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**MODELING SOIL NITROGEN BALANCE USING
GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE
SENSING: THE CASE OF LOWER BILATE RIVER BASIN,
SOUTHERN ETHIOPIA**

Msc Thesis

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Modeling Soil Nitrogen Balance using Geographical Information Systems and Remote Sensing: the case of lower Bilate River basin, Southern Ethiopia.

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List of Abbreviations

CSA = Central Statistics Authority

DEM = Digital Elevation Model

EHRIS = Ethiopian High land Reclamation Study

ETM⁺ = Enhanced Thematic Mapper Plus

FAO = Food and Agriculture Organization of the United Nations

GPS = Global Positioning System

HIR = Harvest Index Ratio

IFDC = International Fertilizer Development Center

IN = Inflow

LAPSUS = Landscape Process Modeling at Multi-dimensions and Scales

LU/LC = Land use and Land Cover

MAX = Maximum value

MIN = Minimum value

N = Nitrogen

NDVI = Normalized Difference Vegetation Index

NIR = Near Infrared Band

NUTMON = Nutrient Monitoring Tool

OECD = Organisation for Economic Cooperation and Development

OUT = Outflow

PCA = Principal Component Analysis

SNNP = South Nations Nationalities of People

SRTM = Shuttle Radar Topographic Mission

STD = Standard Deviation

USLE = Universal Soil Loss Equation

UTM = Universal Transverse Mercator

WGS = World Geodetic System

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Abstract

The consideration of soil fertility decline primarily referred to the exploitation of soil nitrogen. Nitrogen could be added to the soil via Commercial fertilizers, Organic inputs, Biological nitrogen fixation and Deposition. Conversely, it may be lost from the soil through Leaching, Erosion, Denitrification, Crop yield harvest and Crop residue removal. The study area was located in lower Bilate River basin within the Ethiopian rift valley which was characterized by an arid climatic condition with an erratic and unreliable rainfall characteristic. The core objectives of this research were modeling of the soil nitrogen balance and the plant available stock soil nitrogen by using a spatially explicit methodology of Remote Sensing and Geographical Information Systems. Moreover, the uncertainties and source of errors were assessed. To accomplish the mentioned objectives the study had integrated various primary and secondary data from various sources. The main inputs were digital soil map, Landsat-ETM⁺ satellite imagery, SRTM data, Rainfall data, and Agricultural data. The basic methodology of Stoorvogel and Smaling (1990) was adapted for soil nutrient balance estimation while the plant available stock soil nitrogen was determined using simple empirical relations. The research found out that in general croplands are endowed with lower amount of plant available stock soil nitrogen than non croplands. The addition of Commercial fertilizers like DAP and Urea were the main inflows in maize land while the fertilizer NPK was the major source of inflow in tobacco farm. Animal manure was the main source of nitrogen inflow in lands of Sweet potato, Cotton and Bush and Scattered shrub land. Harvested crop yield was the major source of nitrogen loss in crop lands. The removal of crop residues was the second most important source of nitrogen outflow in the area followed by Denitrification and Erosion. The soil nitrogen balance modeling revealed that 6 % of the area was very strongly depleted (> 40 N), 31 % was strongly depleted (20-40 N), and 61 % was slightly depleted (< 20 N). Flows such as Commercial fertilizer, Harvested yield and Residue removal were the possible sources of errors in the final soil nitrogen balance estimation. Land and water management technologies which maximize inflows of nitrogen while reducing the outflows like addition of Commercial and Organic fertilizers as well as soil and water conservation structures were the possible remedial measures that could alleviate soil fertility decline problem in the area.

Key words: GIS/RS, Inflow, Outflows, Soil Nitrogen Balance, Plant Available Stock Soil Nitrogen, Lower Bilate River Basin

1. INTRODUCTION

1.1 Background and Justification

Agriculture supplies 51.8% of the gross product and 90% of the export earnings of Ethiopia. It supplies significant proportion of the raw materials for the agro-industries and 86% of the population was engaged in agriculture (CSA, 1999). Thus, the national development goal of the country relies primarily on the agricultural sector. Crop production was the dominant component and taking the lion share of the sector. However, the rain-fed agriculture of the nation, though it attained better improvement in recent years, is unable to satisfy the country's need in parallel with the increasing population.

There were various factors threatening productivity of land, among these the poor soil fertility status was important one. Soil nutrient stocks were not static entities and studies in different parts of Africa at different spatial scales showed that nutrients were being depleted at alarming rates (Stoorvogel and Smaling, 1990). Nutrients were annually taken up by crops or lost in processes such as leaching and erosion which far exceeded the nutrient inputs through fertilizers, deposition and biological fixation (Smaling and Braun, 1996).

Many researches were undertaken dealing with assessing soil nutrient balances. For instance, Nutrient mining was estimated to average 660 kg of nitrogen (N), 75 kg of phosphorus (P) and 450 kg of potassium (K) per hectare per year during the last 30 years from about 200 million hectares of cultivated land in 37 countries in Africa (Stoorvogel and Smaling, 1990).

A study in central highlands of Ethiopia in Gare-arera at farm level revealed an average nitrogen balance of -9 kg N and the depletion was highest in poor household farms. However, the same study resulted, -79 kg N ha⁻¹ as mean balance in soil fertility group classes. The study also indicated that Nutrient depletion varied between the crops and Crop removal was the primary contributor to nutrient depletion followed by erosion. However, Enset and Maize were had a positive nutrient balance (Balesh et al., 2002). On the other hand, a farm level study in Southern Ethiopia of Kindo-Koisha area per household group and per farm component showed values ranging from -55 to -6 N kg/ha (Elias, 1998).

Eyasu (2004) indicated that the nutrient flow analysis was a useful diagnostic tool for assessing the consequences of farming on soil fertility. It allowed an evaluation of farm resources use through discussion with farmers, and it could thus play a practical role in decision-making concerning the areas where soil fertility improvement requires most attention. The identification of areas with negative

balances or systems already in dis-equilibrium should lead to management changes with the objective of resource conservation for sustainable cropping.

In order to quantify soil nutrient-balances, estimation of inflows and outflows was mandatory. Flows in general such as, Mineral fertilizer, Organic inputs, Erosion, Leaching were strongly associated with the land use systems. This was because nutrients were added or lost within the land use management units.

On the other hand, an exclusive estimation of soil nutrient balances did not give much relevance. That is, the determination of stock soil nutrients especially the fraction of which available to plant was significant in the overall effort of soil nutrient management.

Many methodologies of soil nutrient balance estimation as well as the determination of stock soil nutrient were not spatially explicit. However, the development of a spatially explicit methodology benefited a lot in an endeavor of enhancing agricultural production and productivity. The techniques and technologies of remote sensing and Geographical information systems earned a vital role in development of a spatially explicit methodology. Therefore, by devising a spatially explicit approach using remote sensing and Geographical information systems, it was possible to obtain the advantages of cost minimization, time reduction and enabled large area management.

1.2 Problem Statement

The study area was located in lower Bilate River basin within the Ethiopian rift valley which is characterized by an arid climatic condition. The rainfall is erratic and unreliable and poses a limit for crop production. Crop production system in the area is generally categorized in to two broad classes. The commercial production of tobacco for cigarette industry which was owned by the state was the first class. Rain-fed crop production by small holder farmers, covering the majority of the area, was the second type of crop production system in the study area. The system is characterized by minimum inflow of inputs and lower level of crop yield. Free livestock grazing was practiced in vast area of bush and scattered shrub land.

The fact that lower earn of income from farming and the absence or very low amount of income from off farm activities did not enable farmers to utilize improved agricultural technologies. Previous studies in the area were also depicted that biomass degradation was severe and became a big challenge in the Bilate River basin affecting the livelihood of the population of the area.

Soil erosion in the form of rill, sheet and wind were active in the area due to the lack of the use of soil and water conservation technologies and practices. Soil nutrient mining like nitrogen is an inevitable phenomenon in an area where less input was added to the soil. The availability and dissemination of agricultural technologies are also minimal. Thus, as the result of the above mentioned natural and anthropogenic processes and practices, devastating conditions for crop production were prevalent in the area. Consequently, the lower level of soil fertility is a big challenge for sustainable crop production in the study area.

1.3 Objectives

1.3.1 General Objective

The general objective of this research was modeling of plant available stock soil nitrogen and soil nitrogen balance as well as identification of land uses/covers which were vulnerable to soil nitrogen decline problems in lower Bilate River basin.

1.3.2 Specific Objectives

- To determine the plant available stock soil nitrogen across soil depth of Lower Bilate river basin
- To quantify the different sources of inflows and outflows of soil nitrogen on the basis of land use / cover classes of Lower Bilate River basin
- To produce a map revealing the soil Nitrogen balance in Land use / cover classes of Lower Bilate River basin
- To determine the soil nitrogen balance in the soil groups of the study area
- To determine the uncertainties associated with the determination of soil nitrogen balance
- To apply a spatially explicit methodology for modeling of soil nitrogen using the techniques of GIS and remote sensing

1.4 Major Assumptions, Limitations and Gaps of the research

- The study had used the Universal Soil Loss Equation (USLE) rather than the LAPSUS Model. This was because the area was almost uniformly flat that LAPSUS model which considers area of erosion and deposition did not produced much difference. Instead using the USLE model the soil that was eroded was assumed to be transported out of the area.

- The study only considered the production of crops during summer (June- September) season by ignoring the production of crops during the winter or off-season as insignificant based on the crop production statistics.
- The study did not estimate the contribution of wind erosion which could be relevant to be considered in arid environment as an outflow. This could be taken as a limitation of the study.
- Dry atmospheric deposition, which is called Harmattan dust, which is one possible source of nitrogen inflow is not considered in this study and can be taken as limitation of the study.

1.5 Research Questions

- ❖ How can RS and GIS be applied for Plant Available Stock Soil Nitrogen and soil nitrogen Balance estimation?
- ❖ How much was the plant available stock soil nitrogen in plant rooting depth in the study area?
- ❖ What were and how much the major Nitrogen inflows and outflows in the soil system?
- ❖ How much was the soil Nitrogen Balance in major soil groups of the study area?
- ❖ How much was the soil Nitrogen Balance in major land use / cover of the study area and hence which land uses were prevalent for soil fertility decline problems?
- ❖ How much the plant available stock soil nitrogen, the inflows, outflows and soil nitrogen balance were correlated?
- ❖ What were the values of uncertainties in soil Nitrogen balance estimation in major crops and land use / cover of the study area?
- ❖ Which parameters were the possible sources of errors in soil nitrogen balance estimation?

2. LITERATURE REVIEW

2.1 General Overview of Soil Nutrient Decline

Land degradation refers to the loss of land productivity, either quantitatively or qualitatively through various processes such as soil erosion, salinization, water logging, and depletion of soil nutrients. Accordingly, soil nutrient depletion or decline is part and parcel of soil degradation/land degradation. The discussion or the study of land degradation directly or indirectly involved the issue of soil nutrient decline. Soil erosion was became a national threat to Ethiopia. In the mid 1980s 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation (EHRS, 1987). In crop lands erosion rates were estimated to be 130 tons/ha/yr and 35 tons/ha/yr for all land uses in the high lands (EHRS, 1987).

2.2 Review of Methodologies in Soil Nutrient Balance Calculations

2.2.1 The Basic Methodology

An old and widely used methodology of calculating soil nutrient-balances was introduced by Stoorvogel and Smaling (1990). Subsequent studies often adopted such basic approach and modified to the study objectives and particular location. The basic approach defined a soil nutrient balance as a net balance of five inflows and five outflows. The five inflows were Mineral fertilizer (IN 1), Organic inputs (IN 2), Atmospheric deposition (IN 3), Nitrogen fixation (IN 4), Sedimentation (IN 5) while the outflows were Crop products (OUT 1), Crop residues (OUT 2), Leaching (OUT 3), Gaseous losses (OUT 4) and Erosion (OUT 5). The net balance was then calculated as the difference between the sums of inflows and outflows. Land use systems or land water classes were the basic calculating units. These were Low rainfall (LR), Uncertain rainfall (UR), Good rainfall (GR), Problem area (PR), Naturally flooded (NF), Irrigated area (IR).

However, the above methodology was criticized for lack of validation, the use of simple transfer functions and regression equations, the non consideration of spatial and temporal variability and unknown uncertainties.

Lesschen et al. (2007) was produced a new methodology which was spatially explicit relied on the approach of Stoorvogel and Smaling. The Authors re-estimate the original regression model of Stoorvogel and Smaling as well as set land use maps for substituting land/water classes for better assessment of soil nutrient balances. Moreover, the methodology was advantageous in developing an approach for assessing

the uncertainties of soil nutrient balance estimates. Database program and GIS were used for calculating nutrient flows and creating maps respectively. The methodology was tested in Burkinafaso at macro level.

A study by Balesh et al. (2002) was one of the studies conducted under Ethiopian case. The study was set with the objectives of assessing how nutrient balance was influenced by wealth category and soil fertility and crop types as well as monitoring flows at farm level. The study was located on a small holder farming system in Central Ethiopia, Gare-arera.

NUTMON, nutrient monitoring computer toolbox which often used at micro level was used to calculate nutrient-balances. Inflows and outflows were estimated by direct measurement and from literature sources. The basic difference of the study in contrast with many studies was that the incorporation of human excreta (OUT 6) based on the Vlaming et al. (2001). However, the study was not spatially explicit and since it was conducted on nine farmers' farm lands, the conclusion drawn was only had limited importance.

Another small scale study on soil nutrient balance was conducted in Kindo-Koisha farms in southern Ethiopia (Elias et al., 1998). Four socio economic groups; Rich, Medium, Poor and Very poor and two agro-ecological zones (high land and low land) were used as a base for selecting study farms. The study utilized the structure of decision support-model for monitoring nutrient balances developed by Smaling and Fresco (1993). The inflows were Mineral fertilizer, Manure, Leaf litter, Deposition, and Biological Nitrogen fixation while the outflows were Harvested product, Crop residues, Leaching, Denitrification and Erosion. Denitrification, Deposition and Leaching were determined based on equations. The rest parameters were adopted from literatures and direct measurement.

2.2.2 Nutrient-Balance Studies in Africa, IFDC Approach.

IFDC developed a new methodology relied on previous work on nutrient balances. The methods and procedures for estimating nutrient balances were linked with attribute database and GIS. The methodology specified the balance of nutrients in soils of agro-ecosystems at a country or regional scale by an equation. This study selected only few numbers of flows namely: Harvested product, Crop residues, Leaching, Gaseous losses and Erosion. The balance of nutrient inflows and outflows per year or nutrient depletion in kilograms per hectare per year for a country and crop was estimated. Among many similar studies the methodology was unique due to the incorporation a method for calculating nutrient requirement of crop. Here the nutrient requirement referred the amount of nutrient uptake required to achieve a specific target yield without depleting the soil nutrient (Hena, 1999).

2.2.3 National Soil Surface Nitrogen Balances, OECD

The study considered Fertilizers, Net input of livestock manure, Biological nitrogen fixation (BNF), Seeds and Planting materials and Atmospheric deposition as inflows. And the outflows were Denitrification, Total harvested crops and Total forage. Thus, losses such as Gaseous, Erosion and leaching were ignored. Subsequently, the final result was biased by overestimating the nitrogen in the soil (FAO, 2003).

However, the study provided an interesting result as the methodology was converted in to software and database program. The usage of the database in developing countries was limited due to high requirement of data.

2.2.4 Sub-Saharan Africa Soil Nutrient Balance Study

Owing to the objectives of producing a methodology working in meso-scale, the study conducted in three African countries namely; Ghana, Kenya, and Mali. Like most similar works the approach followed was adopted from the procedure of Stoorvogel and Smaling (1990).

The fact that making the methodology spatially explicit and calculating the net balance on land uses enabled the use of the methodology for better results. A grid map with a cell size of 1 km was combined with other spatial data needed for the nutrient balance calculation. The outcome of the model was a net erosion-sedimentation map with units in meters, convertible to tones per hectare (FAO, 2003).

2.3 Scales of Soil Nutrient Balance Calculations

In terms of Spatial extent soil nutrient-balance calculations was calculated in three scales namely: Macro-level, Meso-level, and Micro-level (FAO, 2003).

Macro level: Studies undertaken at a country level were considered as macro level. The methodology was that of Stoorvogel and Smaling. Studies such as Sub-Saharan Africa soil nutrient-balance by FAO and Nutrient-balance studies in Africa, IFDC approach were good examples. The output from the FAO study was presented as N, P, K balances by land use system and by country. Hence, the approach enabled for comparison between countries.

Meso level: studies which were set at district level were in this category. The simplification of the macro level to suit to a well inventoried district deserved paramount significant in the management of soil fertility problems in an effective manner.

Micro level: in this level the methodology used was the NUTMON toolbox. Farms, which were the bases for land management, were the calculation units. Moreover, Participatory approach, socio-economic house hold groups, and integrated nutrient management aspects could be effectively addressed. Micro level studies provide a picture of the variation within a meso level unit.

Results of nutrient depletion were highly dependent on the scale of the study. That is values in meso level and micro level showed significant difference. Moreover, even within the same level, values had got diverse variability. This was probably attributed to, though the studies were within same level, the objectives and focuses of the studies usually differ. For instance, some could be interested in identifying the relationships between the wealth groups and nutrient balance rates. On the other hand, other results were revealed the relationships among crop types, farming systems and nutrient balances. Therefore, it was very difficult to compare most results of nutrient balances on a common reference scale.

2.4 Role of GIS in Soil Nutrient Balance Calculations

A geographic information system is a computer-assisted system for acquisition, storage, analysis and display of geographic data. Nowadays, GIS is becoming an essential tool in the effort to understand complex processes at different scales: local, regional and global. In GIS, the information coming from different disciplines and sources as traditional or digital maps, databases and remote sensing, can be combined in models that simulate the behavior of complex systems (Mueksch, 1996).

The incorporation GIS in nutrient balance studies was quite valuable as it was possible to take spatial variation of soils and climate in account.

At the macro and meso levels GIS was important for aggregating data and producing maps. However, the main problems were data quality, lack of spatial data, resolution differences and ground checking. GIS was important at micro level for up scaling results to larger areas.

2.5 Benefits and Uncertainties in Soil Nutrient Balance Calculations

2.5.1 Implication

The implication of soil nutrient results was linked with the scale of the study. An out put from macro level raised awareness of soil fertility problems, indicated areas of nutrient depletion or accumulation. It also provided a basis for selecting areas for soil fertility improvement.

Meso level results provided information that could not be deduced from macro level or micro level. It offered a suitable entry point for policy-makers and private sector intervention, where macro level and micro level were not appropriate for policy-making at the sub-national level. It was possible to identify specific constraints, use quantified flows for planning purposes and extrapolate results to other similar areas.

Micro level studies provided a picture of the variation within the meso level unit. Relevant management factors could be included and monitoring could be checked whether changes in nutrient management had a bearing on the nutrient balance and farm income. That is, the NUTMON-toolbox is a useful application, which also includes the monetary part. Locally specific packages could be promoted.

The interpretation of negative nutrient balances was strongly associated with the nutrient stock. A negative nutrient balance on a rich soil should not affect yield in the short term, while on a poor soil, crop yield might declined each year as a result of nutrient depletion. Hence, nutrient depletion did not manifest itself clearly, but problems were likely to occur for the future generations (FAO, 2003).

2.5.2 Uncertainties

The basic data for nutrient inputs and outputs were usually selected from literature and production statistics. Data from literature pertained to various sites however, might not necessarily be representative for the selected area. The data sources used for such analyses had different confidence limits attached to them.

Therefore, it was quite important to select models considering the appropriate area of application, and understanding the basic assumptions while they were developed. And sufficient accuracy was required from the results so as to be meaningful and draw conclusions. That is, the uncertainties associated with results had to be assessed (Lesschen et al., 2007).

2.6 Summary of Previous Researches and Findings in Soil Nutrient Balance Studies

2.6.1 Overview of Results of Nutrient Balance Studies in Africa and the World

Table 2.1. Results of Soil nutrient balance studies.

Scale	Site	Special remark	N(kg/ha/yr)	Source
Macro	Sub-saharan Africa	-	-22	Stoorvogel and Smaling (1990)
	China	-	-8	Sheldrick, Syres and Lingard (2003a)
	Ghana	Spatially explicit	-27	FAO (2003)
	Kenya	Spatially explicit	-38	FAO (2003)
	Mali	Spatially explicit	-12	FAO (2003)
Meso	Kissii District Kenya	-	-112	Smaling, Stoorvogel and Windmeijer (1993)
	Southern Mali	Optimistic and Pessimistic view	-25	Van der Pol (1992)
	Andra Pradesh, India	-	18	Singh et al. (2001)
	Nkawie District, Ghana	Cocoa-based system	-18	FAO (2003)
	Wassa Amenfi District, Ghana	Cocoa-based system	-4	FAO (2003)
	Embu District, Kenya	Tea-coffee-dairy system	-96	FAO (2003)
	Koutiala Region, Mali	Cotton-based system	-12	FAO (2003)
Micro	Southern Mali	Participatory approach	-8.2	Ramisch (1999)
	Northwest United Republic of Tanzania	Banana-based system	-76 to 80	Baijukya and Steenuijzen de Pijters (1998)
	Eastern and Central Uganda	-	-125 to -3	Wortmann and Kaizzi (1998)
	United Republic of Tanzania	Sisal plantation	-13	Hartemink (2001)
	Southern Mali	Partial balance	-36 to -27	Kante (2001)
	Asia	Agriculture-aquaculture system	-9 to 72	Dalsgaard and Prein (1999)

Source: FAO (2003).

