ADDIS ABABA UNIVERSITY

College of Social Sciences Department of Geography and Environmental Studies Land Resource Management Stream

ESTIMATING SOIL NUTRIENT BALANCE OF CEREAL LANDS OF TIGRAY REGION, NORTHERN ETHIOPIA.

By
ABRHAM BELETE ASSEFA

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, College of Social Science, Department of Geography and Environmental Studies for Partial Fulfillment of the Requirement for the Degree of Master of Art.

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Signed by the examining committee:

Examiner ____________________ Signature ___________Date___________

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Advisor____________________ Signature ___________Date___________

Chairman, Department ______________________Signature ________________Date____________

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LIST OF ABBREVIATIONS AND ACRONYMS

BoARD	Bureau of Agriculture and Rural Development of Tigray.
CSA	Central Statistics Agency.
E.C	Ethiopian calendar.
EGP	Ethiopian Government Portal.
G.C	Gregorian calendar.
GCS	Geographic coordinate system.
GDP	Gross Domestic Product.
GIS	Geographic Information System.
HI	Harvest Index.
IFDC	International Fertilizer and Development Center.
Kg	Kilogram.
M.A.S.L	Meter above Sea Level.
MoARD	Ministry of Agriculture and Development of Ethiopia.
Mt	Metric Ton.
NMA	National Meteorology Agency.
NPK	Nitrogen, Phosphorus, Potassium.
NUTMON	Nutrient Monitoring.
OECD	Organization for Economic Co-operation and Development.
Qt	Quintal.
SSA	Sub Saharan Africa.
Yr	year.

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ABSTRACT

Nutrient depletion is one of the major causes that contribute to decline in soil productivity in the highlands of Ethiopia. In this study, four outflows: Nutrient harvest, Crop residue, Leaching and Erosion and four inflows: Organic fertilizer, Manure, Deposition and Nitrogen fixation were taken into account. The nutrient balance conducted as a yearly basis using 2010/2011 cropping year as a reference. Estimations of inflows and outflows employed empirical and transfer functions; results of estimations linked to ArcGIS for visualization purpose (i.e. presented in map form). All macro nutrient balance for each zone of cereal lands of the region was negative. It was mainly due to very low inputs from mineral fertilizers and relatively low organic fertilizers. And also it associated with huge export of NPK through nutrient leaching and soil erosion from the system. The average nutrient depletion rate in the cereal lands of the region was -65Nitrogen, -27Phosphorous and -45Potassium kilogram/hector or (-137 NPK kg/ha). Finally this study estimated that averagely 78, 30 and 54 N, P and K kg/ha amount had required in the cereal lands of the region for cereal production without depleting the soil nutrient respectively in the year 2010/2011.

Key words*: inflows, outflows, macro-nutrients, soil nutrient balance and requirements.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background and Justification

The economic development of Africa, more than any other region depends on the development of agriculture and agro-industry sectors, which are fundamentally affected by productivity of land resources. This is particularly true for sub-Saharan Africa.

Agriculture accounts for more than 25% of the GDP of most African countries, and is the main source of income and employment at least 65% of Africa's population of more than 750 million. Thus, agricultural development is vital to Africa's economic growth, food security and poverty alleviation (Henao and Baanante, 1999).

In Ethiopia about 11.7 million smallholders accounts for approximately 95% of agricultural GDP and 85% of employment. The agricultural sector accounts for roughly 43% of GDP and 90% of exports. Cereals dominate Ethiopian agriculture accounts for 70% of agricultural GDP. Over the past decade, cereal productions has more than doubled to nearest 15 million tones, as a result of horizontal expansion and increased yields. Nevertheless, food security remains a critical issue of many households, and for the country as a whole. Moreover, expansion of the cropped area to marginal lands has led to sever land degradation in some areas (MoARD, 2010).

Soil nutrient stock is the reserved of nitrogen, phosphorus and potassium and other essential elements in the soil that can be available to plants during time scale of 5 to 10 years (Sanchez and Palm, 1996). Soil nutrient balance studies in Africa show evidence of widespread nutrient mining leading to severe nutrient deficiency across ecological zones. Soil nutrient stocks are not static entities and studies in different parts of Africa at different spatial scales show nutrient are being depleted at alarming rates (Stoorvogel and Smaling, 1990; Vanderpol, 1992). Nutrients are annually taken away in crops or lost in processes such as leaching and erosion which far exceed the nutrient inputs through fertilization, deposition and biological fixation (Smaling and Braun, 1996). Nutrient mining has been estimated to average 660kg of N, 75kg of P, and 450kg of K per hectare per year during the last 30 years from about 200 million hectares of cultivated land in 37 African countries (Stoorvogel and Smaling, 1990; Sanchez et al., 1997). Losses of 130kg N, 5kg P and 25kg K per hectare per year have been reported in the East African highlands (Smaling et al., 1996).

Several studies employed in Sub-Saharan Africa (SSA) countries showing N, P and K stocks have been declining. The major causes of nutrient stock depletion are less attention paid to the rural areas, land degradation, inadequate nutrient replenishment and late adoption of improved soil fertility management techniques, poor agronomic practices, nutrient mining and lack of ample natural land resource management practices (Sanchez et al., 1997; Stoorvogel and Smaling, 1990). Consequently, per capital food production is diminishing in the continent and thousands of peoples are depending on food aid (FAO, 2001).

The concern for soil nutrient depletion and low soil fertility has led to the development of several integrated soil fertility management technologies that offer potential for improving soil fertility management in Africa (Scoon and Toulmin, 1999). These including improved soil erosion control using living barriers or micro- catchment, inoculation of grain legume for improved N-fixation, efficient use of manure and other locally available organic materials, use of green manure and cover crops.

1.2 Statement of the problem

Nutrient depletion (mining) is a net loss of plant nutrients from the soil or production system due to negative balance between inputs and outputs. Typical channels of nutrient depletion are nutrient removal through harvest, leaching, denitrification, soil erosion, and runoff (Drechsel and Gyiele, 1999).

Soil degradation and nutrient depletion have gradually increased and have become serious threats to agricultural productivity in Ethiopia (Fasile Kebede., 2009). Currently, land degradation is a chronic problem in the soils of crop lands, one form of degradation is soil nutrient mining that most smallholder farmers have faced. In Ethiopia soil nutrient depletion mainly caused by inappropriate farming practices, low level of external inputs and nutrient use efficiency, application of organic resources for other activities and loss of nutrient due to biophysical processes which includes leaching, erosion, and so forth.

Nutrient balance studies conducted in different parts of Ethiopia at various scales such as field, farm section, farm, watershed and national showing N, P and K depletion is taking place in the smallholder farms (Eyasu et al., 1998).

In addition, a macro level nutrient depletion and requirement study by IFDC (2003) categorized Ethiopia with countries where nutrient depletion exceeds averagely 60kg NPK/ha/year. However, the calculation was on a country basis and differences within the country are not shown. Moreover, in the study area a geo-referenced NPK rate of depletion and requirement at regional level is not studied. Therefore, the study was conducted to estimate and present the spatial nutrient depletion and requirements in the soils of major cereal lands of Tigray region.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of the study is to evaluate and create awareness about the state of soil nutrient balance for better understanding of the situation for sustainable crop production and food security of the region.

1.3.2 Specific Objectives

The Specific objectives of the paper are listed down as follow:

- Calculating N, P and K flows in the cereal lands of the region for the period of 2010/2011.
- Estimating 2010/2011 nutrient depletion and requirement of the region cereal lands.
- Establishing a geo-referenced nutrient depletion and requirement map based on the 2010/2011 year data.

1.4 Significance of the Study

Since macro level nutrient balance model raises awareness of soil fertility problems; indicating areas with nutrient depletion or accumulation and gives a quantified pictures of the nutrient flows. The concerned bodies either at national or regional level can be used the result (finding) to formulate effective measures on the actual condition of the problem on one hand and it may be used as a reference to conduct other studies at meso and micro scale on the other.

1.5 Major Assumptions, Limitations and Gaps of the Study

- The study carried on in an annual basis, and 2010/2011 growing season as a base of the research.

- Aggregate soils/lands of teff, barely, wheat, sorghum, maize and millet in each zone of the region considered as a defined production system called cereal land which has been assumed as homogeneous entities. This may be the major limitation of the study since, they are not exactly the same in their nature and there is also spatial difference and temporal variation in terms of soil type, climate and agro-ecology.

- Although sedimentation is one source of inflow (gain) of resources and nutrients, the study ignored sedimentation process; this is mainly because of the nature of the study which emphasis on rain fed subsistence farming. Sedimentation has been imperative in the areas of naturally flooded and irrigated land (Henao and Baanante, 1999).

- The study is general and conducted mainly based on secondary data sources. Additionally it did not estimate gaseous losses, wind erosion and dry deposition, the latter two could be more relevant in arid environment as an outflow and inflow respectively.

1.6 Organization of the paper

The thesis is organized as follows: chapter one is an introductory part which contains statement of the problem, research objectives and assumptions, limitations, and gaps of the paper. The next chapter presents an overview of literatures on the nature of macro-nutrients and calculation and estimation procedures and methods. Chapter three deals with methods and materials which also include study area description. Chapter four presents estimation and analysis of nutrient flows in the study area. Chapter five presents results and discussions and the last chapter deals with conclusions and recommendations based on the major findings.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Theoretical and Conceptual Framework

Plant growth is the result of a complex process whereby the plant synthesizes solar energy, water and nutrients from the soil. Soil supplies 13 essential plant nutrients. It is a major source of nutrients needed by plants for growth. The three major nutrients are nitrogen, phosphorus and potassium. Together they make up the trio known as NPK. Other important nutrients are calcium, magnesium and sulfur. Plants also need small quantities of iron, manganese, zinc, copper, boron and molybdenum known as trace elements because only traces are needed by plants. The role these nutrients play in plant growth is complex (Gruhn et al., 2002).

2.1.1 Nitrogen

It is a key element in plant growth. It is found in all plant cells, in plant proteins and hormones, and in chlorophyll. Atmospheric nitrogen is a source of soil nitrogen. Some plants such as legumes fix atmospheric nitrogen in their roots; otherwise fertilizer factories use nitrogen from the air to make ammonium sulfate, ammonium nitrate and urea. When applied to soil, nitrogen is converted to mineral form nitrate so that plants can take it up. Additionally, it plays a vital role in nearly all aspects of plant growth and development, and plants need a large amount of nitrogen to grow well. Soils high in organic matter such as chocolate soils are generally higher in nitrogen than podozolic soils. Nitrate is easily leached out of soil by heavy rain, resulting in soil acidification. If it is applied in small amount leaching is reduced (http://www.dpi.nsw.gov.au/).

2.1.2 Phosphorus and Potassium

Phosphorus helps to transfer energy from sunlight to plants, stimulates early root and plant growth, and hastens maturity. Sources of phosphorus are mineral phosphate made from rock and manures; particularly getting from grain fed animals are rich sources.

Potassium increases disease resistance abilities of plants, which helps to form and move starches, sugars and oils in plants, and can improve fruit quality. Potassium is heavily removed from soils used for intensive grazing and intensive horticultural crops such as bananas and custard apples. Marinate of potash and sulfate of potash are the most common source of potassium (http://www.dpi.nsw.gov.au/).

According to Smith (1993) in mixed and animal based systems animal feeds and bedding represent relatively large inputs of P and K to organic farms. Any necessary additional P and K applied strategically within the rotation, with an application of rock phosphate expected to supply P for a number of following crops. However, organic farming seeks to optimize the recycling of P and K and to keep imports as small as possible. In animal-based and mixed systems, good manure management is therefore essential. Manure as slurry is used to redistribute nutrients around the farm. However, the grazing patterns of livestock, such as "camping" under trees, in the lea of hedges and at fixed troughs, can increase the spatial heterogeneity of P and K returns, which may persist for many years. Phosphorus dominantly occurs in organic forms in manures, while K is found in soluble forms, large leaching losses of K can therefore occur during manure storage and composting.

A soil nutrient is classified as a primary nutrient, secondary nutrient, or micronutrient based on the amount needed by plants. If a soil's nutrient supply is deficient, fertilizers can provide the additional nutrients needed for healthy plant growth (Smith, 1993).

2.1.3 Agricultural Development

According to Wendt (2012) SSA is characterized by a diversity of soil type, agro-ecological zones and cropping systems, with some similarities to those of South America. SSA largely missed the green revolution of the 1950's and 1970's which led to dramatic increase in productivity throughout the world due to the use of improved germplasm, mineral fertilizers, irrigation and good management practices. Mineral fertilizer use is fundamental to increasing yields and replacing nutrients removed in harvested products and loss through volatilization (nitrogen), leaching and soil erosion. The increase in N, P and K consumptions in Asia and Latin America over this time was huge, while consumption in Africa stagnated.

The fertility of any soil will decline if the nutrient content of the harvest removed from the system (as grain, timber, and livestock and so on) exceeds the nutrient inputs from natural and anthropogenic sources (Gruhn et al., 2002).

A significant proportion of agricultural soils, mainly in developing countries are suffering nutrient deficiencies. In large areas of Africa the nutrient balance is negative (Sanchez et al., 1997) leading to declining soil fertility. In the case of South America, the magnitude of the imbalance appears to be decreasing as incomes rise and farmers can afford more fertilizer. In Africa, the cost of fertilizer to low-income farmers is usually prohibitive.

