but still there was high concentration of TN and $NH_4$ lost associated with runoff.

Figure 23 Temporal variability of nutrient loss trends (a) at MMS, (b) at GMS

But when we see their quantity, the concentration of nitrogen mainly $NH_4$ was higher than that of phosphorous although both were the major important nutrient that were applied to crops in the area in the form of inorganic fertilizers (Table 8). This is due to their chemical property or characteristics against transport by runoff in which N ($NH_4$ and $NO_3$) are more mobile compared with that of P, so that those nutrients are easy to transport by water through runoff process (Haregeweyn *et al*., 2008).

Similarly when we observe the nutrient concentration between the sediment and runoff water, dissolved phosphate and nitrate were very high than ammonia due to the easily solubility of these nutrients, and on the contrary ammonia is highly adsorbed by the soil colloids and easily volatile nature than nitrate and phosphate (Lal, 1998). However the mean statistical test at 0.05 level of significant showed that there is no significant difference in all nutrient concentration from the off set of August (D6) to the end of sampling period (D9)(p-value=0.008).

Hence it is possible to conclude the loss of nutrient through runoff was the most potent form of land degradation threatening sustainable agricultural production in Meja watershed since the eroded sediments and runoff was almost always accompanied by the export of sediment-bound nutrients and organic matter.

## 4.4 Summary of Eroded Parameters and Scheming Variables in Erosion Process

Pearson's pair-wise correlation was used between all pairs of both dependent and independent analyzed parameters in the process of erosion to establish whether variables are related linearly and to discriminate the variables in terms of their relation strength in the process of erosion. The Sediment yield and associated parameters from the three monitoring stations of the watershed are presented in Table 9.

Table 9 Correlation matrix between eroded parameters and discharge and catchment areas of the three stations

| | SSC(g/L) | Q (m3/s) | TN | NH4-N | NO3-N | P-P2O5 | SOM | Clay (%) | Silt (%) | Sand (%) | Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SSC(g/L)** | | 0.59247* | 0.4447 | 0.6542* | 0.6542* | 0.6439* | 0.46408 | 0.82648** | 0.7034** | -0.89087** | 0.4136151 |
| **Q(m3/s)** | | | 0.9872** | 0.5576* | 0.4396 | 0.308 | 0.57545* | 0.73035* | 0.7034* | -0.50953* | 0.8960504** |
| **TN** | | | | 0.9984** | 0.8545** | 0.7203* | 0.99908** | 0.53575* | -0.0425 | -0.34944 | 0.3659765 |
| **NH4-N** | | | | | 0.861** | 0.7351* | 0.99788** | 0.54944* | -0.0245 | -0.36633 | 0.3578591 |
| **NO3-N** | | | | | | 0.8503** | 0.86042** | 0.62943* | 0.3525 | -0.59287* | 0.2270481 |
| **P-P2O5** | | | | | | | 0.72539* | 0.61404* | 0.5349* | -0.66744* | 0.1325782 |
| **SOM** | | | | | | | | 0.56159* | -0.0266 | -0.37446 | 0.3831599 |
| **Clay (%)** | | | | | | | | | 0.4756 | -0.90112** | 0.5534643* |
| **Silt (%)** | | | | | | | | | | -0.78064* | -0.056166 |
| **Sand (%)** | | | | | | | | | | | -0.3433556 |
| **Area(km2)** | | | | | | | | | | | |

*Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Among those eroded parameters (Table 8), particle size of the sediment soil is one of the parameters that explain part of the variation in SSC and SY. A significant positive correlation ($R^2$=0.826) is observed between SSC and % of Clay while it was strongly with negative correlation to % of sand ($R^2$=-0.89). On the other hand, particle size of the catchment soil was a major part of the variation of SSC but it is not 100% which means that other catchment characteristics and situations probably differ so that different sediment yields was obtained for catchments of similar particle size sediments. For example, the mean soil textural class of the sediment collected at Kollu and Galessa sub catchment monitoring stations were Clay loam but have different SSC. On the other hand the correlation between Q and SY is found to be positive significant ($R^2$=0.59) which implies that Q is also an important parameter next to particle size for SSC of runoff losses in /or from Meja watershed.

## 4.5 Cost of Erosion in the Watershed

This chapter contributes information on the livelihood impact of erosion to the local people as a result of soil and nutrient losses along with runoff; since it will be essential for decision making process on taking or not taking any measurement actions from their economic perspectives for sustainable watershed management.