2.6.2 Overview of Results of Nutrient Balance Studies in Ethiopia

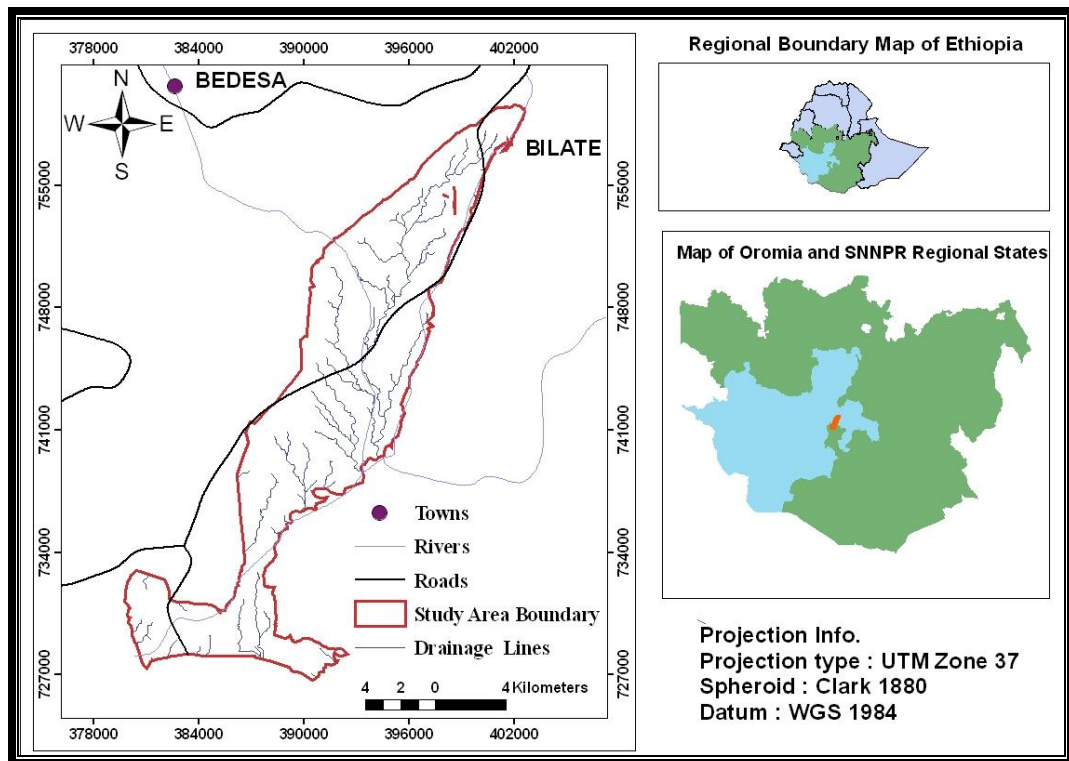
A study in Ethiopia at micro level, specifically at farm level revealed that the average nitrogen balance was -9kg N and the depletion was highest in poor household farms. However, the same study results in -79kg N ha⁻¹ as mean balance in soil fertility group classes. Nutrient depletion varied between the crops and grasslands had got severe depletion. Crop removal was the primary contributor to nutrient depletion followed by erosion. Enset and Maize had a positive nutrient balance (Balesh et al., 2002).

Likewise, a farm level study in Southern Ethiopia kindo-Koisha area per household group and per farm component, showed varied results. For highland, farms with household groups of Rich, Medium, Poor, and Very poor, the values were -47,-51,-19 and -6 N kg/ha respectively. In contrast, in lowlands with household groups of Rich, medium, poor and very poor the values were -49,-41,-55,-20 N kg/ha N respectively. A study at macro level in sub-Saharan Africa gave a value of -41N in kg/ha/yr for Ethiopia as national average (FAO, 2003). On the other hand, the IFDC study presented a value greater than 60 kg NPK/ha/yr for Ethiopia for the years 1993-95.

3. STUDY AREA

3.1. Location and Extent

The lower Bilate River basin, and specifically the study area was located in southern part of the country and it stretched over some part of Humbo and Damot Weide woredas in Wolaita Zone. It lies between 724550 and 759663 UTM north and 379217 and 402594 UTM east with in altitudinal range of 1200 and 1350 masl. The study area was some 19,993 ha, in Bilate and Abbaya delta region.



3.2. Climate

The study area falls within the traditional Kola agro-climatic zone, which can be classified as semi-arid climate. There were six observation stations for recording climatic data near by the study area. These metrological stations were located at Amaro-Kelo, Bilate Agricultural State, Dilla, Hagere-maryam, Wajifo and Boditi.

3.2.1. Rainfall

The average annual rainfall recorded was 1303 mm with minimum of 34.9 mm in January and maximum of 208.3 mm in April. This pattern of rainfall indicated the possibilities of rain fed crop production from May to October

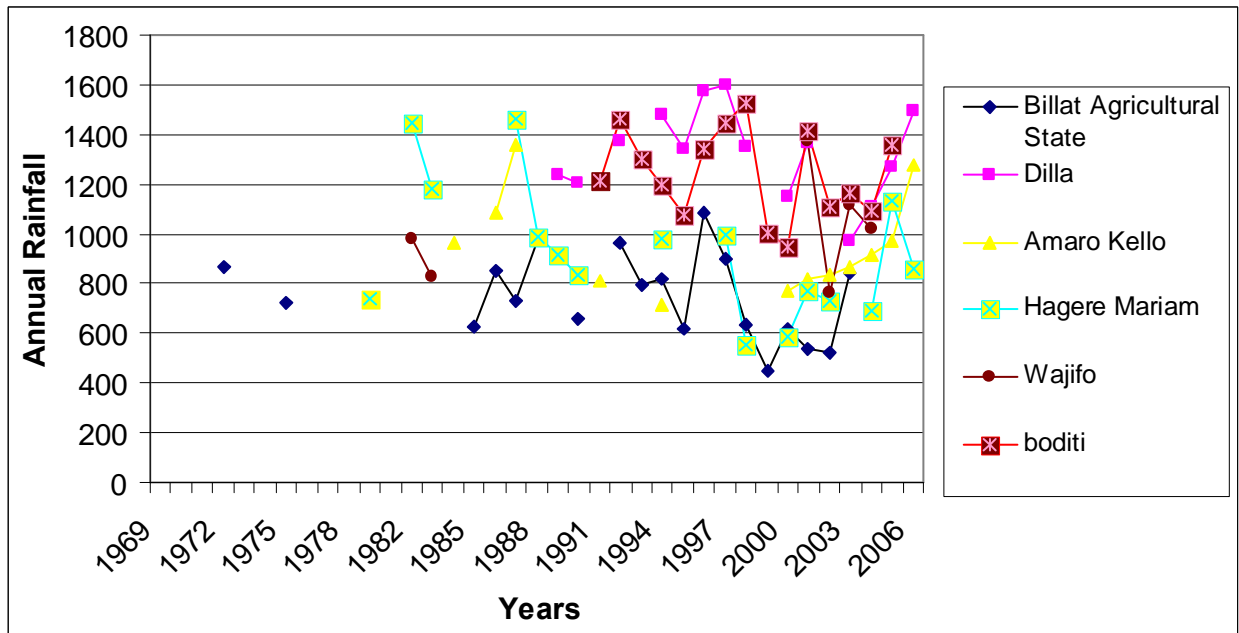


Chart 3.1. Variation of Long term Annual rainfall in the study area.

3.2.2. Temperature

The average minimum temperature varied from 10.2 °C in Dec to 12.3 °C in July and the maximum temperature ranged from 25.8 °C in July to 30.5 °C in February. Air temperature regulated the growth and development of many plants by regulating the rate of biochemical processes. The growth of many crops ceased below a critical temperature of 5 °C or above 35 °C adversely affecting the yield.

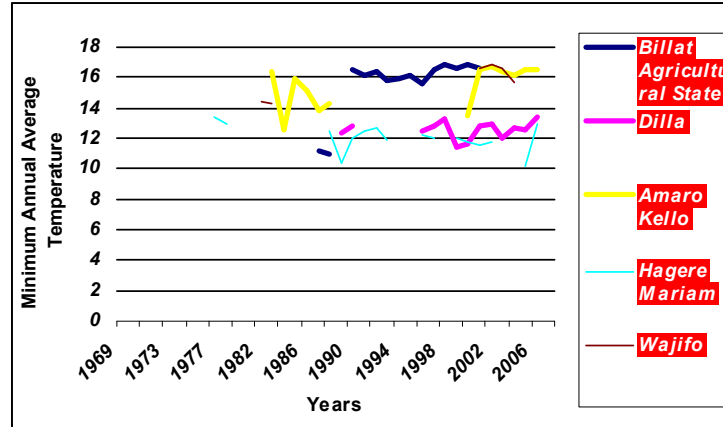


Chart 3.2. Variation of Minimum Annual average temperatures in the study area.

3.3. Major Production Systems and Land Degradation

The field data collection output resulted in the following livelihood and Production systems as well as Land degradation features.

I) Livelihood and Production system

Production Systems ranging from mixed crop-livestock, crop dominated, commercial tobacco cultivation (Tembaho Monopole) and semi-nomadism were found. Livestock species such as cattle, goat, sheep and donkey were components of the farming systems. The major crops grown in the area were Maize, Tobacco, Sweet potato, Cotton and Sugar beet. The crop production was characterized as subsistence arable rain-fed. Figure 3.2 showed some of the components of the Production systems of the study area.



Figure 3.2. Mixed crop livestock system and Crop dominated systems in the study area.

II) Land degradation

The study area was located in the Ethiopian rift valley and characterized by fragile ecosystem due to a number of anthropogenic and Natural threats. Such threats were observed in the study area in the form of erosion features of rill, sheet, and gully. Bushes, Scattered shrubs and grazing lands which were degraded also observed in the study area.



Figure 3.3. Erosion features and degraded shrub lands in the study area.

3.4. Soils and Rivers

According to FAO-1998 classification, the soils of Bilate Irrigation Project broadly fall into twelve major soil groups, i.e. Haplic luvisols, Fluvic Cambisols, Vertic Cambisols, Eutric Fluvisols, Chromic Vertisols, Eutric Cambisols, Vertic Nitisols, Chromic Luvisols, Arenosols, Vertic Fluvisols, Vertic Luvisols, and Gleyic Luvisols. The Bilate River and Small River called Bisare were the main rivers crossing the study area and drain in to Lake Abaya (Ministry of water resources, Unpublished, 2006).

4. METHODOLOGY

4.1. Materials and Data used

Table 4.1. Materials and data used with their source.

Ser.No.	Material/data	List/description	
1	Software and Programs	ERDAS IMAGINE 9.1, ArcGIS 9.2, Global Mapper 8, Microsoft Excel	
2	Topo sheet	1:50 000 from Ethiopian Mapping Authority	
3	Field equipments	GPS Magellan	
4	Climatic data	Rainfall and Temperature data from Ethiopian Meteorological agency	
5	Digital data	Digital Soil data of the year 2006 / 2007 in shapefiles and Geodatabase format of the lower Bilate River basin site obtained from ministry of water resources which was at scale of 1:50000	
		SRTM image 30m resolution	
		Kebele Shapefiles of the study area from FAO documents	
Satellite imagery			
Landsat type	Path(P) and Row(R)	Acquisition date	Bands used and Spatial resolution
Landsat ETM+	P =169 R = 55	November 26, 2000	Bands :1,2,3,4,5,7 - 28.5 * 28.5 Band : 8 -14.25 * 14.25

4.2. Data Collection

A reconnaissance field survey was conducted with the objectives of gathering and understanding information on soil fertility decline problem, soil erosion severity, and agricultural production systems. The main tools for collecting such information were through the field observation, informal interviews, group discussions with farmers, and discussion with local agricultural development workers.

Literatures from various sources were the main inputs in the preparation of this thesis. Moreover, the Topo-sheet and Collected Ground truth data were also the major inputs for identification and mapping of the different Land use / cover classes during supervised image classification process.

4.3 Image Classification Techniques

4.3.1 Image Preprocessing

Image preprocessing operations are activities which ought to be performed before image classification with the objectives of correcting geometric and radiometric distortions. Some of the distortions related with variation of flight altitude, earth curvature, velocity of the platform and the likes were solved at the satellite data receiving station. However, the following data preparation techniques were performed before image classification.

Image stacking using bands of 1, 2, 3, 4, 5, and 7 were performed and the study area was subsetted using boundary shapefile of the study area in ERDASIMAGINE 9.1 software.

4.3.2 Image Enhancement

Image enhancement is the process of making an image more interpretable for a particular application. Enhancement can make important features of raw, remotely sensed data and aerial photographs more interpretable to the human eye. Enhancement techniques are often used instead of classification for extracting useful information from images (ERDAS Field Guide, 2005).

The following image enhancement techniques used before image classification was performed.

A) NDVI: Normalized Difference Vegetation Index. It is given by the following formula;

$NDVI = \frac{NIR - R}{NIR + R}$, where, NIR is Near Infrared Band and R is Red Band.

B) Texture: Many portions of images of natural scenes are devoid of sharp edges over large areas. Image texture measurements can be used to segment an image and classify its segments.

C) PCA: Principal Component Analysis

Since bands of satellite imagery convey information which correlates highly; Principal Component Analysis with three numbers of components was undertaken. PCA with three number of component holds information about 90% and the risk of losing important information for the study was minimal.

D) Spatial Resolution Merge

Images having higher spatial resolution often result in better classification output enabling the identification of features.

4.3.3 Supervised Classification

Ground truth data which were collected during field survey were used for supervised image classification using the algorithm of Maximum likelihood classifier. The classification was undertaken on the PCA image which was spatially merged with band eight.

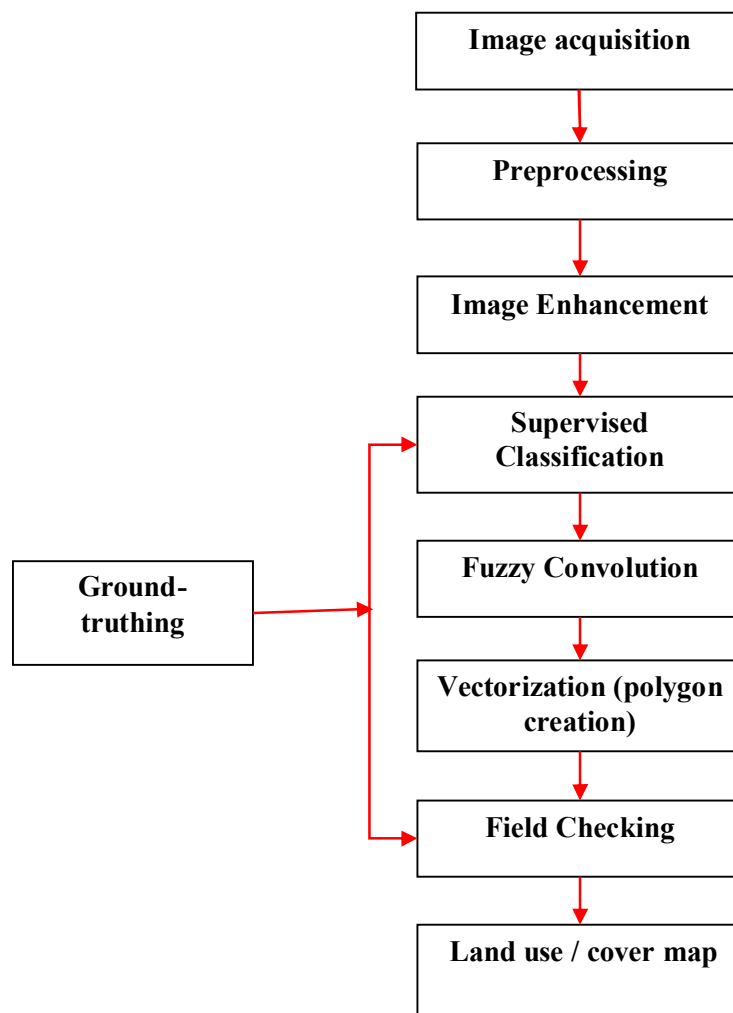


Figure 4.1. Schematic diagrams of image classification procedures.

4.3.4 Post Image Classification

Classified data often manifest a salt-and-pepper appearance due to the inherent spectral Variability encountered by a classifier (Lillesand and Kiefer, 1994). And classified images often suffer from a lack of spatial coherence. Therefore, it was often desirable to smooth the classified output to show only the dominant (presumably the correct) classification. Thus, the classified image was further processed to correct such mentioned errors in fuzzy Convolution of ERDAS IMAGINE. The operation was performed using Kernel size of 7*7.

4.4 Mapping of Crop lands

So far the classification output did not discriminate the crop types. However, it was quite necessary to further classify the cultivated land in to the four major crop types of the study area. Therefore, the classified image was converted in to polygons in ArcGIS software and Point vector data with an attribute holding the four crop types prepared from Ground-truth data, were draped on the polygon classes (See Appendix 1). Then, each polygon was characterized by the four crop types, swampy land and Bush and Scattered shrub land. And the descriptions of each land use / cover classes in the current study was presented in table 4.2.

Table 4.2. Land use / cover classes and their description.

LU / LC	Descriptions
Maize land	Areas which were part of the crop land. However, mainly cultivated for maize crop for considerable years as main or dominant land use system.
Tobacco farm	Areas covered with tobacco farm which were cultivated by commercial tobacco industry.
Sweet potato land	Areas which were part of the crop land. However, mainly cultivated for sweet potato crop for considerable period of time as main or dominant land use system.
Cotton	Areas which were part of the crop land. However, mainly cultivated for cotton crop for considerable period of time as main or dominant land use system.
Bush and Scattered shrub land	Areas covered by bush and sparse shrubs, without clear demarcation, and intermingled with degraded grass lands, used for animal grazing and patches of rural settlements.
River and Swampy land	Areas covered by Permanent and seasonal waters such as, river as well as seasonal waterlogged areas not suited for cultivation.

4.5 Soil Nitrogen Modeling

Soil nitrogen could be assessed via many approaches. However, in this study two approaches which were spatially explicit were used for assessment of the Plant Available Stock Soil Nitrogen across soil depths and the Soil Nitrogen Balance in annual basis.

4.5.1 Plant Available Stock Soil Nitrogen Modeling

Plant available stock soil nitrogen is the amount of soil nitrogen that remains in the soil and avail to plants for uptake after the various flows were operated. Soil nitrogen can be assessed through point measurement of soil organic carbon. The study used digital soil map as an input for modeling the plant available stock soil nitrogen.

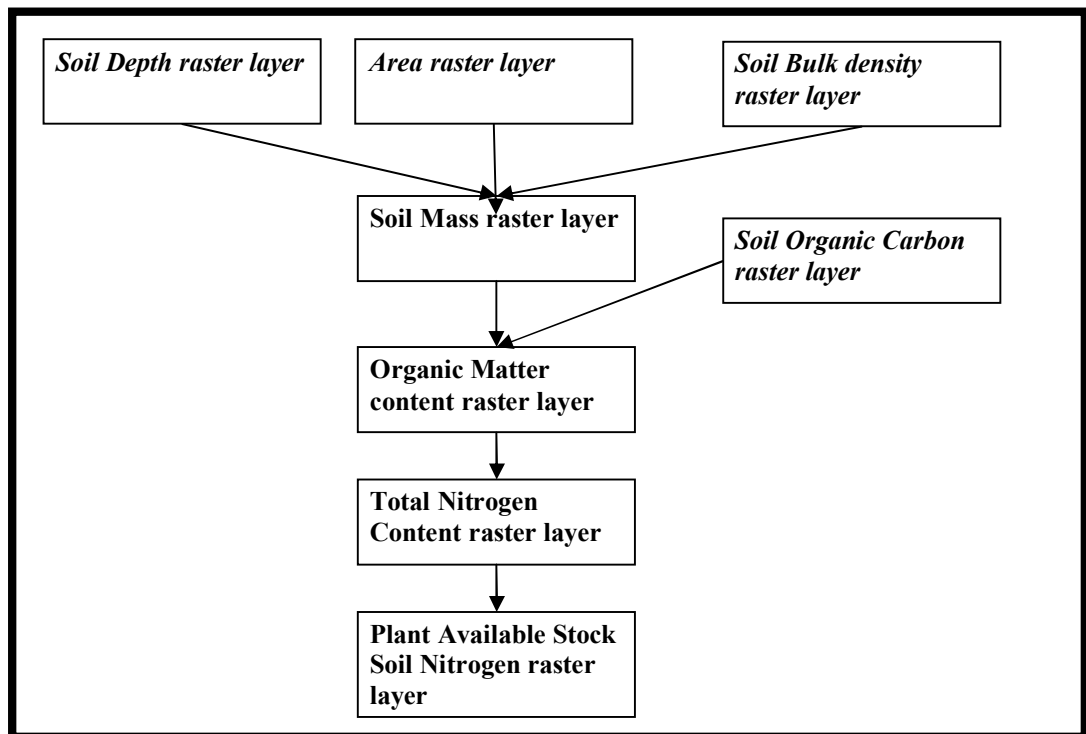


Figure 4.2. Flow diagram indicating the steps required for determining the plant available stock soil nitrogen.

The flow diagram presented above only showed the major steps used in modeling plant available stock soil nitrogen. However, some equations were used and they were presented in their respective section under the next new separate section: the spatial data analysis.

4.5.2 Soil Nitrogen Balance Modeling

This was the second methodology adopted for the study in order for modeling the soil nitrogen balance in annual basis. Thus, the study adapted the widely applicable methodology used for modeling soil nutrient balance developed by Stoorvogel and Smaling (1990). However, the study aimed to make the methodology spatially explicit using various spatial data and Geographic information system applications. The methodology considered the different flows paths of nitrogen in the soil system. The flows were classified in to two categories: Inflows and Outflows. Five inflows and five outflows were the basic components in the model. However, depending on the study objectives and significance of the components some may be dropped from the model.

Accordingly, in this paper four inflows: Mineral fertilizer, organic inputs, Atmospheric deposition, and Nitrogen fixation and five outflows: Harvested product, crop residues, Leaching, Denitirification and Erosion were considered. The soil nitrogen balance was calculated in yearly basis and can be presented mathematically as:

Nitrogen balance = Sums of nitrogen inflows per year \ominus Sums of nitrogen outflows per year.

$$NB = (IN\ 1 + IN\ 2 + IN\ 3 + IN\ 4) - (OUT\ 1 + OUT\ 2 + OUT\ 3 + OUT\ 4 + OUT\ 5)$$

Flow diagram 4.8 showed the basic components of the methodology of soil nitrogen balance estimation. However, in the methodology each flow was computed using either equations or by aggregating a number inputs. In this section the simple flow diagram was presented and the equations with their sources were discussed in their respective sections under the spatial data analysis part.

