REMOTE SENSING AND GIS BASED ENVIRONMENTAL SUITABILITY ANALYSIS OF RESETTLEMENT SITES: THE CASE OF CHAWAKA (WESTERN OROMIA, ETHIOPIA)

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February, 2011
Addis Ababa

Addis Ababa University school of Graduate Studies, Faculty of Science,
School of Earth and planetary Science
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A THESIS SUBMITED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILIMENT OF THE REQUIRMENT FOR THE DEGREE OF MASTER OF SCIENCE IN REMOTE SENSING AND GIS

AAU
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Declaration

I, the undersigned, declare that this thesis entitled "REMOTE SENSING AND GIS BASED ENVIRONMENTAL SUITABILITY ANALYSIS OF RESETTLEMENT SITES: THE CASE OF CHAWAKA (WEST OROMIA ETHIOPIA)" is my original work and has not been presented for a degree in any other university and that all sources of material used for this thesis have been dully acknowledged.

Dagnachew Shibru Megersa ______________________________

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February , 2011

This thesis entitled "REMOTE SENSING AND GIS BASED ENVIRONMENTAL SUITABILITY ANALYSIS OF RESETTLEMENT SITES: THE CASE OF CHAWAKA (WEST OROMIA ETHIOPIA)" is an original work of **Dagnachew Shibru Megersa** under my supervision.

Suryabahagavan (Ph.D.)	**Mekria Argaw (Ph.D.)**
Signature ______________________	Signature ______________________
Date ________________	Date ________________

Disclaimer

This document describes the work undertaken as part of post graduate Study program of Addis Ababa University for M.Sc in Remote Sensing and GIS. All views and opinions expressed herein remains the sole responsibility of the author, and do not necessarily represent those of the institute.

Dedicated to

My mother, Nadhi Fite Fufa (Etete)
Whom I Cherish Most
For her support, inspiration and blessing all in my Progress

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Acronyms

AAU	Addis Ababa University
CSA	Central Statistical Agency
DEM	Digital Elevation Model
DIDR	Development-Induced Displacement and Resettlement
EMA	Ethiopian Mapping Authority
ENVI	Environment for Visualizing Images
EPRDF	Ethiopia People's Revolutionary Democratic Front.
ERDAS	Earth Resource Data Analysis
ESA	Environmental Suitability Analysis
ETM+	Enhanced Thematic Mapper Plus
GCPs	Ground Control Points
GIS	Geographic Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
ILRI	International Livestock Research Institute
MCDA	Multi Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
MCE	Multi Criteria Evaluation
NASA	National Aeronautics and Space Administration
NCFS	New Coalition for Food Security in Ethiopia
NMSA	National Meteorological Services Agency
ODPPB	Oromia Disaster Prevention and Preparedness Bureau
SDSS	Spatial Decision Support System
SMCA	Spatial Multi-Criteria Analysis
SNNP	South Nations and Nationality People
SPOT	System Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
UTM	Universal Transverse Mercator
WBISPP	Woody Biomass Inventory and Strategic Planning Project
WCD	World Commission of Dams
WGS	World Geodetic System
WOA	Weighted Overlay Analysis

Abstract

Environmental suitability analysis of resettlement site is a complicated integration of various ecological and social factors that affect human livelihood. It is a crucial step for the achievement of the objectives of the resettlement programs as well as for guarantying the sustainability of the environment. Remote sensing and GIS technology offers a convenient and powerful platform to integrate spatially complex and different ecological factors for performing environmental suitability analysis. Hence, the main purpose of this study is the objective analysis and mapping of environmental suitability of Chewaka resettlement site in terms of the basic bio-physical and socio-economic environmental factors and eventually identifying the suitable and unsuitable areas using Remote Sensing and GIS. The weighted overlay techniques are applied to arrive at the final environmental suitability mapping. The bio-physical and socio-economic factors used for evaluation of environmental suitability of the resettlement site are land use/land cover, climate, soil, topography, malaria prevalence, proximity, and infrastructural facility. The result showed that 34% of the area has highly suitable climate for human resettlement. However the majority of the area has a moderately suitable topography and soil, while only about 5% of the area has highly suitable infrastructural facility. Generally, the overall weighted suitability analysis of the area indicates that only 2% of the area has high suitability condition. The remaining 32% and 65% is moderately and marginally suitable for human resettlement.

Key words*: Resettlement, Chewaka wereda, Multi Criteria Evaluation, Weighted Overlay Analysis.*

1. Introduction

1.1 Background

Ethiopia is one of the poverty stricken countries faced with various socio-economic problems. Currently, the total population is around 73 million (CSA, 2007). Due to its mountainous topography the land resource of the country is also one of the most fragile. The soils are eroded and degraded particularly in the high land areas. Natural forests cover is shrinking from time to time. The problem is more acute and pressing in some parts of the country where there is high population density. The socio-economic challenges are also complicated and pressing.

The government of Ethiopia has been taking various remedial measures in order to sustainably solve the problems. Resettlement has been one of the most important measures that are believed to address the multi-faceted problems of the country. Resettlement have been sought as a means to utilize the unused land for development by settling landless peasants, unemployed persons and farmers from drought prone and overpopulated high land areas (Kloos *et al.*, 1990). It has also served as a basic tool to settle pastoral nomads and to ensure continuation of farming in private and state farms.

Even though there are some variations in the scale, population resettlement has been generally adopted as a major and essential component of strategic endeavors aimed at addressing the paramount socio-economic and food insecurity problems in different periods in modern history of Ethiopia (Solomon, 2005).

Recently the federal government of Ethiopia has adopted resettlement as a part of national socio-economic development policy by incorporating it within the ten years development plan (1984-1993). The intention of the resettlement program during this time was ensuring food self sufficiency of the settlers and increasing their productivity by providing adequate agricultural land for those people whose agricultural productivity is deteriorated largely due to ecological problems. Accordingly large scale resettlement has been executed in four regions of the country. Chawaka site is one the areas in the western part of Oromia Regional State selected for resettlement. In the first round resettlement alone, 12, 390 household settlers originated from Harerge were settled in this area.

However, none of these resettlement programs have utilized remote sensing and GIS technology in identifying suitable areas for human resettlement. Therefore this thesis tries to objectively and systematically integrate the biophysical and socio-economical environmental factors that directly or indirectly affect the suitability of human settlements.

In this research Chawaka resettlement site is selected as GIS and Remote Sensing based analysis as it is the largest resettlement site in Oromia Regional State and the situations in here are believed to represent the other resettlement programs.

1.2 Statement of the problem and justification

Human settlements are foci for many economic, social, and governmental processes. The government has taken resettlement program as the best strategy to address the multi-faceted socio-economic and food security problems in areas where there is high population density and severe ecological degradation.

In a country like Ethiopia, where the majority of the people are agrarian and directly depends up on the natural environment for their livelihood, environmental suitability analysis is necessary for settling people in a new resettlement site. In Oromia regional state Chawaka is one of the areas resettled by people originated from East and Western Harerge. Currently the area is inhabited by 56,106 residents (CSA, 2007). The criteria used by the administration of Oromia Regional State to identified Chawaka site for resettlement was simply based on the existence of ample vacant space with productive virgin agricultural land. This criterion has not incorporated the other important bio-physical and socio-economic environmental factors that are appropriate and vital for human settlement. On top of that it is highly susceptible to individual value judgment for it is recommended by government delegates recruited from various administrative offices.

Therefore there is an urgent need to consider other vital environmental factors that have a direct impact up on human settlement as well as to evaluate those factors in an objectively integrated manner in order to analyze environmental suitability of the resettlement site. For this purpose the application of Remote Sensing and GIS technology is the best alternative. It helps to integrate multiple environmental criteria to evaluate their sustainability for human resettlement.

1.3 Objectives

1.3.1 General Objective

The main objective of the study is to evaluate the environmental suitability of Chawaka resettlement site using multi-criteria evaluation procedure using GIS and remote sensing technique.

1.3.2 Specific Objectives

The specific objectives of the study are:

- To examine some of the most important bio-physical and socio-economic environmental factors that affect human settlement;
- To evaluate the suitability of the resettlement site in terms of various environmental suitability parameters;
- Produce thematic map of environmental suitability for different environmental factors; and
- To identify the most suitable and environmentally sustainable places in the study area.

1.4 Significance of the study

Remote Sensing and GIS are recently developed technological advancements vital to objectively integrate various environmental factors that affect the ecological suitability of human resettlement. Furthermore the most suitable areas that fulfill all the set parameters can also be indicated using this technology.

It is expected that the final outcome of this research will help governmental and non-governmental organizations as well as policy and decision makers that work on resettlement issues to revise their action in an informed manner. It will have a special contribution in identifying the most important environmental factors that dictate the suitability of human settlement in the study area.

1.5 Scope of the study

Environment has a transboundary nature. Its effect is not limited within a specific political boundary. However, for the purpose of avoiding complications due to broader areal extent only a manageable study area that can represent the surrounding situation is selected. As a result the environmental suitability analysis treated in this particular study is restricted within the boundary Chawaka wereda.

1.6 Research questions.

Throughout this research work an attempt was made to find potential answers for the following questions.

- What are the most important bio-physical and socio-economic environmental factors that affect the suitability of human settlement in the study area?
- To what extent Chawaka resettlement site is suitable for human settlement in terms of the major environmental factors?
- Which part and what percentage of the study area are suitable /unsuitable for human settlement?

2. Literature Review

2.1 General Over view of Resettlement

2.1.1 Definition of Resettlement

Resettlement is equivalent with the term relocation. However, these two terms are different for one is narrower while the other is broader. According to Gebre Yntiso, (2001) resettlement is different from relocation in that it is more than change of place and for it consists of all the social, psychological, moral and spiritual values carried with the victim unlike change of place for the other inanimate materials.

For the purpose of this research work the author has preferred the definition given by Mengistu Wube (1992) for it incorporate all the necessary concepts related in the process from the beginning to the end. According to him Resettlement is the process by which individuals or groups of people leave spontaneously either voluntarily or involuntarily their original settlement sites to resettle in new areas; where they can begin new trends of life by adapting themselves to the biophysical, social and administrative systems of the new environment (Mengistu Wube, 1992). Therefore, the concept has to be understood in this context throughout this thesis.

2.1.2 Types of Resettlement

Resettlement can take different forms. It could be spontaneous or planned and voluntary or involuntary. Categorization of resettlement as spontaneous or planned is based on the involvement of government (in most cases) and other parties like NGOs and the private sector. Sometimes people resettle themselves in new areas only based on the push factors in their area of origin and the pull factors in the new resettlement sites without the intervention of any other external forces. This can be the case when people occupy new area of land to satisfy their needs following the pavement and construction of new road (World Bank, 1999; 2001).

Spontaneous and planned settlement has nothing to do with reasons or motivations for leaving the original residence for new area (Thayer, 1998). The basic difference between these two concepts is that in spontaneous resettlement settlers lack legal access to land and secure land tenure but not in planned resettlement program.

Resettlement can also be categorized as Voluntary or involuntary based on the willingness or interest of the resettlers. Voluntary resettlement has issues of legality, legitimacy, consent of settlers, and participation of settlers on planning and implementation of the program. However, involuntary resettlement may take issues of legality but is not based on the willingness or interest of the settlers (Scudder, 1982, 1993; Cernea, 1992, 1995, 1997; Downing, 1996; Mathur *et al.*, 1998).

Similarly there is a time when people unwillingly choose resettlement due to drought and other ecological and environmental factors. This is particularly true in areas where there is high population pressure on the limited environmental resources. This situation will eventually force the landless rural community to choose resettlement into new environment.

2.1.3 Historical Back ground of Resettlement in Ethiopia

In Ethiopia resettlement of people from North to South in search of Agricultural land has been practiced for hundreds of years (Kloos *et al.*, 1990). During the Imperial regime in 1959, a resettlement program that accommodated about 700 farmers from the over populated upland areas were made at Abela in Sidama province (Mengistu Wube, 1992). The spontaneous resettlement carried on between 1940s and 1970 was resulted in the movement of more than one million people from the chronically overpopulated and environmentally degraded highlands of central and north Ethiopia to less populated frontier lowlands (Kloos *et al.,* 1990). However, the program failed due to improper planning, limited fund, lack of stakeholder's participation, and it's semi-voluntary and semi-involuntary nature.

The socialist government has initiated planned resettlement programs between 1975-83 and 1984-91 as a means of dealing with famine, overpopulation, land degradation, environmental rehabilitation, food security and socio-economic problems (Kloos *et al.,* 1990; Janson, 1987).

The federal government of Ethiopia has launched a large scale resettlement program in June 2003 through its Sustainable Development Poverty Reduction Program (SDPRP). The program focuses on improving agricultural productivity that will have a multiplier effect on the livelihoods of the rural people as one of the strategies aimed at reducing food insecurity through moving people from areas where the environment is highly degraded into relatively fertile ones. The main objective of the resettlement program is to solve food security by assuring access to land through voluntary resettlement.

2.2 Theoretical Framework of Resettlement

Researchers from diverse academic disciplines have studied resettlement programs from different perspectives and they have generated theoretical frameworks to explain the complex and dynamic processes involved in resettlement program and environmental suitability of resettlement site.

Scudder's four-stage framework represents one of the earliest attempts to formulate a coherent analytical framework for resettlement (Scudder, 1981; 1982; 1991; 1993; 1997). This framework considers how the majority of resettlers can be expected to behave during a successful resettlement process. Scudder defined success as development that is environmentally, economically, institutionally and culturally sustainable into the second generation. He has divides the process of resettlement into four graded stages: (1) planning and recruitment; (2) adjustment and coping; (3) community formulation and economic development; and, (4) handing over and incorporation. This framework deals with how re-settlers will respond to the process of resettlement. It emphasizes two different but interrelated factors: stress and process (Scooder, 2005). This framework is very instructive, enabling resettlement institutions to work objectively and to plan resettlement with a temporal dimension. However, as Scudder (2005) recognizes, some concerns have been raised when it is applied to the real-world cases of development. Accordingly, one key concern in his theory is directly or indirectly related with environmental suitability and sustainability of resettlement site.

2.3. Environmental Suitability of Resettlement Sites

Environmental suitability analysis largely depends up on the purpose of the particular study. The suitable environment for a given plant species may not be conducive for another species. This largely depends up on the ecological variation. The same is true for animal species as well.

The situation becomes more complicated when it comes to the issue of environmental suitability for human settlement. This is because the interaction between these two factors is not unidirectional like in the case of other species of flora and fauna. Like all other organisms in the ecosystem human being is affected by environmental factors. However unlike all organisms in the ecosystem human being can put an immense impact on the environment the effect of which in one way or the other affect man himself and other components of the natural environment.

Therefore, suitability of environment for human settlement has to be evaluated based on individual analysis of the major human as well as natural environmental factors that affect human ecology. Some of the natural and biophysical factors include land use/land cover, climatic variables (like rainfall and temperature), topographic factors (slope and elevation), hydrologic factors (that include availability and accessibility of water and drainage system), as well as geologic and geomorphologic factors. Equally, important in the analysis of environmental suitability for human settlement is the human environment itself. This includes factors like socio-economic parameters, demographic characteristics, cultural variables and spiritual values of the society.

According to FAO (1985), environmental suitability is mainly evaluated based on the land quality. Land quality is a complex attribute of the environment that has a direct effect on land use (FAO, 1993). In addition to land, the inherent characteristic of environmental elements like climate, slope, topography, land use/land cover, spread of malarial infection and hydrology enables the calculation of quantitative values that affect ecological suitability of sites for human settlements. The value of these environmental elements is the function of the assessment and grouping of factors into orders and classes in the framework of their fitness.

Based on land suitability factor alone, FAO (1985) categorized environmental suitability in to two major classes: suitable (S) and not suitable (N). Accordingly the first class suitable (S) denotes environmental features that are suitable for use with good benefits. Whereas the second major category not suitable (N) denotes environmental qualities which do not allow the comfortable outcome.

FAO has devised a supplementary evaluation method of environmental suitability analysis that depends up on land capability (also considered as land suitability). According to this method environmental suitability of land can be measured primarily based on the potential biological productivity of the land to afford human needs (FAO, 1985). Therefore productivity of land can be determined by the major environmental components such as climate, slope and topography (roughens, steepness, exposure), soil type and existing vegetation. Thus, environmental suitability evaluation involves not only the identification of land use patterns, but also the economic and environmental feasibility and sustainability of its use.

2.4 Multi-Criteria Spatial analysis and Decision making

A decision is a systematic choice between competent alternatives. The alternatives may represent diverse courses of action, different hypotheses about the character of a feature and different classifications.

Historically, due to inaccessibility of places that creates an obstacle in synthesizing spatial problems, decisions that require geographic data were hardily possible to make. In modern time, however, an integrated systematic approach, such as a Spatial Decision Support System (SDSS) provide an immense contribution in solving these problems and eventually in making spatially referenced critical decision.

SDSS refers to a computer assisted systems that combine the application of GIS technology with spatially referenced environmental factors to make a valid and sound decision. It provides a means to objectively analyze a couple of competent and incommensurate alternatives. Based on all rounded and complete spatial information, the system helps to make a decision on how to wisely and sustainable utilize the limited environmental resources.

Multi-Criteria Decision Making (MCDM) is a wide ranging methodology that offers a technique and practice to uncover real-world management problems based on GIS applications. MCDM implies the assignment of values to alternatives that are evaluated along multiple decisions or criteria (Pereira *et al.*, 1993). It is the special application of Multi-Criteria Analysis (MCA) that deals with the spatial decision problems (Chakhar *et al.*, 2008). Spatial decision problems are those challenges in which the decision implies the selection among several potential alternatives that are associated with some specific locations in space.

MC-SDSS involve a set of geographically defined alternatives (events) from which a choice of one or more decision is made with respect to a given set of evaluation criteria (Malczewski, 1996). To meet a specific objective, several criteria will need to be evaluated and have called "*Multi-Criteria Evaluation*". A *criterion* is the basis for a decision that can be measured and evaluated. It is the evidence upon which an individual value can be assigned to a decision set.

The multi-criteria decision-making techniques implemented in IDRRISI Andes GIS soft ware apply Analytical Hierarchy Process (AHP) for pairwise comparison. In this process weights are derived by taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria. Hence suitability will be determined based on the relative importance of the two criteria.

Spatial multi-criteria analysis (SMCA) is different from conventional MCDM techniques due to the inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, SMCA requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria. This means analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two considerations are of paramount importance for SMCA: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives).

Generally, MC-SDSS tools and MCDA offer unique capabilities for automating, managing, and analyzing single-user and collaborative spatial decision problems with large sets of feasible alternatives and multiple conflicting and incommensurate evaluation criteria. In addition it provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating, and prioritizing alternative decisions (Malczewski, 2006).

Environmental Suitability Analysis (ESA) can be conceptualized in terms of MCDM. Environmental suitability is a bio-physical and socio-economic convenience of an ecological area for a given set of uses. In this regard, each component of environmental factors in a database is taken as an alternative to be evaluated for its quality or appropriateness for the purpose of human settlement. Similarly, environmental suitability of resettlement site can be analyzed using MCDM procedures in order to prove the appropriateness of the site for human settlement.

There are many criteria that are detrimental to ESA for human settlement. Therefore, ESA involves the integration of information from various streams of sciences. ESA evaluates many alternative socio-economical and bio-physical factors under various criteria from various disciplines.

Criteria are both qualitative and quantitative. Hence, decisions have to be taken at various levels starting from selecting different environmental factors as an evaluation parameter until the allocation of these groups of factors for area that suite best for human settlement. So the suitability analysis is a multiple criteria decision making process.

2.5 Role of Remote Sensing and GIS for Environmental suitability Analysis of Resettlement Sites

2.5.1 Remote Sensing for environmental Suitability Analysis

One of the major applications of remotely sensed data obtained from satellites is environmental monitoring. Because of repetitive coverage at short intervals and consistent image quality, the data obtained from remotely sensed satellites are vital for monitoring the gradual alteration of the dynamic environmental resources.

Remote sensing techniques have assisted mapping and monitoring environmental resources. Changes observed in remotely sensed data can complement ecological assessments of settlement sites. Both restoration and long term management efforts require location and monitoring of the spatial patterns of changes. Besides, regional maps of natural resources provide environmental resource managers with information for settling long term and sustainable development decisions.

2.5.2 GIS for Suitability Analysis

GIS is a computer based system that offers a convenient & powerful platform for performing suitability evaluation. GIS techniques and procedures have an important role to play in analyzing decision problems. Indeed, GIS is often recognized as a decision support system involving the integration of spatially referenced data in problem solving environment.

Site suitability assessment is inherently a multi-criteria problem that involves several competent factors appearing at the same time. GIS, through its spatial analysis tools that are particularly suited for an overlay analysis of various competent factors, ease the task of decision makers. On the other hand, GIS can facilitate the spatial analysis of the detected change through time by overlaying the spatial components of the same feature during two or more periods of time. Accordingly, many spatial decision problems give rise to the GIS based multi criteria decision analysis (Malczewski, 2006).

Therefore an important advantage of using GIS technology is to perform a spatial MCDM study. Through this application of GIS various criteria can be developed based on neighborhood analysis operations (Malczewski, 1996; Pereira *et al.*, 1993). Hence, the integration of multi-criteria methods of suitability assessments in to a GIS environment offers the system not only spatial capabilities but also analytical power for formal MCDM tools. Furthermore, integrating Multi-Criteria Evaluation (MCE) with GIS for spatial decision making purposes is a mainstay application of GIS technology (Carver, 1991). This will in turn create the opportunity for the increased use of GIS based technology as the basis of decision support system.

Finally it is important to note, however, that GIS and MCE techniques are merely tools, which provide a means to an end. Without knowledge and expertise of the operator and decision maker, and without appropriate data, such tools will be useless (Carver, 1991). Nevertheless, GIS and MCE applications appear to represent potentially fruitful areas for further research and development.

2.6 Previous Research in the Study Area

Research into resettlement of any type has tended to focus on the direct economic costs and benefits expected from the projects and, to a lesser extent, their environmental and social ramifications (Tan *et al.*, 2005a; 2006). There has been comparatively limited research undertaken on the potentially far-reaching and long-term social impacts of the resettlement processes. In this study area, however, no research work was conducted regarding the suitability of the environment for human settlement. As a result this thesis is attempting to fill this gap by analyzing major bio-physical and socio-economic factors in terms of their suitability for human settlement.

