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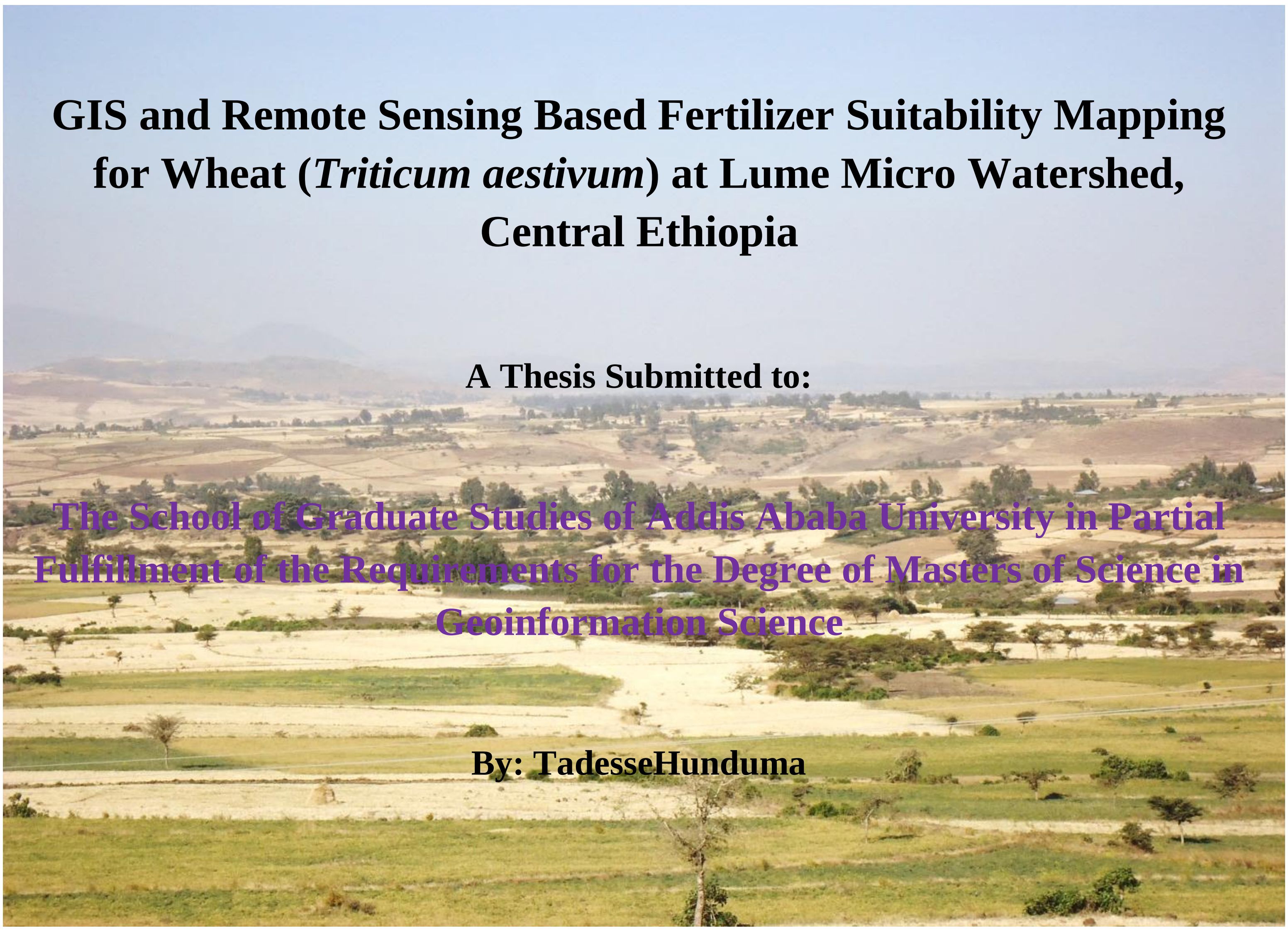
School of Graduate Studies
Department of Earth Sciences



GIS and Remote Sensing Based Fertilizer Suitability Mapping for Wheat (*Triticum aestivum*) at Lume Micro Watershed, Central Ethiopia

A Thesis Submitted to:

The School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Geoinformation Science

By: TadesseHunduma

Advisor: Dr. K.V. Suryabhagavan

March, 2012

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ADDIS ABABA UNIVERSITY
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GIS AND REMOTE SENSING BASED FERTILIZER SUITABILITY MAPPING FOR WHEAT (*Triticum aestivum*) AT LUME MICRO WATERSHED, CENTRAL ETHIOPIA.

A Thesis Submitted to the institute of Earth and planetary science of Addis Ababa University. In Partial Fulfillment of the Requirements for the Degree of Master of Science in Geoinformation Science

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List of Abbreviations

AHP	Analytical Hierarchy Process
ANOVA	Analysis of Variance
CR	Consistency Ratio
CV	Coefficient of variation
CSA	Central Statistical Agency
DAP	Diammonium phosphate
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resource Data Analysis
EROS	Earth Resources Observation Systems
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization of the United Nations
GCPs	Ground Control Points
GDP	Gross domestic product
GIS	Geographical Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
IFPRI	International Food Policy Research Institute
LSD	Least Significance Difference
LQ	Land Quality
LU/LC	Land use / Land cover
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
MCE	Multi-Criteria Evaluation
NASA	National Aeronautics and Space Administration
NMSA	National Metrological Service Agency
PCM	Pairwise Comparison Matrix
SLC	Scan Line Corrector
SMCDM	Spatial Multi-Criteria Decision Making
SRTM	Shutlle Radar Topographic Mission
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WOA	Weighted Overlay Analysis

ABSTRACT

Fertilizer suitability mapping is the way of determining fertilizer demanded by specific crop type on the basis of soil sample testing results. It is a very important method for modern precision agriculture to increase fertilizer use efficiency and environmental friendliness. Hence, in order to make efficient fertilizer application for wheat at Lume Micro Watershed, the study tried to map the plant macro nutrients, physical land suitability map and diammonium phosphate (DAP) suitability map for wheat. Starting from soil sample collection, laboratory analysis, spatial interpretation and mapping, standard analysis methods and GIS and remote sensing tools were used. The soil factors (drainage, depth, texture, pH, organic carbon, and phosphorus), temperature, rainfall, slope, elevation and land use/cover were considered in land suitability evaluation for wheat. In addition multi criteria evaluation was also used to generate values of relative influence for each factor of the objective. The diammonium phosphate suitability map was made by determining phosphorus critical level for wheat in the reference to initial soil phosphorus level in the soil. Finally by applying Krignig interpolation diammonium phosphate suitability was mapped for wheat. The potassium level in the study site is about 221.53 to372.11ppm.Total nitrogen and organic carbon are used as indicators of nitrogen in soil which is very low in the study area. The available phosphorus level in the study area ranges from very low, low, moderate to high level which demand variable rates of fertilizer requirement application. Initial land suitability for wheat is 9.45% highly suitable, 85.8% moderately suitable, 3.21% marginally suitable and 1.54% permanently not suitable. The diammonium phosphate requirement map of the area reveals that about 51.38%, 20.25%, 18.40% and 8.43% need 50 to75 kg/ha, 75 to 100kg/ha, 25 to 50kg/ha and greater than 100kg/ha respectively. The results are further verified by using soil sample points and their available soil phosphorus compared to diammonium phosphate suitability map and initial wheat suitability map. The validation revealed that the result is in good conformity with the actual soil available phosphorus.

Keywords: Diammonium phosphate, Fertilizer requirement, GIS and Remote Sensing, Land suitability, plant macronutrient, Multi criteria evaluation and Wheat

1. INTRODUCTION

Agriculture is one of the world's most important activities supporting human life and it is in a continuous dynamics changing from ancient archaic system to the present precision agriculture. On a global scale, agriculture has the proven potential to increase food supplies faster than the growing demand, a pattern to be expected in the foreseeable future (Davidson, 1992). By the year 2025, 83 % of the expected global population of 8.5 billion is expected to live in developing countries. Yet the capacity of available resources and technologies to satisfy the demands of this growing population for food and other agricultural commodities remains uncertain (FAO, 1993). There is food insecurity in Africa and especially in sub-Saharan Africa. While the aggregate global food supply/demand picture is relatively good, there will be worsening food insecurity in sub-Saharan Africa (FAO, 1993).Until 2025, food production must grow by at least 40% to meet the needs of a 33% increase in population and to satisfy the trends for improved nutrition (Bos *et al*.,2005).

The total Gross Domestic Product (GDP) share of Ethiopia was mainly agricultural which was about 48%, however in recent years the share is exceeded by the service sector it is leading in foreign exchange and employment accommodation (htt://www.accesscapitalsc. com).Ethiopia is expected to feed more than 80 million people, although the agricultural production is tending to be highly dependent on the chemical fertilizers in recent years, it indicates the trend of increasing fertilizer inputs from 2008 - 2010 (CSA, 2010).

Even though Ethiopia faces a wider range of soil fertility issues beyond chemical fertilizer use, it has historically been the major focus for extension workers, researchers, policymakers, and donors. The fertilizer recommendation was blanket, which is not site specific and soil test based but based on out dated very general rate over the whole country. If left unchecked, this wider set of issues will limit future agriculture production across the country. These chemical, physical, and biological issues interact and include loss of organic matter, macronutrient, and micronutrient depletion, topsoil erosion, acidity, salinity, and deterioration of other physical soil properties. In addition, Ethiopia has soil types with inherent characteristics which can be problematic for crop production and which need special management (IFPRI, 2010).

In contrast the current status of soil fertility research is not such as enough to have comprehensive and more accurate conclusion on national, regional and even local level due to its data collection, location mapping and analysis methods and biasedness associated to experimental site selection in the previous soil research outputs. The past soil and other agricultural research including adaptation trials use personal or expert judgment to have flat, less erosion susceptible and suitable agro ecologic zonation and major potential test crop selection.

To have sustainable production in agriculture the nutrient added to soils and removed should be known in relation to its site specific and geographic units. But there is very low soil research outputs and fertilizer recommendation guide line to have balanced nutrient utilization in the soil. To alleviate these problems the National Soil Research of Ethiopia has proposed soil test based fertilizer recommendation calibration study, which has being conducted by seventeen soil laboratories found overall the country. Among these Laboratories Oromia region has four soil test laboratories mandated for these research. Even though they conducted this research since 2002, there are no generalized site specific fertilizer recommendation rates developed for not only the region but also district level. The dependability of the outputs was very vague. These researches are planned to have efficient, balanced and representatives areas of application that are at micro, meso and macro level, But the site selection of experimental plots are personal based, erosion soil loss assessment and distances from main road ,settlements and rivers and soil types are solely personal based or manual agro ecological zonation and suitability assessments. In addition to this the test crop selection should not be simple expert judgment without using any computerized tools. Hence the outputs of the research are not enough to give farm, local, regional and national level conclusions of fertilizer and any other technology recommendation (IFPRI, 2010).

In developed countries, modern agricultural management practices are changing from assuming homogenous fields to attempting to address field variability by dividing the field into smaller zones and managing these zones separately. Precision farming which is the gathering of information dealing with spatial and temporal variation within a field and then using that information to manage inputs and practices (Alan *et al*., 2009).

In order to improve the accuracy, reduce time consuming and reducing personal biasedness application of GIS and Remote Sensing tools are crucial in soil fertility assessment for primary nutrients like potassium, nitrogen and phosphorus. Ethiopian soil fertility is constrained from many factors therefore the sustainable production is also in problem .The GIS application helps in situation where integrated soil fertility management research outputs faster than the traditional research practices. These could be brought to real through application of GIS and remote sensing tools particularly, spatial analyst tool interpolation like Inverse Distance Weighted (IDW) and Kriging for point data to coverage and the image analysis techniques. Therefore this research is designed to solve the problem of blanket fertilizer recommendation with the following objectives:

Objectives

General

- To prepare map of fertilizer requirement for wheat at Lume micro watershed

Specific

- To prepare available phosphorus, total nitrogen and potassium map for the study area
- To evaluate land suitability for wheat(*Triticum aestivum*) production
- To prepare Diammonium phosphate (DAP) suitability map for the wheat crop.

2. LITERATURE REVIEW

2.1.Precision Agriculture

Modern agricultural management practices are changing from assuming homogenous fields to attempting to address field variability by dividing the field into smaller zones and managing these zones separately. Precision farming can be defined as the gathering of information dealing with spatial and temporal variation within a field and then using that information to manage inputs and practices (Robert *et al*., 2009).

Precision farming basically depends on measurement and understanding of variability, the main components of precision farming system have to address the variability. According to (Patil *et al*., 2005) there are three basic steps in precision farming; Assessing variation, Managing variation and Evaluation. The available technologies enable understanding the variability and help in giving site specific agronomic recommendations. That means, it is possible to manage the variability that makes precision agriculture viable. And finally evaluation must be an integral part of any precision farming system. Precision farming technology enabled, information based and decision focused, the components include; Remote Sensing, Geographical Information System (GIS), Global Positioning System (GPS), soil testing and yield monitors and variable rate technology.

2.1.1. Role of GIS and Remote Sensing in Precise Agriculture

Recently, use of GIS in agriculture has increased because of misuse of resources like land, water, etc. GIS is the principal technology used to integrate spatial data coming from various sources in a computer. GIS techniques deal with the management of spatial information of soil properties, cropping systems, pest infestations and weather conditions. This is primarily an intermediate step because it combines the data collected at different times based on sampling regimes, to develop the subsequent decision technologies such as process models and expert systems (Robert *et al*., 2009).

Because precision farming is concerned with spatial and temporal variability and it is information based and decision focused. It is the spatial analysis capabilities of GIS that enable precision agriculture. GPS, DGPS has greatly enabled precision farming and of great importance to precision farming, particularly for guidance and digital evaluation modeling position accuracies at the centimeter level are possible in DGPS receivers.

More advancement had been made in USA to the field level computer farming for fertilizer application and yield harvesting and sensors for soil nitrogen. This is made possible by linking computers, on-the-go sensors, Global Positioning Systems (GPS), and other devices (Alan *et al*., 2009). The geographic information system (GIS) created by computing background makes possible to generate complex view about our fields and to make valid agro technological decisions (Nemenyi*et al.*, 2003).

2.2. Status of Soil Fertility Research in Ethiopia

2.2.1. Soil fertility knowledge and research

Data on soil fertility that farmers are using for fertilizer application rate in Ethiopia is largely out-of-date at the national level and is very locally specific, fragmented, and difficult to access at the local level meaning that it would take significant time and effort to obtain an actionable view of the current soil status. There is no centralized source of soil data or soil research, although early stage efforts to establish such a source are underway through the Ethiopian Institute of Agricultural Research (EIAR) and the National Soil Laboratory. Regional Research Institutes and national and regional soil laboratories exist. These have seen progress in terms of resources and output, and are currently carrying out research on various areas of soil and water management, fertilizer recommendations, management of problematic soils, and other relevant areas. However, much of this knowledge is specific to particular areas selected for study and currently cannot be compiled, compared, or accessed at a national level to enable policymakers and other stakeholders to draw conclusions on the status of soil in Ethiopia as a whole and its implications for food production. Moreover, there is potential for more networking of soil scientists across Ethiopia and internationally to ensure access to the latest literature to guide research, and to avoid reinventing the wheel .The last major surveys of macronutrient status across the country were conducted in the 1950s to 60s, first at the Alemaya College of Agriculture (IFPRI, 2010).

Current fertilizer recommendations deal with N and P dosage only, and are at least 15 years old, and are largely standardized for the country. In other words, they are specified for major crop groups but do not take into account agro ecological variation.

Some studies were done by Institute of Agricultural Research at Holetta, Werer, and Bako research centers. These studies did identify major soil problems such as erosion and inadequate water conservation, drainage, and irrigation; however, the most comprehensive findings of these studies were on macronutrient levels.

Since the FAO studies from the 1980s, no further major soil mapping or surveys have been carried out at a national level. As a result, the major soil fertility issues are currently only understood at a high level. Key parameter required include soil physical characteristics, pH, organic matter content, topsoil thickness, macro and micro-nutrient levels, and salinity levels. Recommendations for liming acid soils are particularly lacking. Regional calibration efforts are underway through MoARD and EIAR's regional centers, currently not completed. What limited data is available suggests that the current outlook is far from positive: Even in 1986, 24 percent of Ethiopia's soil faced moderate to very severe fertility constraints, affecting key farming regions.FAO (1998); Eyasu Elias (2002); Amare Haile *et al*.(2005) indicated that this has more than likely worsened after 24 years with little soil fertility management (such as the use of fertilizer or manure or good practices like fallowing or crop rotation), high rates of soil erosion, and high population growth and increasing population density in the highlands.

2.2.2. Macronutrients in plants

There are at least sixteen essential chemical elements for plant growth. Carbon, hydrogen, and oxygen, obtained in large amounts from air and water, make up the bulk of plant dry matter in the products of photosynthesis, but usually are not included as "nutrient" elements. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl) are obtained from the soil and required by all plants. Sodium, silicon, and nickel are essential elements for some plant species and, although not required, have positive or beneficial effects on the growth of other species. Cobalt is essential for nitrogen fixation by legumes. Additional elements, such as selenium and iodine, are not required by plants, but can be important in plant nutrition because they are essential nutrients for humans and other animals that consume plants (Peter and Carl, 2005).

All essential nutrients are equally important for healthy plant growth, but there are large differences in the amounts required. N, P, and K are primary macronutrients (Samuel *et al*., 2003).

2.2.3. Plant Growth Limiting Nutrients

Every plant species has particular conditions where they will flourish. There are various physical factors that affect the growth rate of plants; however, all plants share one universal growth limiting factor. Minimally stated it is the rate of any growth process controlled by two or more factors is limited by the factor in least supply. Most Ethiopian soils including Vertisols are deficient in P when analyzed by chemical methods, yet, with the addition of P fertilizers, field crop P responses on these soils, particularly in the central highlands are low, even under improved drainage conditions (Tekalgn Mamo *et al*., 1993).Next to N, P is usually the most limiting nutrient, but responses to P fertilizers are variable. Though P content varies from region to region, Fassil Kebede and Charles (2009) revealed that the available P content is very low, ranging between 0.43 ppm in Shire 1.95 ppm in Adwa. Responses to added P are usually lower in Vertisols of basaltic origin because of their higher P status than those developed on granites and sedimentary parent materials.