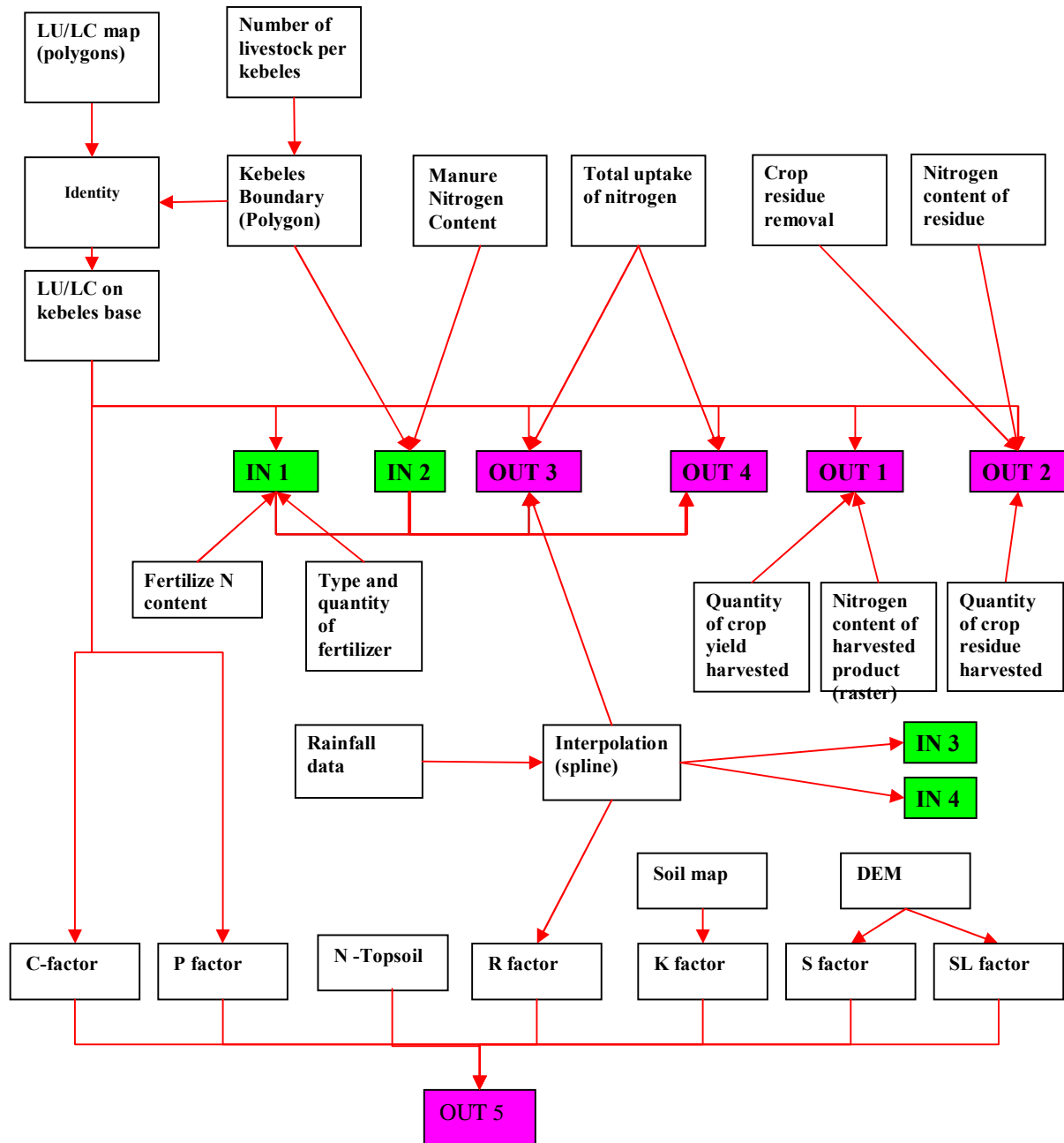


Figure 4.3. Schematic view of the methodology used for Soil Nitrogen Balance Modeling

5. Spatial Data Analysis

Spatial data analysis in a GIS ranges from simple mapping to creating complex spatial models. A model is a representation of reality used to simulate a process, predict an outcome, or analyze a problem. In this section the spatial analysis used which included image classification, the plant available stock soil nitrogen modeling and the Soil nitrogen balance modeling were discussed with the purpose of presenting important preliminary results, the model parameters, and the models.

5.1 Image Classification Application

5.1.1 Image Enhancements

Image Enhancement techniques were very important in enabling for visual image interpretation before the final image classification was performed. NDVI image was enabled in discriminating vegetation cover while the texture aid in identification of patches of settlements. PCA which reduced data redundancy was conducted with an out put of three components as well as Spatial resolutions merge of the PCA image (with 28.5 m spatial resolution) and Band 8 (with 14.25m spatial resolution) was performed and the resulting image possessed better spatial resolution, that is 14.25m and used for the classification (see figure 5.1).

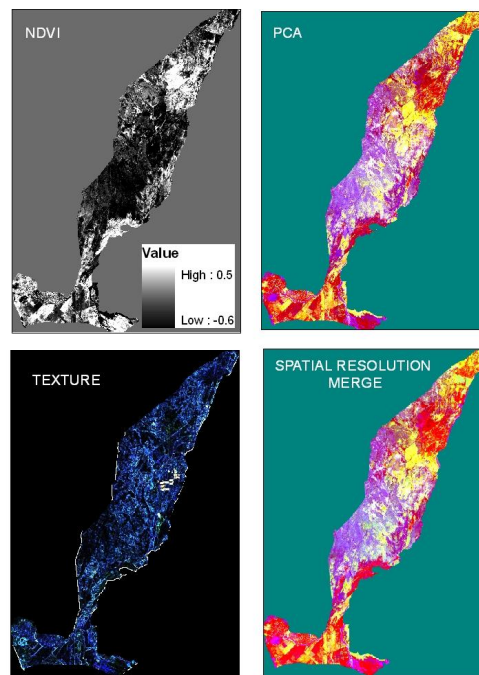


Figure 5.1. Images resulting from Image enhancement techniques.

5.1.2 Land use / cover classes of the study area

The supervised image classification that was conducted on the enhanced image resulted in six land use / cover classes. The resulting land use / cover classes were presented in figure 5.2.

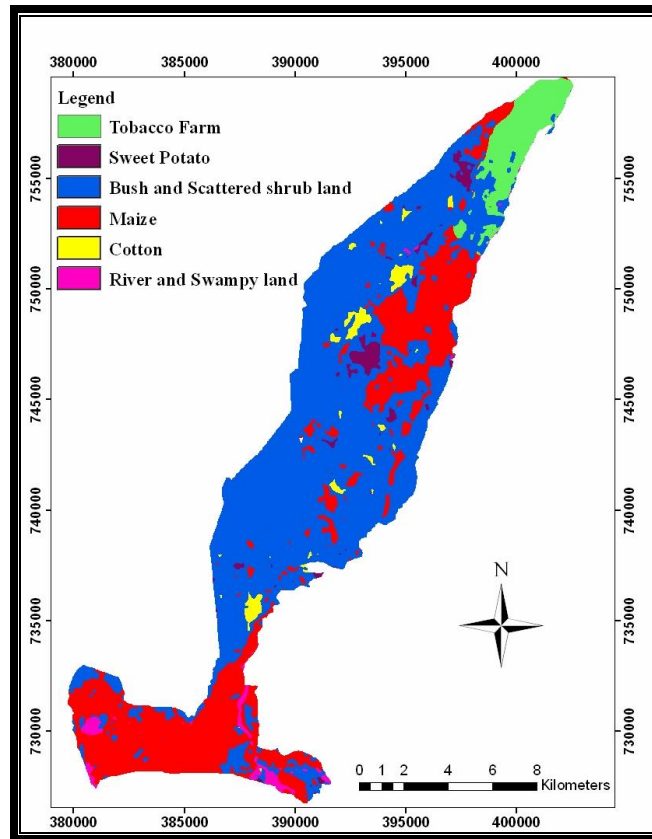


Figure 5.2. Land use / cover map of the study area.

5.2 Plant Available Stock Soil Nitrogen Modeling

So far in the previous section the material used together with the basic methodology including the flow diagram were presented.

However, the main target of the study was making the models spatially explicit and in this section the model parameters, the equations used as well as the spatial analysis functions performed under the GIS platform were presented.

5.2.1 Model Parameters

The input soil data were in vector format and keeping the soil groups as a base the attributes such as area, soil depth and soil bulk density were converted in to raster format by feature to raster in analysis tools of ARCGIS software.

A) Soil Depth

Soil organic carbon varies down the soil depth and the measurement was performed considering the variation. Three depths were considered for modeling the stock soil nitrogen; Depth one (0-15 cm), Depth two (15-75 cm) and Depth three (75-120). The total depth up to 120 cm was taken based on the rooting depths of the crops, a depth which was accessible for plant roots to up take nutrients. That is, the crops in the study area were classified in to two categories as medium rooted (50-100cm) and deep rooted (90-150cm) crops. However, rooting depth to 120 cm was taken to avoid over estimation of nutrient by considering the maximum depth (150 cm) (See figure 5.3).

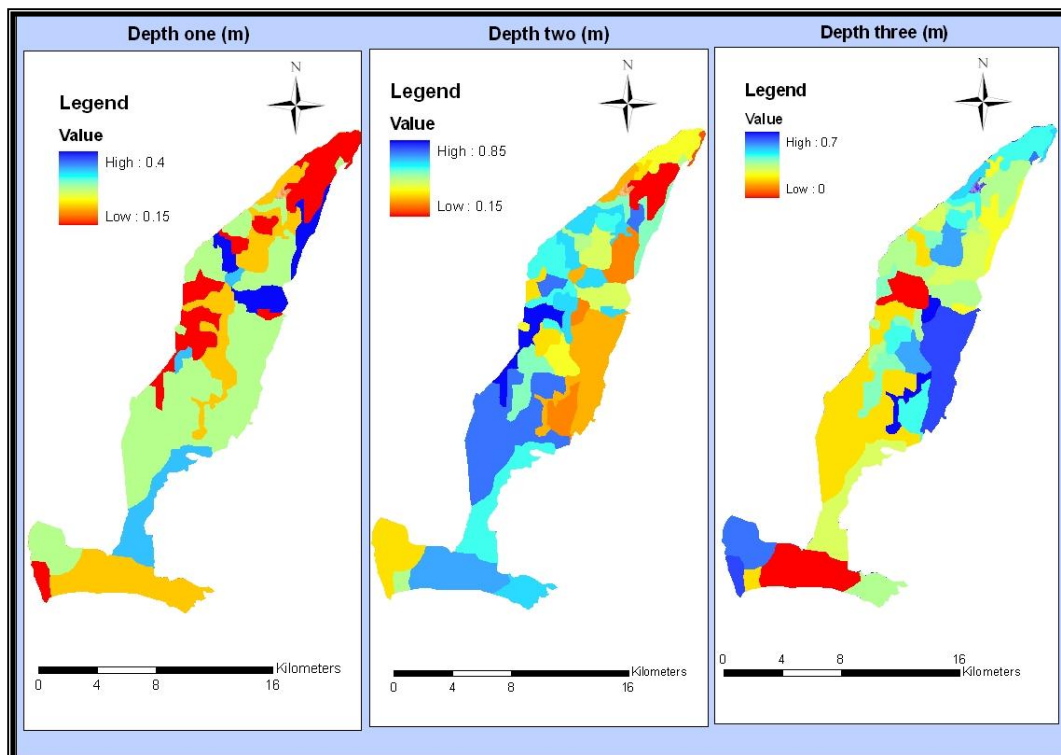


Figure 5.3. Soil depth classes in the study area.

B) Area

The area of each Soil groups was prepared in raster format by converting from vector format and the result was presented in figure 5.4.

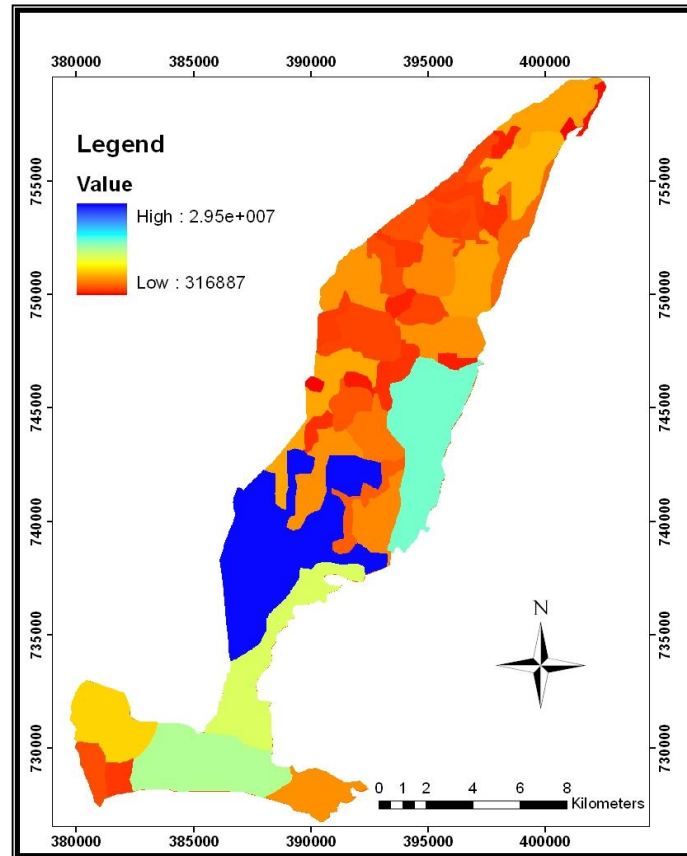


Figure 5.4. Area (m^2) of the soil groups of the study area.

C) Soil Bulk Density

Soil bulk density was also another important parameter in plant available stock soil nitrogen modeling. The secondary soil map used for this study was not entail full measurement of Soil bulk density for all profiles and depths. However, the measurement was on few profiles. Therefore, an average value of the measured values was taken. Thus, a constant value of 1.375 g/cm^3 was used in the calculation for all soil groups.

D) Soil Mass

By incorporating soil depth, soil area and soil bulk density in an empirical equation, soil mass raster layer was prepared. The determination of soil mass considered in three depths as it was quite important for accurate determination of the parameter and the final output of soil nitrogen stock modeling. The analysis was performed in raster calculator of spatial analyst tools in ArcGIS software.

$$\text{Soil mass (kg)} = \text{Area (m}^2\text{)} * \text{Soil depth (m)} * \text{Soil Bulk density (g/cm}^3\text{)} * 1000$$

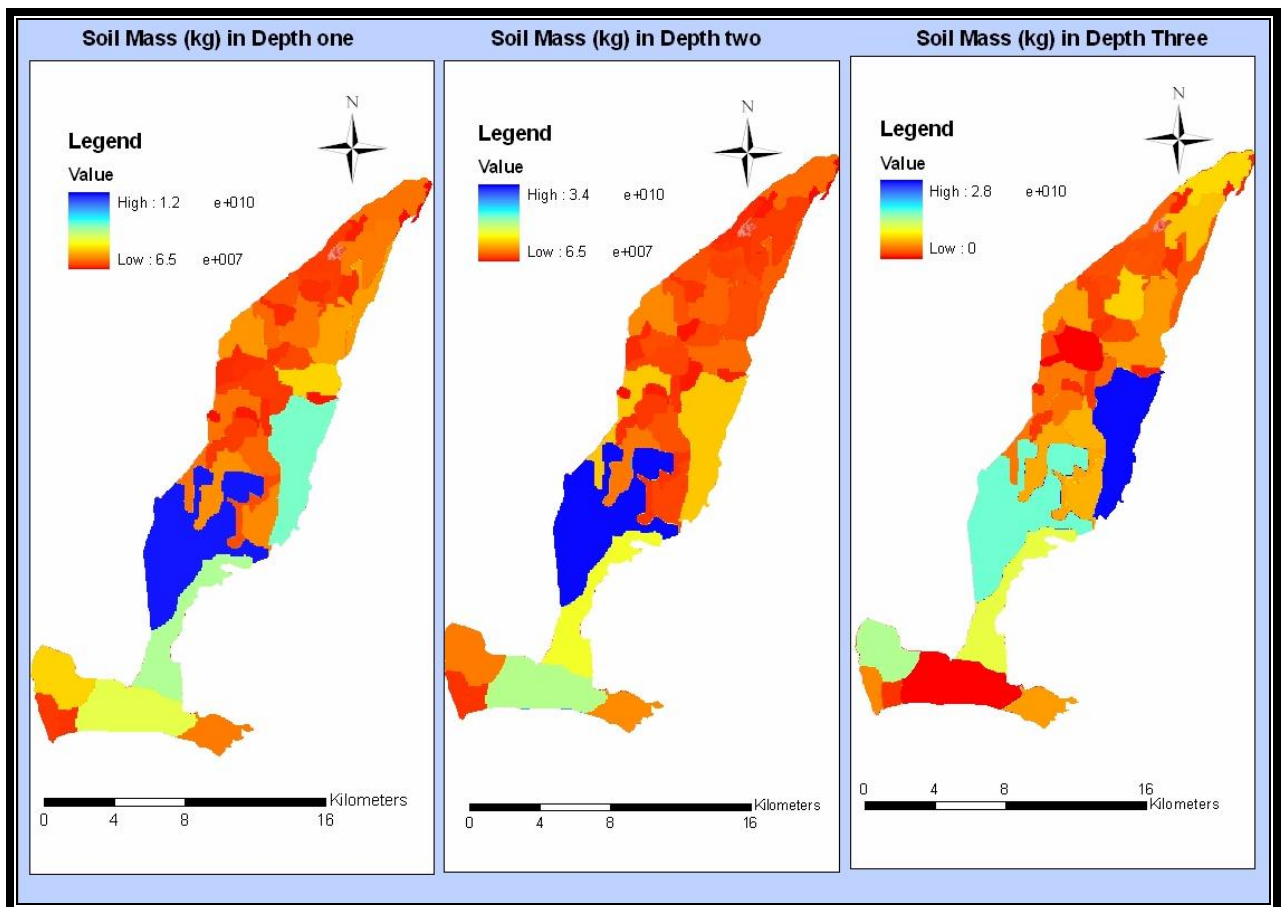


Figure 5.5. Soil Mass (kg) in depth one, two and three.

E) Soil Organic Carbon

Soil organic carbon varies across soil depths and the measurement of soil organic carbon was performed considering such variations.

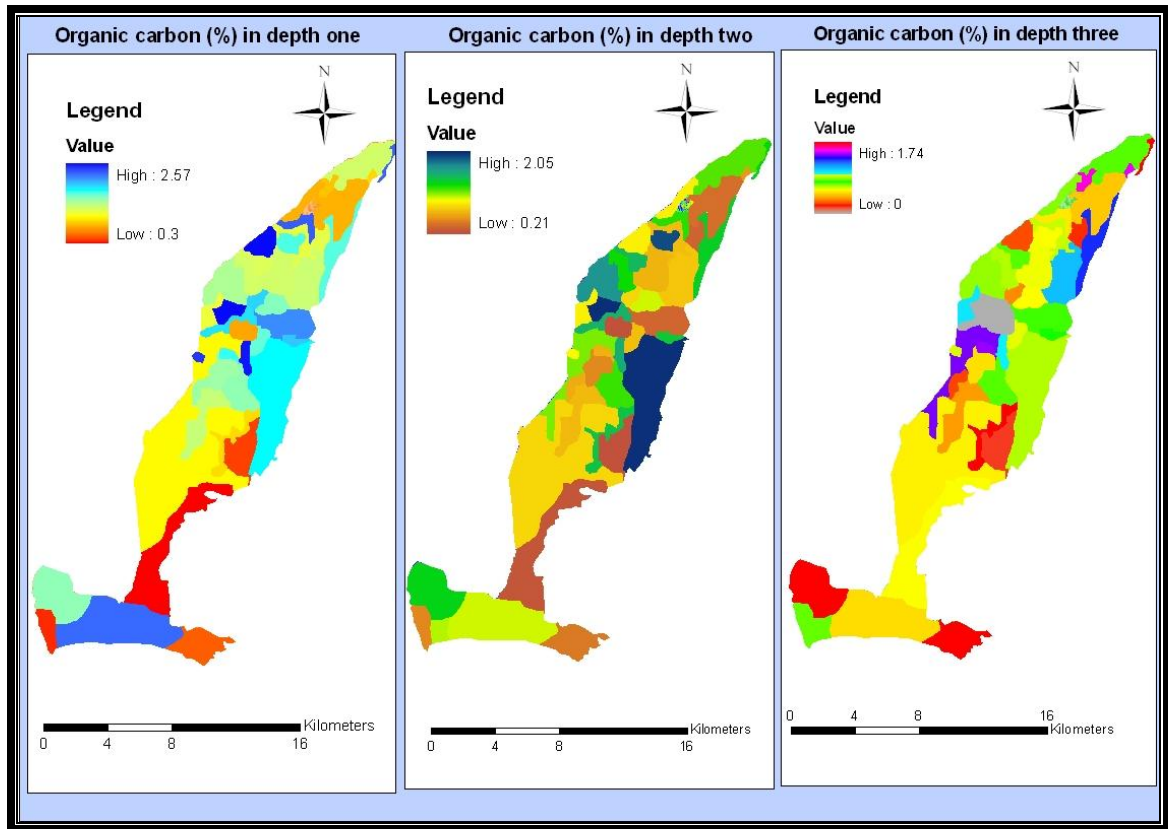


Figure 5.6. Soil Organic carbon (%) in depth one, two and three.

F) Soil Organic Matter Content

Soil organic matter contains 58% C. Conversion of % carbon to % organic matter was therefore, done with the empirical factor of 1.724 which was obtained by dividing 100 by 58 (Sahlemedhin and Taye, 2000).

$$\% \text{ Organic matter} = 1.724 * \% \text{ Soil organic carbon}$$

As the main target of the study was to develop spatially explicit method; relying on the above equation the following empirical formula had been produced for determination of soil organic matter.

$$\text{Organic matter Content (kg)} = \text{Soil mass (kg)} * \text{organic carbon \%} * 1.724 * 10^{-2}$$

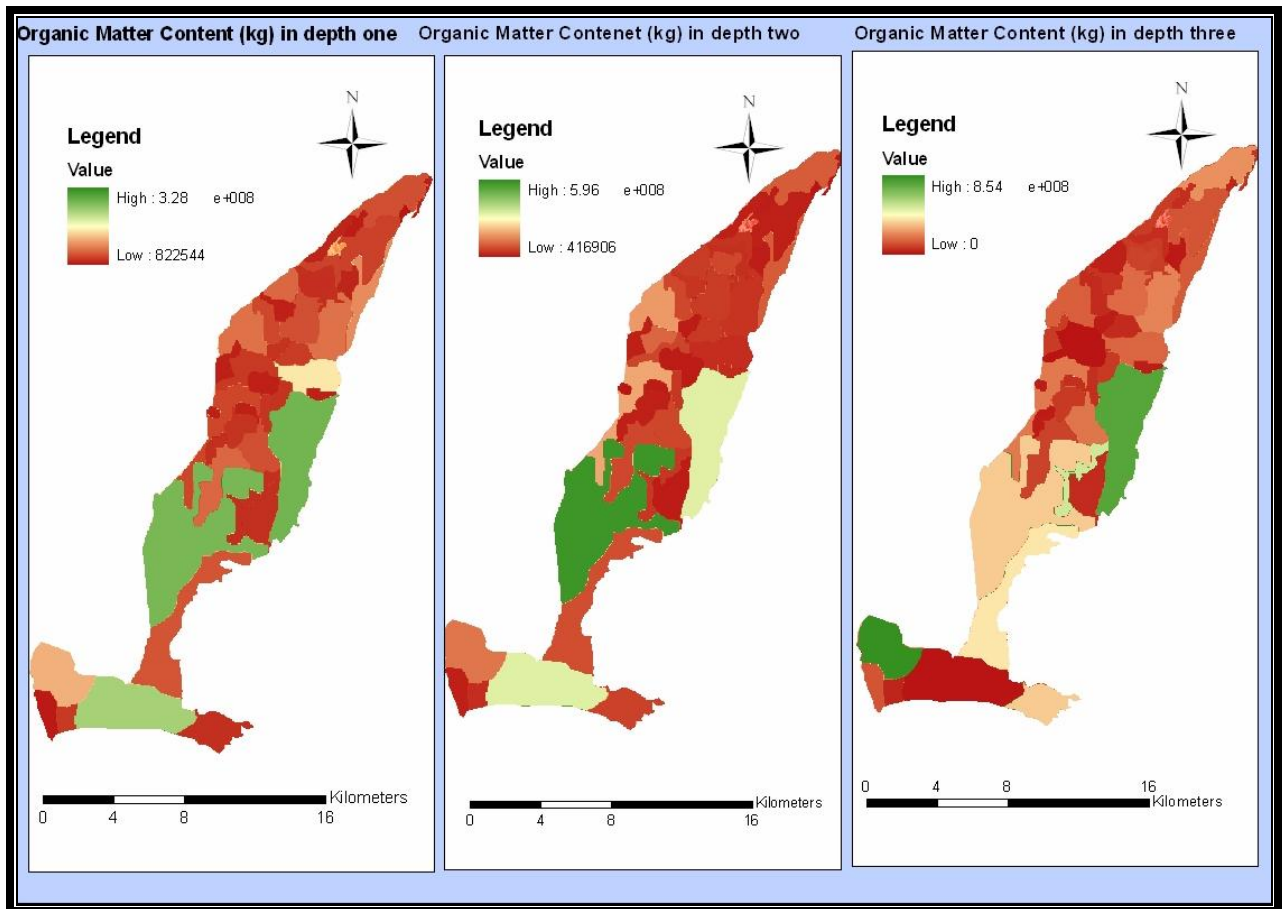


Figure 5.7. Soil Organic Matter Content (kg) in depth one, two and three.