The situation is characterized by two factors: ecological features and farmers' perception of risk in many of the poorest developing regions. First much of the agricultural population in nutrient deficiency areas lives on soil derived from basement rock, on very old, stable land surface. The P and basement cation content of these soils is inherently low; as a result, natural biological N-fixation is also low. Because the soils are sandy and low in organic C, they lose N through leaching. Their low N status leads them to be burned frequently (since the grass that grows on them is too low in N for cattle to digest in the wintertime) causing further N loss. Nitrogen is the key component of protein and it is precisely these areas that show a steady decline in per capita protein consumption, to levels well below the recommended daily intake.

Where farmers' perceive that there is a risk of not achieving an acceptable level of yield at harvest (perhaps because of drought) to cover their inputs costs, they are often unwilling to invest in fertilizers to replace nutrients like P and K removed in the harvested produce (Wendt, 2012).

2.1.4 Nutrient Deficiency

Nutrient deficiency, excess nutrients and nutrient available to plants discussed as follows based on Asmeret et al. (2010). The most common deficiencies are for the primary nutrients N, P and K which are in large demand by plants. Sulfur is recommended for optimum growth of grain and forage crops in many areas. Calcium and magnesium may be deficient in acid soils. Each nutrient causes characteristics symptoms. In addition, it affected plants growth, yield become less and less healthy than plants with adequate levels of nutrients.

2.1.5 Excess Nutrients

Excess nutrients can be a problem for plants and the environment. Excesses usually result because too much of a nutrient is applied or because a nutrient is applied at the wrong time. Too much nitrogen can lead to excessive foliage production, increased risk of diseases, wind and delayed flowering, fruiting, and dormancy. Available nitrogen left in the soil at the end of the growing seasons has the potential under certain conditions to leach into groundwater and threaten drinking water quality. The key to apply fertilizer is to meet plant needs without creating excesses that can harm plants or the environment.

2.1.6 Nutrient Available to Plants

Plants can take up only nutrients that are in solution (dissolved in soil water). Most soil nutrients are not in solution; they are tied up in soil mineral and organic matter in insoluble forms. These nutrients become available to plants only after they are converted to soluble forms and dissolved into the soil solutions.

This process occurs through weathering of mineral matters and biological decomposition of organic matter. The rate of nutrient release from soil organic matter is somewhat faster than nutrient release due to weathering and it depends on the amount of biological activity in the soil. Nutrient release from soil organic matter is fastest in warm and moist soil. Thus, the seasonal pattern of nutrient release is similar to the pattern of nutrient uptake by plants. About 1 to 4 percent of the nutrients in soil organic matter are released in soluble form each year.

Soluble, available nutrients are in ionic chemical form. An ion has either positive or negative charge. Positively charged ions are cations and negatively charged ions are anions potassium (k^+), calcium (Ca^{++}) and magnesium (Mg^{++}) are examples of nutrient cations. The nitrate (NO_3^{-+}) form of nitrogen is an example of a nutrient anion.

Clay particles and soil organic matter have negative charges on their surfaces and can attract cations. They hold cations a ready reserve form that can be released rapidly into soil solutions to replace nutrients taken up by plant roots. This reserve supply of nutrients contributes to soils fertility. A soil's capacity to hold cations is called its cation exchange capacity or CEC. In addition to nutrient retention, CEC affects pH buffering capacity and the amount of lime required to change the pH of an acid soil (Asmeret et al., 2010).

2.1.7 Nutrient Cycle and Flows

Soil nutrient availability changes over time. The continuous recycling of nutrients into and out of the soil is known as the nutrient cycle. The cycle involves complex biological and chemical interactions, some of which are not yet fully understood. A simplified version of this cycle of plant growth, based on Smaling (1993), classified as "inputs" that added plant nutrients to the soil and "outputs" that export them from the soil largely in the form of agricultural products. Important input sources include inorganic fertilizers, such as manure, plant residues, and cover crops, nitrogen generated by leguminous plants and atmospheric nitrogen deposition. Nutrients are exported from the field through harvested crops and crop residues, as well as through leaching, atmospheric volatilization and erosion.

The difference between the volume of inputs and outputs constitutes the nutrient balance. Positive nutrient balances in the soil occurring when nutrient additions to the soil are greater than the nutrients removed from the soil indicate that farming systems are inefficient and, in the extreme, that they may be polluting the environment. Negative balance could well indicate that soils are being mined and that farming systems are unsustainable over the long time. In the latter instance, nutrients have to be replenished to maintain agricultural output and soil fertility into the future (Gruhn, 2000).

2.1.8 Overview of Land Degradation and Nutrient Mining

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 became a national threat to Ethiopia. In the mid 1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation (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

A 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), and 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) 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 (Eyasu E. 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, denitirification and erosion. Denitirification, 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 using 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 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 of method for calculating nutrient requirements of crop. Here the nutrient requirement referred the amount of nutrient uptake required to achieve a specific target yield without depleting the soil nutrient (Henao and Baanante, 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 denitirification, 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 adopted its methodology from the procedure of Stoorvogel and Smaling (1990). The fact that making the methodology spatially explicit and calculating the net balance on land uses which 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 Spatial 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 and continental level were considered as macro level. The methodology was that of Stoorvogel and Smaling (1990). 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 and 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 where 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 that can be used in the NUTMON toolbox. Farms, which are the bases for land management, for the calculation units. Moreover, participatory approach, socio-economic household 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 spatial 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 of 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 Overview of Results of Nutrient Balance Studies in Ethiopia

A study in Ethiopia at micro level, specifically at farm level by Balesh et al (2002) 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 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.

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.

A partial macro-nutrients (NPK) balance conducted in Teghane, in the northern highlands of Ethiopia indicated that soil nutrient depletion proceeds at an alarming rate at both ‘farm field’ and ‘plot scales’ of different wealth group and it showed that the highest rate of nutrient mining in the rich farm group, followed by the medium and the poor groups. In addition, the result indicates that significant quantities of manure had been used for household energy supply, equivalent to 52.3, 21.9 and 26kg ha^{-1} yr^{-1}, respectively by rich, medium and poor. Furthermore, due to inappropriate management of manure in the stable and compost heap, significant losses take placed, averagely 23.3kg N, 5.8kg P, and 23.8kg K ha/year for the rich, 25kg N, 5.5kg P and 33kg K ha year for the medium, and 8.8kg N, 2.4kg P and 8kg K ha^{-1} year^{-1}for the poor group. Moreover, the balance in grazing land, including small pastures plots, borders of crop fields and areas around homesteads, are overgrazed and depletion rates were highest for all groups: -115kg N, -5.8kg P, -112kg K ha for the rich, -56.2kg N and -42.5kg K for the medium and -56.5kg N and 34.6kg K/ha for the poor. For the latter tow groups, P was almost in balance. Like wise, K balances in barley fields were negative for all groups. In contrast the N balance was positive for the poor groups (5.1kg $^{-1}$ha^{-1}). For wheat, all balances were negative for all farmers. Whereas, N balance for faba bean and pea were positive for the medium and poor farmers, with values of 4.0 and 20.3kg/ha, respectively with the exception of negative balance for the rich farmers (-10.5kg ha) (Assefa et al., 2007).

A study in Gobo Daguat watershed, Tigray, northern Ethiopia using NUTMON at farm scale indicated that there was an annual deficit of 27kg N ha^{-1}. Expressing the N balance on a plot basis, without taking into account internal flows, showed an even larger depletion rate, i.e. 34kg N per ha per year. This negative balance showed that urgently appropriate management practices must be identified which able to stop further depletion of soil N stocks in Tigray. In addition, the study also stated that crop residues used as mulch hardly contributed to lower soil nitrogen depletion at farm level as the total amount of nitrogen in crop residues was limited while, part of the crop residue nitrogen returned to the soil anyway in the form of manure and compost (Hengsdijk et al., 2004).

2.6 Benefits and Uncertainties in Soil Nutrient Balance Calculations

2.6.1 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).

2.6.2 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 is 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).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study Area Description

3.1.1 Location, Extent and Population

Tigray region is located at the northern limit of the central highlands of Ethiopia, situated between 12° 13' to 15º 00' North latitude and 36º 27' to 40° 18' East longitude. The region shares common borders with Eritrea in the north, the state of Afar in the east, the state of Amhara in the south and the republic of the Sudan in the west. Based on 2007 census the region has an estimated area of 80,000km^2 with a total population of 3,136,267 of which 1,542,165 (49%) are males and 1,594,102 (51%) are females. The urban dwellers account 468,478 (15%) and 2,667,789 (85%) are rural residents. Generally the region consist 5 administrative zones, 35 weredas and 74 towns. Mekele is the capital city. (http://www.ethiodemographyandhealth.org/Tigray.htmlhttp).

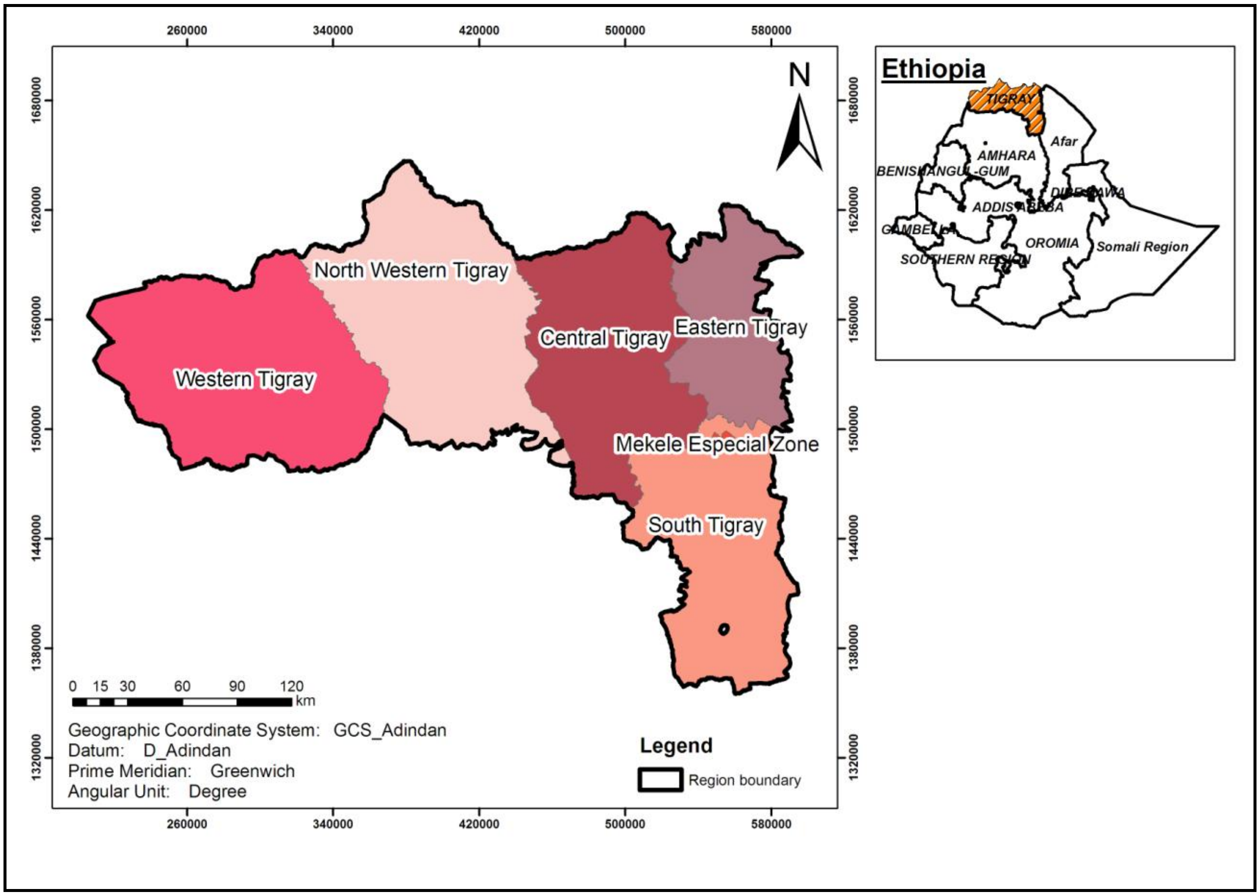

Figure 3.1 Location map of the study area

3.1.2 Topography and Climate

The region contain the three main traditional divisions of agro-ecological belts of Ethiopia: the “kolla-lowland” (semi-arid) 1400-1800 m.a.s.l accounts 39% with relatively low rainfall and high temperature; “woina-dega”(warm temperate) 1800-2400 m.a.s.l accounts 49% with moderate temperature and rainfall, and “dega-highland”(temperate) 2400-3400 m.a.s.l accounts 12% with high rainfall and low temperature of the total area coverage. The two altitude extremes; the elevation of the region rises from 600-2700 m.a.s.l, the Tekeze Gorge 550 m.a.s.l and the “Kisad-Gudo” peak at 3935 m.a.s.l are among the region natural sceneries which are classified in to the central highland, the western lowland, and eastern escarpments. The average annual rainfall is between 450-980mm (EGP, 2013; MoARD, 2008).

3.1.3 Soils

According to FAO-1998 classification the dominant soils of the region are broadly grouped as leptosols, nitosols, vertisols, cambisols, calcisols, luvisols, fluvisols and regosols (MoARD, in shapfile).