3. Materials and Methods

3.1 Description of the study area

Chawaka wereda is one of the 258 weredas in the Oromia National Regional State. It is found in the western part of the region in Ilu Aba Bora administrative zone. It has 26 Kebeles (the lowest administrative units). The total land area of the wereda is 627km^2. According to the recent report of the national population and housing censes of Ethiopia the total population of this wereda is 56,106 (CSA, 2007). The first settlers (about 12, 390) arrived in the area in 2001. Now, the area is totally inhabited by resettlers originated from East and West Harerghe Zone of Oromia region (Masresha Taye, 2008). Chewaka is also the largest resettlement scheme in the region.

3.1.1 Bio-physical Description.

3.1.1.1 Location.

Chawaka Wereda is located in Ilu Aba Bora Zone of Oromia Regional State in Ethiopia. It shares common boundary with Benishangul Gumuz Regional State, Gimbi, in north and digga and Leka Dulecha weredas in the east. Similarly Dabo Hana and Mako and Haru Weredas share boundary with the study area in south and in the west respectively.

The absolute location of the study area is between latitude of 8^{0}44’48” N and 9^{0}15’5” N and a longitude of 33^{0}57’20” E and 36^{0}16’17” E. The city of Ilu Harer (Capital city of the Wereda) is established in 2003 at the time of the arrival of the resettlers from Harerghe. It is located at a distance of 556km away from Addis Ababa, 90km away from Nakamte to the south-west and 70km away from Bedele to the north-west direction. Location Map of the study area is indicated in Figure 1.

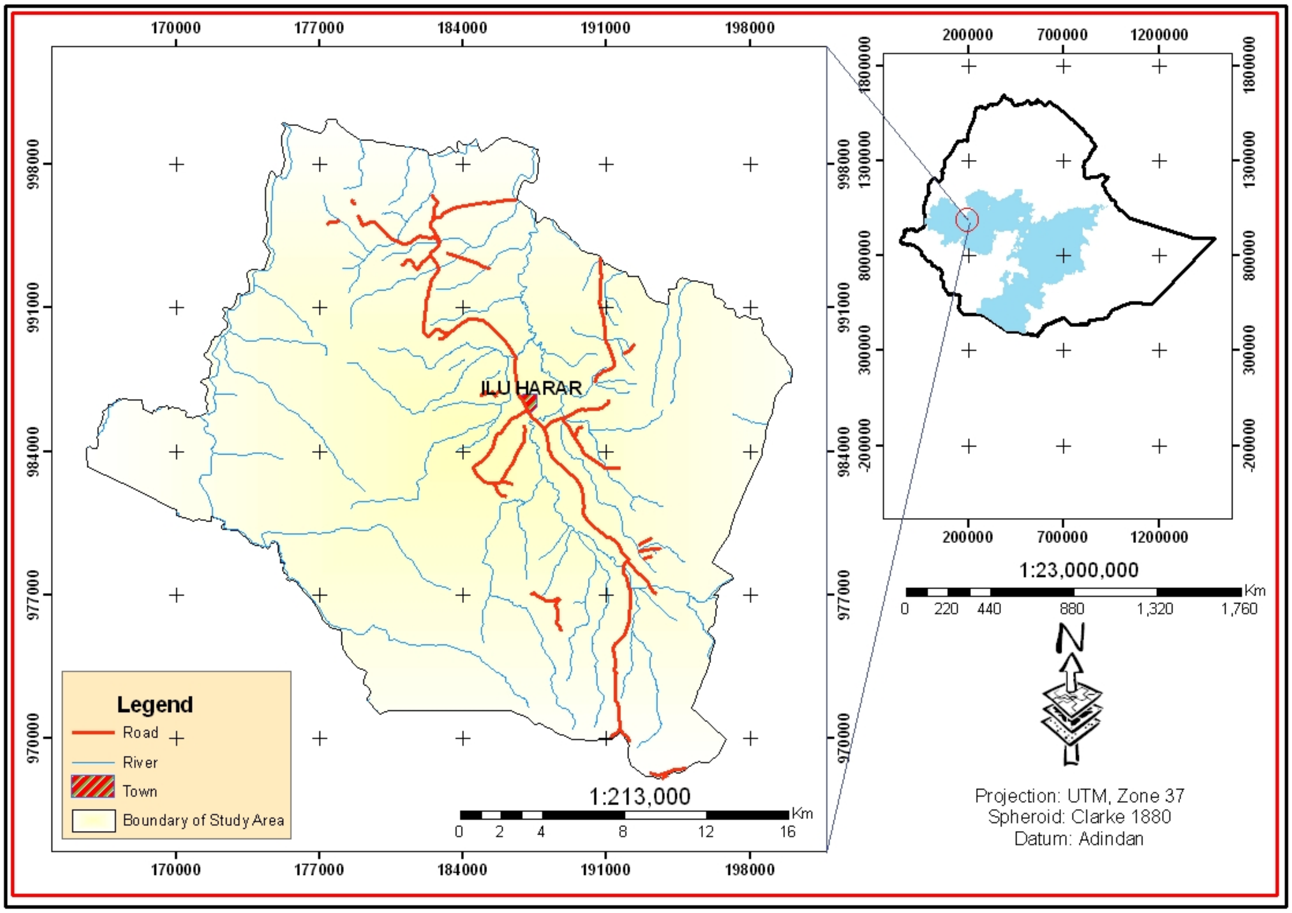

Figure 1: Location map of the study area

3.1.1.2 Topography, Slop and Drainage system

- **Topography**

Slope analysis of the area both from topomap with the scale of 1: 50,000 and the SRTM data with the resolution of 30m reveal that the majority of the study area is flat. It has 252.7km^2 (40%) of its total area under slope of 8%, which is characterized mainly by flat and gently sloping lowlands. In terms of elevation the topography varies from 1,105m to 2,004m above m.s.l. The average elevation, of the area, is 1,556m above m.s.l. The lowest point is at the northern part and the highest is at eastern corner of the wereda.

Drainage system

The study area, Chewaka, completely falls within *Dhidhessa* water shade system which is part of *Abay* water shade. Apart from the many smaller intermittent streams that exist within the boundary of the wereda, Chawaka is almost surrounded by three major perennial rivers. These are *Dhidhessa* to the south-east and *Darbena* and *Senkora* to the north and to the west respectively.

3.1.1.3 Climate

Rainfall

The area gets rainfall almost throughout the year. The mean annual rainfall of the area is 1,816mm. The amount of precipitation obtained in the area varies from the lowest 1,396mm to the highest 2,104mm/year Table 12. The spatial distribution of rainfall showed that south eastern and western parts of the Wereda receive highest rainfall while the northern portion receives the lowest. It has mono-modal rain that attains its maximum in the summer season (June, July and August) and followed by the rain of spring and autumn seasons. The mean annual rainfall of the five metrological stations during different months of a year are indicated in Figure 2.

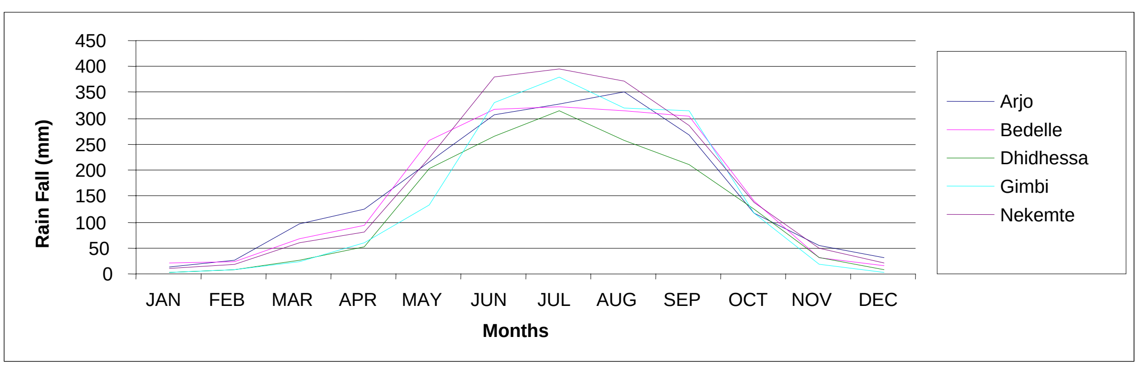

Figure 2: Mean monthly rainfall of metrological stations from 1969 to 2009.

The rainy season (Jun, July and August) yields more than half (54%) of the total annual precipitation (Figure 3). During the consecutive seasons of autumn (September to November), winter (December, January and February) and spring (March, April and May) it receives 24%, 2% and 19% of the total annual rainfall respectively.

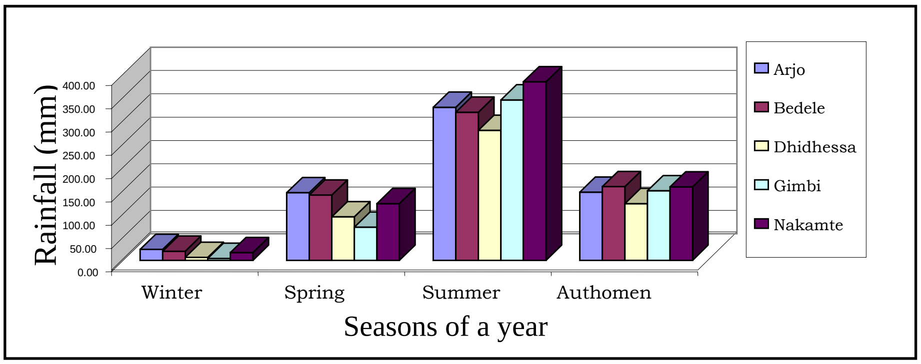

Figure 3: Seasonal rainfall distribution of the study area.

Temperature

The average annual temperature of the study area is 20^0C. Annually the temperature varies by 14^0C from the lowest 13^0C to the highest 26^0C annual mean temperature. The average monthly temperature of the five metrological stations from 1969-2009 is indicates in Table 1.

Table 1: The average monthly temperature (1969 – 2009 GC) in ^OC

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Arjo	17.39	18.07	18.71	18.42	17.52	15.79	14.8	15	15.7	16.5	16.66	16.92	16.79
Bedelle	18.88	19.71	20.38	20.2	18.86	17.57	16.7	17.01	17.72	18.24	18.63	18.8	18.56
Dhidhessa	20.79	22.06	22.9	22.57	21.23	19.99	18.87	19.09	19.53	19.96	20.06	20.15	20.6
Gimbi	20.5	21.85	22.34	21.86	20.69	18.64	17.89	17.94	18.23	19.18	19.28	20.36	19.9
Nakamte	18.91	19.95	20.29	20.22	18.86	17.11	16.28	16.45	17.03	17.76	18.21	18.5	18.3
MonthlyAverage	19.3	20.33	20.92	20.65	19.43	17.82	16.91	17.1	17.64	18.33	18.57	18.94	18.83

As it can be observed from Figure 4, the area has a regular pattern of temperature variation. It raises and attains its maximum level during February and March and declines during the months of July and August.

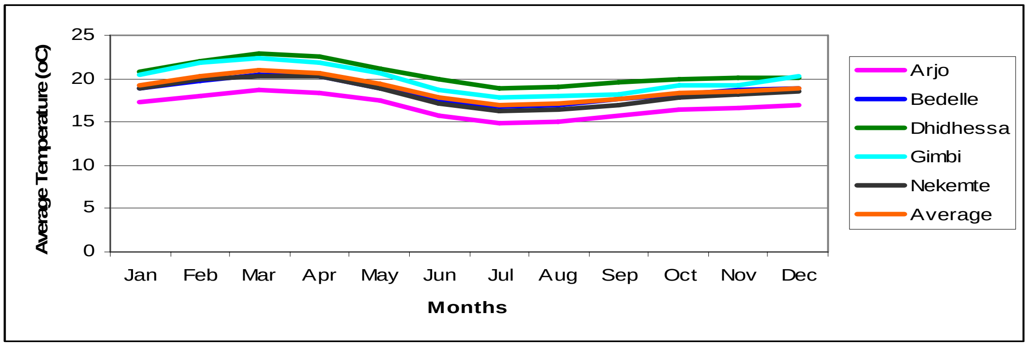

Figure 4: The average monthly temperature of the five metrological stations

Generally the wereda has "*Weynadega*" and Kola agro-climatic condition.

3.1.1.4 Soil

There are two major types of soil in the study area. These are Dystric Cambisols and Lithosols. Dystric Cambisols are well distributed throughout the wereda and they are found almost everywhere covering 99% of the total area. However the second type of soil, Lithosols, is restricted only around the southern extreme corner of the study area. These two soil groups have dominantly vertic properties. They are often dark colored. The chemical and physical properties of the soil in the study area have variation based on the local slope of the area. The larger proportion of the study area has a deeper soil with abundant organic matter concentration particularly in the plain and gently sloping part of the study area. Generally, the wereda is dominated by soils with more acidic property.

3.1.1.5 Land use/ land cover.

Land use land cover is the reflection of the overall environmental condition of an area. Fertility of the soil, favorable climatic condition, variability of the local slope, the intervention of the community and all the other environmental components put their influence and eventually reflect their effect through land use/land cover.

Based on the data obtained from the remotely sensed satellite image land use/land cover of the study area is classified in to five categories. These are dense forest, bush and shrub land, cultivated agricultural land, built up area and grass land.

- **Bush and shrub land**

The largest proportion (285.01km^2) of the area is dominated by bush and shrub land. It covers about 46% of the total area. It is composed of diversified species of plant that grow to a height of two meters. It is under high risk of clearing for expansion of agriculture.

- **Cultivated agricultural Land**

The second largest proportion, this land is cultivated agricultural land. By covering about 142.14km^2 of the total area it takes 22%. Crops like Sorghum, maize, rice, soya bean, sesame, ground nut and haricot bean are the dominant ones that are harvested in the area. In addition cash crops including *'chat',* different kinds of spice and other tree crops are also cultivated in the area.

- **Dense Forest**

This class of land cover is dominated by high growing trees with diversified species. It usually found around rivers and streams where water is abundant. In terms of areal extent it covers 107.05km^2, which is about 17% of the total area of the wereda. It is the major energy source of the local community by providing fire wood for house hold energy consumption.

- **Grass land**

This category of land use land cover dominated by grasses of different species mixed with sparsely distributed trees, bushes and shrubs. In terms of areal extent it covers 92.23km^2 which is about 15% of the total area of the wereda. It is a potential area for the expansion of crop cultivation.

- **Built up area**

These are small pockets of land where the resettlers have constructed houses and other social service providing facilities like school clinics and other administrative buildings. Compared to the other land use/land cover classes it covers smallest proportion (0.1%).

3.1.2 Socio-economic Description

3.1.2.1 Economic Activities

Agriculture is the dominant economic activity of the people in the studyarea. Cereals (like maize and sorghum), oil crops (such as sesame and sunflower) and various types of legumes are the major crops in the area (ODPPB, 2003). In addition cultivation of cash crops like *"Chat"* is expanding in the recent years. Animal fattening for commercial purpose is also becoming a common practice in the area. There are also some trade practice in the form of retailing consumer goods and other smaller industrial products and commodities. These commercial commodities are largely obtained from the nearby bigger towns like Bedele and Nakamte.

3.1.2.2 Population and Demographic Characteristics

According to the recent population and housing censes report of CSA, the wereda has a total population of 56,106. About 98% of the people live in rural areas, while the remaining 2% live in the town of Ilu Harer. The sex ratio of the population is roughly 112%. This is due to male dominated migration in to the new resettlement site. In terms of age distribution, 50% of the total population is in the age between 14-60 years. About 43% of the population is under the age of 14 years while the remaining 7% are above 60 years of age. From this we can infer that the dependency ratio in the area is 1:1.

3.1.2.3 Infrastructure.

Compared to the total size of the population, it is possible to say that there is scarcity of infrastructural facility in the area. There is only one all weather road in the wereda that connects the town of Ilu Harer with the other wereda towns in the surrounding area. There are also limited feeder roads, which are functional only during the dry season. There are six schools which are at elementary and junior levels. Compared to the total number of school aged children, these are not sufficient. Furthermore, they are not fairly distributed throughout the wereda. Similarly, there are only two health centers within the boundary of the study areas which are not easily accessible for the majority of the settlers due to its physical distance. On the other hand, there are about 51 water points that are providing portable water for the resettlers. Among these, 33 are ‘bono’ based pipe water while the remaining 18 are spring water. These water points are again concentrated around road sides only.

3.2 Data Source, Materials, and Methods

3.2.1 Data sources

According to LO and Yeung, (2002), GIS can contain a wide variety of geographic data types originating from many diverse sources. The collection of spatial data is one of the most time consuming, expensive, and tiresome. As a result the most critical stage in the application of GIS technology is the collection of high quality geographic data that will be used as an input for spatial analysis. Generally, for the achievement of the objectives both primary as well as secondary raster and vector data sets were gathered for this thesis from various data sources.

3.2.1.1 Primary data

The most popular form of primary raster data source used in Remote Sensing and GIS application is remotely sensed imagery (Lo and Yeung, 2002). Accordingly satellite images have been extensively utilized throughout this thesis as one of the most important primary data source. A Landsat image for the study area is identified as path-170 and row 054. The image captured in 2005 was used throughout this study.

The Shuttle Radar Topographic Mission (SRTM) data of NASA was the primary data used for slope and other topographic analysis. The data has a 30 meter resolution. In addition Ground Control Points (GCPs) were collect during field data gathering for the purpose of geo-referencing, image rectification and ground verification for the accuracy of land use/land cover classification. These and other location sensitive data was collected using Garmin 72 GPS satellite signal receiver.

3.2.1.2 Secondary data

The most important secondary data sets gathered for this research work include the data of Climatic, soil, topography, population and infrastructural. Regarding the climatic data, the mean annual rainfall and the mean monthly temperature, as well as Relative Humidity (RH) and Wind data were collected from National Meteorological Service Agency (NMSA). These Climatic data were recorded for the last forty one years (1969-2009) at five different metrological stations, namely *Arjo, Bedelle, Dhidhessa, Gimbi and Nakamte*, that are found surrounding the study area. However, only rainfall and temperature data, which are used in this study, are complete.

On the other hand, data about the physical and chemical property of Soil like depth, drainage, texture, organic matter, and pH were obtained from the office Oromia Water Works Design and Supervision Enterprise (OWWDSE). All of these data are used in the analysis of soil suitability of the study area.

Topographic maps of the study area at the scale 1:50000 were obtained from the Ethiopian Mapping Agency (EMA). These maps were originally prepared from an aerial photo series acquired from 1986 and1987.

Most of the socio-economic data sets were obtained from the respective government organizations working on the area. For instance, the distribution and health service provided in the wereda were obtained from the zonal health bureau of Ilu Aba Bora. Similarly, infrastructural data about the school facility, water facility and road network are obtained from Educational Bureau, Water Resource Development Bureau, and Trade, Transport and Communication Office of Chewaka wereda respectively.

3.2.2 Materials

For the accomplishment of this study various materials and software were utilized. Digital camera and GPS satellite receiver are among the materials used during field work for gathering primary date. In addition, topographic maps to the scale of 1:50000, satellite imagery and diverse ancillary data have been used. Generally, summary of materials used in this study are indicated in Table 2.

Table 2: Materials used in the study and their sources

S/N	Type	Description	Source
1	Maps	Topographic map To the scale of 1:50,000	EMA
		Digital soil maps	FAO, OWWDSE
		Weredas and Kebele Shape files	CSA
2	Software’s	ArcGIS 9.3, ERDAS IMAGINE 9.2,IDRISI Andes 15.0, Global Mapper, 3DEM, GPS Utilities	AAU, GIS Lab
3	Instruments	GPS (GARMIN 72), Digital Camera (12mp)	Rented

3.2.3 Methods

Human resettlement is a complicated phenomenon. So many different factors are interacting at the same time. Hence it is the outcome of the complicated interaction between naturally existing bio-physical component and the socio-economic constituent of human being. As a result, the analysis of environmental suitability in a newly founded human resettlement site has to consider all the critical factors that affect human settlement from both types of environment. However, exhaustive treatment of all these variables may be time consuming and it requires large financial budget. Because of these reasons, it could be very difficult for a private researcher to carry out the study under such time and financial constraints. However, in GIS and remote sensing environment, there are some best alternative methods where every variable will be treated individually and reflect its relative influence through the weight assigned to it compared to other variables.

The major factors considered from the bio-physical environment were climate, land use/land cover, topography, soil, and health aspect in terms of malaria epidemics. From the socio-economic environment infrastructure, proximity and population density were considered.

The two most important climatic variables (rainfall and temperature) are used for rainfall analysis and factor development of precipitation as one major component of climatic variable and eventually for climate suitability mapping. A surface interpolation was carried out in a GIS Environment using Spatial Analyst's Tool of ArcGIS by Inverse Distance Weighted (IDW) method.

These elements of climatic variables were reclassified and standardized. To find out their relative importance and to give them a weight in the analysis they were compared with each other by using a pairwise comparison method within EDRISI

Andes GIS environment. Consequently, the integrated outcome was used as one of the major environmental suitability parameters under the name of climate factor.

The other component of the bio-physical environment used in environmental suitability analysis was the land use/land cover. The Landsat ETM+ image with path and raw of 170 and 054 captured at months of January in 2005 was used to classify the land use/land cover pattern of the area. To maintain the compatibility of this data with the other maps it was standardized using the reclassification method of ArcGIS spatial analyst tool. The satellite image data were utilized in the analysis after radiometric and geometric errors were corrected.

The topographic data used in this study was generated from SRTM & DEM data, as well as the Topographic map. The major elements of topographic factors like slope and elevation were used after they were reclassified using the spatial analyst tool of ArcGIS. Hence topographic suitability was mapped from slope and elevation weighted overlay technique after they were compared with each other and weighted according to their relative importance using EDRISI Andes GIS software.

The soil data used in this study was analyzed based on the chemical and physical properties of the soil. The chemical properties like PH and organic matter content and the physical properties such as depth and texture were reclassified and standardized using the spatial analyst tool of ArcGIS. Next to that pare wise comparison matrix was applied to the soil suitability measuring variables using EDRISI Andes GIS software. Accordingly the four major properties of the soil are ranked and mapped based on their respective weight.