G) Total nitrogen content

Total nitrogen content, as the naming indicated, is the total amount of soil nitrogen which is found in the soil system. The total nitrogen content of the soil was estimated from the measurement of the soil organic matter content (Sahlemedhin and Taye, 2000).

$$\text{Total Nitrogen (kg)} = \text{Organic matter Content (kg)} * 0.05$$

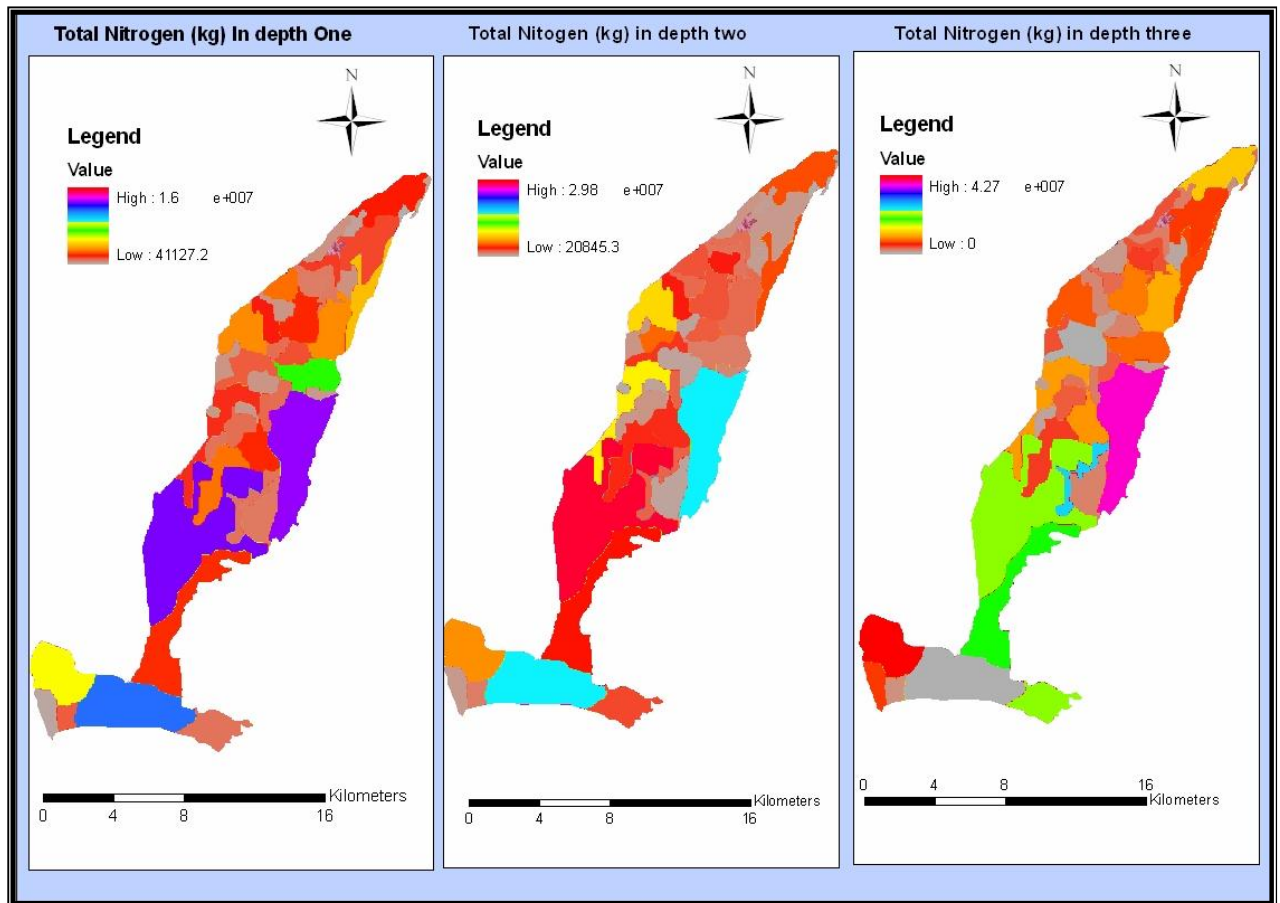


Figure 5.8. Total Nitrogen (kg) in depth one, two and three.

5.2.2 Model Output

A) Plant Available Stock Soil Nitrogen

Plant available stock soil nitrogen is the amount of soil nitrogen which is readily available for plants to be taken up by their roots. It is the fraction from the total soil nitrogen. That is, 3 % of the total soil nitrogen is conventionally considered to be the plant available soil nitrogen (Sahlemedhin and Taye, 2000).

The study estimated the plant available stock soil nitrogen using an equation for each of the soil depths considered. The total plant available stock soil nitrogen was then prepared by summation of the values of plant available stock soil nitrogen across the three depths.

$$\text{Total nitrogen available to plant (kg/ha)} = \text{Total nitrogen (kg)} * 0.03 * 10^{-4} \text{ m}^2$$

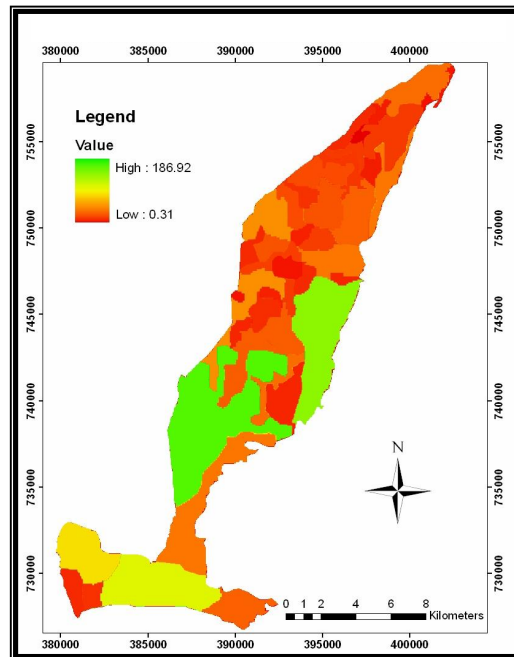


Figure 5.9. Total Plant Available Stock Soil Nitrogen (kg/ha) in rooting depths of crops.

5.3 Soil Nitrogen Balance Modeling

The basic methodology used for calculating nutrient balance was adopted from Stoorvogel and Smaling (1990). The model considered total inflows and total outflows in annual basis and calculates the balance as the difference between total inflows and total outflows. In this study, the soil nitrogen balance was calculated taking the year 2006/2007 as reference. Accordingly, all the data used for the soil nitrogen balance modeling were collected for the same year. The spatial analysis Performed in GIS platform for analyzing each inflow and Outflow was discussed in this section.

5.3.1 Model Parameters

5.3.1.1 Inflows

A) Mineral Fertilizer (IN 1)

The four major crops in the study area were Maize, Tobacco, Sweet potato and Cotton. The three crops excluding tobacco which was cultivated for commercial purpose in a factory called Tembaho monopole were growing in each kebele.

The distribution of agricultural inputs like commercial fertilizer had been based on kebele level. Therefore, data on the rate of application of commercial fertilizer for specific crops was gathered from the beuro of Agriculture of seven kebeles and from a factory called Tembaho-Monopole which found in the study area (see appendix 9). The crop lands which were mapped previously were used together with kebele shapefile of the area. That is, in identity function of ArcGIS software crop lands in each kebele were identified. Then, the nitrogen application rate was associated with attribute table of the resulting shapefile. The analysis was performed in Raster calculator after converting all the inputs in to raster format according to the following simple mathematical equation.

$$IN\ 1(\text{kg N/ha}) = (\text{Fertilizer application rate per ha (kg/ha)} * \text{Nitrogen content of fertilizer (\%)}) / 100$$

The Nitrogen content of Urea, DAP and NPK was 46 %, 15 % and 6 % respectively (Pius, 1998).

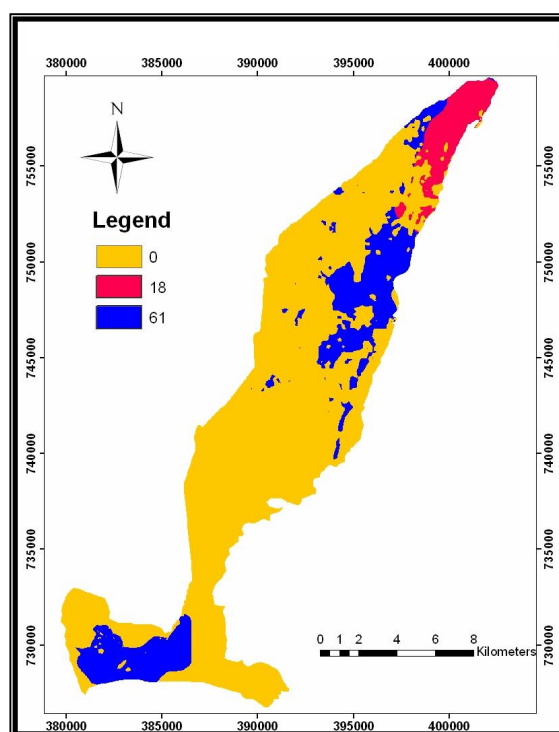


Figure 5.10. Nitrogen Inflow from Commercial fertilizer source (kg/ha).

B) Organic Inputs (IN 2)

According to the methodology by Stoorvogel and Smaling (1990) inflow two (IN 2) quantified the amount of nitrogen added to the soil from organic inputs. The field data collection resulted that Manure produced from livestock population was the main source of organic input in the study area. Manure is an excellent fertilizer containing nitrogen, phosphorus, potassium and other nutrients.

Cattle, sheep, goat, and donkey were the major livestock population in the study area. The density of each species was obtained at kebele level (See Appendix 4). Then, the number of animals was taken based on the proportion of land area found in respective kebeles and the total area of kebele.

A formula adopted for calculation was;

$$IN_2 \text{ (kg N/ha)} = (((N * MP * NC) / 100) / \text{Area}) * 10000$$

Where; N = Number of animal
 MP (kg) = Annual Manure Production per head
 NC (%) = Nitrogen content of fresh Manure
 Area (m²) = total area coverage of the animals

The Nitrogen content of manure and the Annual manure production per head was adopted from secondary sources (see Appendices 2 and 3). Accordingly, 0.76% N for cattle and 0.79% N for sheep and goat, and 0.6% N for donkey were taken. The analysis was undertaken using the formula presented above and the nitrogen inflow to the soil from each animal species was determined separately and then added in Raster Calculator of ArcGIS software.

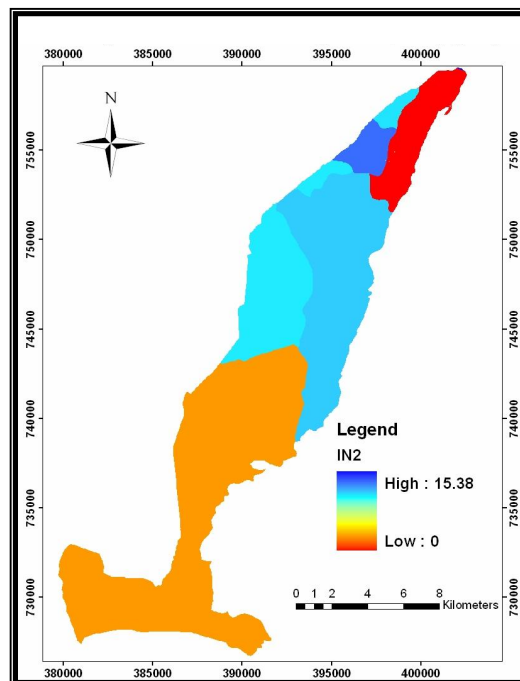


Figure 5.11. Soil Nitrogen inflow from livestock manure (kg/ha) source in the study area.

C) Deposition (IN 3)

Rainfall data from seven meteorological stations located inside and adjacent to the study area were collected from Ethiopian meteorological agency. The data were then put in Excel and saved in DB IV format and added in ArcMAP using the Add x-y function in tools menu bar. The data was in event format and conversion in to point features was accomplished. It followed that, the point data were interpolated using the spline function in the spatial analyst tools within the toolbox and a rainfall raster surface layer was created. Then, the raster rainfall layer was clipped using the study area boundary shapefile as a mask using the extract by mask function within the spatial analyst tools. Finally, the rainfall raster layer was used and IN 3 was calculated in Raster Calculator using the following equation.

$$\text{IN 3 (kg N/ha)} = 0.14 * (\text{rainfall})^{1/2} \quad \text{Source: Stoorvogel and Smaling (1990)}$$

Where: rainfall is in mm year^{-1}

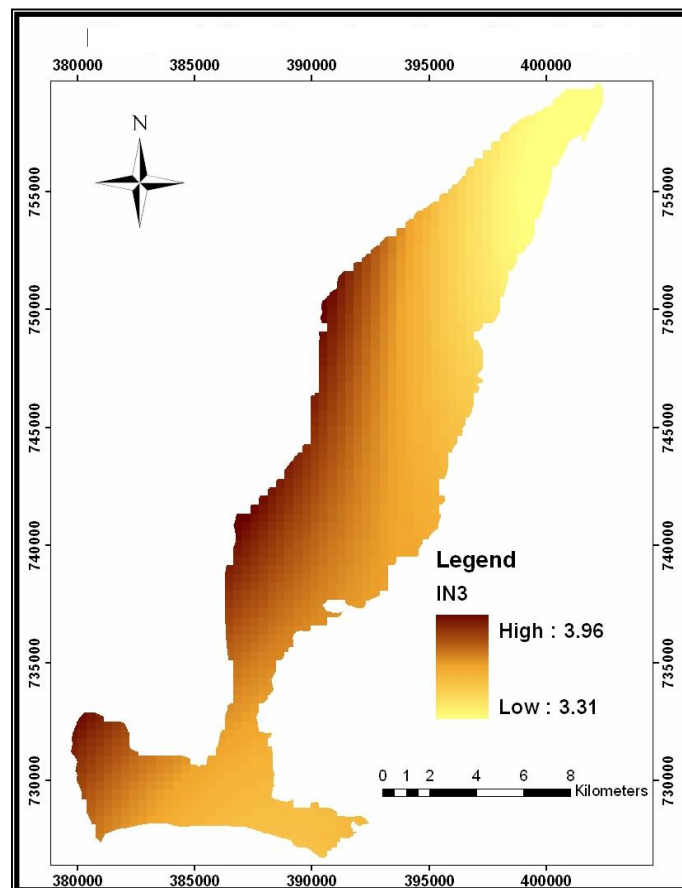


Figure 5.12. Nitrogen inflow (kg/ha) from Deposition source.

D) Nitrogen Fixation (IN 4)

Biological nitrogen fixation is an important source of nitrogen for leguminous crops through symbiosis; however, other crops could also benefit either from non-symbiotic nitrogen fixation or nitrogen fixing trees. The crops in the study area were mainly non-leguminous therefore non-symbiotic nitrogen fixation and from nitrogen fixing trees were considered. Lesschen et al. (2007) produced an equation for estimating nitrogen from the two sources based on the work by Stoorvogel and Smaling (1990). It was assumed that a positive relationship between rainfall and N fixation.

$$N \text{ fixed (kg/ha/yr)} = 0.5 + 0.1 * \text{Rainfall}^{1/2}$$

Where: rainfall is in mm year^{-1}

Using the rainfall raster layer and the above equation; nitrogen inflow (IN 4) was produced in raster format and the result was presented in figure 5.13.

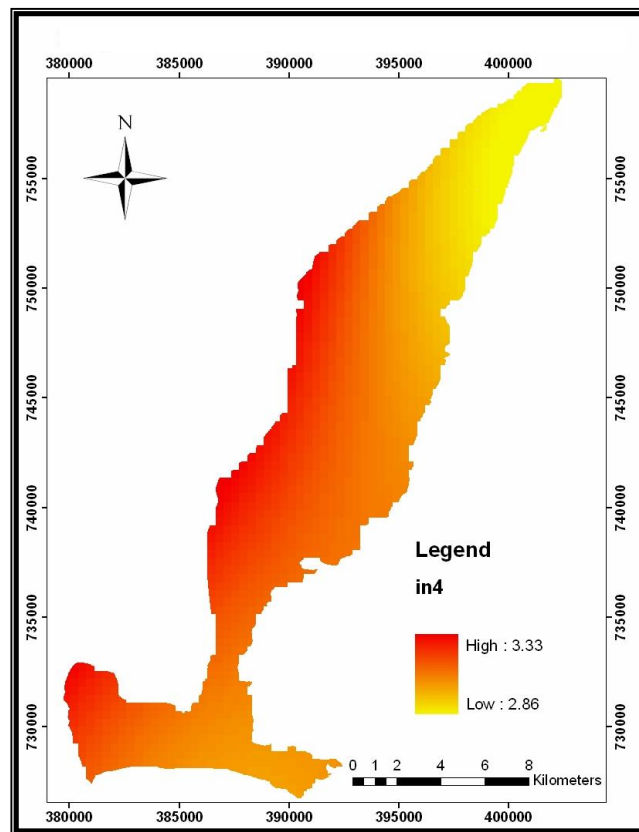


Figure 5.13. Nitrogen inflow (kg/ha) from Non-Symbiotic and Nitrogen fixing trees.

5.3.1.2 Out flows

A) Harvested Products (OUT 1)

Yield of crops harvested from farmlands were one of the major ways in which soil nutrient was depleted. These entailed seeds, fruits, roots, leafy parts that were collected from the field. As these parts were composed of Nutrients such as nitrogen, the withdrawal of such parts means nutrients too.

So as to determine the nitrogen outflow (OUT 1), data on productivity of crops and nutrient content of crops was mandatory. Accordingly, the yield harvested per each crop was collected from Kebele Agricultural beuro (see Appendix 5). On the other hand, the Nitrogen content of each crop type was obtained from Stoorvogel and Smaling (1990) (Appendix 6).

Then, OUT 1 was determined using the following mathematical relation.

$$\text{OUT1 (kg N/ ha)} = \text{Yield (t/ha)} * \text{Nitrogen content of Crop (kg/t)}$$

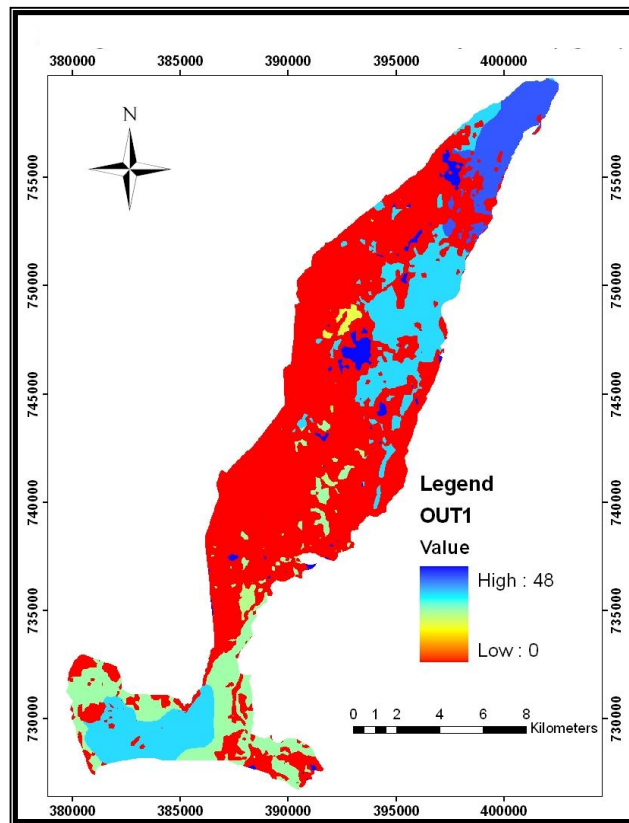


Figure 5.14. Nitrogen outflow from harvested product source (kg/ha).

B) Crop Residues (OUT 2)

It is a very common practice that gathering of crop residues from the field and utilizing for animal feeding or fuel in many parts of Ethiopia. The practice was also practiced in the study area and accordingly all the tobacco residue was collected from the field and burned with a removal factor of 1. However, it was not easy to determine the removal factor for other crops during the field work. Thus, removal factors were determined based on information from the field and previous study by sub-Saharan Africa (Appendix 6).