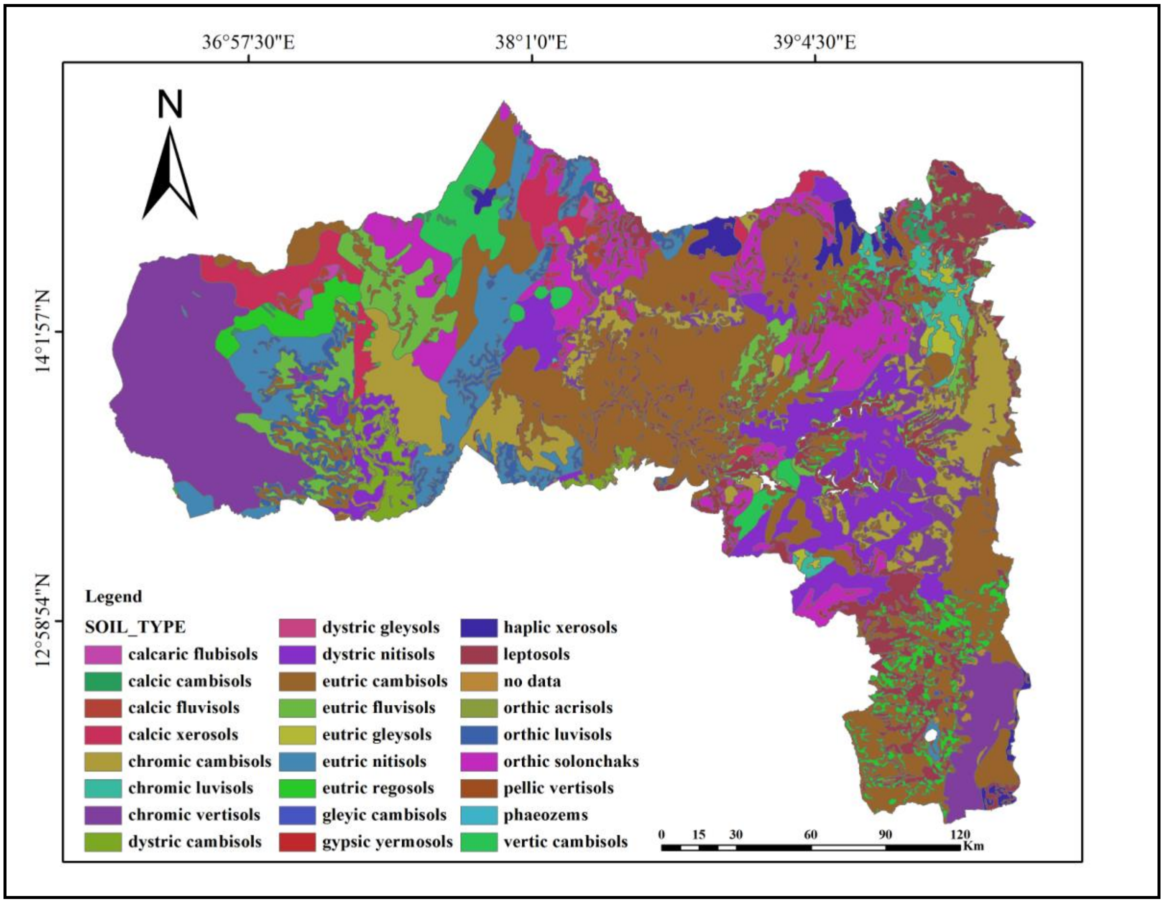

Figure 3.2 Spatial distribution of major Soil types in Tigray.

3.1.4 Major Economic Activities

About 83% of the population are agrarians. Teff, wheat, and barely are the main crops. Other agricultural products include beans, lentils, onions, and potatoes. Irrigation and terrace farming are used on the steep slopes. The region is also known for its export items of cottons, incense, sesame and minerals. Around 1.5 million hectares of land in the region is cultivable, of which one million are cultivated (67%), while 420,877 hectare of land is terraced (28%). In addition, the region claims to have about 11.51 million domestic animals of which 2.15 million are cattle, 5.63 million are sheep and goats and 392,000 are pack animals (EGP, 2013).

3.1.5 Rivers and Lakes

Tekeze and Mereb are transboundary rivers that pass through the region with their sources in the Amhara and Eritrea mountains, respectively. There are small rivers such as Geba, Worii, Berber, Arqua, and Teter, which are suitable for irrigation development. Tekeze is a promising source of hydro-electric power. Lake Ashenge, which is found in the southern zone of the region, is an interesting area for observing birds and fishing.

3.2 Materials and Data

Table 3.1 Summary of materials and data with their sources

No.	Material/data	Sources/descriptions
1	MS Office	To manage, manipulate and analyze statistics
2	Arc GIS 10	To visualize study result in the form of map
3	Crop production	CSA
4	Fertilization	BoARD of the region
5	Climate	NMA
6	Soil types	MoARD
7	Livestock production	CSA
8	Shapefiles/ GIS files	CSA

3.3 Data Sources and Collection

Field observation were conducted to obtain information about soil fertility management practices, organic mineralization and also informal discussion used as a major technique to collect data and information concerning soil fertility decline problem, soil erosion severity, and agricultural production system.

Literatures were the main sources used to obtain information about crop harvest index, nutrient uptake by cereals and residues, enrichment value, nutrient content of manure for varieties of livestock species.

3.4 Methodological Approach

Soil nutrient balance could be assessed via different approaches. However, the study mainly depends on the model developed by Henao and Baanante (1999). In addition model developed by Lesschen et al. (2007) were also employed to estimate inflows like phosphorus and potassium deposition and nitrogen fixation non-symbiotically and by trees. The methodological approach used here to estimate nutrient depletion and requirements combines information on:

- Agricultural production (land use, crop production, use of mineral and organic fertilizers)
- Soil characteristics
- Biological constraints and
- Method and procedures designed for such estimation.

The model considered total inflows and total outflows in an annual basis expressed in kg/ha/yr. In this study, the soil N, P and K balance was calculated by taking 2010/2011 or 2003 E.C cropping year as a study ground. Accordingly, all the data used for the soil nutrient balance modeling were collected for the same year. In this paper, four inflows: mineral fertilizer, organic inputs (manure), atmospheric deposition, and nitrogen fixation and four out flows: harvested crops, crop residues, leaching, and erosion were considered.

The database linked to geographic information system (Arc GIS) that used for producing geo-referenced input data and map analysis and for presenting results in the form of maps or spatial outputs.

Flow (Figure 3.1) show the basic components of the methodology of soil nutrient balance estimation, and each flow was computed using empirical and transfer functions. In this section the simple flow diagram presented and the equations with their sources were discussed in their respective sections under the analysis part.

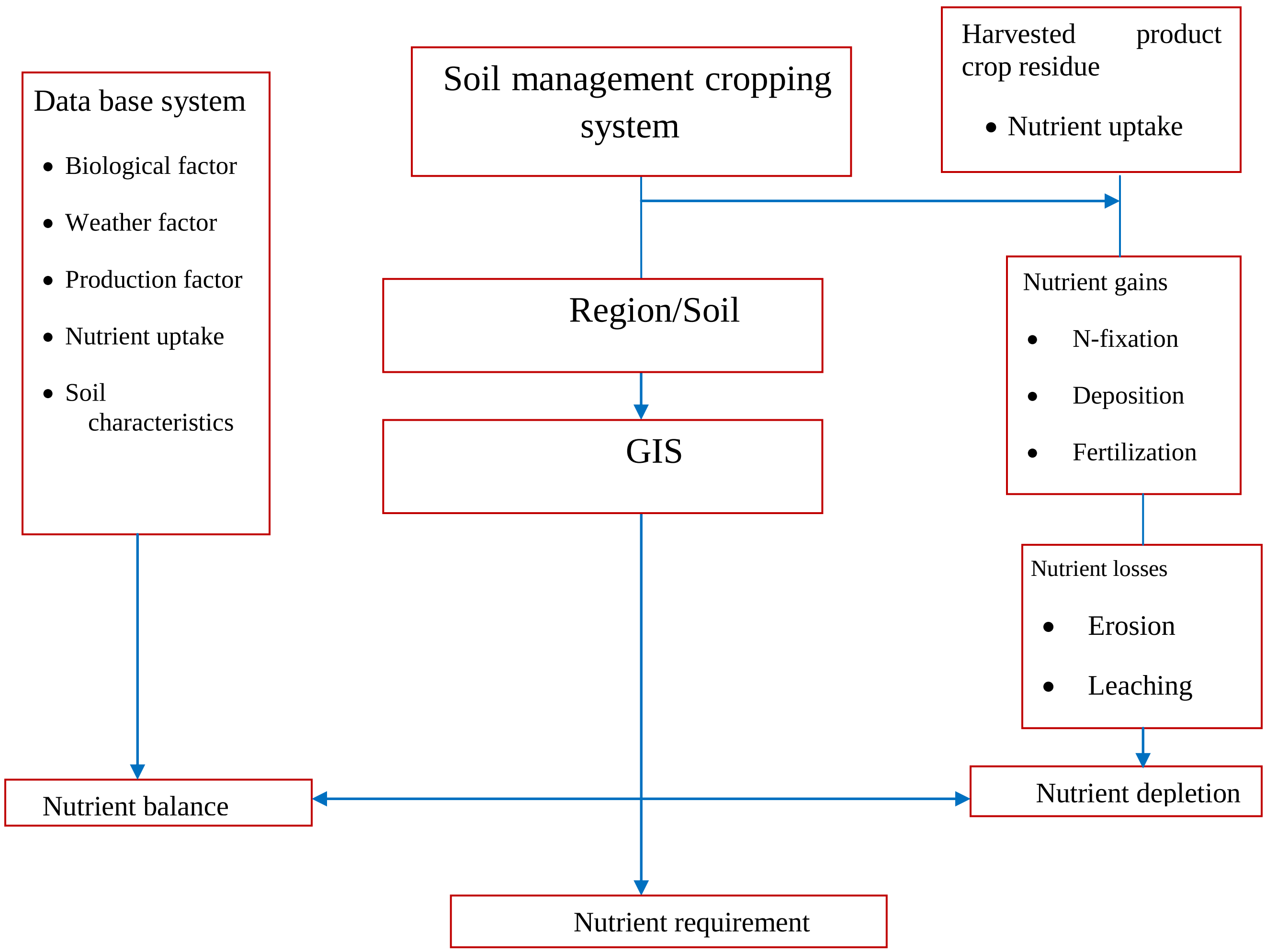

Figure 3.3 Work flow of nutrient balance estimation (Henao and Baanante, 1999).

Many researchers have calculated soil nutrient depletion by using various approaches and methods to estimate soil nutrient balances. A simple specification of the balance on nutrient (NPK) in soils of agro-ecosystem at regional scale is given by the following equation:

$$Rn = \Sigma\ (AP + AR)\ - RM)\ - L))\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{equation1.}$$

Where: Rn = the quantity of inorganic and organic nutrient remaining in the soil.

AR = the soil inorganic and organic nutrients added or returned to the soil.

RM = the estimate plant nutrients removed with the harvested production and residual management.

L = the inorganic and organic nutrient lost from the soil due to other processes.

Since the study carried out in an annual basis some parameters, the previous nutrient stock (AP) in the soil dropped out from consideration.

3.5 Bases for Estimating Nutrient Inflows and Outflows

- The production of crop outputs and residues were used to calculate total crop nutrients uptake from the soil.
- Nutrient depletion and requirements were assessed by calculating and using estimates of nutrient gains attributable to the application of minerals and organic fertilizers and biophysical processes of deposition, sedimentation, and fixation.
- Information on weather, soil constraints, soil characteristics and agro ecological zones will be used to estimate soil nutrient losses due to erosion, leaching, and gaseous losses.

Estimates of nutrient gains and losses are developed from assumed soil nutrient transfer functions and from estimates of empirical statistical models.

CHAPTER FOUR

4. ESTIMATING AND ANALYZING NUTRIENT FLOWS

4.1 Assessment of Nutrient Outflows

A. Harvested product (Nu)

Nutrient removal by crop production is normally the most important factor for nutrient export from agricultural lands. So as to determine outflow (Nu), data on productivity of crops and their nutrient content is mandatory. So that, data on the subject obtained from Central Statistic Agency (see appendix 4) and the nutrient content of each crop under study were derived from Henao and Baanante (1999) (see appendix 1). It could be calculated using the following equation.

$$Nu = Cp\ (NI) \qquad \text{equation 2.}$$

Where: Nu = nutrient uptake by the crop.

Cp = total crop production.

NI = nutrient uptake indices.