**As** indicated in section 4.1, a total of 6812 tons of sediment was lost from the watershed in three months, but this can make sense only when translated to its income and livelihood impacts. From the average bulk density of the catchment soil (IWMI, 2011) which is 1.23 g/cm$^3$ which means about 0.24 mm/ha depth of soil was lost only in one rainy season from Meja watershed. On the other hand, according to FAO, (1994) soil formation takes from 300 to 1000 years to replace 2.5 cm of lost topsoil. Therefore, the local people must wait at least 7 to 9 years to reverse this lost soil assuming erosion can be stopped. However, due to the existing human activities in the watersheds, it is speculated that the sediment yield in the area is likely to increase in future. Yet, according to Hurni (1993) finding on cost of erosion in the highlands of Ethiopia, in economic terms of sediment loss, these sediment was estimated the loss of 1200-2260 birr/ha for the people of Meja watershed. Thus; this result indicated erosion has tremendous economical and environmental impacts both for the present and the future survival of the local people of the watershed.

### Computation of Cost value of nutrient losses

Here for the purpose of calculating the onsite economic cost of erosion, only inorganic form of available nitrogen ($NH_4$-N and $NO_3$-N) as a source of nitrogen fertilizer and $P_2O_5$ as phosphorous fertilizer both in the sediment and dissolved in runoff water were considered based on the stchiometric principles as per the following table.

Table 10 Conversion factors for different forms of nutrients

| Source of loss | From | To | Multiply by | Total losses of N and $P_2O_5$ during the rainy period (Kg) at | | |
|---|---|---|---|---|---|---|
| | | | | Melka | Kollu | Galessa |
| **Fixed with sediment** | $NH_4$-N | N | **0.778** | 30126 | 1584 | 112 |
| | $NO_3$-N | N | **0.226** | 24352 | 848 | 18 |
| | P | $P_2O_5$ | **2.29** | 28846 | 972 | 500 |
| **Dissolved in runoff water** | $NH_3$ | N | **0.824** | 10010 | 925 | 248 |
| | $NO_3$ | N | **0.226** | 18437 | 1064 | 105 |
| | $PO_4$ | $P_2O_5$ | **0.75** | 23124 | 459 | 269 |
| **Total average** | **N**/ha* | | | **9** | **17** | **3** |
| | **P2O5**/ha* | | | **6** | **5** | **3** |

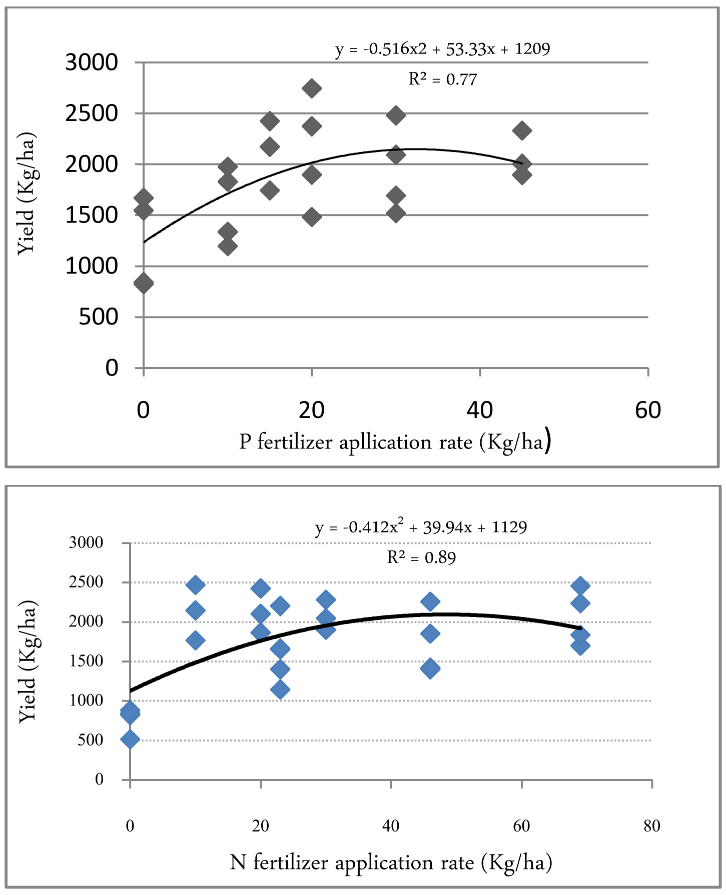
**For the average losses in three months in available forms from the catchments of each station*

Therefore economic analysis of erosion in Meja watershed is based on the potential revenue or profit to the local people caused by this amount of nutrient change as a result of erosion. Here based on the Jeldu district bureau of agriculture and rural development (2011), Potato (*Solanum tuberosum*) for Galessa and Barley (*Hordeum vulgar*) for Kollu and Melka are the major crops for the upper sub catchments of the stations.

