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ADDIS ABABA UNIVERSITY

School of Earth Sciences: Remote Sensing and GIS Stream

IDENTIFICATION OF SUITABLE LAND FOR RICE CULTIVATION USING REMOTE SENSING AND GIS IN ETHIOPIA: GAMBELLA REGIONAL STATE: A CASE STUDY IN GOG WOREDA

BY

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School of Earth Sciences: Remote Sensing and GIS Stream

Msc Program

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A CASE STUDY IN GOG WOREDA

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Declaration

I, Solomon Tesfamariam declare that this work entitled **“Identification of Suitable Land for Rice Cultivation Using Remote Sensing and Geographical Information System (GIS) In Ethiopia: Gambella Regional State: A case Study in Gog Woreda”**, is outcome of my own effort and study. All sources of materials used for the study have been duly acknowledged. I have produced it independently except for the guidance and suggestion of the Research Advisor.

This study has not been submitted for any degree in this University or any other University. It is offered for the partial fulfillment of the Msc degree in Remote Sensing and GIS.

By: **Solomon Tesfamariam**

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Advisor: **Dr. Epherm Geberemariam**

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ABSTRACT

Ethiopia in the present day is posed with tremendous pressure on the intensive commercialization of agricultural crops and products. Amongst the target commodities that have offered emphasis in promotion of agricultural production, rice is identified as a major crop. The increasing rates of population and demands for food consumptions in the country, perhaps difficult to manage with limited agricultural land resources and outdated system of agricultural production techniques. While it is un-denied tasks to offered immediate attention to the utilization, identification and evaluation of suitable land assessment techniques particularly in the agricultural lands. Geographic Information System (GIS) is a very powerful tool in a wide range of disciplines. Since the peak time of the communication era (early 20th C) the trends of using GIS and remotely sensed imagery have increased dramatically due to several factors. This study is intended to determine suitable land for rice cultivation in Gog Woreda; the Regional State of Gambella using multi-criteria decision schemes through GIS and Remotely Sensed imagery processing. It covers a total area of about 322,273.71ha of 10 Kebels. The required primary data such as Normalized Difference vegetation Index (NDVI), Land use/land cove (LULC), Land Surface Temperature (LST) and Digital elevation Model (DEM) were obtained from SPOT, USGS and ASTER space shuttles satellites respectively. In addition to these; the calibrated meteorological ancillary gridded data of Ethiopia such as annual rainfall and temperature also obtained from the Ethiopian Meteorological Agency. The secondary data such as the soil data that incorporated the soil type, the physical and chemical property of soil was acquired from Gambella regional state land utilization & environmental protections Authority. Weight overlay analysis was applied to classify the study area into four Rice suitable zone classes. Accordingly the result indicated that that 15.8 % the study area is determined as Highly Suitable (HS), 29.5 % of the study area also determined as moderately Suitable (MS), 18 % of the district area also determined as low suitable (LS) and the remain 36 % of the district analyzed as not suitable for rice cultivation.

Key Words: CWDI, DEM, NDVI, LAI, LST, VCI, WSVI

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ACRONMS

$Cmol^{(+)}$ kg^{-1}	Concentration Mole per Kilogram
CWDI	Crop Water Deficit Index
DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
ENVI	Environment for Visualizing Images
GTP	Growth and Transformation Plan
IRRI	International Rice Research Institute
LAI	Leaf Area Index
LPGs	Level-1 Product Generation System
LST	Land Surface Temperature
LULC	Land-use/Land-cover
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
PPM	Part Per Million
SPIRITS	Software for Processing and interpretation Remotely Sensed Image Time Series
USGS	United State Ground Survey
UTM	Universal Transverse Mercator
VCI	Vegetation Condition Index
WLC	Weighed Linear Combination
W/m^2	Watt Squared Meter
$Wm^{-2}sr$ -1μm	Watt Meter squared * str * Micrometer
WSVI	Water Supply Vegetation Index

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Geographic Information System (GIS) is a very powerful tool in a wide range of disciplines. Since the peak time of the communication era (early 20th C) the trends of using GIS and remotely sensed imagery have increased dramatically due to several factors. One is the recognition of its application in a wide range of disciplines such as agriculture, land-use and land cover, forest and vegetation, soil and land degradation, urban and regional planning, water resource management, atmosphere and ocean management, natural disaster management and mitigation, fishing and mineral exploration and so on (Clarke, 1996; Moore and Carpenter, 1999).

Another factor that contributed for the utilization of GIS is the advent of powerful, inexpensive personal computers and the development of easy to use menu-driven GIS software made it possible for persons with little or no expertise to design and conduct spatial studies. The acquisition of spatial data has become easier to download from internet for the public-domain also other factor contributed for the utilization of GIS in wide range (*Ibid*).

All crops require abundant water, suitable topography and geomorphology, fertile soil and favorable climate. As many of the underlying processes influencing the suitability of crop cultivation; spatially heterogeneous soil chemistry and land features can be easily identified by GIS and Remote sensing software applications. Recently, there has been great curiosity in applying GIS software to study and distinguish suitable land for certain crops (Perveen, 2007).

Although rice is a staple food nearly half of the world population, however, in the Ethiopian context, it has been only one of the recent trends that have been undertaken mostly by foreign investors. In particular, rice production in the Regional State of Gambella is one of the major recent trends that have been undertaken by foreign investors and it is also hardly keeping pace with the rapid rising of international and national market demands (GPRSARDB, 2001).

Traditionally, the inhabitants in the low land areas of the Regional Sate of Gambella rely on a subsistence farming of cereal crops such as maize, sorghum, banana, coffee, mango and sweet potatoes. The inhabitants are also engaged on exploitation of livestock production and conventional fishing activities. One of the most burning needs in the Regional State of Gambella is to improve the agricultural land management and to impart suitable cropping patterns in order to increase the agricultural production with efficient use of land resources (GPRSARDB, 2001).

Thus, this research has been envisaged with a view to determine physical land suitability for rice crop using Multi-Criteria Evaluation and Decision approach using GIS and remote sensing tools.

1.2. Justification and Problem of the Statements of the Research

1.2.1. Justification of the Research

The geographical location of Ethiopia is endowed with a broad diversity of climates ranging from humid tropics to alpine climates suitable for successful growth of most types of both temperate and tropical crops. The total mean annual flow from all the river basins is estimated to be 122 billion cubic meters and the ground water potential is estimated at 2.6 billion cubic meters. These water resources can potentially be used for production of different crops including rice (MoARD, 2010).

The GTP which is recently designed by the government of Ethiopia that gives recognition to and focuses on the commercialization of agricultural crops and productions. Amongst of the target commodities that have offered emphasis in promotion of agricultural production, rice is putting in the midst of the crops. Rice is also considered as the “Millennium crop” which expected to contribute a lot in ensuring food security, source of income and employment opportunity due to its relative high productivity as compared to other cereals, which have been recognized by farmers and governments as well as by private investors in the country (Kebebew, et al., 2011).

According to studies conducted by the Ethiopian Institute of Agricultural Research, the Regional State of Gambella has vast suitable rain-fed and irrigation lowland and suitable areas for rice production that, covered an area of around 133,710 ha and able to produce a total production of more than 748,550 tons per year (Kebebew, *et al*., 2011).

1.2.2. Problem of the Statements

Although the involvement of different actors both at public and private sectors have been revealed a great interest in the production of rice in the Regional State of Gambella, the current trends of the assessment of land suitability and ecological study techniques are outdated. According to the official report released by the Oakland Institute in June 2011; around 438,000 ha of land have been awarded to investors, in early 2008 in the vicinity of the Gambella National Park. This report also presented that some wetlands, with abundant fish populations and birdlife, are presently being altered for commercial crop production while extensive forest cover in nearby areas has been completely cleared (Institute of Oakland, 2011).

The integration of image processing systems and multi-dimensional spectral data as provided by satellite sensors with spatial and non-spatial databases is more essential than that of the conventional field surveys in the course of identification and evaluation of suitable land, digital mappings and analysis. The conventional field surveys are consuming much of the time and involving expensive ground truth surveys, which are no longer affordable by the surveys of individual districts during identification of suitable land (Behrens and Scholten, 2006).

While the modern survey which has been created an irrepressible integration with the Geospatial information, GIS application and digital geographic databases are employed efficiently by solving the challenges, which have been observed on the conventional field survey. Consequently it has been also enhanced the assessment, identification, evaluation and decision techniques and create conducive atmosphere for development of more suitable plot of lands for crop cultivation and land-use managements. However a report revealed by Gambella Regional State Agriculture and Rural Development Bureau (GPRSARDB) in 2001, indicated that the conventional survey methods are employed to identify and evaluate suitable land for cultivation of different crops including rice in the region. In addition to other constrains, perhaps this situation could laid their own influences on the land suitability identification and land management of rice and other crop production in the region.

Thus, this research is developed to find out a relatively new method of multi criteria evaluation and spatial analysis method using GIS and Remote Sensing platforms for determining the most suitable areas for rice cultivation in Gog Woreda of Gambella Regional State.

1.3. Objectives of the Research

1.3.1. General Objective

This study is intended to determine suitable land for the rice cultivation in Gog Woreda of the Regional State of Gambella using Multi-Criteria Decision schemes through GIS and Remotely Sensed imagery processing.

1.3.2. Specific Objectives

The specific objectives of this study to

- ✓ Develop a Choropleth map that able to provide a visual view of all potential and suitable lands for rice cultivation within the study area.
- ✓ Present how the Multi-Criteria Evaluation approaches with GIS application to provide decision in handling the land suitability analysis.
- ✓ Generate the Land Quality Grade, LULC, WSVI, VCI, CWSI and LAI Maps that able to use as a major parameter through the determination and evaluation processes of suitable lands for rice cultivation.
- ✓ Develop Land Surface Temperature and mean, maximum and minimum NDVI Maps that able to use as an input to determine the precipitation and surface moisture level of the study area.

1.4. Significance of the Study

GIS is now firmly established in different modern survey practices and are used for map production, deriving suitability maps to meet users' requests for special-purpose information and for modeling environmental processes. In a study carried out by Abu Bakar (2007), it was observed that if the application of GIS and remotely sensed imagery realized in many careers; it could assess easily by the managerial, policy makers and researchers, for developmental purposes and in advisory programs. Consequently, it could be utilized effectively for decision making processes.

Jayasinghe (2008) also developed an interactive web-based GIS consulting portal with crop-land suitability analysis, which provides information on Tomato and Cabbage cultivation in Sri Lanka using important and selective criteria to determine crop-land suitability such as, soil pH, topography, average annual temperature, and average annual rainfall. Their application utilized most of the open source components and is considered as a low cost application which will be suited for developing countries.

Like the above researchers Muralikrishna, *et al., (2009)* used FAO methodology in a computer assisted program to establish areas which have potentials to support rice cultivation in Ghana. His methodology utilized for establishing of GIS approach for a spatially inventory of land resource database and to assess potential suitable areas for sustainable rice production. Thus based on the aforementioned background this research will help to gain relevant to suitable land for rice cultivation in Gambella Regional State; Gog Woreda.

1.5. Application of Results

The results of this study will be applied by the Regional, Woreda, and Kebele Agricultural Officers, decision makers and agricultural practitioner society;

- ✓ During geographical allocation of suitable land for the rice cultivation.
- ✓ During agricultural policy implementation, land management and resettlement operations.
- ✓ During the distribution and re-distribution of plots of rice cultivation land for local, national and international investors and agricultural research institutes.

1.6. Scope of the Study

This study is limited to Gog Woreda in Gambella Regional State. It covers a total area of about 322,273.71 ha of 10 Kebels. The study is only concentrated on the identification of suitable land for rice cultivation by using multi-criteria decision approaches through GIS and remotely sensed imagery processing techniques. Moreover, this research also employed only on the following six parameter such as; Storie Land Quality Model, Land-use-land-cover, Agricultural drought index, Water Supply Vegetation Index, Crop Water Deficit Index, and Leaf Area Index to determine and evaluate the land suitability level of the study area for rice cultivation. Closed ended questioner also employed to compute weight for the above six different factor parameters through GIS processing techniques.

CHAPTER TWO

2. LITERATURE REVIEW

Suitable land identification and evaluation based on the efficient and effective land surveys is the first and foremost step to putting the land into optimal usage. In suitable land identification and evaluation aspect, comprehensive information focusing on the distribution of bio-physical, technical, socio-economic and eco-environmental spatial data's is a prerequisite. A brief review of literature related to the identification of suitable land for crop production and cultivation using a remote sensing and GIS application are described below:

2.1. Application of Remote Sensing and GIS

This is the fact of strong governments in many countries that have been spent considerable amount of expenses to develop large geographical databases that describing their natural resources. Particularly this situation is improved after a significance progress was observed on the computing sciences, including Geographical Information System (GIS) and Multi Criteria Decision Analysis (MCDA). These data sets can help the planners; decision and policy makers by providing convince land information's about the entire areas which have been under ongoing projects and it have been reduced delays in decision-making processes (Marius and Andrew 2001).

Although the decision support and multi-criteria decision analysis (MCDA) approaches are the major pillar for the choosing of an appropriate location for different activities, while the question is what must be done and where it should be realized (Malczewski and Ogryczak 1990, Malczewski 1991). Basically the application of GIS and MCDA contributed a lot for different field of studies, while this paper only limited to the contribution of GIS and MCDA on land use suitability assessment.

2.1.1. Remote Sensing and GIS for Land-use/Land-cover Analysis

Today, remote sensing image data of the Earth's surface acquired by spacecraft platforms is readily available in a digital format. Digital remote sensing systems convert electromagnetic energy (color, light, heat, etc.) to a digital form. Specially, the data is composed of discrete picture elements, or pixels, and radio-metrically quantized into discrete brightness levels. The great advantage of having data available digitally is that it can be processed by computer either for machine assisted information extraction or for the enhancement by an image interpreter. (Malczewski 2004).

In contemporary land use and land cover mapping studies, land cover classes are often derived from satellite imagery by utilizing computer-assisted image classification techniques. There are two primary methods of image classification utilized by image analysts, unsupervised and supervised classification. For this study, image classification is defined as the extraction of distinct classes or themes, land use and land cover classification categories, from satellite imagery by using supervised classification techniques.

2.1.2. Remote Sensing and GIS for Land Evaluation

Soil variability according to the soil surveyors are best depicted based on topographic variations. The dynamic relationship between the physiography and soils is utilized while deriving information on soils from multi-temporal data. This is because the soils are resultant of same natural processes and conditions that sculpture the land, which they inhabit.

Multi-spectral satellite data provides better information about the various landforms geomorphic processes. Another recent development in the use of satellite data is to take advantage of increasing amounts of geographical data available in conjunction with geographic information systems to assist in interpretation. Ziadat (2007) prepared large-scale of soil maps, with adequate accuracy, cost and time consuming. Recently, models that utilize terrain attributes derived from digital elevation models (DEM) are used to predict soil attributes. The objective of his research is to explore the accuracy of land suitability classifications derived from predicted soil attributes versus those derived from traditional soil maps. The results indicated that the accuracy of the suitability classification derived from predicted soil attributes compares favorably with the accuracy of classifications derived from traditional soil maps.

Nidumolu et.al, (2004) analyzed land use class maps and soil series to identify areas having specific priorities with respect to agricultural land use analysis under the project Integrated Mission for Sustainable Development (IMSD) in India. IMSD used remote sensing data supported by field investigations to generate land use and soil maps. The approach identified specific agricultural land use analysis objectives, which match the farmers needs and objectives.

According to Sarkar (2008) presentation on his paper; developed soil taxonomy map, based on the FAO Soil Map of the World, which together with other data, is used to make continent-level assessments of land productivity and sustainability. A soil quality analysis and an evaluation of sustainable production, based only on biophysical considerations, suggest the need for major investments to enhance the productivity of the soil resources of this continent.

Due to some major constraint such as acquisition of high resolution satellite data this research was not engaged on soil taxonomy map using remote sensing data, while the evaluation of the land quality attributes that most influence crop suitability (long-term) was carried out in a geographic information system environment to assigning the land suitability for crops in the study area of Gog Woreda.

2.1.3. Remote Sensing and GIS for Agro-Climatic Suitability Analysis

Climate is a predominant controlling factor in rain-fed agriculture due to spatial and temporal variability in rainfall and temperature. In rain-fed agriculture, the moisture supply to plants depends on the precipitation and the water-holding capacity of the soil. Under the tropical conditions, moisture regime is the most important factor in influencing agricultural production, as thermal regime is optimum to better crop growing environment. In the rain-fed regions, over 80 % of the annual rainfall is received during the rainy season, although variability in rainfall increases with decrease in its volume. The climate of a region is the sum of its atmospheric conditions like temperature, precipitation, wind, humidity etc. It is a composite picture of the variety of day-to-day weather conditions. It is therefore obvious that the weather conditions vary from day-to-day and climate differs from place to place (Geerts et al., 2006).

Geerts et al., (2006) prepared an agro-climatic suitability library for crop production was generated by using climatic data sets from 20 to 33 years for 41 meteorological stations in the Bolivian Altiplano. Four agro-climatic indicators for the region were obtained by validated calculation procedures. The reference evapotranspiration, the length of the rainy season, the severity of intra-seasonal dry spells and the monthly frost risks were determined for each of the stations. To get a geographical coverage, the point data were subsequently entered in a GIS environment and interpolated using ordinary kriging, with or without incorporating anisotropy.

Sepaskhah et al. (2006) used soil water budget and simple relationships for evapotranspiration partitioning, leaf area index (LAI) determination, and the transpiration functions for dry matter and for harvest index to develop a model for growth and yield production of cowpea under soil water stress conditions.

Corresponding to the above reviewed literatures; this research also engaged to LAI, WSVI, VCI and CWDI to determine the soil water stress conditions, root zone water stress and drought level of the study area using remote sensing data.

2.1.4. Remote Sensing and GIS for Land Suitability Analysis

Based on the American landscape architect's MCHarg; who was using the convectional hand drawn cartographic overlay techniques in late 19th and early 20th century considered as a pioneer to put-down the cornerstone for GIS-based and more advanced overlay approach to land-use suitability analysis (Malczewski, 2004). Computer-assisted overlay mapping, Multi-criteria evaluation methods, and Artificial Intelligence (soft computing or Geo-computation) methods are the three different and major group approaches that should be distinguished by the users in GIS based land use suitability analysis (Collins *et al*.,2001). This literature review only focusing on Computer-assisted overlay mapping and Multi-criteria evaluation methods.

2.2.6.1. Computer Assisted Overlay Mapping

Computer-assisted overlay techniques were developed in the Harvard laboratory in an attempt to reduce the weaknesses which have been revealed in manually mapping techniques. A computer assisted overlay mapping techniques are stored the models in numerical form as matrices in the computer after marked the series of suitability factors in color scales and improved the limitation on the capacity of merging large datasets alleged in to the convectional hand-drawn cartographic overlay techniques (MacDougall, 1975; Steinitz et al., (1976).

The map overlay analysis which has been assisted by computer is one of the focal point used to handling problems which has been related to land-use suitability map algebra approach. This approach has been typically applied to land use suitability in the form of Boolean operations and Weighed Linear Combination (WLC). The primary reason for the popularity of these methods is that they are easy to implement within the GIS environment using map algebra operations. The methods are also easy-to-understand and intuitively appealing to decision makers.

Although the computer assisted map overlay methods are reduced the challenges caused by hand-drawn cartographic overlay techniques; while in many case studies the overlay land-use suitability models have been applied incorrectly due to analysts (decision makers). Consequently the unconvinced results were observed and it led the users in specious ways (Malczewski 2004).

Besides of the facts; the limitation caused by the decision makers have been occurred due to ignored or been unaware of the following underlying assumptions. The classical Boolean operations and WLC methods over simplify the complexity of the process underlying on land use planning problems by focusing on the facts (that can be effectively represented in GIS) rather than a right combination of facts and value judgments (that are difficult to represent in a computer environment in general and in GIS in particular). This limitation can be removed by integrating GIS and multi criteria decision making (MCDM) methods (Malczewski 2004).

2.2.6.2. Multi-criteria Analysis and GIS for Decision Making models (MAGISDM)

GIS-based multi criteria decision making (MCDA) can be thought of as a process that combines and transforms spatial and a spatial data (input) into a resultant decision (output). The MCDM procedures (or decision rules) define as a relationship between the input maps and the output map (Malczewski 2004). This conceptual definition helps peoples to have an idea of how the multi modal criteria decision and assessment methods used to determine the quality and reliability of the output maps.

Generally the procedures of MCDM consist of the utilization of geographical data, the decision maker's preferences, the manipulation of the data and preferences according to specified decision rules. On the other hand it provided a significance emphasis for the two major importance concepts which have been critical for spatial MCDA. These are (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences into one-dimensional values of alternative decisions (Malczewski 1999).

2.2.6.2. Type of Decision Rules in Suitability Analysis

The decision rules which have been used by the analyses during distinguishing of suitable use of land can be classified into Multi-objective and Multi-attribute decision making methods (Malczewski, 1999).

Multi-objective Approaches: - The multi-objective approaches are mathematical programming model oriented methods, it consisting of two or more objective functions and a set of constraints imposed on the decision variables. The multi-objective approaches also define as the set of alternatives in terms of a decision model. This model implicitly defines the alternatives in terms of decision variables. Even if the multi-attribute approaches are much easier to implement in GIS (especially, for the raster data model); but some complexities are occurred during the computation of criteria and variables. This is one of the major reasons that create barriers during the implementation of multi-objective optimization methods in the GIS environment (Malczewski, 2004). This research also described that, a considerable effort in terms of developing mathematical programming algorithms or integrating commercially available optimization packages (solvers) and GIS to solve the problem created due to computational complexity.

Generally the linear programming, Heuristic algorithms and Artificial Intelligence (AI) techniques such as genetic algorithms (GA) approaches are major assigned model for to the optimal land suitability pattern in the raster GIS environment. Their ability to map the patterns of location rent and opportunity costs which have been used for evaluating the robustness of land suitability patterns and allow making modifications on identifying areas without significant impacts are considered as the main advantage of the models (Malczewski 2004).

Other research conducted by Eastman et al. in 1993, quoted by Malczewski (2004) explained that; the rapidly increasing problem size, particularly if the allocation decisions are defined as the integer variables, is perhaps the major barrier blocking more rapid integration of optimization techniques with GIS. These researchers also indicated that; the convenient using of heuristic algorithms is the only possible solution to avoid the barrier created by allocation of very large land during decisions. Cromley and Hanink (1999) suggested that Heuristic approaches are appropriate only if they generate near optimal solutions and if an exact method cannot be developed to work within the existing limitation of computing technology (Cromley, 1994; Cromley and Hanink, 1999). While this algorithm does not guarantee when the allocation is near optimal because such kind of problems can be handled effectively in the formal linear/integer programming format than that of the heuristic algorithms.

Multi-Attribute Decision Approaches: - Multi-attribute decision making methods are data oriented techniques; it is also referred as discrete methods because it assume that the number of alternatives (plans) is given explicitly. Unlike the multi-attribute decision approach the multi-objective approach is not focusing on planed and data oriented techniques; while in the multi-objective methods the alternatives must be generated. Tthey are identified by solving a multi-objective mathematical programming problem (Malczewski 2004).

Weighed Linear Combination (WLC) and its variants, Ideal point methods, Concordance Analysis (CA) and Analytic Hierarchy Process (AHP) some of the multi-criteria evaluation methods that have been implemented over the last decades in GIS environment. However recently the WLC and Boolean overlay operations, such as intersection (AND) and union (OR), are frequently employed and thought as the most straightforward approaches in GIS environment during suitability analysis and other related studies and d analytic hierarchy process (Marius and Musy 2001). For the sake of simple understanding and clarity let's elaborate the type of multi-attribute decision approaches in the subsequent paragraphs.

Weighed Linear Combination (WLC) or simple additive weighting:- is based on the concept of a weighted average. This weighted average is derived after the evaluation of each criterion seated from different input data, at an appropriate scale and with a specific model. The decision maker directly assigns the weights of 'relative importance' to each attribute map layer. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes. This method executed in both raster and vector GIS environments. For most of the criteria, spatial analysis procedures using a raster GIS were an important part of the evaluation process (Malczewski 2004).

According to the research conducted by Jiang and Eastman (2000) on the Application of fuzzy measures in multi-criteria evaluation in GIS; they explained that some the fundamental limitations are observed with the use of WLC procedures during the decision making processes. They also suggested that the Ordered Weighted Averaging (OWA) approach in order to solve some related limitation with the WLC.