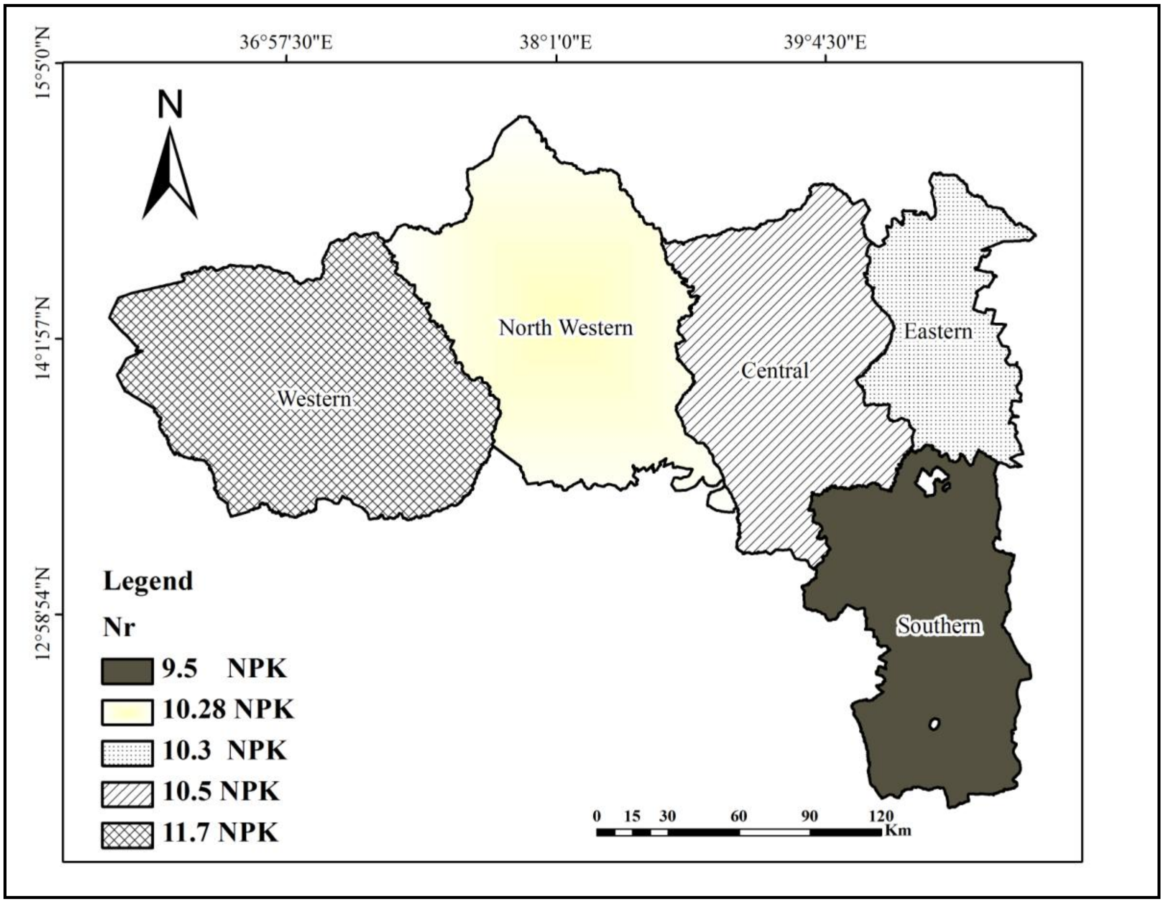

Figure 4.1 NPK outflows (kg/ha) from cereal lands of each zone due to Nu.

B. Crop Residue (Nr)

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. 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 crop yield multiplied by harvest index set as 0.45 averagely for most cereals in developing countries derived from Gallagher et al. (2012) and the percentage of residue left on the field after harvest set as 30% (http://www.fao.org/wairdocs/ilri/x5491e/x5491e17.htm) It could be calculated as follow.

Nr = Cp (1-HI) NI Ref……………………………………………..equation3

Where: Nr = nutrient uptake by the residue.

HI = harvest index.

Ref = the approximated percentage of residue left on the soil after crop harvesting.

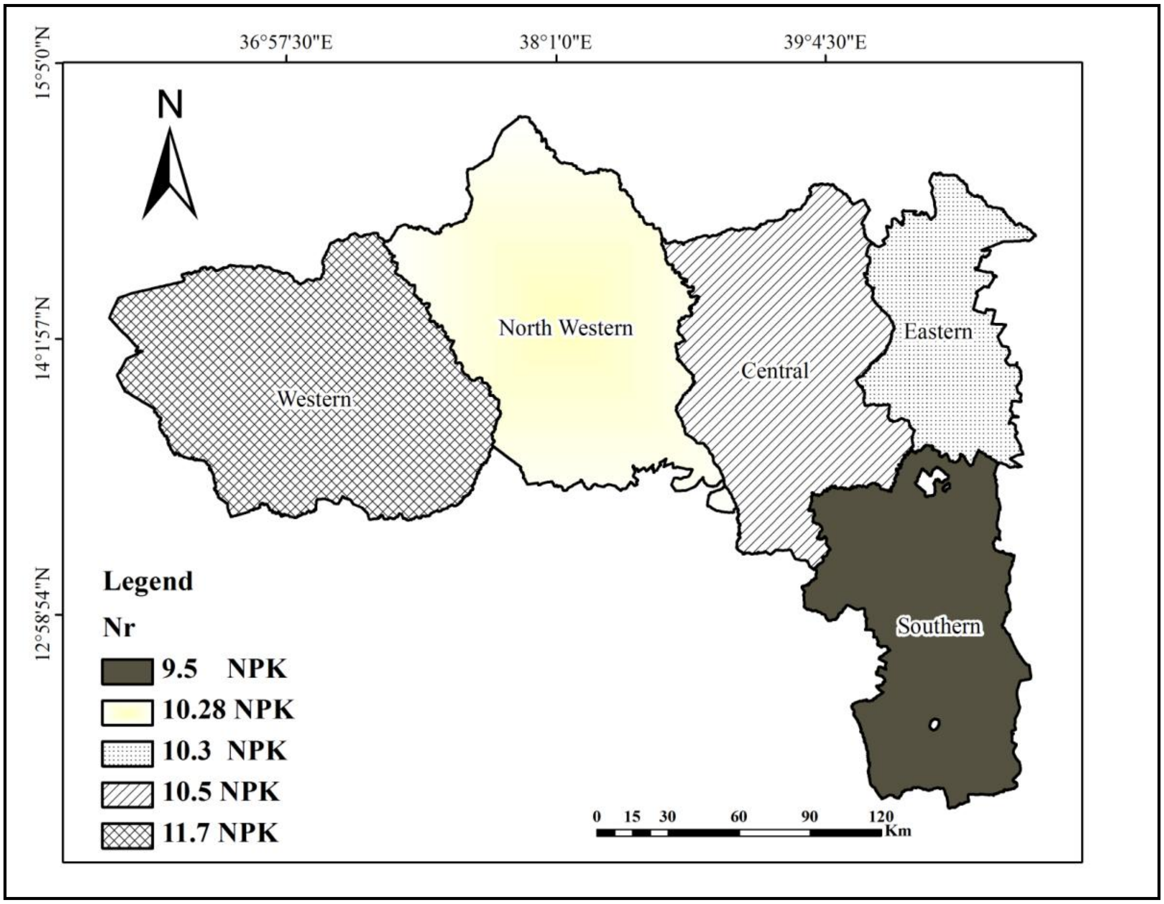

Figure 4.2 NPK outflows (kg/ha) from cereal lands of each zone due to Nr.

C. Leaching of Nutrient (Nl)

Rainfall Data

Rainfall data from fifteen (15) meteorological stations located inside and adjacent to the study area were collected from Ethiopian Meteorological Agency (NMA). However, in the northern, eastern, and western part of the region all the stations were found within the study area due to the geographical location that shares international boundaries that limited the function and result of the analysis. The data were then put in Excel and saved in dbf IV format and added in Arc Map using the Add x-y function then the event format converted to point feature. After this, the point feature were interpolated using the kriging function in the spatial analyst tools and a rainfall raster layer was created. The raster layer was clipped using the boundaries of each zone shapefile as a mask using the extract by mask function. Finally, average rainfall value for each zone was derived.

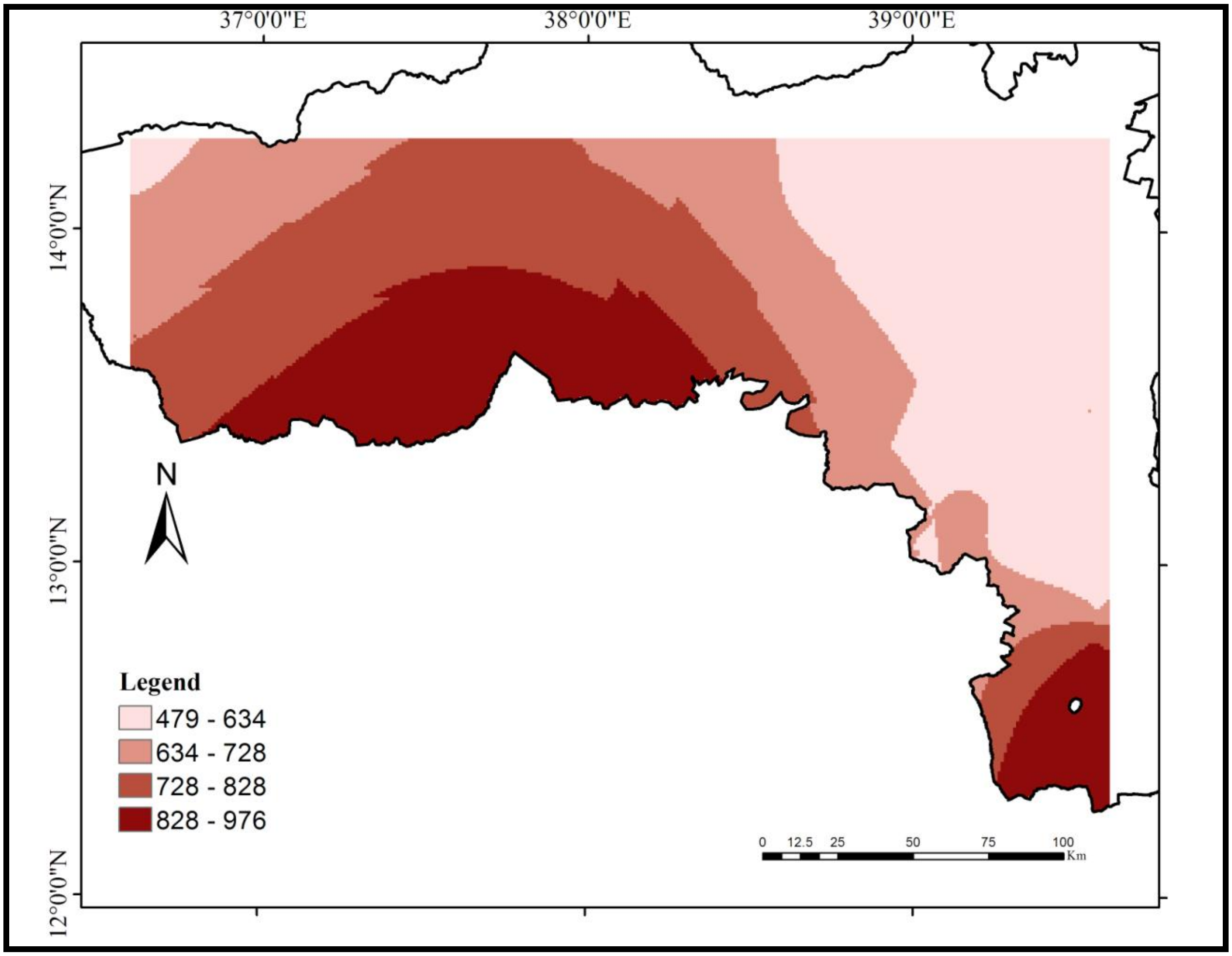

Figure 4.3 Average annual rainfalls (mm) of the region 2010/2011.

Regression models have been estimated to predict nutrient leaching at regional levels. The general specification of this model includes as variables: the fertility of the soils expressed as soil fertility class (*Fc*), the average rainfall (*R*) for the region/site, and the nutrients applied (*Cn*). The model was specified as follows:

$$Nli = \alpha + (\beta 1 + \beta 2\ R)\ Fc + \beta 3\ \log(R) + \beta 4\ Cn + \in i \text{ ....equation4.}$$

Where: 100 < *R* < 3 300; *Nli* is the amount of leaching of N or K at site *i*, expressed as percentage of the quantity applied; the parameter estimates α, β*1*, β*2*, β*3* and β*4* measure the effects of site management, soil fertility class (*Fc*), rainfall (*R*), and nutrient applied in the form of mineral and organic sources (*Cn*), respectively. The soil fertility class *Fc* is included to account for the fertility and management of the soil as determined by soil classification and the availability of soil nutrients. This is assessed broadly as: 1 = low; 2 = moderate; and 3 = high. The parameter ∈ *i* is the error associated with the estimation of the model.