2.2.4. Role of GIS and Remote Sensing in Soil Fertility Mapping

The role of GIS and remote sensing in soil fertility is very vast starting from soil sample collection using GPS, interpolation of sampled points and generation of soil fertility management tool boxes. Detailed soil spatial and attribute information is required for many environmental modeling and land management applications (Jury, 1985; Beven and Kirkby, 1979; Burrough, 1996; Corwin *et al.,* 1997). Soil information products derived through the GIS and remote sensing are of high quality in terms of both level of spatial detail and degree of attribute accuracy. The technology shows promise for improving the efficiency of soil survey and subsequent updates through reducing time and costs of conducting a soil survey (Zhu *et al*., 2001).

Soil variation is a spatial variable. Water-holding capacity or organic matter variation, along with topography, provides even a more interesting view of a field in which a producer places inputs or disturbs the soil. Other variables could be layered within this field to create a series of interacting elements. The central question is how to quantify soil variation.

Wollenhaupt *et al*.(1997) provided a detailed summary of soil sampling and interpolation techniques that potentially could be used to quantify soil variation. They defined these sampling methods as judgmental sampling, simple random sampling, stratified sampling, cluster sampling, nested or multistage sampling, systematic sampling, stratified systematic unaligned sampling, and search sampling.

Soil survey constitutes a valuable resource inventory linked with the survival of life on the earth. The technological advancements in the field of remote sensing and Geographical Information System have been a boom for soil surveys by mapping and characterizing soils at various scales (Manchanda *et al*., 2002).

2.3. Multi Criteria Decision Making

Decision analysis can be defined as a set of systematic procedures for analyzing complex decision problems. Differences between the desired and the actual state of real world geographical system is a spatial decision problem, which can be approached systematically by means of multi-criteria decision making. Many real-world spatially related problems give rise to geographical information system based multi-criteria decision making. Geographical information systems and multi-criteria decision making have developed largely independently, but a trend towards the exploration of their synergies is now emerging (Samo and Anka, 2009).

Multi-criteria decision-making problems can be classified on the basis of the major components of multicriteria decision analysis: multi-objective decision making (MODM) versus multi-attribute decision making (MADM), individual versus group decision-maker problems, and decision under certainty versus decision under uncertainty. The distinction between MODM and MADM is based on the classification of evaluation criteria into attributes and objectives (Malczewski, 2004).

3. MATERIALS AND METHODS

3.1.Description of the Study Area

The study area is located in Lume district which is found in Mojo watershed of upper Awash basin. The geographical extent of Lume micro watershed ranges from $8^o38'42''$ to $8^o48'29''$N and $39^o6'54''$ to $39^o14'32''$E. Its area coverage is 151 km^2 and its map is indicated in figure 1.The total area of Lume micro watershed is found in the Lume district of East Showa zone of Oromia regional state central Ethiopia.

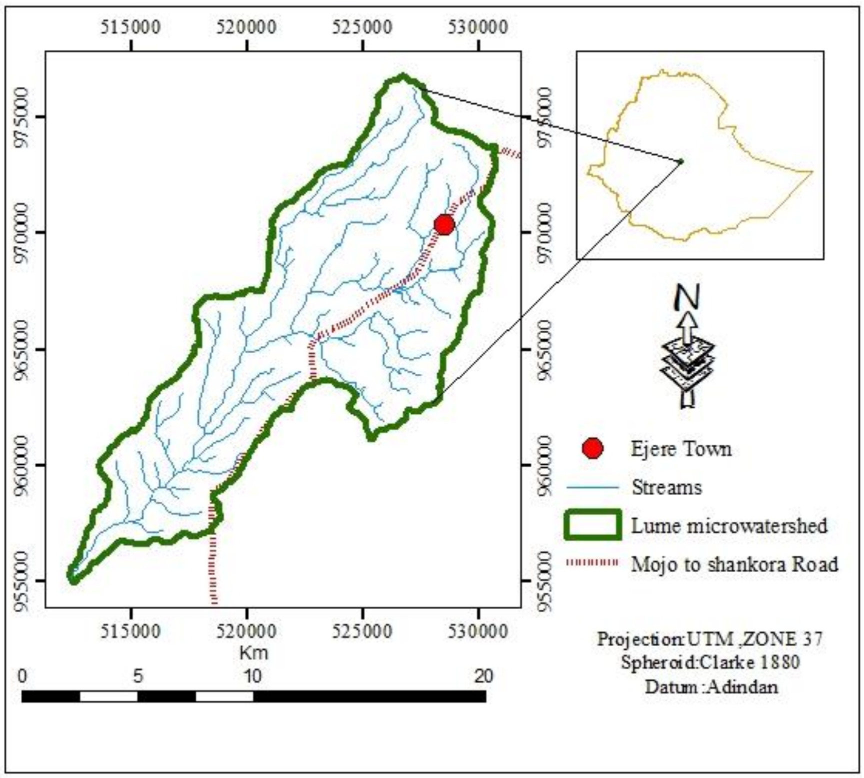

Figure1. Location map of Study Area

3.1.1. Soils

Soil is defined by (Davidson, 1980) as a natural body consisting of layers or horizons of mineral and / or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biologicalcharacteristics.Table1 shows the proportion of soil types in the study area, which is mainly dominated by EutricVertisol accounts about 86% of the area.

Table1. Soil Types

No.	FAO Soil class name	Area(km^2)	Area(%)
1	VerticCambisols	3	2.00
2	EutricVertisols	129	86.00
3	HaplicLuvisols	19	12.00
Total		151	100.00

3.1.2. Climate

Climate of an area includes the combination of temperature and rainfall at different extent, which further may be subdivided to evapotranspiration, relative humidity, sunshine hours and etc. In this study only the major two factors rainfall and temperature is discussed and used for the objective of the research directly.

3.1.2.1. Rainfall

Lume micro watershed is generally characterized by semi-arid and sub-humid climate based on the moisture index classification of climate (Lemma Gonfa, 1996). The long term average seasonal (June -September) rainfall which influence the rain fed agricultural practices of the year, the area receives total seasonal rainfall which ranges from 571.86 to 920.44 mm. The minimum monthly average rainfall of 2.70 mm was recorded at Mojo station month of December and maximum monthly average rainfall of 276.07 mm at the same station month of July. The mean monthly rainfall of five stations within and nearest to the study area were calculated from the 20 years of data from 1999 to 2009, which was collected from National Meteorological agency (NMA) and shown in figure 2.

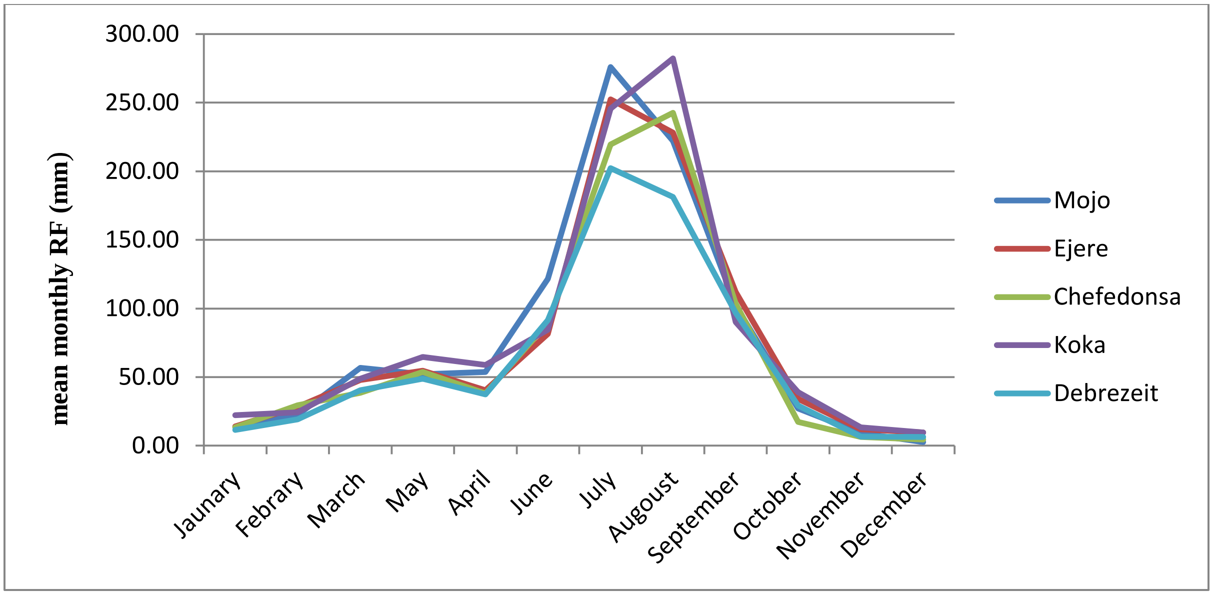

Figure 2.Monthly rainfall of five stationswith in and nearestto watershed

3.1.2.2. Temperature

Climate influences the physical and cultural environments, the types of vegetation, animals reared and crops to be grown, the land use patterns and ultimately the economy. Agricultural activities and land use patterns are closely related to the temporal and spatial patterns of climatic elements and success of land use strongly. Figure 3 shows the monthly minimum and maximum temperature of four stations within and nearest to Lume micro watershed. The maximum mean monthly temperature of 32.13^{o}C is recorded at Koka dam station in month of April whereas the lowest minimum mean monthly temperature of 6.86^{o} C was recorded at Chefedonsa station in month of December. The wheat growth is influenced by total daily mean heat accumulated, which is related to the daily mean temperature (White *et al.*, 2001).

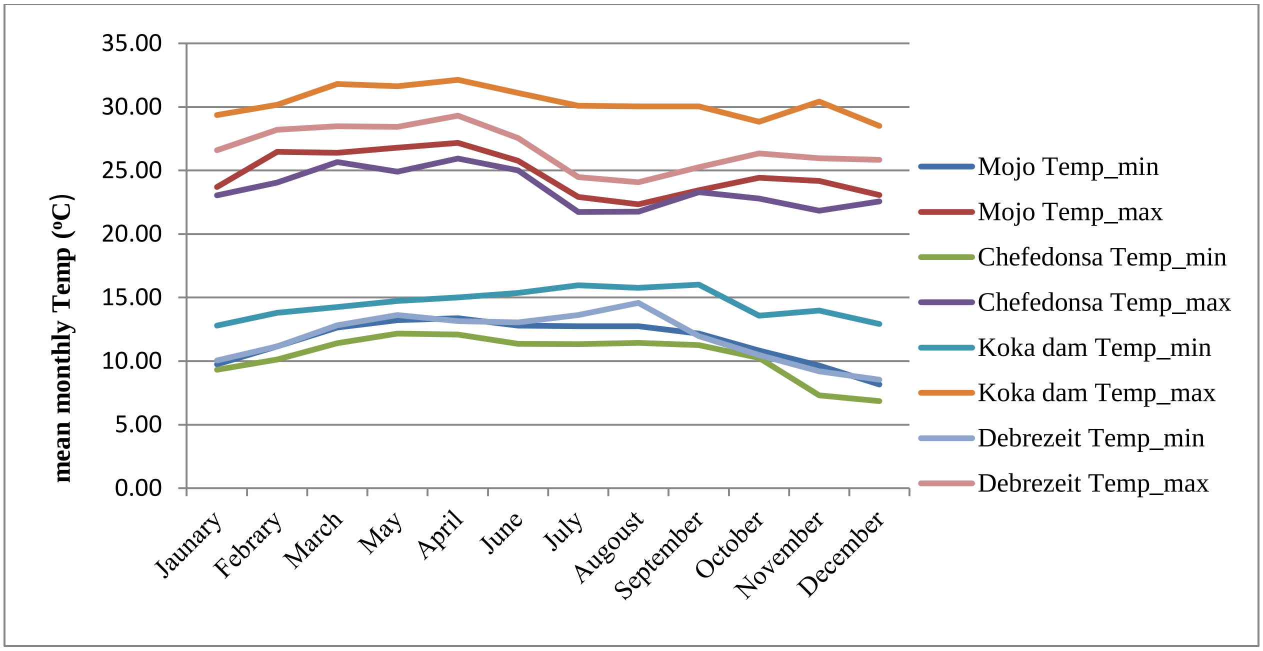

Figure 3.Monthly minimum and maximum temperature of the watershed

3.1.3. Crop production

The farming system of the study area is sedentary agriculture and crop rotation is also one of the systems of soil fertility management in advancement. Chemical fertilizer application is another system to increase crop production per unit area and agricultural economic benefit. The major crop types in the area are teff, chickpea and wheat. These crops are scaled up by development agents and farmers on the basis of their economic benefits. This indicates that no crop type mainly dominate the area for a long year as the past historical farming systems with less inputs and market assessment and prediction. The field picture has been taken for illustration of representative farming system components. At the year of 2011 Farmers cultivated mainly on large areas like indicated in the Plate 1, 2 and 3.

The most productive zones are between 3,200 and 1,500 meters asl, i.e. between highland (‘dega’) and lowland (‘Woinadega’). In this agro-ecological zone a wide range of crops are grown and many species of livestock kept for different ends. Production systems are, in fact, of a mixed crop plus livestock type with draught power being important. Rainfall is generally not limiting except in the far north and growing seasons are often very long, with two crops per year in some areas. Due to high population, farming is dominated by smallholdings, which is characterized by subsistence farming.

Plate 1.Chickpea Crop

Plate 2.Wheat Crop

Plate 3. Teff Crop

3.2.Methods and Data Sources

Methods and data sources used in the study are summarized in the flow diagram as shown in figure 4.

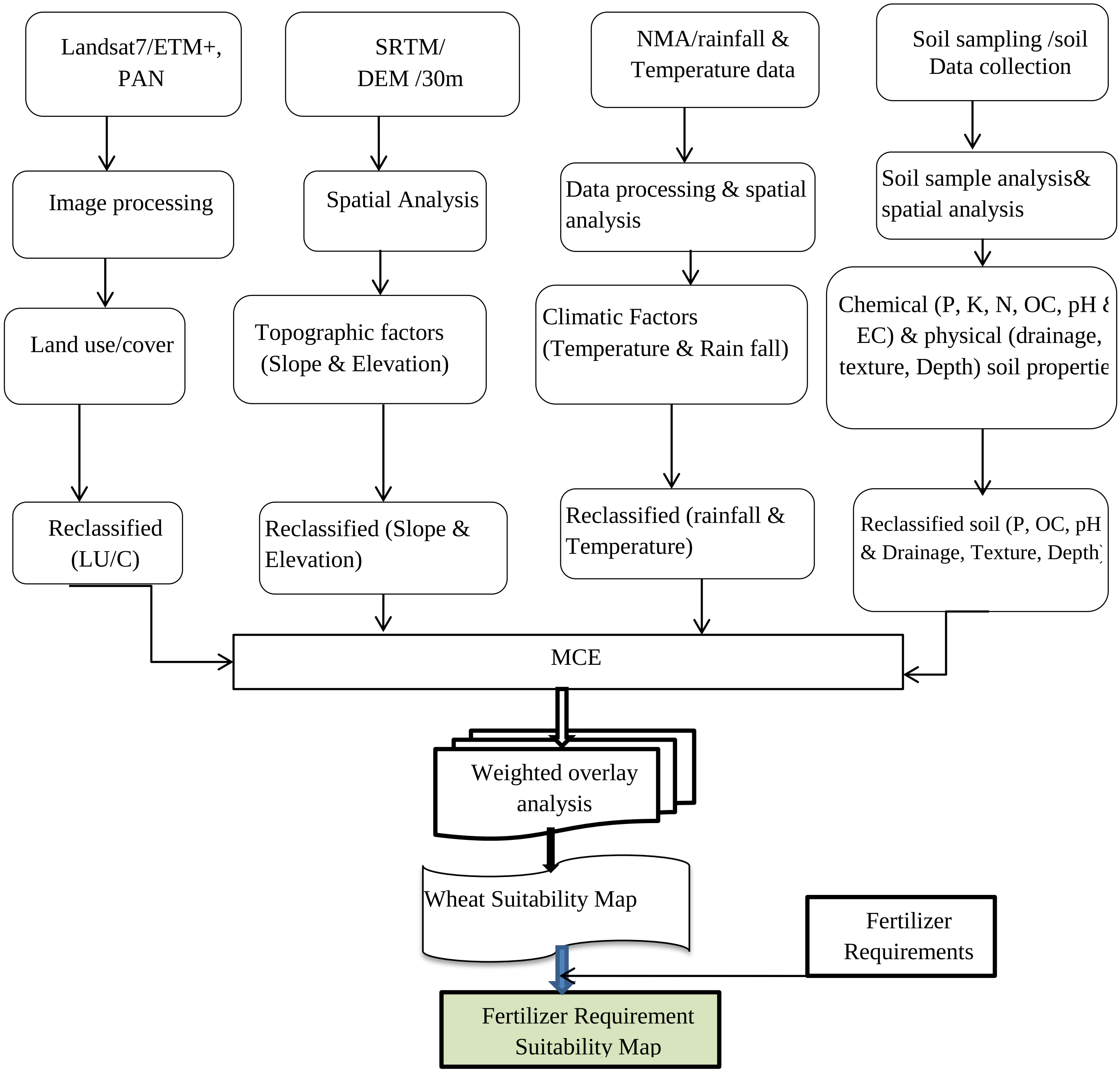

Figure 4. Flow diagram of the Methodology

3.2.1. Data sources

The metrological data was collected from NMA (National MetrologyAgency) and some of secondary soil data was collected from Ethiopia Ministry of Agriculture Department of Soil and Water Conservation. Satellite images and topo sheet were collected from EMA (Ethiopia Mapping Agency).The types of images and top sheet used were shown in table 2.

Table 2.Types of images used and their purposes

Year	Date	Satellite data	Resolution	Path/raw	Purposes
2011	November,18	ETM^{+} (landsat7)	30m	168/054	Mapping of LUC
2011	November,18	PAN (landsat7)	15m	168/054	Resolution merging
	DEM	SRTM	30m		To generate slope, aspect
	Topo sheet (1:50,000)		0839A1, 0839A2 0839A3, 0839A4		To collect ground control points

3.2.2. Soil sampling

The sixty composite soil samples were collected from the study area. The method of soil sampling was stratified composite soil sampling, that is a field is broken down into areas of similar topography, management history and/or crop performance. Each area is then sampled separately. The depth of sampling was from 0-30cm since it was for agricultural purpose. The samples labeled at field and prepared for further analysis at the Ziway Soil Research Center. The sampling augur used and soil color of the major soil type found in the study area are indicated inPlate4.