Ordered Weighted Averaging (OWA) approach: - is a class of multi-criteria operators; it provides an extension to and generalization of the conventional map combination methods in GIS (Malczewski 2004). As the explanation given by Malczewski (2004) indicated that different parameters which have been associated with the OWA operations serves as a mechanism for guiding the GIS based land-use suitability analysis and land use strategies. They also explained that these land use strategies can be ranging's from an extremity pessimistic through all intermediate the neutral-towards-risk strategy to an extremely pessimistic strategy (Malczewski 2004). The Ordered Weighted Average involves two sets of weights: Criterion importance weights and Order weights.

- **Criterion importance weights**:- such kind set of weight is assigned to a given criterion (attribute) for all locations in a study area to indicate its relative importance (according to the decision-maker's preferences) in the set of criteria under consideration

- **The Order weights**: - are associated with the criterion values on a location-by-location (object-by-object) basis. They are assigned to a location's attribute values in decreasing order without considering which attribute the value comes from.

The order weights are central to the OWA combination procedures. They are associated with the degree of ORness, which indicates the degree to which an OWA operator is similar to the logical connective OR in terms of its combination behavior. The parameter is also associated with a trade-off measure indicating the degree of compensation between criteria. The ORness measure allows for interpreting the results of OWA in the context of the behavioral theory of decision making (Malczewski 2004).

Analytical Hierarchy Analysis (AHP):- Analytical Hierarchy Analysis (AHP) is another multi-attribute technique approach which has been incorporated into the GIS-based land-use suitability procedures and having a particular importance when some difficulties occurred to perform a pairwise comparison of the alternatives due to representation of large numbers of alternatives by means of raster data model and vector-based GIS. AHP also used as a consensus building tool in situations involving a committee or group decision makes (Malczewski 2004).

This approach particularly in the GIS environment can be applied in two distinctive ways. First, it can be employed to derive the weights associated with suitability (attribute) map layers. Then, the weights can be combined with the attribute map layers in way similar to the linear additive combination methods.

Second, the AHP principle can be used to aggregate the priority for all level of the hierarchy structure including the level representing alternatives. In this case, a relatively small number of alternatives can be evaluated (Banai 1993).

Ideal Point Approached :- Infect the multi-attribute method is one of the decision rule used in GIS environment for land-use suitability analysis, but sometimes difficulties associated with the multi-attribute methods such as the independence among- attributes assumption are occurred. Thus intruder to avoid such kind of difficulties advised that; the ideal point approach as the best solution makers. It orders a set of alternatives on the basis of their separation from an ideal point. The ideal point method can be implemented both in the raster and vector GIS environment. But it is more appropriate and suitable in the raster GIS environment (Malczewski, 2004).

The ideal point represents a hypothetical alternative (decision outcome) that consists of the most desirable levels of each criterion across the alternatives under consideration. The alternative which is closest to the ideal point is the best alternative. The separation is measured in terms of a distance metric. A wide range of decision rules can be developed that combine the different definitions of separation measures.

2.1.7. Problems Associated with MCDM

There are several problems associated with implementing the MCDM methods in GIS. First, it is well-known that the input-data to the GIS-multi-criteria evaluation procedures usually have the probability of inaccuracy, imprecision, and ambiguity. In spite of this knowledge the methods typically assume that the input data are precise and accurate. Some efforts have been made to deal with this problem by combining the GIS-multi-criteria procedures with sensitivity analysis and error propagation analysis. Another approach to deal with impression and ambiguity in the input data (attribute values and decision maker’s preferences) is to use fuzzy logic methods (Malczewski 2004).

The second problem is related to standardization of non-commensurate criteria. There are many different standardization methods that can be used in GIS-based multi-attribute analysis. To this end, it is important to note that different standardization methods may lead to different land-use suitability patterns. The most common approach to criterion standardization is the linear transformation method. Given that evaluation criteria (attributes) act as proxy measures of the decision maker's utility, the different criterion values reflect different levels of utility for the decision maker. If the values are changed or distorted by the transformation process, the intra-attribute and inter-attribute preference structure can be affected (Malczewski 2004).

Third, given the wide variety of MCDM rule there is a question which of the methods is the best one to be used in particular situation. This is a largely unsolved problem in decision analysis. Several studies demonstrate that the different multi-criteria evaluation rules generate considerably different land use suitability patterns like a multi-criteria procedures available in Idrisi and SPANS. Malczewski 2004 suggested that application of two or more methods and integratation of MCDA and Artificial Intelligence (soft computing or Geo-computation) techniques should be applied to dilute the effect of technique bias (Malczewski 2004).

2.2. General Overview of Soil and Its Influences on Crop Cultivation

2.2.1. Soil Fertility

Soil fertility can be used to describe the availability of nutrients for plant uptake and in the broader context can be derived from soil type, soil organic matter status, soil properties including pH, as well as the concentration of available nutrients and should be reflective of land use. The fertility of soil is not only the turnover of organic and inorganic inputs, but also the management of soil condition. Soil fertility has over time become increasingly depleted in soil organic matter and nutrients. Inappropriate soil and plant management practices have often contributed to the development of constraints to continued production. Optimum plant growth depends on balanced nutrition and the availability of all nutrients in sufficient quantities, as soil fertility declines, organic matter input is reduced, soil structural degradation and soil erosion may increase (Hillel 1971).

Soil organic matter is a major storehouse of nutrients, where soil organic matter has declined, and the ability of the soil to provide adequate nutrients for crops will be impeded. Soil having poor fertility characterized by distinct features. These are; concentration of low nutrients, low soil organic matter content, crop or pasture symptoms as described in the nutrient fact sheets for nitrogen, phosphorous, potassium and sulfur, early senescence (haying off) and small grain due to lack of nitrogen (N), soil acidification due to conversion of NH_4^+ to NO_3^- and subsequent NO_3^- leaching, nutrient enrichment of waterways; algal blooms (N, P), nutrient toxicity, poor growth and vigor, low yields, plant death resulting from Baron (B) or Aluminum (Al) toxicity Hillel 1971).

2.2.2. Soil PH and Its Influences on Soil Health

Soil PH describes the soil's acidity or alkalinity. Extremely high or low pH (on a scale from 0 to 14, and in which 7 is neutral) can have a negative effect on the health of plants and soil biota. In soils with pH below 5.5 acid-sensitive agricultural plants are adversely affected and the risk of subsoil acidification increases. Soil pH is an important indicator of chemical processes that occur in soil, since it affecting the soil processes and governing nutrient availability (http://soilhealthknowledge.com.au/).

Although soil acidification is a natural process, it can be accelerated under agriculture. Soil pH represents a significant constraint to production in many areas of Australia, with the economic loss from soil acidification across Australia, estimated to be up to six times higher than from dry land salinity. The chemical environment of the soil can be acid, neutral or alkaline. The movement of strongly acid balancing ions such as sulphate or nitrate through the soil generates excess acidity and the accumulation of strongly basic ions (i.e. calcium and sodium) generates alkalinity(*Ibid*).

Soil pH can be measured in soil extract obtained with deionized water or a dilute calcium chloride ($CaCl_2$) solution. Soil pH values measured in $CaCl_2$ solution are closer to the true soil pH in the field. For most soils pH values in water are between 0.5 and 1.0 pH unit higher than values in $CaCl_2$. A soil pH (in $CaCl_2$) between 6.5 and 7.5 is considered close to neutral, less than pH 6.5 slightly acid, less than pH 5.5 moderately to strongly acidic and extreme acidity associated with soils of pH less than 4.5. Acid sulphate soils (ASS) can have pH values much less than 4. Above pH 7.5, soils are considered alkaline with soil between pH 7.5 and 8 often associated with free calcium carbonate (lime equivalent) and above pH 8.5 are sodium salts (*Ibid*).

2.2.3. Soil Water Balance and Relationship

Water is held in the soil because of the attraction between soil solids and water. This force can be measured by moisture tension. A knowledge of the amount of water held by the soil at the various tensions is required if we are to calculate the amount of water that is available to plants, the water that can be accommodated before percolation starts, the amount of water that needs to be used for irrigation, etc. All plants need water to grow and produce good yields. When plants are water stressed, they close their stomata (the small holes in the leaf surface) and cannot photosynthesis effectively. Best growth can be achieved only if plants have a suitable balance of water and air in their root zones. Some stages in the growth of a crop are particularly sensitive to moisture stress. This requires an understanding of the movement and storage of water in the root zone of the crop and the rate of water use by the crop (Aditi 2008).

Soil water dynamics can be thought of as comparable to a sponge. When a sponge is saturated by soaking it in water, it is lifted out of the water any excess water will drop off it. This is equivalent to drainage from the macro-pores in the soil. Once the sponge has stopped dripping it is at field capacity. When the sponge is squeezed it is easy to get the first half of the water out. This first squeeze is equivalent to draining the sponge to the stress point and the water is removed like the RAWC (Readily Available Water Capacity). Squeezing the second half of the sponge out is much harder. This is like draining the sponge to permanent wilting point. The total water squeezed out of the sponge from when it stopped dripping is the TAWC (Total Available Water Capacity). However, no matter how hard the sponge is squeezed there is no way to get all the water out of it. The water left is the equivalent to the hygroscopic water found in soil. From field capacity to the stress point, it is easy to get the water. From the stress point to the permanent wilting point, plants find it much harder to draw water from the soil and their growth is stunted. Below the permanent wilting point, no further water can be removed and the plant dies (Aditi 2008).

Aggarwal, (1995) verified water balance of agro-ecological systems as a key parameter for most physical and physiological processes within the soil-crop-climate system. Therefore it is of high importance to calculate the water budget to reduce potential uncertainties in simulated outputs. Soil water retention term used in soil science literature, which can be defined as predictive functions of certain soil properties from other more available, easily, routinely, or cheaply measured properties. This concept arises in soil science as information on soil survey is now highly demanded. Varadan and Jayakumar (1991) studied the hydro physical characteristics of typical soil series in a rolling topography in a humid tropical region. The relationship of these properties to water management problems like excess or low available water, water logging and drainage were worked out in the process. One of the main functions of soil is to store moisture and supply it to plants between rainfalls or irrigations. Evaporation from the soil surface, transpiration by plants and deep percolation combine to reduce soil moisture status between water applications. If the water content becomes too low, plants become stressed. The plant available moisture storage capacity of a soil provides a buffer, which determines a plant's capacity to withstand dry spells. When soil is saturated, all the pores are full of water, but after a day, all gravitational water drains out, leaving the soil at field capacity. Plants then draw water out of the capillary pores, readily at first and then with greater difficulty, until no more can be withdrawn and the only water left are in the micro-pores. The soil is then at wilting point and without water additions, plants die.

The amount of water available to plants is therefore determined by the capillary porosity and is calculated by the difference in moisture content between field capacity and wilting point (FC - PWP). This is the total available water storage of the soil. The amount of water in a soil can be expressed as a percentage, or in millimeters per meter of soil. Hillel, (1971) opined that the water content in soil affects the way the energy flux affects the state and movement of water. To evaluate the field water cycle as a whole and the relative magnitudes of the various processes comprising it over a period, it is necessary to consider the field water balance.

2.2.4. Evapotranspiration

The impact of climate on crops is always transformed into evaporation, which in turn depends upon the available water and energy. In case of cropped surfaces, the continuous loss in form of vapor is called evapotranspiration. Since water loss is due to the combined evaporation from soil and transpiration through plant surfaces. For crops, it is essential to estimate maximum water loss under certain climatic conditions and under unlimited water availability at root system level, i.e. the maximum evapotranspiration (ETM). The major factors controlling evapotranspiration are water availability, available radiant energy and transport mechanism to remove water vapor from the surface. They depend on soil moisture, land surface temperature, air temperature etc. Nishida *et al.* (2003) used a combination of remote sensing data, ancillary data and atmospheric data to account for all these factors for a final estimation of evapotranspiration. This research also derived evapotranspiration maps using remote sensing data. This calculation used different inputs like albedo, emissivity and roughness that are derived from surface temperature. Maps of net radiation are generated to derive evapotranspiration maps. The combination of two separate processes where water is lost from soil surface by evaporation and from crop by transpiration is referred to as Evapotranspiration (Allen 1998).

CHAPTER THREE

3. DESCRIPTION OF THE STUDY AREA

3.1. Location of the study Area

Gog is one of the Woreda in the Anuak zone in the Gambella Regional State. Geographically, Gog is found between the geographical coordinates of latitude 7^{o} 35' 00'' – 7^{o} 58' 33'' E and longitude 34^{o}15' 00'' - 34^{o} 25' 00'' N which covers an area of about 322,273.71ha (Fig.1) . The Woreda is bordered on the south by Dimma, on the southwest by the Akobo River which separates it from South Sudan, on the West by Jor, and on the North by Abobo. Fugnido is the capital of Gog Woreda.

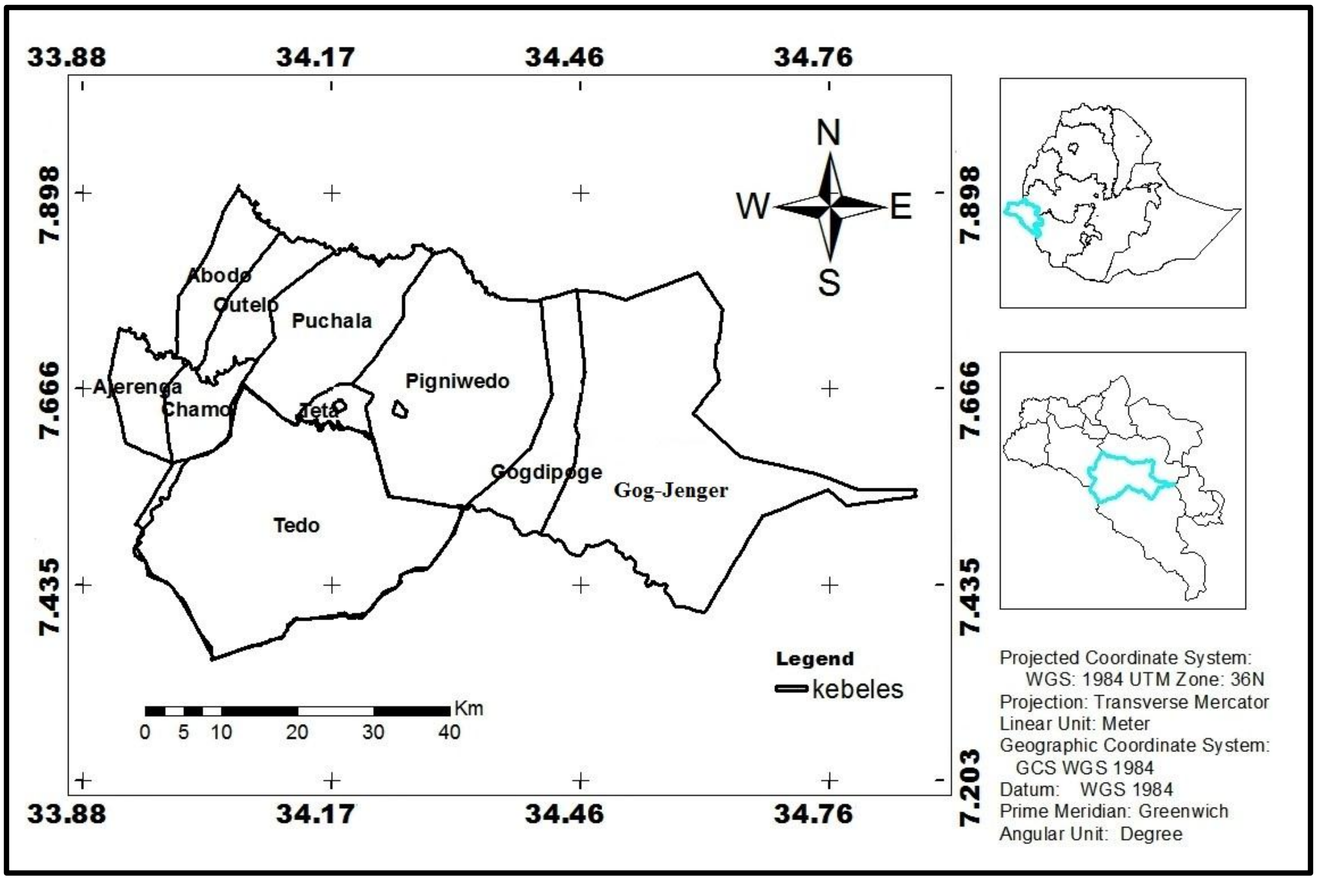

Figure 1: Location Map of the Study Area.

Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), Gog Woreda has a total population of 16,836, of whom 7,751 are men and 9,085 women; with an area of 3,250.25 km^2, Gog has a population density of 5.18 (CSA 2007).

3.2. Vegetation Cover of the study Area

The vegetation cover types of the study areas are identified as Dense wood lands, Bush lands, swampy areas and grass lands. The land cover in the highlands of the study area generally has been dominated by dense broad lived and disturbed forests with patches of cultivation and the lowlands are open wood land with grassland and wetlands (MoFED 2006).

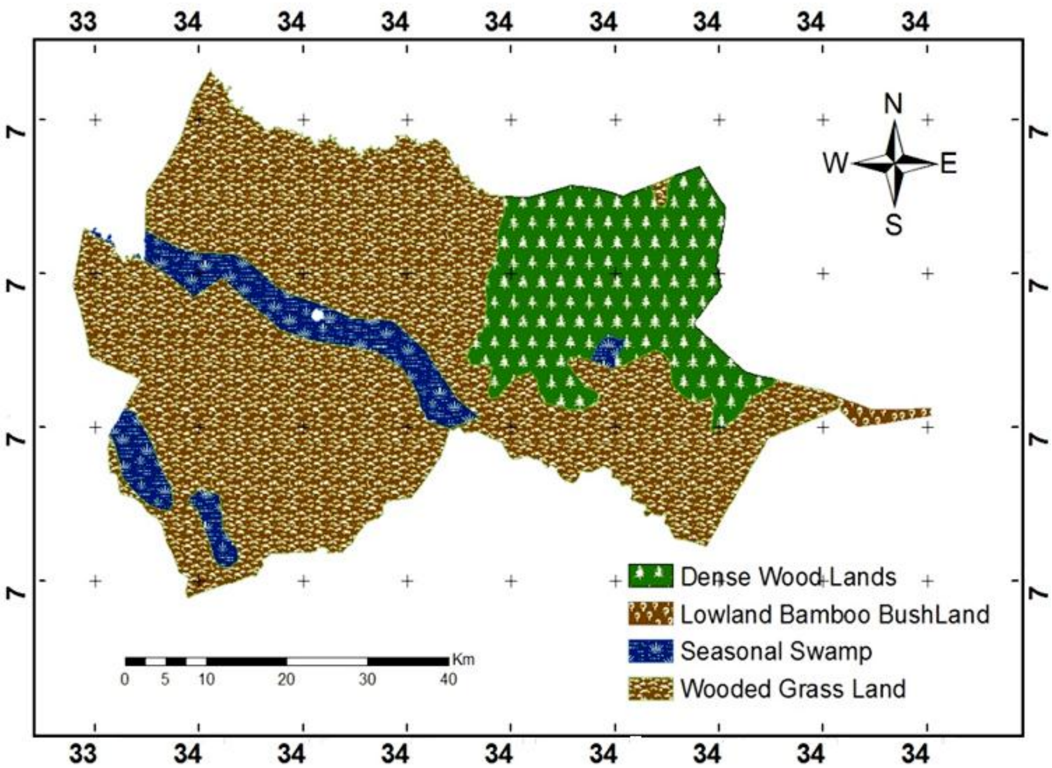

Figure 2: Vegetation cover map.

3.3. Drainage of the study Area

The Region is drained by a number of perennial rivers and their tributaries. Among the major rivers are; the Baro, Alwero, Gilo and Akobo. Gog Wereda is drained by Gilo River and Lake Tata. In general the flows of the rivers are from East to West crossing the Gog plain via Jore Wereda eventually flow to Sudan. It increases from May to September (the main rainy season) and decreases from October to April. The extraction of the drainage network of the study area carried out from an ASTER DEM, in raster format with 30m*30m grid cell size. It was downloaded from the http://gdem.ersdacjspacesystem.or.jp in May 2014. Hydrological tools in ArcGIS 10 software, was used to extract drainage channels. The automated method for delineating streams followed a series of steps starting with a filled DEM (Fig. 3).

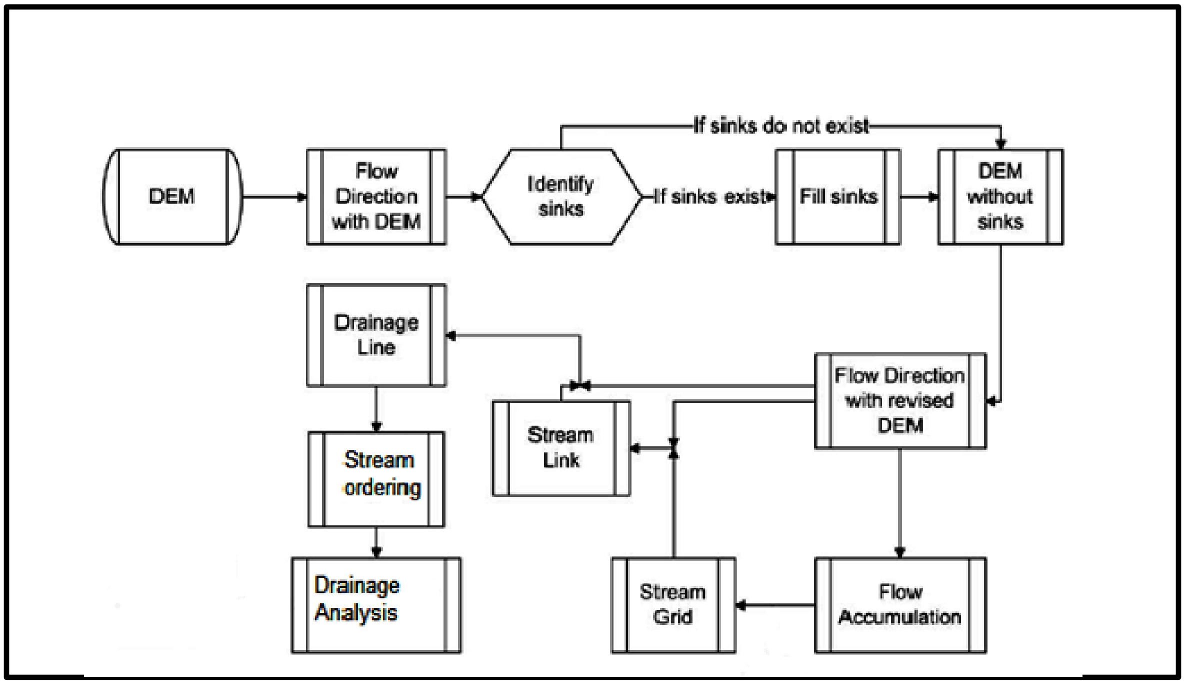

Figure 3 : Schematic flow Chart of Drainage Pattern.

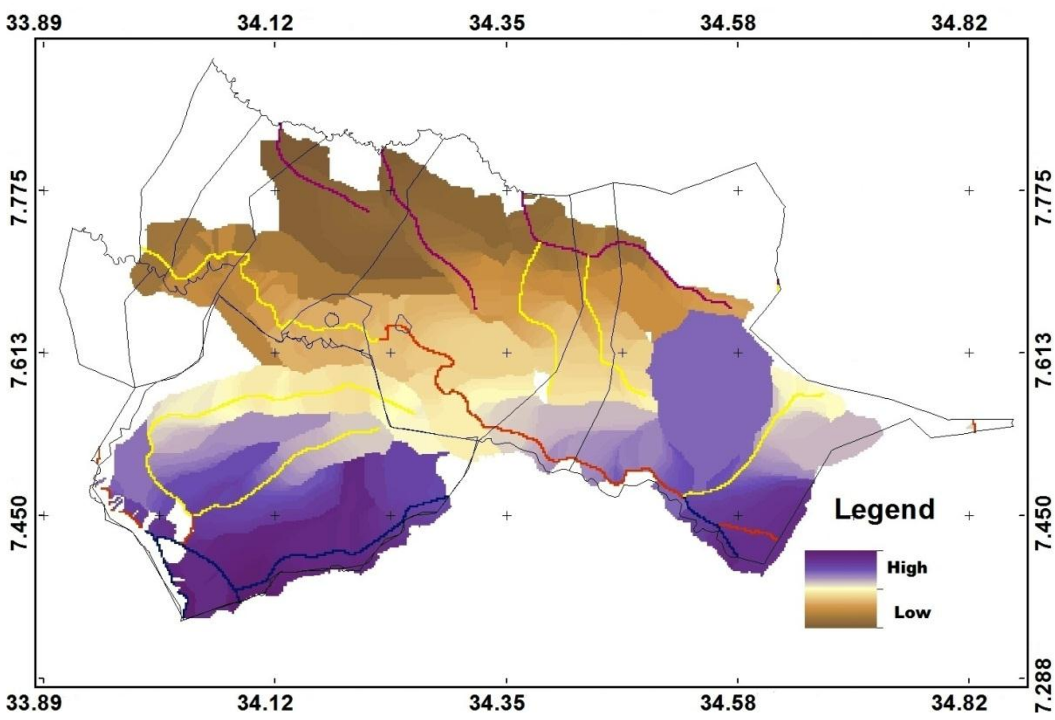

Figure 4**:** Watershed map.