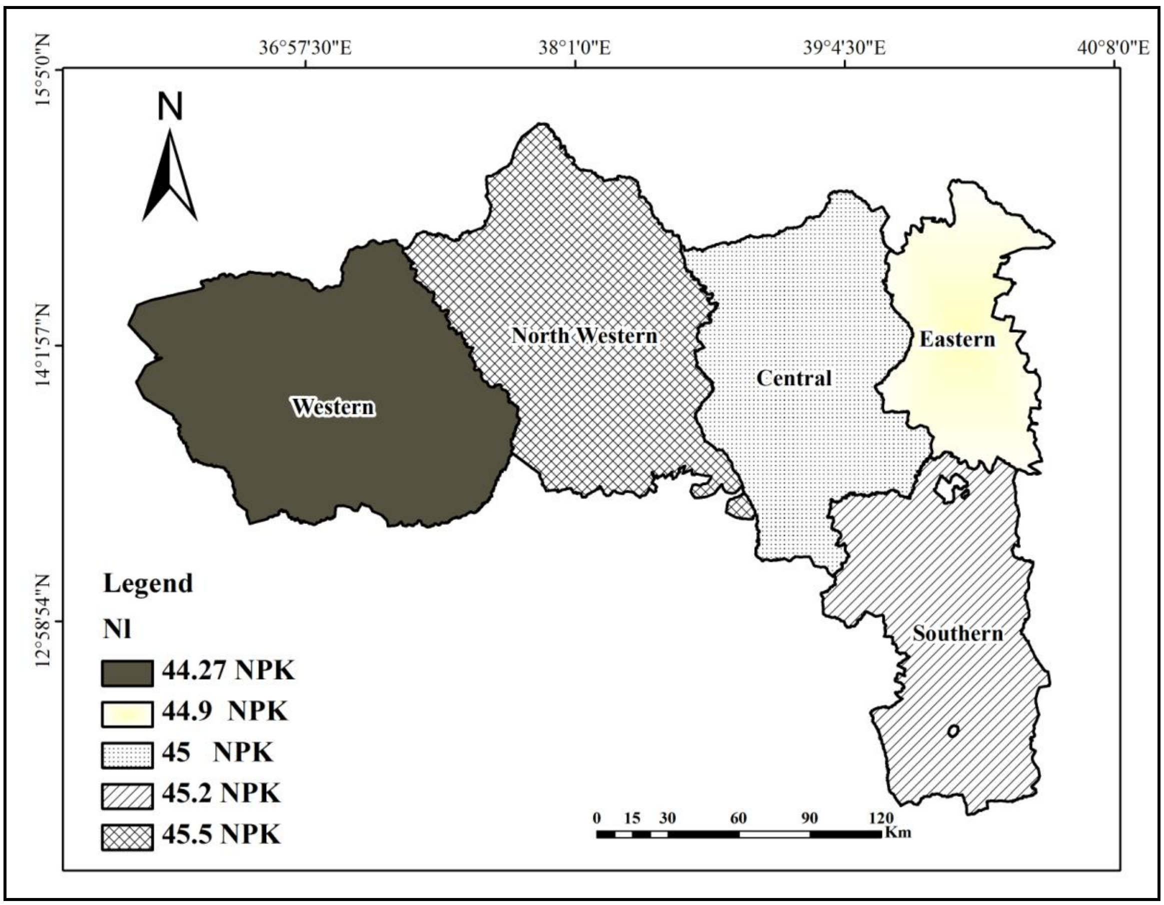

Figure 4.4 NPK outflows (kg/ha) from cereal lands of each zone due to Nl.

D. Soil Erosion (Ne)

Erosion mainly caused by wind and water, the estimate of nutrient losses due to wind erosion was ignored. It is because of, the situation of the study area and lack of necessary both primary and secondary data for estimation.

There are different ways and models used to estimate and predict soil erosion, USLE is the prominent one. However, the study used the following regression function model to adjust and predict the amount of nutrient eroded:

$$Nei = \alpha + \delta 1 + \delta 2 + \beta 1Fc + (\beta 2 + (\beta 3\ Fc)\ Cn + \in i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation5.}$$

Where: *Nei* is the percentage of nutrient loss through soil erosion in the selected crop/region; and α, δ*1* and δ*2* are parameters measuring the effects of factors that are not included in the models but characterize the Sudano-Sahelian, humid, and sub-humid regions, respectively. The parameters β*1*, β*2* and β*3* measure the effects of the soil fertility class (*Fc*) and the mineral and organic Nutrients applied (*Cn*) on the amount of nutrient eroded. The variable ∈ *i* is a random error.

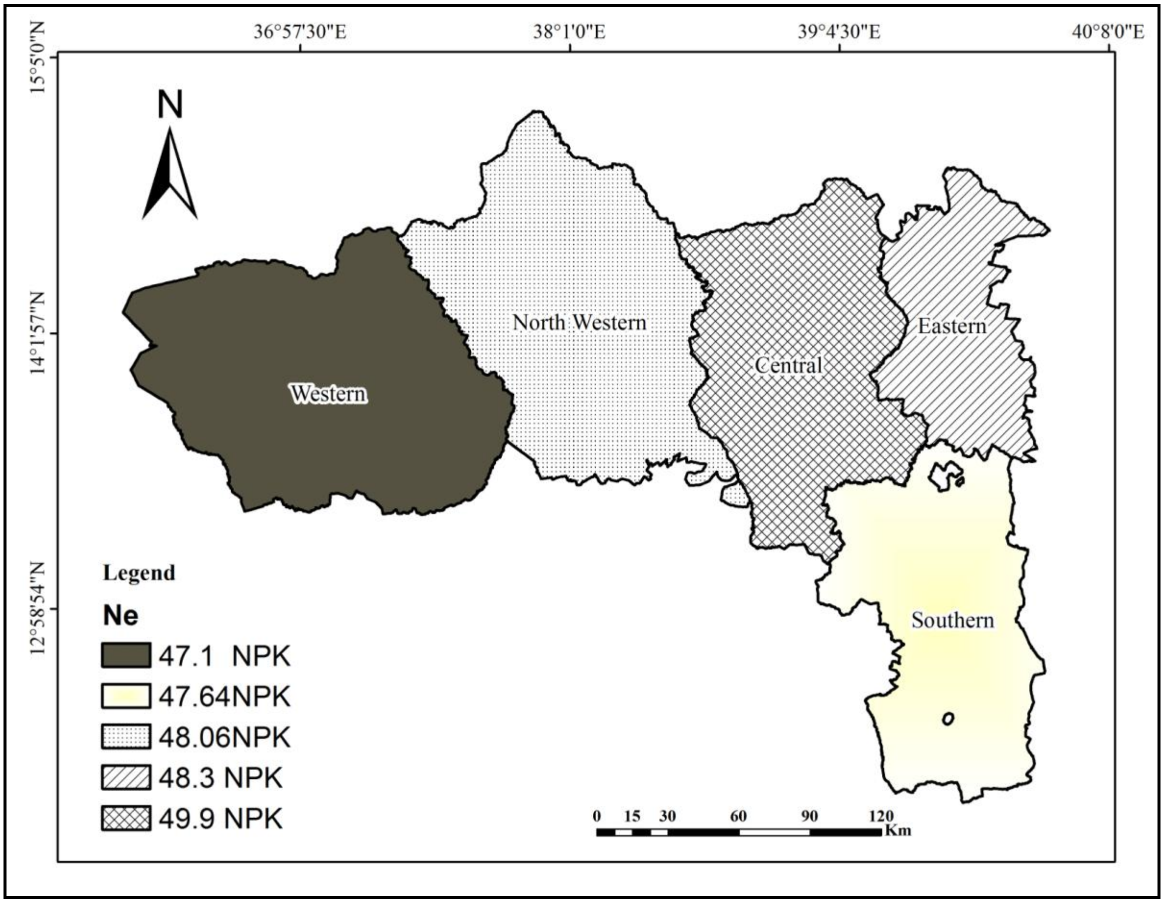

Figure 4.5 NPK outflows (kg/ha) from cereal lands of each zone due to Ne.

4.2 Assessments of Nutrient Inputs and Inflows

A. Use of Mineral Fertilizer (Mf)

There was no available data on consumption of mineral fertilizer per zone or per crop the available data was only at regional level which was obtained from Bureau of Agricultural and Rural Development of the region (see appendix 5). So it made difficult the calculation. On this condition, mineral fertilizer input was calculated per zone as a proportion of the total cereal lands of each zone with an assumption of all mineral fertilizer used for cereal crops. The amount of fertilizer applied multiplied by its nutrient content (IFDC).

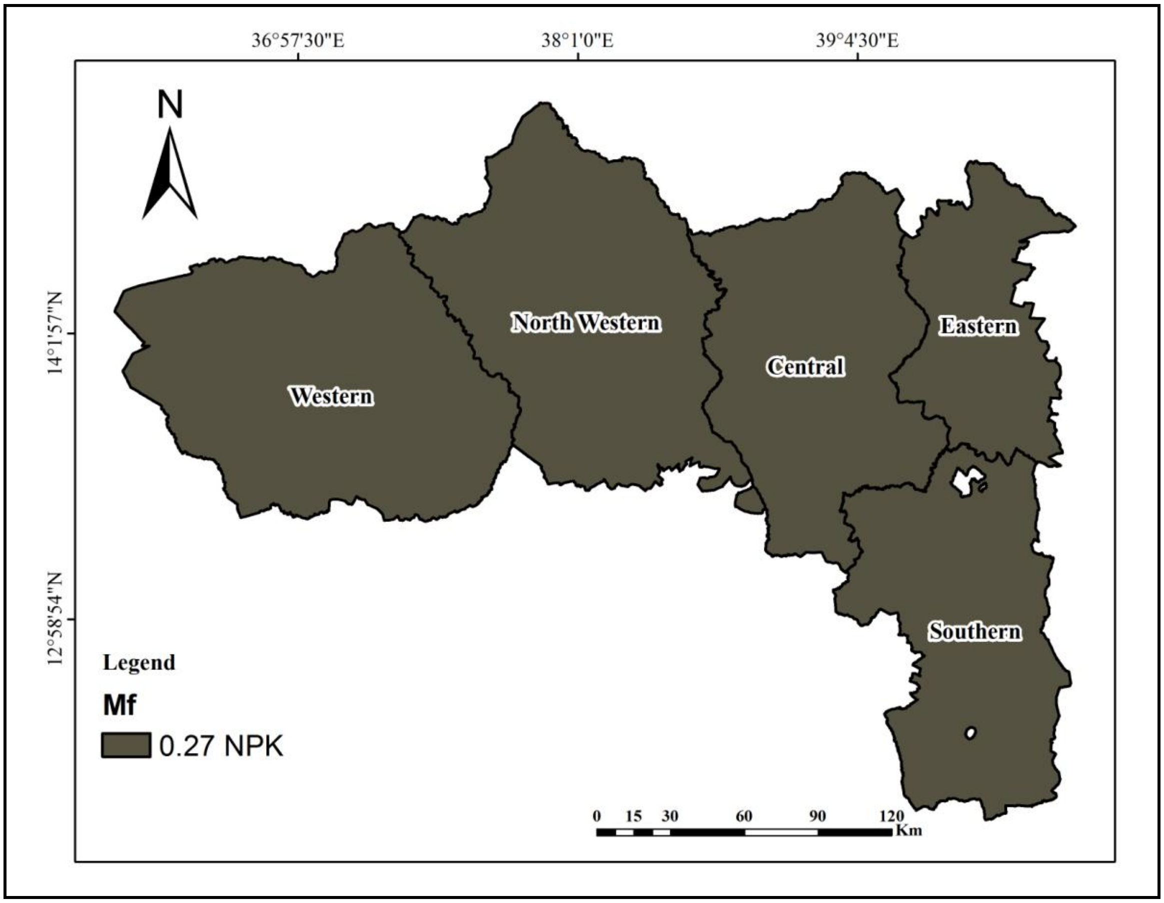

Figure 4.6 NPK inflows (kg/ha) from cereal lands of each zone due to Mf.

B. Use of Organic Fertilizer (Of)

Manure is the main organic input for most of African countries and is related to the number of livestock. The data required to calculate organic nutrient inputs mainly in the form of animal manure include**:**

- Livestock population and their species.
- Amount of manure reaching arable land, and
- Its nutrient content.

Data on total number of livestock population mainly on cattle, sheep and goat obtained from (CSA) (see Appendix 3). Since, they were the major livestock species and availability of data on them. To acquire livestock density of each species per hectare, first, the total livestock population of each species converted into tropical livestock unit as 0.70 and 0.10 for cattle and sheep/goat respectively then multiplied by 250 as TLU is equivalent to 250kg according to Jahnke et al. (1988), finally divided by the total area in hectare.

The N, P and K content of manure and the annual production per weight of fresh matter of each species was adopted from secondary source (see Appendix 2). So, the total amount of NPK from manure was calculated by multiplying livestock density by amount of excreta and nutrient content as follows:

$$\text{Of (kg/ha)} = \text{LD} \times \text{MP} \times \text{NC}$$

Where: LD = livestock density per weight per hectare.

MP = manure production per weight.

NC = nutrient content.