Finally a Weighted Overlay Analysis (WOA) in a GIS environment was used to map the land suitability for each environmental suitability factors after weights are calculated in Analytical Hierarchy Process (AHP) weight derivation module of IDRISI Andes 15.0. Finally Environmental suitability map of the study area was constructed using vector overlay analysis in a GIS environment.

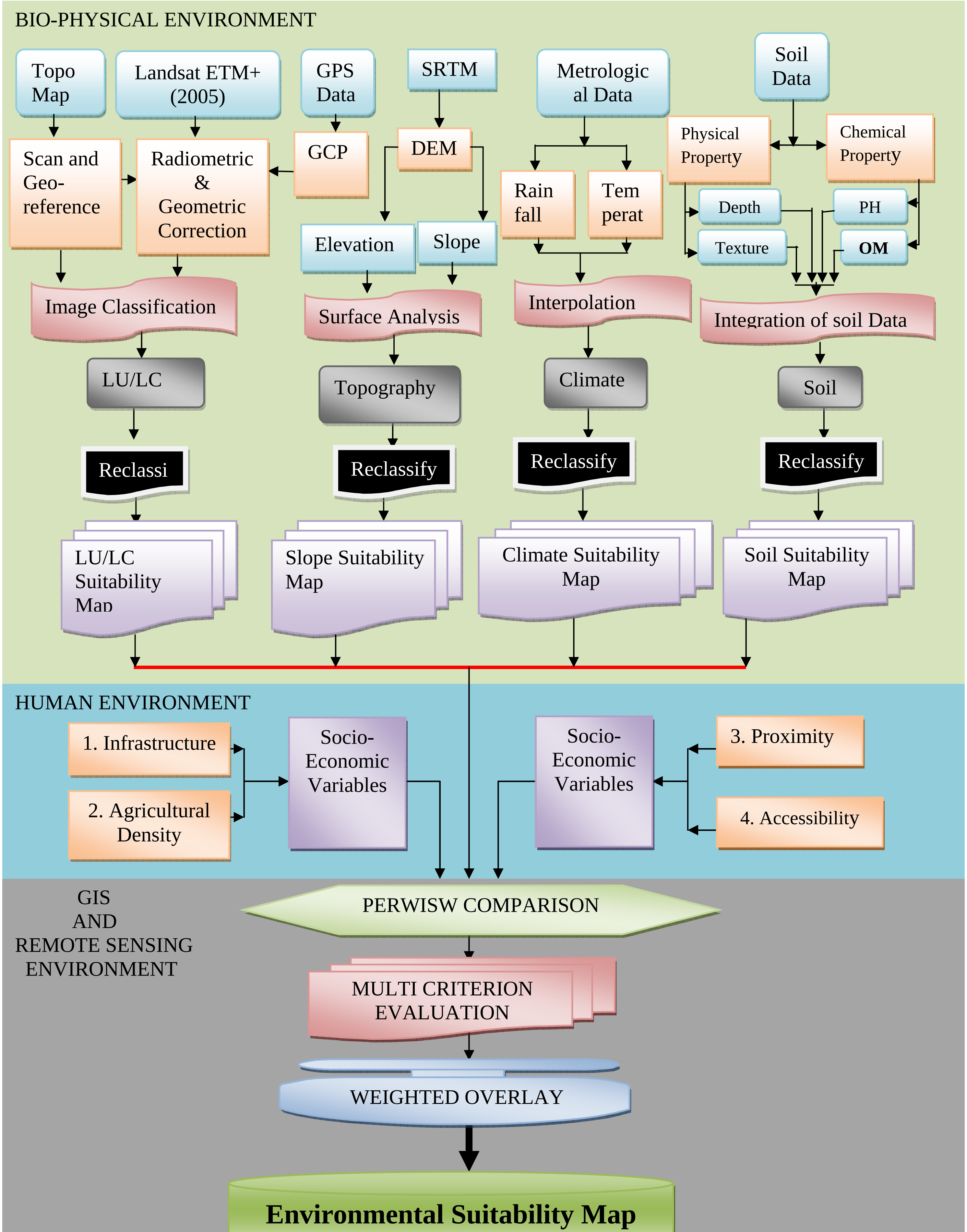

Figure 5: Methodology Flow Chart

As field surveying is one of the most important constituent of primary data collection, field investigation was made twice throughout the research time. During the first visit GPS records were gathered for Geo-referencing the image. On the second field work sample points for training area of digital classification was collected image classification accuracy assessment.

Likewise the elements of socio-economic factor such as infrastructural facilities, proximity and population density were selected and used for the analysis of environmental suitability passing through the same process of reclassification, standardization, parewise comparison and weighted overlaying serially.

Finally ground verification was made for accuracy assessment of land use/land cover classification and ground truething of the final suitability classes. Pictorially, the overall methods and procedure applied in this study are indicated in the flow chart presented in the Figure 5.

3.2.4 Selection of Evaluation Criteria

Criteria are the bases up on which decision about suitability will be measured (Eastman *et al.*, 1995). Evaluation criteria that include the attributes and their objectives should be designed after determination of the problems (Keeney and Raiffa, 1976; as cited in Jankowiski, 1995). This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problems and measures for achieving those objectives which are defined as attributes. Since the evaluation criteria are related to the geographical entities with the relation between them they can be presented with the form of maps which can be referred as attribute maps. The capability of GIS to handle and analyses spatial data can be used to generate inputs for spatial decision making (Malczewski, 1999).

Identification of criteria is a technical activity which is based on theory, empirical research or common sense. Evaluation criteria, objectives and their attributes should be identified with respect to the situation of the problem. A set of criteria selected should adequately represent the decision making environment and they must contribute towards the final goal. Therefore, identification of the criteria can be done through discussion with expertise in the respective disciplines in addition to scientific research findings. Accordingly, scientific journals, literatures and comments of experts are utilized for selecting, standardization and rating of suitability criteria used in the study.

3.3. Data Processing and analysis

3.3.1 Data Processing

Image data may have either radiometric or geometric or both type of distortion. These distortions could be caused by sensor and plate form errors during data acquisition. Therefore, before any analytical processing on satellite image, it has to be corrected for these distortions. This pre-processing operation is called image restoration or rectification (Lillesand *et al.*, 2004). Both of these corrections are done for the image used in this study. The row satellite image data which originally existed in WGS projection was defined in to UTM to suit with the new local projection using Clarke 1880 spheroid and the Adindan Datum.

3.3.2 Environmental Suitability Factor Development and Data Analysis

3.3.2.1 Bio-Physical Factors

3.3.2.1.1 Land use /Land Cover Factor

One of the most important factors in the analysis of environmental suitability analysis for human settlement is the land use/land covers. It is the direct reflection of the environmental situation of the area. The analysis of land use/land cover largely depends up on satellite image classification.

3.3.2.1.1.1 Land Use /Land Cover Classification

Image classification is the process by which a raster or image data set is converted in to thematic data for a particular purpose. The process involves compressing a mosaic of pixels that belongs to a common and relatively homogenous class in to one theme. The intention of image classification is to ease the analysis of thematic characteristics of some environmental features like land use/land cover with in GIS based modeling. This is particularly true due to the data reduction process involved in the technique; i.e. the n multi spectral bands involved in the analysis of raster data will be summarized into only single band raster file.

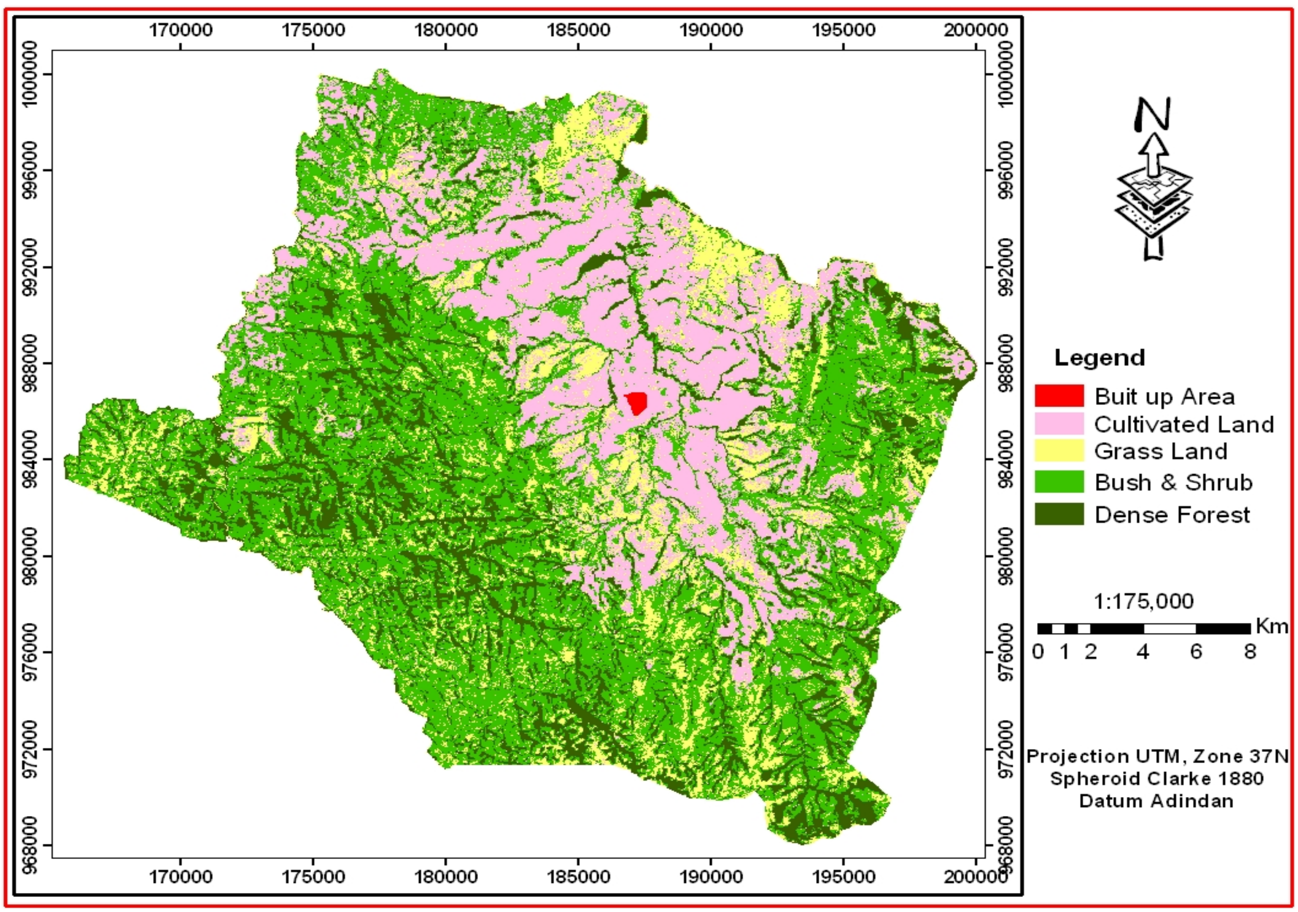

Figure 6: Land use/Land cover map

Supervised and unsupervised classifications are the two types of image classification (Lillesand *et al.,* 2004) procedures. Unsupervised image classification is the algorithms that compare the spectral signatures of a pixel with a computer determined cluster of signatures and finally assigns each pixel in to one of these clusters (Lillesand *et al.*, 2004). On the other hand supervised classification is the process whereby a cluster of pixels in a data set are grouped in to classes corresponding to user-defined training classes. Both of these image classification procedures are applied in this study before and after field verification respectively using ERDAS IMAGIN 9.2 software. The area has five LU/LC classes (Figure 6).

3.3.2.1.1.2 Classification Accuracy Assessment

Errors are inevitable in any digitally generated land cover maps obtained from remote sensing imagery. These errors may occur from the source itself because of errors during data acquisition or from classification techniques during image processing. As a result, a robust and through assessment of the classification accuracy is required in order to guaranty the reliability of the result. One of the very effective and most commonly used methods of expressing classification accuracy is the preparation of a classification error matrix or a confusion matrix (Congalton, 1991; Lillesand *et al.*, 2004).

There is some similarity between accuracy assessment and training classifiers in that both use the same data sets. However, there is a possibility for overestimation of classification accuracy simply because of using the same data sets both for training and testing purposes. To avoid this problem, it is good to use randomly selected pixels, which can be checked with reference to ground verified data. Similarly, the same methodology was applied in the Landsat ETM+ data utilized in this study.

Accordingly the overall accuracy of image classification in this study is 86% and its Kappa index agreement is 0.8204. This implies that the classification process is avoiding 82% of the errors that a completely random classification generates. On the other hand, the accuracy of individual class varies from 65% to 92% for producer's accuracy and from 74% to 96% for user's accuracy. However, user's accuracy for bush and shrub land showed a value slightly less than 75%. With regard to producer's accuracy, all classes are accurate by more than 75% except for dense forest (Table 3).

Table 3: Error matrix of Land use/Land cover classification result

	Classified Data	Reference Data					RT	NC	PA	UA
		CL	DF	BSL	GL	BUA				
Classified Data	CL	22	1	0	0	0	23	22	91.67%	95.65%
	DF	0	11	1	0	1	13	11	64.71%	84.61%
	BSL	2	5	26	2	0	35	26	96.30%	74.29%
	GL	0	0	0	10	1	11	10	76.92%	90.90%
	BUA	0	0	0	1	17	18	13	89.47%	94.44%
	CT	24	17	27	13	19	100	82		

CL= Cultivated Land, DF= Dense Forest, BSL= Bush and Shrub Land, GL= Grass Land, RT=Row Total, CT=Column Total, NC= Number Corrected, Producer Accuracy, UA= User Accuracy,

It is important to note that producer's accuracy is calculated as the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data. This accuracy measure indicates the probability of a reference pixel being correctly classified. On the other hand, if the total number of correct pixels in a category is divided by the total number of pixels that are classified in that category, it is said to be user's accuracy is reliability.

After the land use/land cover of the study area are evaluated for their accuracy they were reclassified and standardized. Finally they were assigned a suitability class based on their suitability for human resettlement. Accordingly the built up area were mapped as highly suitable. Again agricultural areas were classified as moderately suitable, while grass lands were labeled as marginally suitable. Similarly, shrub and dense forest were mapped as currently not suitable.

3.3.2.1.2 Climatic Factors

Climate affects the environmental suitability of a resettlement site in different ways. Directly or indirectly, it influenced the physical and cultural environment through its complex relation with almost all environmental variables. The type of vegetation grows in an area, the species of animals reared, the crops cultivated; all depend up on the climate.

Climate strongly affects and determines the inputs of human livelihood. The availability of water for human consumption for various purposes, the productivity of agricultural activity and forestry are all in one way or the other connected and affected by climate. Generally, it plays a vital role in determining the environmental suitability of an area. Therefore, climate must be given due consideration in the analysis of environmental suitability for human settlement.

Compared to all the other components rainfall and temperature are the major climatic elements that influence the suitability of human resettlement sites. Hence, the analysis and interpretation of climatic factor in this study depends up on these two elements.

3.3.2.1.2.1 Precipitation

Precipitation has a direct or indirect connection with all environmental components. As rainfall is the source of water for rain fed agriculture, the productivity and potential of agricultural systems in an area is determined by its amount and distribution. The volume of rivers, groundwater potential, level of salinity, water supply, and so on that in one way or the other affect environmental suitability of a resettlement sites are among the factors that have direct relationship with the amount and level of precipitation (Gerick, *et al.*, 2000; Kirshen, 2002; Ruth *et al.*, 2007). Moreover, extreme level of precipitation like storms can cause floods, and other severe weather events that may eventually affect other infrastructural facilities, including sanitation systems, transportation, and supply lines for food, energy and communication. Generally, environmental suitability of human settlement directly or indirectly depends up on rainfall condition of the area in addition to the other factors.

Suitability of a rainfall pattern can be assessed by using different data sets and applying various methods. The mean monthly annual rainfall data was used in this particular study. The rainfall data recorded at five metrological stations for forty one years (1969-2009) (Table 13) are interpolates with in GIS environment by using the Inverse Distance Weighted (IDW) technique in the spatial analyst tool of ArcGIS 9.3. The outcomes of this interpolated data were finally reclassified in to rainfall suitability classes based on the standard set by agronomist and agricultural experts in Ministry of Agriculture and Rural Development. These standards are designed based on the rainfall requirement of the crop that grow in the area.

As it can be observed from Table 4, those areas that obtain a mean annual rainfall of 1800-2000mm per year are mapped as highly suitable. Moderate and marginal suitability classes are assigned for those places were the mean annual rainfall is between 1500-1800mm and more than 2000mm, respectively. Figure 7 indicate the rainfall suitability maps of the study area.

The unsuitable classes were mapped as currently not suitable and permanently suitable wherever the mean annual rainfall was 100 to 500mm and less than 100mm respectively. However, having the rainfall variation that ranges from 1396mm to 2104mm per year the study area falls only within three suitability classes such as: highly suitable, moderately suitable, and marginally suitable rainfall condition. The rainfall suitability map of the study area is indicated in Figure 7.

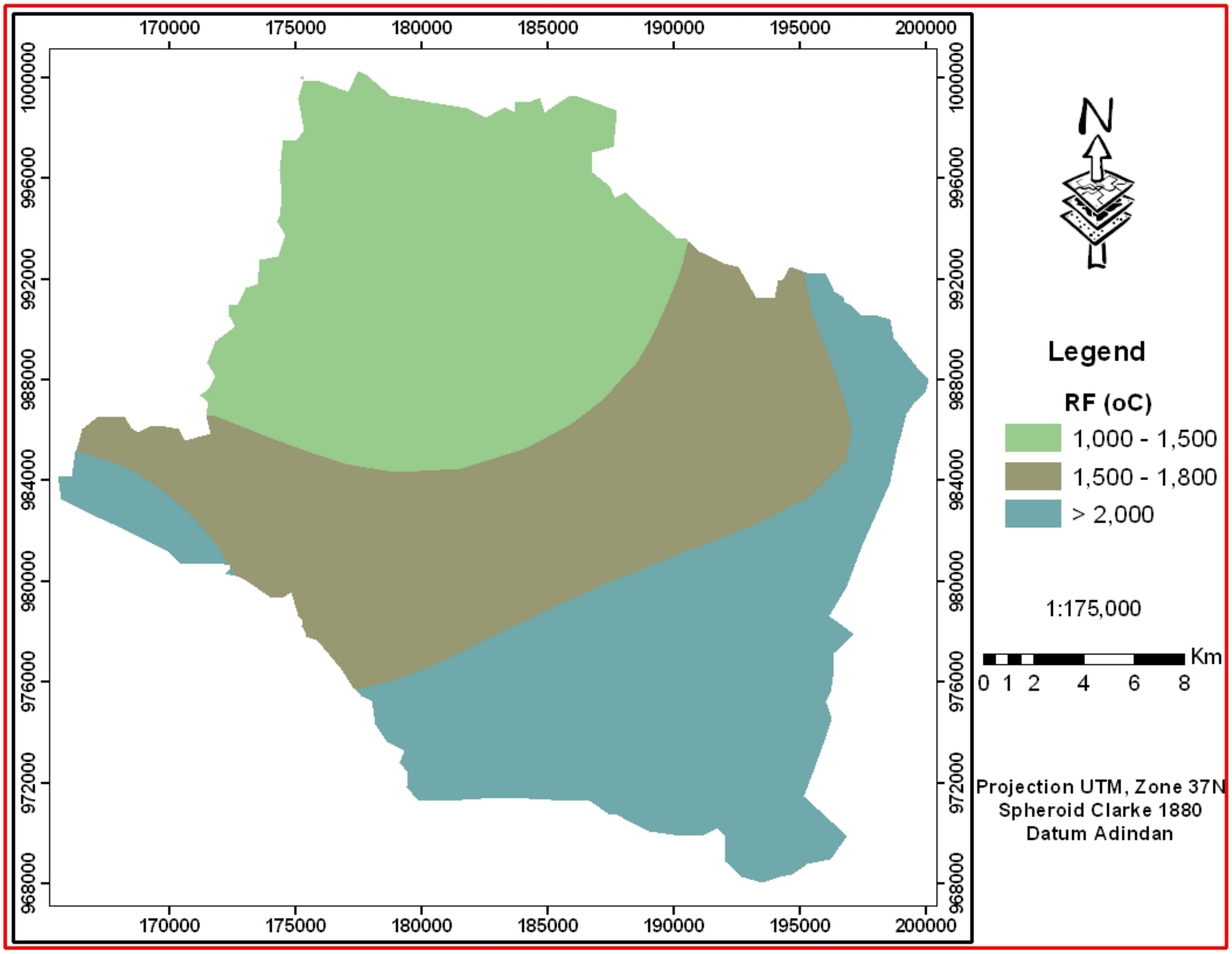

Figure 7: Rainfall Suitability Map

3.3.2.1.2.2 Temperature

Temperature has also a relation with the suitability of an environment for human settlement. In terms of human health, it is well established that higher temperatures are related with a couple of health related complications such as respiratory and cardiovascular problems (Patz *et al.*, 2001). There is also some evidence that the effects of heat stress may result in health complication including psychological depression (Patz *et al.*, 2001). Historical data also show the relationships between mortality and temperature extremes (Rozenzweig *et al.*, 2001a). Medical experts on the other hand explain that the probability of human exposure to water, food and vector-borne diseases will be higher due to temperature variables.

Agricultural productivity depends up on environmental temperature of the area. Prolonged mild temperature and high temperature has negative effects on the productivity of crops. Most plant species does not grow at a very low temperature (<6.5^{o}C). Similarly, very high temperature, usually above 35^{o}C, causes an adverse effect on the appropriate growth of most plant species. Furthermore, the incidence of hazards like wild fire, particularly in grass land areas, is strongly related with high environmental temperature. As a result consideration of temperature variable in the analysis of environmental suitability for human settlement is very important.