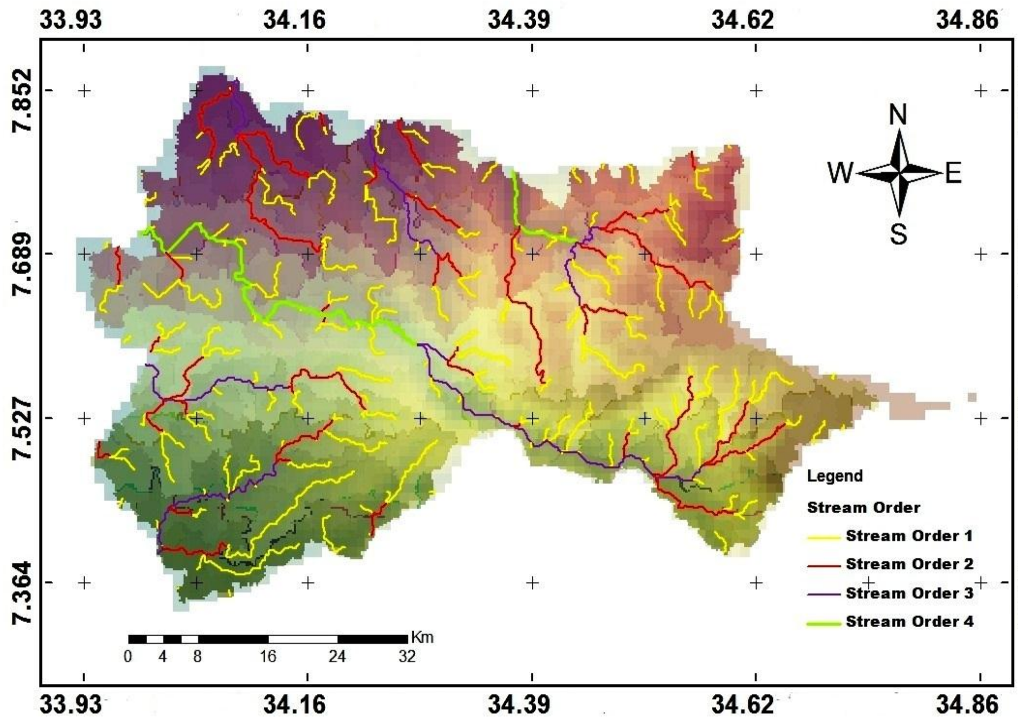

Figure 5 : Drainage map.

3.4. Soil of the Study Area

The soil data was obtained from National Regional State of Gambella Land Utilization & Environmental Protection Authority. The Soil survey was carried out by taking auger observation up to 1.2 meter depth and dug up to 2 meter depth unless it is restricted by bedrock. The laboratory works of the collected soil samples were analyzed in the Oromia Water Works Design and Supervision Enterprise laboratory. The morphological and some physical characteristics of the soils were described at field condition based on the FAO, 2006 Guidelines for soil description.

Accordingly in Gambella regional state 12 soil types are registered. The summary of their description and nutrient status soil are described in Appendex 1. Similarly Gog Woreda also predominately covered by deep to very deep heavy clay, reddish brown to dark reddish brown iron and manganese concentration in sub-surface similar to Abobo (plithosols) and non-stratified cracking soils (fluvisols) of the Gilo valley, which are extending to Jor. These soils are heterogeneous nature in terms of texture; consistence, drainage, mottling and structure (Fig.6).

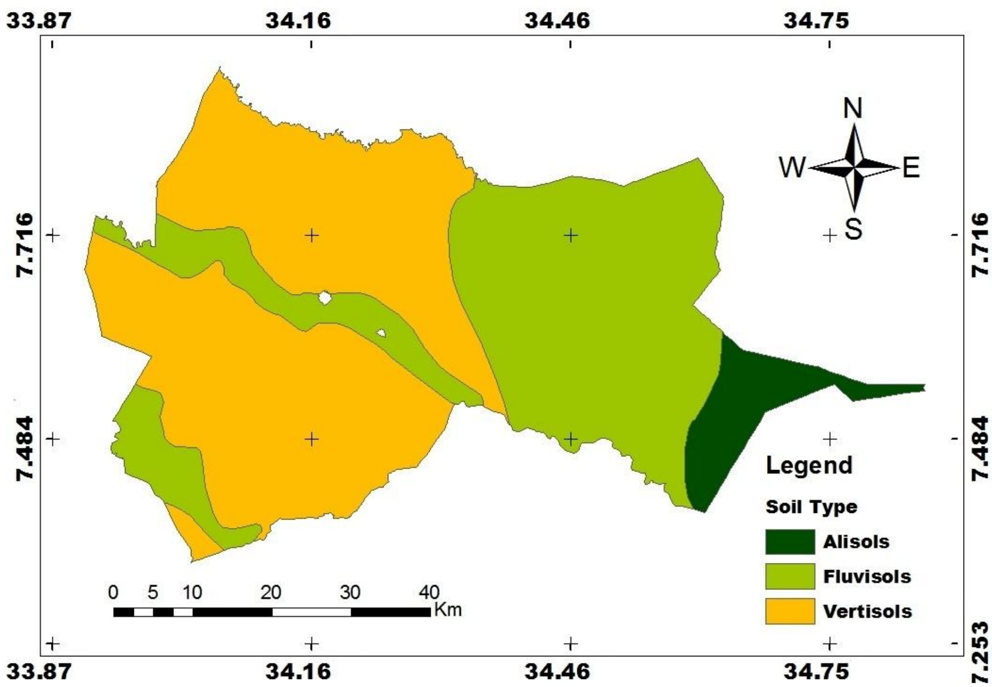

Figure 6: Soil map.

3.5. Rainfall of the study Area

The gridded ancillary data that described monthly, maximum and minimum rainfall data for the study area was obtained from the Ethiopian Meteorological Agency (EMA). The mean annual rainfall of Gog Wereda varies from 89.91 mm to 114.41 mm. (Fig. 7)

3.6. Temperature of the study Area

The mean annual temperature of Gog Wereda varies from 17.3^{o}C to 28.3^{o}C and annual monthly temperature varies throughout the year from 27^{o}C to 33^{o}C. The absolute maximum temperature occurs in mid-March and is about 45^{0}C and the absolute minimum temperature occurs in December and is 10.3^{o}C. (Fig 8).

3.7. Elevation of the study Area

The elevation map of the study area was derived from the ASTER DEM, which was downloaded from the http://gdem.ersdacjspacesystem.or.jp in May 2014. The elevation of Gog Wereda lays between 424 to 683 m above sea level (Fig. 9) and the slope also ranges between 1 and 4% (Fig.10). The Gilo river is dissected the Woreda in to two parts.

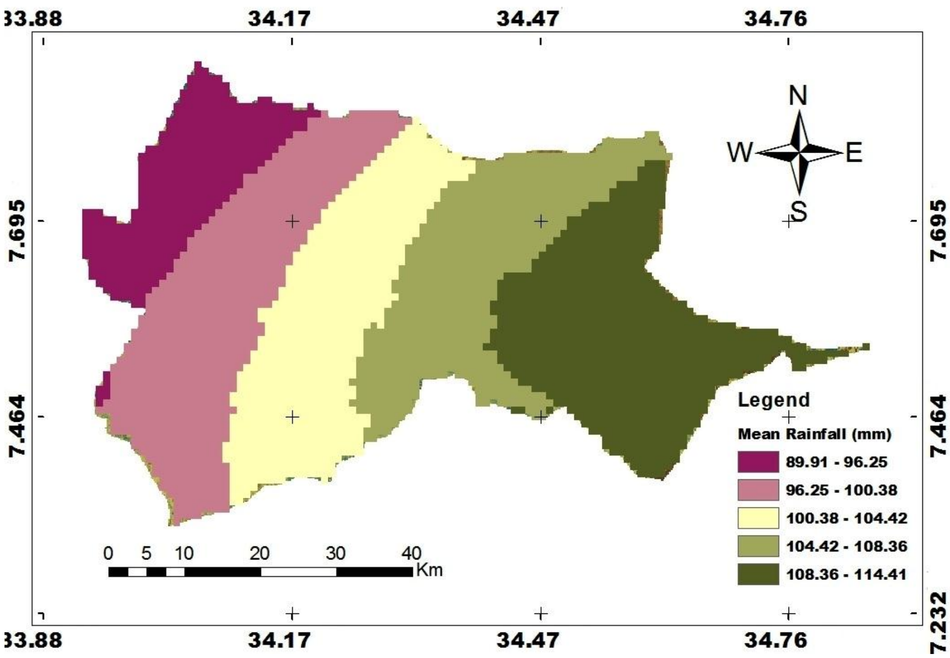

Figure 7: Mean Annual Rainfall map.

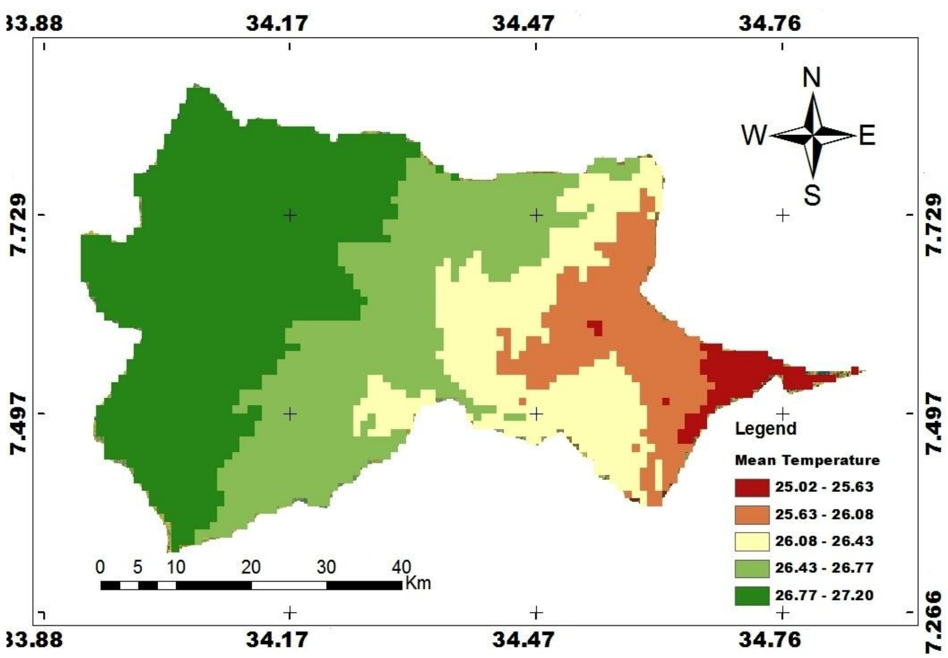

Figure 8 : Mean Annual Temperature map.

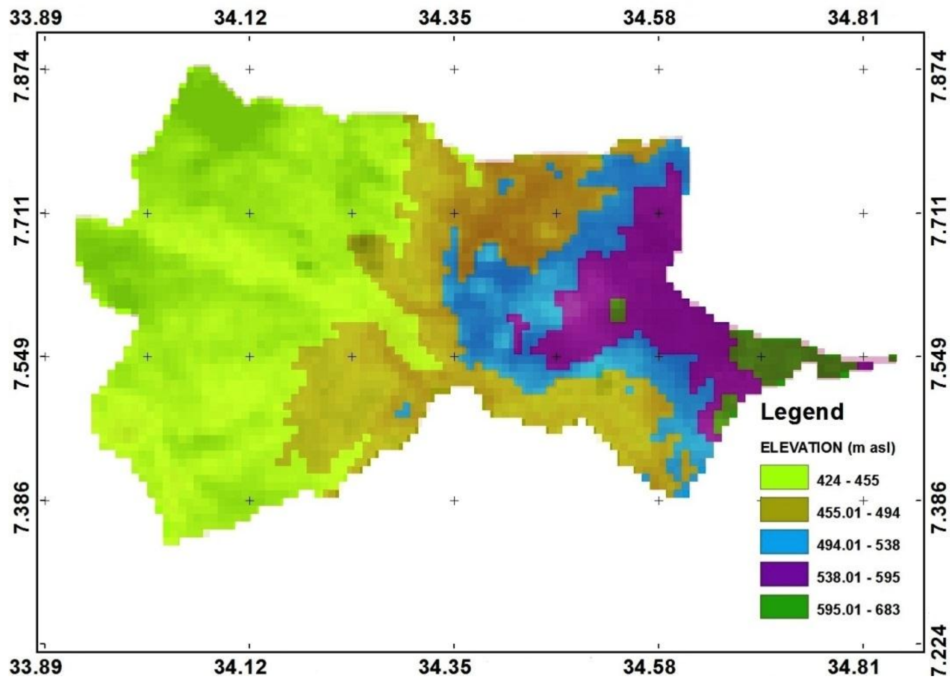

Figure 9: Elevation map.

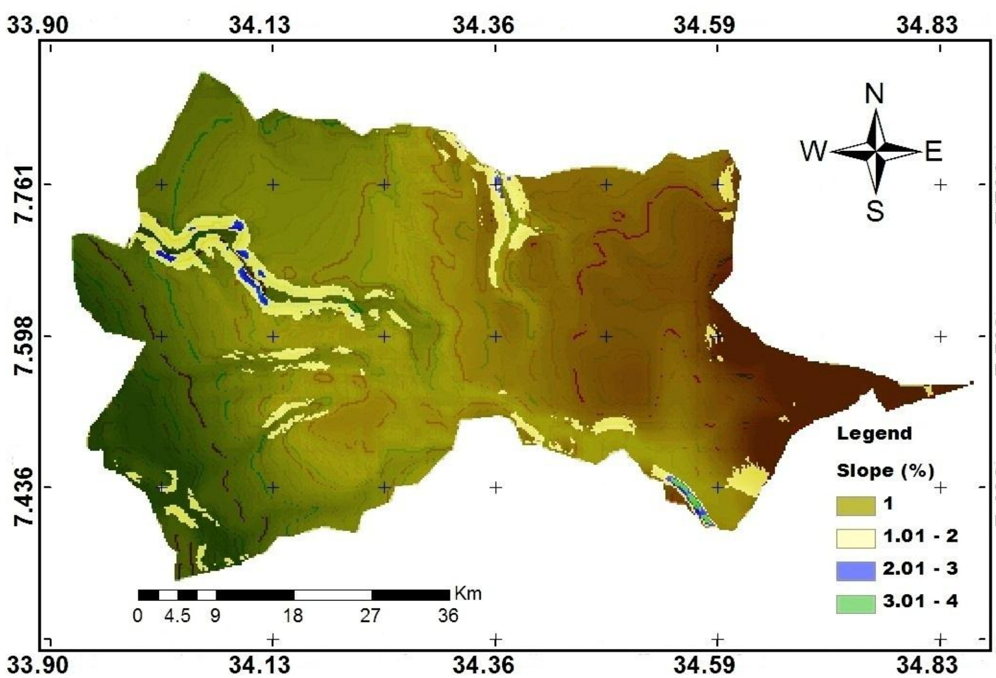

Figure 10: Slope map.

CHAPTER FOUR

4. METHODOLGY AND DATA PRE-PROCESSING

4.1. General Methodology and Methods of Data Collection

In this study a number of steps were employed to investigate the land requirements and derive suitable land map for rice cultivation in the Gog Woreda regional state of Gambella; Ethiopia. The required primary data such as Normalized Difference vegetation Index (NDVI), Land Surface Temperature (LST) and Digital elevation Model (DEM) were obtained from SPOT and ASTER space shuttles satellites. In addition to these; the calibrated meteorological ancillary gridded data of Ethiopia such as annual rainfall and temperature also obtained from the Ethiopian Meteorological Agency. The very important secondary data such as the soil data that incorporated the soil type, physical and chemical property of soil was acquired from Gambella regional state land utilization & environmental protections Authority.

The general methodological process for land suitability analysis and identification are employed based on the Multi-Criteria Evaluation (MCE) approaches (Fig.11). In this process, suitable lands are selected based on the combination of different parameters such as; Land Quality Index (Storie LQI) derived from the soil data, Agricultural drought levels, Water Supply Vegetation index (WSVI), Leaf Area Index (LAI), land-use/Land-cover (LULC) and the Crop Water Deficit index (CWSI).

These very important and necessary land suitability requirements are organized and form overlaid map layer using GIS spatial analysis methods. The decision rules which have been used to distinguish the most suitable lands are employed based on the Multi-Attribute Decision Making approaches. In order to determine which criteria (at what levels or weights) affect the land suitability level; the selected ten expert’s judgments are considered (See Appendix 7 for detail). Based on the consultation and judgments of the experts, weighted the criteria using the Analytical Hierarchy Process (AHP) technique. Finally the weighted overlay are employed to distinguished suitable land areas and produce suitability map for rice cultivation in Gog Woreda of Gambella Regional State. All methods were employed based on their significance priority stages. The general methodological process is presented in the precceding flow chart as follow;

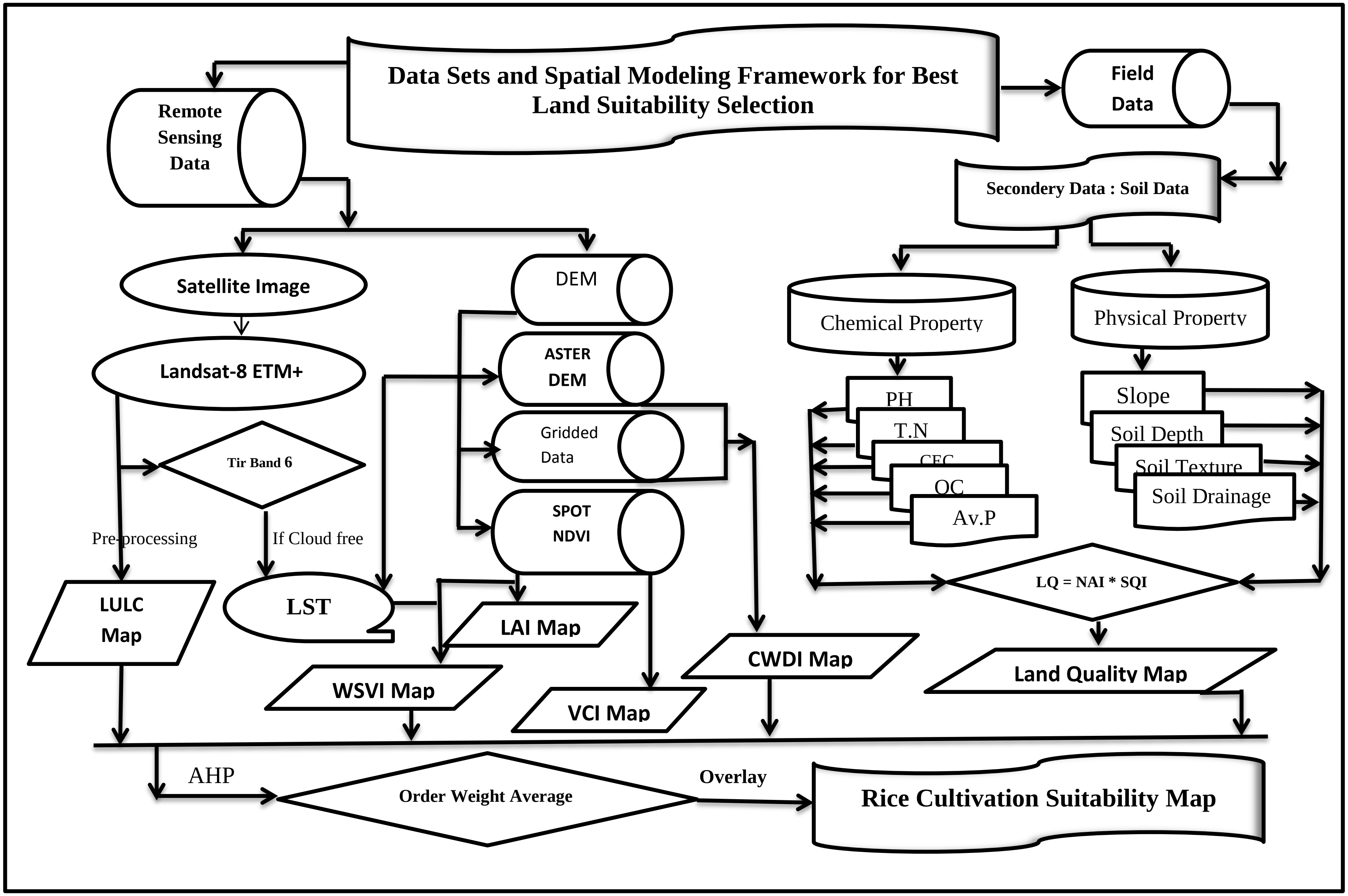

Figure 11: Schematic Flow Chart of the Research Methodology.

4.2. Data Pre-Processing

4.2.1 Land Quality Evaluation Model

Land utilization types were described by a set of land use requirements or land quality parameters, which are the land conditions necessary for successful farming characteristics and influence their suitability for given, land utilization types (Van Diepen et al. 1991). To determine and evaluate suitable land for rice cultivation the model in terms of topographic and soil physicochemical criteria; the Storier model of land evaluation was employed to evaluate the land status of the study areas.

Accordingly the importance of this evaluation model was pronounced by different literatures including, the studies conducted by the FAO (1983, 1996), Orhan Dengiz (2013), Mongkolsawat et al. (2002), Bunting (1981) and Yamada et al. (1995).

4.2.1.1. Storie Land quality Model

The soil Stories land quality model is required the physical and chemical properties of soil. This includes the soil PH value, organic Carbon, Total Nitrogen, Availability of Phosphorous, Cation Exchange capacity (CEC), soil texture, soil depth, slope and the drainage capacity of the soil.(Fig.12).

This study was employed land quality parameters and factor ratings normally employed in physical land evaluation in order to develop set of themes for evaluation to produce a suitability map for rice cultivation. The land quality attributes such as the Nutrient Availability Index (NAI) and the Soil Quality Index (SQI) used for evaluation. The land quality index evaluation model defined by using the following factor rating method;

LQI = NAI * SQI*---*Equation 1

Where LQI is Land Quality Index, NAI is Nutrient Availability index and SQI is Soil Quality index.

The soil Nutrient Availability Index (NAI) was calculated using the following formula:

NAI = Ph × T.N × Av.P × CEC × OC*---*Equation 2

Where TN is the total Nitrogen (%), Av.P is Availability of Phosphorous (mg Kg^{-1}), CEC is the Cation Exchange Capacity, and OC is Organic Carbon Content (%).

The Soil Quality Index (SQI) was calculated using the following formula:

SQI = Factor A* Factor B* Factor C* Factor X---------------------------------Equation 3

Where Factor A is the developmental stage I. It focused on the presence of clay stratification in the sub-soil. Factor B is indicated the surface texture of the soil; Factor C is indicated that the slop of the area and Factor X indicated the drainage capacity of the soil. The general information for soil quality evaluation and rating in Stories index is given in (Appendix 3).