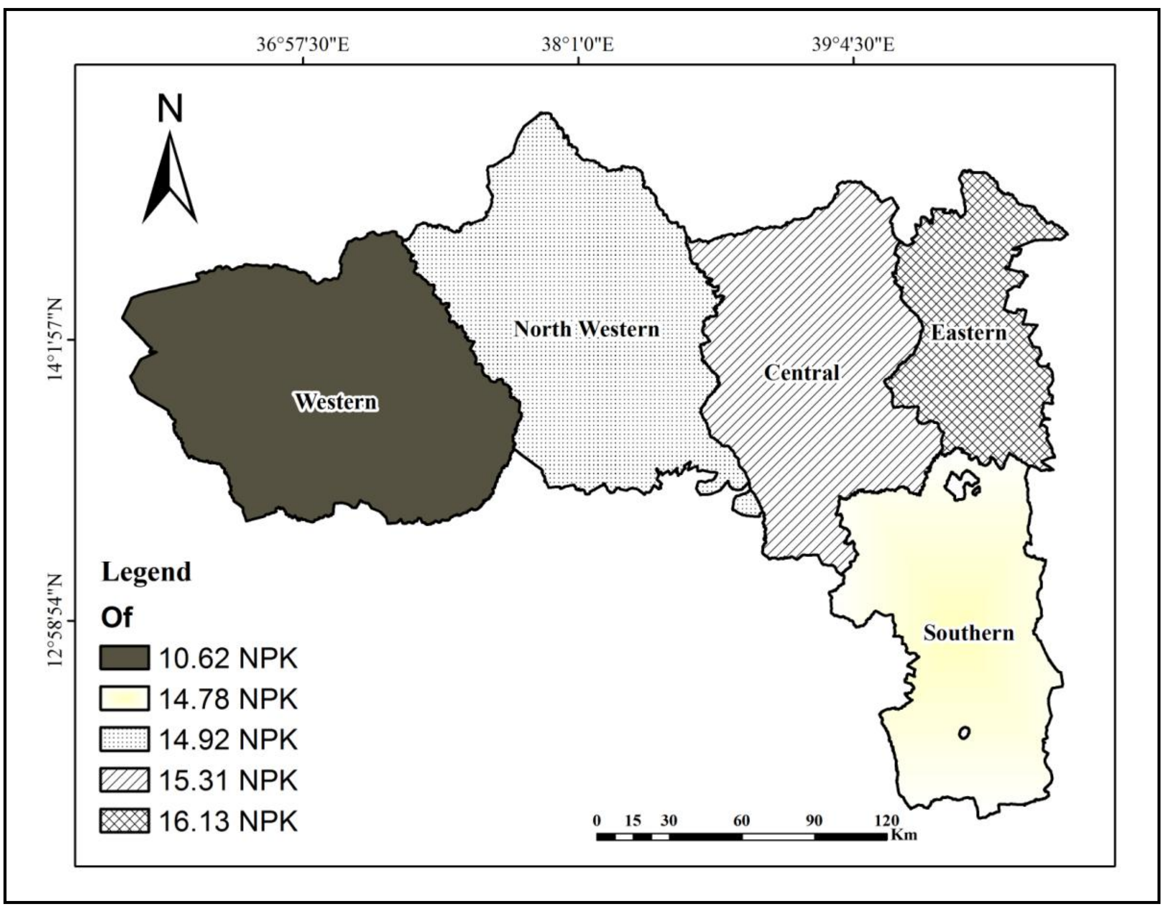

Figure 4.7 NPK inflows (kg/ha) from cereal lands of each zone due to Of.

C. Nutrient Deposition (Nd)

Although the amount of nutrients that return to the soil by deposition are difficult to estimate, the following model used to estimate nitrogen gain through wet deposition.

$$Ndi = \alpha + \delta 1 + \delta 2 + \delta 3 + \beta 1Fc + (\beta 2\ (R^{)\ 1/2} + \in i \ldots\ldots\ldots\ldots\ldots\ldots \text{equation6.}$$

Where: *Ndi* is nutrient deposition as a percentage of total nutrients; α, δ*1*, δ*2* and δ*3* are parameters of discrete variables included to account for variability due to regional factors; β*1* is the parameter measuring the effect of soil fertility on nutrient deposition; β*2* is the parameter measuring the effect of rainfall on nutrient deposition; and ∈ *i* is the error term.

In addition, the following transfer functions used to estimate the amount of P and K gains through wet deposition (Stoorvogel and Smaling, 1990).

$P = 0.053 \times R^{1/2}$.

$K = 0.092 \times R^{1/2}$ whith rainfall in mm/yr and P and K deposition/kg/yr.

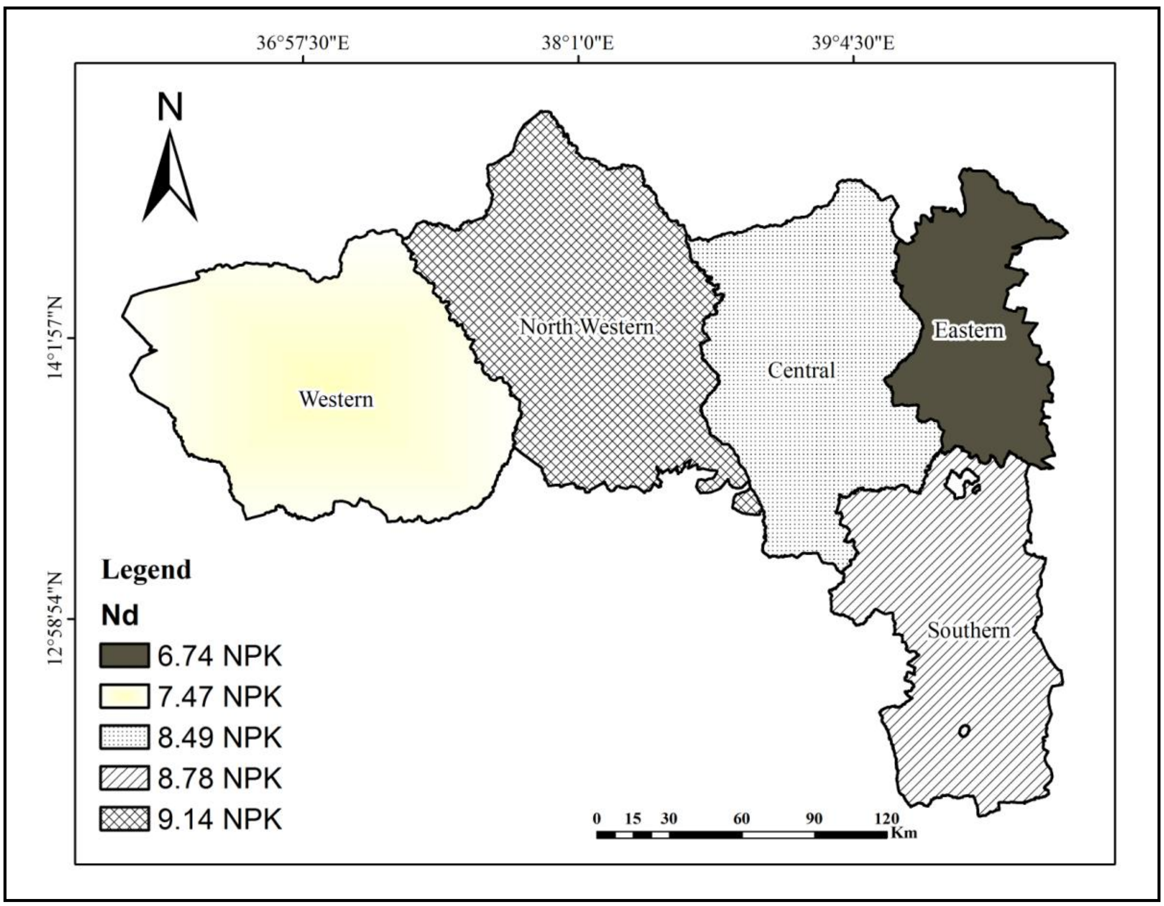

Figure 4.8 NPK inflows (kg/ha) from cereal lands of each zone due to Nd.

D. Nitrogen Inputs Due to N-fixation (Nf)

Biological nitrogen fixation is an important source of nitrogen for leguminous crops, but other crops can profit indirectly through non-symbiotic N-fixation and N-fixing trees.

Non-symbiotic N-fixation by cyanobacteria is an important process in soils under wetland rice. It estimated the contribution at 15kg N/ha/yr, which is lower than most experiments revealed, but accordingly to Giller (2001) the effect of cyanobacteria is overestimated and does not occur in all fields. It only occurs under wetland rice, for non-symbiotic and N-fixation by trees assuming a positive relationship between rainfall and N-fixation. The calculation defined as the following equation (Lesschen et al., 2007).

$N_{fixed} = 0.5 + 0.1 \times Rainfall^{½}$, with rainfall in mm/yr and N-fixed in kg/ha/yr.

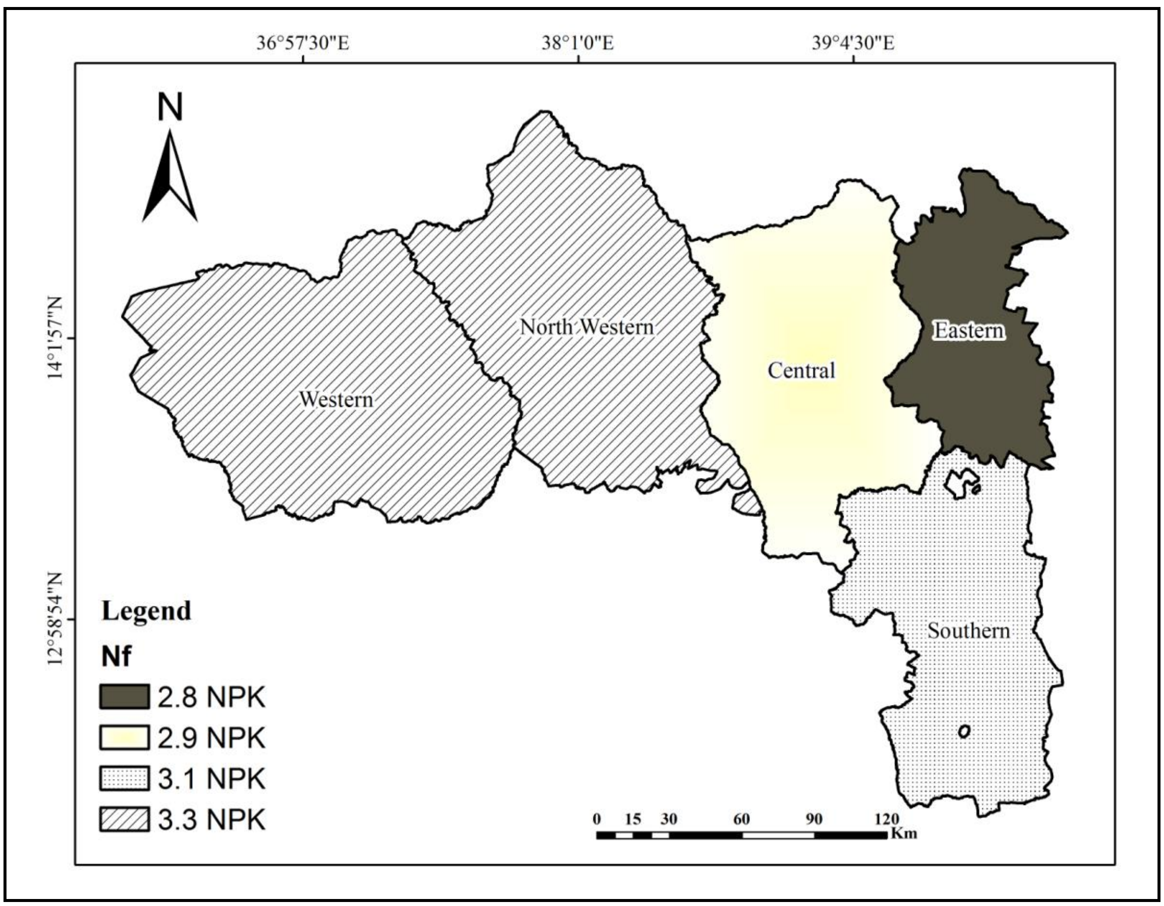

Figure 4.9 NPK inflows (kg/ha) from cereal lands of each zone due to Nf.

4.3 Assessment of Nutrient Depletion and Requirements

A. Nutrient Balance (Nb)

The quantity or rate of nutrient depletion is estimated as the difference between the amounts of nutrients exported annually from cultivated fields and the amount added or imported annually in the form of fertilizers, manure, fixation, and the physical processes of deposition. The balance of nutrient inflows and outflows (*Nbi*) per year or nutrient depletion in kilograms per hectare per year for a region (*i*) and crop (*j*) is assessed and estimated as follows:

$Nbi = \Sigma ij\ (Mfij, Ofij, Nfij) + (Ndi) - (\Sigma ij\ (Nuij, Nrij) + \Sigma i\ (Nli, Nei))$.........equation7.