Table 4: Rainfall and temperature suitability classes and their areal coverage

Climate Factor	Class	Suitability	Area (km^2)	Percentage
Rain Fall	1500-1800mm	Moderately High	211.07	33.66%
	1800-2000mm	Highly Suitable	210.16	33.52%
	>2000mm	Marginally Suitable	205.77	32.82%
Temperature	10-15^{o}C	Moderately High	325.30	51.88%
	15-25 ^{o}C	Highly Suitable	301.70	48.12%

Suitability of temperature can be assessed in a variety of ways. However, the mean monthly temperatures were utilized for this study. The temperature data of the area was interpolated using the Inverse Distance Weighted (IDW) technique in the spatial analyst tool of ArcGIS 9.3. Accordingly the temperature suitability map was constructed from the reclassified and standardized temperature suitability classes indicated in Table 4. Having temperature variation that ranges from 17^{o}C to 21^{o}C, the study area falls within high and moderate temperature suitability classes. The average annual temperature of 15-25^{o}C is mapped as highly suitable for it is an optimum amount of temperature required by most plants and animal species; (Figure 8).

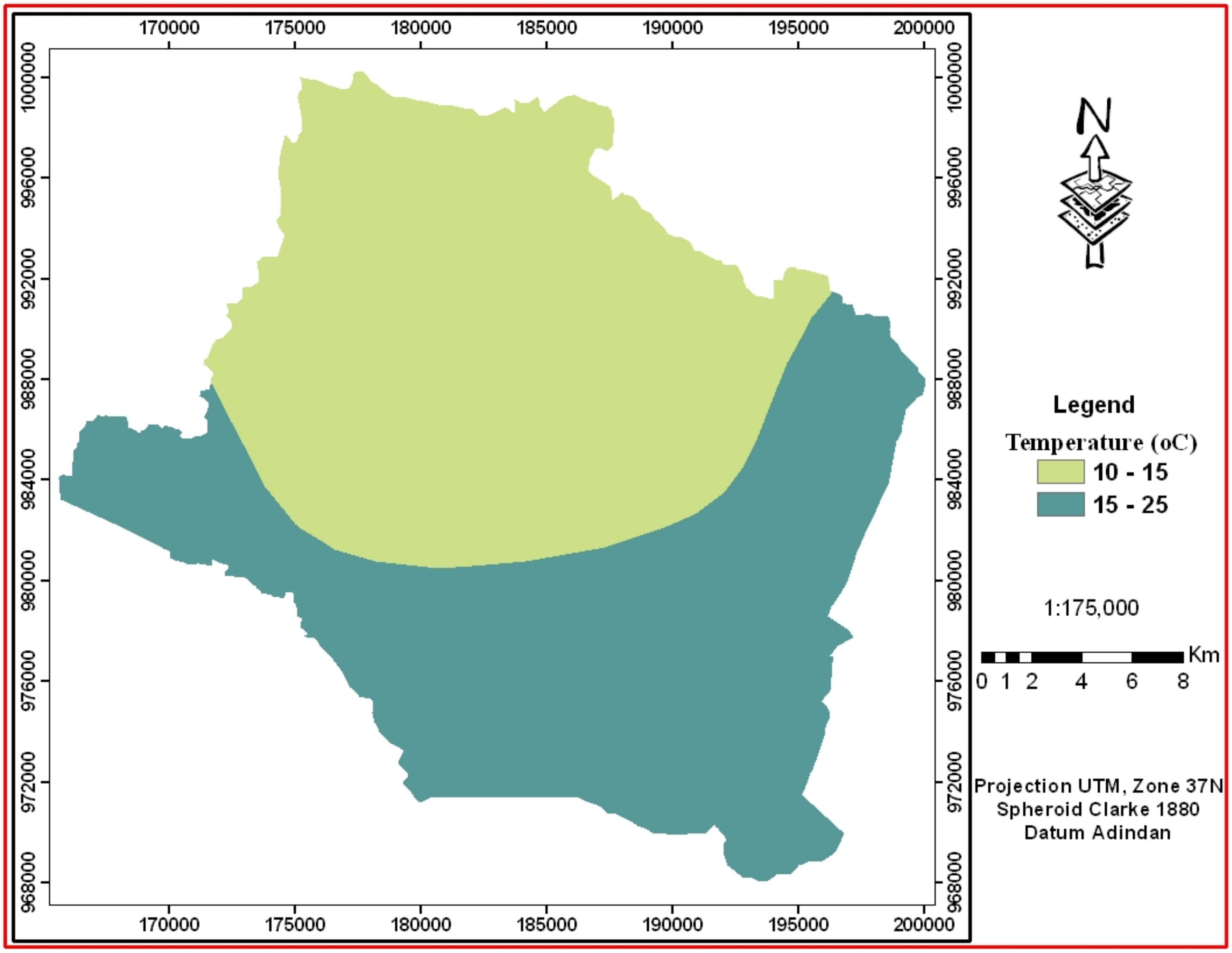

Figure 8: Temperature Suitability Map

3.3.2.1.3 Topographic Factors

3.3.2.1.3.1 Slope

One of the most important factors in any physical planning and environmental suitability analysis is the slope. It can affect the suitability of human settlement in a couple ways. The stability of surface materials is largely depends up on slope. The cost of construction and building of settlement utilities and infrastructure are also affected by slope. Furthermore, both the chemical and physical properties of the soil largely depends up on slope variation of the area as compared to the other environmental factors. As a result, it is very important to consider slope factor in the analysis of environmental suitability for human settlement.

Resettlement sites must encompass adequate areas of flat or gently sloping land for house construction and agricultural developments. These areas must also be largely contiguous to enable the development of irrigation systems and associated structures. Slopes must be less than 15 percent for effective development of terraced farm land. Steeper slopes would facilitate the movement of excessive amounts of top soil and eventually leads in to uncovering of infertile sub-soil horizons or even underlying parent material in the shallow surface soils. In addition, slope can exacerbate the risk of soil erosion in steeper sloppy areas.

The slope data of the study area was generated from the DEM and SRTM data at 30m resolution. According to this data, Chawaka wereda has the slope variation that ranges from 0% to 106%. Based on the slope classification parameter adopted from FAO (2005) and OWWDSE the slope of the study area was grouped in to five categories as less than 2%, 2 – 8%, 8 – 16%, 16 - 30% and greater than 30%.

These slope categories were further reclassified using the spatial analyst tool of ArcGIS 9.3 in order to identify slope suitability for human settlement. Accordingly, the slope class between 2 – 8% is taken as the most suitable because of is very good drainage condition and relatively good soil depth. Stability of the unconsolidated earth materials is also good in such areas. Furthermore the cost of construction and agricultural mechanization is also good in this slope class.

Even though thick soil with better nutrient content is expected in plain and gently sloping areas of less than 2%, this class is assigned with a moderate suitability, mainly due to its poor drainage condition and very high susceptibility to the risk of flooding, particularly during rainy season.
Areas with the slope of 8 – 16% are mapped as marginally suitable for the reason of difficulty to implement mechanized cultivation, more cost of construction, increased rate of material instability, and relatively poor rate of soil development. Similarly, the other two classes of slope are mapped as limited suitability (16 –

30%) and not suitable (more than 30%) due to the maximized effect of the drawbacks mentioned above (Figure 9).

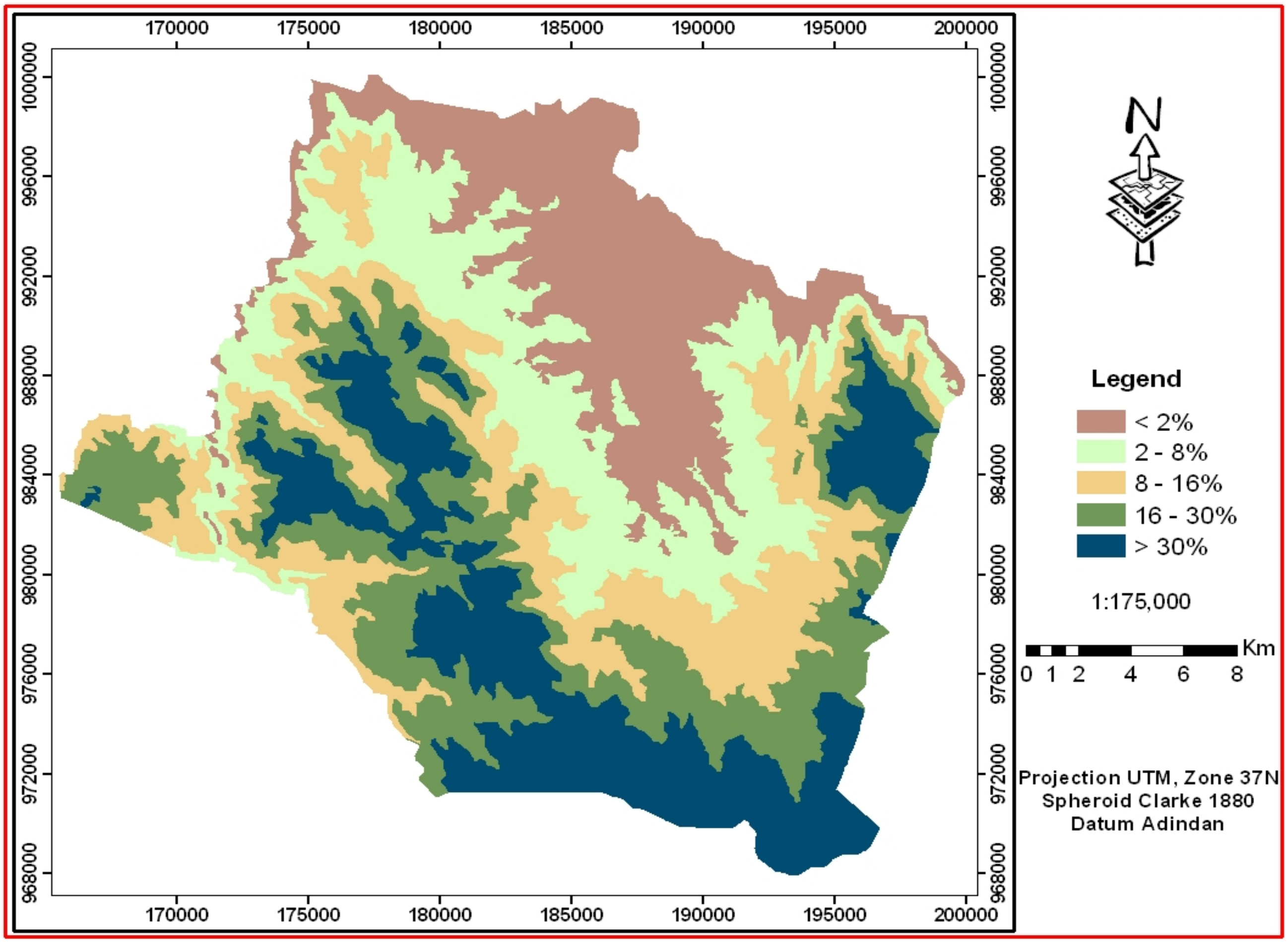

Figure 9: Slope Suitability Map

3.3.2.1.3.2 Elevation Factors

Elevation of an area has a vital role to play in human settlement. Some species of plants and animals have adapted themselves only in a limited elevation above mean sea level.

It also affects agricultural activity and productivity. Classification of agro climatic zones mainly depends up on elevation. As a result it is important to consider elevation factor in the analysis of environmental suitability for human settlement. Depending up on elevation factor Ethiopia is classified in to five agro climatic zones. These are *Wurch, Dega, Weyna Dega, Kola* and *Bereha* where the elevation is more than 3200m, 2300 – 3200m, 1500 – 2300m, 1000 – 1500m, and less than 1000m above m.s.l respectively, (Table 5).

Table 5: Topographic suitability classes and their areal coverage

Factor	Classes	Suitability	Area (km²)	%
Slope	< 2%	Moderately	125.24	19.97
	2 - 8%	Highly	127.12	20.27
	8 - 16%	Marginally	125.07	19.95
	16 - 30%	Currently Not	125.40	20.01
	> 30%	Permanently Not	124.17	19.80
Elevation	1000 - 1500	Marginal	479.00	76.39
	1500 - 2300	Moderate	148.00	23.61

Each of these classes has its own unique type of crop cultivation and human settlement pattern. However the *dega* agro climatic zone is agreed to be the most suitable area for human settlement due to its comfortable climatic variables like rainfall, temperature, humidity, and evapotranspiration. Apart from that, almost all places with in this zone are free of malaria risk.

Based on this criterion an attempt was made to categorize elevation of the study area in to different agroclimatic zones. Chawaka wereda has an elevation variation that ranges from 1,105m to 2,004m above m.s.l. That means no part of it falls out of *weyna dega* and *Kola* agro climatic category (Figure 10).

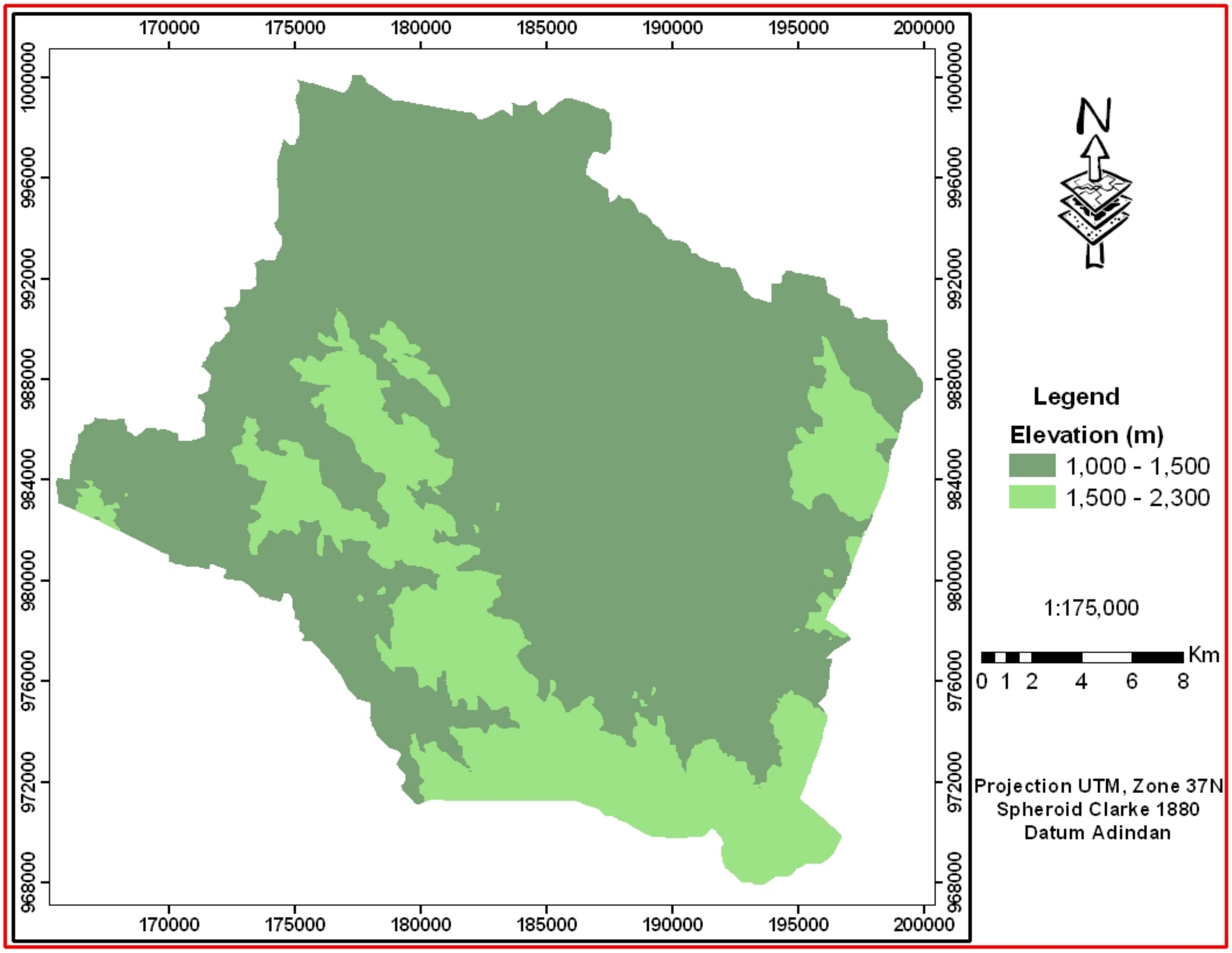

Figure 10: Elevation suitability map

3.3.2.1.4 Soil Factors

Soil, being one major component of the natural environment, needs a due consideration in the analysis of environmental suitability of human resettlement site particularly in rural areas where the livelihood of the society largely depends up on agriculture.

The soil data used in this study was obtained from FAO at scale of 1:50,000. It was over lied with the local slope to come up with the Soil Mapping Units that serves as soil category (Figure 11).

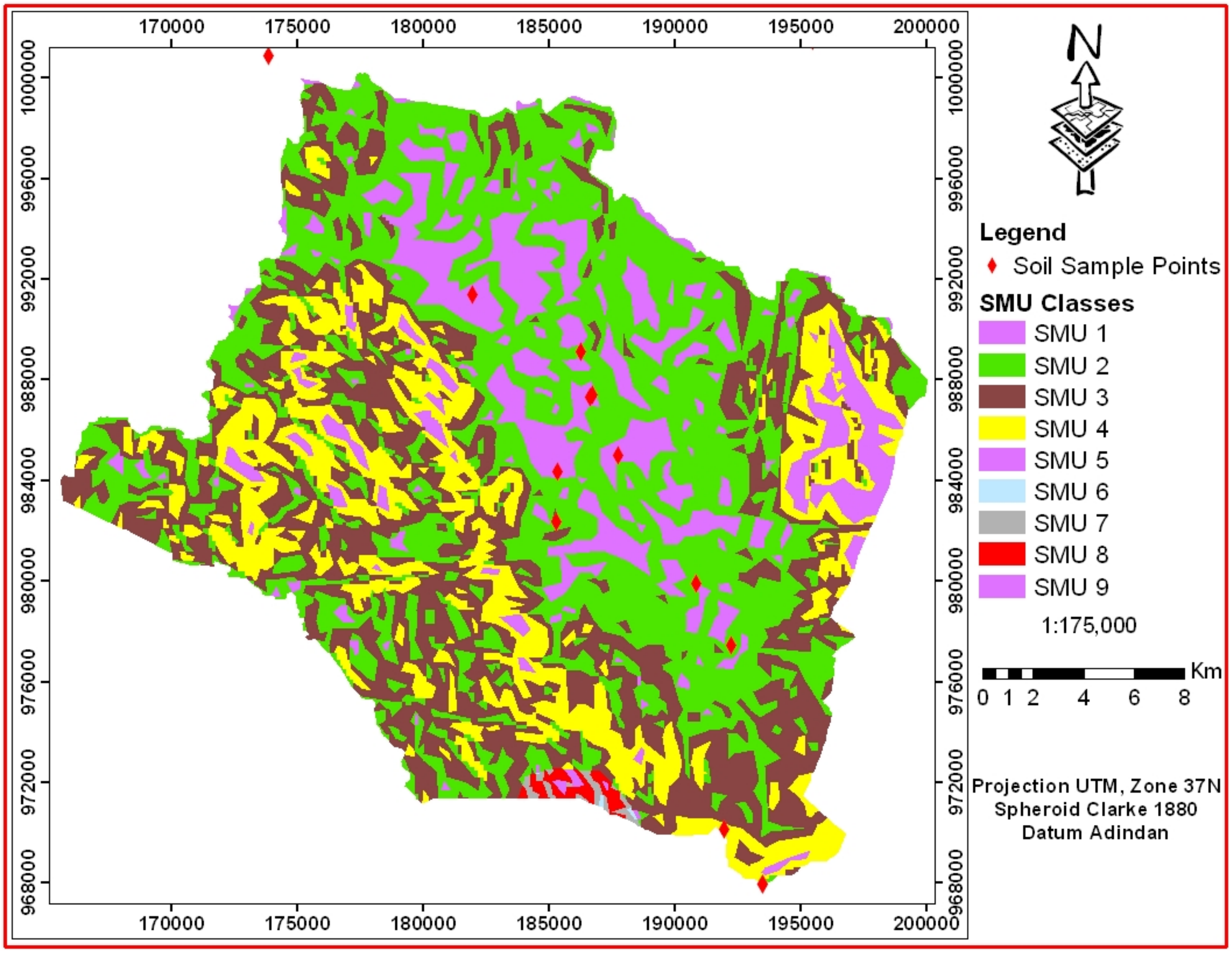

Figure 11: Map of Soil Mapping Units

The interpretation and analysis of soil suitability was performed based on the soil laboratory test results of the sample soil data obtained from OWWDSE (Table 6). The enterprise has collected the data from nine sample points that are unevenly distributed throughout the wereda.

Basically the physical and chemical properties of the soil vary depending up on variation of the local slope. In this particular study, both the physical and chemical properties of the soil were used to analyze soil suitability of the study area.

Table 6: Laboratory test results of soil sample at different slope

Major Soil	Soil Type	SMU	Slope	Depth (cm)	Texture	pH	OM
Lithosol	Lithosols, 1	SMU 1	0-2%	200	Loam	4.7	3.2
	Lithosols, 2	SMU 2	2-8%	140	Sandy Loam	5.3	2.75
	Lithosols, 3	SMU 3	8-16%	80	Clay	6.1	2.3
	Lithosols, 4	SMU 4	16-30%	30	Loam	5.6	1.4
Dystric Cambisols	Dystric Cambisols, 1	SMU 5	0-2%	193	Sandy Clay Loam	5.1	3.5
	Dystric Cambisols, 2	SMU 6	2-8%	147	Sandy Loam	5.4	2.6
	Dystric Cambisols, 3	SMU 7	8-16%	75	Clay Loam	6.1	2.1
	Dystric Cambisols, 4	SMU 8	16-30%	30	Loam	5.5	1.4
	Dystric Cambisols, 5	SMU 9	>30%	20	Clay Loam	5.6	0.75

3.3.2.1.4.1 Physical Property of the Soil

The physical property of the soil can be explained in a variety of ways. However, only the two most important elements (Depth and Texture) that affect agricultural productivity are treated in this study.