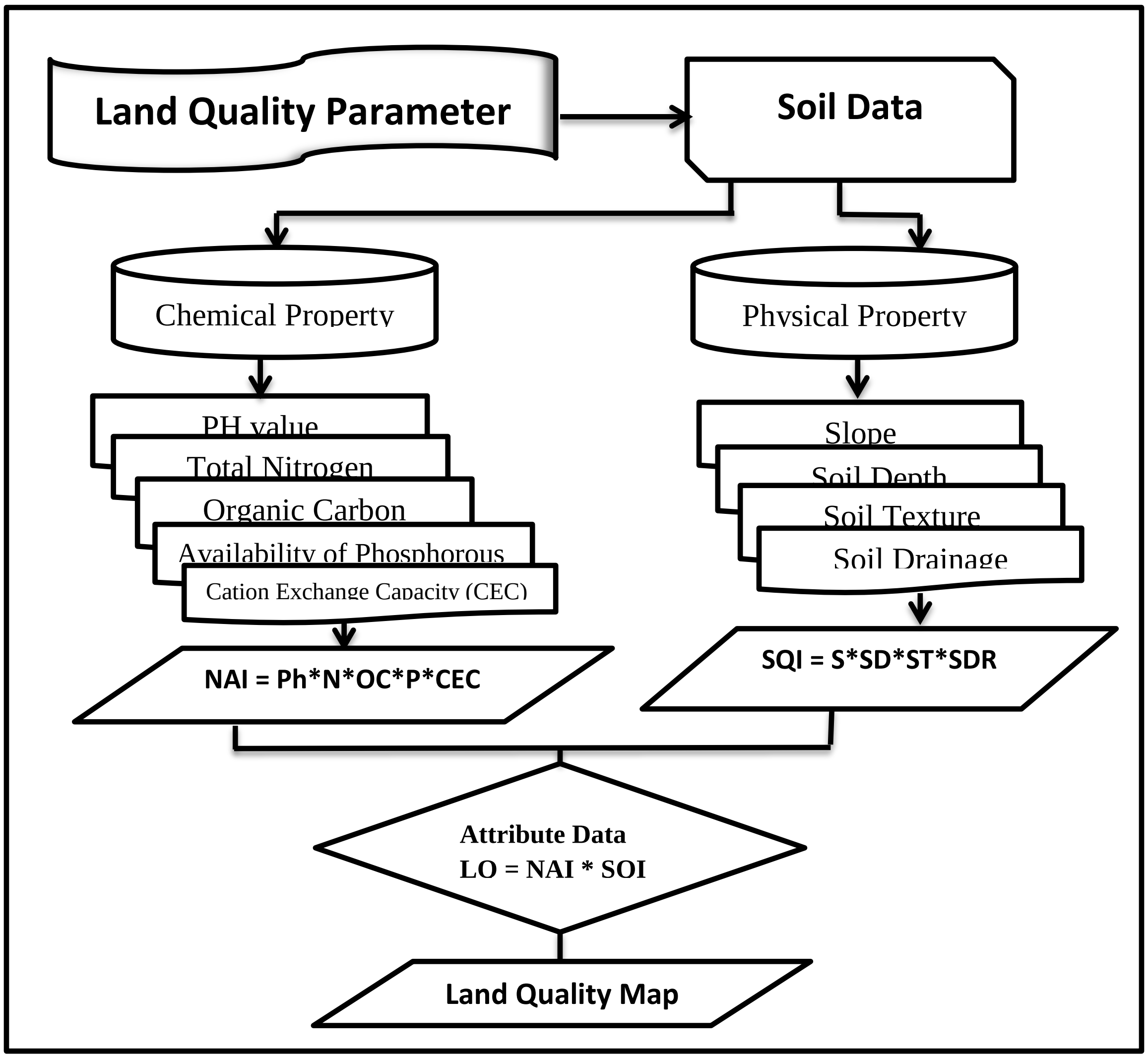

Figure 12: Schematic Chart of land Quality Evaluation Model.

The factor rating for the evaluation ranging between 0.2 and 1.0. The least favorable value of factor rating is 0.2 and the most beneficial value of factor rating is 1.0 for plant growth. In other words, the limiting nature of each suitability class is taken into account by its effect in reducing productivity. According to Willy Verhey (2001), this kind of factoring methods are discussed as most important and currently employed for land evaluations and it is also known as Storie index.

The soil mapping units are combined based on the content and level of the following nine parameters such as; Nitrogen (N), Availability of Phosphorous (Av.P), Cation Exchange Capacity (CEC), Organic Carbon (OC), Ph value, clay stratification, soil textural, slop and the drainage capacity of the soil. The Land suitability classification also involves the comparison of the land qualities of a land mapping unit and other facactors described in the next sub-chapters.

The results obtained from this anaiysis indicated that the land which have been found in the study area classified as a first, second and third level lands (Appendix 1).

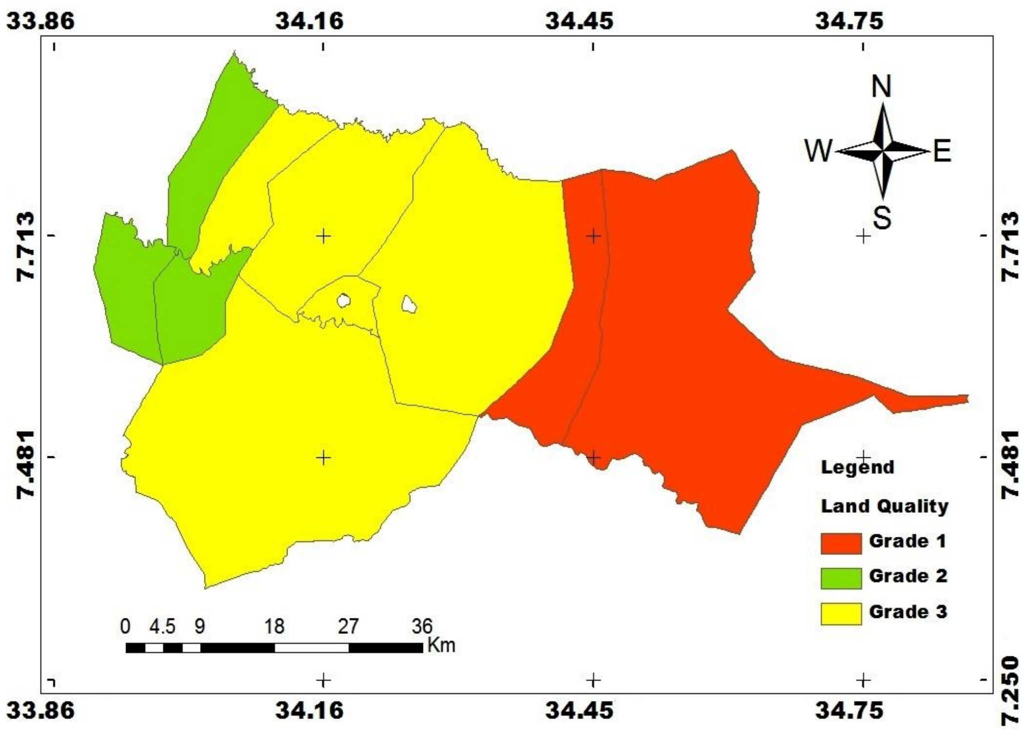

Figure 13 : Land Quality map**.**

4.2.2. Vegetation Condition Index (VCI)

The SPOT NDVI vegetation map was imported into the Software for the Processing and Interpretation of Remotely Sensed Image Time Series (SPIRITS). SPIRITS is windows-based software aiming at the analysis of time series remotely sensed earth observation data. Although it includes a wide range of general purpose functionalities, this study is only lies on the processing of time series SPOT NDVI statistics extraction.

Hereafter, the extraction of NDVI for Gambella Regional State, Gog Woreda was performed and the computation starts from 1st January 2003 to September 21st 2013 on decadal basis using the maximum, minimum and mean NDVI. These were then computed to the recent 2013 NDVI value in order to analyze the agricultural drought. The raster caluculation was performed using ArcGIS spatial analysis raster map caluculation tools. The overall process of the methodology is presented in (Fig 15).

Agricultural drought is defined more commonly by the availability of soil water to support crop and vegetation growth. Agricultural drought has a center focus in the precipitation deficits and its impacts. It has a great relationship with the meteorological and hydrological characteristics, and also indicted the difference between the precipitation and potential evapotranspiration balance. This difference can also reduce water content in soil and reservoirs levels, as affects plant water demand in both physical and biological growth properties (Kogan and Sullivan 1993).

Vegetation Condition index (VCI) is one of the most important indicator of the status of agricultural drought by computed the vegetation cover as fraction of the NDVI minimum and maximum for a given ecosystem (Jaint *et al.*,2010). The equation also described as follow;

$$\boldsymbol{VCI = 100\ \left(\frac{NDVI_{Mean} - NDVI_{Min}}{NDVI_{Max} - NDVI_{Min}}\right)}$$ **---Equation 4**

Where $NDVI_{Max}$ = Maximum NDVI, $NDVI_{Min}$ = Minimum NDVI and $NDVI_{Mean}$ = Mean NDVI.

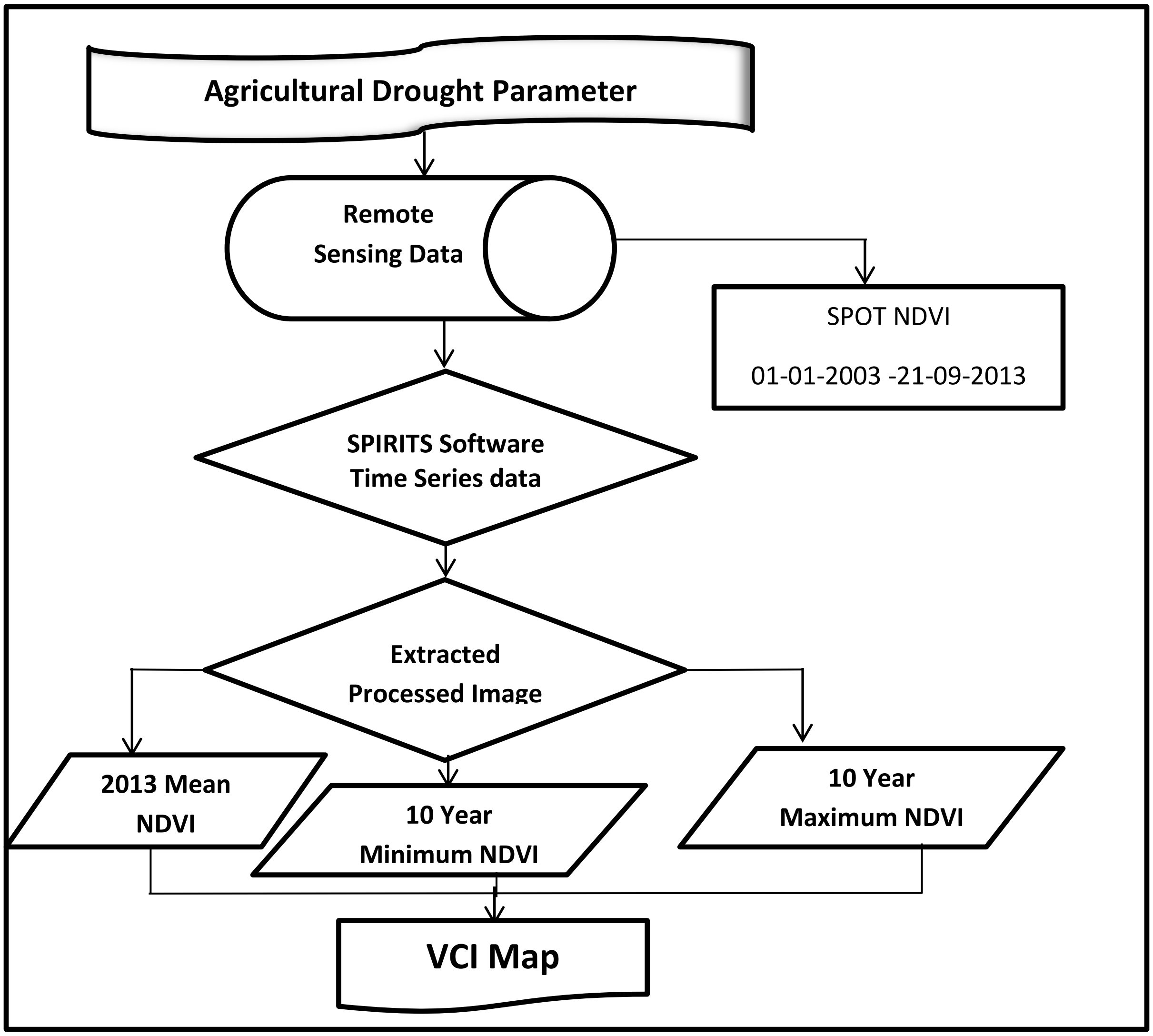

Figure 14: Schematic Chart of Vegetation Condition Index.

The NDVI value ranges from -1.0 to 1.0. The negative value indicates that the area might be covered by clouds and water. The positive value near to zero indicated the area may be covered by bare soils, whereas the higher positive value (i.e. 0.1 to 0.5) can be described as spares vegetation cover areas and dense green vegetation indicted by the highest positive value (i.e. > 0.6) (Galiano, 2012)

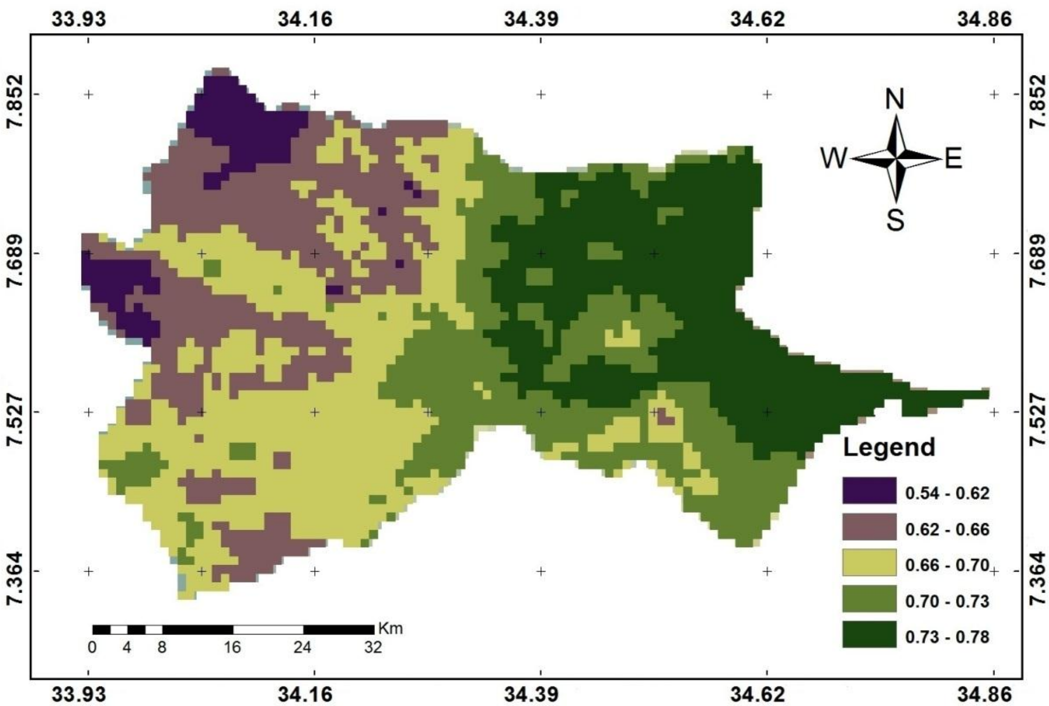

Figure 15: Normalized Difference Vegetation Index map.

The following table summarized how the value of VCI class can be described agricultural drought condition. (Table.1).

Table 1: VCI based agricultural drought severity class

VCI (%)	Interpretation	Remark
50 % – 100 %	No Drought	Crop Cultivated
36 %- 49 %	Slightely drought	Crop Stressed
< 35 %	Complete drought	Crop Failed

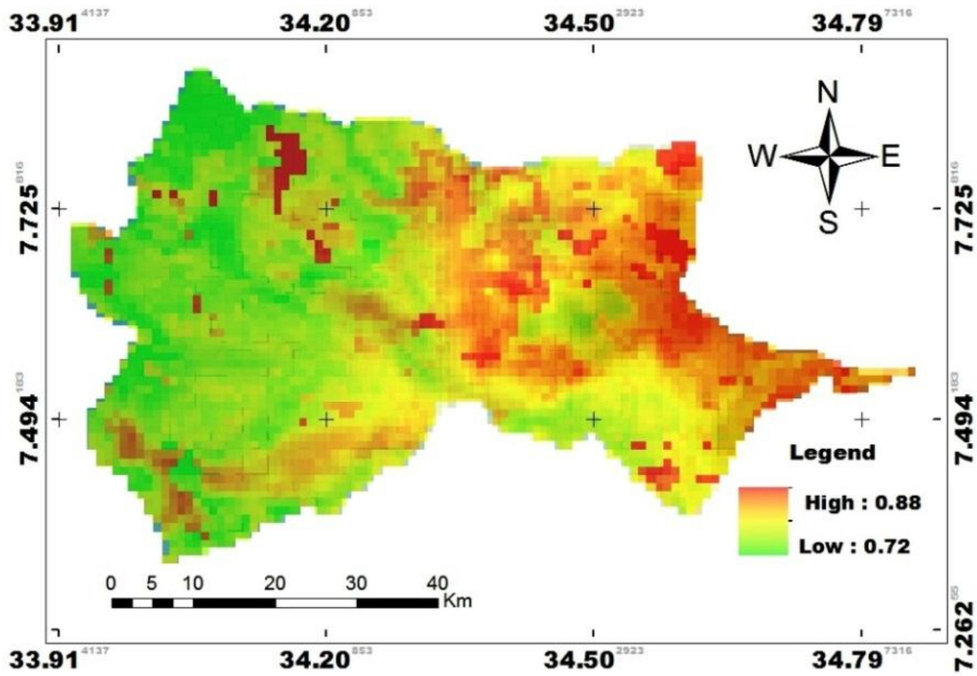

Figure 16: Maximum NDVI of year (2003-2013) map.

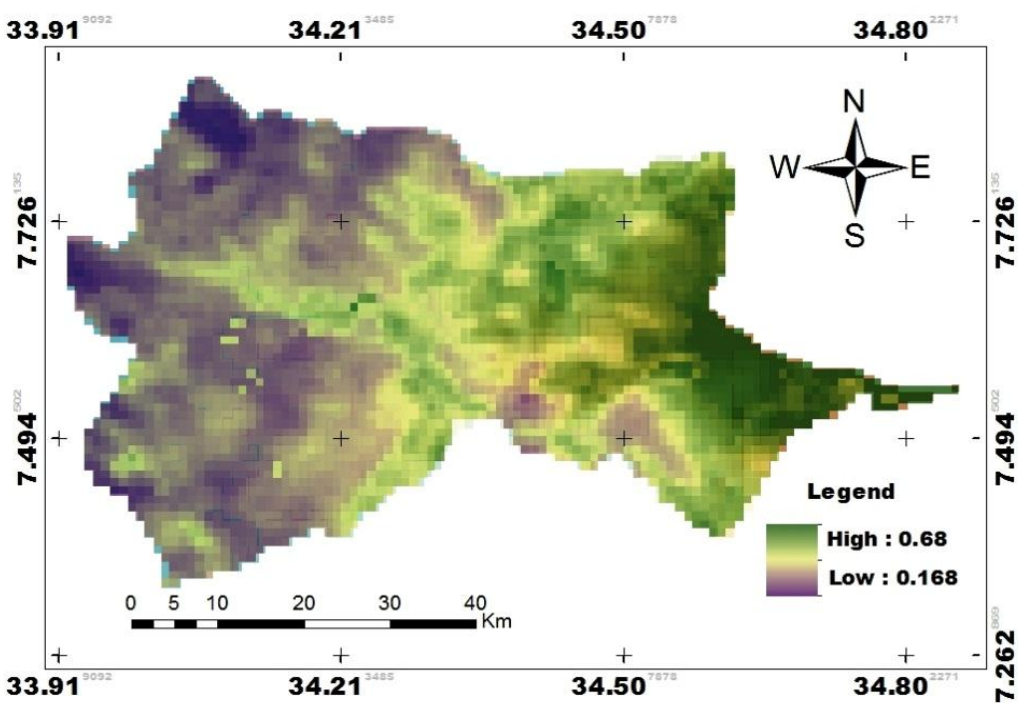

Figure 17: Minimum NDVI map of year (2003-2013).

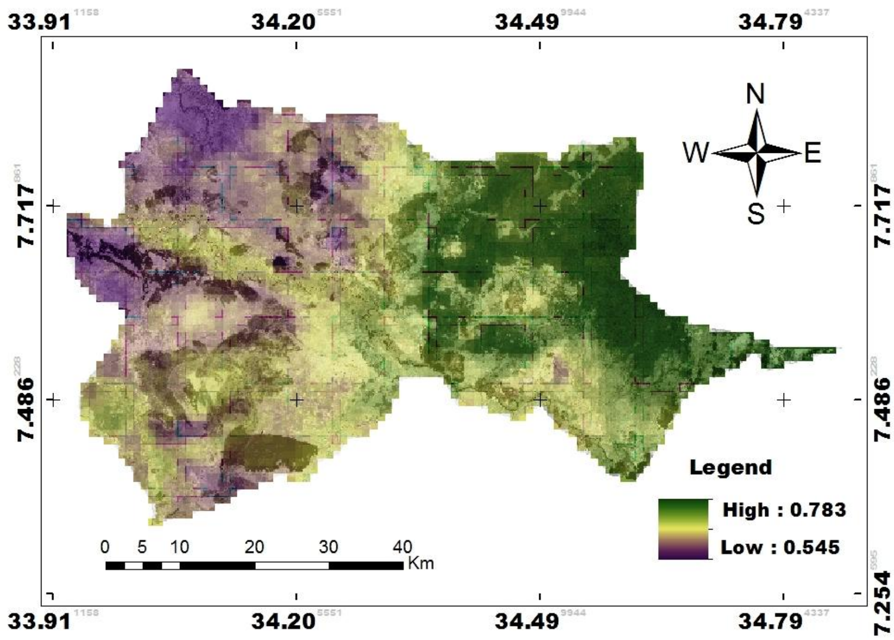

Figure 18: Mean NDVI Map of year (2003 -2013).

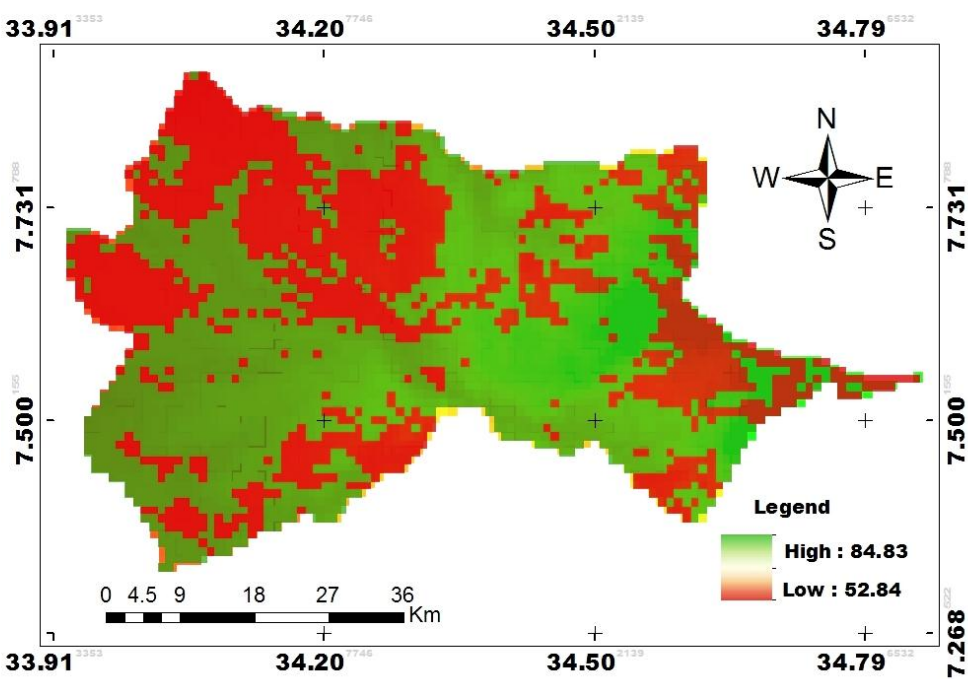

Figure 19 : Vegetation Condition Index map.

Therefore; the results indicated that; the VCI value of the study area ranges from 52.82 % - 84.83 % the minimum and maximum value respectively (Fig 19).