It was also uncommon quantifying and recording of crop residues in the production systems of the study area and no direct measured data on crop residues were available. Therefore, the amounts of crop residues were estimated using a biomass harvest index ratio of 1:2 (Seyoum and Zinash, 1991). That is, the quantities of yields of crops collected at the kebele level were converted in to equivalent quantities of residues multiplying by factor two. On the other hand, the nitrogen contents of the residues were obtained from Sub-saharan Africa study (Appendix 6). Then, the following simple mathematical relation was used for determination of OUT 2.

$$\text{OUT 2 (kg/ha)} = \text{N content of residue (kg N/tonne)} * \text{Removal factor} * \text{Amount of residue (t/ha)}$$

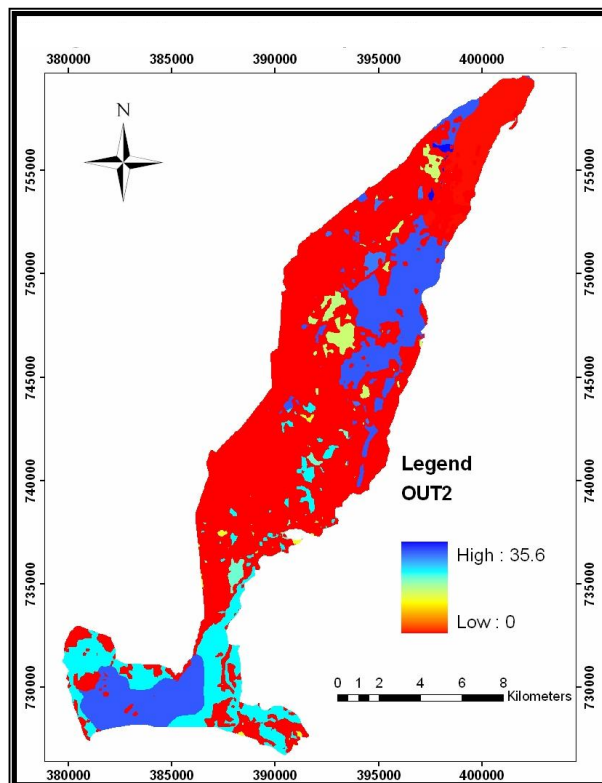


Figure 5.15. Soil Nitrogen outflow (OUT 2) from removal of crop residues (kg/ha).

C) Leaching (OUT 3)

Leaching is a natural process dominant in humid environments where soil nutrients are eluviated or washed down the soil horizons. It is one of the process by which Nitrogen is lost from the soil system. Leaching could be measured using different methodologies. However, the study used a regression equation developed by Smaling et al. (1993). The equation was advantageous as it entailed few variables. The equation was presented as follows.

$$\text{OUT 3 (kg/ha/yr)} = 2.3 + (0.0021 + 0.0007 * F) * R + 0.3 *(IN1 + IN2) - 0.1 * UN$$

Where: F: Soil fertility class (1- low, 2- Moderate, 3- high), R: annual average rainfall (mm)

IN 1: Nitrogen inflow from commercial fertilizer source (kg/ha), IN 2: Nitrogen inflow from organic inputs (kg/ha), UN: the total nitrogen uptake (crop and yield specific in kg/ha/year)

A value 1 was assigned for F, which was for low soil fertility class. R was the rainfall raster surface prepared for the study area. UN, the total nitrogen uptake by crop, was dependent on crop type and yield of crops. Based on the values of the previous studies and the yield harvested of each crop, the UN was determined by simple proportion of Nitrogen removal and yield (see Appendices 5 and 7). Then, nitrogen outflow from leaching source was determined based on the above regression equation.

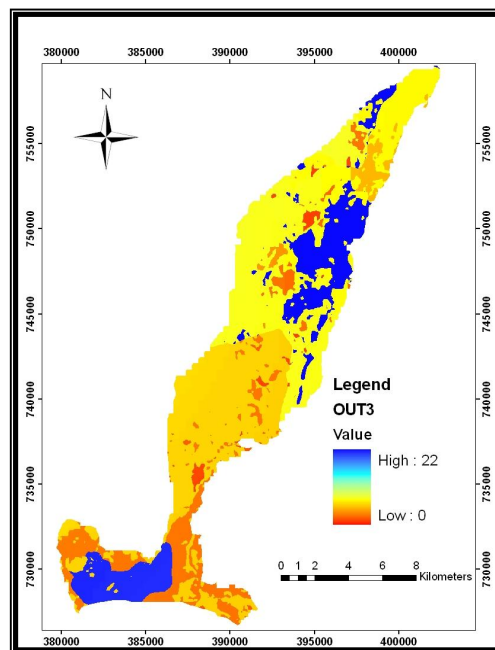


Figure 5.16. Nitrogen Outflow from the process of Leaching (kg/ha).

D) Denitrification (OUT 4)

Nitrogen could be lost to the atmosphere in gaseous forms via volatilization and Denitrification. Denitrification was significant in wet climates, on fertilized soils and clayey texture. On the other hand, Volatilization was valuable to be considered in alkaline environment. As the pH values attached at Appendix 13 indicated the soils of the study area were not alkaline. Thus, volatilization was not important while Denitrification did since soil fertilization was practiced in the study area. The equation used for determining Denitrification was obtained from sub-saharan Africa soil nutrient balance study (Stoorvogel and Smaling, 1990).

$$\text{OUT 4 (N kg/ha/year)} = -\text{Base}\phi + 2.5 * F + 0.3 * (\text{IN1} + \text{IN2}) \phi 0.1 * \text{UN}$$

Where, $-\text{Base}\phi$ a constant value covering relative wetness of the soils specific for LWCs (Land/Water classes), F: soil fertility class (1- low; 2-moderate; 3- high), IN 1 + IN 2: sum of inflows from commercial fertilizer and organic input (Kg/ha/year), UN: total uptake of N (crop and yield specific; in Kg/ha/year)

The study area is found in the Ethiopian rift valley, where the rainfall in the area was characterized by low quantity and erratic nature. Thus, a land/water class of uncertain was selected with a Base value 5 kg/ha/year and a value 1, which was for low fertile soils selected for F. The table for referencing the base denitrification per land/water classes was presented in Appendix 8.

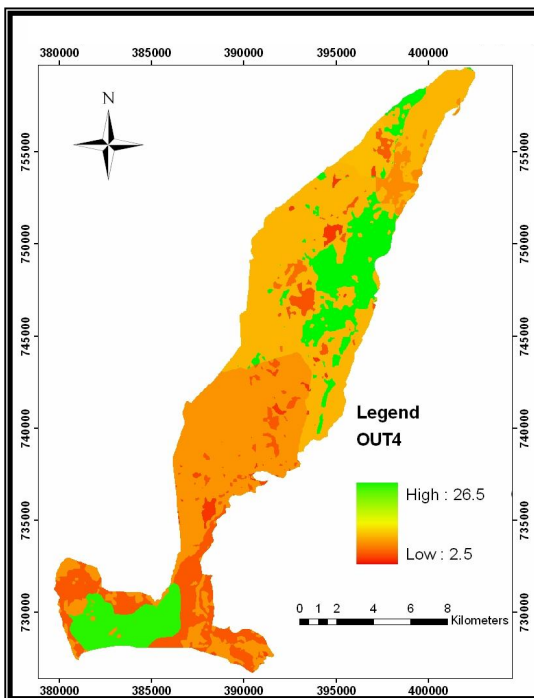


Figure 5.17. Nitrogen out flow in kg/ha from the process of Denitrification.

E) Erosion (OUT 5)

Soil erosion has been one of the major threats in Ethiopia and specifically in the study area was prevalent in the form of sheet and rill as it was assessed during field work. Previous studies undertaken in Bilate River basin found out also that soil erosion in the form of sheet, gully and rill had been a crucial problem causing natural resources degradation (Degelo, 2007).

Any form of soil erosion specifically rill and sheet are primarily active in the top soil which is often fertile. Therefore, as the top soil is eroded through rill and sheet erosion, soil nitrogen does too. Universal Soil Loss Equation is one of the widely used models for quantifying soil loss through rill and sheet types. In this study USLE modified for Ethiopian case by Hurni (1985) and top soil nitrogen content were used in order to quantify nitrogen loss through eroded soil. The parameters of the USLE model inline with the analysis performed in each step were discussed in the following section.

USLE considers six factors: Rainfall Erosivity (R), Soil Erodibility (K), Slope Gradient (S), Slope Length (SL), Land Cover (C), and Land Management (P).

1. Rainfall Erosivity Factor (R)

The calculation of erosivity factor totally relied on the mean annual rainfall by using the following formula.

$$R = -8.12 + (0.562 * P) \quad \text{Where, P- is mean annual rainfall and R-erosivity factor}$$

2. Soil Erodibility Factor (K)

Soil Erodibility is a measure of the susceptibility of a given soil to erosion by rainfall and runoff. The soils of the study area which were classified following FAO soil Classification procedure, was used for assigning K values based on Hurni (1985) work (See Appendix 10).

3. Slope Gradient Factor (S)

Digital elevation model was prepared from SRTM data of 30 m spatial resolution. By using spatial analyst surface interpolator in ArcGIS software, the slope percent or gradient layer was prepared. Then, the Slope gradient factor (S) was determined using an equation developed by Hurni (1985).

$$\text{Gradient factor(S)} = 0.344 + 0.0798 * \text{slope gradient (\%)}$$

The maps of Erosivity (R), Soil Erodibility (K), and Slope gradient factor (S) produced were presented together in figure 5.18.

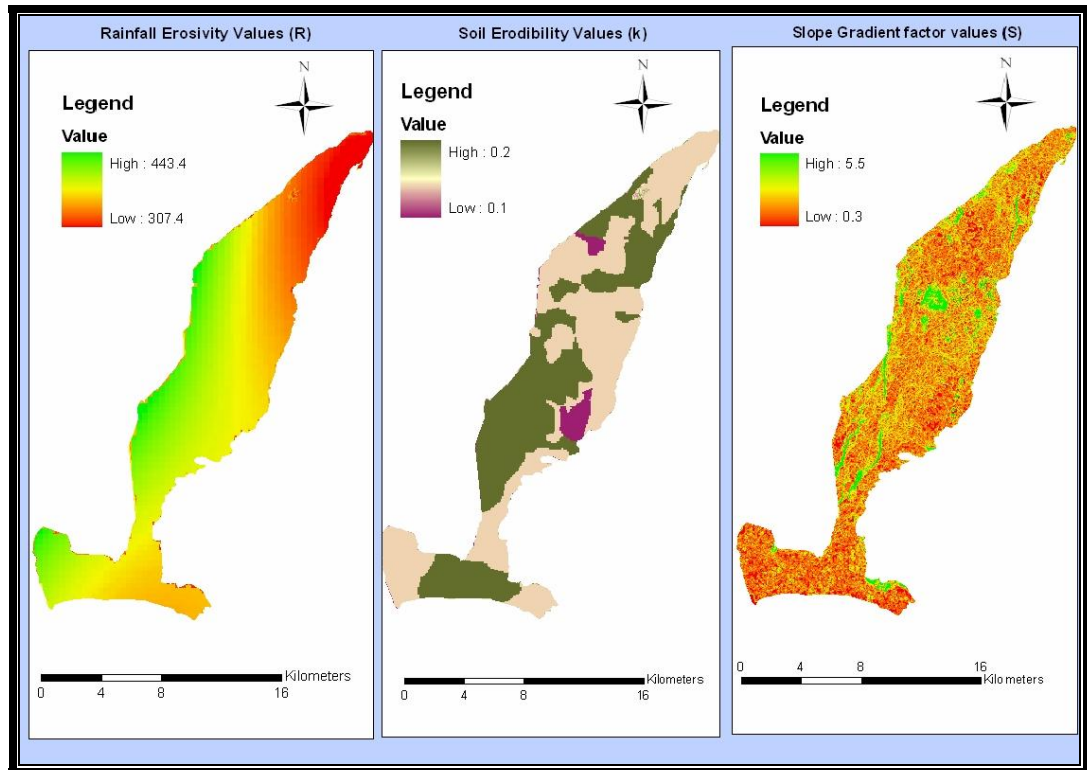


Figure 5.18. Maps showing the Rainfall Erosivity (R), Soil Erodibility (K) and Slope Gradient factor (S) values of the study area.

4. Slope Length Factor (SL)

According to the conventional approach of the USLE, the slope length was the determining variable of the SL factor. The raster digital elevation model of the study area prepared from the SRTM data was changed in to slope percent raster layer in surface analysis of ArcGIS software. The slope percent raster layer was changed in to flow direction and then to flow accumulation in hydrology function of Arctoolbox. Now, the flow accumulation raster layer represents the slope length and the slope length factor was determined based on the following equation.

$$SL = 0.799 + 0.0101 * \text{slope length}$$

5. Land Management Factors (P)

Land Management factor, P was determined based on Land use / cover map using the work by Hurni (1985). For assigning the p factor for the tobacco plant which was planted in a furrow or arrow, a P factor

value 0.8 was selected which was for strip cropping in Hurni (1985) table of P values (See Appendix 11). Ploughing on contour with a p factor of 0.9 was used for the rest of the crops. On the other hand, since the shrub-bush cover was similar to natural intercropping system a p factor 0.8 was selected. Finally, a P value 0 was assigned for Swampy land.

6. Cover Factor (C)

The cover and management factor, C, is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land. C factor was assigned on the basis of land use and cover map by using values of c factor developed by Hurni (1985) (See Appendix 12).

Table 5.1. Values of Cover and Management factor in the study area.

Management practice	C Factor
Tobacco land (sown in a row)	0.10
Maize, cotton, sweet potato in subsistence farming	0.10
Shrub-Bush land	0.05
Water and swampy bodies	0

The maps produced for Land management factor (P), Cover factor (C) and Slope Length Factor (SL) are presented in figure 5.19.

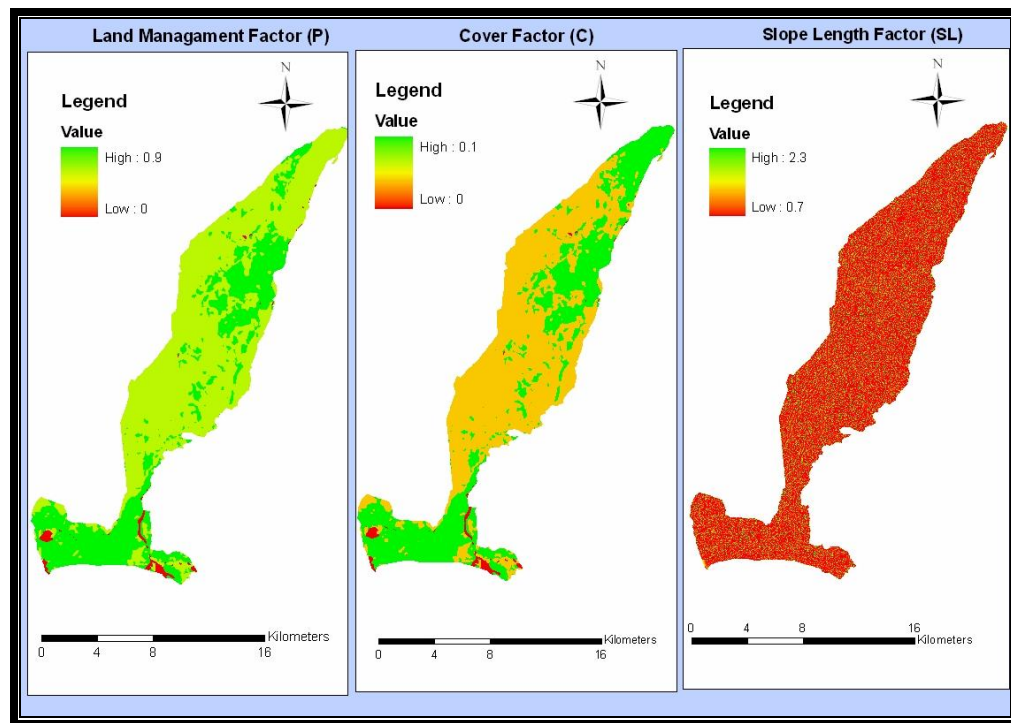


Figure 5.19. Maps of Land Management factor (P), Cover factor (C) and Slope Length factor (SL).

7. Soil Loss Rates

The USLE model combines the six factors which were discussed above in the following formula.

$$A \text{ (tonne/ha/year)} = RKSSLPC$$

The six factors which were discussed and presented above were combined using the above formula in Raster Calculator of ArcGIS and soil loss tonne/ha/year was determined. The top soil nitrogen content on the basis of the classes of the Soil groups was prepared using digital data of the study area. Consequently, Nitrogen loss due to erosion was determined in raster calculator (See figure 5.20).

$$\text{OUT 5 (N kg/ha)} = \text{Soil loss (Kg/ha)} * \text{Nitrogen content of top soil (\%)} / 100.$$

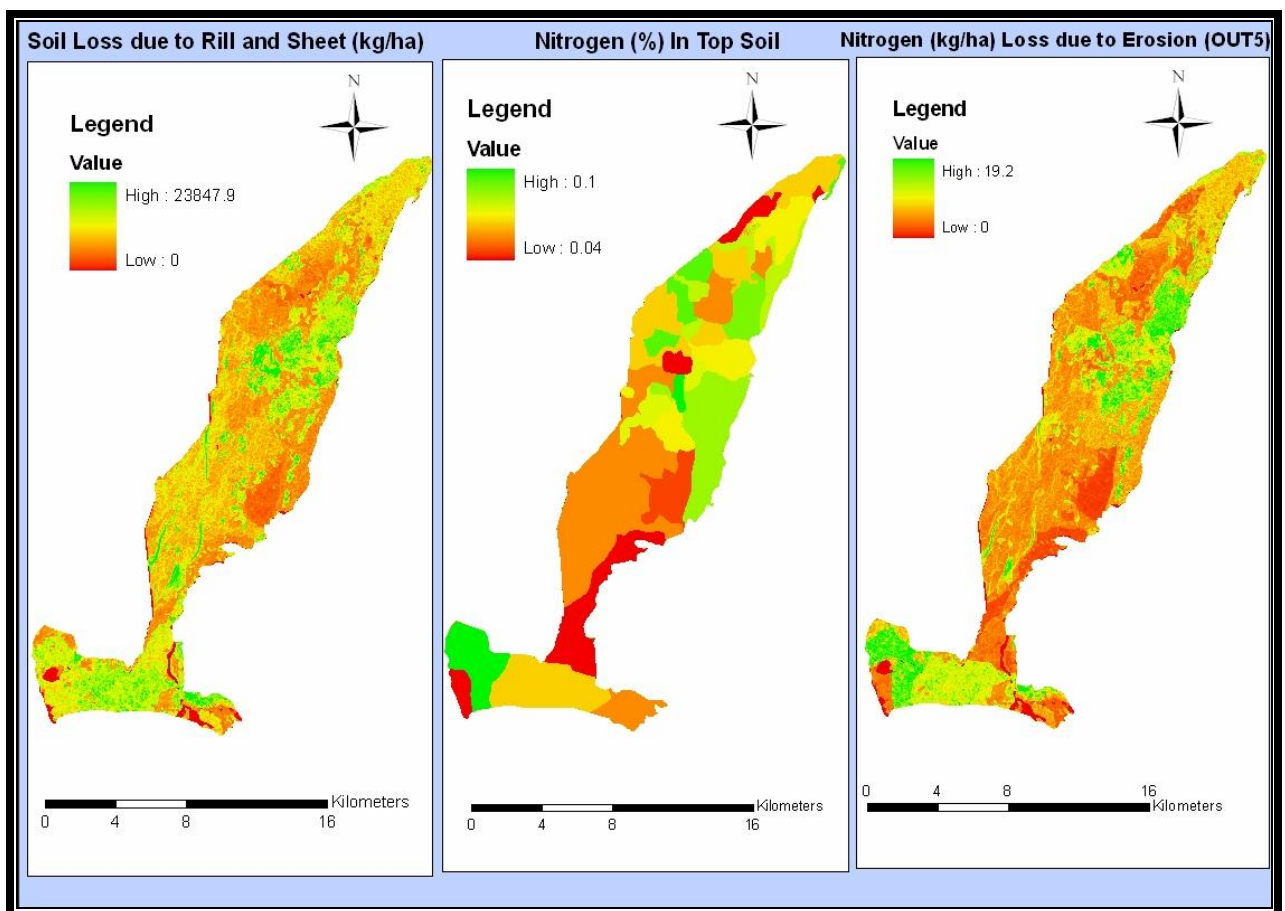


Figure 5.20. Maps of Soil loss rates, Topsoil nitrogen content, and Nitrogen Loss due to erosion of the study area.

5.3.2 Model Output

5.3.2.1 Most Probable Value of Soil Nitrogen Balance

The soil nitrogen balance was calculated as the difference between the sum of inflows and outflows. The four inflows and the five outflows that were analyzed and presented above were summed separately. Then, the soil nitrogen balance (kg/ha) was determined as the difference between the sum of inflows and outflows. Such values of soil Nitrogen Balance were considered as the most probable value as the calculation was based on the most likely assumptions. That is, most likely assumptions were considered while adopting the equations of inflows and outflows as well as the inputs in each parameter.

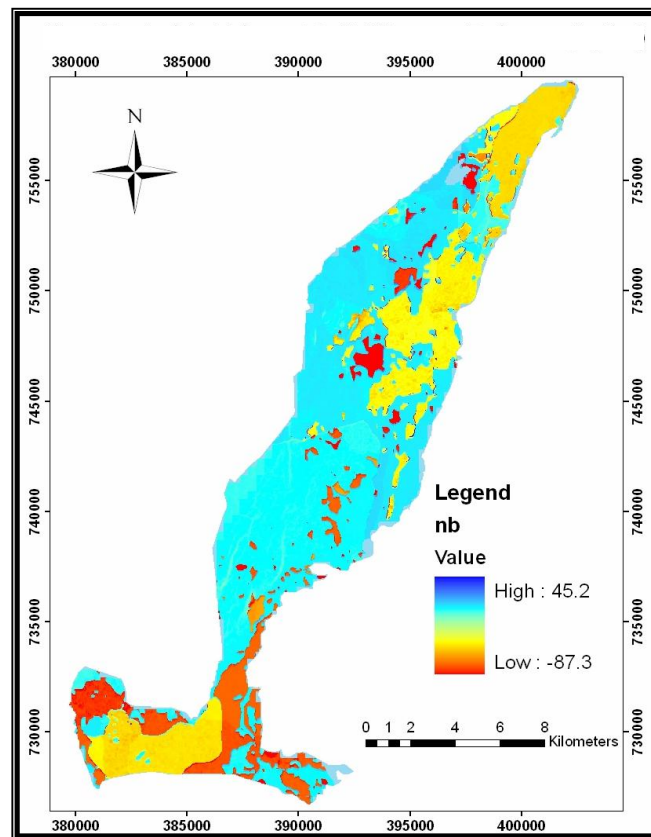


Figure 5.21. The Most Probable value of Soil Nitrogen Balance (kg/ha).

5.3.2.2 Pessimistic and Optimistic Values of Soil Nitrogen Balance

Since some variables used in Soil Nitrogen Balance were obtained from secondary data, there could be some variability in the final result. Such variability was assessed by calculating optimistic and pessimistic

values of Soil Nitrogen Balance. The result from analysis of Optimist and Pessimist estimates revealed uncertainty range that was likely to encompass the real value (Elias, 1998).