Soil depth refers to the thickness of the upper top earth materials that determines the plough depth. The effective soil depth is therefore the thickness of the loose soil above a limiting layer, which is impermeable for roots and/or percolating water. In areas where the soil is deep and well drained it allows the penetration of plant roots up to 150cm below the surface. However the penetration will be restricted at a shallower depth where the soil lays above hard and resistant rock basements. Variation of soil depth depends up on the slope of the terrain. In the upper and steep sloppy area, the soil has a shallow depth, while it is deeper in gently sloping and flat areas.

Based on the experience of OWWSDE the soil depth was categorized in to five depth classes as very shallow, shallow, moderately deep, deep, and very deep if it has a depth of less than 25cm, 25-50cm, 50-100cm, 100-150cm and more than 150cm, respectively (Table 6).

This soil depth categorization was further reclassified to determine the depth suitability classification. Accordingly the soil that has more depth value has assigned the most suitable for most agricultural purpose and the vice versa. However, it is important to note that soil suitability varies depending up on the soil depth preference of the plant species. For instance, long rooted crops grow only on deeper soil, while short rooted crops like *Teff* and other crops can grow and give better yield on shallow soil. As a result, the above depth suitability classification was made by consulting crop and soil experts from Ministry of Agriculture and Rural Development as well as OWWDSE depending up on depth requirement of majority of crops that grow in the area. Finally a map layer of soil depth suitability was constricted based on this classification (Figure 12).

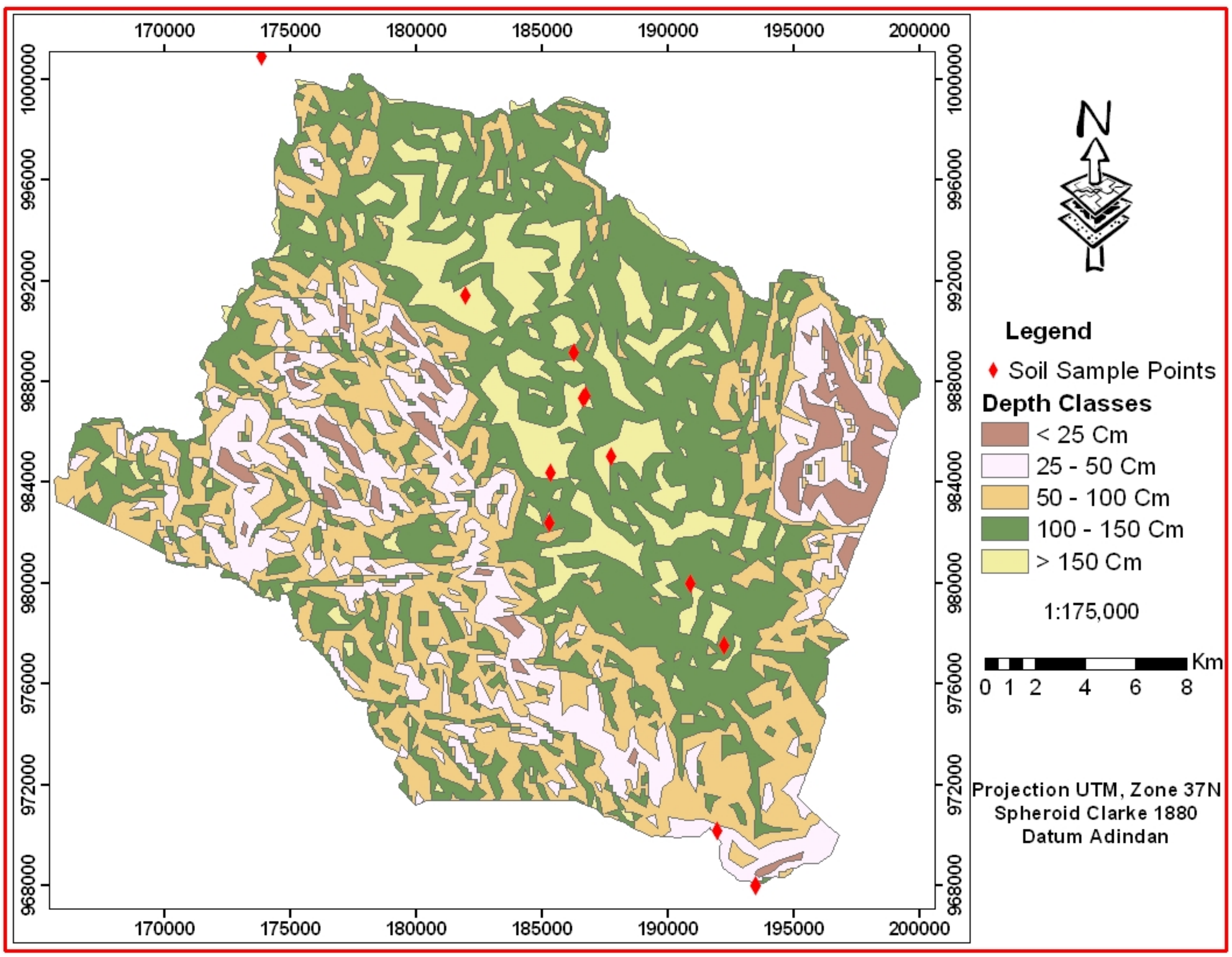

Figure 12: Soil depth suitability map

Texture is the other physical property of the soil that can be used to analyze environmental suitability of the soil. Some of the most important physical properties of the soil are reflected through its texture. The smooth transportation of determining materials like water and air are limited by the texture of the soil. This will eventually affect the chemical reaction in the soil, which in turn determines the development of the soil. Like in the other cases, the suitability classification was also made for soil texture based on the recommendations of soil experts. Accordingly, five classes of soil texture are identified in the study area are clay, clay loam, loam, sandy loam and sandy clay loam (Figure 13)

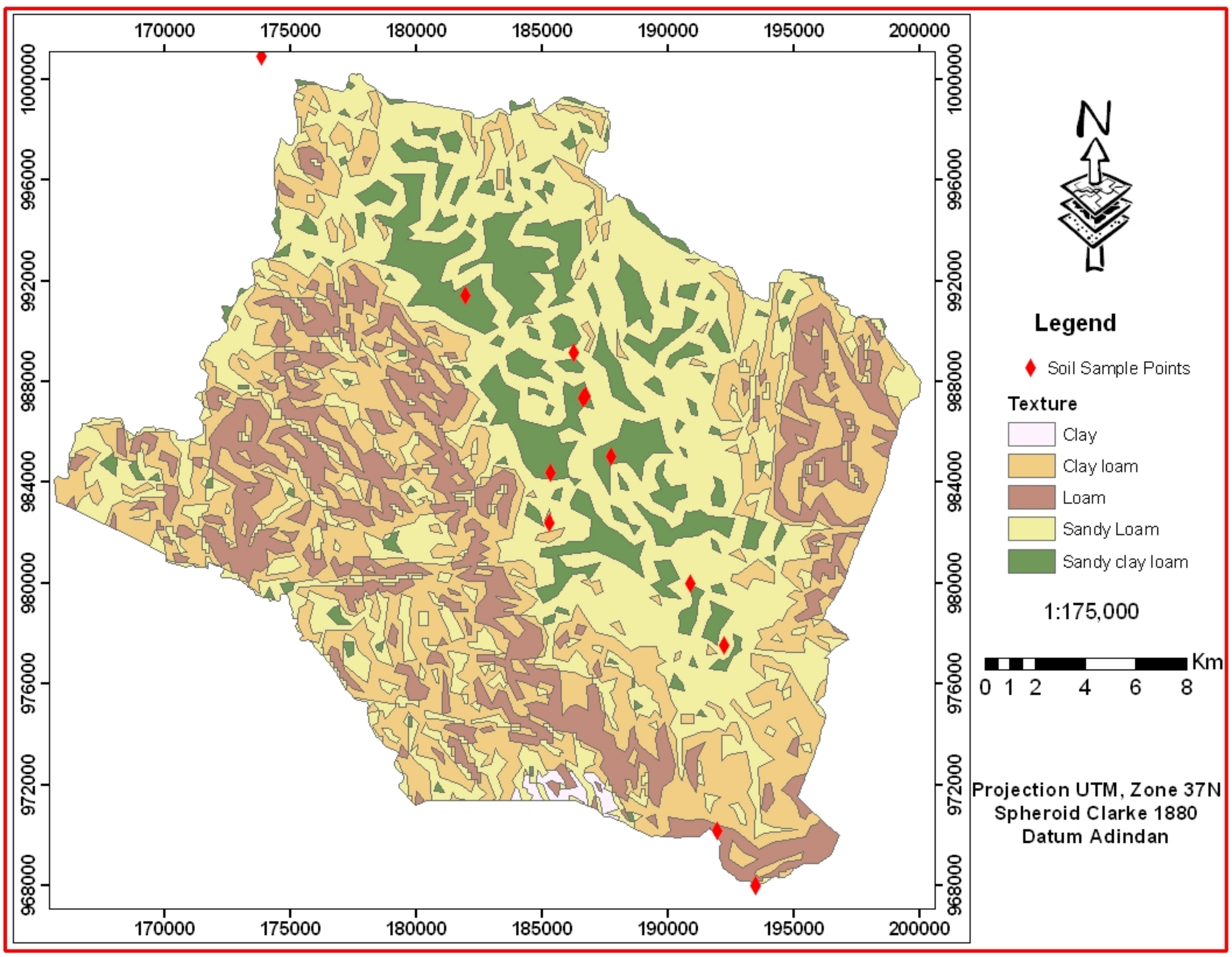

Figure 13: Soil texture suitability map

3.3.2.1.4.2 Chemical Property of the Soil

Soil has so many chemical properties depending up on the components of its parent material. The historical process through which the soil has passed though out its formation also determines its chemical property. pH and organic matter content are the two most important soil chemical properties that can sufficiently characterize the nature of soil in an area. Accordingly, these two components of the soil in the study area are thoroughly analyzed to map the chemical suitability of the soil for human resettlement.

Generally, the pH water tolerance limits vary for different plants. However, for most of the crops, a neutral range of 6.6-7.3 is highly suitable. Soils become acidic as crops remove cat ions or through leaching with climate being the dominant factor.

Acidification is most rapid in soils derived from minerals low in cat ions and in coarse soils that can easily be leached. The soil pH significantly affects the availability of most of the chemical elements important to plants and microbes at low pH (<5), there is a tendency for toxicity of elements such as iron, manganese and aluminum. The availability of nitrogen, sulfur and molybdenum are somewhat restricted at low pH, whereas that of phosphorous is best at intermediate pH level.

Based on the standard set by FAO (2005) an attempt was made to categorize the soil of the study area depending up on its pH value. Accordingly, the soil of Chawaka falls within five soil pH suitability classes. These are: highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable (Figure 14).

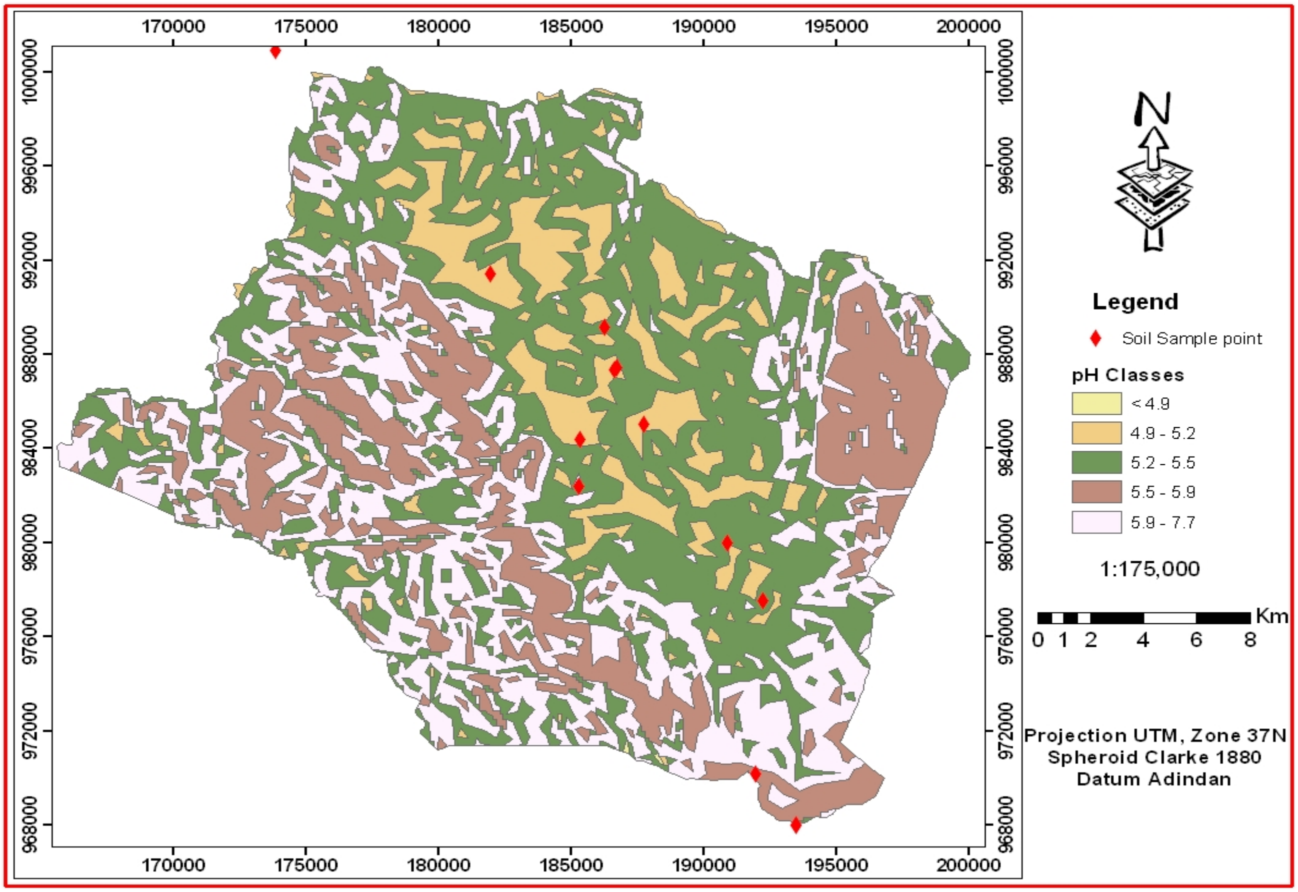

Figure 14: Soil pH suitability map

Organic matter has a crucial role in the analysis of soil suitability. It is an ideal source of plant nutrients in soils. The measure of organic matter (OM %) is conducted to evaluate availability of plant nutrients and physical condition of the soil. Soil organic matter consists of plant, animal and microbial residues in various stage of decay. Organic matter contains about five present total nitrogen, so it serves as a store house for reserve nitrogen, but nitrogen in organic matter is in inorganic form and not immediately available for plant use, as decomposition usually occurs slowly. Organic matter gives dark color to many soils, holds water 20 times of its weight, provides aggregation, and has high cat ion exchange capacity.

The organic matter content of the soil obtained from the laboratory soil test result as indicated in Table 6 was grouped in to five suitability classes depending up on

FOA's standard and the experience of OWWDSE. The organic matter content of the soil was mapped after the data was reclassified and standardized within the spatial analyst tool of ArcGIS (Figure 15).

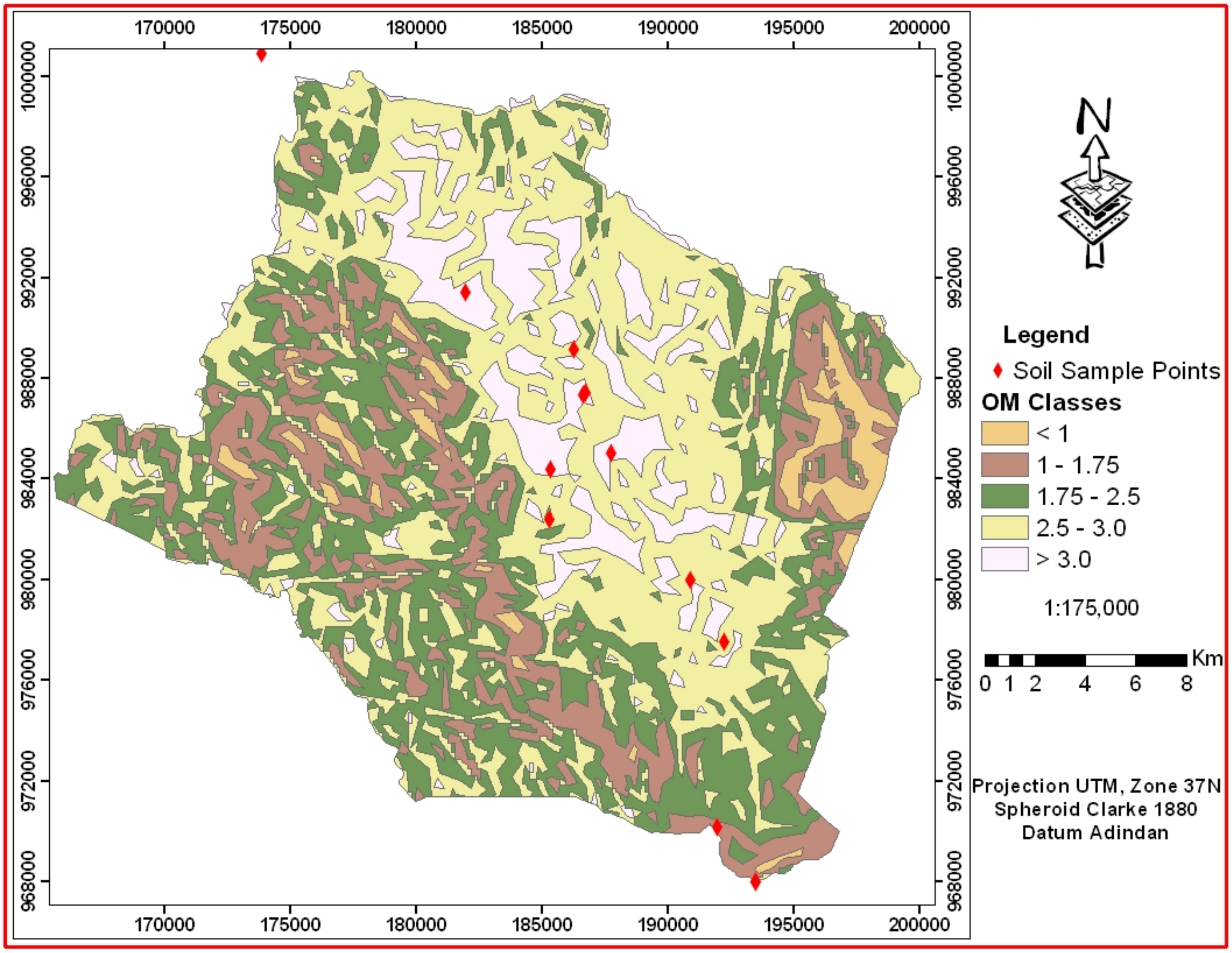

Figure 15: Soil Organic matter suitability map

3.3.2.1.5 Health Factor

It is wise to consider the suitability of a resettlement site in terms of its appropriateness for human health. Historical documents revealed that some resettlement schemes have failed as they were executed on areas, where malaria is prevalent. This is particularly true in low land areas, where mosquitoes and other parasites are dominantly prevailing.

Even though, health problems associated with resettlement are many and complicated, malaria infection is the most dominant and pressing (Kloos *et al.*, 1990). Malaria is the most prevalent disease in area where the altitudinal elevation is less than 2000m a.m.s.l (Kloos *et al.,* 1990). Such area covers more than three-fourth of the total area of Ethiopia. About 45% of the total population of Ethiopia lives in such areas. At the same time, it is also the leading epidemic disease in terms of morbidity and mortality. As a result, the environmental suitability analysis treated in this particular research mainly focuses on the prevalence of mosquito in relation to the suitability of a resettlement site.

Malaria occurs as an epidemic at altitudes, between 1700 and 2400m above m.s.l. There is also a seasonal transmission prevailing in the semi arid lowlands and continues transmission around lakes and swamps, along streams and in irrigation schemes (Kloos *et al.*, 1990). Based on the parameters set by Ministry of Health and other prominent researchers, suitability map of the study area was constructed in terms of malaria prevalence depending up on altitudinal factor.

Based on the prevalence of malaria risk the categories were further reclassified and standardized in to five suitability classes as highly suitable, moderately suitable, marginally suitable and not suitable Table 7.

Table 7: Malaria risk suitability classes

No	Suitability Class	Reclassified Value	Suitability Description	Area (Km)	%
1	< 1600	1	Not Suitable.	252.36	40
2	1600-1800	2	Marginally Suitable	251.30	40
3	1800-2000	3	Suitable	114.67	18
4	2000-2300	4	Moderately Suitable	8.73	2
5	>2300	5	Highly Suitable	0	

Accordingly, in the study area there are four malaria risk classes as indicated in Figure 16.