4.2.3. Land-use/Land-cover

The Landsat ETM+ satellite image obtained freely from the NASA satellite USGS archival and earth explore and distribution website (http://edcsns17.cr.usgs.gov/EarthExplorer/) classified with ten classes, based on the land cover and land use classification system developed by Anderson *et al*., (1976). The development of an appropriate land-use/land-cover database based on remotely sensed image analysis is presented in this section possessed with different activities such as: pre-processing, classification and accuracy assessment. The Pre-processing involves the stacking of different bands of image scenes obtained and creation of image mosaics for different path and row part of Gog Woreda. The classification of geometrically corrected Landsat ETM^{+} Level-1 Product Generation System (LPGS) downloaded from the USGS web site, begins with defining the training area. The training regions are determined based on the previous knowledge of the area, topography map of Gambella regional state, and from visual interpretation of the images. Next to this process; supervised classification method employed using the maximum likelihood algorithm. The general flow Char of the process is presented in as follow in (Fig 20).

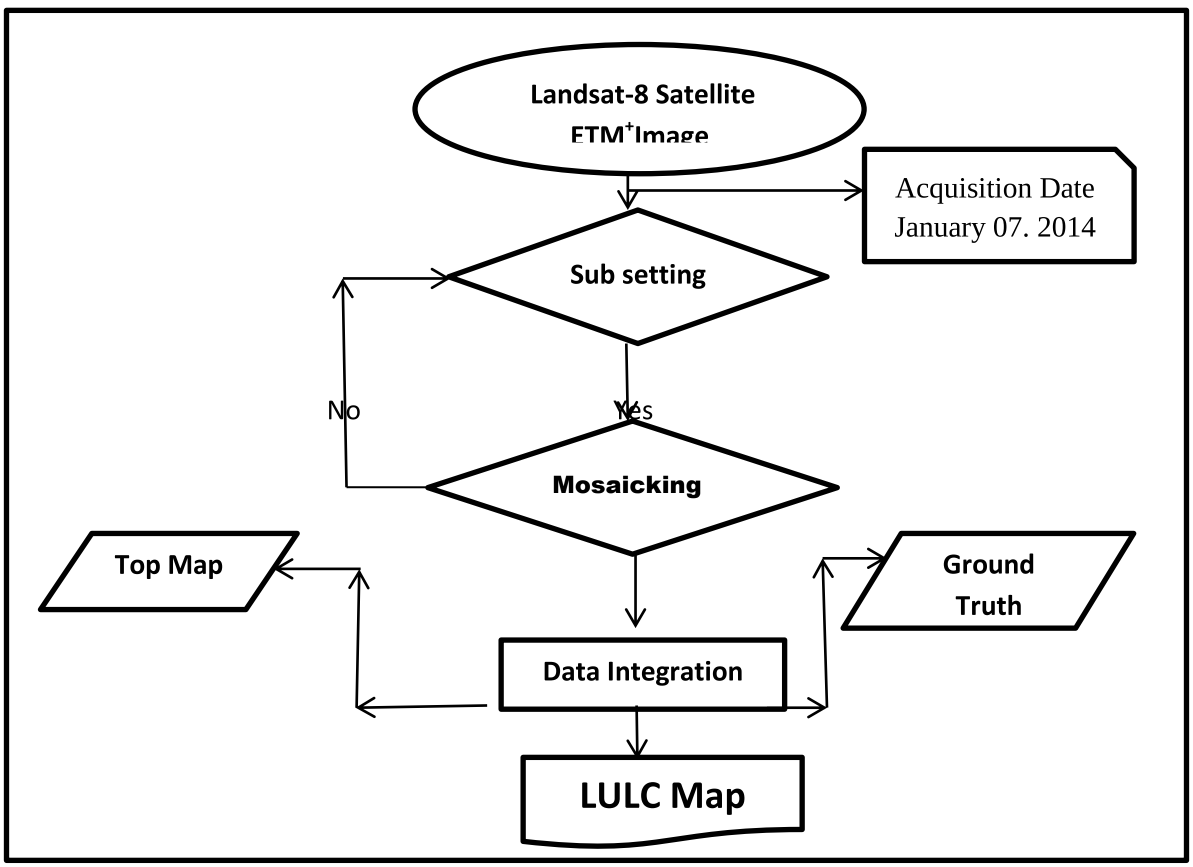

Figure 20 : Schematic Chart Follow of Land-usese and Land-cover map.

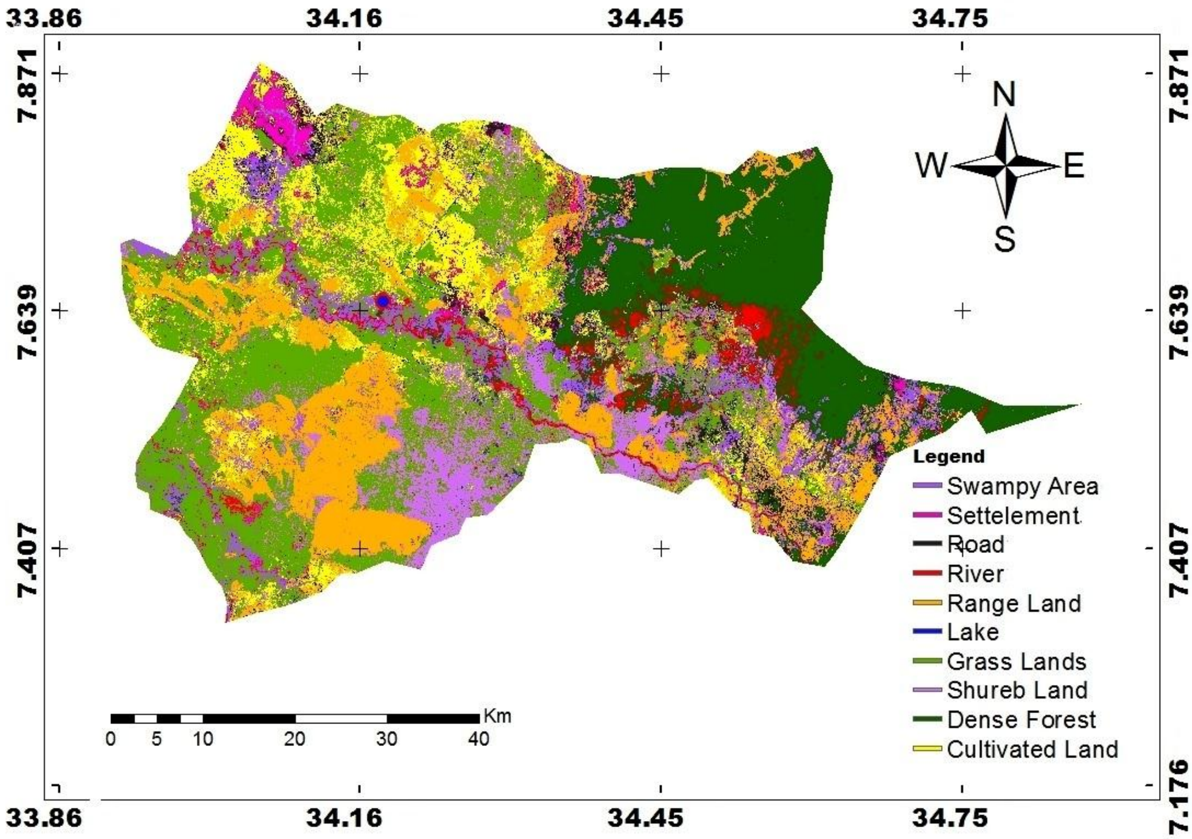

Figure 21: Land-use/ Land-cover map of year 2014.

Table 2: Land-use/Land-cover Area in Hector and Percentage.

Class Name	Area/ha	% of Areas
Range land	53,589.24	16.63
Lake	11.88	0.004
Dense forest	17.71	17.71
Settlement	9,529.74	2.96
Forest with shrubs	29,471.67	9.14
Cultivated land	74,454.12	23.10
Grass land	74,454.12	23.10
Swampy area	32,394.51	10.05
Road	15,231.96	4.73
River	9,055.89	2.81
Total Are	322,273.71	100

4.2.4. Land Surface Temperature

The land surface temperature (LST) as a climatic variable is related to surface energy balance and integrated thermal state of atmosphere and it acts as an indicator of climate change due to its upward terrestrial radiation influencing sensible latent heat flux exchange of air (Kipterer and Omowumi 2010).

In this study the land surface temperature is used as input data to determine the surface water supply of the study area. Hence the following methodology was employed to extract the land surface temperature from remotely sensed Landsat imagery and SPOT vegetation NDVI (Fig 22).

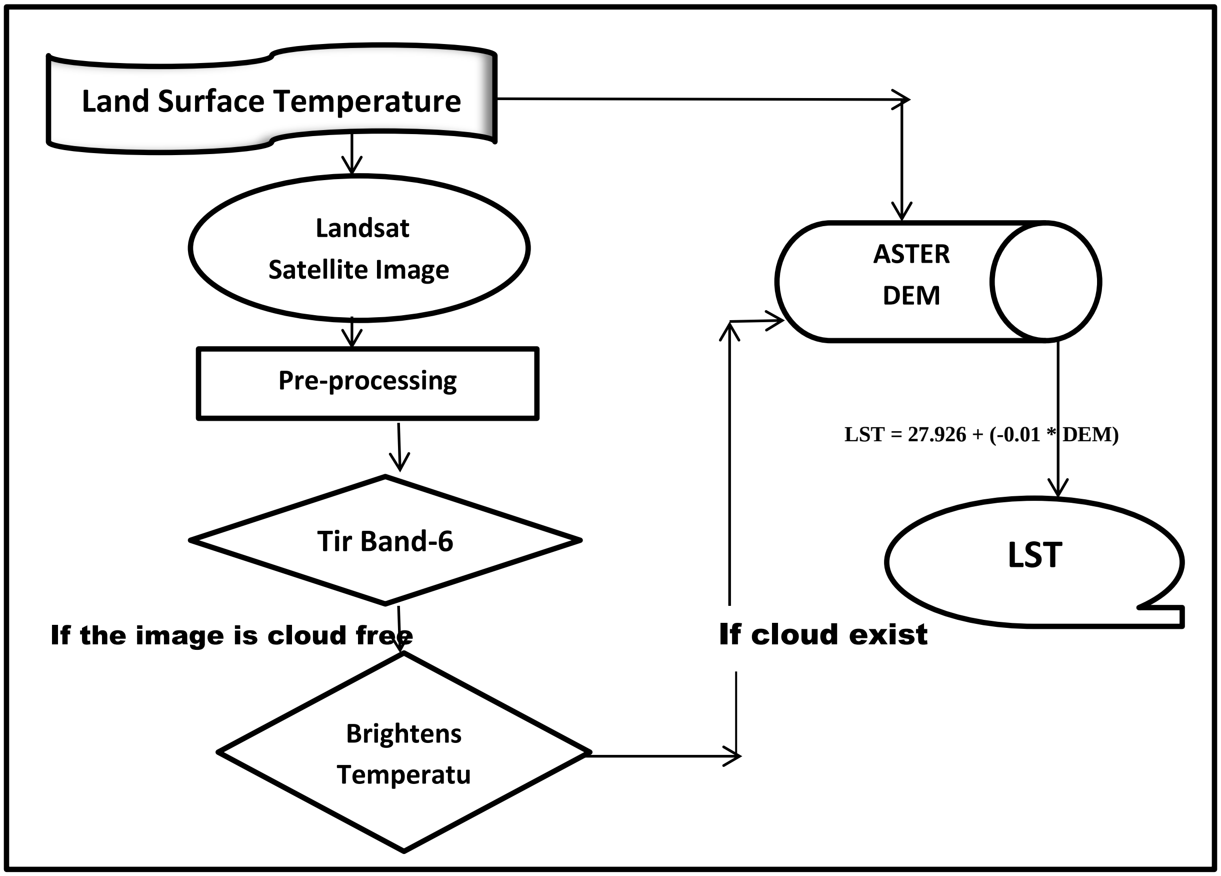

Figure 22: Schematic flow chart of Land surface Temperature Extraction**.**

LST is a very important variable required for a wide variety of applications for instance climatological, hydrological, agricultural, biochemical and change detection studies (Kipterer and Omowumi 2010). The land surface temperature can provide information about surface physical properties and climate which plays a great role in environmental processes. Kipterer and Omowumia 2014 summarized the LST as follows; the surface emitted radiance is altered by atmosphere before reaching the top of Atmosphere (TOA) sensors. The radiance measurement by sensor are made in one direction which is not necessarily representative for upper hemisphere, hence angular characterization of emissivity is difficult depending on anisotropy and separation of temperature from surface radiance is unfeasible because of under determination for sensor with spectral channels.

Based on the procedure described on the Landsat book -7, for this study the Landsat image band-6 Level-1 Product Generation System (LPGS) downloaded from the USGS web site was adjusted to convert the digital numbers to surface temperature reflectance (reflectance above the atmosphere) using the following algorithm in Environment for Visualization Image (ENVI) software. The specific procedures are listed as follow;

Radiance and Temperature brightness Retrieval: - Radiance refers to the flux of energy (primarily irradiant or incident energy) per solid angle leaving a unit surface area in a given direction. Radiance corresponds to brightness in a given direction toward the sensor, and is often confused with reflectance, which is the ratio of reflected versus total power energy. Radiance is what is measured at the sensor and is somewhat dependent on reflectance.The radiance is computed through the following algorithm presented in Landsat7 Science user data Handbook 2002;

$$L\lambda = Gain \times DN + Bias$$ --**Equation 5**

Where: Lλ is Radiance, DN is digital Numbers values recorded, Gain is **(Lλmax – Lλmin)/255** and **Bias** is the Lmin (intercept response function). $L\lambda_{max}$ is the highest and $L\lambda_{min}$ is the lowest radiance measured at detector, (saturation in $MWcm^{-2r-1}$). But bias correction is not employed because the bias errors on all post 12/20/00 Level-1 Product Generation System (LPGS Level 1) products are calibrated before distributed to the users (NASA 2002). The value of $L\lambda_{max}$ and $L\lambda_{min}$ were obtained from Landsat 8 ETM^+ metadata presented in (Table 3).

Table 3 : Value of $L\lambda_{max}$ and $L\lambda_{min}$

Band	Radiance Maximum	Radiance Minimum	Reflectance Minimum	Reflectance Maximum
6	95.18391	-7.86032	-0.099980	1.210700

The radiance brightness temperature was thereafter extracted based on the sensor algorithm available in the Landsat Handbook as follow;

$$TB = \frac{K2}{In\left(\frac{K1}{L\lambda + 1}\right)}$$ --**Equation 6**

Where, TB is the sensor brightness temperature (Satellite temperature) in Kelvin (K), K1 is calibration constant 1 equal to 666.09 $Wm^{-2}sr\ -1\mu m$, K2 calibration Constant 2 equal to 1282.71 watts/m2sr µm, Lλ is spectral radiance expressed in Watts/m2sr µm.

The Sensor Calibrations Constants for the Landsat TM and ETM+ is expressed in the (Table 4). These constant values are developed by NASA for the calibirartion of Landsat images.

Table 4: Thermal Band Calibration

TM and ETM+ Thermal Band Calibration Constants		
	Constant 1-K1 ($Wm^{-2}sr\ -1\mu m$)	Constant 2-K2 (Kelvin)
ETM+	666.09	1282.71
TM	607.76	1260.56

Source : (NASA 2002)

Land surface Emissivity Estimation :- The emitttance that reference to the energy initially absorbed, and then re-emitted as a longer wavelengths and heats up the objects. The Landsat-8 system is designed to collect 8 bands or channels of reflected energy and one channel of emitted energy. A well-calibrated ETM^+ enables one to convert the raw solar energy collected by the sensor to absolute units of radiance (NASA 2002).

After calculated the radioactive surface temperature, the next step is to correct this surface temperature for emissivity effect of the surface. Based on Kipterer and Omowumi 2010, the algorithm to compute emissivity (Ɛ) of mixed pixels composed of bares soil and vegetation as expressed in the equation;

$$\mathcal{E} = \mathcal{E}v\,PV + \mathcal{E}s\,(1 - PV) + \mathrm{d}E$$ ---**Equation 7**

Where; Ɛv and Ɛs is emissivity's of vegetation (0.99) and soil (0.97) respectively, dE is the effect of geometric distribution of natural surfaces and internal reflection with plain surface assumed to be of negligible unit and heterogeneous and rough surfaces e.g. forest among others takes a value of 0.55. The term PV is vegetation proportion obtained by using the following equation

$$PV = \frac{NDVI - NDVI_{Min}}{NDVI_{Max} - NDVI_{Min}}$$ --**Equation 8**

Where; NDVI Max = 0.78 and NDVI Min = 0.54. These directly extracted from the NDVI value obtained from SPOT Vegetation for te stuy area.

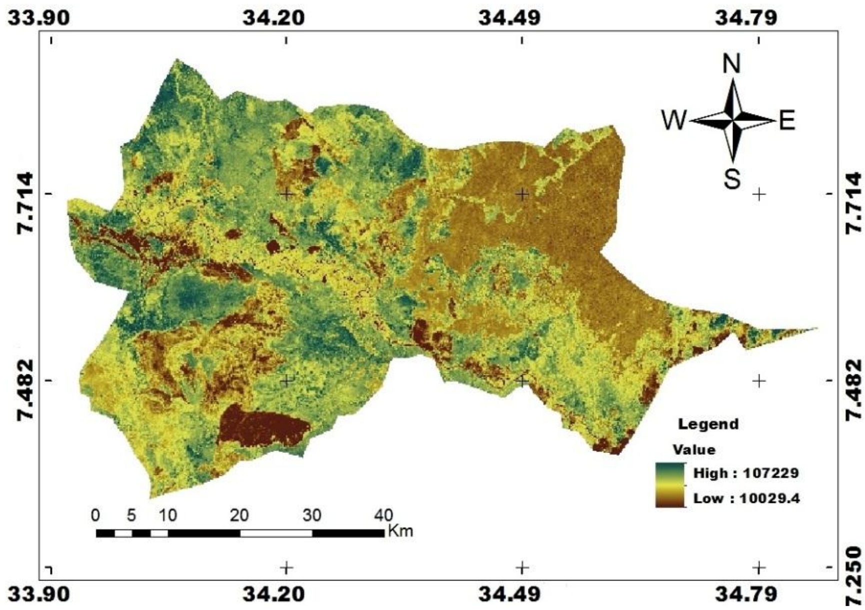

Figure 23 : Temperature brightness map.

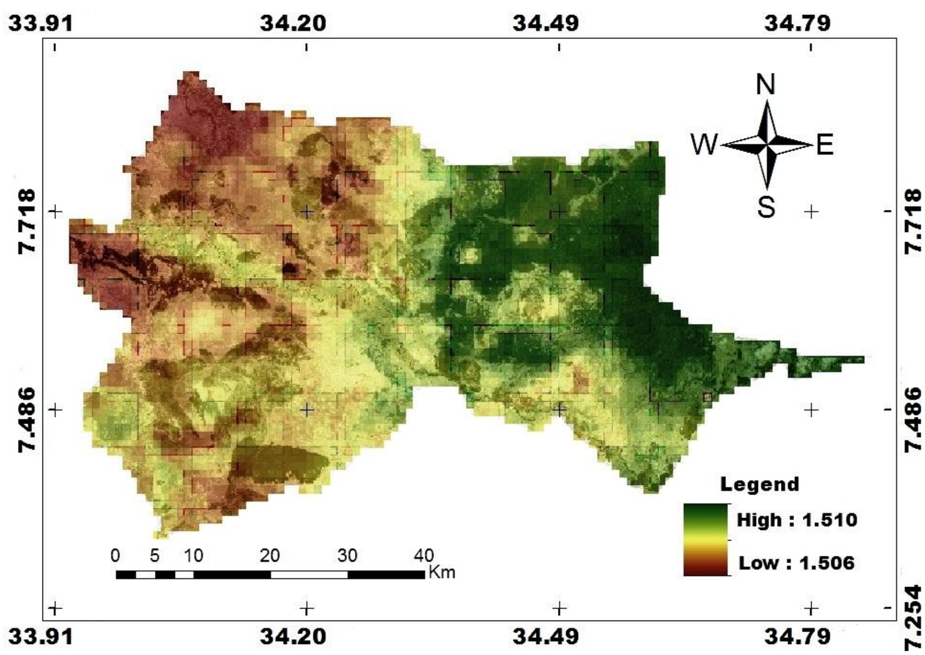

Figure 24: Land Surface Emissivity map.

Before proceeding to calculate the land surface temperature; the brightness values which obtained from Landsat band-6 data was converted to radioactive surface temperature (T^R) by using the following conversion methods discussed on the G. J. Roerink and Menenti (1999). The steps are discussed as follow; the law of Stefan Boltzmann equation is used to caluculate the outgoing (emitted) Long Wave radiation from the earth surface and atmosphere (L_{TOA}). The equation is expressed as follow;

$$\boldsymbol{L^{\uparrow}_{TOA} = \sigma T^{4}_{sat}} \text{--} \textbf{Equation 9}$$

Where; $L^{\uparrow}_{TOA}$ is lw radiation from the earth surface and atmosphere, Ϭ is the Stephan Boltzmann constant ($5.67*10^{-8}$ W rn- ^{2} Kw^{4}). Hence the radioactive surface temperature (T^R) is calculated to estimate the surface energy balance by using the inverting equation of Stephan Boltzmann law. The invert equation of Stephan Boltzmann law described as follow;

$$\boldsymbol{T^{R}_{o} = \sqrt[4]{(L^{\uparrow}_{TOA}/\sigma)}} \text{--} \textbf{Equation 10}$$

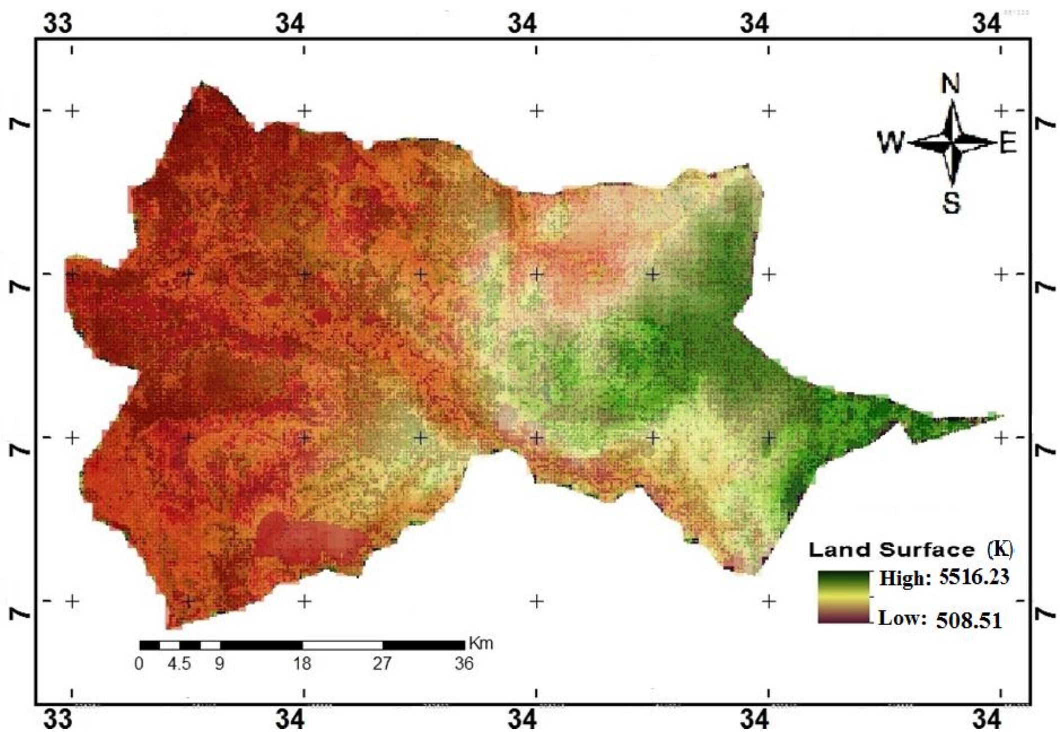

Figure 25 : Land Surface Temperature map.

Unfortunately; the image obtained based on the above equation was not trusted and confidential; because it shows very high or highly exaggerated land surface temperature for the study area. This kind of miss interpretation may be ocuured due to the the prevalence of cloud in the downloaded image. Thus to avoid such kind of problem, this study was forced to employeed another calibiration procedures. The image presented in (Fig 25) is only depicted for the comparison but it is not used as an input for the further analysis of this study.