Thus a partial economic or monetary valuation of nutrients loss associated in the sediments and runoff as a consequence of erosion was based on the cost of Barley and Potato and the yield were from the calibrated curve developed (Figure 21 and 22) using the data by **Holeta Agricultural Research Center (HARC)**; since this center is most preferable for this work because of the representativeness in terms of agro ecology and soil type. This is also because these crops were harvested in this year and the monitoring period of nutrient losses was assumed to be one complete growing season.

Table 11 Effects of N and P on Barley grain yield

| N fertilizer (Kg/ha) | Barley yield (Kg/ha) | P fertilizer (Kg/ha) | Barley yield (Kg/ha) |
|---|---|---|---|
| 0 | 824 | 0 | 824 |
| 0 | 884 | 0 | 1547 |
| 0 | 843 | 0 | 843 |
| 0 | 518 | 0 | 1670 |
| 10 | 2148 | 10 | 1830 |
| 10 | 2469 | 10 | 1337 |
| 10 | 1769 | 10 | 1197 |
| 20 | 2426 | 10 | 1976 |
| 20 | 2104 | 15 | 2172 |
| 20 | 1867 | 15 | 2424 |
| 23 | 1146 | 15 | 1744 |
| 23 | 1658 | 20 | 1898 |
| 23 | 2205 | 20 | 1483 |
| 23 | 1665 | 20 | 2745 |
| 23 | 1403 | 20 | 2374 |
| 30 | 2049 | 30 | 2093 |
| 30 | 2284 | 30 | 1521 |
| 30 | 1902 | 30 | 2480 |
| 46 | 2259 | 30 | 1693 |
| 46 | 1422 | 45 | 2005 |
| 46 | 1403 | 45 | 2331 |
| 46 | 1854 | 45 | 1896 |
| 69 | 2457 | | |
| 69 | 1702 | | |
| 69 | 2238 | | |
| 69 | 1838 | | |

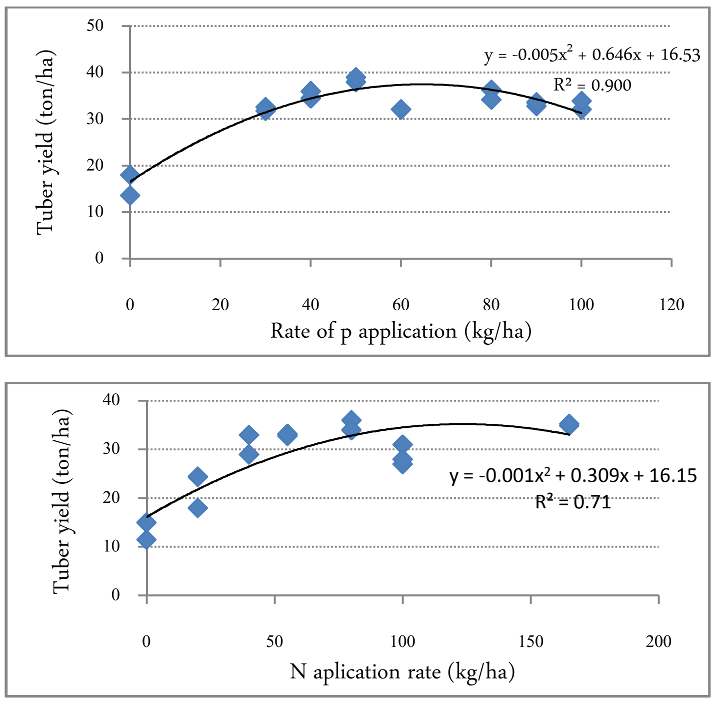


Source- Holeta agricultural research center (HARC) - Research achievements in Barley, Getachew *et al*, 2010

Figure 24 Yield response curve of barley with N and P fertilizers rate

Table 12 Effects of N and P on potato tuber yield

| N **application** (kg/ha) | Tuber yield(t/ha) | P application | **T**uber yield(**t/ha**) |
|---|---|---|---|
| 0 | 11.5 | 0 | 18 |
| 0 | 15 | 0 | 14 |
| 20 | 24 | 30 | 32 |
| 20 | 18 | 30 | 31 |
| 40 | 33 | 40 | 34 |
| 40 | 29 | 40 | 36 |
| 55 | 33 | 50 | 38 |
| 55 | 33 | 50 | 39 |
| 80 | 36 | 60 | 32 |
| 80 | 34 | 80 | 36 |
| 100 | 27 | 80 | 34 |
| 100 | 31 | 90 | 33 |
| 100 | 28 | 90 | 34 |
| 165 | 35 | 100 | 32 |
| 165 | 35 | 100 | 34 |