A) Pessimistic Values of Soil Nitrogen Balance

The pessimist estimate combined high values for outflows and low values of inflows. Low values for inflows of Deposition (IN 3) and Nitrogen fixation (IN 4) were estimated using low values of rainfall within their respective regression equations. In contrast, high values for outflows of Leaching (OUT 3) and Erosion (OUT 5) were estimated using high values of rainfall and Erosivity factor respectively. High value of Erosivity was determined using high value of rainfall. However, the remaining flows: IN 1, IN 2, OUT 1, OUT 2 and OUT 4 were taken the values from the most probable determination.

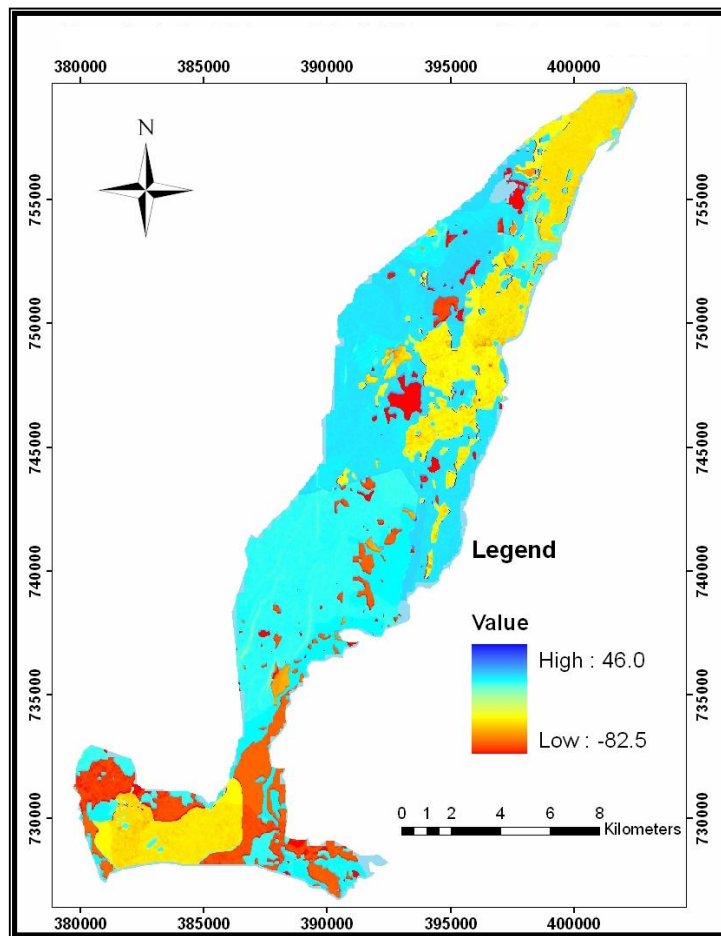


Figure 5.22. Pessimistic values of Soil Nitrogen Balance (kg/ha).

B) Optimistic Values of Soil Nitrogen Balance

The optimistic nutrient balance was calculated by integrating high estimates of inflows and low estimates of outflows. High values for inflows of Deposition (IN 3) and Nitrogen fixation (IN 4) were estimated using high value of rainfall within their respective regression equations. Conversely, low values of outflows for Leaching (OUT 3) and Erosion (OUT 5) were determined using low value of rainfall and erosivity factor respectively. Low value of Erosivity was intern estimated using low values of rainfall in the equation of Erosivity. On the other hand, the rest flows were taken from the most probable determination of soil nitrogen balance.

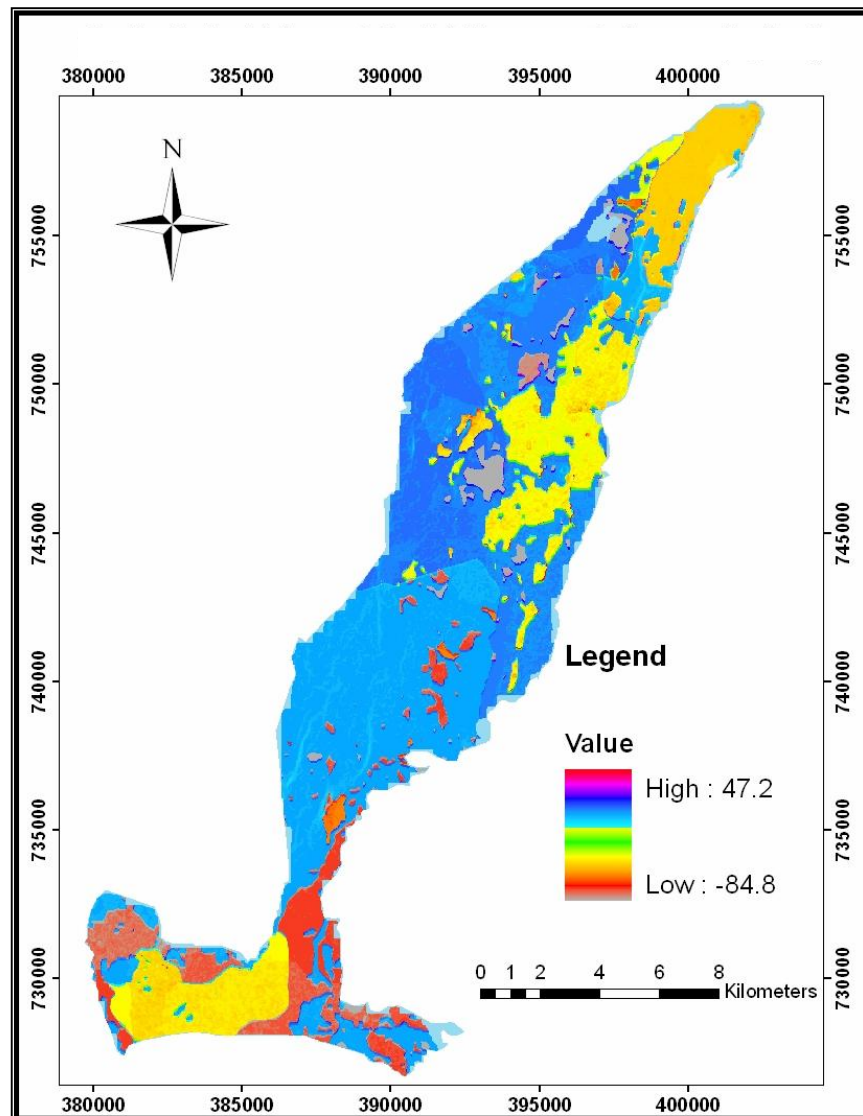


Figure 5.23. Optimistic values of Soil Nitrogen Balance (kg/ha).

6. Results and Discussion

6.1 Plant Available Stock Soil Nitrogen

6.1.1 Plant Available Stock Soil Nitrogen across Soil Depths

Plant Available Stock soil Nitrogen is the fraction of total soil nitrogen which is assumed as ready to be taken up by plant roots and it is very significant to determine from plant nourishment point of view. The total plant available stock soil Nitrogen across plant rooting depth varied from 0.3 to 186.9 kg/ha (See figure 5.9). However, as figure 6.1 portrayed, the majority of the area: 23.5% and 29.9% had plant available soil nitrogen values of 0.31-10 kg/ha and 10-20 kg/ha respectively and these areas were mainly located in crop lands. Higher values of soil nitrogen: > 90 kg/ha were found in bush and scattered shrub land, however covered only 15.6%. Therefore, the stock soil nitrogen in the area was very low from plant nourishment point of view.

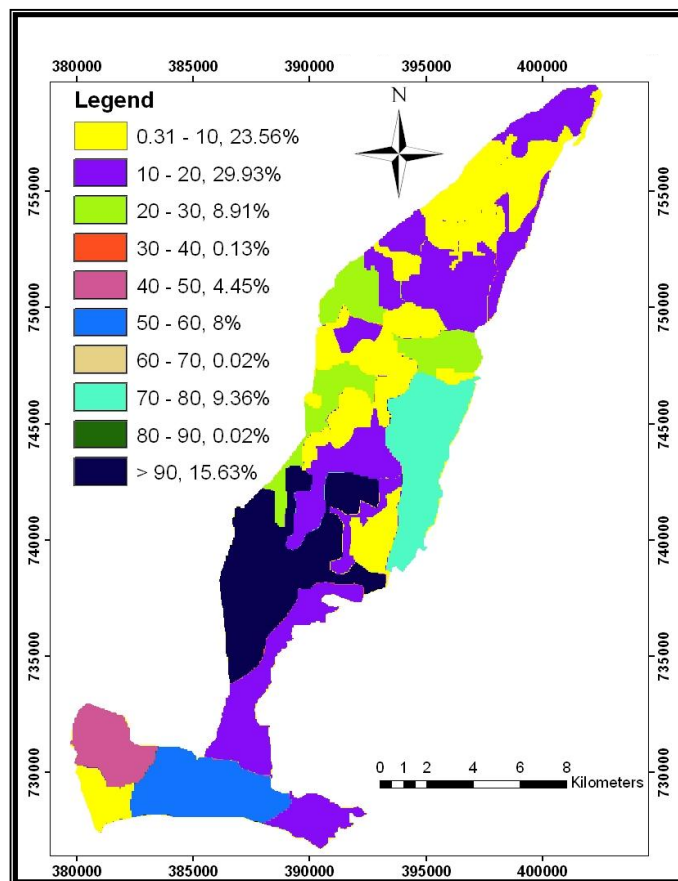


Figure 6.1. Reclassified Total Plant available Stock Soil Nitrogen in rooting depths (kg/ha).

6.1.2 Plant Available Stock Soil Nitrogen versus Land use /cover Classes

The amount of plant available stock soil nitrogen in an area was expected to vary across different Land use / cover classes. This was because various paths of inflows and outflows of nitrogen in the soil system varied spatially and either the addition or removal was often based on land use / cover classes. Accordingly, important statistical out puts of the plant available stock soil nitrogen in different land use / cover classes were presented in table 6.1 and figure 6.2. Generally, croplands had lower value of stock soil nitrogen than non croplands. The highest mean value of soil Nitrogen was 40.1 kg/ha from Bush and Scattered shrub land while tobacco farm deserved the lowest Mean Plant Available Stock Soil Nitrogen value of 12.5 kg/ha.

Table 6.1. Land use / cover Classes and plant available stock soil nitrogen

Land uses / covers	AREA (m ²)	Plant available stock soil nitrogen (kg)				
		MIN	MAX	RANGE	STD	MEDIAN
Tobacco	1.0E+07	0	37	37	6.5	18
Sweet Potato	3350960	1	91	90	26.7	6
Bush and Scattered shrub land	1.12E+08	1	186	185	36.1	19
Maize	5.23E+07	0	186	186	24.4	20
Cotton	3307760	1	186	185	31.0	12
River and Swampy land	2563400	2	77	75	17.9	14

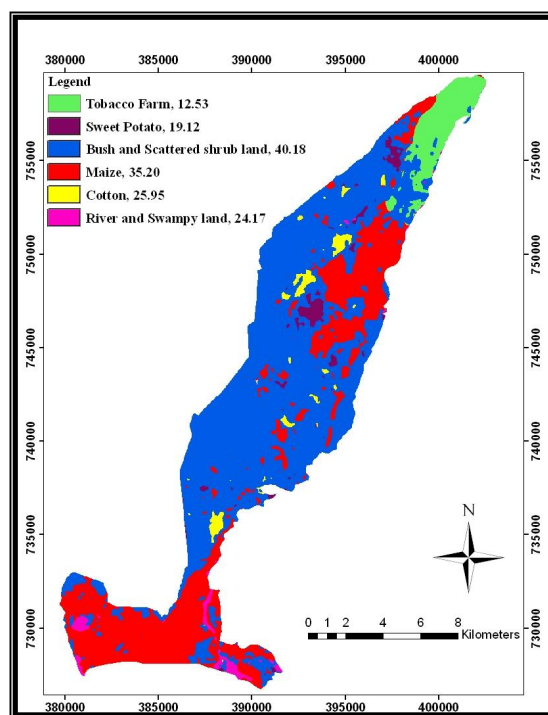


Figure 6.2. Land use / cover classes and plant available stock soil nitrogen (kg/ha).

6.2 Soil Nitrogen Balance

6.2.1 Inflows and Outflows in Different Land use /cover Classes

I) Land use / cover versus Inflows

The major sources of nitrogen inflows in the study area were analyzed and the summary of the resulting statistics was presented in table 6.2.

Chart 6.1 summarized the mean inflows in land use / cover classes. Inflow one or addition of commercial fertilizer was the highest source of soil nitrogen in maize (38.7 kg/ha) and tobacco farm (18 kg/ha). Inflow two, animal manure, was the major source of nitrogen inflow in lands of Sweet potato (6.5 kg/ha), Cotton (5.2 kg/ha), and Bush and Scattered shrub land (4.4 kg/ha). Inflows three and four were less significant in the study area however, were found as sources of soil nitrogen inflow in all land use / cover classes. In all land use / cover the addition from inflow three was slightly higher than inflow four.

Table 6.2. Summarized statistics of inflows in different land use/cover classes.

	Statistics	Maize	River and swampy land	Bush and Scattered shrub land	Sweet potato	Tobacco Farm	Cotton
In1	MIN	0.0	0.0	0.0	0.0	18	0.0
	MAX	61.0	0.0	0.0	0.0	18	0.0
	STD	-	0.0	0.0	0.0	0.0	0.0
In2	MIN	0.0	0.0	0.0	1.7	0.0	1.7
	MAX	15.3	7.3	8.5	8.5	8.5	8.5
	STD	2.7	1.2	2.8	2.1	0.4	2.6
In3	MIN	3.3	3.3	3.3	3.3	3.3	3.4
	MAX	3.9	3.8	3.9	3.8	3.4	3.8
	STD	0.1	0.1	0.1	0.1	0.0	0.1
In4	MIN	2.8	2.8	2.8	2.9	2.8	2.9
	MAX	3.3	3.2	3.3	3.2	2.9	3.2
	STD	0.1	0.1	0.1	0.1	0.0	0.1

Soil Nitrogen inflows In Land uses / covers Classes

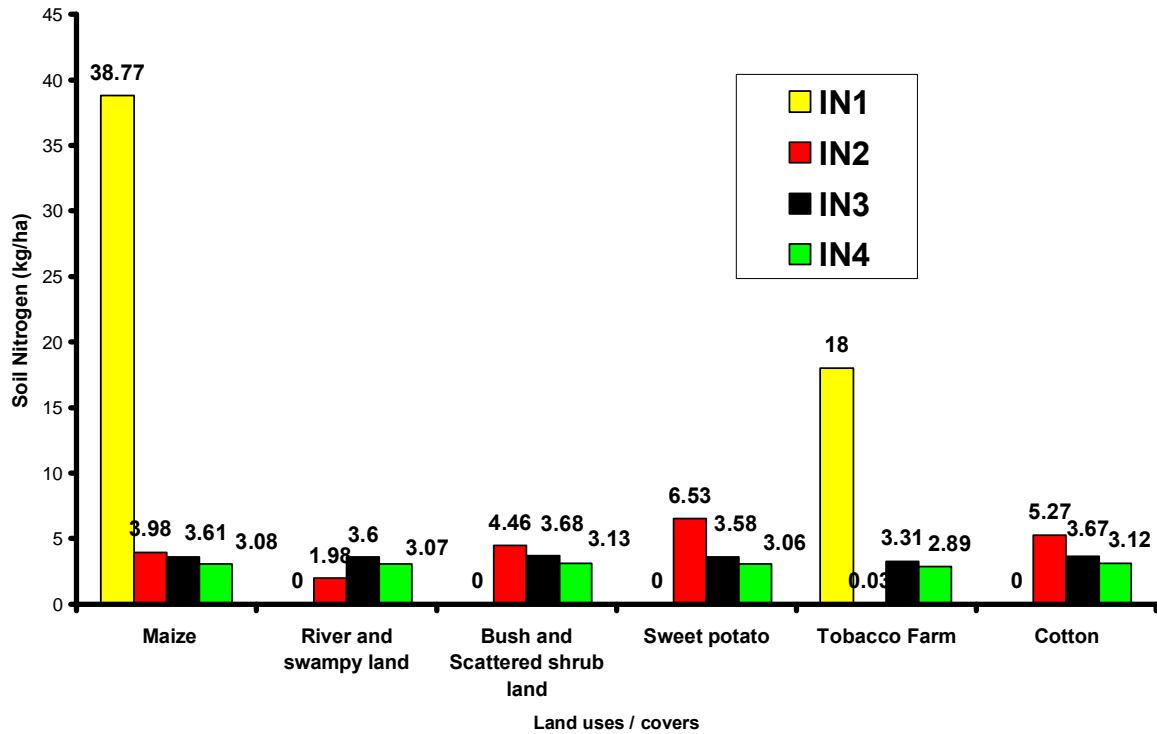


Chart 6.1. Mean Soil nitrogen inflows in different land use /cover classes

II) Land use / cover Classes versus Outflows

Outflow one, harvested crop yield, was the major source of nitrogen outflow in croplands. It yields an average value of 44.2 kg/ha, 33.6 kg/ha, 23.9 kg/ha, 20.2 kg/ha in sweet potato, tobacco, maize, and cotton lands respectively. Outflow two, collected residue, was the second most important source of soil nitrogen outflow in the area. The values were 22.1 kg/ha, 18.0 kg/ha, 11.6 kg/ha in lands of maize, cotton and sweet potato respectively.

Outflow four, Denitrification, was the third significant source of nitrogen outflow in the area. Average values of 16.8 kg/ha, 9.7 kg/ha, 8.8 kg/ha, 5.0 kg/ha and 4.5 kg/ha were found in lands of maize, tobacco farm, Bush and scattered shrub land, sweet potato, and cotton farm respectively.

Outflow three was less significant in the study area than outflow four. However, like outflow four, it was found in all land use / cover classes. Its highest average value (12.6 kg/ha) was on maize land while lowest value was on cotton land (1.4 kg/ha).

The highest average nitrogen outflow from rill and sheet erosion, 2.5 kg/ha, was obtained from maize and cotton lands. Average values of 2.3 kg/ha, 1.7 kg/ha, and 1.1 kg/ha were found in lands of sweet potato, tobacco and bush and scattered shrub land respectively.

In the majority of lands Erosion was less significant as source of nitrogen outflow compared with the rest outflows. Since the considered model, that is, the USLE assessed only rill and sheet erosion and as the area was located in Ethiopian rift valley in an arid environment; wind erosion could be more important. The summarized statistics of outflows was presented in table 6.3.

As it was indicated clearly in chart 6.2, all the outflows in maize land were proportional and relatively higher. That is, the outflows were proportional in maize land compared with other land use / cover classes. As a result, soil and water conservation practices in the area should be primarily focused on lands of maize and cotton.

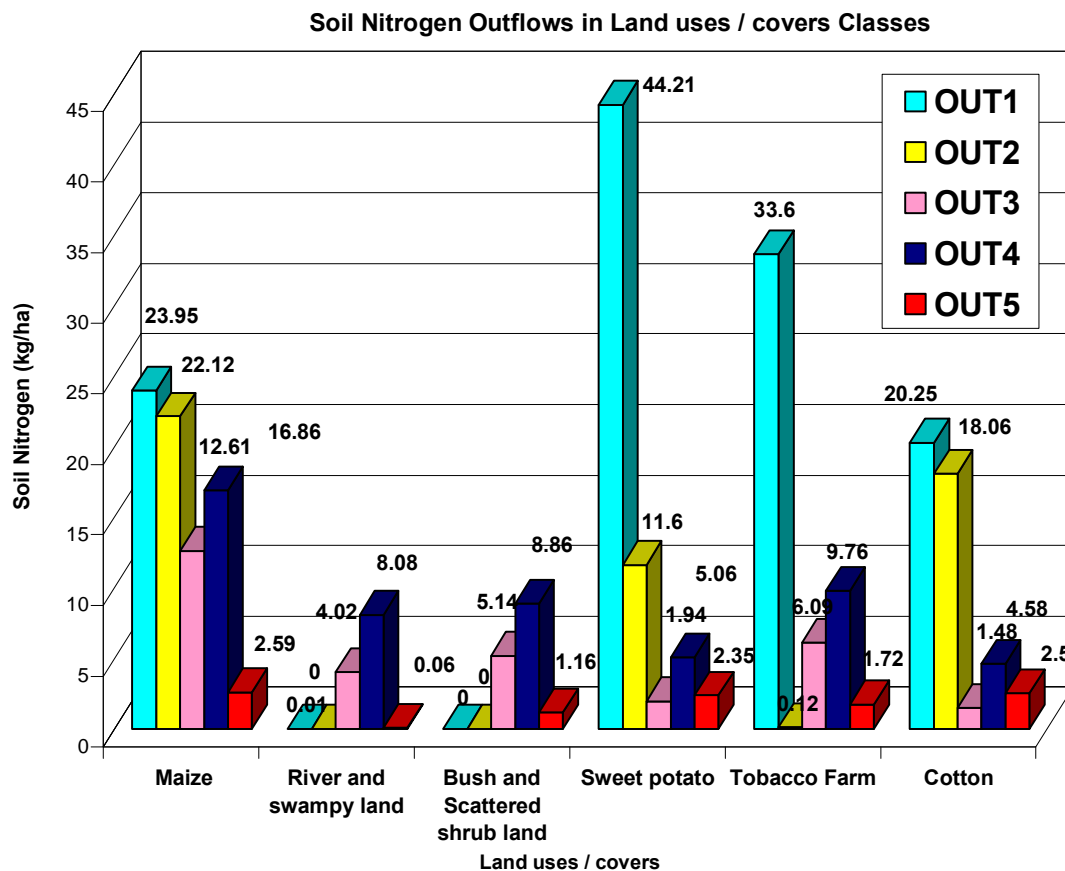


Chart 6.2. Mean Soil nitrogen outflows in land use / cover classes.

Table 6.3. Summarized statistics of outflows in different Land use / cover classes.

	Statistics	Maize	River and swampy land	Bush and Scattered shrub land	Sweet potato	Tobacco Farm	Cotton
OUT 1	MIN	0.0	0.0	0.0	38.4	33.6	0.0
	MAX	38.6	0.0	0.0	48.0	33.6	26.1
	STD	3.4	0.0	0.0	4.6	0.0	4.7
OUT 2	MIN	0.0	0.0	0.0	10.1	0.1	0.0
	MAX	35.6	0.0	0.0	12.6	0.1	23.3
	STD	3.1	0.0	0.0	1.2	0.0	0.0
OUT 3	MIN	0.0	0.0	0.0	0.0	3.0	0.0
	MAX	22.0	20.0	20.0	20.0	22.0	6.0
	STD	8.7	2.3	2.2	1.9	1.7	2.0
OUT 4	MIN	2.5	4.3	3.6	4.3	7.5	3.7
	MAX	26.5	24.1	24.1	10.1	24.1	10.1
	STD	8.8	0.8	1.1	0.8	0.8	1.3
OUT 5	MIN	0.0	0.0	0.0	0.0	0.0	0.2
	MAX	19.2	4.6	11.0	10.8	7.8	16.6
	STD	1.3	0.3	0.6	1.2	0.6	2.1

6.2.2 Soil Nitrogen Balance in Land use / cover Classes

Table 6.4. Soil Nitrogen Balance in Land use / cover Classes.