Instead of this the land surface temperature derived from ASTER DEM was employed for further analysis and evaluation of the suitability land for rice cultivation. Tinebeb on her thesis described that; if there is clouds cover in the pixel of images; DEM was used to interpolate and obtain the continuous spatial distribution of land surface temperature using the following linear square fitting method (Tinebeb, 2012). The equation for fitting is described as follow;

$\mathbf{LST = 27.926 + (-0.01 * DEM)}$**--Equation 11**

Where LST is land surface temperature, DEM is Digital Elevation Model, 27.926 is the average temperature , -0.01 calibration constant for system errors.

Hence finally the land surface temperature of the study area was calculated using the above algorithm; the calculated land surface temperature is presented as follow in (Fig 26).

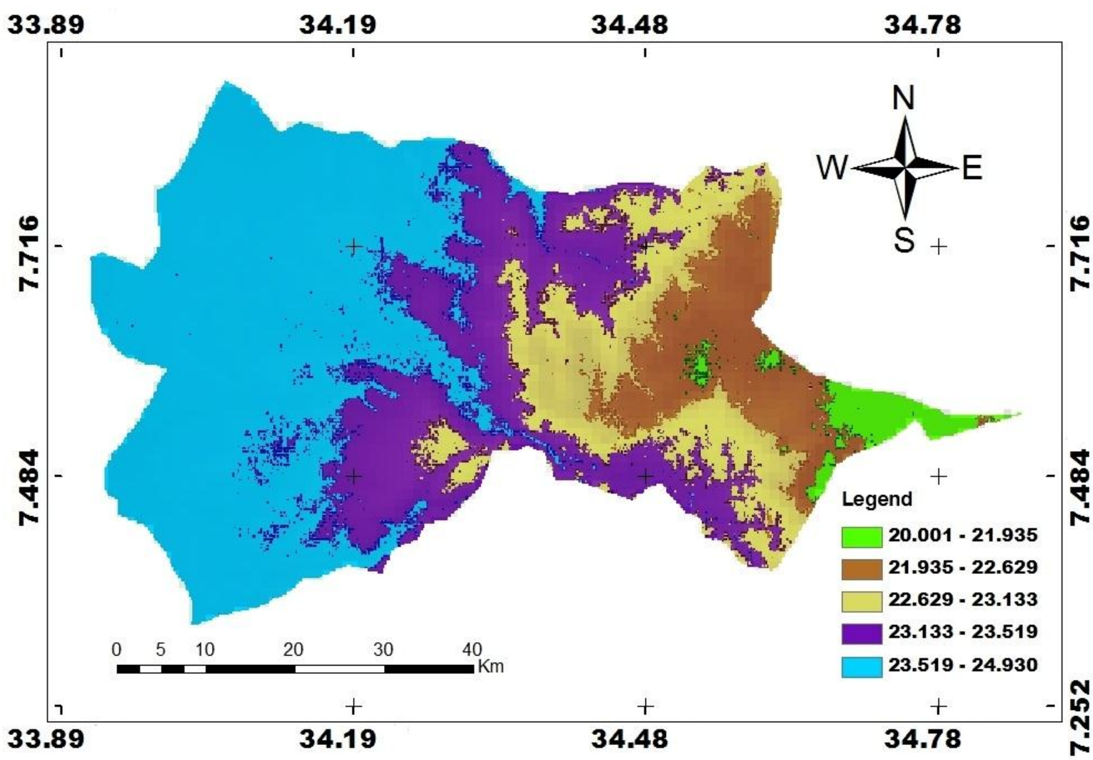

Figure 26: Land Surface Temperature map derived from ASTER DEM

4.2.5. Water Supply Vegetation Index (WSVI)

Water supplying vegetation index is an indicator based on the relationship between normalized difference Vegetation Index and surface temperature. This method provides effective method of estimating surface moisture condition Luke, *et al*, (2001). The Land Surface temperature derived from Landsat image or ASTER DEM and normalized difference vegetation Index (NDVI) derived from SPOT satellite used to generate the water supplying vegetation Index (WSVI) of the study area. (Fig.27).

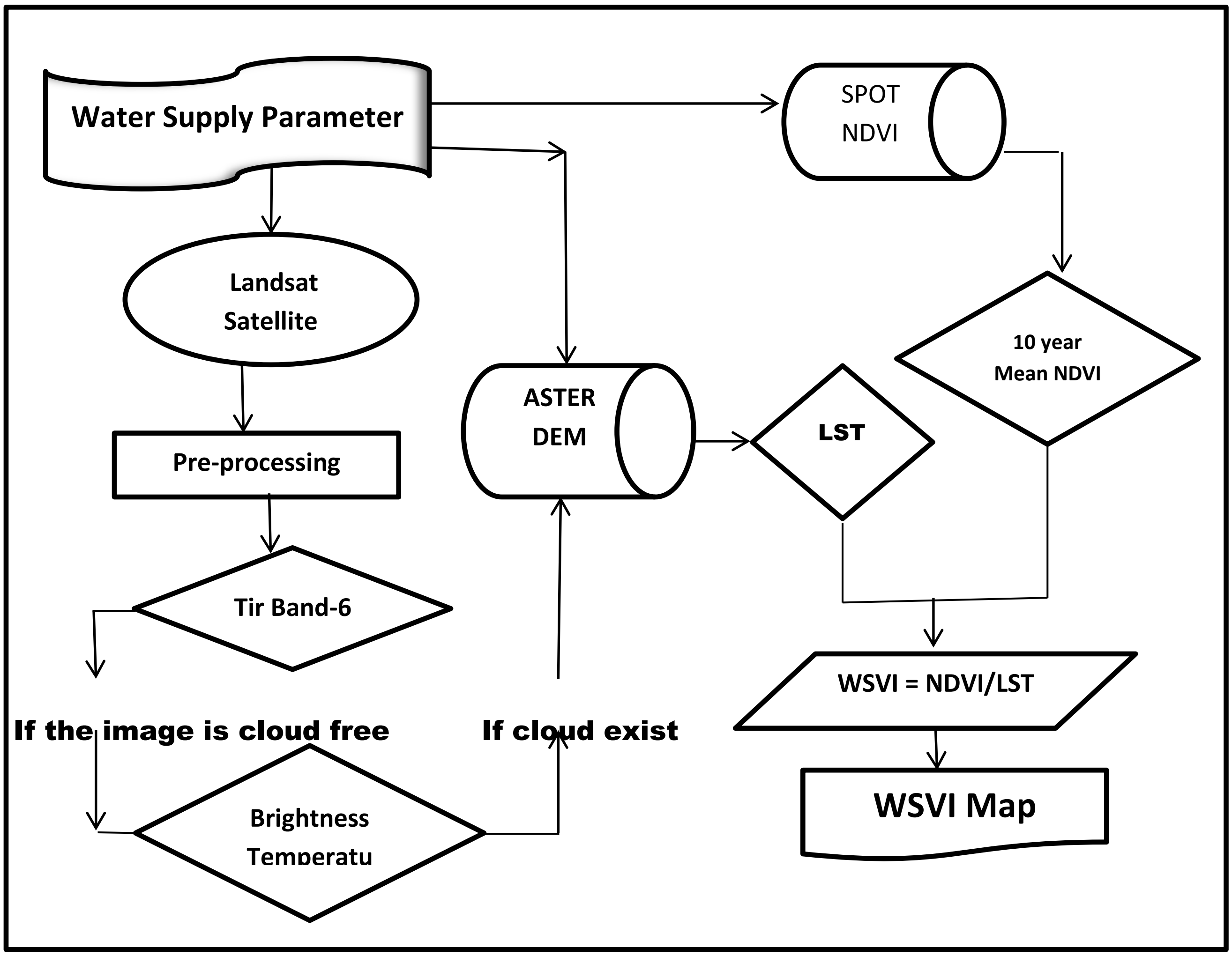

Figure 27: Schematic Flow Chart of Water Supply Vegetation Index.

The WSVI was developed by Yang *et al.*, (1997) is expressed as shown

$$WSVI = \frac{NDVI}{T_s} \quad \text{--} \textit{Equation 12}$$

Where NDVI = is the mean NDVI of the study area, *Ts= is* the brightness temperature channel or related remote sensing imagery estimated [K]. The WSVI values ranges from -4 for extreme dry (Arid area) to +4 for highly moist condition, Luke, *et al,* (2001).

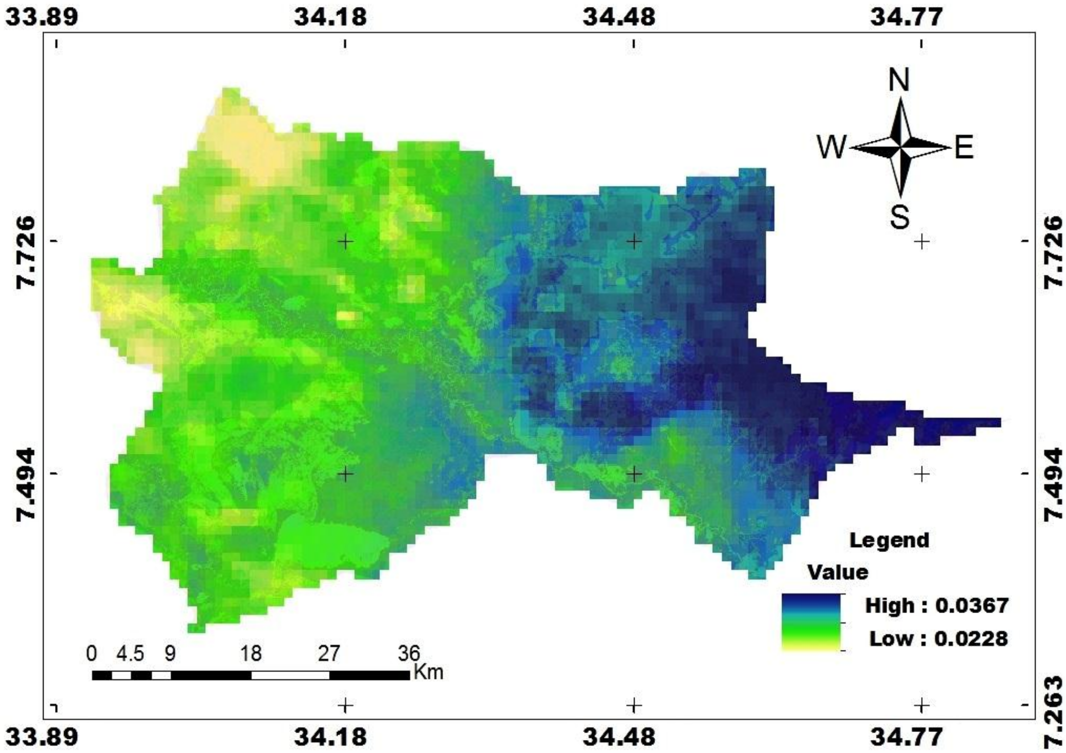

Figure 28 : Water Supply Vegetation Index map.

4.2.6. Crop Water Deficit Index (CWDI)

Canopy surface temperature measured with infrared thermometers (IRTs) or other remote infrared sensors provides an important tool for crop water stress detecting, which has been in practice for some decades. The crop water deficit index (CWDI) is the most often used index to quantify crop water stress based on canopy surface temperature. Much research has been done to evaluate the application of the CWDI in irrigation scheduling for different crops in different places (M. Kacira, *et al.*, 2001).

The research conducted by IRRI (1986) indicated that; the crop-water stress can be occurring at any growth stage is adversely affects the plant growth and reduces yield. Specially the Crop-water stress is most damaging when it occurs at the reproductive stage, because water deficits from the reduction division stage to heading can cause a high percentage of sterility. This studies also indicated that; the yields are greatly reduced when water application rates fall below a certain level.

Thus; for this study CWDI was considered as a key input parameter to determine and evaluate the suitable land for rice cultivation. The CWDI retrieval was derived by using land surface temperature (LST) and ten year average gridded temperature. ASTER DEM obtained from (http://gdem.ersdacjspacesystem.or.jp, 2014) website and the gridded temperature also obtained from Ethiopian Metrological Agency. The general flow chart of the overall methodological process is presented as follow in (Fig 29).

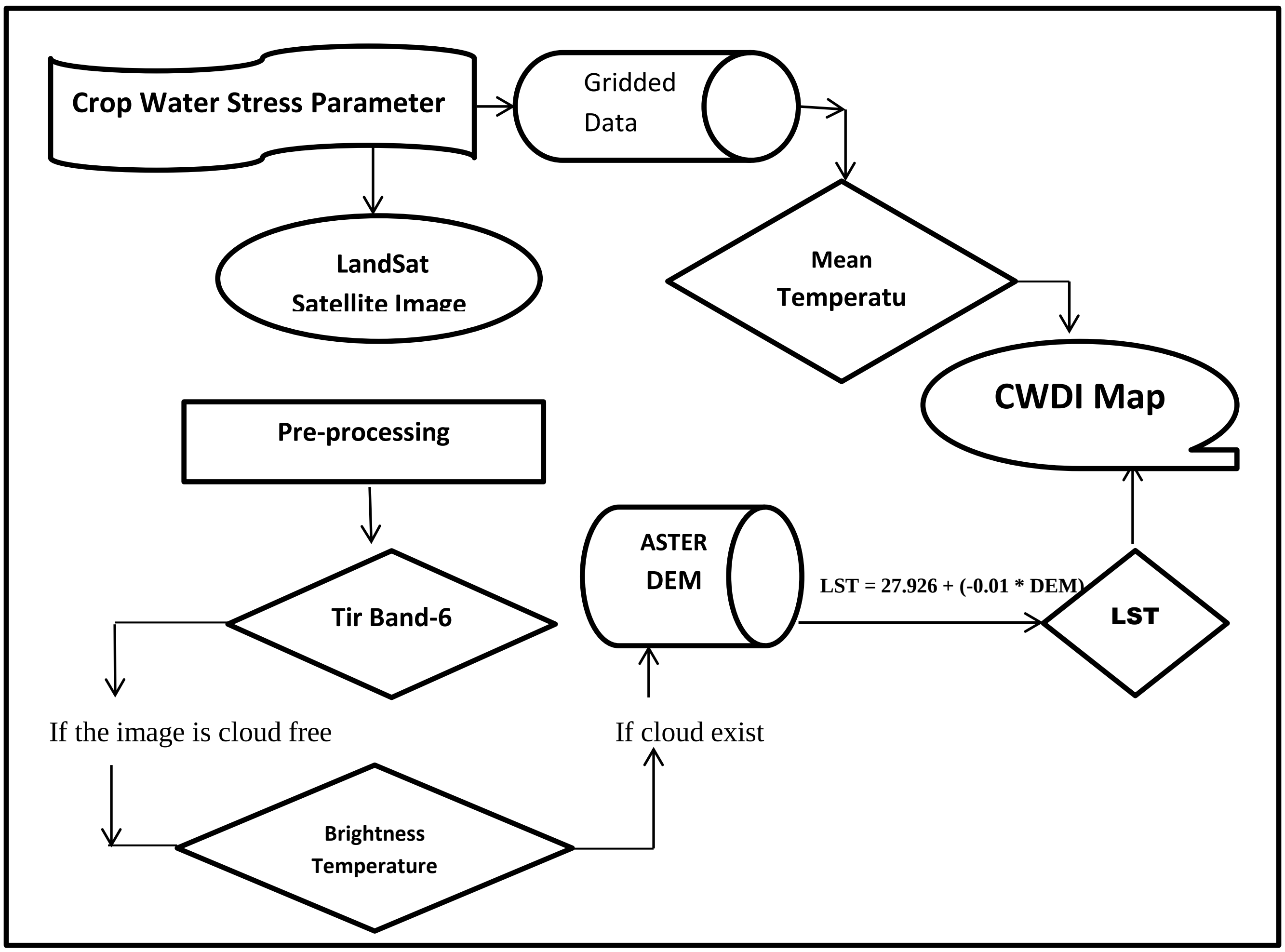

Figure 29: Schematic Chart of Crop Water Deficit Index (CWDI) Model.

The The WSVI is expressed as shown;

$$\boldsymbol{CWDI = 1 - ET_{act/\ ET_{pot}} = 1 - \left[\frac{(LST_{Max} - T_a) - (LST - T_a)}{(LST_{Max} - T_a) - (LST_{Min} - T_a)}\right]}$$ ------------------**Equation 13**

Where *LSTmax* and *LSTmin* are maximum and minimum LST respectively; ETact and ETpot represent actual and potential evapotranspiration respectively, found for a given vegetation cover (or vegetation index) in the left and right edges of the trapezoid VITT (Vegetation index versus difference of temperature). Then, Ta represents air temperature (Garcia 2012).

The CWDI quantifies the relative rate of latent heat flux, so it shows a value of 0 for fully wet surface (evapotranspiration only limited by the atmospheric demand), and 1 for dry surfaces where there is no latent heat flux (Xihua *et al*. 1997).

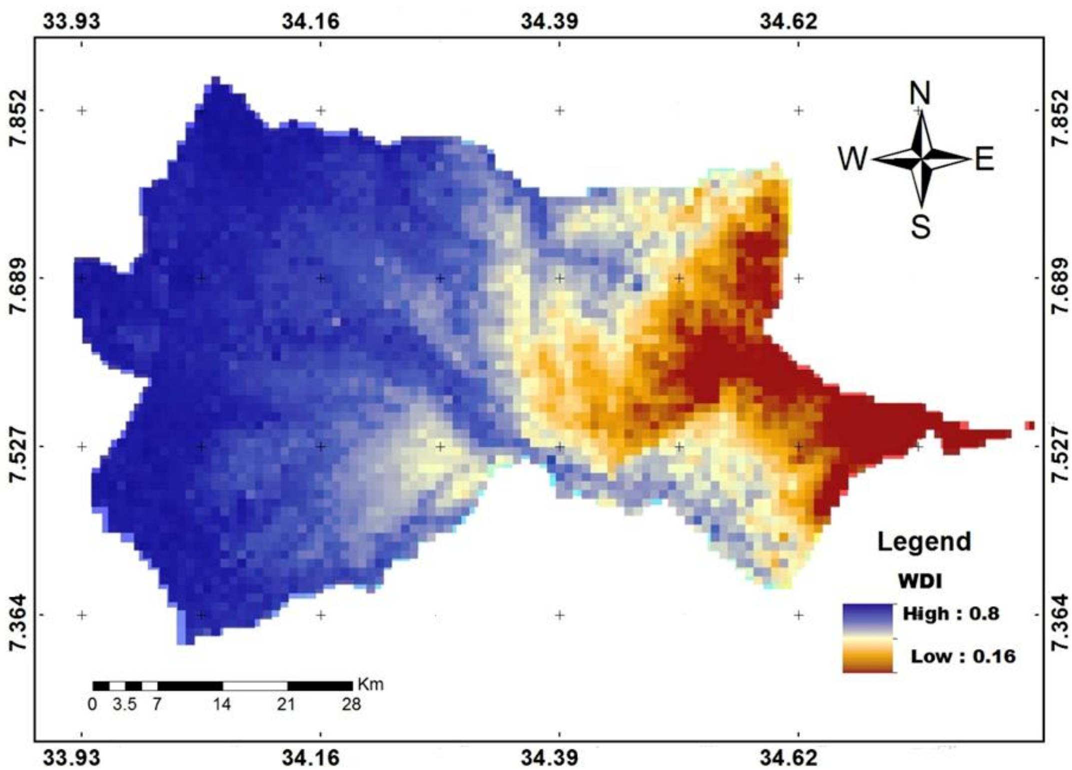

Figure 30 : Crop Water Deficit Index map.

4.2.7. Leaf Area Index (LAI)

The ability to accurately and rapidly acquire leaf area index (LAI) is an indispensable component of process to ecological and agricultural researches. It also facilitating the understanding of gas-vegetation exchange phenomenon at an array of spatial scales from the leaf to the landscape. However, LAI is difficult to directly acquire for large spatial extents due to its time consuming and cost and work intensive nature *(Mohamed Elhag 2014).*

It is important for assessing growth and vigor of vegetation on the planet. It is also fundamentally important as a parameter in land-surface processes and parameterizations in climate models. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration and rain interception *(Mohamed Elhag 2014)*

The following equation is used to determine LAI from NDVI for agricultural land (Asrar *et al.*, 1992).

$\boldsymbol{LAI = NDVI \times 1.71 + 0.4}$ **--Equation 14**

Where LAI is Leaf Area Index. NDVI, Normalized Difference of Vegetation Index and 1.71 and 0.4 are calibration constants for system errors. The optimum values of LAI for plants (vegetations) are between 3 and 5; for forest 6-8 and for crops 2-4 (Scurlock *et al.*, 2001).

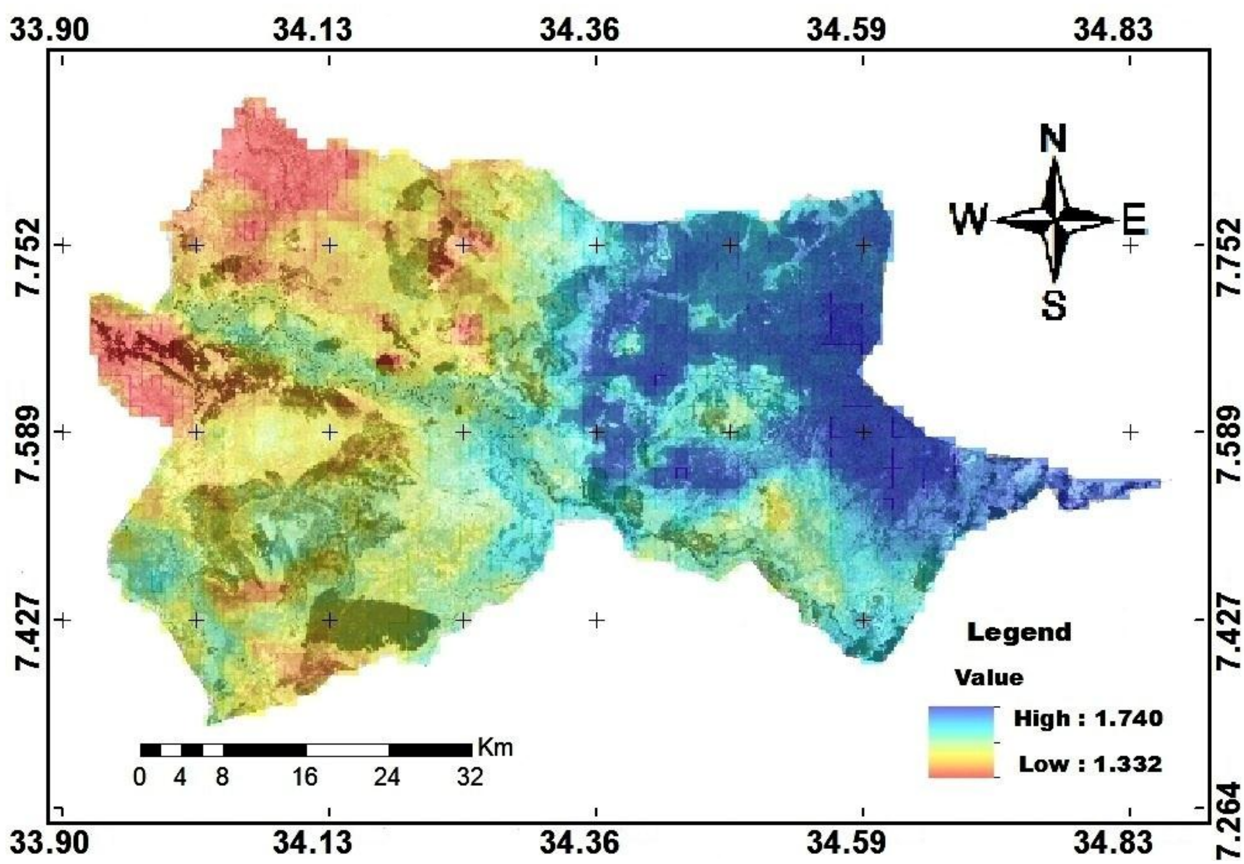

Figure 31 : Leaf Area Index map.