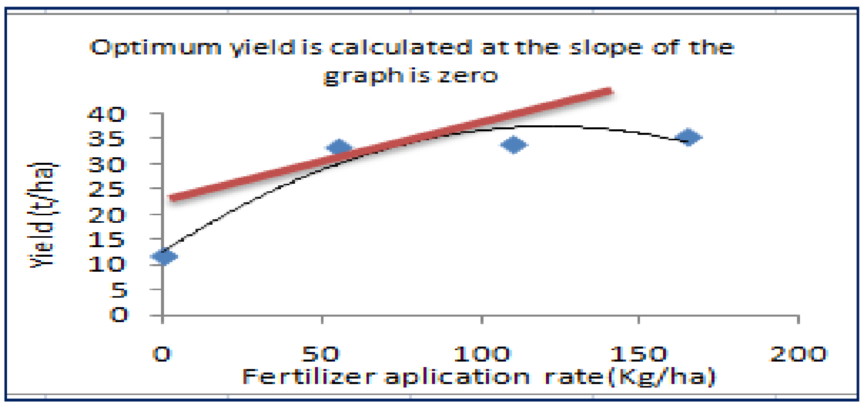


Source-HARC- Root and tuber crop by merging from different plots, Gebremedhin *et al*, 2000

Figure 25 Yield response curve of potato with N and P fertilizers

Thus the optimum production or yield as per loss nutrients of each station is determined when the slope of the graph is zero using the exponential equation of

$Y=ax^2+bx+c$……………………………Equation 6



So that the total benefits that the farmers lost due to erosion can be calculated as:

***Lost benefit (ETB*) = grain cost (ETB*/kg) X Estimated optimum total grain yield (Kg)/ lost nutrient***

Where the seed and tuber cost /kg was determined from the current market price (from Gojo town) and it was 7.5 and 4.5 birr/kg of barley and potato tuber, respectively.

The total amount of potential grain yield for each crop with this lost amount of nutrients was calculated based on the above developed calibrated response curve equations for each crop types in each station. For example from Melka monitoring site a total of 9 kg of N/ha was lost during the rainy season and then by assuming this fertilizer was applied for Barley production, it was able to produce a total amount of 32 kg/ha of barley. On the other hand in case of Galessa there was a total amount of 3 kg of N/ha was lost which implies that if we apply this fertilizer to potato field, farmers was able to get 210 kg/ha of potato tuber. The same procedure was used for P lost in the three stations and this can be summarized in the following table for each site and fertilizer for each assumed grown crops.

Table 13 Estimated monitory values of available nutrient lost due to erosion in three stations

| Monitoring station | Total lost fertilizers(kg/ha) | | Estimated optimum total grain and/or tuber yield (kg)/ha with lost | | Assumed crop | Seed and/or tuber cost (ETB*/ kg) | Subtotal lost benefit (ETB*)/ha | |
|---|---|---|---|---|---|---|---|---|
| | N | P | N | P | | | N | P |
| **Melka** | 9 | 6 | 32 | 47 | Barley | 7.50 | 240 | 356 |
| **Kollu** | 17 | 5 | 25 | 43 | Barley | 7.50 | 187 | 323 |
| **Galessa** | 3 | 3 | 210 | 340 | Potato | 4.50 | 945 | 1530 |

* Ethiopian 17.85 birr = US$ 1

Hence when we scale up this catastrophe in to the watershed scale; this has been noted to reduce income of farmer's of 595 birr/ha because of only N and P nutrient losses through erosion process from Meja watershed. Similarly farmers could lose 510 and 2475 birr from Kollu and Galesssa sub catchments respectively in the watershed as a result of erosion only in one particular rainy season. From Table 13 higher cost of erosion was at Galessa than Kollu while the nutrient concentration lost was higher at Kollu so that erosion was more catastrophic in the upper catchments of Galessa because of its sensitivity in terms of production and market values of the crop type though it needs farther investigations. Thus, it is possible to conclude that the economic impacts of erosion through the depletion of plant nutrients have profound implications in the current as well as the future survival of the people which adds another stress on insufficient food production to the poor of Meja watershed.

Yet; it is also possible estimating the cost of soil erosion in Meja watershed based on the **Replacement Cost Approach (RCA)** though it suffers from some inherent limitations which should be considered on a case by case basis such as the Agro ecology and land management conditions. Anyhow it also possible examines the economic crisis by assigning the monetary values of these depleted major plant nutrients as a result of erosion in the watershed. The value of the nutrients is typically calculated as the cost of purchasing a quantity of chemical fertilizer with a nutrient content equivalent to the quantity lost. It means that the nutrient losses associated with this erosion from the three monitoring stations were translated into equivalent quantities of inorganic fertilizers - nitrogen (N) and phosphorous (P) – lost associated with sediment and runoff water during the study (and particularly the rainy) period. The cost of replacing these equivalent fertilizer losses were then valued in terms current fertilizer prices by assuming that N was replaced by urea and that of P is by DAP commercial fertilizer.