Plate 4.Vertisols and sampling auger

3.2.3. Soil parameter analysis

From sixty soil samples for five parameters were analyzed and used to map available soil phosphorous and potassium, total nitrogen, pH and organic carbon and soil texture. To determine and evaluate and classify the laboratory analysis results standard references are used for each soil parameter in procedures used and purpose of application.

3.2.3.1. Available Phosphorus (P)

The Olsen *et al*.(1954)method was used to determine extractable phosphorus in the soil at Ziway Soil Research Center laboratory since all pH values of soil samples are more than 7 (appendices2) . The map was prepared by using ArcGIS 9.3 spatial analysis of Kriging interpolation method. The steps followed are illustrated in figure5.

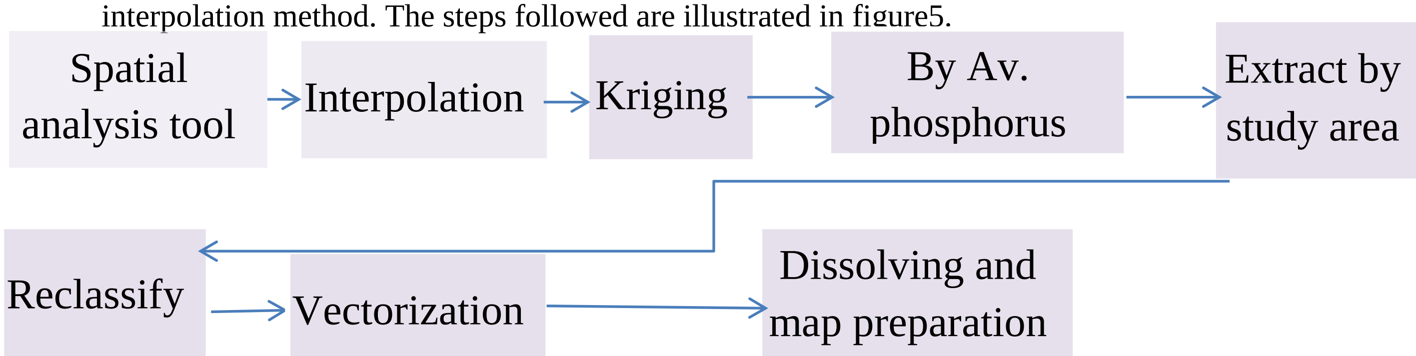

Figure 5. Steps followed to map available phosphorus

3.2.3.2. Available Potassium (K)

Potassium does not readily tie up in calcareous soils and may be found at elevated levels in some saline soils. Potassium fertilizer responses may sometimes be observed on sandy soils with low cation exchange capacities. Critical values for potassium that begin to limit plant growth are around 80 to 200ppm (Gourley, 1999).In this study the potassium values of the study area was determined by analyzing the soil samples collected using of flame photometer. Finally it was mapped by using ArcGIS9.3 software in spatial analyst tool interpolation method of Krging.

3.2.3.3. Soil pH

PH is a measure of soil acidity or alkalinity that gives an indication of the activity of the hydrogen ion (H^+) and hydroxyl ion (OH) in a water solution. Both these ions have a high chemical activity. Their chemical activity is lowest when the solution or soil is close to a neutral pH of 7.0. In this study, the pH values are determined in the laboratory using pH meter. The spatial reference of the soil pH was done to their sampling points; finally maps were prepared by using spatial analysis interpolation of kriging in ArcGIS 9.3.

3.2.3.4. Total Nitrogen and Organic Matter

Organic matter and organic carbon are usually expressed as a percentage of the soil by weight. When results are presented and interpreted, care should be taken to note whether organic matter or organic carbon levels are indicated. Organic matter is calculated from the levels of organic carbon in the soil by multiplying by 1.72. This factor is based on the assumption that the organic matter in the soil has a constant carbon composition of approximately 57%. However, Nelson and Sommers (1996) have pointed out that the actual conversion factors of organic carbon to organic matter vary from 1.72 to 2.00 and they recommend that only organic carbon values be reported. In this study, the Organic carbon and total nitrogen values are determined in the laboratory using Walkley and Black (1934) and Kjeldahl procedure of Bremner and Mulvaney (1982) method of soil analysis respectively. Finally maps were prepared by using kriging interpolation of ArcGIS 9.3.

3.2.3.5. Soil physical properties

Soil physical properties like soil texture soil depth and drainage conditions are some of factors that highly constrain the suitability of the soil for agricultural production. The soil texture is analyzed in the laboratory by using hydrometer method and textural class map was prepared in interpolation of spatial analysis environment. The secondary data of soil depth and soil drainage was collected from Ministry of Agriculture. The area coverage in km^2 and percentage for the soil drainage, soil texture and soil depth classes were indicated in table 3.

Table3. Soil Physical Properties

No	Soil factor	Classes	Area(km^2)	Area(%)
1	Drainage	Moderate well	2.87	1.91
		Well	147.71	98.08
2	Soil Texture	Clay	18.29	12.15
		Clay Loam	132.30	87.85
3	Soil Depth	90 - 120 cm	21.17	14.06
		>120cm	129.42	85.94

3.2.4. Topographic factors

For the evaluation of wheat suitability slope and elevation were derived and used. Slope of the study area was generated from digital elevation model of 30m SRTM image by using ArcGIS9.3 spatial analyst of surface analysis and elevation map was generated from the same DEM.

3.2.5. Digital image processing

Satellite images and techniques of image analysis are mostly used in land use/ land cover estimation in detail to assess their spatial and temporal variability within the area. To generate thematic map about land use/land cover of the study area, the principal techniques of digital image processing have been performed as discussed in the subsequent sections.

3.2.5.1. Gap filling

Landsat Enhanced Thematic Mapper Plus (ETM$^+$) SLC-off image acquired on November 18, 2011 were downloaded from the United States Geological Survey (USGS) Earth Resources Observation Systems (EROS) data center under the Landsat Archive collection. It was difficult to use the image directly, due to the Landsat (ETM$^+$) data acquired after May 31, 2003 Scan Line Corrector (SLC) failure, resulted in 22 percent of the data missing from each scene.

To fill the gap, a model was used “off-to-off” product, which combines an SLC-off image with one or more SLC-off scenes. For this combination Landsat ETM$^+$ scene with the same path and row acquired on November 09, 2008 was used. By using model-maker in ERDAS IMAGINE 9.2 each band in Image 1 (Landsat ETM$^+$ 2011 image) added to the corresponding band in Image 2 (Landsat ETM$^+$ 2008 Image) using the following statement:“Where Image 1 > 0, use Image 1 data, otherwise, use Image 2” .The original

ETM^+ image and the gap filled or corrected image were indicated in figure 6 and figure 8 respectively.

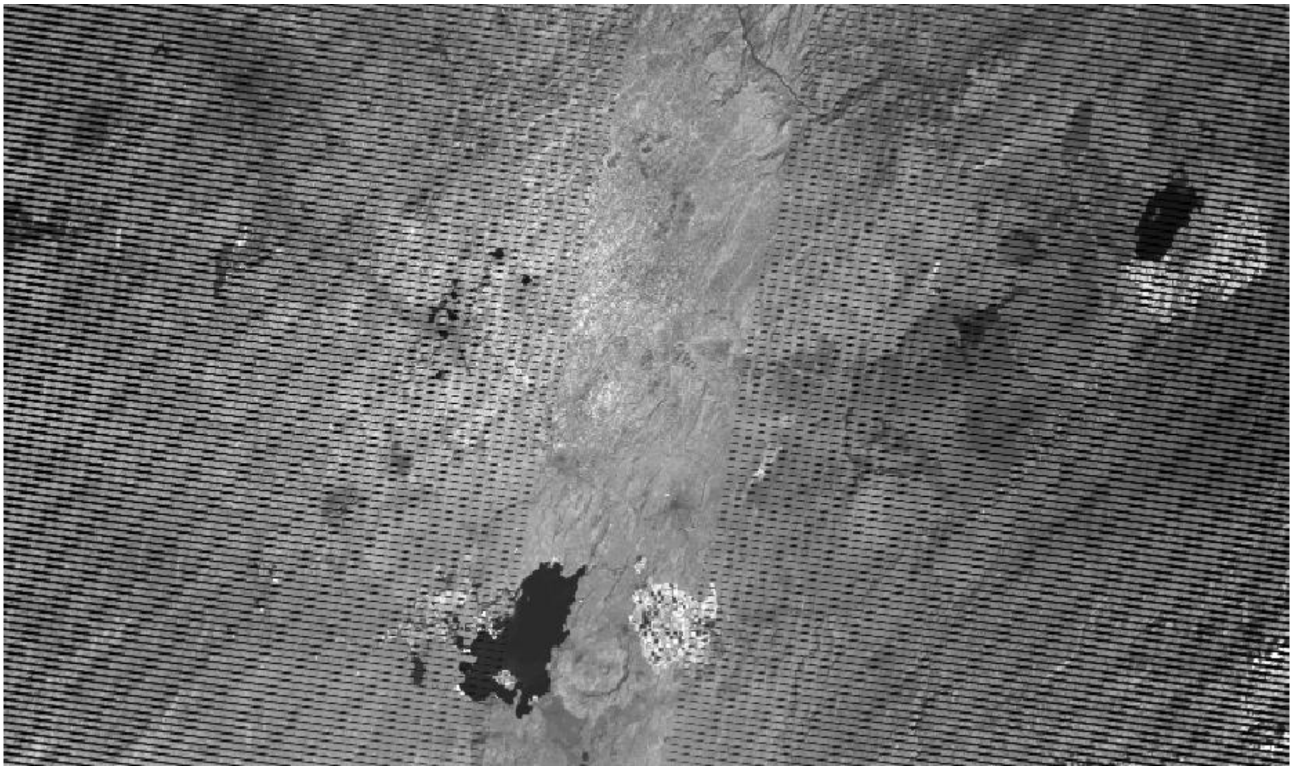

Figure6.Original landsat7 ETM^+ Image date of 18/11/2011

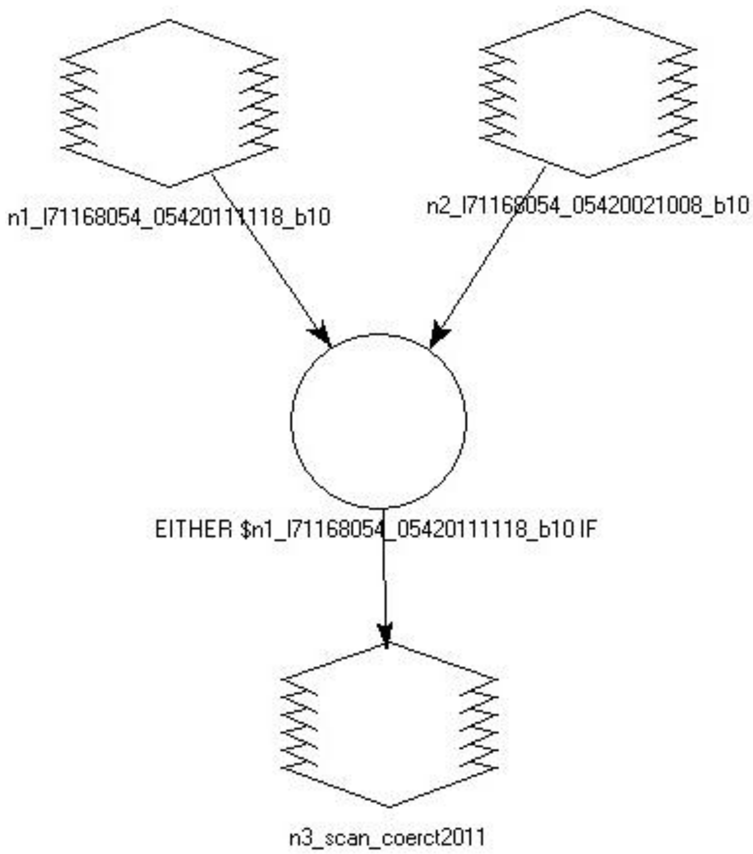

Figure 7. Model used to fill the Gaps of scan line off

The syntax of the above statement is: EITHER $n1_l71168054_05420111118_b10 IF ($n1_l71168054_05420111118_b10>0) OR $n1_l71168054_05420021008_b10 Otherwise. In the ERDASIMAGINE 9.2 of model maker, it is possible to build the model as illustrated in the figure 8 and used in this research to generate the current land use /cover of the Lume Micro Watershed.

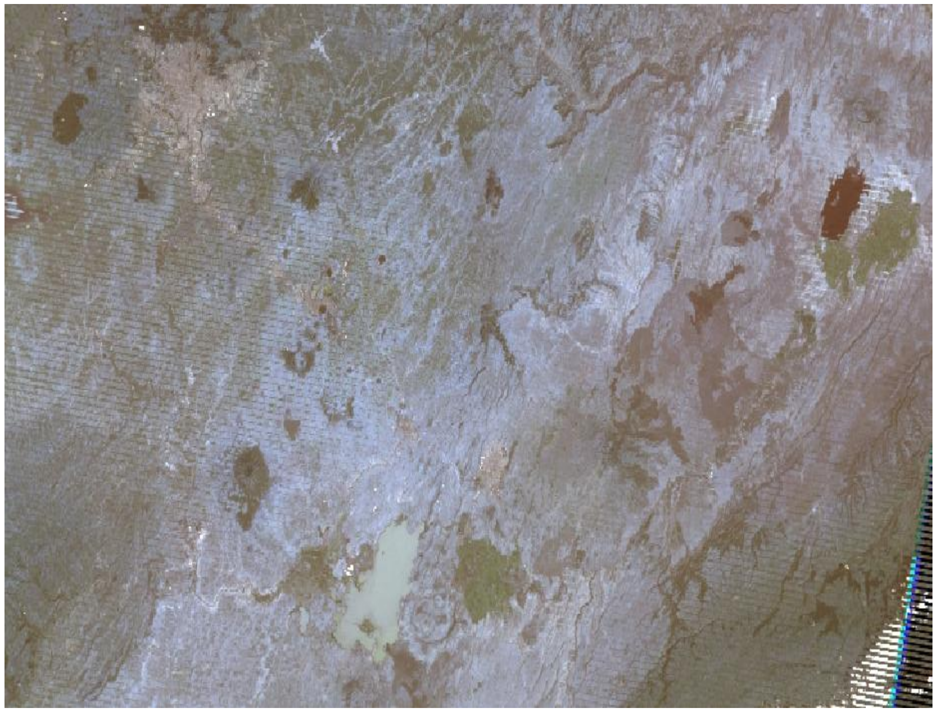

Figure 8.Landsat7 ETM$^+$ image after enhancement

3.2.5.2. Image Enhancement

After the gap filling have been accomplished, image enhancement techniques are applied in order to more effectively display or record the data for subsequent visual interpretation. The resolution merging of spatial enhancement is performed by using band eight of the same raw and path of ETM$^+$ which is PAN of 15m resolution. Contrast stretching is a technique to expand the narrow range of brightness values typically present in an output image over a wider range of gray value (Lillesand and Kiefer, 2000). The visual interpretability of the images used in this study is enhanced by using histogram equalization stretch. In this type of contrast enhancement, image values are assigned to the display levels on the basis of their frequency of occurrence.

3.2.5.3. Image classification

To convert image data to thematic data, image classification is necessary. The present study used supervised classification technique to categorize the image in to different land use/ land cover categories. Supervised classification can be used to cluster pixels in data set into classes corresponding to user defined training classes. This classification type requires selecting training areas for use as the basis for classification. The most common supervised classification techniques are the maximum Likelihood classifier for parametric input data and parallelpiped classifier for non-parametric data.

Supervised classifications require a prior knowledge of the scene area in order to provide the computer with unique training classes. It is the job of the user to define the original pixels that contain similar spectral classes representing certain land cover class.

Accordingly, representative points expected to represent the various land cover classes were marked using GARMIN GPS during the field visit for the accessible places. These points were used to sample representative signatures for the various land cover types identified during the field visit. Following this, supervised land use / land cover classification has been carried out using ERDAS IMAGINE9.2software from Landsat satellite ETM^+ image of November 18, 2011. Accordingly, seven (7) land use / land cover types were identified. These are settlements, Grasses (closed from grazing), Grazing (open grasses), Forest/plantation, cultivated land (teff, wheat, and chickpea).Hence, the larger part of the study area is cultivated land (which accounts about 91%). The total area percentage coverage of each land use/cover are; grasses with vegetation 0.16%, settlements 0.08%, forest 1.45%, and grazing land account about7.23%. The table 4 illustrates current LU/C, Area (km^2) and Area (%) of Lume micro watershed. Figure 9illustrates the land use/land cover map of the study area in year2011.

Table 4.Land use/Land cover of 2011

no	Current LU/C	Area(km2)	Area (%)
1	Forest	2.19	1.45
2	Chickpea	10.73	6.97
3	Grasses /closed	0.29	0.16
4	Grazing Land/open grasses	10.88	7.23
5	Settlement	0.14	0.08
6	Teff	70.85	46.97
7	Wheat	55.92	37.13
	Total	**151.00**	**100.00**

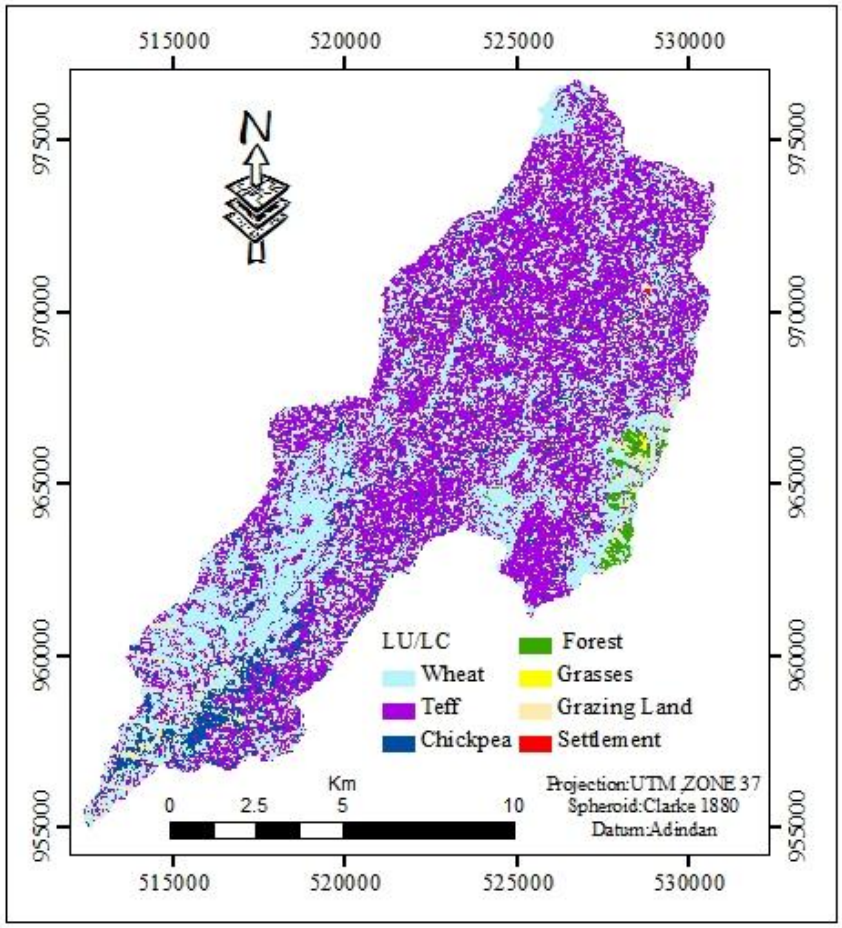

Figure 9. Land use/ Land cover of 2011

3.2.5.4. Accuracy Assessment

Since image classification without accuracy assessment is incomplete, in this study next to the supervised image classification, by collecting about 417 points randomly using GPS and the accuracy assessment was conducted. The error matrix of the classification was performed as indicated in table 5.