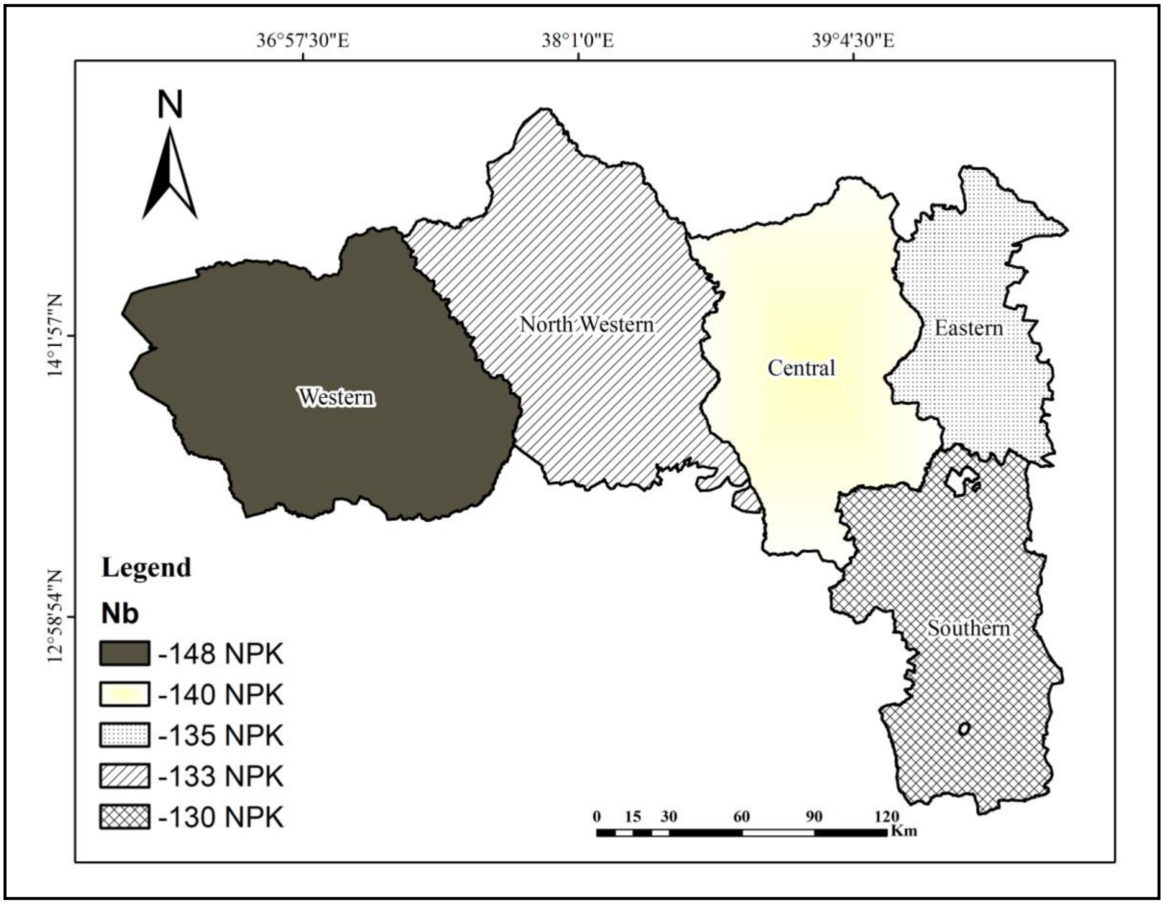

Figure 4.10 NPK nutrient balance (kg/ha) in cereal lands of each zone.

B. Nutrient Requirement (Nur)

The calculation of nutrient requirement is indicated by:

$$Nuri = \Sigma ij\,(Cpij)\,(NIj) + \Sigma ijNrij + \Sigma i\,(Nli, Nei) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation8.}$$

The nutrient requirement (*Nuri*) is calculated as the amount of nutrient uptake required to achieve a specific target yield without depleting the soil nutrient. The calculated nutrient uptake requirements are minimum requirements. A crop could take up more than Nur and this would result in increasing production or yield or improved quality of product.

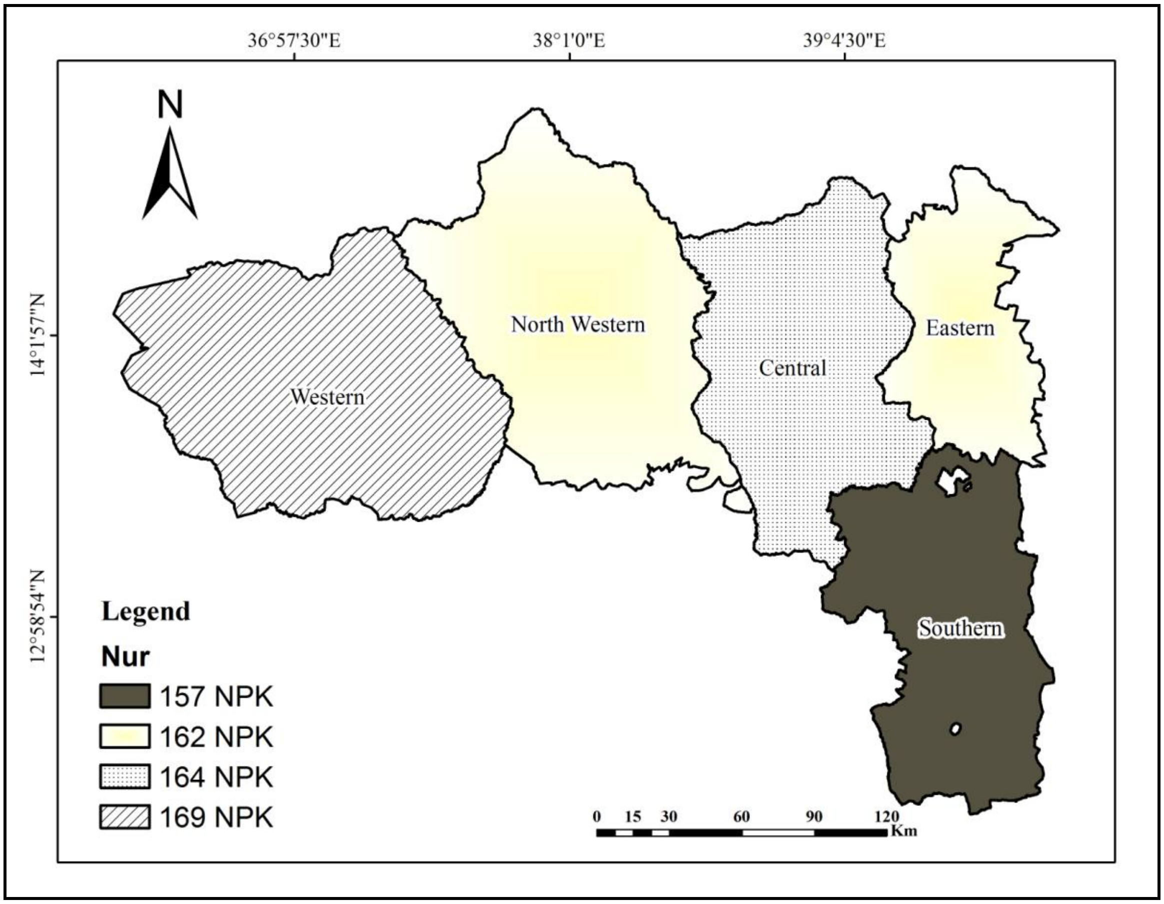

Figure 4.11 NPK nutrient requirements (kg/ha) in cereal lands of each zone

CHAPTER FIVE

5. RESULTS AND DISCUSSIONS

5.1 Inflows Over Cereal Lands of Each Zone of the Region

The major sources of N, P and K inflows in the study area were analyzed and presented in the following chart 5.1.

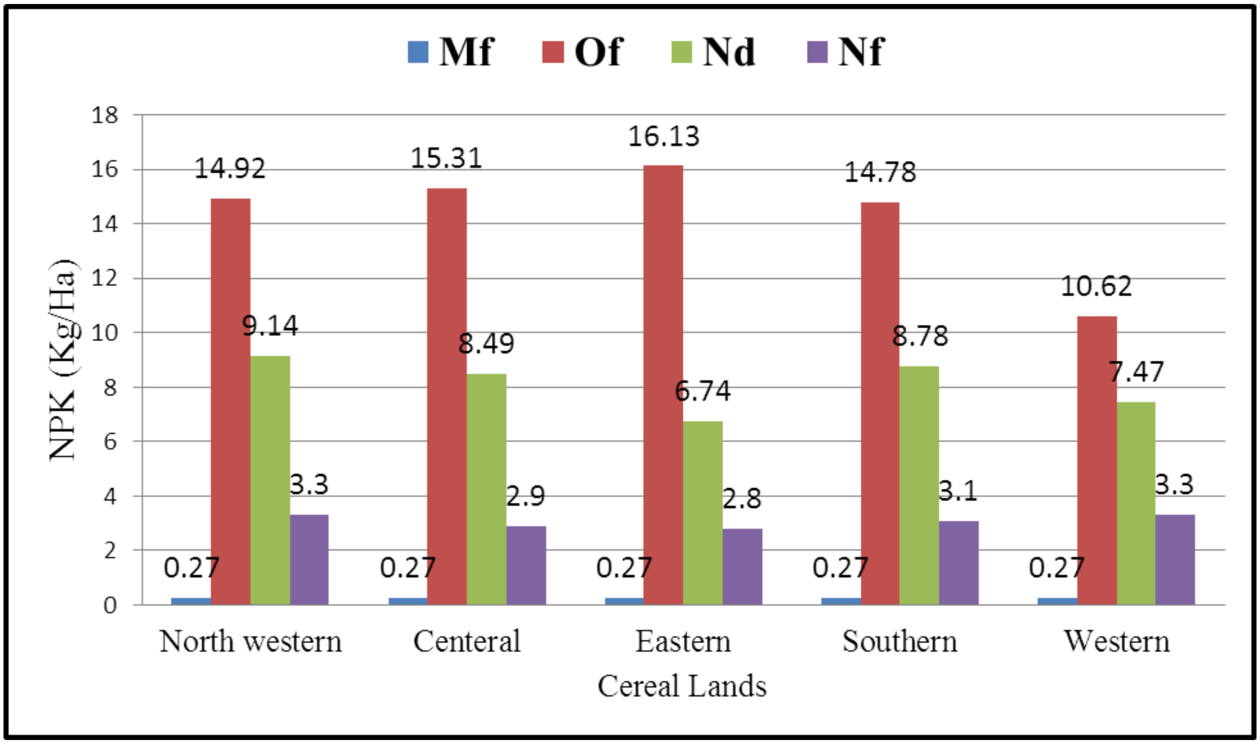

Figure 5.1 Inflows of (NPK/kg/ha/yr) in each zone of the region cereal lands.

For North Western zone, the major source of NPK inflows to the cereal land was manure (Of) it valued 14.92NPK kg/ha. The nutrient value which found from mineral fertilizer (Mf) was very small averagely 0.27NPK kg/ha. The second larger contributer of soil nutrient gain was deposition (Nd) estimated as 9.14NPK kg/ha. The contribution of N-fixation (Nf) also very small on the cereal land that was 3.3NPK kg/ha.

For all zones of cereal lands of the region the primary source of soil macro nutrients were derived from Of, the same was true for centeral zone, it valued 15.13NPK kg/ha. The lowest amount gained from Mf (0.27NPK kg/ha). Nd and Nf were second and third next to Of valued 8.49 and 2.9NPK kg/ha respectively.

For Eastern zone, similarly, inflows from mineral fertilzer had the same value for all zones of cereal lands which was not significante. Inflows from organic fertilzer, nutrient deposition and N- fixation had found defferently valued 16.13, 6.74 and 2.8NPK kg/ha respectively.

For the cereal land of southern zone, 14.78, 8.78, 3.14 and 0.27NPK kg/ha imported from organic fertilizer, deposition, biological fixation, and mineral fertilizers respectively weighted from highest to lowest.

For Western zone, the cereal land benefited from manure 10.62NPK and mineral fertilizer 0.27NPK kg/ha added to the system. Physicall process of deposition and biological process of N- fixation also contributed an estimated anmount of 7.47 and 3.3NPK kg/ha respectively to the cereal land of the zone.

Table 5.1 Summary of inflows (kg/ha) in each zone of cereal lands.

	N_ western			Centeral			Eastern			Southern			Western		
Inflows	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Mf	0.14	0.13	-	0.14	0.13	-	0.14	0.13	-	0.14	0.13	-	0.14	0.13	-
Of	7.42	1.27	6.27	7.53	1.58	6.20	7.93	1.67	6.53	7.20	1.48	6.10	5.12	1.01	4.49
Nd	4.66	1.48	3.00	4.45	1.31	2.73	2.61	1.52	2.61	4.53	1.38	2.87	2.90	1.48	3.09
Nf	3.30	-	-	2.90	-	-	2.80	-	-	3.10	-	-	3.30	-	-

5.2 Outflows Over Cereal Lands of Each Zone of the Region

Based on chart 5.2 the causes for nutrient removal from the cereal land of each zones of the region was directly related to nutrient exported by crop harvest (Nu), erosion (Ne), leaching (Nl), and crop residue (Nr) from highest to the lowest respectively. The case was true for all zones of cereal lands in the region. Each outflows described as follows:

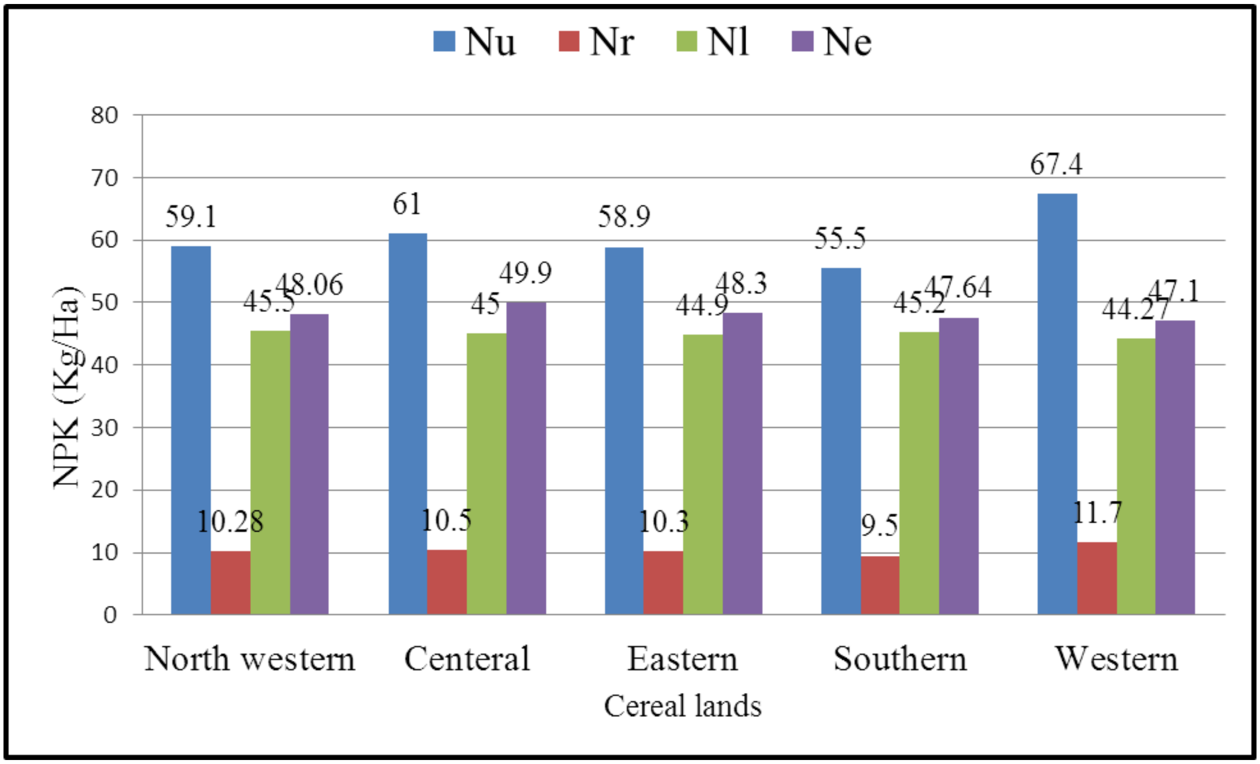

Figure 5.2 Outflows of (NPK/kg/ha/yr) in each zone of the region cereal lands

For North Western, the amount of NPK removed from the cereal land was 59.1, 48.06, 45.5 and 10.28NPK kg/ha due to Nu, Ne, Nl, and Nr respectively. The two extremes were 59.1NPK kg/ha and 10.28NPK kg/ha by crop harvest and crop residue. Both were biological causes.