So that based on the data obtained from the sediment and runoff water analysis at Melka monitoring station (out let of the watershed); a total of 6 kg/ha of $P_2O_5$ was lost from Meja watershed which is equivalent to 0.03 quintal/ha of DAP (i.e. DAP contain 20% of P and 18% of N) and 9 kg/ha of N which is equivalent to 0.02 quintal/ha of Urea (46% is N in Urea) commercial fertilizer. Thus from the cost of fertilizer got from the Beauro of agriculture and rural development of the study district, the cost of DAP and Urea fertilizer was 1250 and 1080 birr/quintal respectively. Then it means that farmers lost 32 and 21 ETB /ha (through the loss of P and N plant nutrients respectively in Meja watershed as a result of erosion. Here even though the cost of erosion calculated using CPA is by far greater than RCA, it revealed that there was still greater economic crisis because of erosion which adds stress on their survival and wellbeing both at the present and for the future of the local peoples in the watershed.

One more out of sight but most significant economic loss of erosion in the watershed was loss of runoff water. For example only during the rainy period (almost in three months) **24.9** billion $m^3$ of water was lost from Meja watershed in the form of runoff which has a potential to irrigate a sizeable ha of land, so that one could understand the valuable benefits gained by farmers if this water was used during dry season through water harvesting technologies though it needs detail feasibility study.

Unfortunately, the application of these approaches to estimating the on-site cost of soil erosion through nutrient loss estimation is only straight forward that leads ignoring other very important costs lost with erosion that were not consider; mainly SOC and TN. This is because Getachew *et al* (2010) and Gebremedhin *et al* (2000) indicated that mixing application of N and P fertilizer with manure/compost give a better yield than sole application of NP fertilizers both in Barley and potato production. So, if OC and TN loss were consider in the calculation; the estimated economic crisis of erosion would be much greater than the above estimated amount.

Here, even though the methodologies for measuring off-site costs i.e. the present value of any external costs arising from sedimentation and other downstream impacts and environmental was not investigated in this paper. This also another crisis of erosion in the highlands and the basin that needs farther and detail feasibility studies, the researcher believed that this lost was also another economic worth of erosion that hinder the poor farmers to unfetter from poverty. Therefore for better economic analysis of erosion in the study watershed and similar areas of the basin, the researcher believed that the economic aspects of erosion should be detailed analyzed and then come to a conclusion of the cost and benefit analysis of any watershed management interventions (since it is not a costless exercise) in Meja watershed in particular and Abay basin in general.

# 5 CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In general accelerated erosion in the form of sediment and sediment and plant nutrient loss pose a serious threat to land management sustainability and crop water productivity in Meja watershed due to natural and anthropogenic factors. The loss of sediment associated with runoff during the rainy season was one of the challenges for sustainable crop-water productivity both in terms of its sediment and runoff water quality.

From the general observation; both SSC and SY there were highly variable both in temporal and spatial situations. The general trend is lower towards the end of the rainy season in all the three stations while the spatial distribution of sediment loss showed that the lower and middle part of the watershed was relatively severed than the upper catchments of Galessa though it has higher SSY. Particle size of the sediment has a strongly correlated to almost all sediment parameters either positively or negatively; e.g. ($r^2$=0.826) between SSC and % of Clay while a strong negative correlation to % of sand ($r^2$=-0.89).

Analysis of sediment and runoff samples indicated that there was a significant amount of plant nutrients mainly TN, $NH_4$-N, $NO_3$-N, available phosphorus (Pav) and organic matter was lost. Nutrients concentration varies among monitoring stations depending on the LULC in which Melka has the highest nutrient loss per unit area for TKN, Pav, NH4 and $NO_3$, where as highest OC loss at Galessa.

All the data regarding to the loss of sediment and associated plant nutrients during the rainy period indicated that the Ridge of Meja River along with the middle part of the watershed was the most critical source areas; though it needs further detail investigation on the catchment properties in terms of the complex interaction of multiple natural and anthropogenic factors.

Finally; the economic effect of erosion due to the loss of plant nutrients of NP revealed that it had greater economic stress on the survival and wellbeing for the peoples of Meja watershed and in the country. Thus this result indicated erosion has tremendous economical and environmental impacts both for the present and the future survival of the local people of the watershed and in the basin. This is because the study watershed was fateful at the head of the Nile (Abay) basin where there is an intensive economic activity held in the country; so that there were also many off-site impacts of erosion that result from runoff and sedimentation process in Meja watershed.