Table 5.Error matrix of classification

Layers names		Reference Data							
		Forest	Chickpea	Settlement	Grasses	Grazing	Teff crop	Wheat crop	**Row Total**
Classified Data	Forest	15	1	0	0	0	0	0	16
	Chickpea	0	30	0	0	3	5	2	40
	Settlement	0	0	8	0	0	0	0	8
	Grasses	0	0	0	11	0	0	0	11
	Grazing	1	1	0	3	43	3	2	53
	Teff crop	2	15	5	2	16	83	31	154
	Wheat crop	0	11	3	2	12	10	97	135
	Column Total	18	58	16	18	74	101	132	**417**

The producers', users' accuracy and kappa statics of each land use /land cover was presented in the table 6.The overall classification accuracy and overall kappa statistics are 68.82% and 59.44% respectively.

Table 6. Accuracy totals and kappa statics

Class Name	**Reference Totals**	**Classified Totals**	**Number Correct**	**Producers Accuracy**	**Users Accuracy**	**Kappa**
Forest	18	16	15	83.33%	93.75%	93.47%
Chickpea	58	40	30	51.72%	75.00%	70.96%
Settlement	16	8	8	50.00%	100.00%	100%
Grasses	18	11	11	61.11%	100.00%	100%
Grazing	74	53	43	58.11%	81.13%	77.06%
Teff crop	101	154	83	82.18%	53.90%	39.16%
Wheat crop	132	135	97	73.48%	71.85%	58.81%
Totals	417	417	287			

Overall Classification Accuracy =68.82%

Overall Kappa Statistics = 59.44%

3.3. Suitability Analysis for Wheat

As Ethiopia is highly characterized in very much diversified agro ecologic zones, accordingly very small areas may be suitable for different land utilization types. Hence the suitability analysis for major crops in the study area is very critical before conducting any applied researches or agricultural developments. In the respect of the above statement, to conduct fertilizer requirement map the conditional suitability of wheat in the Lume micro watershed has been done.

3.3.1. Wheat requirements

Ethiopia is the second country in wheat production next to South Africa among sub-Sahara African countries (White *et al.,* 2001).To maintain the production in sustainable way the fertilizer application efficiency should be made on the basis of wheat requirements. Therefore its requirements are indicated in the following table accordingly to FAO (1976) land evaluation frame work.Table7 shows the major factors required for wheat and their suitability rating.

Table 7.Wheat requirement factors and their suitability ranges

No	Factors/ Criteria	Range of Suitability				
		Highly Suitable (S_1)	Moderately Suitable (S_2)	Marginally Suitable (S_3)	Currently not suitable(N_1)	Permanently not suitable(N_2)
1	Soil depth(cm)	>100	75-100	50-75	25-50	<25
2	Texture(class)	C, Si, SiC, SiL,SC	L, CL, SiCL	SCL	Sandy Loam	Sandy
3	Drainage(class)	well	Moderate	Imperfect	Poor	Very Poor
4	Soil pH	6-8	5.2-6.0 and 8.0-8.3	5.0-5.2 and 8.3-8.5	5.0-4.8	<4.8 and>8.5
5	Organic matter (%)	> 3.0	2.5-3.0	2.0-2.5	1.0-2.0	<1.0
6	phosphorus(ppm)	>22,22-14	7-14	1-7	0-1	0
7	Temperature(0c)	14.9-18.4	14.4-14.9, 18.4-19.4	13.4-14.4,19.4-20.8	12.4-13.4, 20.8-21.3	<12.4, >21.3
8	Rainfall(mm)	450-650	350-450,650-850	300-350, 850-1000	250-300, 1000-1200	<250, >1200
9	Slope (%)	0-13	13-25	25-40	40-55	>55
10	Elevation(m)	1787-2000	2000-2300	2300-2500	2500-3300	>3300
11	Land use/cover	Cultivated land	Teff, wheat		Grazing land	Water body, Forest, Settlement

Source: FAO (1976), FAO (1984) and White *et al.*, 2001

3.3.2. Factors used in land suitability evaluation for wheat

In order to supply the requirements of wheat, the factors used in suitability analysis are generally categorized as soil, climate, topography and land use. These factors are subdivided into particular parameters and evaluated in terms of their importance for wheat crop production.

3.3.2.1. Soil factors

For wheat suitability analysis soil physical and chemical properties that limit growth performance of wheat are soil phosphorus, soil organic matter, soil pH, soil potassium, soil total nitrogen. The major physical properties are soil texture, soil depth and drainage condition. Among the chemical properties of the soil the phosphorus, organic matter and soil pH have been used in wheat suitability analysis. Figure10 shows the map of soil chemical and physical properties those influence the growth performance of wheat in Lume micro watershed.

3.3.2.1.1. Soil phosphorus

Soil phosphorus availability is low in many sandy low humus soils, oxisols and other soils high in sesquioxide clays, iron oxides, and aluminum oxides. These often have high phosphorus adsorption capacities, rapidly adsorbing added soluble phosphate. Because soil pH has influence on the presence and solubility of calcium, iron, and aluminum, and because of its effect on bacterial growth, it greatly influences the availability of soil phosphorus. Excess phosphorus is mostly retained in the soil, but excess application of phosphorus may cause some micro nutrient deficiencies. Mostly soil phosphorus deficiency is remedied by application of phosphate fertilizers (Raymond and Donahue, 1997).In this study the phosphorus level of Lume micro watershed were evaluated in respect of wheat requirement and classified as very low, low, moderate and high according to Esteban (2011)as indicated in figure10 A.

3.3.2.1.2. Soil pH

The pH is a measure of soil acidity or alkalinity that gives an indication of the activity of the hydrogen ion (H^+) and hydroxyl ion (OH) in a water solution. Both these ions have a high chemical activity. Their chemical activity is lowest when the solution or soil is close to a neutral pH of 7.0. The pH characterizes the chemical environment of the soil and may be used as a guide to suitability of soils for various pasture and crop species. Acidification is most rapid in soils derived from minerals low in cations and in coarse soils that can easily be leached. The soil pH significantly affects the availability of most of the chemical elements important to plants and microbes; at low pH (<5) there is a tendency for toxicity of elements such as iron, manganese and aluminum. The availability of nitrogen, sulfur and molybdenum are somewhat restricted at low pH, whereas that of phosphorous is best at intermediate pH level that is from 5 to 8.5 of pH level. In this study the two levels of soil pH was generated and classified as moderately alkaline and slightly alkaline as shown in figure 10 C.

3.3.2.1.3. Organic matter

Organic matter and organic carbon are usually expressed as a percentage of the soil by weight. The role of organic matter in soils is very important. It is an ideal source of plant nutrients in soils. The measure of organic matter (OM %) is conducted to evaluate availability of plant nutrients and physical condition of the soil. Organic matter contains about five percent total nitrogen, so it serves as a store house for reserve nitrogen, but nitrogen in organic matter is largely in inorganic form and not immediately available for plant use, since decomposition usually occurs slowly. Organic matter gives dark color to many soils, holds water 20 times of its weight, provides aggregation, and has high cation exchange capacity. It is reported that many parts of Ethiopian agricultural fields are very low in organic matter; in the same manner Lume Micro Watershed also reveals results that are in the range of very low organic matter, it is the one limiting crop productivity particularly wheat. For this study the three levels of organic matter has been illustrated in figure 10 B.

3.3.2.1.4. Soil texture

Soil texture is related to other physical properties and chemical properties of soil; generally influence physical soil fertility. Clay loam and clay textural classes are found in the study area whereas clay loam is the dominating in areal coverage. Clay loam has between 30 to 35% of clay particle size and clay has greater than 35% of clay particle size. Particle size distribution describes the relative amounts of gravel, sand, silt and clay within the soil. These are the building blocks for the soil and can have a large effect on the soil properties. Clays have high surface area 5 to 750 m^2/g depending on clay type and can have a high amount of chemical and physical activity. Sands have a smaller surface area (0.100 to 0.01m^2/g) and tend to be less chemically and physically active (McKenzie *et al.* 2004).The rest vary between these extremes. The textural classes of the study area are indicated in figure10 E.

3.3.2.1.5. Soil Drainage

The soil textural classes are related to drainage condition of the soil. Drainage classification could be well drained, means free from mottling in the surface and sub surfaces, moderately well means well oxidized and free from mottling except in the lower part of the sub soil, improperly drained well oxidized surfaces, sub soil mottled and poorly drained soil surface is dark and grey of mottled sub soil. The feature of land drainage is marked on the basis of surface characteristics of the soil like color. In this study area there are moderately well and well drained whereas the dominating condition in area coverage is well drained. Heavy rainfall combined with heavy clay soils creates water logging that limits wheat production. Hence water logging is a common occurrence at the beginning of the wheat cycle. The situation is further exacerbated by the black vertisols of Ethiopia, consisting of heavy clays that inhibit infiltration, swell and crack severely (Samad *et al*., 2001).The drainage condition of the study area is indicated in figure10 D.

3.3.2.1.6. Soil depth

Although soil is nonrenewable natural resource in short period of time, it can be degraded in short period of time by different process such as erosion and improper land use. The effective soil depth is the thickness of soil existing above the bed rock or impermeable layers. For categorizing land, suitability for particular class, the effective depth can be deep, moderate deep, moderate shallow, shallow and very shallow which is greater than 1.2m,0.9 to 1.2m,0.5 to 0.9m,0.20 to 0.5m and less than 0.20m respectively (Surash, 2004).In this study, the total area has effective soil depth greater than 0.9m, which could be moderately deep and deep. Deep well drained soil shows a root penetration until below 150 cm for most crops, however, root penetration might be stopped at shallower depth because of root restricting physical or chemical soil properties (presence of cemented, toxic, compacted or indurated layers, hard rock or gravel layers). The soil depth categories of the study area are classified as indicated in figure 10F.

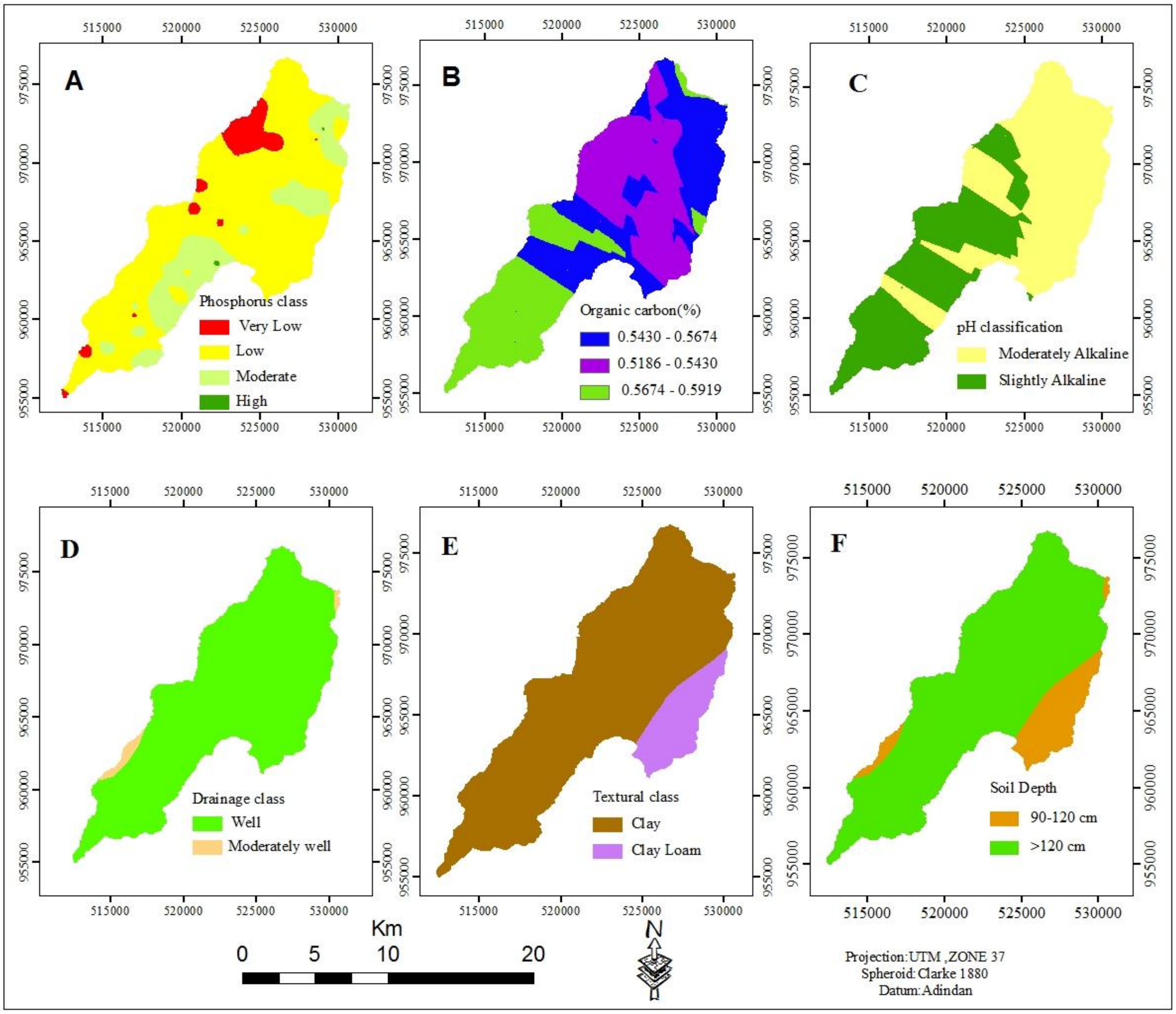

Figure 10. Soil factors: Phosphorus (A), organic carbon(B),pH(C),Drainage(D),Texture(E)and Soil depth(F).

3.3.2.2. Agro Climatic factors

For analysis of land suitability for wheat at Lume micro watershed slope, Elevation, rainfall, temperature and present land use/cover are consideredfigure11shows the total Agro climatic factors used as evaluation criteria for wheat production.

3.3.2.2.1. Slope

Slope is very influencing factor of agricultural production and land utilization type. As the slope steepness changes; crop type, tillage method and instruments, soil and water conservation structure use, generally land utilization type also vary with respective to the slope variation. The steeper areas are highly susceptible to water erosion whereas flat area on clay soils is prone to water logging and soil deposition from up slopes. Generally, slope greater than 30% is not advisable for agricultural crop production (RELMA, 2005). The topography of the study area is generally characterized by gently undulating terrain. Of the total area, 85% (128.59 km^2) lies within the slope range of 0-13% which is generally flat to gently undulating topographic feature the five slope classes indicated in figure11A B and table 8.

3.3.2.2.2. Elevation

Elevation has impact on the growth performance of wheat higher elevation more than 2300m altitude is characterized by growing early, intermediate and late varieties. The soil, moisture and disease conditions in the 1900-2300m altitude zone are favorable for the production of early and intermediate maturing varieties of bread wheat. The elevation is correlated with rain fall areas above 1500m altitude receive substantially greater rain fall than do lowlands below 1500m, except the lowlands in the west where rainfall is high. Generally average annual rainfall of areas above 1,500m exceeds 900 mm. In the lowlands rainfall is erratic and averages below 600 mm. There is strong inter-annual variability of rainfall all over the country (FAO,1984).Elevation of Lume Micro Watershed varies between 1787 m to 2510m above mean sea level, the elevation classified in to three according to their wheat suitability levels as shown in table 9. The elevation map of the area is shown in figure 11.

Table 8.Slope classes of Lume Micro Watershed

No	Slope (%)	Area(km2)	Area (%)
1	0-13	128.59	85.16
2	13-25	17.87	11.84
3	25-40	4.11	2.72
4	40-55	0.38	0.25
5	>55	0.04	0.03
	total	151.00	100.00

Table 9. Elevation ranges of Lume Micro Watershed

No	Elevation(m)	Area(km^2)	Area (%)
1	1787 - 2000	29.67	19.65
2	2000 -2300	107.96	71.50
3	> 2300	13.37	8.86
Total		151.00	100.00

3.3.2.2.3. Climatic factors

Climatic elements such as precipitation, temperature, humidity, sunshine, wind, are affected by geographic location and altitude. Since Ethiopia is near the equator and with an extensive altitude range, has a wide range of climatic features suitable for different agricultural production systems. Climatic heterogeneity is a general characteristic of the country.

Temperature and rainfall are the most important climatic factors for agricultural production in Ethiopia. Elevation is a factor that determines the distribution of climatic factors and land suitability; this influences the crops to be grown, rate of crop growth, natural vegetation types and their species diversity. There is strong inter-annual variability of rainfall all over the country. Despite variable rainfall which makes agricultural planning difficult, a substantial proportion of the country gets enough rain for rainfed crop production (FAO, 1984).

The thermal regime is the other basic climatic parameter used to define the agro-ecological zones. The thermal regime refers to the amount of heat available for plant growth and development during the growing period. It is usually defined by the mean daily temperature during the growing period. There are also disadvantages linked to growing wheat in tropical areas; foremost among them are the different types of high temperature stress that affect the crop (Reynolds *et al*., 2001).Generally, the stress could be continual heat stress and terminal stress .Continual heat stress is defined by a mean daily temperature of over 17.5°C in the coolest month of the season (Fischer and Byerlee, 1991). The rainfall and temperature maps of the study area are shown in figure 11 C and figure11 D.