LAND COVER	AREA (km ²)	Percentage	Soil Nitrogen Balance (kg/ha)				
			MIN	MAX	RANGE	STD	MEDIAN
Tobacco Farm	10.4	5.8	-56	11	67	3.6	-26
River and swampy land	2.3	1.3	-58	41	99	6.8	-3
Bush and Scattered shrub land	108.0	60.5	-79	44	123	4.8	-3
Maize	51.0	28.6	-87	45	132	9.2	-26
Sweet potato	3.2	1.8	-67	7	74	13.5	-54
Cotton	3.2	1.8	-51	9	60	10.1	-32

Table 6.4 shows valuable statistical results from the analysis of soil nitrogen balance in Land use / cover classes. On the other hand, figure 6.3 revealed average soil nitrogen balance in land use / cover classes. The discussion that follows referred to the table and figure.

The minimum and maximum values of the soil nitrogen balance in the study area were found in maize land: -87 kg/ha and 45 kg/ha respectively. The mean soil nitrogen balance revealed a negative value on the

entire study area implying the depletion of soil nitrogen. Croplands were more depleted than non croplands. Bush and Scattered shrub land (60.5 %), Maize (28.6 %), Tobacco farm (5.8 %), Cotton (1.8 %), and Sweet potato (1.8 %) had mean soil nitrogen balance values of -3.6 kg/ha, -28.5 kg/ha, -26.2 kg/ha, -32.2 kg/ha, and -51.0 kg/ha respectively.

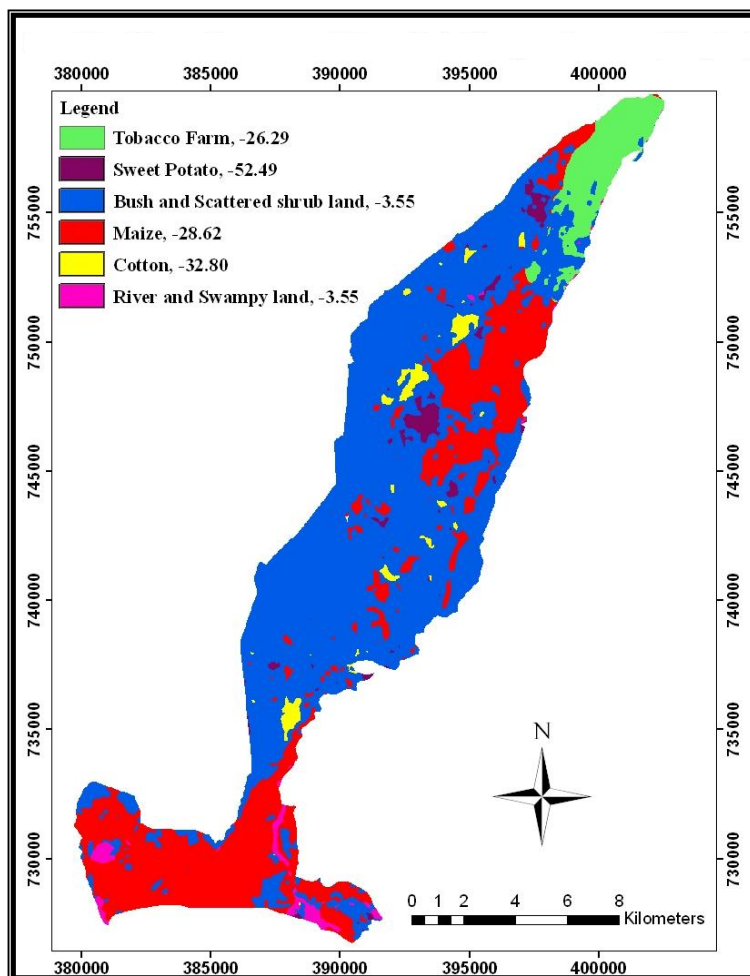


Figure 6.3. Land use / cover classes and Mean Soil Nitrogen Balance (kg/ha).

The values of soil nitrogen balance in arable fields of sub-Saharan Africa were classified in to very strong (> 40 N), Strong (20-40 N), Moderate (10-20 N) and Slight (< 10 N) (Smaling, 1993). Based on such classification Soil nitrogen balance in Sweet potato farm was classified as very strongly depleted while depletions on lands of Cotton, Maize, and Tobacco were strong. However, the depletion on Bush and Scattered shrub Land and River and Swampy land were slight.

Moreover, the qualitative classification of soil nitrogen balance in the study area was considered and presented in figure 6.4. Thus, from the total land area, the percentage of very strongly depleted, strongly

depleted and moderately depleted were 6.0 %, 31.0 % and 1.0 % respectively. However, the large area, 61 % was slightly depleted while only 1 % was not depleted at all.

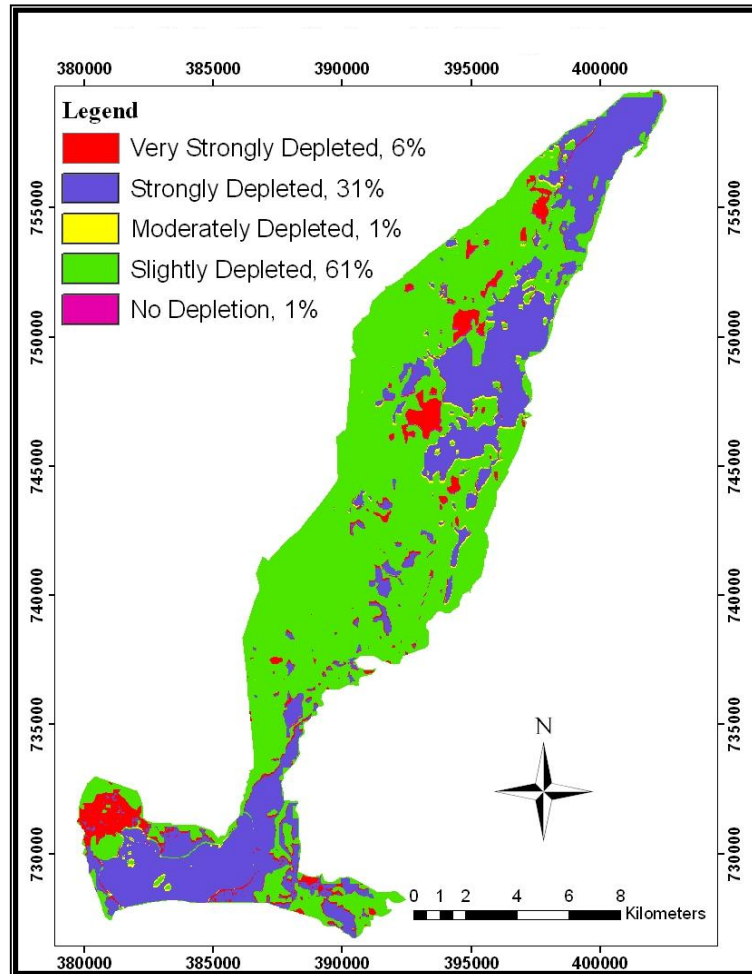


Figure 6.4. Qualitative Classification of Soil Nitrogen Balance.

6.2.3 Soil Nitrogen Balance in Soil Groups

There were twelve soil types in the study area and the soil nitrogen balance for each soil group was calculated based on average values. In all soil groups the balance was negative indicating Nitrogen was depleted. The highest average soil nitrogen depletion values are -27.0kg/ha, -26.9kg/ha and -23.8kg/ha from Vertic Fluvisols, Vertic Luvisols and Gleyic Luvisols respectively. In contrast, lower values of -4.62 kg/ha and -4.5 kg/ha were obtained from Arenosols and Vertic Nitisols respectively. Table 6.5 showed soil nitrogen balance per each soil type in the study area.

Table 6.5. Average values of Soil Nitrogen Balance in Soil groups

Soil groups	Area (m ²)	Percentage	Mean N (kg/ha)
Haplic Luvisols	33687670	18.8	-18.2
Fluvic Cambisols	3.02E+07	16.9	-14.8
Vertic Cambisols	1.56E+07	8.7	-13.5
Eutric Fluvisols	2.50E+07	14.0	-15.0
Chromic Vertisols	3.26E+07	18.2	-6.3
Eutric Cambisols	6458540	3.6	-8.8
Vertic Nitisols	1493640	0.8	-4.5
Chromic Luvisols	3949520	2.2	-9.0
Arenosols	4520780	2.5	-4.6
Vertic Fluvisols	7760490	4.3	-27.0
Vertic Luvisols	1.48E+07	8.2	-26.9
Gleyic Luvisols	2201560	1.2	-23.8

6.2.4 Comparison of the Research Output with other Results

The adoption of various methodologies, the difference in assumptions considered, the variations in the scale of studies, and the difference in objectives in many researches of soil nutrients balance estimation had resulted in a range of variations in the final output. Owing to the mentioned fact, the results of this research were compared with other results and presented in table 6.6

Table 6.6. Comparisons of the findings of soil Nitrogen balance.

Scale	Site	Special	N(kg/ha/yr)	source	
Macro	Ethiopia	National average	-41	FAO, 2003	
Micro	Ethiopia (Central highlands)	Farm level	-9	Balesh et al 2002	
		Soil fertility group classes	-79		
Micro	Ethiopia (Southern)	High land	Rich	-47	Elias, 1998
			Medium	-51	
			Poor	-19	
			Very Poor	-6	
		Low land	Rich	-49	
			Medium	-41	
			Poor	-55	
			Very Poor	-20	
Micro	This study	Low land (southern Ethiopia)	Maize	-28.6	This study
			Cotton	-32.8	
			Tobacco	-26.2	
			Bush and Scattered shrub land	-3.5	
			Sweet potato	-52.4	
			Soil groups	-14.3	

As table 6.6 portrayed, various results were produced from soil nitrogen balance estimation under Ethiopian condition. The study by FAO (2003) results -41N kg/ha/yr as national average and it is greater than the findings of current study for lands of cotton, maize, and tobacco. However, the result from sweet potato land from current study was greater than the national average given by FAO study. The outputs from current study were more comparable to results of the study by Elias in southern Ethiopia in low lands.

6.4 Uncertainties in Soil Nitrogen Balance Determination

The methodology of soil nitrogen balance as explained previously was based on some assumptions and environmental variables. The discussion on the previous sections was based on the most probable value. Therefore, it was quite important to devise a methodology for assessing the uncertainties associated with the final outputs.

The determination of the optimistic and pessimistic values of soil nitrogen balance was one such approach. Accordingly, from an estimate of pessimistic soil nitrogen balance, values ranging from -82.5 to 46.0 kg/ha were found (see figure 5.20). In contrast, the optimistic estimate resulted in values ranging from -84.8 to 47.2 kg/ha (see figure 5.21). On the other hand, as presented previously the most probable estimate was resulted in values from -87.3 to 45.2 kg/ha.

However, comparisons based on average values across Land use / cover classes expressed the scenario far better. Chart 6.3 revealed the average soil nitrogen balance values based on estimates of the probabilistic, Optimistic and Pessimistic assumptions. Generally, the three curves were well correlated and the probable curve was between the other two curves. This was well matched with an expectation that higher values were expected from pessimistic determination while lower value from optimistic determination and the probable between the two. The attached table on chart 6.3 clearly revealed for all land use / cover classes that all higher values were from pessimistic estimate and all lower values from optimistic estimates.

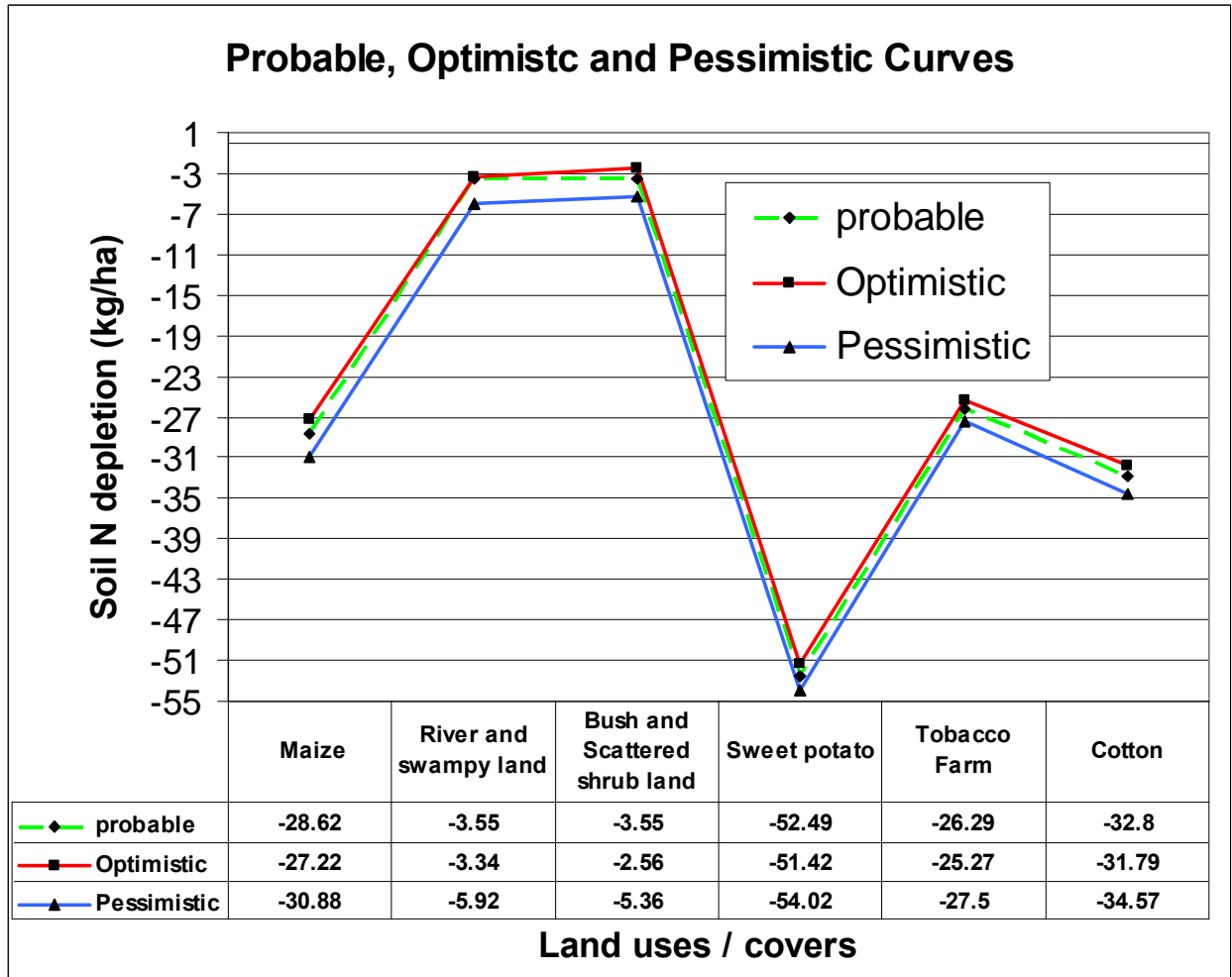


Chart 6.3. Curves of Probable, Optimistic and Pessimistic Values of Soil Nitrogen Balance.

Furthermore, the difference between the most probable estimate and optimistic / pessimistic determination was considered as the value for uncertainty. Accordingly, chart 6.4 was prepared by considering the most probable as reference or zero line and measuring the pessimistic and optimistic values. The distance between the most probable curve and pessimistic curve was greater than the distance between the most probable curve and optimistic curve. This indicated that higher values of uncertainty were from pessimistic estimates.

The values of uncertainties in land use / cover classes: Maize (1.3/-2.2), River and Swampy land (0.2/-2.3), Bush and Scattered shrub land (0.9/-1.8), Sweet potato (1.07/-1.2), Tobacco farm (1.02/-1.2) and Cotton (1.01/-1.7).

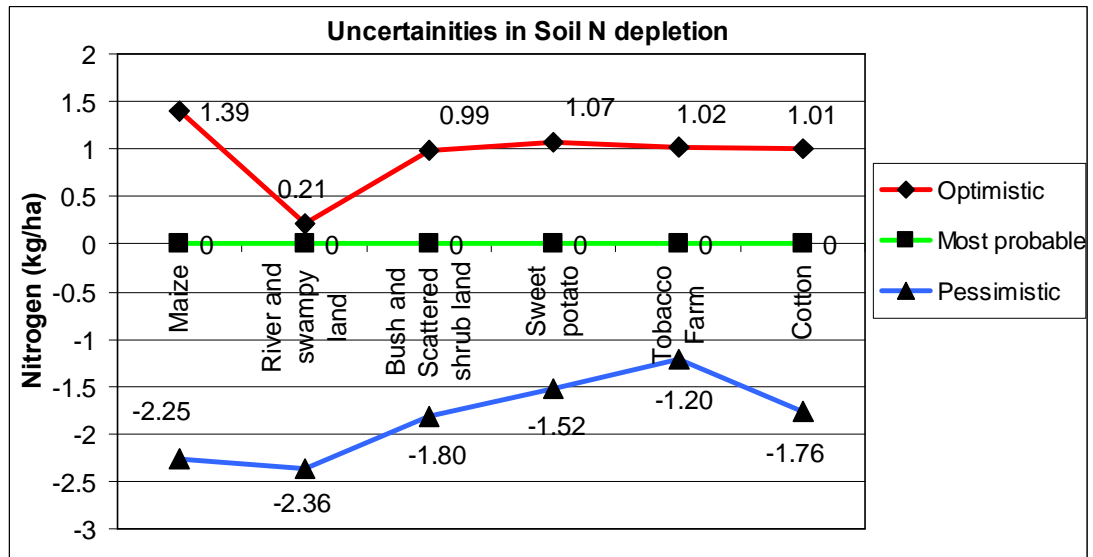


Chart 6.4. Uncertainties in Soil Nitrogen Balance.

6.5 Sources of Errors in Soil Nitrogen Balance Determination

The determination of the basic statistics of the inflows and outflows was helpful in identification of sources of errors in final output. Table 6.7 was a summary of the statistics of inflows and outflows.

The standard deviations in inflow one (Commercial fertilizer), outflow one (Harvested yield), and outflow two (Residue removal) are 23.4 kg/ha, 13.6 kg/ha and 10.4 kg/ha respectively. These values were much higher than other values and higher values of standard deviation implied the wide distribution of measured values around the mean. On the other hand, the values of the three mentioned flows were obtained from secondary source. Thus, values of commercial fertilization, crop yield, and crop residues were the possible sources of errors in the final output.

Table 6.7. Basic statistics of Inflows and Outflows.

	MIN	MAX	MEAN	STD
IN 1	0.0	61.0	12.1	23.4
IN 2	0.0	15.3	4.1	2.8
IN 3	3.3	3.9	3.6	0.1
IN 4	2.8	3.3	3.1	0.1
OUT 1	0.0	48.0	10.4	13.6
OUT 2	0.0	35.6	7.2	10.4
OUT 3	0.0	22.0	7.2	6.1
OUT 4	2.5	26.5	11.0	6.1
OUT 5	0.0	19.2	1.6	1.1

6.6 Comparison between Plant available stock soil nitrogen and Flows

A correlation was made between plant available stock soil nitrogen and flows and result was presented in Table 6.8. The correlation coefficient between plant available stock soil nitrogen and commercial fertilization (IN 1) was -0.05 and that of stock and erosion was 0.03, which were nearer to zero indicating that the absence of correlation.

When comparing the flows dividing in to inflow and outflow, a positive correlation coefficient was existed between inflows and plant available stock soil nitrogen while a negative was found between the plant available stock soil nitrogen and outflows. This was well complementary with the fact that outflows reduce the plant available stock soil nitrogen while the inflows increase. Nevertheless, the relation between the plant available stock soil nitrogen and manure addition (IN 2) was contradicting the above fact and could be considered as an outlier.

However, all the correlation coefficient values between Plant available stock soil nitrogen and inflow/outflow did not revealed strong correlation as the values deviate largely from -1 and 1.

Table 6.8. Correlation matrix of plant available stock soil nitrogen, Inflows and Outflow.

	STOC K	IN1	IN2	IN3	IN4	OUT1	OUT2	OUT3	OUT4	OUT 5
STOC K	1									
IN1	-0.1	1								
IN2	-0.2	0.1	1							
IN3	0.3	-0.2	-0.1	1						
IN4	0.3	-0.2	-0.1	1	1					
OUT1	-0.1	0.6	-0.1	-0.4	-0.4	1				
OUT2	-0.0	0.7	0.1	-0.1	-0.1	0.7	1			
OUT3	-0.1	0.8	0.2	-0.2	-0.2	0.4	0.5	1		
OUT4	-0.0	0.9	0.3	-0.2	-0.2	0.4	0.6	0.9	1	
OUT5	0.0	0.4	0.1	-0.1	-0.1	0.4	0.5	0.4	0.4	1

On the other hand, from the analysis of plant available stock soil nitrogen and soil nitrogen balance in the study area, an r value of 0.09 was resulted indicating no correlation between the stock and the balance (See Table 6.9).

Table 6.9. Statistics from comparison of the plant available stock soil nitrogen and Soil Nitrogen Balance.

	Min	Max	Mean	STD
Stock	0.3	186.9	36.4	32.4
Balance rate	-87.3	45.2	-13.9	14.5

Further more, a correlation analysis was performed to detect the existence of any relation ship between the average values of Plant available stock soil nitrogen and Soil nitrogen balance. A correlation coefficient of 0.4 was obtained implying that a less strong positive correlation was existed (See Table 6.10).

Table 6.10. Plant Available Stock Soil Nitrogen and soil Nitrogen balance in land use / cover classes.

	Maize	River and swampy land	Bush and Scattered shrub land	Sweet potato	Tobacco Farm	Cotton
Stock N	34.5	23.4	39.7	18.4	12.0	25.5
Soil N Balance	-28.6	-3.5	-3.5	-52.4	-26.2	-32.8

7. Conclusions and Recommendations

7.1 Conclusions

The research found out that values of plant available stock soil nitrogen that varied from 0.3 to 186.9 kg/ha. The majority of the area: 23.5% and 29.9% had values of 0.3-10 kg/ha and 10-20 kg/ha Plant available stock soil nitrogen respectively. Only 15.6 % of the area has higher values > 90 kg/ha which was found in bush and scattered shrub land. In general croplands endowed with lower amount of plant available stock soil nitrogen than non croplands.