## 5.2 Recommendations and out looks

Based on available data on sediment and nutrient loss in this study; therefore beneficiaries, who involved in planning, design and environmental related activities in Meja watershed and similar areas in the basin, the researcher recommend the following actions should be taken to have a sustainable watershed.

- Any interventions and prescribing solutions better to give priority to those erosion prone indentified areas in the study watershed and when erosion is more hazardous i.e. at the beginning of the rainy season;
- Runoff water harvesting should be an opportunity for enhancing rural livelihoods and food security and at the same time minimize the risk of erosion in the watershed and the basin;
- Nutrient loss should give due attention along with soil loss through awareness creation for land users in any watershed management interventions in simultaneously reverse the land degradation;
- The data can also be used to calibrate, validate, and evaluate models to provide valuable information in evaluating land management alternatives to help find solutions for land degradation of the watershed; and
- Further work is therefore needed to determine the dynamic watershed response of runoff and erosion process to specify different land use scenario especially for eucalyptus plantations on their land.

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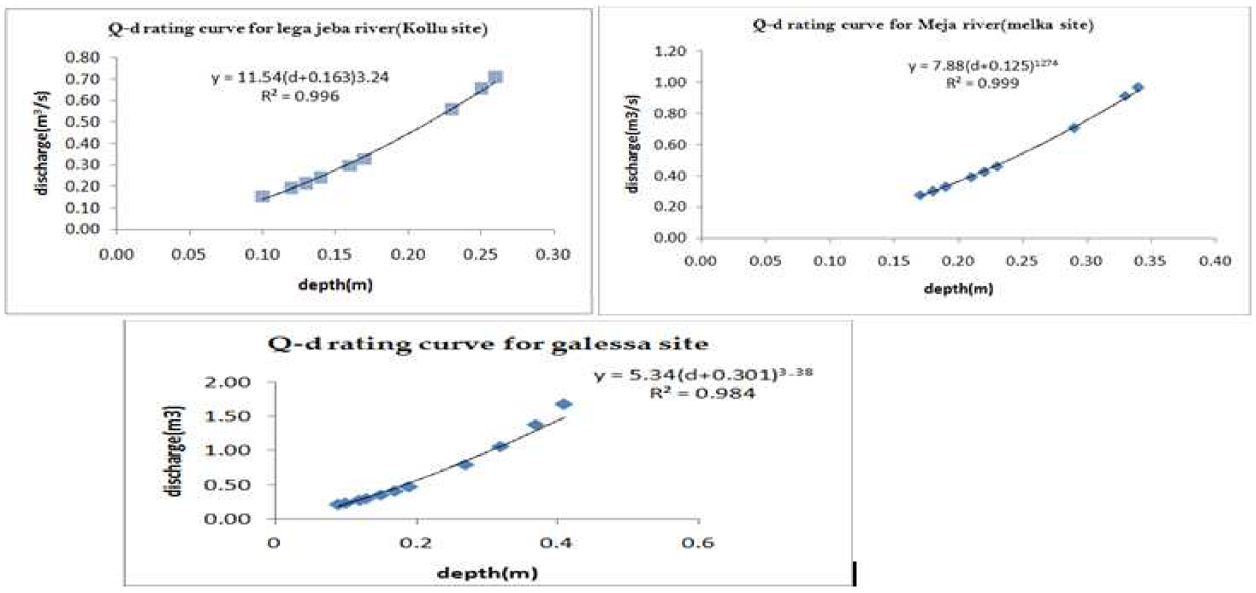
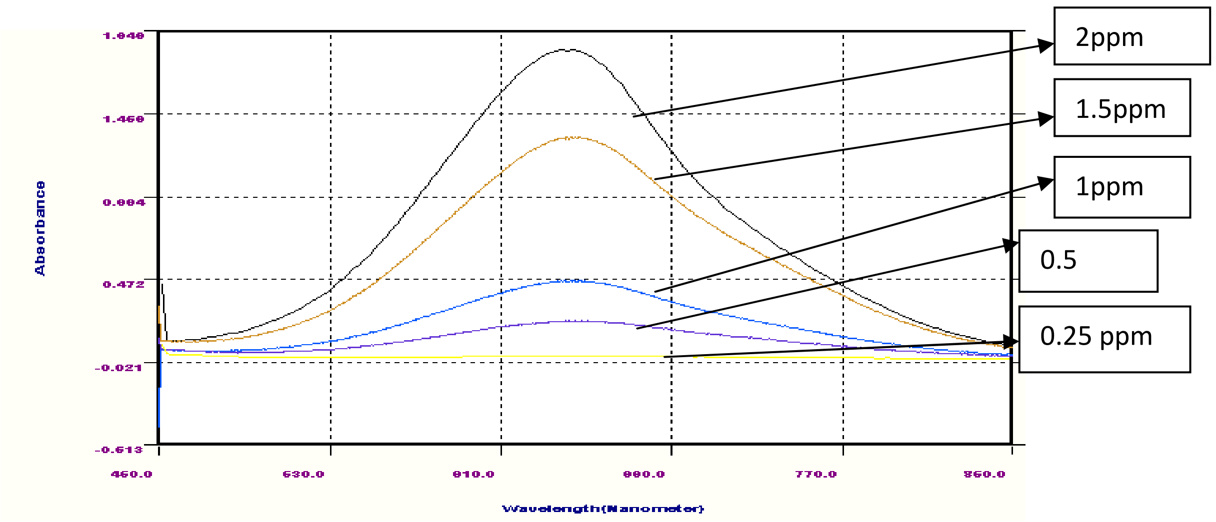
# 7 APPENDIX