CHAPTER FIVE

5. DATA ANALYSIS AND WEIGHT DETERMINATION

5.1. Data Analysis

This study involved a Multi-Criteria Evaluation (MCE) decision making approach to find out and identifying suitable lands for rice cultivation. Different valuable parameters are analyzed and evaluated to produce the suitability map based on multi-criteria evaluation approach. To illustrate this, each criterion can be assigned as a specific weight that reflects its importance, relative to other criteria under consideration. Before proceeding to the decision; the criteria which needs to evaluate was re-classified through criterion map layers prepared using GIS database. The succeeding sequential sub-topics will presented the detail reclassification processes.

5.1.1. Reclassification of Land Quality Land Quality

Based on the soil and topographic data, which were obtained from Gambella Land Utilization & Environmental Protection Authority the land quality of the study area was determine. And to create conducive atmosphere for further weightage analysis the land quality dataset was reclassified in to three classes and assigning scale value for each class (Fig.32).

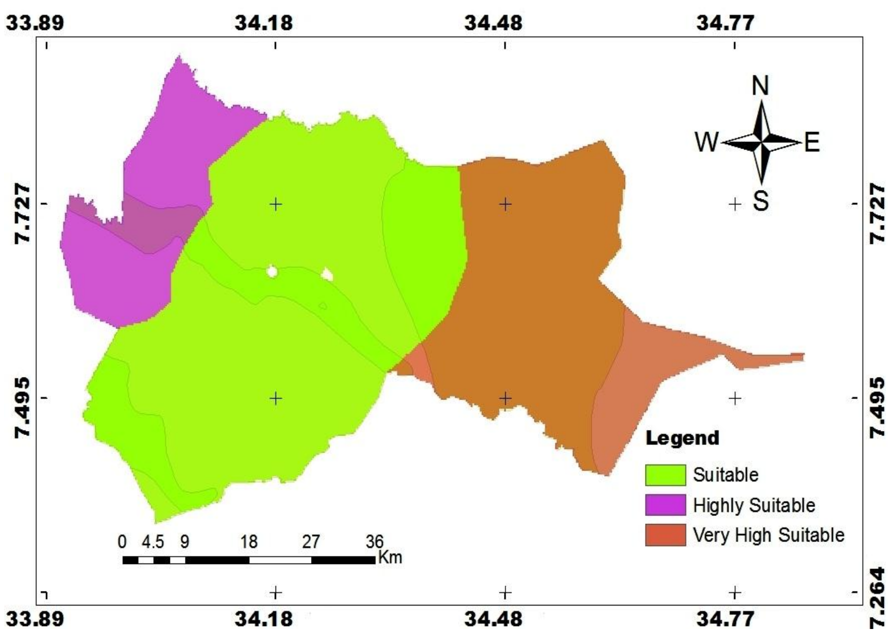

Figure 32 : Land Quality Suitability Map of Gog Woreda

Table 5: Rating Assigned to land Quality Classes

Class Scale	Land Quality Classes	Suitability Level	Remark
5	Grade 1	Ver High Suitable	Storie Land Quality
4	Grade 2	Highly Suitable	
3	Grade 3	Suitable	

5.1.2. Reclassification of Land-use/Land-cover (LULC*)*

The land-use/land-cover map of the study area derived from Landsat-8 ETM+ used a visual interpretation through ERDAS software and reclassification is carried out in ArcGIS 10. The output of land-use/land-cover reclassified in to five classes and assigning scale value for each class (Table 6).

Table 6: Rating Assigned to land use and land cove classes

Clas Scale	LULC Classes	LULC Suitability Level	Remark
1	Roads , Lake and Rivers	Not Suitable	
1	Densed Forest & Settlement Areas	Not Suitable	
3	Grass Lands	Moderately Suitable	
4	Range Lands & Forest With Shrubs	Highly Suitable	
5	Swampy & Cultivated Lands	Very High Suitable	

During assigning of scale for each class caution is made as to which class value should be given highest scale and vice versa. In this regard settlements, all weathered roads, dense forests and part of water body areas are assigned by less scale and restricted during the reclassification processes and also categorized under non-suitability levels. This assigning method was engaged by considering the pervious socioeconomic, biodiversity and ecological challenges caused due to agrological zone delineation in the region (Fig 33).

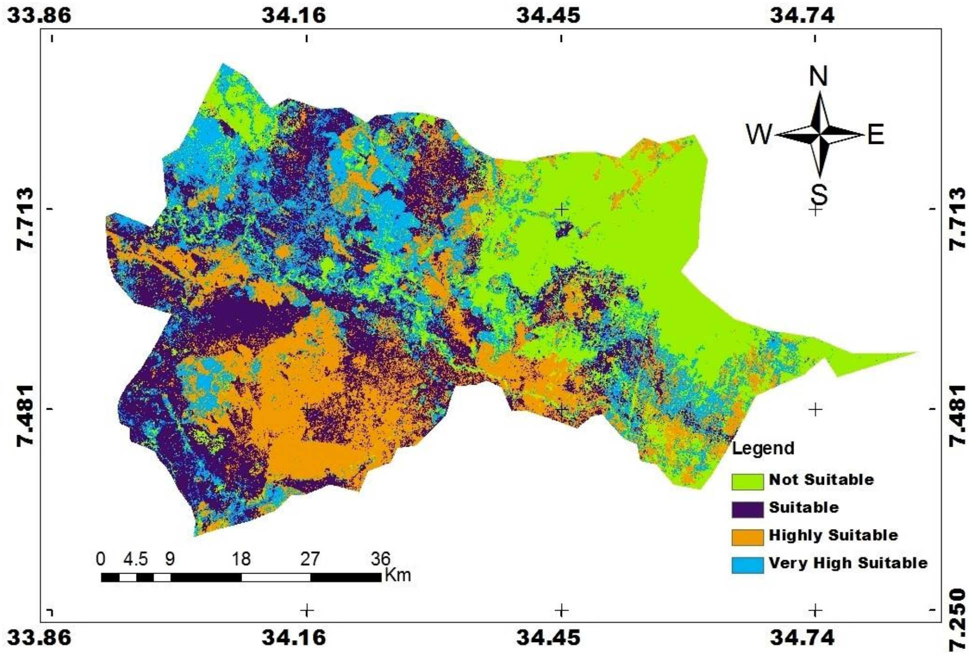

Figure 33: Land-use/Land-cover Suitability Map of Gog Woreda.

5.1.3. Reclassification of Vegetation Condition Index (VCI)

The VCI map of the study areas derived from SPOT NDVI satellite 10 years data. The output of this analysis shows that the study area VCI ranges from 52.84% up to 84.83%. This output is then reclassified using reclassify analysis tool in to five classes assigning scale for each class value (Fig 34).

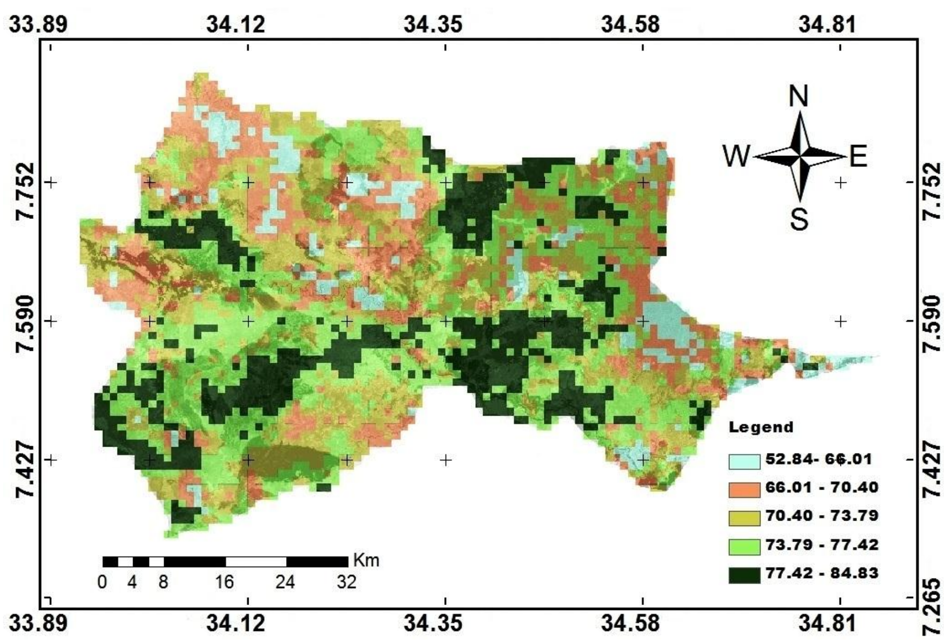

Figure 34: Classes of Vegetation Condition Index map.

Table 7: Relative Rating Assigned to Vegetation Condition Index.

Class	Index	Agr.Drought Level	Remark
1	52.84 – 66.01	Slightelу drought	Suitable
2	66.01- 70.40	Slightely drought	Marginally Suitable
3	70.40 – 73.79	No Drought	Moderately Suitable
4	73.79 – 77.42	No Drought	Highly Suitable
5	77.42 – 84.83	No Drought	Very High Suitable

5.1.4. Reclassification of Water Supply Vegetation Index (WSVI)

In areas where the rice crop is entirely dependent on rainfall, has to consider short period rainfall on a pentad, weekly, or decade basis. The coincidence of ample precipitation is very beneficial to agriculture, especially to rice production. The saturation of soil moisture also directly related to the prevalence of ample precipitation and it is also highly required for rice in the rainy season.

Thus for this study to determine the precipitation of the study area; the WSVI was calculated. The WSVI is an indicator based on the relationship between normalized difference Vegetation Index and surface temperature, which provides effective estimation of surface moisture condition. In the classifications of WSVI; Higher values are indicative of greater moisture amounts, whereas the lower values are an indicative of lees moisture and dry conditions. The WSVI values ranges from -4 for extreme dry (Arid area) to +4 for highly moist condition (Luke, *et al.*, 2001).

The output of this analysis shows that the study area WSVI ranges from 0.0228 up to 0.0367. The output is then reclassified using reclassify analysis tool in to five classes assigning scale for each class value (Table 8).

Table 8: Rating Assigned to Water Supply Vegetation Index.

Class	Index	Moisture Level	Remark
1	0.0228 – 0.0268	Very Low Moisture	Not Suitable
2	0.0268 – 0.0288	Low Moisture	Marginally Suitable
3	0.0288 – 0.348	Moderate	Moderately Suitable
4	0.348 – 0. 0331	High Moisture	Suitable
5	0.0331 – 0.0367	Very High Moisture	Highly Suitable

Thus; the result indicated that; the moisture level in most of the study areas are less experienced moisture deficit, the moisture levels ranged from moderate to very high moisture levels, which is an indication of optimal rainfall performance and mean average rainfall. Based on this, the suitability ranges of the areas are hetrogenously classified for rice cultivation as well as other crop (Fig 35).

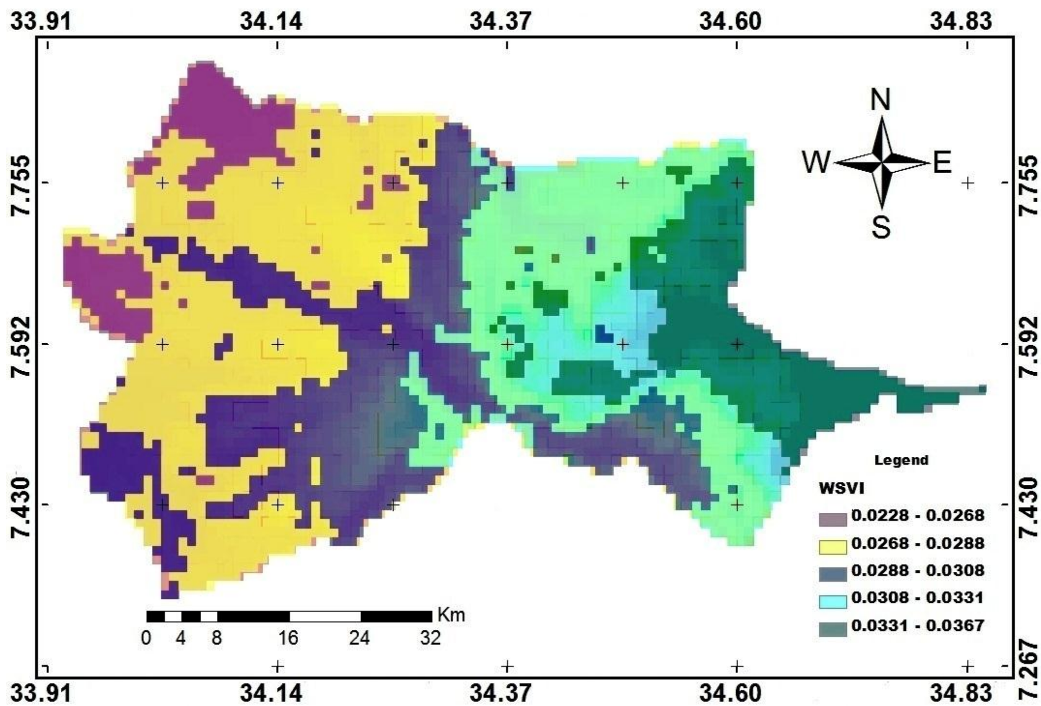

Figure 35: Classes of Water Supply Vegetation Index (WSVI) map.

5.1.5. Reclassification of Crop Water Deficient Index (CWDI)

Meeting the optimum evapotranspiration demand of the rice plant is essential to attaining potential grain yield. The CWDI values of well–watered areas were near zero and CWDI values of the treatment plants increased from near zero to their highest values in response to decreased availability of soil water, which led to reduced evapotranspiration rates and increased plant leaf temperatures (Jackson et al., 1981).

The CWDI has been shown to be closely related to available water in the root zone of crop cultivation areas. It is an index which is based on canopy temperature to detect crop water stress. CEDI uses leaf temperature and vapor pressure deficit data to determine a relative degree of plant water stress (Ezemonye and Emeribe 2013).

The CWDI index reaches a value of 1 for conditions of extreme stress of the vegetation, and 0 for crop evaporation to its potential rate and the lowest limit of CWDI is 0.50. The values of CWDI were recorded in Gog Woreda range from 0.16 being the lowest stress value to 0.80. It is noteworthy that some water stress values in the study area exceeded the lowest limit range described on the above i.e 0.50 (Figure 36).

Table 9: Rating Assigned to Crop Water Deficient Index layer.

Class	Index	Water Stressed Level	Remark
5	0.16 – 0. 38	Very Low	Highly Suitable
4	0.38 – 0.53	Low	Marginally Suitable
3	0.53 – 0.63	Moderetely Stressed	Moderately Suitable
2	0.63 – 0. 071	Highly Stressed	Suitable
1	0.71 – 0.80	Very High Stresed	Low Suitable

5.1.6. Reclassification of Leaf Area Index (LAI)

Leaf Area Index is defined as amount of leaf area in a vegetation canopy per 1 square meter . Leaf Area Index is an important measure of canopy structure. Leaf area index (LAI) is key crop growth variable in process-based models to quantify the exchange of flow of mass and energy between vegetation and the atmosphere and so it is widely used to describe photosynthetic and transpiration behavior of plant canopies, and further used for estimation of crop yield. (Scurlock *et al*., 2001).

According to the International Rice Research Institute (IRRI 1986) was established in 1960 by the Ford and Rockfeller Foundations I indicated that, the optimum rice leaf area index for maximum photosynthesis is 4.0. Excessive tillering, leafy growth, and tallness are not conducive to photosynthesis. All these features would be suppressed more by lower earlyseason temperatures than by the temperatures that prevail in rainy weather (Fig 37).

Table 10: Rating Assigned to Leaf Area Index layer.

Class	Index	LAI Level	Remark
1	1.33 – 1. 47	Very Low	Low Suitable
2	1.47 – 1.54	Low	Marginally Suitable
3	1.54 – 1.59	Moderetely	Moderately Suitable
4	1.59 – 1.66	Highly Optimum	Suitable
5	1.66 – 1.74	Very High Optimum	Highly Suitable

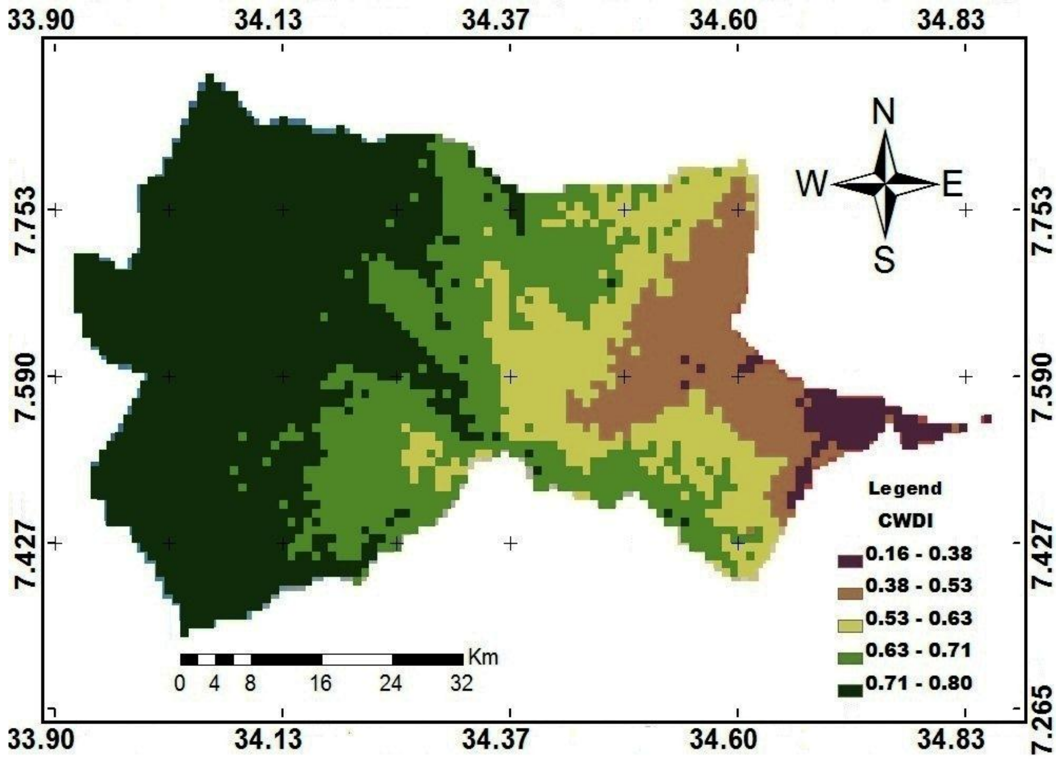

Figure 36: Classes of Crop Water Deficit Index map.

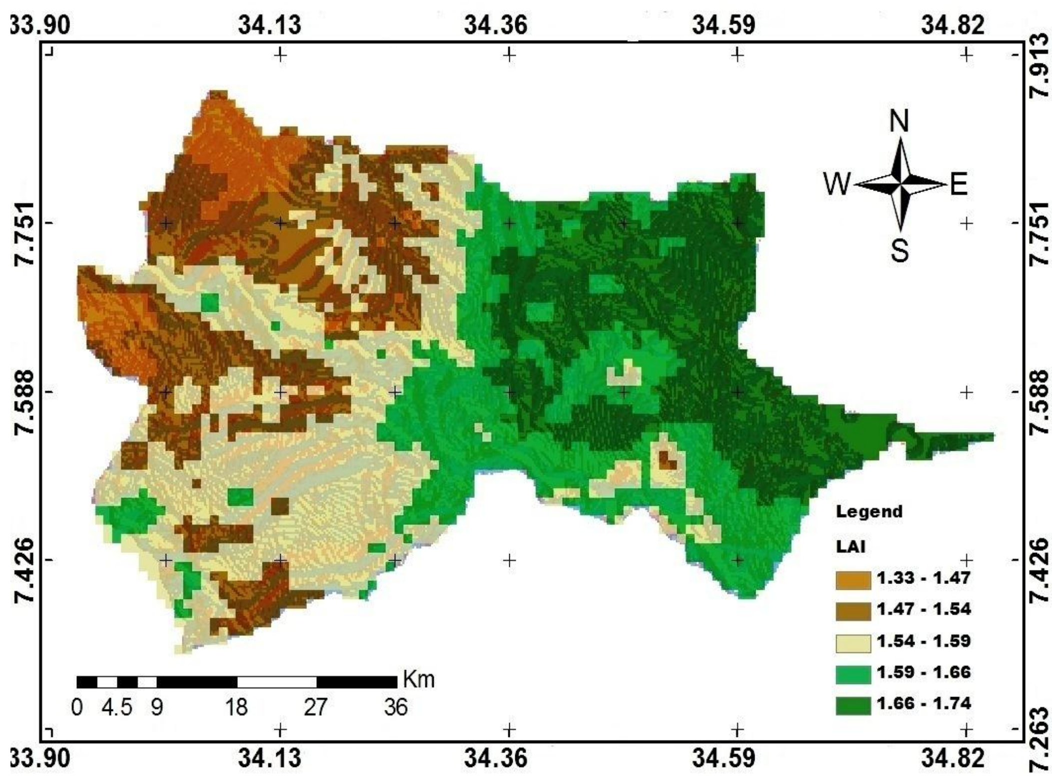

Figure 37: Classes of Leaf Area Index (LAI) map.

5.2. Weights Determination

The weight of all parameters is determined based on the input acquired from the selected respondents. Then the pairwise comparison method employed; which was developed by Saaty Mohamed Elhag (2014) in the context of decision rule called Analytic Hierarchy Process (AHP). Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty. Generally; it is a method to derive ratio scales from paired comparisons. The keys of reciprocal matrix are illustrated in (Table 11) is used for factors rates.

Table 11: Distribution of the Reciprocal Matrix keys

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very	Strongly	Moderately	Equally	Moderately	Strongly	Very	Extremely
	Less Important		→	→	→	More Important		

Thus; in order to determine the priority vector and which criteria (at what levels or weights) affect the land suitability level of the study area; the response of eight experts (out selected ten experts) was analyzed and weightages through normalization of the pairwise comparison matrix (Appendix 7). The computed weight for different factors with composite layers is shown in (Table 12).

Table 12: Normalization of the Pairwise Comparison Matrix

Criteria	WSVI	LULC	LAI	LQ	CWDI	VCI	Normalization Weight	Priority Vector
WSVI	1	0.906	1.115	0.9666	1.2083	1.380	0.1711	17.11 %
LULC	1.103	1	1.23	1.066	1.333	1.523	0.2291	22.91 %
LAI	1.034	0.9375	1	0.8666	1.0833	1.238	0.1372	13.72 %
LQ	1.034	0.9375	1.1538	1	1.25	1.428	0.1904	19.04 %
CWDI	0.8275	0.75	0.923	0.8	1	1.1428	0.1559	15.59 %
VCI	0.724	0.656	0.807	0.7	0.875	1	0.1163	11.63 %
Sum	5.586	5.5062	6.23	5.4	6.75	7.714	1.00	100 %

Aside from the relative weight, the consistency ratio of priority weightage also checked by the overall consistency ratio. If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, it needs to revise the subjective judgment. The overall consistency ration calculated based on the following equation

$$\boldsymbol{CI = \frac{\lambda \mathrm{max} - n}{n-1}}$$ **--Equation 15**

Where λ_{max} is the principal (largest) Eigen vector and n is number of parameters

Based on this the overall consistency ration for the study area was obtained 0.018 or 1.8 %. Therefore the calculated consistency ratios for the study area is less than 10%, the inconsistency occurred level is acceptable (Appendix 8).

The above six different types of factor criteria such as; land quality, LULC, WSVI, VCI, CWSI and LVI were applied to determine and evaluate the suitability level of the land in the study area. These factor criteria are served to enhancement or detract the suitability from the specific alternative. Thus by considering the set of standardized criteria, the ordered weight averaging (OWA) approach employed to classified the study area in to different suitability classes.

Once the factor maps and the weight of composite layers were obtained and then the suitability map at four suitability classes (Very High Suitable, Highly Suitable, Low Suitable and Very Low Suitable) were evaluated using weighted overlay spatial analysis tools in ArcGIS environments and developed suitable land for the rice cultivation in the regional state of Gambella;Gog Woreda (Fig. 38).

CHAPTER SIX

6. Results and Discussion

6.1. Results and Discussion

This paper presents the multi-factor decision making approach designing for evaluation and identification of suitable land for rice cultivation under ordered weigh averaging mechanism. The overall identification process possessed in different phases. The first step focused on the identification phase which includes identification of influential factors and pre-processing of alternatives criteria. The second step is focused on the integrating GIS, AHP and Ordered Weigh Averaging (OWA) for calculating the final weights of each input layer. The last steps focused on the aggregation of the criteria and weights assigned to each input layer maps.