3.3.2.2.4. Land use/cover

Among farming systems of Ethiopia high potential cereal production areas compromise in particular crop rotation cropping systems; the proportional allocation among crop species varies with altitude, rainfall, and soil type. Some studies on crop rotation indicated significant rotational effects on wheat grain yield (GY) and the interactions among cropping sequences and N and P fertilizer has also significant effect on the yield of crop. It has simultaneous improvement in soil N status and a reduction in wheat root pathogen and grass weed populations in the cropping sequences (AsefaTaa *et al.,* 1997).In Lume Micro Watershed farmers mainly rotate three crops in the sequences of wheat to chickpea then Teff. Therefore, land use/land cover has great effect on the suitability evaluation of the land for wheat; among cultivated lands chickpea farm is more suitable than any other crop for the next wheat production. The settlement and forest are restricted from suitability evaluation for agricultural crops. The land use/land cover of the study area in year 2011 is shown in figure 11 E.

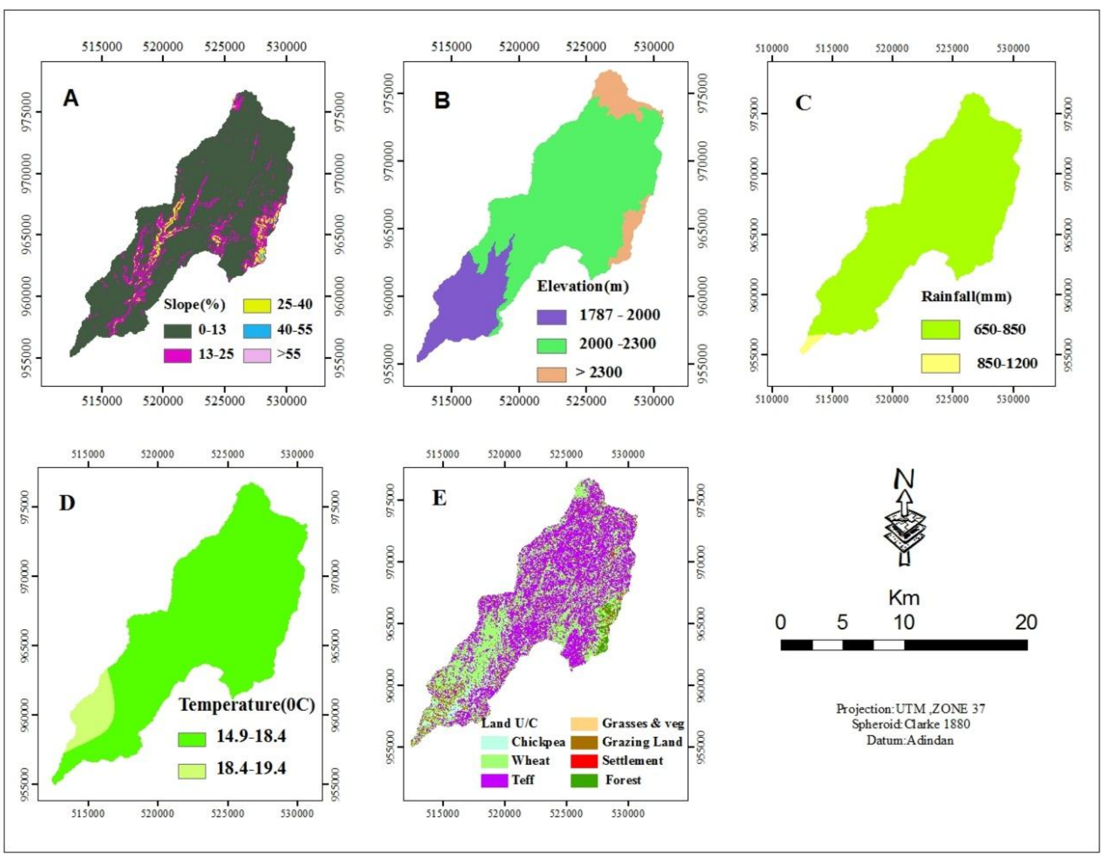

Figure11.Agro climatic factors: Slope (A), Elevation (B), Rainfall (C), Temperature (D) and LU/LC(E)

3.3.3. Determining factor weights

Pairwise comparison has been done for factors used in suitability analysis of the area for wheat cultivation. The standardization also made for layers that are constraints only have (true or false) possibilities. The difference in rating of factors is mostly solved by making scales to the same range and the derivation of the relative criterion importance using the pairwise comparison method. The criterion weights are automatically calculated; once the pairwise comparison matrix is entered in IDRISI-AHP weight derivation module.Table10 illustrate the way of calculating eigen values to know the relative importance of the factors/evaluation criteria.

Table10.Pairwise comparisons of factor layers

Layers name	Depth	Rainfall	Temperature	Phosphorus	Soil pH	Slope	Texture	Drainage	Land use	Elevation	Organic carbon
Depth	1										
Rainfall	1	1									
Temperature	3	1	1								
Phosphorus	1/3	1/3	1/3	1							
pH	1/5	1/5	1/5	1/3	1						
Slope	1/3	1/5	1/3	1/3	1/3	1					
Texture	1/5	1/5	1/5	1/3	1/3	1	1				
Drainage	1/5	1/7	1/7	1/3	1/3	1/3	1/3	1			
Land use	1/7	1/9	1/9	1/7	1/7	1/7	1/5	1/5	1		
Elevation	1/3	1/7	1/3	1/3	1/3	1/3	1/3	3	3	1	
Organic carbon	1/3	1/5	1/3	1	1	1	3	3	3	3	1

Based on the automatic weight calculation of the matrix factors following eigen values are generated for each criterion as shown in table 11, the Eigen values determine the relative importance of each factor to the objective in this study Wheat suitability evaluation.

Table11.Principal Eigenvector of the pairwise comparison matrix

Factors	Weight	Factors	Weight
Soil depth	0.1659	Texture	0.045
Rainfall	0.2156	Drainage	0.0256
Temperature	0.2114	Land use	0.0136
Phosphorus	0.0949	Elevation	0.0346
Soil pH	0.0713	Organic matter	0.0671
Slope	0.055		

Consistency ratio (CR) is 0.07

3.3.4. Standardization and ranking

In order to compare their relative influence on the objective of the study all factors are reclassified according to requirement of land utilization type of the study. After reclassifying the factors to the requirements of wheat the rank has been given to each class of the criteriaon the basis of FAO (1976) framework. The reclassified thematic maps of layers used in the evaluation are shown in figure 12 and their relative rank of classes according to importance to wheat suitability is also shown in table12.

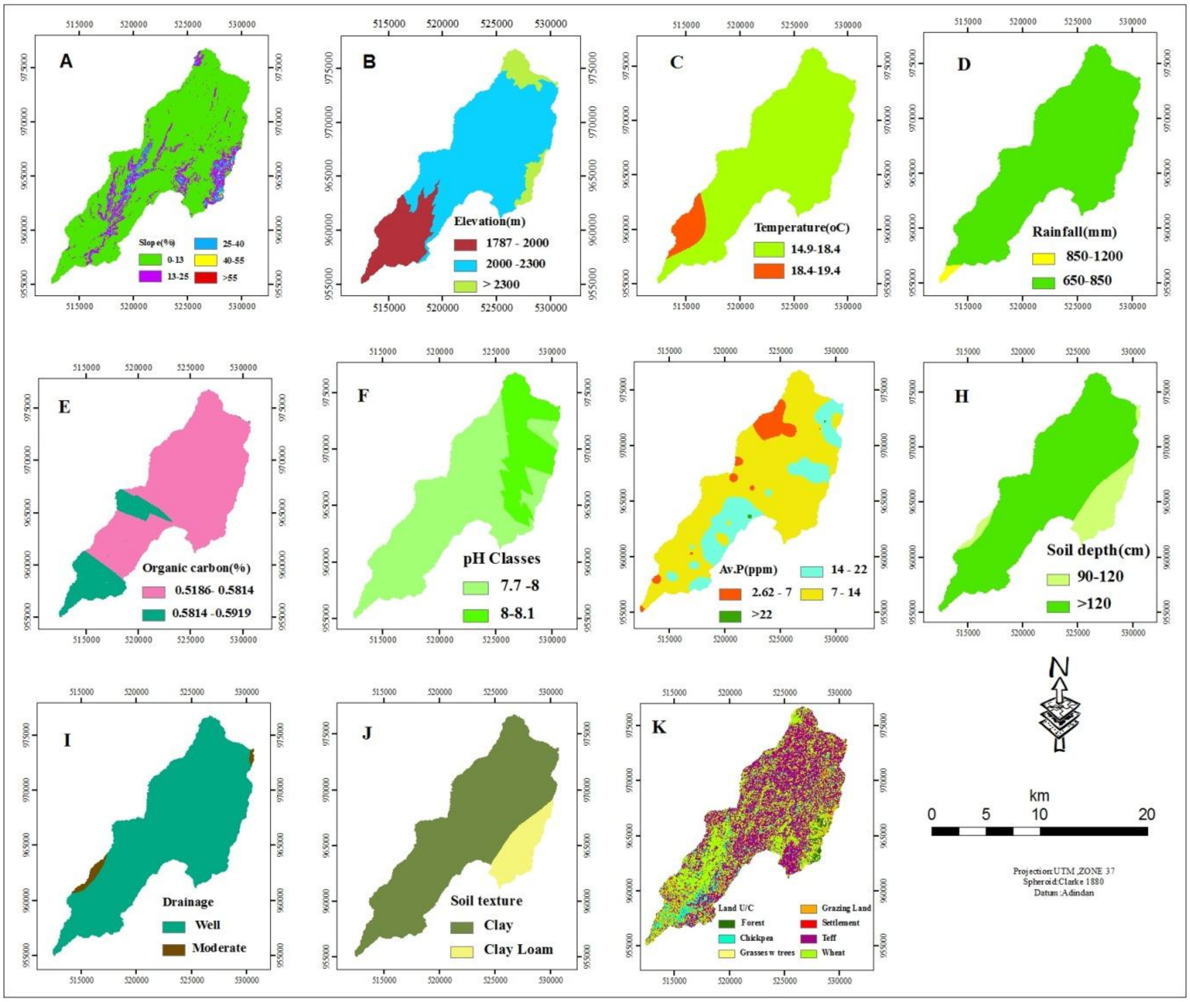

Figure 12.Reclassifiedthematic maps

Table12.Derived Factor maps rank and their suitability

Factor	Rank	Relative suitability	Factor	Rank	Relative suitability
1.Rainfall(mm)			**8.Texture**		
650 -850	5	Highly suitable	Clay	4	Moderately suitable
850-1200	4	Moderately suitable	Clay Loam	5	Highly suitable
2.Temperature(^{0}C)			**9. Slope (%)**		
14.9 -18.4	5	Highly suitable	0 –13	5	Highly suitable
18.4-19.4	4	Moderately suitable	13 -25	4	Moderately suitable
3.Phosphorus(ppm)			25 -40	3	marginally suitable
2.62 - 7	2	Currently not suitable	40 –55	2	Currently not suitable
7.5 -14	3	Marginally suitable	>55	1	Permanently not suitable
14 - 22	4	Moderately suitable	**10.Elevetion(m)**		
> 22	5	Highly suitable	1787 - 2000	5	Highly suitable
4.Soil pH			2000 - 2300	4	Moderately suitable
7.7-8	5	Highly suitable	>2300	3	Marginally suitable
8-8.1	4	Moderately suitable	**11.Land U/C**		
5. Organic carbon (%)			Chickpea	5	Highly suitable
0.5186 - 0.5814	2	Currently not suitable	Teff	4	Moderately suitable
0.5814 - 0.5919	3	Marginally suitable	Wheat	4	Moderately suitable
6.Soil depth (cm)			Grazing Land	1	Permanently not suitable
90 - 120	4	Moderately suitable	Grasses	2	Currently not suitable
> 120	5	Highly suitable	Settlement	Restricted	Permanently not suitable
7.Drainage class			Forest	Restricted	Permanently not suitable
Well	5	Highly suitable			
Moderate	4	Moderately suitable			

3.3.5. Weighted Overlay Analysis

The determined relative importance values were used in the linear weighted overlay analysis, it has been done for the criteria by using ArcGIS9.3 spatial analysis tool. Factors derived have different degree of influence on wheat suitability evaluation. Hence, from the principal eigenvector calculation, the relative importance of each parameter has been determined. The decreasing of importance is rainfall 21.56%, Temperature 21.14%, soil depth 16.59%, phosphorus 9.49%, soil pH 7.13%, organic carbon 6.71%, Slope 5.5%, soil texture 4.5%, elevation 3.46%, Drainage 2.56%, and Land use/land cover 1.36%. Therefore the higher the weight, the more influence a particular factor will have in Wheat suitability evaluation. The suitability map is developed by using the following equation.

$$\mathbf{S} = \sum_{i=1}^{n} \mathbf{W}\boldsymbol{i} * \mathbf{F}\boldsymbol{i} \quad \text{................ (Eqn3.1)}$$

Where;

S = Suitability index (score)

W_i= weight of i^{th} factor

F_i= rank /rating of i^{th} factor

S=0.1659 SD + 0.2156RF+ 0.2114Tm+0.0949P+0.0713pH +0.0671OC +0.055S +0.045 ST + 0.0346EL +0.0256D +0.0136LU/C ………………………(Eqn3.2)

Where; P=Phosphorus ST = Soil texture

SD=Soil depth pH=Soil pH EL=elevation

RF=Rainfall OC = Organic Carbon D = drainage

Tm=Temperature S = Slope LU/C = land use/Cover

The factors involved were examined according to their relative importance in solving the stated problem and weights are assigned and used as indicated in equation3.2. Accordingly, all the reclassified factor layers are used in weighted overlay analysis. Then the suitability map for wheat has been prepared as shown in figure13.The suitability of the land for wheat production is constrained by phosphorus deficiency and organic matter, hence the land could be treated by application of chemical fertilizers those can provide sufficient amount of phosphorus and organic matter for wheat growth. In this study the two criteria P and OC are assumed non limiting factors and given ranking value of 5 (Highly suitable), then overlay analysis was done again to get the conditional suitability i.e. suitability of land after improvements for wheat crop. Hence wheat suitability improvements could be achieved by application of these chemical fertilizers at the rate to attain level of highly suitable (S_1).

Table 13.Wheat suitability

Suitability Classes	Area (km^2)	Area (%)
Permanently Not suitable	2.33	1.54
Marginally Suitable	4.85	3.21
Moderately suitable	129.56	85.80
Highly Suitable	14.26	9.45
Total	151.00	100.00

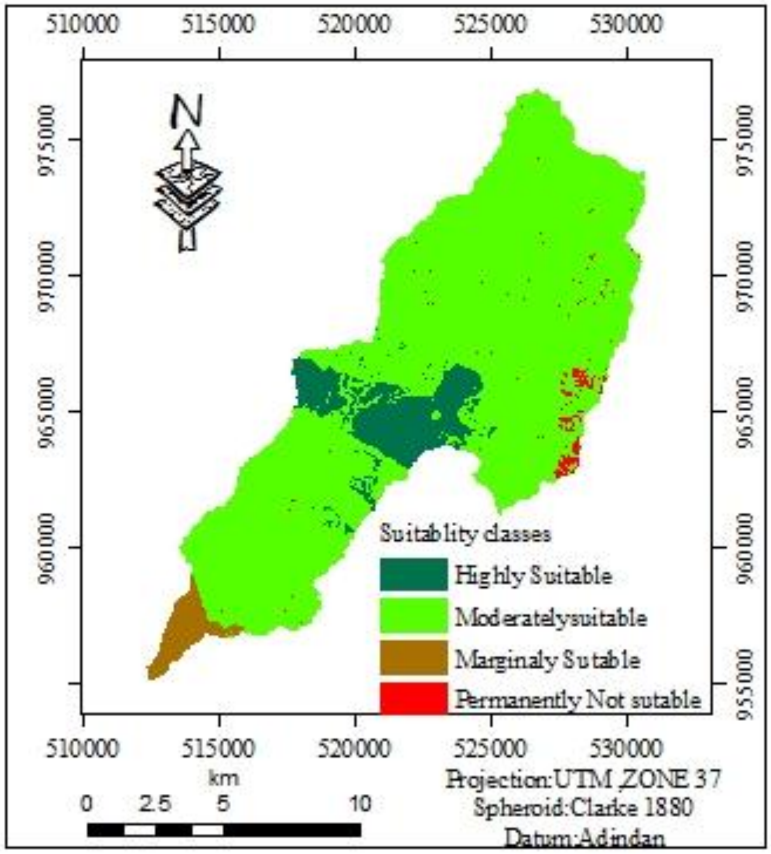

Figure 13.Initial Wheat suitability map

3.3.6. Validation of Wheat Suitability Map

To validate the suitability map of wheat about 50 ground points were collected and their respective land use/ land cover also recorded. These points were overlaid with wheat suitability map and their relative suitability classes were determined as indicated in table14.