The quantities of nutrient exported from the cereal lands of Centeral zones were mainly due to crop harvest, soil erosion and leaching were very huge as much as 61, 49.9, and

45NPK kg/ha respectively. In terms of relativity the amount of nutrient removed owing to crop residue was not significant which was 10.5NPK kg/ha.

Likewise, nutrient losses owing to crop harvest, soil erosion and leaching were the major causes in the cereal lands of Eastern zone, they estimated as 58.9, 48.3 and 44.9NPK kg/ha respectively. And 10.3NPK kg/ha due to crop residue.

For both Southern and Western zones of cereal lands 55.5NPK, 47.64NPK, 42.2NPK, 9.5NPK kg/ha and 67.4NPK, 47.1NPK, 44.27NPK, 11.7NPK kg/ha removal recorded as caused by Nu, Ne, Nl, and Nr respectively. The highest value (67.4NPK kg/ha) export was due to crop harvest (Nu) from the cereal land of Western zone.

Generally, the N and K losses were associated primarily with soil erosion and leaching while losses of P were associated mainly with soil erosion. Losses due to crop harvest was common for N, P and K. Details of N, P and K summerized in table 5.2.

Table 5.2 Summary of outflows (kg/ha) in each zone of cereal lands

Outflows	N_ western			Centeral			Eastern			Southern			Western		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Nu	33.2	15.5	10.4	34.4	15.5	11.1	33.4	14.6	10.9	31.2	14.0	10.3	37.9	17.2	12.3
Nr	2.7	1.28	6.3	2.7	1.3	6.5	2.6	1.3	6.4	2.4	1.2	5.9	2.8	1.6	7.3
Nl	25.2	-	20.3	24.5	-	20.5	24.5	-	20.4	24.6	-	20.6	23.8	-	20.2
Ne	17.5	13.7	16.8	17.5	13.6	16.8	17.6	13.9	16.8	17.5	13.7	16.8	17.0	13.5	16.6

5.3 Soil Nutrient Balance in the Region

Nutrient depletion rates were calculated for all cereal lands of each zone in the region (Table 5.3). The balance was negative for all zones. It was due to net negative losses between inflows and outflows. The value of nutrient balance in each zone of cereal lands explained below:

Table 5.3 Nutrient balance (kg/ha) in each zone of the region cereal lands.

Zone name	Nb (kg/ha)			
	N	P_2O_5	K_2O	Total NPK
North western	-62	-27	-44	-133
Central	-68	-27	-45	-140
Eastern	-64	-26	-45	-135
Southern	-60	-26	-44	-130
Western	-70	-29	-49	-148
Region Average	-65	-27	-45	-137

In the North Western zone, it was -62N, -27P and -44K kg/ha/yr, -68N, -27P and -45K kg/ha/yr for central, -64N, -26P and -45K kg/ha/yr for eastern, -60N, -26P and -44K kg/ha/yr for southern and -70N, -29P and -49K kg/ha/yr for western zone, it was the highest nutrient depletion compered to the previous four zones. The average nutrient depletion of the region was -65, -27 and -45 for N, P and K respectively.

5.4 Soil Nutrient Requirements in the Region

The nutrient requirement was calculated as the amount of nutrient uptake required to achieve a specific target yield without depleting the soil nutrient.

Table 5.4 Nutrient requirements (kg/ha) in each zone of the region cereal lands.

Zone name	Nur (kg/ha)			
	N	P_2O_5	K_2O	NPK
North western	78	30	54	162
Central	79	30	55	164
Eastern	78	30	54	162
Southern	75	29	53	157
Western	81	32	56	169
Average	78	30	54	163

Based on table 5.4 the following amount of N, P and K required to achieve the cereal production or yielding for the year under study without depleting the soil nutrient.

For North Western zone, 78, 30 and 54 N, P and K kg/ha required respectively; 79N, 30P and 55K kg/ha for central; 78N, 30P and 54K kg/ha for eastern. For southern and western zones 75N, 29P, 53K and 81N, 32P, 56K kg/ha required respectively. The highest amount of N, P and K were required for western zone of cereal land.

5.5 Comparison of the Study Result with Previous Studies

Soil nutrient depletion rate in arable fields of SSA by Henao and Baanante (1999) qualitatively classified into three classes high > 60, medium (30 – 60) and low < 30. Based on this classification Tigray is experiencing high depletion rate. Nutrient balance studied by FAO (2003) based on specific land/water classes showed that the nutrient depletion rate of Ethiopia at national level was -47N, -7P and -32K kg/ha in 2000. When compared the study result in Tigray region with that of results mentioned above, there was much difference in the amount but still it showed the same trend with value of -65N,

-27P and -45K kg/ha. Therefore, nutrient mining in the study area was increasing to sever level; it is very important to make corrective measures to reverse the situation urgently.

CHAPTER SIX

6. SUMMARY CONCLUSION AND RECOMMENDATION

6.1 Summary

- The major causes of outflows in the region cereal lands were harvested products, leaching and erosion respectively.
- The major causes of inflows in the region cereal lands were organic fertilizer (manure) and deposition respectively.
- The lowest negative balance estimated for southern zone as -60N, -26P and -44K kg/ha.
- The highest negative balance estimated for western zone as -70N, -29P and -49K kg/ha.
- The average nutrient depletion of the region was -65N, -27P and -49K kg/ha or -175NPK kg/ha.

6.2 Conclusion of the Study

The study result estimated that Tigray region macro-nutrient condition was in high depletion rate. Nutrient balance of N, P and K in the cereal lands of the region were negative for all zones. This was mainly owing to very low import of soil macro nutrients from chemical fertilizers (0.27NPK kg/ha) which was insignificant to restore nutrient exported from the system; relatively low macro nutrient input from organic fertilizers on one hand and enormous outflows of nutrients from the cereal lands mainly due to physical processes of leaching, erosion and that of biological processes of harvested products and crop residues on the other.

Three outflows namely, harvested cereals, leaching and erosion took the lion share of macro nutrients export from the system respectively. The two extremes of negative nutrient balances in the region cereal lands were ranged from -60N, -26P, and -44K (-130NPK) kg/ha for southern zone and -70N, -29P, and -49K (-148NPK) kg/ha for western zone. The macro nutrients depletion rate in the region of cereal lands were severe it demanded more serious integrated soil fertility management practices in order to balance the situation and to guarantee sustainable cereal production and yield.

6.3 Recommendations of the Study

- Farmers and concerned bodies should have a tendency to give more weight for the application of organic and inorganic inputs, proper management of crop residues and sustainable soil conservation measures in order to minimize the negative effect of leaching and soil erosion.
- Future related researches should take into account specific agro – ecosystem, soil type, climate and so forth factors. And also should employed improved and latest models to make more effective, efficient, valid and reliable research results.
- Other researchers in the area should try to include other inflows and outflows, in addition to the renowned five inflows and outflows developed by Stoorvogel and Smaling (1990) like organic fertilizer from household wastes, crop residue cycles, and inflows and outflows not considered in this study which include wind deposition, gaseous losses and sedimentation.
- It should also imperative to carry out soil nutrient assessment and estimations in different land use/cover in order to employ comparative studies among each land use/cover in regional level based on field experiment and reliable data sources.

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LIST OF APPENDICES

Appendix 1

Table 1 nutrient removal of crops and residues from literatures

Crop	(kg/mt)					
	N product	N residue	P_2O_5 product	P_2O5 residue	K_2O product	K_2O residue
Maize	16.1	11.9	6.3	4.4	4.8	17.3
Barley	15.8	6.3	5.8	1.8	8.3	20.6
Wheat	22.3	6.4	11.1	2.8	5.6	24.2
Sorghum	15.3	10.2	7.5	3.8	3.8	18.2
Millet	17.4	6.5	8.7	8.8	6.5	21.8
Teff	17.3	6.1	7.8	4.3	5.8	20.4

Source: Henao and Baanante (1999).

Appendix 2

Table 2 Percentages of nutrient content of manure in fresh weight and excretion.

Livestock type	N (%)	P (%)	K (%)	Excretion*
Cattle manure	0.78	0.15	0.67	6.2
Sheep/goat	0.79	0.20	0.50	7.2
poultry	1.08	0.39	0.35	7.8

**excretion in kg fresh matter per kg weight per year.*

Source: Leschen et al. (2007).

Appendix 3

Table 3 Livestock population and densities in each zone of the region 2010/2011.

Tigray zones	Livestock species	Total population	Livestock density (kg/ha)
North western	Cattle	975, 646	0.77
	Sheep	70, 710	0.06
	Goat	907, 385	0.71
Central	Cattle	732, 701	0.70
	Sheep	287, 625	0.28
	Goat	993,935	0.96
Eastern	Cattle	405, 097	0.73
	Sheep	518, 835	0.93
	Goat	240, 341	0.43
Southern	Cattle	699, 559	0.75
	Sheep	269, 098	0.29
	Goat	398, 503	0.43
Western	Cattle	817, 952	0.61
	Sheep	109, 135	0.08
	goat	509, 322	0.38

Source: (CSA, 2011).

Appendix 4

Table 4 Cereal yields in quintal/ha in each zone of the region in 2010/2011.

Tigray zones	Cereals	Yield quintal/ha
North western	Teff	10.46
	Wheat	19.16
	Maize	25.93
	Barley	13.43
	Sorghum	22.17
	Finger millet	15.23
Central	Teff	13.72
	Wheat	20.06
	Maize	22.76
	Barley	17.25
	Sorghum	23.48
	Finger millet	15.24
Eastern	Teff	12.95
	Wheat	19.61
	Maize	20.64
	Barley	18.39
	Sorghum	22.86
	Finger millet	15.78
Southern	Teff	12.50
	Wheat	18.54
	Maize	21.64
	Barley	18.14
	Sorghum	15.28
	Finger millet	16.21
Western	Teff	14.13
	Wheat	18.38
	Maize	24.77
	Barley	17.24
	Sorghum	25.93
	Finger millet	24.26

Source: (CSA, 2011).

Appendix 5

Table 5 Fertilizer distribution in the region and zones in 2010/2011.

Region and zones	Cereal lands (ha)	Fertilizer distribution		source
		Dap (kg)	Urea (kg)	
Tigray	713, 491	210, 547	142, 249	Regional bureau of agriculture
North western	168, 287	49, 660	33, 550	Own estimation
Central	201, 238	59, 384	40, 120	Own estimation
Eastern	85, 169	25, 132	16, 980	Own estimation
Southern	198, 863	58, 683	39, 647	Own estimation
Western	59, 933	17, 686	11, 948	Own estimation

Source: (BoRAD).

D E C L A R A T I O N

I hereby declare that the thesis entitled. ***Estimating Soil Nutrient Balance of Cereal Lands of Tigray Region, Northern Ethiopia*** has been carried out by me under the supervision of Dr. Assefa Abegaze, Department of Geography and Environmental Studies, Addis Ababa University, Addis Ababa during the year 2013/14 as a part of Master of Art in Geography and Environmental studies specialized on Land Resource Management. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

ABRHAM BELETE ASSEFA

Signature: ________________________

Addis Ababa University

Addis Ababa

Date: June, 2014

C E R T I F I C A T E

This is certified that the thesis entitled ***Estimating Soil Nutrient Balance of Cereal Lands of Tigray Region, Northern Ethiopia***. is a bona fid work carried out by Abrham Belete Assefa under my guidance and supervision. This is the actual work done by Abrham Belete Assefa for the partial fulfillment of the award of the Degree of Master of Art in Geography and Environmental studies specialized on Land Resource Management from Addis Ababa University, Addis Ababa, Ethiopia.

Dr. Assefa Abegaze

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