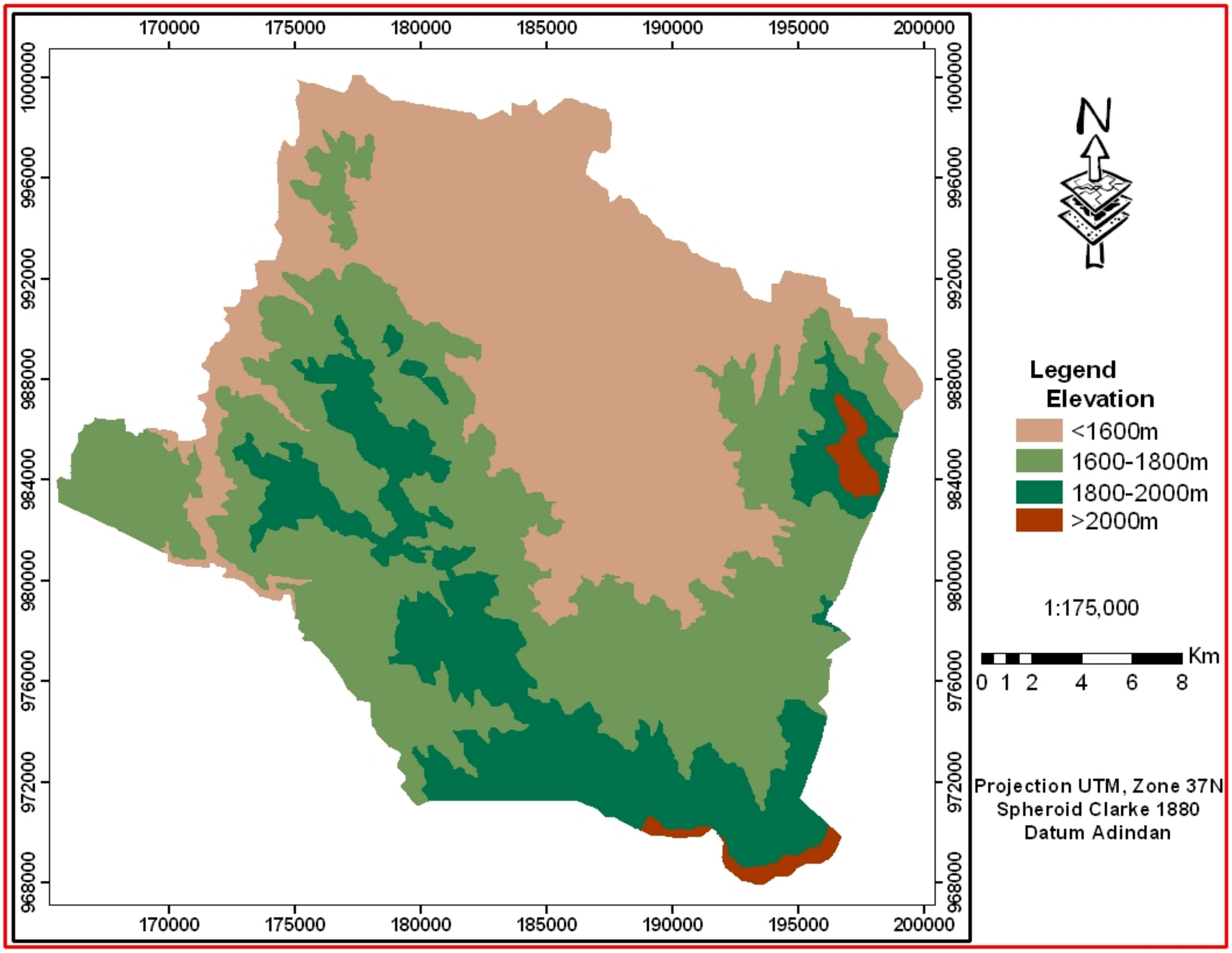

Figure 16: Malaria risk suitability map

3.3.2.2 Socio-economic Factors

3.3.2.2.1 Infrastructure

The infrastructural facilities required in the areas of human resettlement are many and diversified. Consideration of all these facilities at a time may be more complicated and time consuming. Due to this reason only the most important and basic ones (namely school, water facility, road network, and health centers) are thoroughly analyzed in this study.

Water is one of the most important components to be considered in the analysis of environmental suitability for human resettlement. Human society needs water for different purposes including for its daily consumption at home either for drinking and washing or for cattle. They also need it for agricultural purposes. Therefore the existence and distribution of water have to be given due considerations in the analysis of environmental suitability for human resettlement as one component of environmental factor.

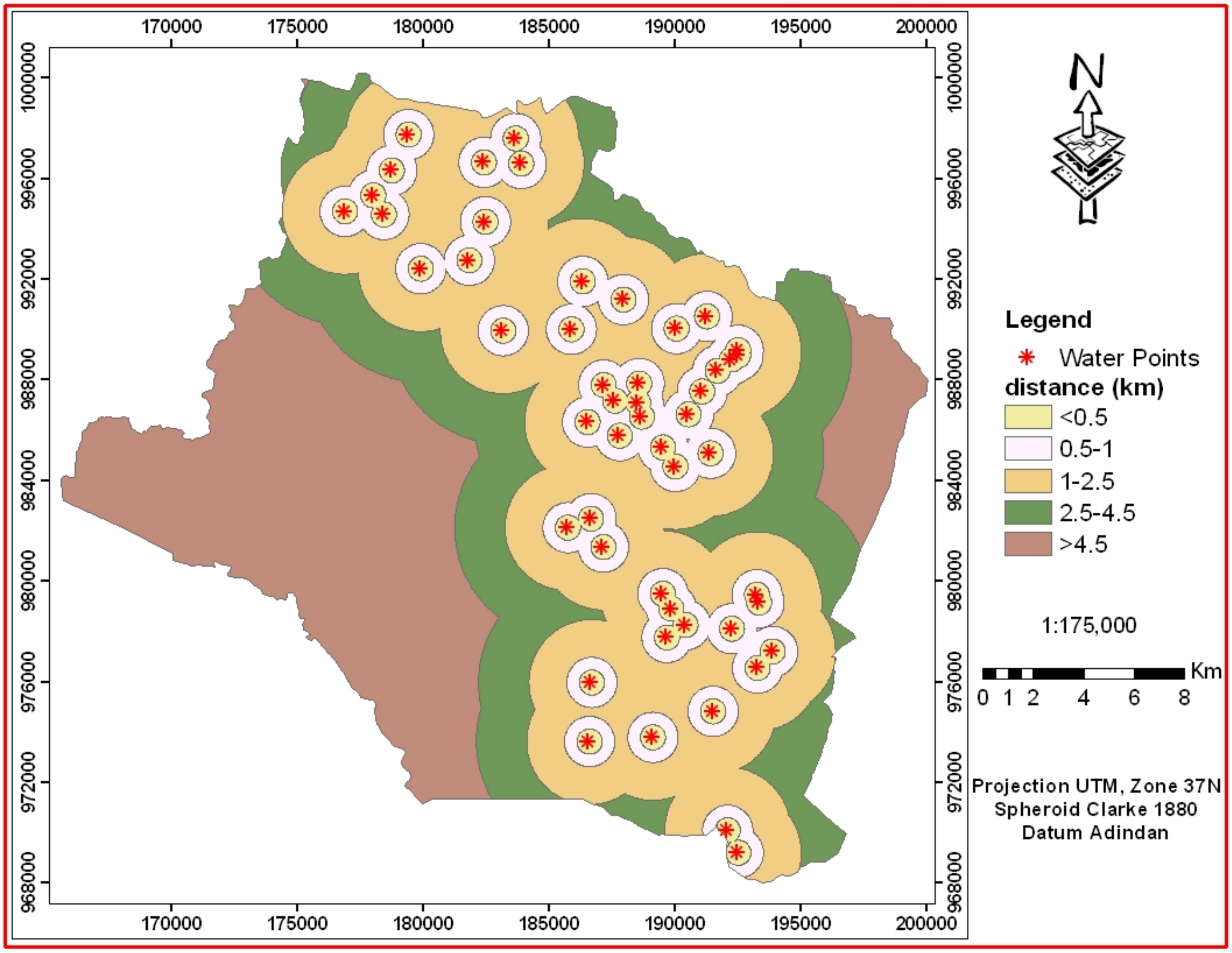

Figure 17: Water facility suitability map

There are fifty one water points within the boundary of the study area. Among these, 33 of them are pipe water while the remaining 18 are spring water. The analysis of environmental suitability in terms of water facility in the study area was based on the multiple rings buffering method of ArcGIS. The suitability map of water facility in the study area was constructed from the reclassified and standardized average distance around water point (Figure 17).

According to recent data obtained from the Educational and Health Bureau of Chawaka wereda and as the writer has observed there are six schools and two clinics within the boundary of the wereda. The suitability analysis for these two facilities (School and Health Center) was made using the multi ring buffering method using the accessibility criteria set after intensive discussion with the senior experts from the respective Bureaus of Education and Health.

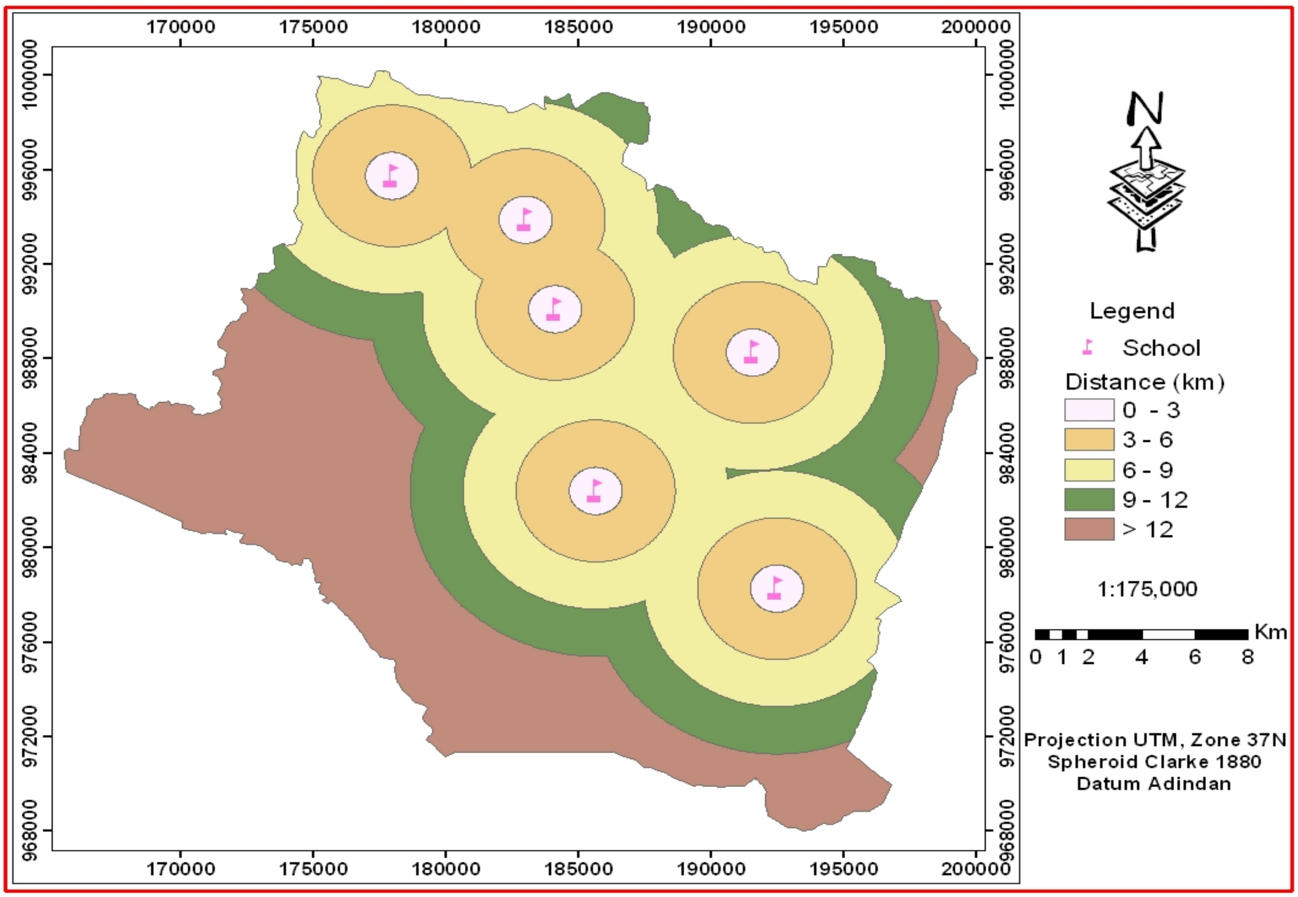

Figure 18: School accessibility suitability map

By using the spatial analyst tool of ArcGIS these distance categories were reclassified and standardized in to different levels of suitability as highly suitable, moderately suitable, marginally suitable, and currently not suitable based on their relative distance from the point of facility. Accordingly, distance of 3km, 6km, 9km, and 12km around each school were used as a standard for high, moderate, marginal, unsuitable classes, respectively, for school accessibility.

Similarly, a distance of 3km, 5km, 7km, and 10km were used as a standard for high, moderate, marginal, unsuitable classes, respectively, for health center facility. The Grouping was made based on the average distance around these two infrastructural facilities (Figure 19).

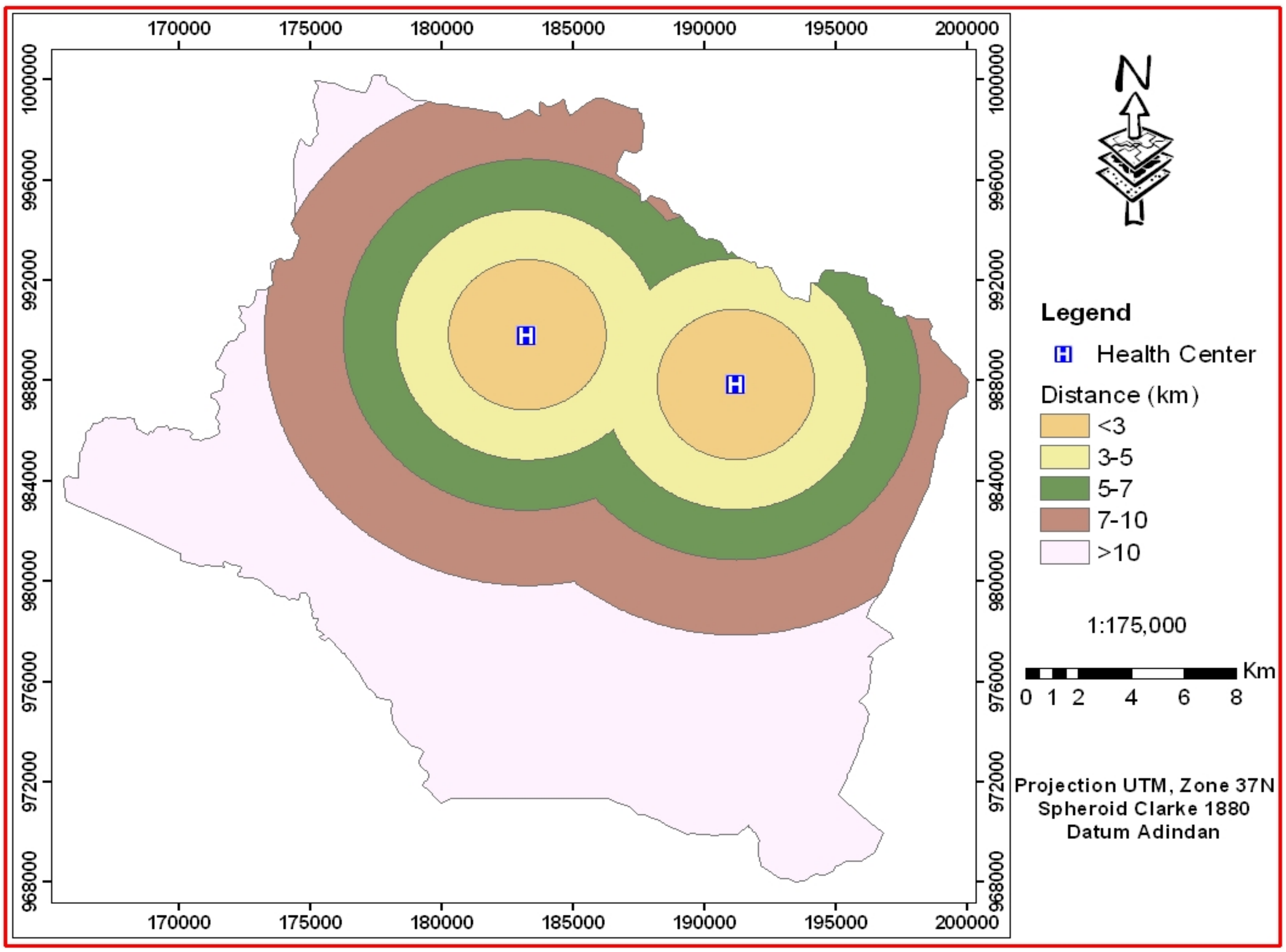

Figure 19: Health facility suitability map

The other most important component of infrastructural facility that can directly or indirectly determine the socio-economic suitability of a resettlement site is the road network. Road network plays a vital role in transporting agricultural inputs into country side and agricultural products into the nearby cities and towns for marketing. As a result, due consideration was given for road network as one component of infrastructural facility in mapping socio-economic environmental suitability factor of the area.

A multi ring buffer around the dry and all weather roads was made based on the suitable average distance for a farmer to get on the main road depending on the principle of the shorter distance from the road more suitable the area will be. These multi ring categories were reclassified and standardized to come up with road network suitability map (Figure 20).

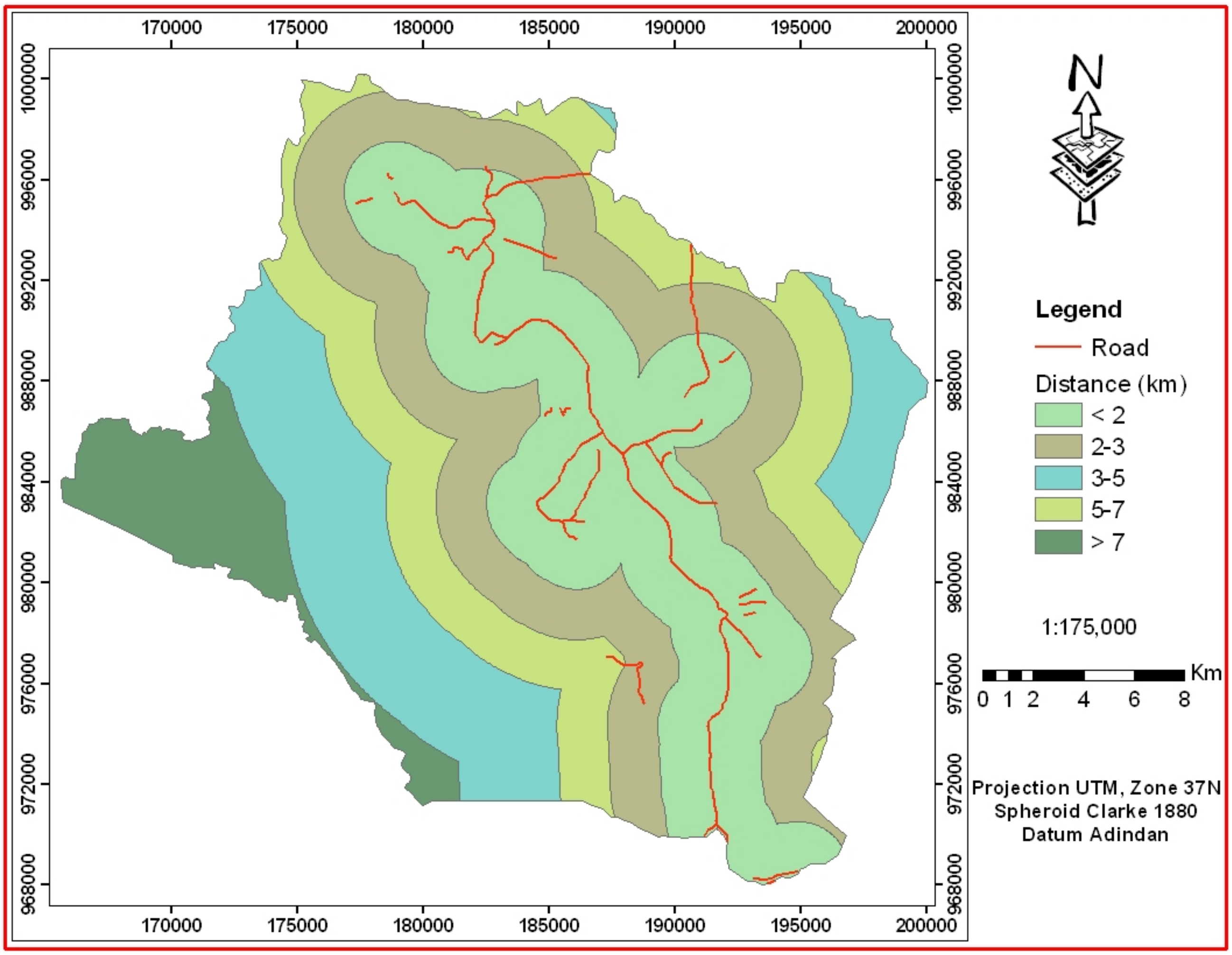

Figure 20: Dry and all-weather roads net work suitability map

3.3.2.2.2 Proximity and Accessibility

Proximity is always important in any geographic analysis. In a rural settlement farmers need to be at a very good location in order to acquire input for their farming activity and at the same time to put their products in to market. Therefore, it is very important to consider the proximity of a resettlement site in terms of its distance from the surrounding previously existing towns and cities.

In this study the proximity of the study area was evaluated by considering all the towns and cities that were found within the radius of 100km around the capital city of Chawaka wereda (Ilu Harer).