The research finding disclose that the addition of commercial fertilizers like Diammonium phosphate and Urea were the main inflow in maize land while the fertilizer NPK was the major source of inflow in tobacco farm. Animal manure was the main source of nitrogen inflow in lands of Sweet potato, Cotton and Bush and scattered shrub land.

Outflow one which is harvested crop yield, was the major source of nitrogen loss in crop lands. An average value of 44.2 kg/ha, 33.6 kg/ha, 23.9 kg/ha and 20.2 kg/ha were found in sweet potato, tobacco, maize and Cotton land respectively. Outflow two which is the removal of crop residues was the second most important source of nitrogen outflow in the area followed by Denitrification (OUT 4) and Erosion (OUT 5). Erosion withdrew more nitrogen from lands of maize and cotton than other land use /cover. Maize land was unique from other land uses that all outflows were proportionally higher.

The soil nitrogen balance modeling revealed that soil nitrogen was depleted in 99 % of the area and only the rest 1% was not depleted. Accordingly, 6 % of the area was very strongly depleted (> 40 N) while 31 % was strongly depleted (20-40 N). 61 % was slightly depleted (< 20 N) which was mainly found in bush and scattered shrub land. Generally, Crop lands were more depleted than non croplands.

Bush and Scattered shrub land (60.5 %), Maize (28.6 %), Tobacco farm (5.8 %), Cotton (1.8 %), and Sweet potato (1.8 %) had mean soil nitrogen depletion values of -3.6 kg/ha, -28.5 kg/ha, -26.2 kg/ha, -32.2 kg/ha, and -51.0 kg/ha respectively. Similarly, the mean soil nitrogen balance in all soil groups was negative.

The research indicted that higher uncertainties were from pessimistic estimate than optimistic estimate. The values of uncertainties in land use/cover classes: maize (1.3/-2.2), River and Swampy land (0.2/-2.3),

Bush and Scattered shrub land (0.9/-1.8), Sweet potato (1.0/-1.2), Tobacco farm (1.0/-1.2) and Cotton (1.0/-1.7).

The standard deviations in inflow one (Commercial fertilizer), outflow one (Harvested yield), and outflow two (Residue removal) were 23.4 kg/ha, 13.6 kg/ha and 10.4 kg/ha respectively. This indicated that the three parameters were the possible source of error in the final soil nitrogen balance estimation. As the three parameters were estimated from secondary sources the errors could be induced.

Though the correlation was not strong, inflows and the Plant Available Stock Soil Nitrogen were positively correlated while the stock and outflows were negatively correlated.

There was no correlation between the Plant available stock soil nitrogen and soil nitrogen balance ($r = 0.09$). Nevertheless, a correlation that was less strong and positive ($r = 0.4$) was found between average values of soil nitrogen balance and the plant available stock soil nitrogen.

The study clearly enabled the application of Remote Sensing and Geographical Information System as a tool for modeling the Plant Available Stock Soil Nitrogen and Soil nitrogen balance estimation in micro scale level of land uses/cover level. Moreover, the uncertainties and source of errors were assessed. In general, the study developed a spatially explicit methodology for modeling Plant Available Stock Soil Nitrogen and nitrogen balance in the study area.

7.2 Recommendations

The strategy of soil nutrient management in the area should be relied on increasing the inflow while reducing the outflows. In cognizant with the above fact, the following were the likely solutions:

- ❖ The application of commercial fertilizer should be practiced on all crops based on the results of soil and plant test results. Blanket recommendation had been used in maize and tobacco fields. This should be replaced with recommendation rate which will be determined based on soil and plant tissue analysis.
- ❖ The removal of crop residues in the study area should be avoided and if it was needed to be practiced, compost should be prepared using the residues and should be applied to high feeder crops in the study area such as sweet potato and maize primarily.

- ❖ Soil erosion was significant in lands of maize and cotton; hence soil erosion practices which were applicable in arid environment should be practiced.
- ❖ Fallowing in the commercial farming of the tobacco land might result for better yield and soil nutrient depletion mitigation.
- ❖ For the subsistence agricultural production system of the area crop rotation that is rotating legumes by cereals could be one solution.
- ❖ As the study disclosed the existence of depletion on bush and scattered shrub land, land management practices ought to be devised in the area. This could be enabled by planting leguminous trees which were multipurpose and adapted to arid climatic condition of the area.

Future similar researches in the area should take in to consideration the following important points:

- ❖ Direct field measurement of crop yields and residue estimation should be undertaken rather than using from secondary sources.
- ❖ The study did not consider an outflow of nitrogen from animal uptake via grazing in bush and scattered shrub land use which was mainly used for grazing purpose and hence future similar researches in the area should take in to account the source.
- ❖ The nitrogen concentration on the plant tissues should be determined for better final result.
- ❖ The equations of Leaching, Denitrification, Nitrogen fixation, and Deposition either should be estimated for Ethiopian case or validated using various methodologies.
- ❖ Future similar researches in arid environment should be considered the outflow of nitrogen due to wind erosion.

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Appendices

Appendix 1. Ground truth data collected during field work using GPS.

S.No	X	Y	Cover Name
1	401363	758710	Tobacco farm
2	399294	754908	Tobacco farm
3	399828	757376	Tobacco farm
4	398761	752706	Tobacco farm
5	398694	752906	Tobacco farm
6	397493	753040	Tobacco farm
7	399962	757043	Tobacco farm
8	400295	756375	Tobacco farm
9	399428	754841	Tobacco farm
10	396974	750423	Maize crop land
11	397199	750461	Maize crop land
12	394047	749147	Maize crop land
13	399113	758041	Maize crop land
14	390670	743781	Maize crop land
15	394160	740366	Maize crop land
16	386204	730253	Maize crop land
17	385566	728376	Maize crop land
18	381663	728677	Maize crop land
19	390219	727175	Maize crop land
20	385153	729427	Maize crop land
21	382113	728526	Maize crop land
22	391683	740573	Maize crop land
23	380162	731529	Maize crop land
24	383615	727288	Maize crop land
25	388005	737308	Maize crop land
26	390257	727213	Maize crop land
27	391720	740535	Maize crop land
28	387968	738659	Maize crop land
29	388043	731529	Maize crop land
30	392283	747365	Maize crop land
31	395060	743762	Maize crop land
32	394835	748416	Maize crop land
33	388080	734080	Maize crop land
34	380913	731416	Maize crop land
35	380162	731303	Maize crop land
36	385904	725074	Maize crop land
37	388981	728864	Maize crop land
38	390257	728902	Maize crop land
39	390332	736895	Maize crop land
40	397650	755058	Sweet potato land
41	397237	756109	Sweet potato land
42	397537	755058	Sweet potato land
43	397650	755508	Sweet potato land
44	395360	750480	Sweet potato land

45	395398	750555	Sweet potato land
46	395848	752243	Sweet potato land
47	393296	747027	Sweet potato land
48	392921	747027	Sweet potato land
49	394347	744513	Sweet potato land
50	391645	743049	Sweet potato land
51	387480	737570	Sweet potato land
52	388418	727251	Sweet potato land
53	388943	726688	Sweet potato land
54	389244	725862	Sweet potato land
55	388418	726725	Sweet potato land
56	388118	735694	Cotton land
57	387893	735356	Cotton land
58	388230	736069	Cotton land
59	391795	741135	Cotton land
60	391983	740985	Cotton land
61	394647	750705	Cotton land
62	394535	750517	Cotton land
63	396974	753932	Cotton land
64	391795	747890	Cotton land
65	398749	753005	Shrub, scattered bush and grass land
66	398566	753118	Shrub, scattered bush and grass land
67	398540	753156	Shrub, scattered bush and grass land
68	398517	753161	Shrub, scattered bush and grass land
69	398343	752291	Shrub, scattered bush and grass land
70	398294	752313	Shrub, scattered bush and grass land
71	398250	752336	Shrub, scattered bush and grass land
72	391079	744288	Shrub, scattered bush and grass land
73	391029	744288	Shrub, scattered bush and grass land
74	391018	744272	Shrub, scattered bush and grass land
75	391009	744237	Shrub, scattered bush and grass land
76	391018	744185	Shrub, scattered bush and grass land
77	390142	743339	Shrub, scattered bush and grass land
78	387001	741910	Shrub, scattered bush and grass land
79	387087	741861	Shrub, scattered bush and grass land
80	387088	741857	Shrub, scattered bush and grass land

Appendix 2. Nutrient content values of manure from literature.

Values based on fresh matter; dry matter assumed to be 50 percent of fresh matter

Cattle manure	N (%)	P (%)	K (%)	
	0.70	0.30	0.67	Lekasi <i>et al.</i> , 2001a
	1.63	0.09	1.13	Smaling <i>et al.</i> , 1999
	0.57	0.14	-	FAO, 1980
	0.64	0.06	0.23	Williams <i>et al.</i> , 1995
	0.79	0.22	1.00	Baijukya <i>et al.</i> , 1998
	0.29	0.03	0.42	Budelman and Defoer, 2000
	0.70	0.26	0.55	Budelman and Defoer, 2000
Average:	0.76	0.15	0.67	
Sheep/goat manure	N (%)	P (%)	K (%)	
	0.75	0.20	0.69	Lekasi <i>et al.</i> , 2001a
	0.75	0.11		FAO, 1980
	0.60	0.22	0.54	Indian Council of Agricultural Research, 1997
	1.10	0.06	0.37	Williams <i>et al.</i> , 1995
	0.20	0.10	0.35	Budelman and Defoer, 2000
	0.65	0.20	0.50	Budelman and Defoer, 2000
	1.45	0.53	0.53	Budelman and Defoer, 2000
Average:	0.79	0.20	0.50	

Source: FAO (2003)

Appendix 3. Annual Manure Production of Livestock species per head.

Livestock Type	Annual Manure Production/hd
Cattle, Equines and Camels	1000kg (1 ton)
Sheep and Goats	708 kg (0.708 tones)

Source: Rift Valley Lakes Basin Integrated Resource Development Master Plan Study Project (2007)

Appendix 4. Livestock population in kebeles of the study area in 2006/2007.

S. N	Kebele Name	Cattle	Sheep	Goat	Mules	Horses	Donkey	Poultry
1	Fango Bijo	2498	228	905	10	1	64	1289
2	Anka Damot	2296	321	688	7	1	131	917
3	Agaza Hoyate Zelan	4201	300	2775	12	nil	167	1506
4	Belate Ersha Lemat	3543	897	725	5	nil	45	2100
5	Abaya Ersha Lemat	159032	13309	23194	3	Nil	6259	59760
6	Zelan Chokari	159033	13310	23195	nil	nil	6260	59758
7	Tembaho Monopolie	nil	nil	nil	nil	nil	nil	nil
8	Fango Sore	2575	603	690	5	nil	1005	1021

Appendix 5. Crops Grown, productivity of crops, residue yield and Nitrogen Uptake in kebeles of study area.

S.N	Kebele Name	Major Crops grown	Yield (t/ha)	Crop residue(t/ha) using HIR of 1: 2	Nitrogen Uptake (kg/ha)(U)
1	Anka Damot	Maize	2.0	4	48
		Cotton	1.4	2.8	60.1
		Sweet potato	10	20	46.7
2	Belate ersha lemat	Maize	1.6	3.2	38.4
		Sweet potato	10	20	46.7
		Cotton	1.4	2.8	60.1
3	Fango Bijo	Maize	1.6	3.2	38.4
		Cotton	1.4	2.8	60.1
		Sweet potato	10	20	46.7
4	Fango sore	Sweet potato	10	20	46.7
		Maize	1.6	3.2	38.4
		Cotton	1.4	2.8	60.1
5	Zelan chokari	Maize	1.2	2.4	28.8
		Sweet potato	8	16	37.3
		Cotton	1	2	42.9
6	Abaya Ersha Lemat	Maize	1.6	3.2	38.4
		Cotton	1.4	2.8	60.1
		Sweet potato	7	14	32.66
7	Agaza Hoyate	*Sweet potato	10	20	46.7

		*Maize	1.6	3.2	38.4
		Cotton	0.8	1.6	34.35
8	Tembaho Monopole	Tobacco	0.6	1.2	31.8

Appendix 6. Nutrient Content of harvested product, crop residues and removal factors for crop residues.

Crops	Harvested Product	Crop residues	Removal factor			
	N	N	Ghana	Kenya	Mali	Study area (Estimated)
	Kg/tonne	Kg/tonne	%			
Cotton	18.7	13.9	60	60	60	60
Maize	16.8	9.7	30	75	80	80
Sweet potato	4.8	2.1	30	20	30	30
Tobacco	56	0.1	10	20	10	100 (from field information)

Source : Stoorvogel and Smaling (1990)

Appendix 7. Nitrogen removal of crops based on quantity of yield harvested.

Nutrient Removal by Crops (kg/ha)

Crop	Yield(t/ha)	Nitrogen (kg/ha)
Maize	3	72
	6	120
Sweet potatoes	15	70
	40	190
Cotton	1.7	73
	5	180
Tobacco	1.7	90

Source: FAO (1978). Fertilizers and their use

Remark- the data used for extrapolating nitrogen removal based on yield is based on the first row of each crop type. This was selected since the data in the study area was more comparable to values in the first row.

Appendix 8. Base denitrification per land / water classes.

Table: Base Denitrification per land/water class

Land/Water class	Denitrification(kg/ha/year)
Low	3
Uncertain	5
Good	8
Problem(> 1200 mm rainfall)	12
Problem(< 1200 mm rainfall)	5
Naturally flooded	12
Irrigated	11

Appendix 9. Commercial fertilizers utilization rates.

S.N	Kebele Name	Major Crops	DAP/ha	Urea/ha	NPK
1	Anka Damot	Maize	100kg	100kg	Nil
		Cotton	Nil	Nil	Nil
		Sweet potato	Nil	Nil	Nil
2	Belate ersha lemat	Maize	100kg	100kg	Nil
		Sweet potato	Nil	Nil	Nil
		Cotton	Nil	Nil	Nil
3	Fango Bijo	Maize	100kg	100kg	Nil
		Cotton	Nil	Nil	Nil
		Sweet potato	Nil	Nil	Nil
4	Fango sore	Maize	100kg	100kg	Nil
		Sweet potato	Nil	Nil	Nil
		Cotton	Nil	Nil	Nil
5	Zelan chokari	Maize	Nil	Nil	Nil
		Sweet potato	Nil	Nil	Nil
		Cotton	Nil	Nil	Nil
6	Abaya Ersha Lemat	Maize	100kg	100kg	Nil
		Cotton	Nil	Nil	Nil
		Sweet potato	Nil	Nil	Nil
7	Agaza Hoyate Zelan	Sweet potato	Nil	Nil	Nil
		Maize	100kg	100kg	Nil
		Cotton	Nil	Nil	Nil
8	Tembaho Monopole	Tobacco	nil	nil	300 kg

Appendix 10. Soil erodibility values adopted for Ethiopia by Hurni (1985).

Soil type	Kvalue	Soil type	K value
Humic Acrisol, moderately deep	0.22	Vertic Luvisol	0.14
Humic Acrisol, very deep	0.16	Eutric Nitosol	0.32
Humic Andosol	0.26	Eutric Nitosol, stony	0.24
Humic Andosol, stony	0.16	Humic Nitosol	0.12
Ochric Andosol	0.25	Haplic Phaeozem	0.20
Cambisol	0.33	Haplic Phaeozem, lithic, shallow	0.19
Chromic Cambisol	0.23	Haplic Phaeozem, lithic, very shallow	0.32
Chromic Cambisol-Regosol	0.20	Haplic Phaeozem, moderately deep to deep	0.31
Chromic Ranker Cambisol	0.27	Haplic Phaeozem, very deep	0.29
Eutric Cambisol	0.35	Luvic Phaeozem	0.16
Fluvisol	0.33	Ranker	0.15
Eutric Fluvisol	0.28	Regosol	0.27
Dystric Gleysol	0.31	Eutric Regosol	0.22
Mollic Gleysol	0.33	Chromic Vertisol	0.19
Lithosol	0.24	Chromic-pellic Vertisol	0.25
Lixisol	0.10	Pellic Vertisol	0.22

Appendix 11. Management practice values proposed by Hurni (1985).

Management practice	P Factor
ploughing up and down	1.00
strip cropping	0.80
applying mulch	0.60
stone cover 80%	0.50
stone cover 40%	0.80
ploughing on contour	0.90
intercropping	0.80
dense intercropping	0.70

Appendix 12. C Factor after Hurni (1985).

Crop	C Factor
dense forest	0.001
other forest	0.05
badlands hard	0.05
badlands soft	0.40
sorghum, maize	0.10
cereals, pulses	0.15
dense grass	0.01
degraded grass	0.05
fallow hard	0.05
fallow ploughed	0.60
Ethiopian tef	0.25
continuous fallow	1.00

Appendix 13. Soil organic carbon, pH (water) and Nitrogen in the study area.

Code	Depth	OC%	N%	pH	Code	Depth	OC %	N%	PH	Code	Depth	OC %	pH	N%
BP-001	0-15	1.20	0.09	6.13	BP-010	0-20	1.11	0.07	9.62	BP-018	0-25	1.34	6.63	
	15-55	1.05	0.09			20-95	0.32	0.04			25-85	1.50		
	55-100	0.56				95-165	0.15				85-140	0.47		
	100-180	0.40				165-200	0.20				140-185	0.33		
BP-002	0-15	2.08	0.15	6.07	BP-011	0-20	1.09	0.09	6.82		185-200	0.32		
	15-35	1.17	0.07			20-85	0.64	0.07		BP-019	0-30	1.77	8.23	0.07
	35-85	1.26				85-120	0.63				30-60	0.73		
	85-130	0.69				120-160	0.54				60-95	0.24		
BP-003	0-25	0.86	0.04	7.20		160-200	1.11				95-130	0.24		
	25-70	0.52	0.03		BP-012	0-25	2.57	0.15	7.05		130-155	0.15		
	70-130	1.05				25-90	0.80	0.09		BP-020	0-15	1.07	7.00	0.09
	100-165	0.46				90-160	0.18				15-50	0.81		0.07
	165-200	0.35				160-120	0.23				50-90	0.70		
BP-004	0-20	0.79	0.04	6.37	BP-013	0-15	1.59	0.09	6.39		90-130	0.64		
	20-55	1.05	0.07			15-75	1.71	0.09			130-180	0.44		
	55-80	1.08				75-140	0.66			BP-021	0-25	1.46	7.10	0.09
	80-140	0.30				140-200	0.28				25-90	0.90		0.07
	140-200	0.21			BP-014	0-20	1.20	0.07	5.63		90-165	0.40		
BP-005	0-15	0.73	0.1	6.13		20-65	0.61	0.03			165-200	0.25		
	15.30	0.37	0.03			65-120	0.41			BP-022	0-15	2.37	6.90	0.15

	35.70	0.32			BP-015	0.15	1.15	0.12	7.70		15-90	7.59		0.04
BP-006	0-20	0.73	0.04	7.12		15.65	1.32	0.14		BP-023	0.20	1.72	5.73	0.09
	20-50	0.80	0.07			65-105	0.56				20-80	1.35		0.07
	50-100	0.48				105-185	0.27			BP-024	0-40	1.96	5.88	0.1
	100-65	0.74				185-200	0.31				40-85	0.33		0.04
	165-200	0.50				200-290	N				85-135	0.55		
BP-008	0-25	2.10	0.12	6.16	BP-016	0-25	1.22	0.14	6.37	BP-025	0-20	0.70	7.65	0.04
	25-80	1.11	0.12			25-50	0.68	0.07			20-85	0.21		0.03
	80-125	0.37				50-80	0.76			BP-026	0-25	1.54	6.70	0.11
	125-170	0.17				80-45	0.89				25-50	0.66		0.05
BP-009	0-40	1.56	0.12	6.10		145-200	0.40				50-120	0.42		
	40-95	1.22	0.07		BP-017	0-35	1.19	0.15	5.98		120-145	0.24		
	95-170	0.91				35-100	1.15				145-200	0.25		
	170-200	0.26				100-150	0.45							
						150-200	0.29							

f .Continued

Code	Depth	OC%	N%	pH	Code	Depth	OC%	pH	N%
BP-027	0-15	0.97	0.07	6.82	BP-036	0-25	1.25	7.55	0.07
	15-100	1.00	0.1			25-80	0.62		0.04
	100-140	0.98				80-150	0.26		
	140-200	0.67				150-200	0.17		
BP-028	0-15	1.80	0.1	6.80	BP-037	0-25	0.97	7.95	0.07
	15-80	1.24	0.11			25-100	0.73		0.07
	80-105	0.53				100-175	0.38		
BP-029	0-25	1.65	0.13	6.92		175-200	0.24		
	25-55	1.78	0.11		BP-038	0-20	0.87	6.53	0.05
	55-120	0.45				20-50	1.28		0.1
	120-200	0.29				50-150	1.74		
BP-030	0-20	2.30	0.17	6.65		150-200	0.82		
	20-85	1.37	0.1		BP-039	0-25	0.40	6.35	0.05
	85-155	0.68				25-50	0.22		0.03
	155-200	0.34				50-95	0.11		
BP-031	0-20	1.62	0.13	6.50		95-120	0.18		
	20-80	0.59	0.04		BP-040	0-30	0.30	6.48	0.04
	80-145	1.00				30-90	0.25		0.03
	145-200	0.77				90-140	0.66		

BP-032	0-25	2.22	0.1	6.85		140-200	0.89		
	25-65	0.85	0.08		BP-041	0.25	1.44	6.90	0.17
	65-100	0.64				25-60	1.19		0.15
	100-140	0.66				60-120	1.28		
BP-033	0-15	1.39	0.11	7.13		120-160	0.77		
	15-50	0.47	0.06			160-200	0.58		
	50-95	0.36			BP-042	0-20	2.06	7.36	0.09
	95-150	0.42				20-70	0.9		0.05
	150-200	0.81			BP-043	0-15	0.35	7.00	0.04
BP-034	0-20	1.43	0.1	7.45		15-50	0.46		0.03
	20-60	1.09	0.07			50-115	0.50		
	60-115	0.56				115-140	0.30		
	115-175	0.25				140-190	0.25		
	175-200	0.16			BP-044	0-20	2.07	6.85	0.17
BP-035	0-30	1.40	0.11	6.87		20-70	0.94		0.06
	30-85	0.58	0.04			70-90	0.50		
	85-160	0.17				90-145	0.45		
	160-200	0.23							

Source : Ministry of Water Resources (2006/2007), Unpublished data

DECLARATION

I hereby declare that the dissertation entitled "Modeling Soil Nitrogen Balance using Geographical Information Systems and Remote Sensing, the case of lower Bilate River basin, Southern Ethiopia" has been carried out by me under the supervision of Dr. Dagnachew Legesse, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2009 as a part of Master of Science programme in Remote Sensing and GIS.

I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa

Date: June, 2009

Andualem Aklilu