Even if there is yet no universal agreed upon mechanism of defining evaluation of criteria for multi criteria decision making approaches, selecting a small number of criteria might result in over simplifications and abused the outcomes. On the other hand each evaluation criterion must be comprehensive and measurable that should cover nearly all aspects of the problem and the spatial distribution of the study area. In this regard the study focused on different parameter that able to determine the status of land quality, agricultural drought experience, the root zone soil moisture and the surface water moisture level of the study area.

The secondary soil data obtained from Gambella Land Utilization and Environmental Protection Authority showed that; the nutrient and heterogeneous physical nature of soils in Gog Woreda are affluent in most basic nutrient elements which not vary considerably from kebele to kebeles. All most all sites are suitable for rice cultivation in terms of land quality parameter. The results obtained from the analysis also indicated that, the land quality of the study area lies between grade one to grade three. Based on the Storie Land quality Model (Appendix 7) interpretation, all plots of lands in the study area are optimum for cultivation of rice and other crops.

In regards to determine the agricultural drought status of the study area, this study assessed by employed the Vegetation Condition Index (VCI). Based on the result obtained by calculating ten year Vegetation Condition Index (VCI) of the study area, the area is generally not suspected by agricultural drought since the last ten years. Thus virtually all the study areas are considered as suitable for rice cultivation as well as any other rain fed agricultural processes.

In regards to the surface moisture level of the study area which is calculated by using the Water Supply Vegetation Index (WSVI) that derived from the NDVI and land surface temperature indicated that; the moisture level in most of the study areas are less experienced moisture deficit, the moisture levels ranged from moderate to very high moisture levels, which is an indication of optimal rainfall performance and mean average rainfall. Based on this, most of the study areas (63.71 %) are determined as highly to moderately suitable for the rice cultivation and the remain (36.29%) of the study areas are identified as less suitable area for rice cultivation.

In terms of the calculated Crop Water Deficient Index (CWDI) generally most part of the study areas are justified as crops stressed area due to lack of moisture in the root zone of crops. Especially the area also highly demonstrated rice root zone stress due to inefficient moisture availability in the root zone of rice. The biggest area (71.05%), the study areas are demonstrated under highly water stressed area, hence these area are determined as moderately to marginally optimum for rice cultivation. The remain (28. 95 %) of the study area determined as low water stressed areas and are highly suitable for rice cultivation.

The spatial diversity of LAI of Gog Woreda derived from SPOT satellite mean NDVI was much more heterogeneous. The maximum value is around 1.74 and the minimum value also reached around 1.33. The biggest area (61%), had values between 1.47 and 1.66. Thus; based this; most of the study areas are demonstrated under the moderately to marginally optimum for rice cultivation.

The study provides the overall insight about suitable land for rice cultivation resulting from spatially and quantitatively integrated basic parameters such as the Land Qualities(LQ), LULC,WSVI, LAI, CWDI and WSVI. It used the AHP to determine the criteria weights through judgments of experts. The research also utilized the Pairwise Comparison Matrix (PWCM) method to calculate the weight consistency ratio (FCR) and obtained 0.018 consistency ratio result.

Based on the Pairwise Comparison Matrix (PWCM) constructed with the six important factors established on questionnaire survey mentioned previously; the relative importance of each of criteria was measured through the calculation of weights. Accordingly for this study, the LULC is significantly put on the first priority level, and followed by land quality factor parameter. The WSVI, CWDI, LAI and VCI put on third, fourth, fifth and sixth priority level respectively.

Table 13: Sumerrized Criteria Classes, Weight and Suitable Land in percentage.

Criteria	Index value	Rank	Evaluation	Suitability class	Area in (%)	Weight
WSVI	0.0228 – 0.0268	1	Very Low Moisture	Not Suitable	6.72	17.11 %
	0.0268 – 0.0288	2	Low Moisture	Marginally Suitable	29.55	
	0.0288 – 0.348	3	Moderate	Moderately Suitable	27.86	
	0.348 – 0. 0331	4	High Moisture	Suitable	21.83	
	0.0331 – 0.0367	5	Very High Moisture	Highly Suitable	14.02	
LULC	Roads , Lake and Rivers	1	Restricted	Not Suitable		
	Densed Forest & Settlement Areas	1	Restricted	Not Suitable	27.36	22.91 %
	Grass Lands	3		Moderately Suitable	26.64	
	Range Lands & Forest With Shrubs	4		Highly Suitable	25.33	
	Swampy & Cultivated Lands	5		Very High Suitable	20.64	
LAI	1.33 – 1. 47	1	Very Low Optimum	Low Suitable	4.82	
	1.47 – 1.54	1	Low Optimum	Marginally Suitable	21.92	
	1.54 – 1.59	3	Moderately Optimum	Moderately Suitable	29.19	
	1.59 – 1.66	4	Highly Optimum	Suitable	20.71	
	1.66 – 1.74	5	Very High Optimum	Highly Suitable	23.34	13.72 %
LQ	Grade 1	5		Ver High Suitable	31.56	
	Grade 2	4		Highly Suitable	13.88	
	Grade 3	3		Suitable	54.55	19.04 %
CWDI	0.16 – 0. 38	5	Very Low Stresed	Highly Suitable	2.51	
	0.38 – 0.53	4	Low Strsses	Marginally Suitable	11.49	
	0.53 – 0.63	3	Moderetely Stressed	Moderately Suitable	14.93	
	0.63 – 0. 071	2	Highly Stressed	Suitable	23.94	
	0.71 – 0.80	1	Very High Stresed	Low Suitable	47.11	15.59 %
VCI	52.84 – 66.01	1	Slightely Drought	Suitable	7.39	
	66.01- 70.40	2	Slightely Drought	Marginally Suitable	16.61	
	70.40 – 73.79	3	No Drought	Moderately Suitable	29.41	
	73.79 – 77.42	4	No Drought	Highly Suitable	28.42	
	77.42 – 84.83	5	No Drought	Very High Suitable	18.15	11.63 %

The output of this study also integrates the different tools (ERDAS, ENVI, SPIRITS and GIS) with AHP and OWA in order to identify and determine appropriate lands for rice cultivation. The overall system was able to generate suitable land model of the case study area (Fig 38).

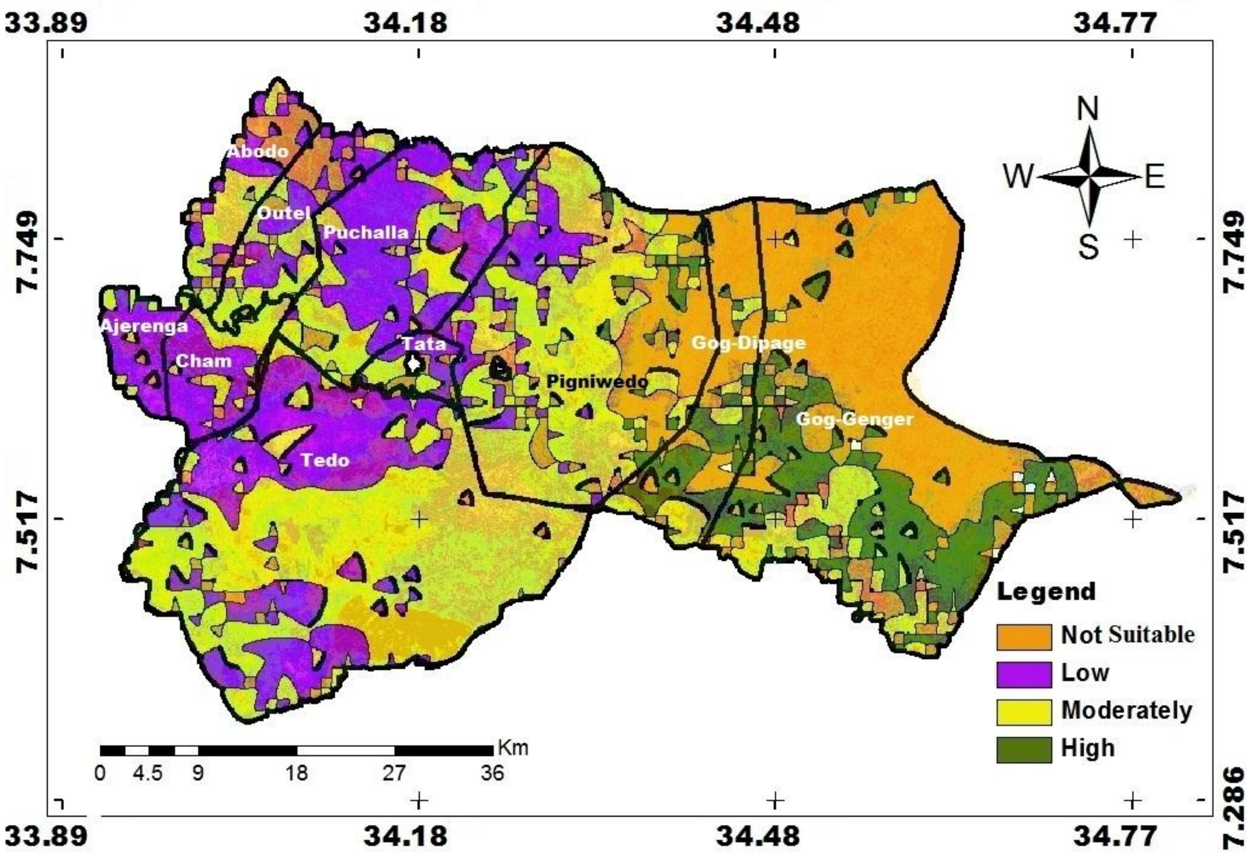

Figure 38 : Rice cultivation suitability map.

It is evident from the study that, over 63% of the study area is determine as highly, moderately and low suitable for Rice cultivation. Highly and moderately suitable lands for rice cultivation cover an area of 15.8 and 29.5% respectively (Table 16). An area cover 18 % of the district area also determined as low suitable and 36 % of the district analyzed as not suitable areas for rice cultivation (Table 14).

Table 14: Rice Land suitability in hectors and Percentage.

Suitability Level	Area in (ha)	Area in (%)
Not Suitable	116,018.3	36
Low Suitable	59,620.52	18.5
Modertely Suitable	95,070.56	29.5
High Suitable	50,919.15	15.8

This result also indicated that; most of high suitable areas are geographically situated in the swampy area of Gog Dipach and Gog Jenjer Kebeles. Furthermore the areas which determined as not suitable for rice cultivation also situated in dense forest and populated areas of Gog Jenjer and Abodo Kebeles respectively. The remain moderate and low suitable areas also distributed heterogeneously in different part Tedo, Abodo, Cham, Puchala and Ageringa Kebeles of the study areas.

6.2. Conclusion

In this study, the application of Remote Sensing (RS) and GIS techniques to identify suitable areas for rice crop employed. The results obtained from this study indicate that the integration of Remote Sensing and GIS application of Multi-Criteria Evaluation using Pairwise Comparison Matrix could provide a superior database and guide map for decision makers. This approach has been used in some studies in other countries including Egypt. However, in Ethiopia context specially in Gambella regional state: Gog Woreda, this approach is a new application in agriculture and evaluation process of to identify suitable areas for rice crop intensively.

The Remote Sensing and GIS-based land evaluation approach can provide thematic layers that enable the formulation of dynamic scenarios for integrating information. The integration process with geographic references is widely accepted for implementing spatial decision support systems. While in this regard, it is important to point out that there will always be an element of subjectivity when applying expert judgment for determining weight of factors. To solve this problem this study has demonstrated that the AHP is best alternative to determine the criteria weights from judgments of decision-making domain of experts..

The study clearly brought out the spatial distribution of lands for rice crop derived from Remote Sensing data in conjunction with evaluation by considered the following six major parameters such as; Land Quality Model, LULC, WSVI, CWDI, LAI and VCI for rice land determination and evaluation and in GIS context. In this regards such kind of evaluation and identification method is very important and convenient interms of time, labor and spatial coverage’s.

The water requirements indices which are commonly considered as challenges in rice cultivation field such as the moisture level of soils, the precipitation and the root zone moisture level in the study area effectively evaluated and analyzed based on the information obtained from remotely sensing imageries. In this context the use of satellite data play a great role as an aid in understanding of the moisture and climatic nature of the study area.

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Appendix 1 : Soil Nutrient Index of the study area.

LQ	Diagnostic factor	Land Quality (Ranges) for Rice Cultivation	Unit	Rated Factor for the top soil Value of Gog Woreda Keble's									
				Abodo	**Ajeringa**	**Cham**	**Gog-Dipach**	**Gog- Jenjer**	**Outel**	**Pigniwdo**	**Puchalla**	Tata	Tedo
NAI	PH	3.1 – 5. 3		0.8	1.0	1.0	0.8	0.8	1.0	1.0	1.0	0.8	0.8
	OC	0.20 – 21.0	%	1.0	0.5	0.8	1.0	1.0	0.5	0.5	0.8	1.0	0.8
	TN	0.10 – 0.02	%	1.0	1.0	0.8	0.8	0.8	0.5	0.5	0.5	1.0	0.8
	Av. P	8.60 – 83.0	PPM	1.0	0.5	0.5	1.0	1.0	0.8	0.8	0.8	0.8	1.0
	CEC	2.12-11.39	Cmol(+) kg^{-1}	0.2	0.2	0.5	0.2	0.2	0.5	0.5	0.5	0.2	0.2

LQ	Diagnostic factor	Unit	Rated Factor for the top soil Value of Gog Woreda Keble's									
		Unit	Abodo	Ajeringa	Cham	Gog-Dipach	Gog- Jenjer	Outel	Pigniwdo	Puchalla	Tata	Tedo
SQI	Factor A	%	90	100	95	95	95	90	95	90	100	90
	Factor B	%	60	100	85	85	95	95	85	85	100	85
	Factor C	%	100	95	100	95	95	95	100	100	85	95
	Factor X	%	100	80	80	85	85	85	80	80	100	80
= A (B/100*C/100*X/100)			**0.83**	**0.76**	**1.08**	**0.96**	**0.96**	**0.69**	**0.64**	**0.62**	**0.85**	**0.58**

Factor A = Development stage I; the presence of clay stratification in the sub-soils (80-95%),

Factor B = Surface Texture Land Quality (Based on Appedex 4)

Factor C= Slope and Overall topographic Condition (Based on Appedex 5) and Factor X = Drainage condition (Based on Appedex 6; Factor.X)

Keble's	Total NAI	Total SQI	NAI * SQI	LQ (%)	Land Grade
Abodo	0.8 %	0.83 %	0.67	70%	Grade 2
Ajeringa	0.97 %	0.76 %	0.74	78%	Grade 2
Cham	0.72 %	1.08 %	0.78	78%	Grade 2
Gog-Dipach	0.88 %	0.96 %	0.83	85 %	Grade 1
Gog- Jenjer	0.88 %	0.96 %	0.85	85%	Grade 1
Outel	0.82 %	0.69 %	0.56	56%	Grade 3
Pigniwdo	0.82 %	0.64 %	0.52	52%	Grade 3
Puchalla	0.72 %	0.62%	0.44	44%	Grade 3
Tata	0.76 %	0.85 %	0.64	64%	Grade 2
Tedo	0.72 %	0.58 %	0.41	41%	Grade 3

Appendix 2: Soil Chemical Property Quality for Rice Cultivation based on Ponnamperuma (1977).

Chemical Properties	Parameter Land Quality (Ranges) for Rice Cultivation
Soil pH	3.1 – 5.3
Organic C %	0.20 – 21.0
Total N%	0.10 – 0.02
Avail P (PPM)	8.60 – 83.0
Ca (CmọL kg-1)	2.70 – 0.85
Mg (CmoL kg-1)	0.84 – 0.10
K/(CmoL kg-1	0.04 – 0.23
CEC (CmoL kg-1)	0.04 – 0.23

Appendix 3: Factor A ratings in the Storie index for soils belonging to development stages

Factor A refers to the profile development which is an expression of the weathering stage of the soil and its inherent chemical composition. Nine soil types are hereby differentiated.

Development stage I groups soils on recent alluvial fans, flood plains or other secondary deposits having A-C profiles; these are rated at a 100% level. This rating may be reduced because of (1) limited soil depth : 80% for soils of 90 cm thick, and 50-60% for soils less than 60 cm deep; (2) the presence of gravelly sub-soils: 80-90%; and (3) the presence of clay stratifications in the subsoils: 80-95%.

Development stage II groups soils on young alluvial fans, flood plains, or other flood plains , secondary deposits having slightly developed A-(B)-C profiles: : 95-100%. Ratings are reduced on the basis of (1) shallowness: 70% on 90 cm deep soils, and 50-60% on 60 cm deep soils; (2) gravel content in the subsoil (80-90%) and (3) stratified sub-soils: 80-95%.

Development stage III refers to soils on older alluvial fans, alluvial plains or terraces having moderately developed A-Bt-C profiles: 80-95%. Rate reductions are applied for (1) shallowness 60-75% for 90 cm deep soils, 40-65 for 60 cm deep soils, and (2) gravelly sub-soils: 60-90%.

Development stage IV is attributed to soils on older plains or terraces having strongly developed A-Bt-C or A-Box-C profiles with ratings of 40-80%.

Soils of the other development stages are mainly rated on the basis of profile depth as indicated in the following table.

Soil development stage	**Depth class (cm)**					
	<**30**	30-60	60-90	90-120	120-180	>180
V. Soils on older plains or terraces having hardpan subsoil layers.	5-20	20-30	30-40	40-50	50-80	-
VI. Soils on older terraces and upland areas with clayey sub-soils on consolidated material	40-80					
VII. Soils on upland areas underlain by hard igneous bedrock.	10-30	30-50	50-70	70-80	80-100	100
VIII. Soils on upland areas underlain by sedimentary rocks	10-30	30-50	50-70	70-80	80-100	100
IX.Soils on upland areas underlain by softly consolidated material.	20-40	40-60	60-80	80-90	90-100	100

Appendix 4: Factor B ratings in the Storie index for soils belonging to development stages

Textural class	Non-gravelly and non-stony	Gravelly	Stony
Coarse Sand	30- 60		
Sand	60		
Fine Sand	65		
Very Fine Sand	80		
Loamy sand	80		
Loamy Fine sand	90		
Very fine sandy loam	100		
Coarse sandy loam	100	70-80	70-80
Sandy loam	70-90	50-70	
Loam	95	50-70	
Silt Soil	100	60-80	60-80
Silty clay loam	90		
Clay loam	85	60-80	50-80
Silty clay	60-70		
Clay	50-60	40-70	40-70

Appendix 5: Factor C refers to the ratings on the basis of slope and overall topographic conditions.

Slope and overall topographic conditions	**Ratings**
Nearly level (slopes between 0 and 2 per cent)	100%
Gently undulating (slopes between 2 and 3 per cent)	95-100%
Gently sloping (slopes between 3 and 8 per cent)	95-100%
Undulating (slopes between 3 and 8 percent)	85-100%
Moderately sloping (slopes between 9 and 15 per cent)	85-95%
Rolling (slopes between 9 and 15 per cent)	85-95%
Strongly sloping (slopes between 16 and 30 per cent)	70-80%
Hilly (slopes between 16 and 30 per cent)	70-80%
Steep (slopes between 30 and 45 per cent)	30-50%
Steep (slopes between 30 and 45 per cent)	30-50%
Very steep (slopes of 45 per cent and over)	5-30%

Appendix 6: Factor X refers ratings conditions

Factor X refers to the rating of conditions other than those identified in factors A, B or C. Conditions which are taken into consideration may or may not be relevant for the specific location, and can therefore be omitted or considered as optimal in the calculations. The most obvious land factors in this respect are: drainage, nutrient or fertility level, acidity and alkali levels, erosion and micro-relief.

- ✓ Drainage - Well drained soils are rated 100%; fairly well drained and moderately waterlogged soils get a 80-90% and 40-80% rating respectively; badly waterlogged land gets a 10-40% value; and areas subject to flooding get a variable rate depending on the length and importance of the overflow.
- ✓ Nutrient status - The nutrient or fertility level holds four classes identified as high, fair, poor and very poor fertility with a corresponding rating of 100%, 95-100%, 80-95% and 60-80%. It should be noted that the nutrient status is not severely penalized in the ratings because natural fertility can rather easily be corrected through the use of fertilizers.
- ✓ Alkali status - Five classes are differentiated with the following corresponding ratings: alkali free (100% rating), slightly affected (60-95%), moderately affected (30-60%), moderately to strongly affected (15-30%) and strongly affected (5-15%).

- ✓ Acidity status - Ratings range between 80 and 95% as a function of the pH level.
- ✓ Erosion:- the following ratings are applied : none to slight erosion (100% rating), detrimental deposition (75-95%), moderate sheet erosion (80-95%), occasional shallow gullies (70-90%), moderate sheet erosion with shallow gullies (60-80%), deep gullies (10-70%), moderate sheet erosion with deep gullies (10-60%), severe sheet erosion (50 80%), severe sheet erosion with shallow gullies (40-50%), severe sheet erosion with deep gullies (10-40%), very severe erosion (10-40%), moderate wind erosion (80-95%), severe wind erosion (30-80%).
- ✓ Micro-relief - Six major classes are distinguished: smooth (100%), channels (60-95%), hogwallows (60-95%), low hummocks (80-95%), high hummocks (20-60%), dunes (10 40%).

Appendix 7: Storie index values into six soil grades:

Storie Land Quality Grades	Level of Quality	Description
Grade 1	excellent quality land	The soil rating is between 80 and 100% and the land is suitable for a wide range of crops, including alfalfa, orchard, truck and field crops.
Grade 2	good quality land	Soils rate between 60 and 79%. They are suitable for most crops, and expected yields are generally good to excellent.
Grade 3	fairly good quality land	They are generally of fair quality, though they have a less wide range of suitability than grades 1 or 2; they give good results with certain specialized crops.
Grade 4	poor-quality land	Soils are rated between 20 and 39%. They have a relatively narrow range in their agricultural possibilities, in the sense that they may give good results for some crops but be unsuitable for other crops.
Grade 5	very poor land	Soils rate between 10 and 19%. They are of very limited use except for pasture, mainly because of critical adverse conditions such as shallowness, roughness and alkali levels
Grade 6	non-agricultural land	Soils rate below 10% and are unsuitable for any economic land use.

Appendix 8: Weightages through normalization of the pairwise comparison Matrix

Addis Ababa University School of Graduate Studies
School of Earth Science: Remote Sensing and GIS Stream

I am gratefully to express my immense institute in advance for your co-operation, interest and enthusiastic response for my research questioner. Honestly speaking this questionnaire is exclusively for academic purpose as a requirement for my partial fulfillment of MSc in Remote Sensing and GIS stream.

Through this questionnaire; I intended to determine the priority level of the attached six spatial data layer variable weights based on their importance of the layer parameters which used to evaluate the land suitability status for rice cultivation in Gog Woreda regional state of Gambella.

Therefore, your genuine support in responding to the raised questions has paramount importance for the attainment of the study's objectives. Hence, I earnestly request you to fill the questionnaire carefully.

Thank you, for your cooperation and timely response in advance

<u>**General Instructions**</u>

- ✓ Please write your name, profession and Academic status
- ✓ In all cases where answer options are available please tick (√) in the appropriate box.
- ✓ If you want to forward any comment and opinion, please try to honestly describe on the space provided at the back of front pages.

Personal Information

Name: ____

Profession: ____

Academic Status: _______________________________________

Criteria	Assign Reciprocal Weight							
	1/9	**1/7**	**1/5**	**1**	**3**	**5**	**7**	**9**
LQ								
LULC								
VCI								
WSVI								
CWDI								
LAI								

List of Acronyms *and Summarized hints for criteria*

LQ = Land Quality (Include the Chemical and Physical Character of the soil)

LULC = Land Use/Land cover

VCI = Vegetation Condition Index (To determine Agricultural Drought)

WSVI = Water Supply Vegetation Index (To determine Precipitation status)

CWDI = Crop Water Deficit Index (To determine Soil water Stress and available water in the root zone of crop cultivation areas)

LAI = Leaf Area Index (To quantify the exchange of flow of mass and energy between vegetation and the atmosphere)

List of *Summarized hints for weight Assigning*

- ✓ 1/9 = Extremely Less Important — 1/7 = Very less Important
- ✓ 1/5 = Strongly Les important — 1/3 = Moderately Less Important
- ✓ 1 = Equally — 3 = Moderately important
- ✓ 5 = Strongly important — 7 = Very Important
- ✓ 9 = Extremely Important