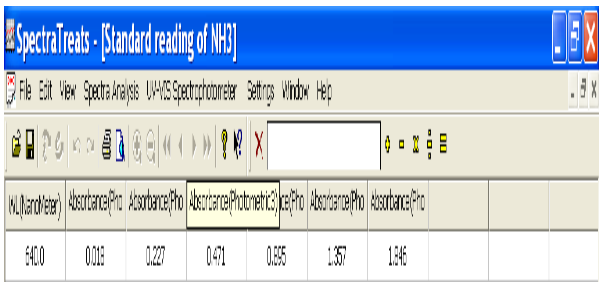
Appendix 1-Discharge-depth rating curve of the three monitoring stations based only for the rainy season



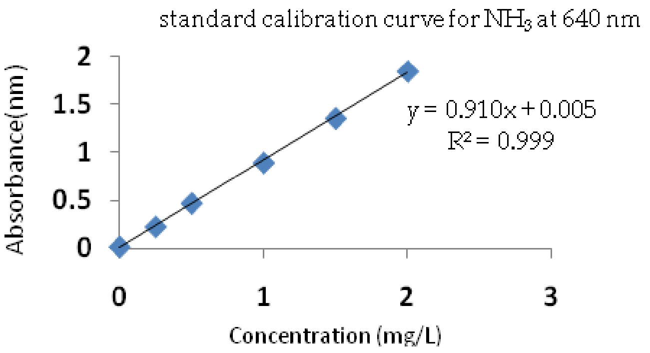
Appendix 2- Dissolved $NH_3$-N, $NO_3$-N and $PO_4$-P analysis using UV-Spectrophotometer

**Parameter 1: Dissolved Ammonia ( $NH_3$-N)**
**Method: Phenate method (UV-Spectrophotometer)**

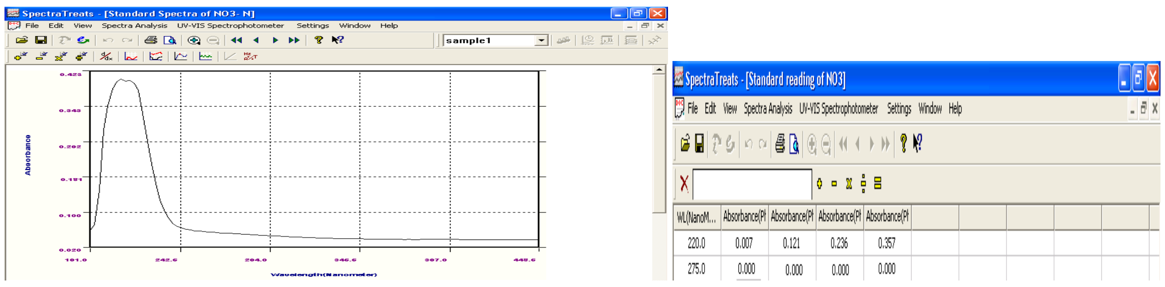




| WL(NanoMeter) | Absorbance(Pho | Absorbance(Pho | Absorbance(Photometric3) | ice(Pho | Absorbance(Pho | Absorbance(Pho |
|---|---|---|---|---|---|---|
| 640.0 | 0.018 | 0.227 | 0.471 | 0.895 | 1.357 | 1.846 |