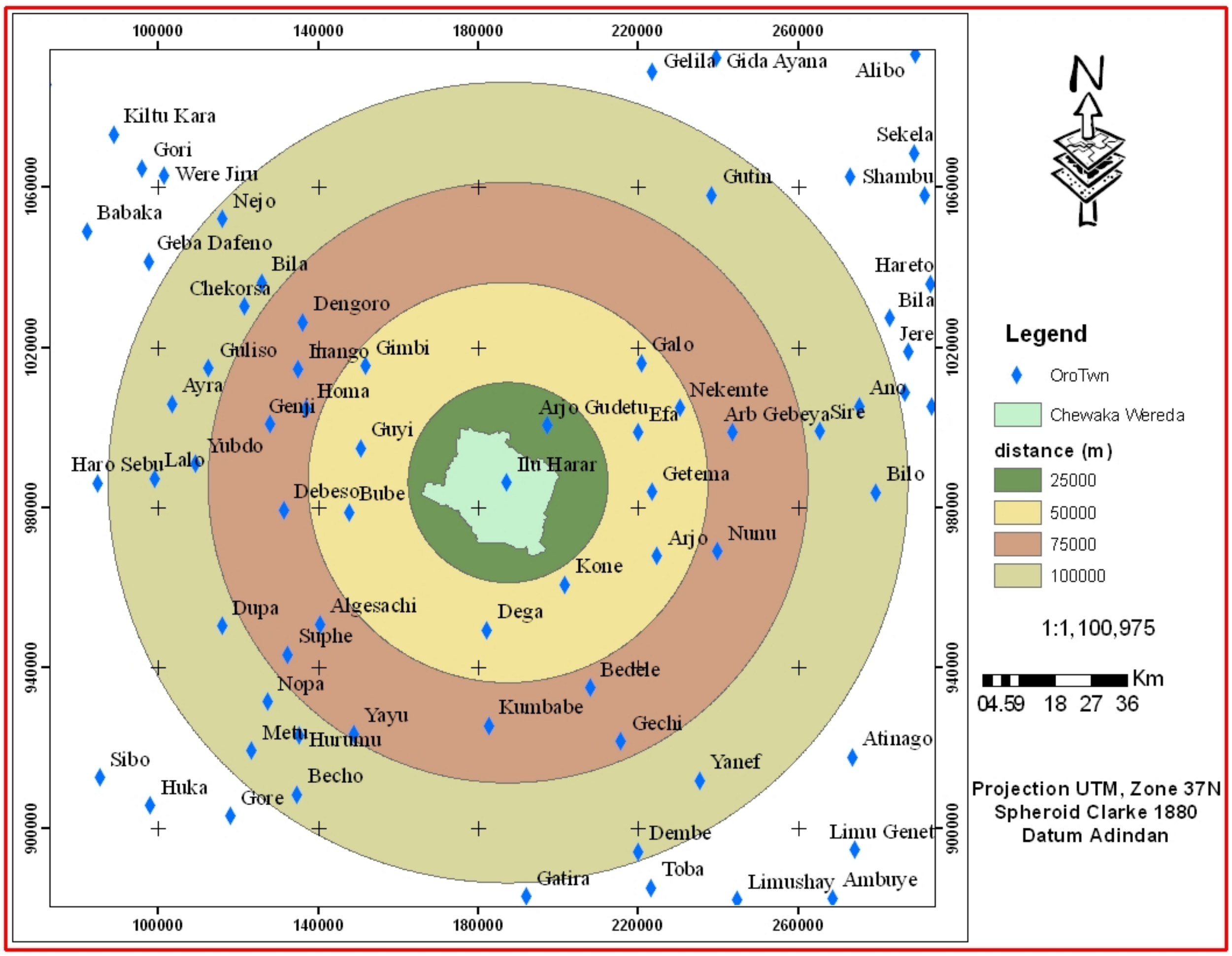

Figure 21: Suitability map of proximity and accessibility.

By making multi ring buffers at an interval of 25km, those areas that were found within the first ring were considered to be the most suitable. Similarly those that were found within the range of the next 25km consecutive buffer i.e 50km, 75km and 100km respectively were mapped as moderately suitable, marginally suitable and currently not suitable (Figure 21). indicates the suitability map of the study area in terms of proximity to the other cities and towns.

3.3.2.2.3 Population Density

For the sustainability of the natural environment the number of the resettled people located in a new resettlement site should commensurate with the pressure on the environment. Population size of resettlers should, therefore, be determined with great caution based on environmental carrying capacity for its sustainability. A the same time both the unplanned surges of people in to the resettlement site as well as the natural population growth must be taken into account in calculating population density. By keeping these two conditions at neutral rate, computation of population density can be made based on the ratio between total population and total area. However, the result of this computation will obviously be crude. As it has been indicated in the introductory section Chawaka wereda has a total land area of 627km^2. At the same time it is inhabited by a total number of 56,106 people (Table 8). Hence the crude density of the area is roughly 89.48 people per square km.

However in order to find the true suitability of the area in terms of man to land ratio it is important to avoid the error of crude density calculation. This is because in rural areas the livelihood of the society mainly comes from agriculture. As a result, population density should be evaluated in terms of either the arable land (potentially cultivable land) or cultivated land for each agricultural rural household.

As it can be understood from land use/land cover suitability class discussed in section 3.3.2.1.1 the majority of the area is covered by bush, shrub and grass land. Keeping the ecological issues aside these areas are potential places for the resettlers to expand in the future searching for farm land. This will particularly be true depending on the rate of population growth. However, it is difficult to predict the future situation at this early stage.

Table 8: Population Number and Density of each Kebeles in Urban and Rural areas

Kebele status	No	Kebele	Population Number				Population Density				
			Male	Female	Both Sex	HH	TA(km^2)	C. L	C D	AD	
										p/km^2	h/HH
Rural Kebele	1	Ada kebana	1204	1119	2323	465	13.35	2.79	174.02	166.38	0.60
	2	Baha Biftu	627	405	1032	206	35.20	5.54	29.31	37.28	2.67
	3	Biftu Ayana	951	502	1413	283	12.92	4.06	113.78	69.52	1.43
	4	Bonaya	454	429	883	177	24.45	2.44	36.87	72.39	1.39
	5	Burka Anani	1631	1438	3069	614	14.04	7.13	226.60	86.10	1.16
	6	Chafe Magartu	594	536	1118	224	9.62	5.19	122.62	43.12	2.32
	7	Chekorsa	1238	1179	2417	483	13.05	3.66	222.86	132.10	0.76
	8	Choman	681	668	1349	270	14.40	2.91	97.07	92.71	1.08
	9	Dabena	633	626	1259	252	17.32	4.88	74.84	51.65	1.94
	10	Damaksa	1174	1051	2225	445	50.96	6.93	44.09	64.18	1.56
	11	Dire Misoma	1745	1711	3456	691	13.02	8.30	276.11	83.25	1.20
	12	Duki	932	865	1797	359	35.86	6.49	50.25	55.39	1.81
	13	Dursitu Misoma	1924	1844	3768	754	12.91	8.10	303.63	92.99	1.07
	14	Gabina	522	507	1029	206	21.70	1.06	48.54	193.50	0.51
	15	Gudure	2110	2068	4178	836	9.89	6.30	422.48	132.69	0.75
	16	Haro Chewaka	1562	1443	3005	601	10.81	8.02	291.44	74.93	1.33
	17	Jiru Balina	1544	1319	2863	573	14.48	5.50	204.78	104.08	0.96
	18	Jogen	1751	1601	3352	670	11.75	8.38	297.90	80.00	1.25
	19	Kanani Janata	799	608	1407	281	33.35	2.43	42.83	115.63	0.86
	20	Mirgisa	679	637	1316	263	72.05	2.01	18.39	130.67	0.76
	21	Ourija Oromia	683	562	1245	249	15.39	7.26	83.61	34.30	2.92
	22	Sere Gudo	891	774	1665	333	19.89	6.25	85.89	53.24	1.88
	23	Shimala Toke	1697	1614	3311	662	10.82	6.70	320.73	98.81	1.01
	24	Tarkamfata Misoma	1785	1357	3142	628	9.43	6.21	333.21	101.16	0.99
	25	Tokkuma Harer	624	589	1213	243	81.68	5.07	14.94	47.89	2.09
	26	Walda Jalala	689	534	1223	245	48.65	8.52	25.14	28.71	3.48
Sub-Total			29124	25934	55058	11012	626.43	142.14	17.59	77.47	0.70
Urban	27	Ilu Harer	557	491	1048	210	0.57	------	368.42	-----	-----
Total			29681	26425	56,106	11222	627	142.14	89.48	-----	------

HH = House Hold, TA = Total Area, C = Cultivated Land, CD = Crude Density, AD = Agricultural Density

As a result population density was assessed on based on the ratio between the number of agricultural households and the total number of cultivated agricultural land in each kebele. Accordingly suitability of agricultural density is determined based on the current land-to-farmer suitability ratio indicated in Table 8.

This ratio is a density standard parameter set by the Ad hock Committee formed to execute the resettlement program in 2003. Based on this parameter an attempt was made to classify suitability of the study area. The resulting cluster of suitability were reclassified and standardized within ArcGIS environment to come up with population density suitability map (Figure 22).

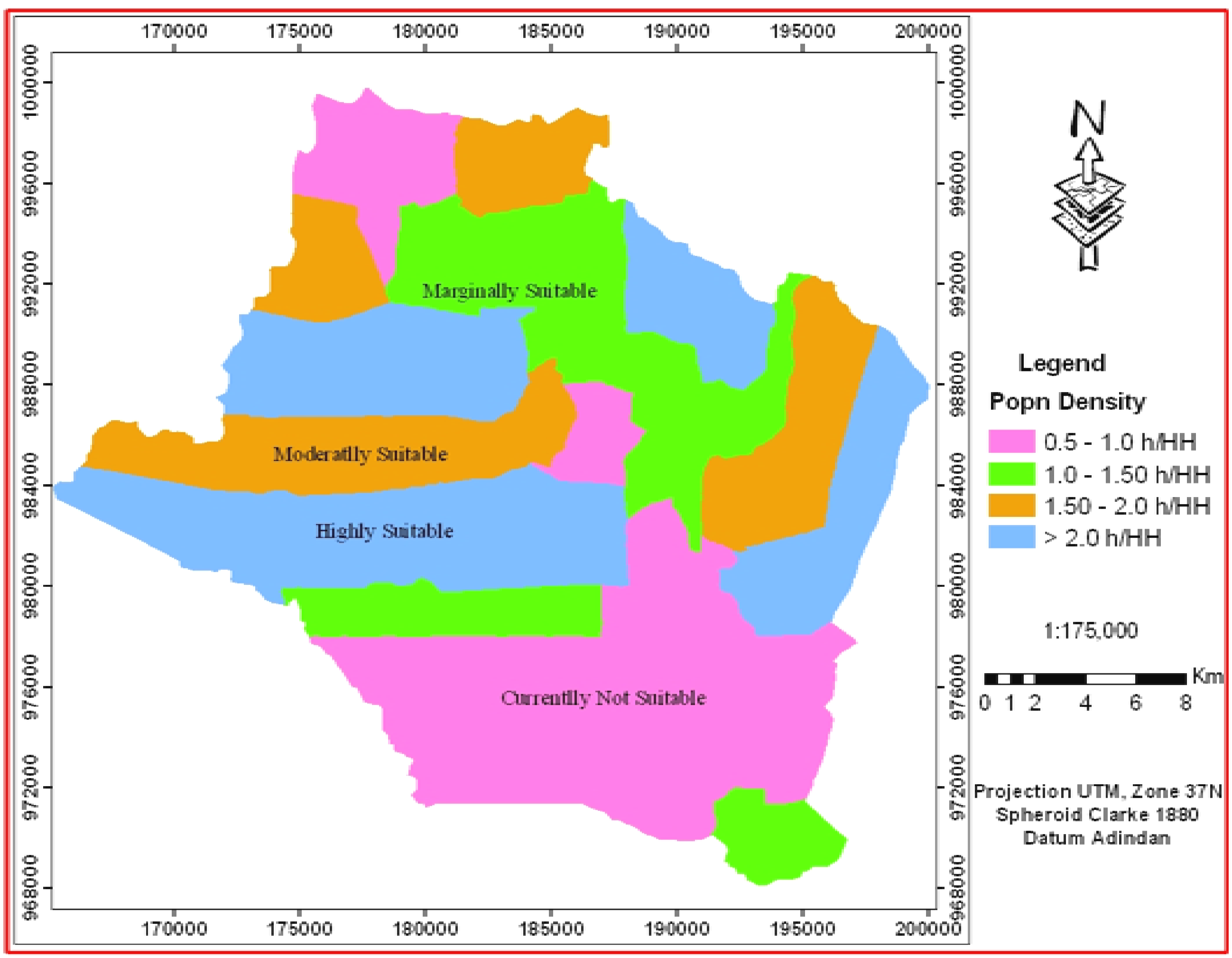

Figure 22: Suitability map agricultural density

3.4 Suitability Requirement of Resettlement Site

Successful implementation of a resettlement program in an area should have specific bio-physical and socio-economic requirements. Therefore, knowledge of basic environmental requirements is necessary for a sound suitability assessment. The selection of the environmental requirements for resettlement was made based on four criteria: 1) importance of the environmental component for the settlers; (2) existence of critical value in the study area in terms of environmental suitability; (3) practicability of environmental information; and (4) the availability of knowledge with which to evaluate the corresponding environmental quality. Accordingly, the following major bio-physical and socio-economic environmental requirements related to suitability conditions of Chawaka resettlement site was selected for characterization and evaluation.

3.4.1 Bio-physical Requirements

Among the bio-physical environment land use/land cover, climate, soil, slope and health aspect are considered. The amount of mean annual rain fall and the average annual temperature are the two major and most important elements of climate that are used in the analysis. The physical property of the soil such as, depth and texture, as well as the chemical properties like pH and organic matter content of the soil were used to characterize and evaluate the suitability of the soil in the study area. Similarly, the physiographic suitability of the study area was evaluated in terms of its slope and its elevation above mean sea level. Likewise, environmental suitability of the area for human health was analyzed in terms of malaria spread. Specific suitability requirement of each bio-physical environmental factor are indicated in Table 7.

3.4.2 Socio-economic Requirements

The socio-economic suitability of the study area was characterized and evaluated in terms three major components: Infrastructure, proximity and population density per arable land. Regarding infrastructure the network of all weather and dry weather roads as well as the accessibility of health centers, schools and water points were used in the analysis and suitability characterization of the study area.

On the other hand, a striate line distance around the city of Ilu Harer (the capital city of Chawaka wereda) was used as a reference for evaluation of proximity and accessibility.

Similarly, population density was also used to evaluate the suitability of the study area. In order to avoid the crude density error and to strengthen the accuracy of the suitability result, density calculation was based on the ratio between the farming households and the total area of arable land in the study area. The parameter used in the analysis of suitability in terms of population density was adopted from the criteria set by the ad hoc committee founded to implement the resettlement program. For the purpose of establishing a plate form for suitability analysis, standard set by various nationally and internationally recognized institutions like OWWDSE and FAO were used.

3.5 Factor/Criteria Rating

A compilation of the environmental requirements that were considered in the evaluation were made and factor rating for suitability of a resettlement site were decided. Factor ratings were sets of values which indicate how well each factor / criterion is satisfied by particular conditions of the corresponding environmental quality.

Rating of environmental factors was usually made in terms of five classes: highly suitable, moderately suitable, marginally suitable, currently not suitable, and permanently not suitable (FAO, 1985; 1993). In establishing a plate form for suitability criterion rating, references were made to the standard set by various nationally and internationally recognized institutions like OWWDSE and FAO.

In addition, review of previous scientific experimental research findings and literature on parameters were made to establish environmental suitability requirement table. Furthermore, reviews were consolidated through consultations and discussion with experienced experts and researchers from various disciplines that include Geographers, Environmental Scientist, Agronomist, Soil Scientists, Hydrologist, Sociologist, Demographers and Educational Planners on various environmental suitability issues considered in this study. The environmental suitability parameters used in this study are indicated in Table 9.

Table 9: Suitability requirements used in the analysis

S/N	Suitability parameter	S/N	Range of Suitability					
			Sub-elements	**Highly Suitable**	**Moderately Suitable**	**Marginally Suitable**	**Currently Not Suitable**	**Permanently Not Suitable**
1	LU/LC	1	Built up area	√				
		2	Cultivated		√			
		3	Grass land			√		
		4	Bush & shrub				√	
		5	Forest				√	
2	Climate	6	Rain Fall (mm)	1500-1800	1000-1500 & 1800-2000	500-1000 &>2000	100-500	<100
		7	Temperature	15 - 25°C	10 - 15°C	25 - 35°C	< 10°C	> 35°C
3	Soil	8	Depth (cm)	> 150	100 - 1500	50 - 100	25 – 50	< 25
		9	Texture	Si, SiC, C	Si CL	SiL, CL,SC	L, SCL	S, LS,SL
		10	pH	5.9-7.7	5.5-5.9 & 7.7-8.0	5.2-5.5 & 8.0-8.2	4.9-5.2&8.2-8.5	< 4.9 & > 8.5
		11	Organic Matter	> 3.00	2.5 - 3.00	1.75 - 2.5	1.00 - 1.75	< 1.00
4	Topography	12	Slope	2 - 8%	< 2 %	8 - 16%	16 - 30%	> 30%
		13	Elevation (m amsl)	2300-3200	1500 - 2300	1000 - 1500	< 1000	> 3200
5	Health Asp	14	Malaria Risk	>2000	1800-2000	1600-1800	<1600	---
6	Proximity	15	Proximity	< 25Km	25 - 50Km	50 - 75Km	75 - 100Km	> 100Km
7	Infras tructures	16	Road network	<2 Km	2-3 Km	3-5 Km	5-7 Km	>7 Km
		17	School	< 1Km	1 - 3Km	3 - 5Km	5 - 7 Km	> 7Km
		18	Health Centers	<3	3-5	5-7	7-10	>10
		19	Water Points	<0.5	0.5-1	1-2.5	2.5-5.5	>4.5
8	Population Density	20	Population Density	>2.0 h/HH	1.5-2.0 h/HH	1.0-1.5 h/HH	0.5-1.0 h/HH	<0.5h/HH

3.6 Criteria Standardization

In a GIS-based environmental suitability evaluation, there is a need to standardize the data in order to integrate the data measured in different units and mapped in different scale of measurement, such as nominal, ordinal, interval and ratio scales (Pereira *et al*, 1993). This process will eventually assure the positive correlation between factors of suitability mapping.

There are a number of approaches that can be applied to compare and standardize the attribute of all the map layers used in the analysis. Among these linear scale transformation is the most frequently used method particularly in GIS-based approach for criteria standardization (Malczewski, 2003). However, the reclassification method of spatial analyst tool with in ArcGIS environment is used in this study. This approach will enable all measurements to have an equivalent value before any weights were applied. Accordingly, all the factors used for this particular study are reclassified in to five classes with the values that range from 1 to 5, where the value of 5 was taken as the most suitable while that of 1 was the least suitable for all factors considered. However, it was important to note that there were some variables that did not fulfill the whole range of the criteria.

3.7 Assigning Criterion Weights

The purpose of weighting in environmental suitability analysis in human resettlement site is to express the importance of each suitability factor relative to the other variables. In the procedure for MCE, it is necessary that the weights sum to 1. Accordingly, IDIRISI, the software applied in this study for weighting the evaluation criteria, applies the pair wise comparison technique to help develop a set of factor weights that will sum to 1.0.

In a pair wise comparison matrix, two factors are compared at a time in terms of their importance related to the stated objective. Weights will finally develop after every possible pairs are compared with each other and the ratings are entered in to a pair wise comparison matrix or *ratio matrix* (Eastman, 2006). The system also calculates a consistency ratio to indicate any inconsistencies that may have been arisen during the pairwise comparison process. As the matrix is symmetrical, only the lower triangle actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangle. For this purpose discussion was held with experts and careful analysis of evaluation criteria was carried on and a pairwise comparison was made based on the result obtained from the EDRISI Andes System which allows repeated adjustments to the pairwise comparisons. It also reports the new weights and consistency ratio for each repetition.

Accordingly all the bio-physical and socio-economic suitability factors used in this study were exported in to the environment of EDRISI Andes GIS software for comparison purpose and eventually obtain their relative weight. Figure 23 reveals the AHP weight derivation interface applied to develop the weights for the bio-physical and socio-economic environmental suitability factors used in the analysis of environmental suitability for human resettlement.

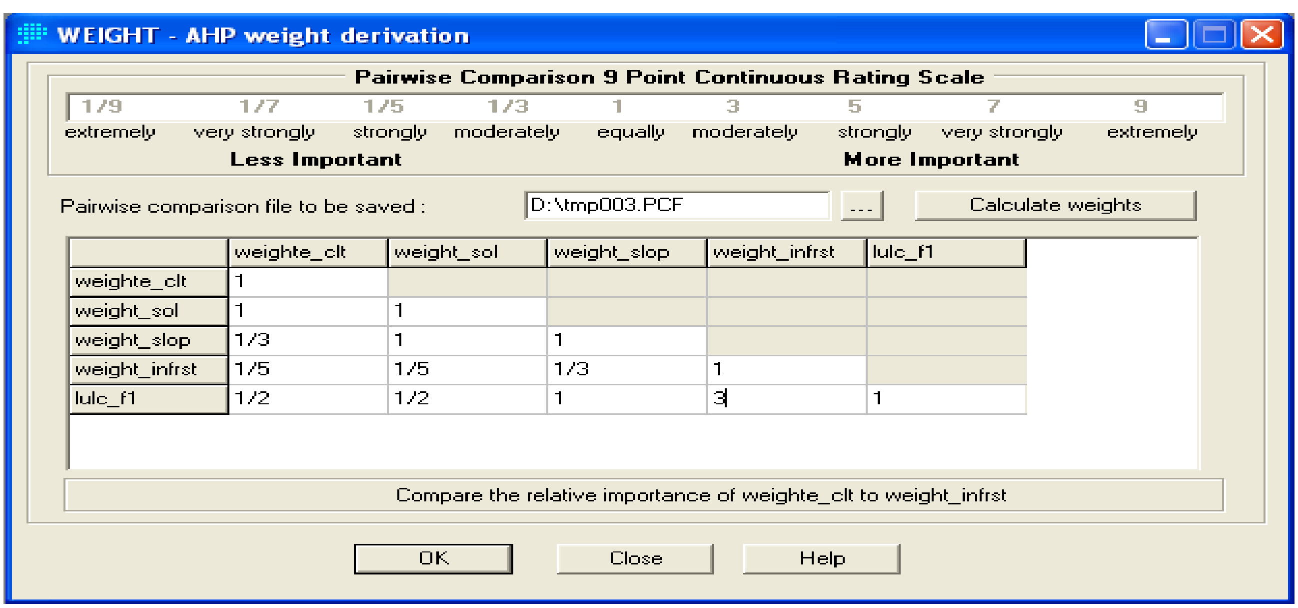

Figure 23: AHP Weight derivation method for environmental suitability parameters

Based on this AHP weight derivation module of EDRISI Andes, eigenvectors of weights for all environmental factors considered in this study were indicated in Table 10.