Table14.Validation of initial wheat suitability

NO	Easting	Northing	Suitability	Land use/ Land cover	NO	Easting	Northing	Suitability	Land use/cover
1	518485.00	957074.00	S1	chick pea	26	527213.52	974492.61	S2	Wheat
2	518481.00	956938.00	S1	chick pea	27	518779.00	958649.14	S2	Wheat
3	521635.31	962643.16	S1	Grasses	28	527258.87	974473.95	S2	Wheat
4	524600.86	964388.86	S1	Grasses	29	527479.29	974332.20	S2	Wheat
5	524548.00	964340.50	S1	Grasses	30	527499.35	974276.72	S2	Wheat
6	517311.00	957606.00	S1	Teff	31	527647.53	974117.67	S2	Wheat
7	518430.00	957215.00	S1	Teff	32	527751.47	974120.86	S3	chick pea
8	518393.00	957020.00	S1	Teff	33	527952.62	974257.52	S3	chick pea
9	518329.00	956954.00	S1	Teff	34	527717.17	974114.93	S3	Wheat
10	523869.47	964123.75	S1	Teff	35	527802.41	974140.72	S3	Wheat
11	518471.00	957133.00	S1	Wheat	36	527850.59	974156.90	S3	Wheat
12	522880.79	964856.88	S2	chick pea	37	527881.39	974260.54	S3	Wheat
13	522913.06	964922.60	S2	chick pea	38	963608.11	528153.64	N2	Forest
14	523034.10	965021.48	S2	chick pea	39	963128.74	527901.34	N2	Forest
15	522916.32	965045.91	S2	chick pea	40	964592.08	527838.27	N2	Forest
16	522554.30	965939.49	S2	chick pea	41	966105.89	528330.25	N2	Forest
17	528016.68	975500.89	S2	chick pea	42	966471.73	528241.95	N2	Forest
18	522422.60	966368.74	S2	chick pea	43	965954.51	528658.24	N2	Forest
19	522462.07	966427.58	S2	chick pea	44	515501.00	958009.00	N2	Grazing
20	527144.31	974550.27	S2	chick pea	45	514934.00	958088.00	N2	Grazing
21	522961.50	966527.68	S2	Teff	46	516150.00	957877.00	N2	Grazing
22	523357.90	966498.68	S2	Teff	47	516730.00	957922.00	N2	Grazing
23	523498.68	966421.25	S2	Teff	48	521744.20	962496.17	N2	Settlement
24	523601.11	966418.76	S2	Teff	49	522786.93	963599.35	N2	Settlement
25	523995.86	966350.95	S2	Teff	50	528941.12	970838.71	N2	Settlement

3.3.7. Wheat Phosphorous Critical Level Determination

Relationships between plant growth and available nutrient supply typically follow a relationship of diminishing curve. The concept is when the plant nutrient is just at sufficiency level, as equal increments of a nutrient are applied to a crop; the yield response becomes smaller with each increment of Nutrient. In order to determine phosphorus critical for Wheat, at the Lume district Ziway Soil Research Center designed field trials for ten sites and conducted research continuously starting from 2005 to 2008, every year many types of data including grain yield for statistical analysis had been collected. The numbers of experimental treatments used were combined from four levels of phosphorus and nitrogen fertilizers to make sixteen treatments and two treatments were added to see response of wheat to potassium chloride (KCL) fertilizer application. The rates of fertilizers in kg per hectare in the each treatment for three fertilizers are illustrated in table15.

Table 15.Treatments and their Fertilizer combination

Treatment. No.	**Nitrogen (kg/ha)**	**Phosphorus (kg/ha)**	**Potassium (kg/ha)**
1	0	0	0
2	0	23	0
3	0	46	0
4	0	92	0
5	46	0	0
6	46	23	0
7	46	46	0
8	46	92	0
9	92	0	0
10	92	23	0
11	92	46	0
12	92	92	0
13	138	0	0
14	138	23	0
15	138	46	0
16	138	92	0
17	92	23	60
18	138	92	60

The above treatments are assigned to the plots randomly in a block with replication of two times by using lottery method randomization. The layout of the experimental design and treatments assigned are indicated in figure14, whereas the field picture of the experimental layout at date of planting is also shown in plate 5. Series of experiments were conducted in randomized complete block design with 18 treatments. The total area of experimental site was 36m*45m which equals 1620m^2 and sub divided into plots of 5m*8m equals 40m^2.The total number of plots at a single site was 36.

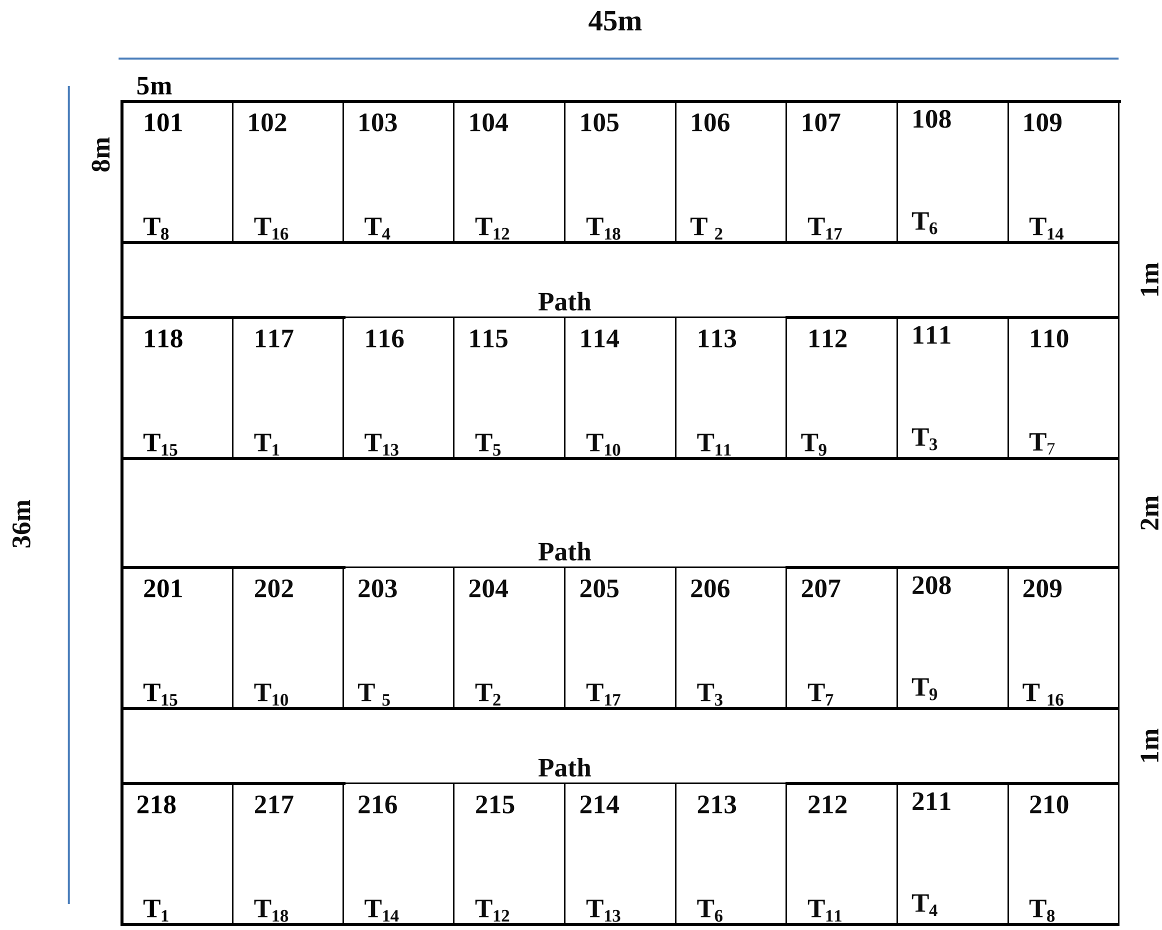

Figure 14. Experimental design of fertilizer calibration for Wheat

3.3.7.1. Field Experimental layout

The field experimental layout looks like as shown in plate5 i.e. a picture taken on date of planting while assigning treatments according to their combination on farm. After words the necessary data collection and managements of the crop provided without interruption until date of harvesting. These managements are to control other factors which influence yield and growth performance of the wheat.

Plate 5. Field experimental layout

3.3.7.2. Statistical Analysis

By using MstatC statistical analysis the wheat response to the applied different rates of fertilizers were determined. The mean separation was also done by using MstatC software to compare response of wheat to variable rate application of Potassium chloride (KCL). The correlation between phosphorus and relative grain yield of wheat was determined by using SPSS software.

3.3.7.3. Critical phosphorus level determination for wheat crop

The soil available phosphorus in ppm and relative grain yield were correlated and peak level was determined that point is critical phosphorus level where rate of grain yield per unit change of phosphorus in ppm starts decrease. The critical level point where yield of wheat in response of diammonium phosphate increase at decreasing rate. In figure15 the point equals to (17.5 ppm of available soil phosphorus and 67.4% of relative grain yield of wheat).This means, if initial phosphorus in soil is zero 192kg/ha DAP fertilizer is needed to bring the wheat grain yield could be none limited by phosphorus. The maximum yield at this point equals 42000 kg/ha.

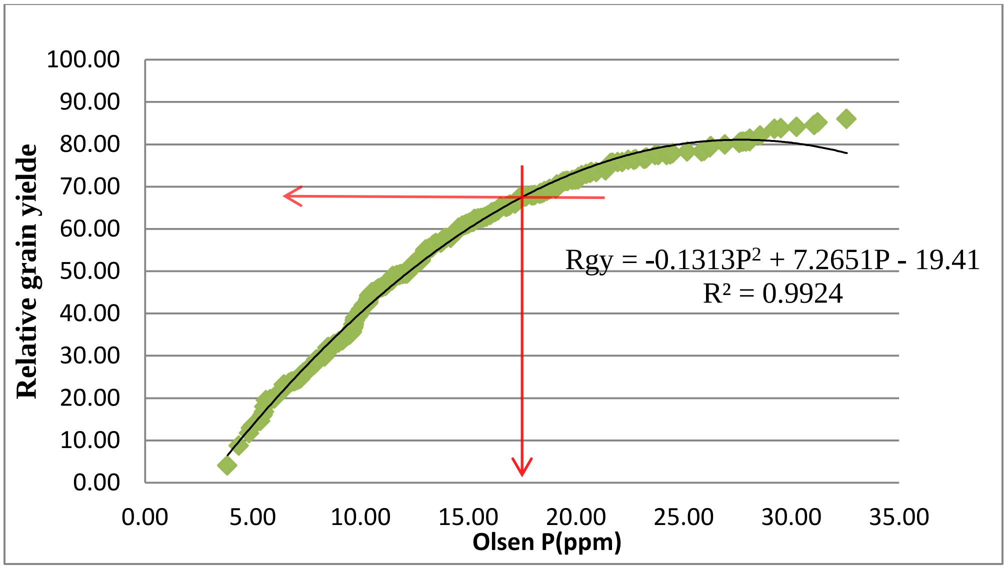

Figure 15. Phosphorus critical level for wheat crop

First used in USA Nelson and Anderson (1977) in Ethiopia Taye Bekele *et al.*(2000) for wheat and Yesuf Assen *et al.*(2005) for teff.

3.3.7.4. Fertilizer requirement mapping

Since the two potassium and nitrogen (urea) have none significant difference on yield of wheat and similar optimum level in using fertilizer respectively, the fertilizer requirement is made only for diammonium phosphate (DAP) in response of varying significantly from very low to high levels of available phosphorus in study area. The phosphorus requirement is calculated from (P_c-P_o) where; P_c is critical phosphorus for wheat at Lume micro watershed and P_o is initial phosphorus in soil in ppm.

Total DAP requirement per hectare was calculated from as the following equation

$$\textbf{DAP (kg/ha)} = \mathbf{P_r * P_f / (0.43*0.46)}$$

Where, P_r is phosphorus requirement in ppm and P_f is phosphorus requirement factor, which raise soil phosphorus by ppm. In this study $P_{f=}$ 2.16(Yesuf Assen *et al.*, 2005).

$$\textbf{DAP (kg/ha)} = \mathbf{P_r*2.16/ (0.43*0.46) =10.92 * P_r}$$

Therefore DAP in kg/ha for sixty sample points of available soil phosphorus have been calculated as indicated in appendices 1A.Then mapping of diammonium phosphate (DAP) was made by applying Kriging interpolation method in spatial analysis tool of ArcGIS9.3 software.

3.3.7.5. Validation of DAP requirement with wheat suitability model

In order to further evaluate the result, after mapping the fertilizer requirement for the study area, thirty five random soil samples with their coordinates were collected and analyzed at laboratory then have been overlain to fertilizer suitability map. Then their respective available phosphorus in ppm, DAP requirement in kg/ha and wheat suitability map were compared as shown in table16.

Table16.Diammonium phosphate requirement validation with wheat suitability

Soil sample points	Easting	Northing	Available P(ppm)	DAP (kg/ha)	Wheat Suitability model result
1	517303.59	959288.48	15.75	**25-50**	Moderately suitable
3	522185.70	963659.14	23.18		Highly suitable
4	521627.75	963194.17	15.37		Highly suitable
5	520465.34	962264.25	18.47		Highly suitable
7	518744.98	962264.25	14.01		Moderately suitable
8	518837.97	960776.36	21.25		Moderately suitable
9	521953.22	964356.58	19.01		Highly suitable
10	520325.85	964356.58	19.09		Highly suitable
12	520372.35	963101.18	12.32		Moderately suitable
13	525207.97	965379.50	8.19	**50-75**	Moderately suitable
14	527951.25	969238.69	10.99		Moderately suitable
16	530136.58	972121.47	7.47		Moderately suitable
17	527253.80	964310.08	9.03		Moderately suitable
18	525579.94	962357.24	7.50		Moderately suitable
19	523022.64	964821.54	10.45		Moderately suitable
20	516931.62	958312.06	10.01		Moderately suitable
21	516513.15	963054.68	8.73		Moderately suitable
22	519302.93	964728.55	9.68		Moderately suitable
23	528044.24	970959.06	10.38		Moderately suitable
24	527393.29	973516.36	7.07	**75-100**	Moderately suitable
25	514002.35	957986.58	5.03		Marginally suitable
26	526044.90	971191.54	6.11		Moderately suitable
27	513358.63	956813.36	6.30		Marginally suitable
28	514908.15	957130.31	5.70		Marginally suitable
29	522139.21	969285.19	7.23		Moderately suitable
30	514048.85	957242.64	7.01		Marginally suitable
31	523766.58	971888.99	2.62	**> 100**	Moderately suitable
32	524789.50	973283.87	4.49		Moderately suitable
33	522071.69	970718.36	5.00		Moderately suitable
34	523221.81	971052.26	4.67		Moderately suitable
35	522813.70	970236.05	3.92		Moderately suitable

4. RESULTS AND DISCUSSION

4.1. Results

Soil is source of nutrients for the growth of plants and proximity where interaction takes place. These conditions vary spatially and need managements and tools suitable for assessment and quantification. By using recommended soil testing methods the soil parameters analyzed to achieve the objectives of the study and the following results have been generalized according to their influence on wheat growth. The soil samples collected with geographical coordinate points those created more conformability for relating soil attribute data and spatial data for the application of GIS in order to generalize in respect of their spatial variability and way of application demanded by development agents, farmers, investors and policy makers.

4.1.1. Potassium

The results of laboratory analysis indicates greater values of potassium in the study site than the plant growth limiting ranges of soil potassium level, which ranges from 221.53 to 372.11ppm. In order to show the results of potassium level at study area, the map was prepared as indicated in figure16C.

4.1.2. Nitrogen and Organic Carbon

The total nitrogen is not suitable to recommend nitrogen fertilizer therefore the organic carbon is used and indicated instead of total nitrogen. That is why; fertilizer application is made on the basis of statistical analysis of wheat responses to variable rate application of Urea fertilizer (Esteban, 2011).The soil organic carbon results are characterized by low coefficient of variation. The statistical analysis of soil organic carbon and total nitrogen were shown in table17. For the sake of illustration organic carbon level and total nitrogen has been indicated in figure16A and B.

Table17.Stastical Parameters of Organic carbon and Total Nitrogen

No	Stastistical parameter	Organic carbon (%)	Total Nitrogen (%)
1	Minimum	0.402	0.07
2	Maximum	0.735	0.138
3	Mean	0.572	0.1124
4	Standard deviation	0.066	0.016
5	Coefficient of variation	11.54%	14.23%

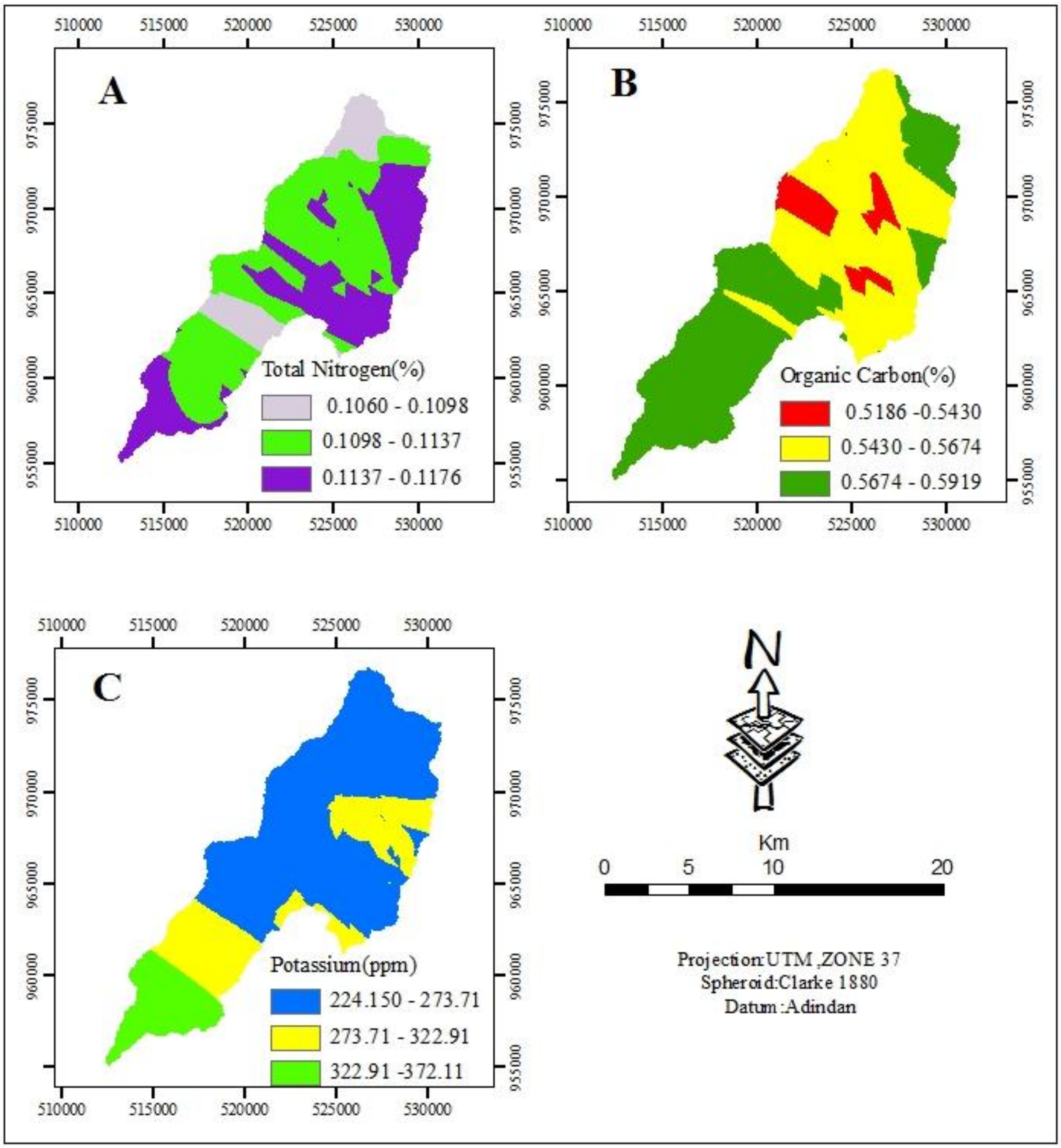

Figure 16. Soil: Total Nitrogen (A), Organic Carbon (B) and Potassium (C)

4.1.3. Phosphorus

The Olsen values of available phosphorus in the soil for the study area ranges from 2.62 to 23.17 in ppm. The classification of phosphorus was made according to Esteban (2011) that was on the basis of its suitability for agricultural crop production and it has four classes as indicated in table18.