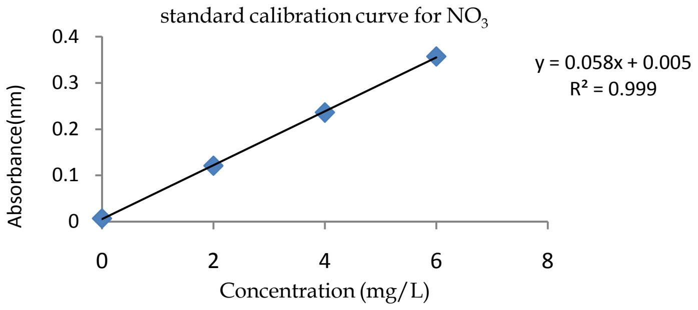


**Parameter 2: <u>Dissolved Nitrate ($NO_3$-N)</u>**
**Method: <u>UV-Spectrophotometer</u>**

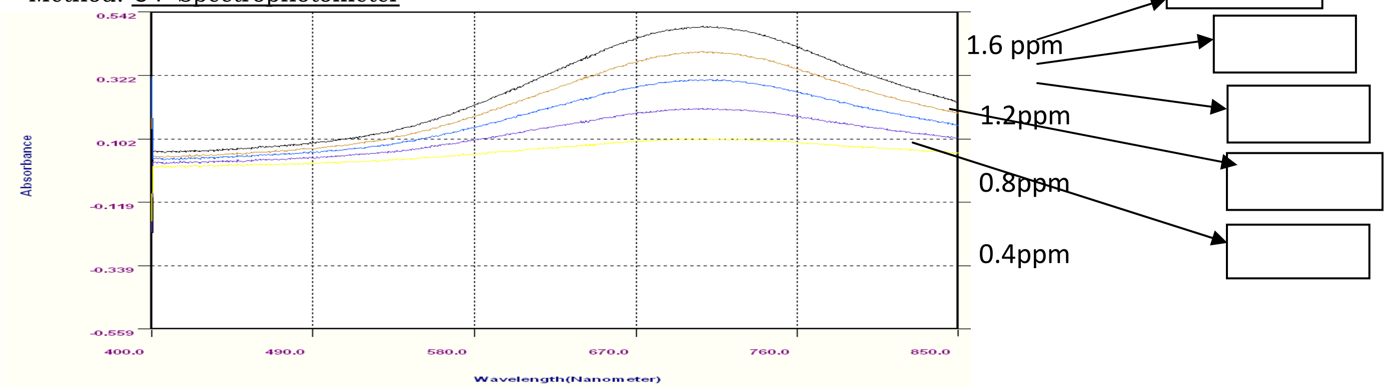


| WL(NanoM... | Absorbance(P | Absorbance(P | Absorbance(P | Absorbance(P |
|---|---|---|---|---|
| 220.0 | 0.007 | 0.121 | 0.236 | 0.357 |
| 275.0 | 0.000 | 0.000 | 0.000 | 0.000 |

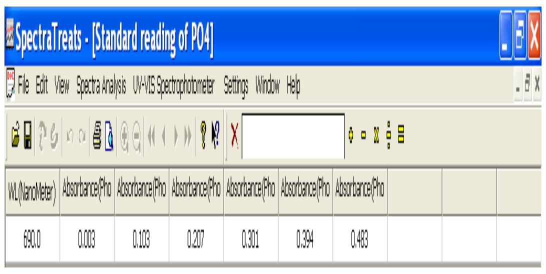
Standard reading of $NO_3$-N at 220nm and 275nm



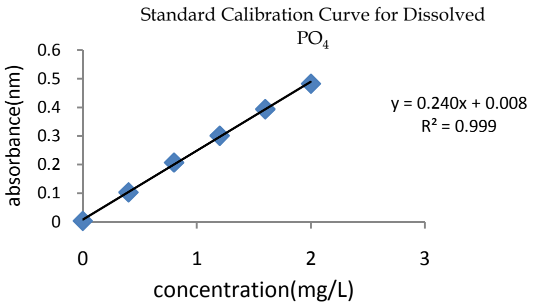
Parameter 3: <u>Dissolved Phosphorus</u>
Method: <u>UV-Spectrophotometer</u>



Spectra of the Standard $PO_4$ Solution at 960 nm



| WL(NanoMeter) | Absorbance(Pho | Absorbance(Pho | Absorbance(Pho | Absorbance(Pho | Absorbance(Pho | Absorbance(Pho |
|---|---|---|---|---|---|---|
| 690.0 | 0.003 | 0.103 | 0.207 | 0.301 | 0.394 | 0.483 |



Standard reading of $PO_4$ at 690

Appendix 3- Runoff Sediment filtering at Ambo University Laboratory

Appendix 4 Kjeldahl digestion and UV-Spectrophotometer reading of samples