Table18.Classification of available phosphorus

No	Av.phosphorus (ppm)	Classification	Area(km^2)	Area(%)
1	2.62-7	Very Low	9.64	6.38
2	7-14	Low	110.48	73.16
3	14-22	Moderate	30.75	20.36
4	22-23.17	High	0.14	0.09
Total			151.00	100.00

The available phosphorus level in Lume micro watershed is categorized as very low, low, moderate and high which account about 6.38%, 73.16%, 20.36% and 0.9% respectively. The dominating class is low which is 7-14ppm of available phosphorus and accounts more than 73% of the area where as the least dominant is high which is less than 1% of the area. The map of available phosphorus for the Lume micro watershed is illustrated in figure17.

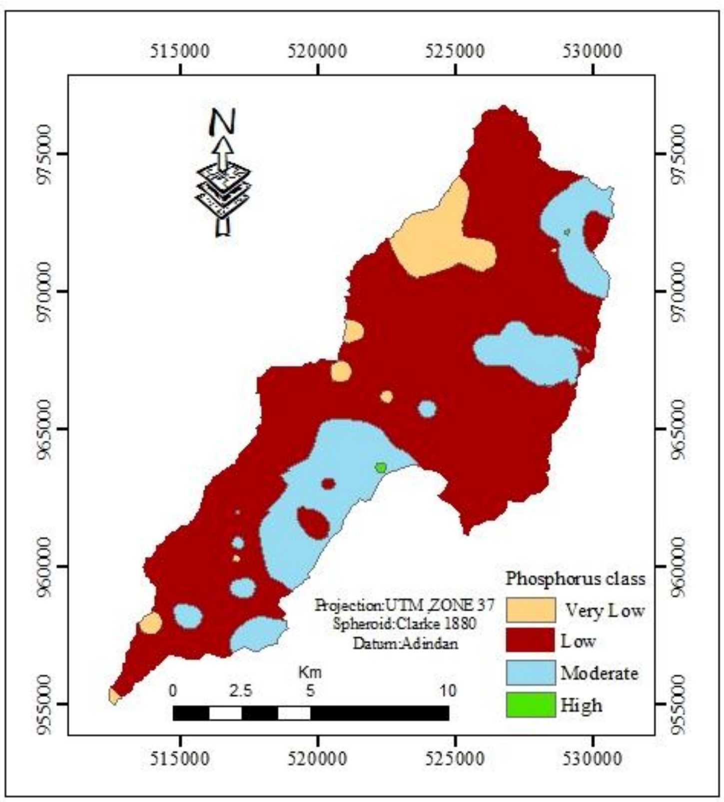

Figure17. Soil available phosphorus

4.1.4. Wheat Suitability Analysis

The application of chemical fertilizers diammonium phosphate and urea can change suitability of the study area for wheat. That mean highly suitable class could be increased by 61.1% of the area and about 3.2% of the area could also be improved from marginally suitable lands for wheat production. Permanently not suitable classes are the forest and settlement those have been restricted from weighted overlay analysis, hence they have no change. Table19 shows the possible suitability improvements in percentage and km^2. The relative graphical comparison of suitability classes improvements are shown in figure 18. The initial map of wheat suitability has been shown as figure 19 A and final map i.e. after possible land improvements is also shown in figure 19 B.

Table19.Suitability improvements

Suitability Classes	Area(km^2)		Improvements	
	Without fertilizers	After fertilization	Change (km^2)	Change (%)
Permanently Not Suitable	2.33	2.33	0.00	0.0
Marginally Suitable	4.85	0.00	-4.85	-3.2
Moderately Suitable	129.56	42.78	-86.78	-57.9
Highly Suitable	14.26	105.88	91.62	61.1
Total	151.00	151.00	0.00	0.0

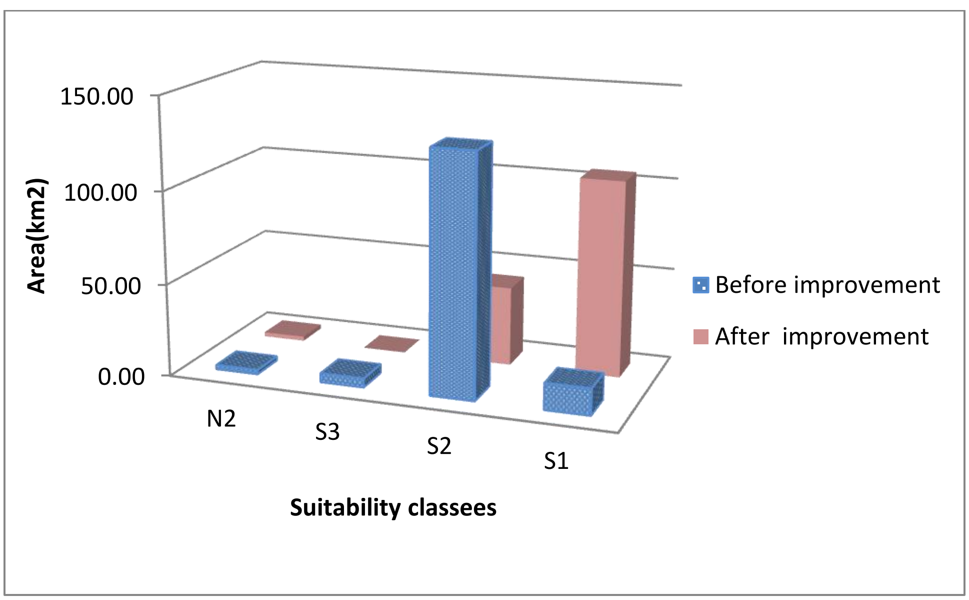

Figure 18. Wheat suitability improvements

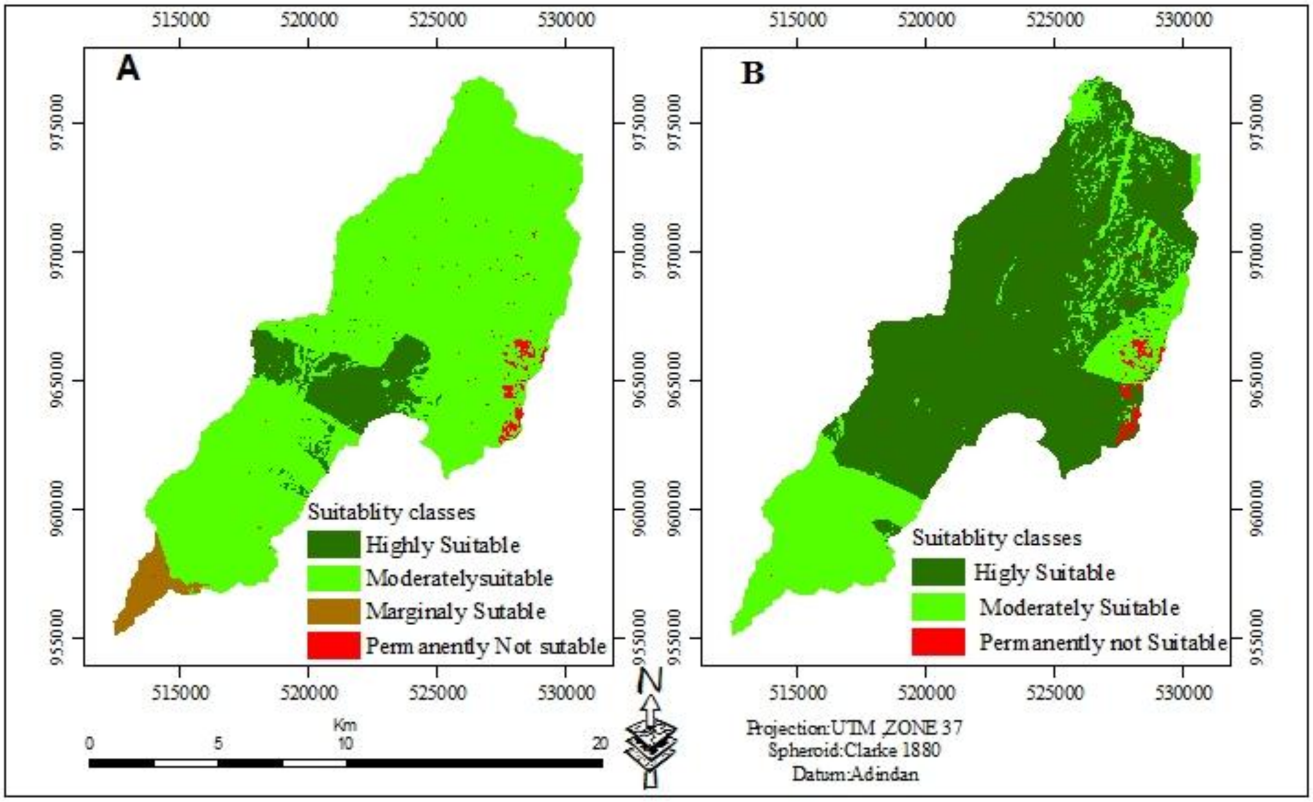

Figure 19.Wheat Suitability: initial (A) and final (B)

4.1.5. Diammonium phosphate (DAP) Suitability Mapping

The fertilizer requirements in Lume micro watershed was mapped by interval of 25kg/ha of diammonium phosphate in consideration of market availability, transportation and packing system.About51.38%,20.25%,18.40%, 8.43% and1.54% are requiring 50-75kg/ha, 75-100kg/ha,25-50kg/ha, >100kg/ha and restricted respectively. The area coverage, DAP requirement and percentage to the whole study area are presented in table20whereas the map of diammonium phosphate is shown in figure 20.

Table 20.DAP requirement in kg/ha

DAP (kg/ha)	Area(km^2)	Area(%)
25-50kg/ha	27.78	18.40
50-75 kg/ha	77.58	51.38
75-100Kg/ha	30.58	20.25
100-115kg/ha	12.73	8.43
Restricted	2.33	1.54
Total	151.00	100.00

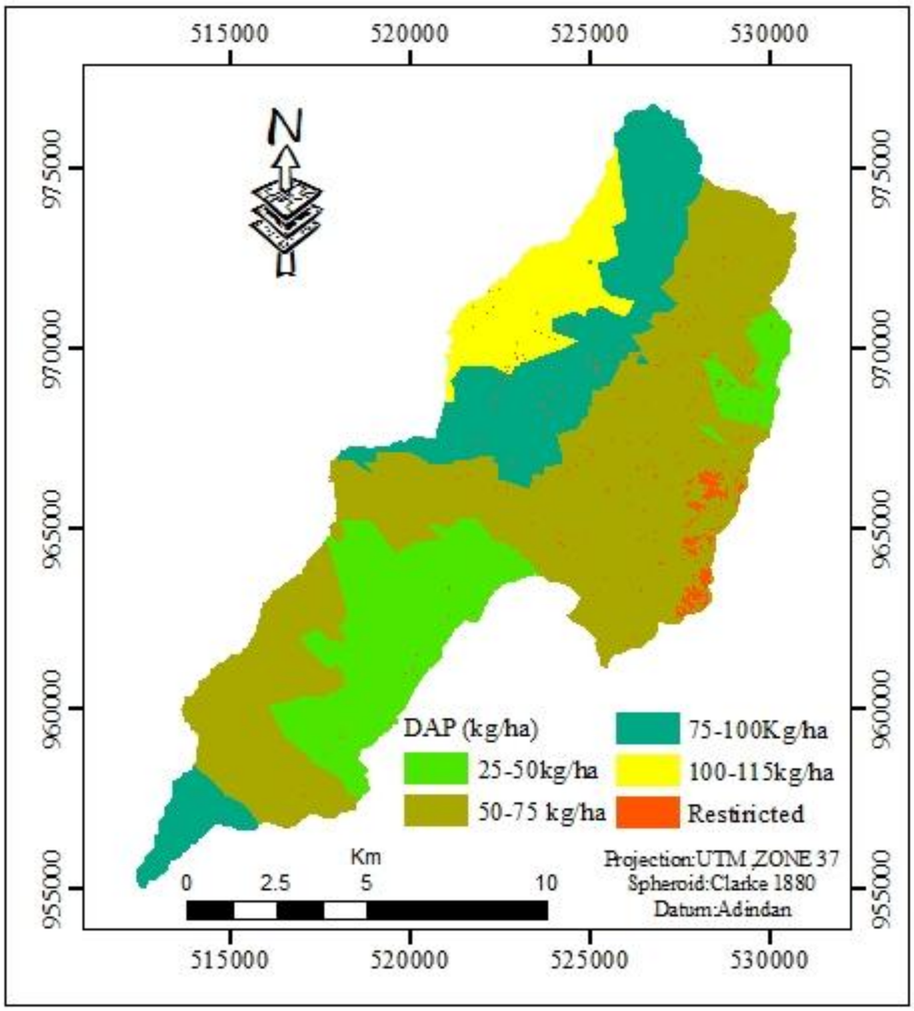

Figure 20. Diammonium phosphate suitability for wheat crop

4.2. Discussion

The evaluation of soil characteristics such as; soil nutrient level, nutrient uptake by crops, and nutrient loss by soil erosion are very much related to spatial data. GIS and remote sensing are very effective tools in modeling nutrient status at various locations of a given study area (Soe*et al*., 2011). The tools also help in determining crop production limiting factors through multicriteria decision analysis. Spatial data used in this study includes; land use/land cover, climatic factors (rainfall and temperature), soil characteristics (texture, depth, organic matter, Phosphorous and Potassium content of a soil system) and topography (elevation and slope percent).

4.2.1. Soil potassium

The results of laboratory analysis indicate greater values of potassium in the study site than the plant growth limiting ranges of soil potassium level, which ranges from 221.53 to 372.11ppm.In addition the response of wheat is none significant to variable rate application of potassium chloride (KCL) fertilizer. The outputs of mean separation analysis of least significance difference (LSD) at significance level of 5% show that treatment18 and treatment16; treatment17 and treatment 15 have none significant difference in grain yield response of wheat. The LSD analysis output is shown in appendixes 4. In the some context Gourley (1999) stated the Critical values for K that begin to limit plant growth are about 80 to 200 ppm. In Ethiopia near Ambo area Louis (2010) reported that there were ranges of available potassium content (240-496 ppm), which was found to be medium in Awaro soil but high in the other three soil samples. Abay Ayalew and Sheleme Beyene (2011) reported that application of K did not significantly influence potato tuber yield, N, P and K concentrations both in leaf and tuber, exchangeable and available potassium in the soil. In case of this study the status of potassium level in the surface soil of Lume micro watershed is much more than the values which limit the growth of wheat in the study area. Therefore, there is no need to use potassium fertilizer input in wheat crop production. If there is greater the proportion of clay minerals high in potassium, there could be greater the potential availability of soil potassium for crop production (Samuel *et al*., 2003). Hence, based on the current finding there is no need to manage potassium variability in the study area to have optimum economic production of wheat. However, as wheat is K demanding crop, periodic checking of the potassium status of the soil and crop response to it is important.

4.2.2. Nitrogen and Organic Carbon

The effects of different land uses on soil organic carbon and total nitrogen were investigated and reported in the manner of soil organic carbon and total nitrogen were responsive to land use change (Yifru Abera and Taye Belachew, 2011). The cultivation of highlands of Ethiopia for long period of time without proper land management systems made low in total nitrogen and organic carbon. The total nitrogen is not suitable to recommend nitrogen fertilizers because of total nitrogen cannot be used as a measure of the mineralized forms of nitrogen (NH_4^+,NO_3^- and NO_2^-)(Esteban,2011). Therefore mostly organic carbon is used and indicated instead of total nitrogen. In this fertilizer recommendation is made on the basis of statistical analysis of Wheat responses to variable rate application of Urea fertilizer; which is about200kg/ha for the whole study area. The ANOVA analysis is shown in Appendixes 3 indicates treatment 15 is optimum urea application combination. The reason is due to organic carbon spatial variability is insignificant i.e. soil organic carbon results are characterized by low coefficient of variation as indicated in Appendixes 6.

4.2.3. Phosphorus

The Olsen values of available phosphorus in the soil for study area ranges from 2.62 to 23.17 in ppm. The classification of phosphorus was made according to (Esteban, 2011) that was on the basis of its suitability for major agricultural crops production. The available phosphorus level in Lume micro watershed is categorized as very low, low, moderate and High which accounts about6.38%, 73.16%, 20.36% and 0.9% respectively. The dominating class is low which is 7-14ppm of available soil phosphorus and accounts more than 73% of the area whereas the least dominant is high, which is less than 1% of the area. In Ambo area Louis (2010) reported that there were similarities in the relatively low content of available phosphorus (1.4-2.4ppm) in all the soil samples. Most Ethiopian soils including Vertisols are deficient in P when analyzed by chemical methods yet (Tekalgn Mamo *et al.*, 1993).

4.2.4. Wheat Suitability Analysis

Land improvements are activities which cause beneficial changes in the qualities of the land itself. Land improvements are different from improvements in land use i.e. changes in the use to which the land is put or modifications to management practices under a given use (FAO,1976). In this paper only the land improvement is proposed to be performed for wheat crop production.

The first two main objectives of land evaluation are; how the land is currently managed and what will happen if present practices remain unchanged, and what improvements in management practices within the present use are possible (FAO, 1976). In this study, to determine the growth limiting or yield reducing factors of the study area for wheat production, factors such as; soil depth, soil texture, drainage, soil pH, organic carbon, phosphorus, temperature, rainfall, elevation, slope and land use/land cover are evaluated to wheat requirements and initial land suitability for wheat has been prepared. The suitability classes are highly suitable, moderately suitable, marginal suitable and permanently not suitable that account about 9.53%, 86.38%, 2.78% and 1.27% respectively. In the upper Awash basin DulaWakassa (2010) reported that only 21.1%, 18.3%, and 2.0% of the study area is highly suitable for teff, wheat, and chickpea, respectively.

In order to indicate land improvements could be possible for wheat production, the amendable chemical properties of the soil like available phosphorus and organic matter of the soil threated individually to the critical requirement level of wheat and the conditional suitability map for Lume micro watershed has been prepared. The level of improvement in suitability classes of the study area are determined and mapped, therefore the optimum level of urea ($CO\ (NH_3)$) fertilizer is 200kg/ha. Diammonium phosphate($(NH_4)_2\ HPO_4$)is varying significantly within the Lume micro watershed, hence variable management is economically beneficial rather than whole blanket recommendation of DAP. The applications of chemical fertilizers DAP and urea can change suitability of the study area. The improvement could be highly suitability increased by 61% of the area and the about 3.2% of the area could be improved from marginally suitable lands for wheat production.

4.2.5. Diammonium phosphate (DAP) Suitability Mapping

Phosphorus (P) is one of the 16 essential nutrients needed for plant growth, and it is the second most important nutrient needed for major crops. Because farming is a business, making any decision to purchase nutrients needs to be based on economic benefits (Charles *et al*., 2009). The fertilizer which is source of phosphorus and mostly used in Ethiopia is DAP. This fertilizer is very expensive than Urea, so that efficient application for each crop production. In this study, wheat phosphorus critical level is determined and DAP requirement is mapped. From the soil samples collected soil parameter available phosphorus, total nitrogen, available potassium, soil pH and organic carbon has been analyzed and interpreted. The soil organic carbon and soil nitrogen are very low; hence need general optimum level of nitrogen fertilizer like Urea is practiced in the study area. These results are indicative of variable farming even to a farm level than past FAO (1980) general fertilizer recommendation at national, regional and zonal level land managements. The diammonium phosphate fertilizer requirements in Lume micro watershed was mapped by interval of 25kg/ha of DAP, about 51.38%, 20.25%, 18.40%, 8.43% and 1.54% are requiring 50-75kg/ha, 75-100kg/ha, 25-50kg/ha, >100 kg/ha and restricted respectively. The results are further verified by using soil sample points and their available soil phosphorus compared to diammonium phosphate suitability map and initial wheat suitability map of the study area. The validation revealed that the results are in good conformity with the actual soil available phosphorus and wheat suitability map.

5. Conclusion and Recommendations

5.1. Conclusion

The study has been conducted to prepare map of variable rate of fertilizer application to soil for Agricultural production .To conduct this research different methodologies were applied starting from soil sampling, sample analysis at laboratories, field experiments of wheat and statistical analysis, using remote sensing for satellite image processing, GIS application for spatial analysis and mapping of outputs. The objectives of the study were particularly to evaluate land suitability for wheat, to map soil NPK and prepare fertilizer requirement map. The results reveal that the study area/Lume micro watershed has not yet been low in potassium for wheat production. The total nitrogen and organic carbon of the area are very low with low coefficient of variation, hence left for uniform optimum recommendation of Urea fertilizer, which is about 200kg/ha. The results of land suitability for wheat shows that initial land suitability for wheat was about 9.45% highly suitable, 85.8% moderately suitable, 3.21% marginally suitable and 1.54% permanently not suitable. If soil organic carbon and phosphorus is treated by Urea and DAP fertilizer application respectively, the suitability for wheat could be improved to70.12% highly suitable, 28.33% moderately suitable and 1.54% permanently not suitable. The DAP requirement map of the area was made by using the phosphorus critical level for wheat growth and the result reveals that about 51.38%,20.25%,18.43% and 8.43% need 50 to75 kg/ha, 75 to 100kg/ha, 25 to 50kg/ha and greater than 100kg/ha of DAP respectively. Due to land use/ land cover of the area such as forest and settlement are considered as restricted which account about1.54% of the study area. More than 51% of the area requires about the 50 to75 kg/ha of DAP for production of wheat crop. Only about 8% of the area needs more than 100kg/ha of DAP. The validation revealed that the results are in good conformity with the actual soil available phosphorus and wheat suitability map.

5.2. Recommendations

- The study should be continued for the different crops like teff and chickpea, in order to determine the soil capability and efficient levels of fertilizer requirements.
- The result only indicates the phosphorus variability and organic matter deficiency and recommended the general optimum level of Urea and variable rate of DAP on the response of grain yield of wheat; but there may also be micronutrients deficiency in the study area, which may not have impact on quantity of grain yield but on nutritional values, therefore this invites further detail studies in study area.
- The map of diammonium phosphate fertilizer rate could be used in the study area by development agents in order to guide farmers as fertilizer application rate with more validation test of soil parameters at laboratories and also independently.
- The use of this approach by incorporating more detail variables/factors for other agricultural researches could also be another research call.
- For farther researches like Nutrients balance, surface runoff and detail soil survey, the watershed delineated can serve as initial base map.
- The result could also be extrapolated to watersheds those have similar morphologies, soils and agro climatic zones.
- The drainage density should be considered while using the result, that is overlay analysis to the recommended buffered drainage stream features.

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Appendices

Appendices 1A. DAP requirement determination for wheat

$P_{critical}$(ppm)	Initial P(ppm)	R $_{requirement}$ (P_c-P_o)	P(kg/ha)(P_r *P_{rf})	DAP(kg/ha)or (P(kg/ha)/.46/.43)
17.5	23.18	-5.68	0	0
	22.72	-5.22	0	0
	21.25	-3.75	0	0
	19.49	-1.99	0	0
	19.09	-1.59	0	0
	19.01	-1.51	0	0
	18.51	-1.01	0	0
	18.47	-0.97	0	0
	17.69	-0.19	0	0
	17.41	0.09	0.19	0.98
	17.28	0.22	0.48	2.40
	16.83	0.67	1.45	7.32
	16.5	1	2.16	10.92
	16.07	1.43	3.09	15.62
	15.98	1.52	3.28	16.60
	15.75	1.75	3.78	19.11
	15.37	2.13	4.60	23.26
	15.12	2.38	5.14	25.99
	15.11	2.39	5.16	26.10
	14.01	3.49	7.54	38.11
	14.01	3.49	7.54	38.11
	13.34	4.16	8.99	45.43
	13.32	4.18	9.03	45.65
	13.04	4.46	9.63	48.70
	12.79	4.71	10.17	51.43
	12.43	5.07	10.95	55.37
	11.65	5.85	12.64	63.88
	11.19	6.31	13.63	68.91
	10.99	6.51	14.06	71.09
	10.77	6.73	14.54	73.49
	10.7	6.8	14.69	74.26
	10.55	6.95	15.01	75.89
	10.45	7.05	15.23	76.99
	10.38	7.12	15.38	77.75
	10.18	7.32	15.81	79.94
	10.1	7.4	15.98	80.81
	9.98	7.52	16.24	82.12
	9.69	7.81	16.87	85.29
	9.28	8.22	17.76	89.76
	9.03	8.47	18.30	92.49
	8.92	8.58	18.53	93.69
	8.73	8.77	18.94	95.77

	8.2	9.3	20.09	101.56
	8.2	9.3	20.09	101.56
	8.19	9.31	20.11	101.67
	8.11	9.39	20.28	102.54
	7.5	10	21.60	109.20
	7.47	10.03	21.66	109.53
	7.23	10.27	22.18	112.15
	7.11	10.39	22.44	113.46
	7.07	10.43	22.53	113.90
	7.01	10.49	22.66	114.55
	6.55	10.95	23.65	119.58
	6.25	11.25	24.30	122.85
	6.25	11.25	24.30	122.85
	6.11	11.39	24.60	124.38
	6	11.5	24.84	125.58
	5.25	12.25	26.46	133.77
	5.03	12.47	26.94	136.17
	5.02	12.48	26.96	136.28
	4.94	12.56	27.13	137.16
	3.21	14.29	30.87	156.05
	2.62	14.88	32.14	162.49

Appendices1B. P requirement factor determination

Fertilizer Treatment Kg P/ha	Olsen P(ppm) Range	Average Olsen P (ppm)	P increase over control	P requirement factor kg P /ppm P
0	3.83 - 23.25	13.54		
4.55	5.36 - 26.23	15.8	2.26	2.01
9.1	4.84 - 31.08	17.96	4.42	2.06
18.2	6.45 -35.77	21.11	7.57	2.40
	Mean			**2.16**

Appendices 2.Soil Analysis Results

No	Easting	Northing	Av. Phosphorus (ppm)	Soil pH	Potassium (ppm)	Total N(%)	Organic Carbon (%)	EC (mmhos/cm)
1	514102.11	514102.11	7.01	7.94	431.86	0.1360	0.5860	220.94
2	516969.58	516969.58	10.10	8.03	327.04	0.0880	0.4860	238.29
3	517030.37	517030.37	6.00	8.12	291.20	0.0700	0.5190	181.68
4	517060.77	517060.77	15.11	7.78	335.69	0.1180	0.6280	223.79
5	517074.54	517074.54	14.01	7.72	291.20	0.1170	0.6280	250.72
6	519360.84	519360.84	9.69	7.91	228.98	0.1060	0.5470	287.06
7	522486.24	522486.24	6.25	7.96	189.34	0.1240	0.5170	253.78
8	526033.12	526033.12	6.11	8.16	189.15	0.1380	0.5560	213.16
9	526554.29	526554.29	13.04	7.60	389.83	0.1160	0.7130	337.73
10	526684.58	526684.58	8.20	8.08	218.86	0.0930	0.5800	295.31
11	520821.38	520821.38	6.25	7.94	169.75	0.1050	0.5240	263.75
12	522115.22	522115.22	8.11	8.12	247.19	0.1190	0.5240	204.62
13	525903.94	525903.94	12.43	7.89	503.23	0.1340	0.5590	287.62
14	526291.11	526291.11	7.11	8.08	170.59	0.1060	0.4860	221.79
15	528614.11	528614.11	5.02	8.42	195.41	0.0960	0.5280	159.60
16	527481.43	527481.43	7.07	7.94	209.49	0.1210	0.5680	238.40
17	524731.47	524731.47	4.94	8.08	218.82	0.1210	0.4020	243.89
18	521700.40	521700.40	10.18	6.82	280.43	0.1180	0.7350	98.76
19	522124.32	522124.32	7.23	7.90	243.64	0.0890	0.5270	174.06
20	521251.10	521251.10	6.55	7.86	290.16	0.1180	0.5840	231.44
21	523752.46	523752.46	2.62	8.16	161.18	0.0890	0.4660	262.24
22	526014.58	526014.58	5.25	8.05	234.35	0.1040	0.5480	252.30
23	520376.16	520376.16	13.32	7.84	277.28	0.1330	0.6290	244.36
24	515293.58	515293.58	10.77	7.82	345.98	0.1190	0.6090	218.95
25	518811.84	518811.84	14.01	7.82	294.32	0.1170	0.6280	250.72
26	530151.27	530151.27	7.47	7.88	272.07	0.1180	0.6280	241.91
27	513083.84	513083.84	8.92	7.94	431.86	0.1360	0.5860	220.94
28	530685.79	530685.79	16.50	7.89	272.08	0.1180	0.6280	241.91
29	527298.51	527298.51	8.20	8.08	218.86	0.0930	0.5800	295.31
30	513474.87	513474.87	8.92	7.94	431.86	0.1360	0.5860	220.94

Appendices 3.ANOVA1 analysis for mean separation

Title: ANOVAwheat
Function: ANOVA-1
Data case no. 1 to 288
One way ANOVA grouped over variable 4 (Treatment (1-18)) with values from 1 to 18.
Variable 8 (Grain yield (kg/ha))

A N A L Y S I S   O F   V A R I A N C E   T A B L E

	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob.
Between	17	243912362.338	14347786.020	26.777	0.0000
Within	270	144670553.570	535816.865		
Total	287	388582915.908			

Coefficient of Variation = 20.91%

Var. V A R I A B L E No. 8

4	Number	Sum	Average	SD	SE
1	16.00	30957.190	1934.824	671.02	183.00
2	16.00	30011.980	1875.749	613.65	183.00
3	16.00	32034.980	2002.186	910.90	183.00
4	16.00	32259.180	2016.199	669.85	183.00
5	16.00	50440.490	3152.531	673.20	183.00
6	16.00	53321.840	3332.615	879.99	183.00
7	16.00	52667.560	3291.722	784.84	183.00
8	16.00	52979.310	3311.207	837.73	183.00
9	16.00	61850.951	3865.684	774.15	183.00
10	16.00	65985.120	4124.070	1043.95	183.00
11	16.00	64194.350	4012.147	651.81	183.00
12	16.00	66920.161	4182.510	629.89	183.00
13	16.00	65958.250	4122.391	525.82	183.00
14	16.00	68152.100	4259.506	664.41	183.00
15	16.00	71244.190	4452.762	778.54	183.00
16	16.00	70735.880	4420.993	423.40	183.00
17	16.00	65141.590	4071.349	786.80	183.00
18	16.00	73422.671	4588.917	600.80	183.00
Total	288.00	1008277.793	3500.965	1163.59	68.57
Within				732.00	

Bartlett's test

Chi-square = 21.177
Number of Degrees of Freedom = 17
Approximate significance = 0.000

Appendices 4.Mean separation analysis by LSD

```
Data File: TADE12
Title: ANOVAwheat
Case Range: 289 - 306
Variable 8: Grain yield (kg/ha)
Function: RANGE
Error Mean Square = 5.358e+005
Error Degrees of Freedom = 17
No. of observations to calculate a mean = 16
Least Significant Difference Test
LSD value = 546.0      at alpha = 0.050

       Original Order                 Ranked Order

Mean    1 =    1935.        F     Mean   18 =    4589.  A
Mean    2 =    1876.        F     Mean   15 =    4453.  AB
Mean    3 =    2002.        F     Mean   16 =    4421.  AB
Mean    4 =    2016.        F     Mean   14 =    4260.  ABC
Mean    5 =    3153.       E      Mean   12 =    4183.  ABC
Mean    6 =    3333.      DE      Mean   10 =    4124.  ABC
Mean    7 =    3292.       E      Mean   13 =    4122.  ABC
Mean    8 =    3311.       E      Mean   17 =    4071.  ABC
Mean    9 =    3866.     CD       Mean   11 =    4012.   BC
Mean   10 =    4124.  ABC         Mean    9 =    3866.    CD
Mean   11 =    4012.   BC         Mean    6 =    3333.     DE
Mean   12 =    4183.  ABC         Mean    8 =    3311.      E
Mean   13 =    4122.  ABC         Mean    7 =    3292.      E
Mean   14 =    4260.  ABC         Mean    5 =    3153.      E
Mean   15 =    4453.  AB          Mean    4 =    2016.       F
Mean   16 =    4421.  AB          Mean    3 =    2002.       F
Mean   17 =    4071.  ABC         Mean    1 =    1935.       F
Mean   18 =    4589.  A           Mean    2 =    1876.       F
```

Appendices 5. ANOVA analysis for two factor interaction

```
Data file:TADE12
Title: ANOVAwheat
Function: FACTOR
Experiment Model Number 8: Two Factor Randomized Complete Block Design
Data case no. 73 to 104.
Factorial ANOVA for the factors: Replication (Var 3: Replication (1-2))
with values from 1 to 2
Factor A (Var 5: Nitrogen (1-4:1=0; 2=46; 3=92; 4=138kgUrea/ha)) with
values from 1 to 4
Factor B (Var 6: Phosphorus (1-4:1=0; 2=23; 3=46; 4=92kDAP/ha)) with
values from 1 to 4
                      Variable 8: Grain yield (kg/ha)

Grand Mean = 3840.293   Grand Sum = 122889.380   Total Count = 32
```

T A B L E   O F   M E A N S

3	5	6	8	Total
1	*	*	3856.564	61705.030
2	*	*	3824.022	61184.350
*	1	*	2213.119	17704.950
*	2	*	3868.001	30944.010
*	3	*	4474.680	35797.440
*	4	*	4805.372	38442.980
*	*	1	3613.446	28907.570
*	*	2	3922.136	31377.090
*	*	3	3994.506	31956.050
*	*	4	3831.084	30648.670
*	1	1	2030.715	4061.430
*	1	2	2425.325	4850.650
*	1	3	2127.090	4254.180
*	1	4	2269.345	4538.690
*	2	1	3642.540	7285.080
*	2	2	4467.670	8935.340
*	2	3	3756.985	7513.970
*	2	4	3604.810	7209.620
*	3	1	4197.745	8395.490
*	3	2	4200.945	8401.890
*	3	3	4521.730	9043.460
*	3	4	4978.300	9956.600
*	4	1	4582.785	9165.570
*	4	2	4594.605	9189.210
*	4	3	5572.220	11144.440
*	4	4	4471.880	8943.760

A N A L Y S I S   O F   V A R I A N C E   T A B L E

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	1	8472.104	8472.104	0.0509	
2	Factor A	3	31858312.625	10619437.54	63.7916	0.0000
4	Factor B	3	656194.441	218731.480	1.3139	0.3066
6	AB	9	2907016.828	323001.870	1.9403	0.1232
-7	Error	15	2497062.359	166470.824		
	Total	31	37927058.357			

Coefficient of Variation: 10.62%

$s_{\bar{y}}$ for means group 1: 102.0021 Number of Observations: 16

$s_{\bar{y}}$ for means group 2: 144.2527 Number of Observations: 8

$s_{\bar{y}}$ for means group 4: 144.2527 Number of Observations: 8

$s_{\bar{y}}$ for means group 6: 288.5055 Number of Observations: 2

Appendices 6.Correlation analysis for total nitrogen and organic carbon

```
Datafile: SOILPNK
Title: correNOC
Function: CORR
Data case no. 1 to 30
 ------------------------------------------------------------------------
TN (%)
 Variable    4   Average =       0.11
 Variance =        0.00
 OC (%)
Variable    5   Average =       0.57
 Variance =        0.00
 Number = 30
 Covariance =   0.00    Correlation =    0.345
 Intercept =    0.41    Slope =    1.392    Standard Error =    0.716
 Student's T value =     1.945    Probability = 0.062
 ------------------------------------------------------------------------
```

D E C L A R A T I O N

I hereby declare that the thesis entitled "GIS and Remote Sensing Based Fertilizer Suitability Suitability Mapping for Wheat (*Triticum aestivum*) at Lume Micro Watershed, Central Ethiopia"has been carried out by me under the supervision of Dr. K. V.Suryabhagavan, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2012 as a part of Master of Science program in Geoinformation Science. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Tadesse Hunduma

Signature: ________________________

Addis Ababa University

Addis Ababa

Date: June, 2012