Table 10: Weights assigned for each of the suitability parameters

Factors Category	No	Sub-elements	Sub-weight	No	Major Variables	Weight	Weight (%)	Rank
Bio-physical Environment Factors	1	LU/LC	1.00	1	LU/LC	0.1369	14	3^{rd}
	2	Rain Fall	0.57	2	Climate	0.3089	31	1^{st}
	3	Temperature	0.43					
	4	Depth	0.27	3	Soil	0.2298	23	2^{nd}
	5	Texture	0.34					
	6	pH	0.25					
	7	Organic Matter	0.14					
	8	Slope	0.54	4	Topography	0.1240	12	4^{th}
	9	Elevation	0.46					
	10	Malaria Risk	1.00	5	Health Aspect	0. 0276	3	8^{th}
Socio-economic Environmental Factors	11	Proximity	1.00	6	Proximity	0. 0497	5	6^{th}
	12	School	0.12	7	Infrastructure	0.0885	9	5^{th}
	13	Road network	0.29					
	14	Health Centers	0.21					
	15	Water Facility	0.38					
	16	Population Density	1.00	8	Popn Density	0. 0346	3	7^{th}
Total						1.0000	100.00	
Consistency Ratio (CR) or Error						0.02		

3.8 Aggregating the Criterion Weights and the Standardized Criteria Maps

Apart from its capability to generate maps, one of the most important advantages of GIS is its capacity for integration and analysis of spatially referenced multisource datasets (Malczewski, 2003). These data are manipulated and analyzed to obtain information useful for a particular application such as environmental suitability analysis and sustainability prediction of a resettlement site.

Once the criteria maps (factors and constraints) are developed, an evaluation (or aggregation) stage is undertaken to combine the information from various factors and constraints. In the context of GIS, three decision rules i.e. Boolean overlay, weighted overlay and ordered weighted averaging are common for MCE (Jiang *et al.*, 2000; Malczewski, 2000; 2003). The simplest type of aggregation is the Boolean intersection or logical AND. This method is used only when factor maps have been strictly classified into Boolean suitable/unsuitable images with values 1 and 0. The evaluation is simply the multiplication of all the images. The present study, however, adopts both the weighted and vector overlay analysis technique for developing environmental suitability maps for each environmental factor and for the overall suitability map as well.

4. Results and Discussion

4.1 Environmental Suitability of Chawaka Resettlement Site

As described in the previous chapter, a weight has been given for all individual suitability parameters considered in this study based on their relative importance by comparing one factor against the other. Accordingly, the outcome of the weighted overlay analysis for each suitability factors are presented as follow.

4.1.1 Bio-Physical Suitability

4.1.1.1 Climatic Suitability

The individual analysis of temperature and rainfall as major components of climatic factors reveals that 48% and 33% the total area of the wereda has highly suitable temperature and rainfall conditions, respectively. Furthermore, 52% and 34% of the area has a moderately suitable temperature and rainfall condition, respectively. The remaining 33% of the area falls within marginal suitability class of rainfall condition.

The weighted overly analysis of the climatic factor indicates that 34% of the total area of the wereda has highly suitable climatic, while the remaining 66% of the area has moderately suitable climatic conditions. The major reason for the area to have most of its portion in moderate suitability is due to low topographic elevation dominated by plane and gently sloping land that affects to the extent of regulating its temperature. Climatic suitability was scaled based on rainfall and temperature requirement for most of the crops that dominantly grow in the area (Figure 24A).

4.1.1.2 Topographic Suitability

Result of independent analysis of the topographic factors, indicate that the area has slope in all the five suitability classes. Accordingly 20%, 19.97%, and 19.95%, of the study area has high, moderate, and marginally suitable slope respectively.

While the remaining 40% of the area is found to have unsuitable slope either currently or permanently.

Having 479.04km^2 (76%) of its total area between 1500 and 2300m a.m.s.l, the study area falls within a *Weyna Dega* agro-climatic condition in termsof its elevation. This category of agro-climatic zone is moderately suitable for human resettlement. Having an altitudinal range of 1000m to 1500m a.m.s.l the remaining 148.04km^2 (24%) of the area falls within *Kola* agro-climatic zone. This is suitable only marginally for human resettlement due to its scarce rainfall and relatively high temperature as well as rate of evapo-transpiration.

By putting these two variables together the topographic suitability was made. Accordingly, the general weighted topographic analysis of the area indicates that 60% of the study area is moderately suitable and the remaining 40% is only marginally suitable (Figure 24B).

4.1.1.3 Soil Suitability

The largest percentage (80%) of the soil has a suitable depth. More specifically 11% of the soil has highly suitable soil depth, while 40% is moderately suitable and the remaining 29% has marginally suitable depth. However, about 20% of the area has a soil depth which is not suitable either currently or permanently.

Regarding the texture of the soil, all parts of the area are suitable by having 16%, 43% and 41% of high, moderate and marginally suitability level. Similarly, the largest part of the area has suitable soil in terms of both Organic matter content and pH measures. Accordingly about 80% of the soil contains a suitable organic matter for adequate crop production. Except 11% of the area almost all the soil of the wereda has a pH value that is suitable for human resettlement at various degrees.

Each of these soil suitability determinant factors discussed are compared with each other and weighted according to their relative importance for crop production of the resettlers. The weighted analysis of soil suitability factors reveal that no part of the study area falls within high suitability soil class. However, the largest proportion (80%) of the area has a moderately suitable soil. The remaining 19% has a marginally suitable soil. This indicates that almost all types of soil within the boundary of the study area are suitable even though there is some variation of suitability, for human resettlement (Figure 24C).

4.1.1.4 Suitability in terms of Health

No part of the area is completely free from malaria incidence. As can be seen from the malaria risk map (figure 10), about 80% of the study area has high risk of malaria incidence while the remaining 20% is only safe with great care.

4.1.2 Socio-economic Suitability

4.1.2.1 Infrastructural Suitability

The weighted overlay analysis of these infrastructural factors indicates that large part (63%) of the area is suitable for human resettlement under various degrees. However, under the currently existing infrastructural facility the remaining 37% of the study area is not suitable (Figure 24D). This is because they lack either one or more of the basic elements of infrastructural facilities that determine the suitability of the site for human resettlement.

4.1.2.2 Suitability in terms of proximity

As it can be observed from Figure 21, that there are only two towns that are found within a radius of 25km from the town of Ilu Harer. The average distance to any town within a radius of 100km from this town is about 67km. Even though, this number looks smaller it can be considered as far distance under the currently existing relatively poor road network and insufficient transportation and means of communication.

Based on this fact and principle, an attempt was made to categorize the area in to different suitability classes. Accordingly, the wereda falls within marginal suitability class. This is because the people at any corner in the study area accesses the other towns in the surrounding area after an average distance of 67km.

4.1.2.3 Suitability in terms of Population Density

Only four percent of the farmers are holding two or more hectares of agricultural land, which is in high suitability class. The largest proportions of the farmers, however, own a plot of land, which is less than two hectares per household that is mapped as either moderate or marginally suitable.

The overall suitability level of the entire bio-physical and socio-economic environmental suitability factors used in this study are summarized in Table 10 in terms of their areal coverage and percentage. As it can be observed from this table almost all bio-physical environmental factors, except health aspect and land use/land cover, are suitable for human resettlement under different degree of suitability. However, unlike bio-physical factors, all socio-economic variables except proximity have even distribution of suitability level. More specifically 34% of the study area has a highly suitable climatic condition. The remaining 66% of the area that covers about 414.7km^2 of the area is moderately suitable for human resettlement.

On the other hand, the soil and the topography of the study area is moderately and marginally suitable. About 80% of the soil and 60% of the topography are moderately suitable. At the same time 40% and about 20% of topography and soil respectively are marginally suitable.

In terms of land use/land cover only less than 1% of the total area is highly suitable. Being covered by dense forest, bush and shrub land more than 60% of the area is currently not suitable. However due to the absence of water body no part of the area is permanently not suitable for human resettlement.

Table 11: The Suitability level and areal extent of each environmental factor

Major Factors	Sub-Factors	Suitability Level									
		Suitable						Not Suitable			
		High		Moderate		Marginal		Currently		Permanently	
		Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
Bio-physical	Climate	210.66	33.69	414.70	66.31	---	---	---	---	---	---
	Topography	---	---	251.96	59.77	374.39	40.23	---	---	---	---
	Soil	---	---	504.38	80.44	122.69	19.56	----	---	---	---
	LU/LC	0.50	0.09	142.14	22.40	92.26	14.71	393.79	62.8	---	---
	Health aspect	---	---	8.73	2	114.67	18	251.30	40	252.36	40
Socio-economic	Infrastructure	29.38	4.68	173.64	27.69	191.88	30.60	132.14	21.07	100.04	15.96
	Proximity	----	---	---	---	627	100	---	---	---	---
	Popn Density	28.06	4.47	425.61	67.88	172.83	27.56	0.50	0.09	---	---

Less than 5% of the area has adequate infrastructural facility that enabled this part to be highly suitable. In contrary of this, about 16% of the area is permanently not suitable for human settlement even if all the necessary infrastructural facilities are developed. This is may be due to ragged topography that highly magnifies the cost of living. Generally, the standardized suitability maps of the most important bio-physical and socio-economic environmental factors are indicated in Figure 24 (A – D).

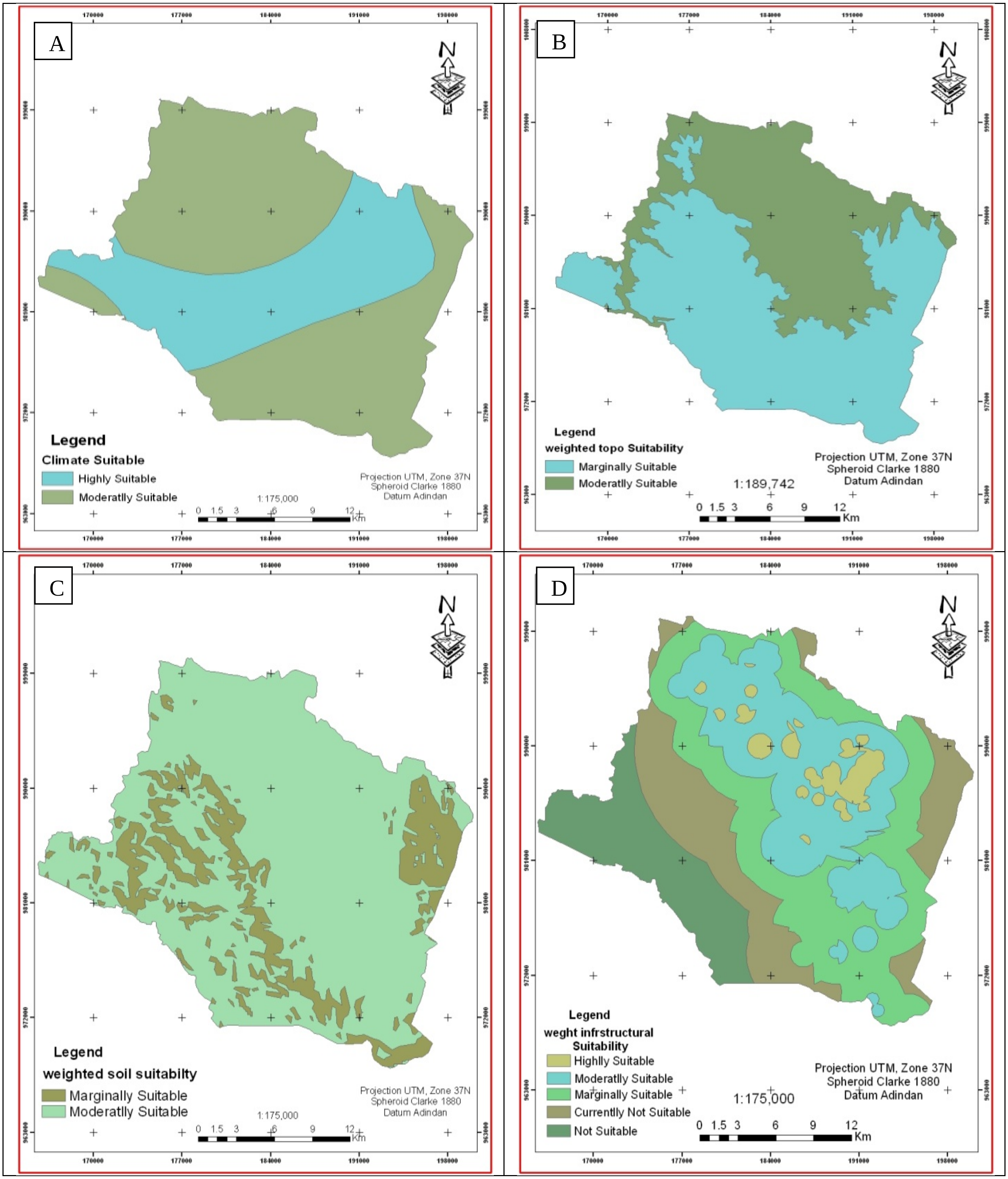

Figure 24: Standardized Suitability Maps of Environmental Factors; A: Climatic Suitability, B: Topographic Suitability, C: Soil Suitability, D: Infrastructural Suitability

Each of the above discussed environmental suitability parameters are compared against each other, weighted and overlaid based on their relative importance for the purpose of human resettlement. As it can be observed from table 9 that bio-physical suitability factors takes the first four ranks. Accordingly, climate, soil, lands use/land cover, and topography respectively ranks from first to fourth by scoring 32%, 23%, 14% and 12% of the weight. From socio-economic variables infrastructural suitability takes the fifth position by taking 9% of the weight. The other variables such as proximity, population density and health aspect takes the remaining 16% of the weight.

The overall weighted overlay environmental suitability analysis of the study area revealed that the more than half 412.20km^2 (66%) of the study area is moderately suitable for human resettlement. Having an area of 202.12km^2 about one third (32%) of the wereda is only marginally suitable. However, only 2% of the area has highly suitable environmental condition (Table 12).

Table 12: The overall suitability level and their areal extent

Suitability	Area (Km^2)	Percentage (%)
Highly Suitable	12.68	2.02
Moderately Suitable	412.20	65.66
Marginally Suitable	202.12	32.32
Total	627.00	100.00

The area mapped as highly suitable environment is where the bio-physical and socio-economic conditions meets all the highest suitability requirements for human resettlement. Compared to the other areas infrastructural facilities are sufficiently there to counterbalance the other unsuitable conditions. For instance the existence of health facility helps to withstand unsuitable health condition. Similarly the existence of good road network facilitates environmental suitability of the area.

Those areas mapped as moderately suitable are having all the necessary requirements. However, they are found where there are minor limitations. For instance, they are found in low land areas where the temperature is slightly higher.

Similarly marginally suitable areas found relatively in higher topographic areas where the soil, climate, land use/land cover are suitable only marginally. At the same time they are marginal areas where infrastructural facilities are not easily inaccessible. The overall suitability map of the study area is indicated in figure 24.

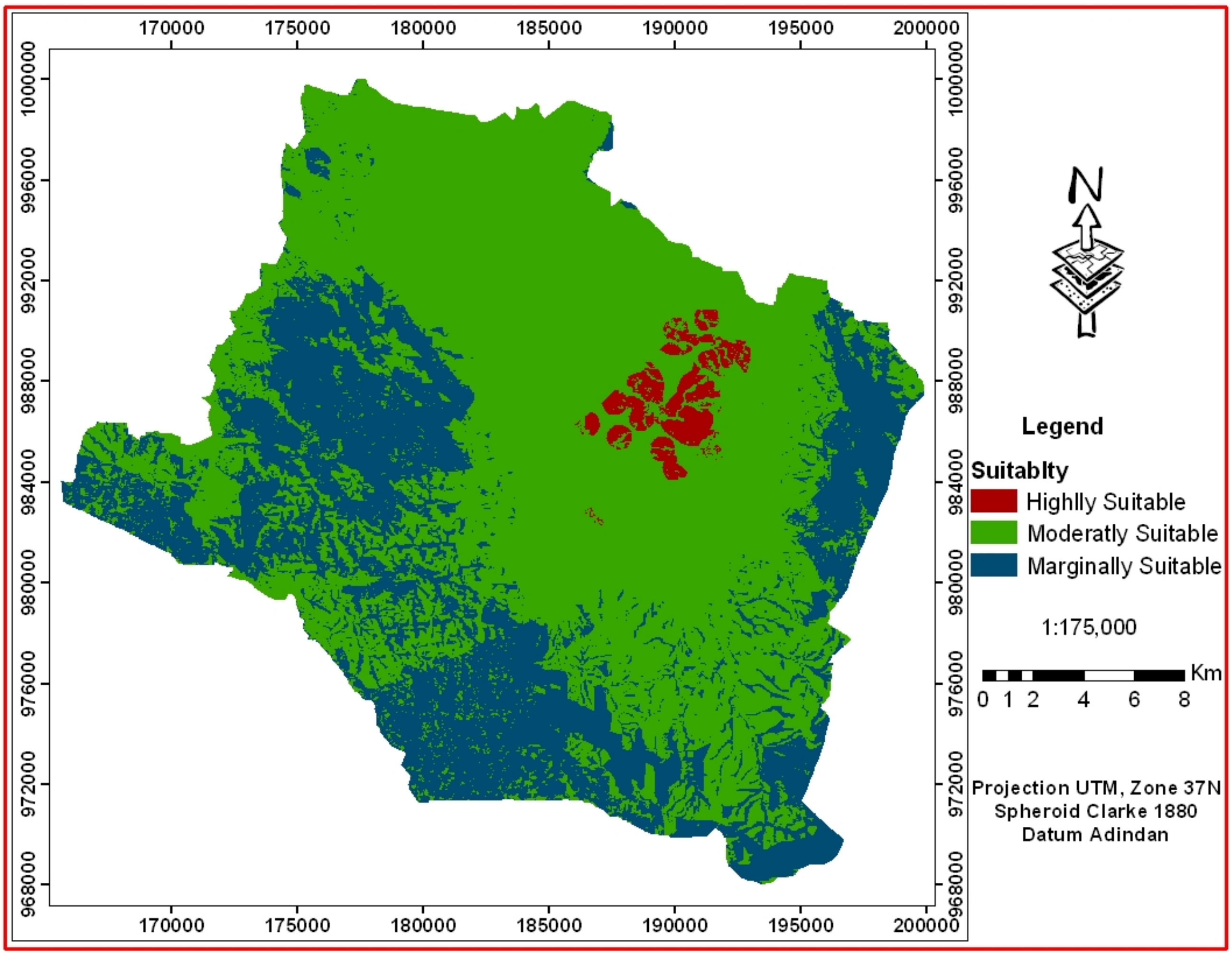

Figure 25: Environmental suitability map of Chewaka

5. Conclusion and Recommendations

5.1 Conclusion

Environment is one of the issues composed of the interaction of complicated variables. It is difficult to consider only one variable separately for the analysis of its suitability for human resettlement. This is particularly because they are naturally interwoven in a complicated system. Paradoxically, it is equally difficult to evaluate all environmental factors at a time. However, GIS and remote sensing is an ideal platform that provides adequate facilities for the systematic integration and due consideration of the most important environmental factors. For this purpose, environmental suitability of Chawaka resettlement site has been analyzed in this study in terms of bio-physical and socio-economic environmental factors.

Some of the bio-physical factors look inevitable in the analysis of environmental suitability for human resettlement. They have a crucial role to play in determining the suitability of the resettlement site. These include climate, soil, topography, land use/land cover and the prevalence of malaria. The individual analysis of these factors indicated that 210.66km^2 (34%) of the study area has highly suitable climatic condition. This is slightly more than one third of the total area. The remaining large proportion (66%) has a moderate climatic condition. The area has marginal to moderately suitable soil and topographic set up. In terms of land use/land cover, the largest proportion of the study area is currently not suitable for human settlement. This is due to the fact that the majority of the area is currently covered with dense forest and bush as well as shrub which are not recommended for settlement.

In terms of health aspect only one fifth of the total area is suitable for human resettlement. The remaining largest proportion is currently not suitable. This is mainly because about 80% of the study area is found to be conducive for the prevalence of malaria which is a potential threat for human health. Generally, only climate and land use/land cover from bio-physical factors have classes within high suitability category. Almost all bio-physical factors, except land use/land cover and health aspect, have no plot of land within unsuitable category. It is possible to conclude that the area has a moderate and marginal level of suitability for most of the bio-physical parameters.

Factors like proximity and accessibility, infrastructural facility, population density are some of the most important socio-economic factors that are unavoidable in the analysis of environmental suitability for human resettlement. In terms of proximity and accessibility only two towns are found within the radius of the first 25 km around Ilu Harer.

With reference to the density of population the largest proportion of the area falls within moderate and marginal suitability classes. This implies that most of the farming households own an arable land which is less than two hectares. Unless a wise environmentally friendly remedial measure is urgently taken the recurrent cultivation of the same plot of land will eventually leads to environmental degradation of these areas. People will also be forced to expand in to nearby forested areas, the consequence of which will obviously be the disruption of the ecosystem.

Compared to the other socio-economic factors, the study area has good distribution of suitability levels. However, it is important to note that still large proportion of the area has moderate and marginal suitability in terms of infrastructural facility. This implies that there is an urgent need for all stakeholders to work together to expand the basic infrastructural facilities. For instance, since the largest proportion of the area falls within high risk of malaria, incidence the number of health facility needs to be increased.

All parts of the study area falls within three categories of environmental suitability classes and nowhere within the boundary of the wereda is unsuitable for human resettlement. More than 65% of the area has an environment which is moderately suitable for human resettlement. Having 200km^2 out of the total 627km^2, about one third (32%) of the study area has an aggregated environmental condition, which is marginally suitable for human resettlement. Only the remaining small proportion (2%) of the area has high environmental suitability condition that adequately satisfies all the major and most important suitability requirements of human resettlement.

5.2 Recommendations

- Being unsettled for a certain land does not guaranty its environmental suitability and sustainability for a resettlement site. Apart from the virginity of a land, other environmental factors like climate, soil, slope, geology, accessibility, infrastructural development and other socio economic factors has to be considered in evaluating the suitability of resettlement site. Therefore before planning and implementing any resettlement program environmental suitability, ecological carrying capacity and sustainability of the area has to be analyzed thoroughly.
- To avoid the allocation of unsuitable areas for resettlement and to overcome the misuse and degradation of the land and other natural resources, environmental suitability of new resettlement sites has to be identified by well-trained and qualified experts applying GIS and remote sensing techniques.
- Expand the basic and most important infrastructural and socio-economic facilities throughout the wereda and assuring their even distribution.
- For maintaining the sustainability of the environmental suitability it is important to relocate the people who settled in marginally suitable areas in to moderate and high suitability areas based on the carrying capacity.
- Strengthen community-based environmental resource protection practices in the resettlement sites through efficient land registration systems and creating community awareness. Providing an alternative energy source, like rural electrification for the settlers so that natural forest clearance for fire wood can be minimized.

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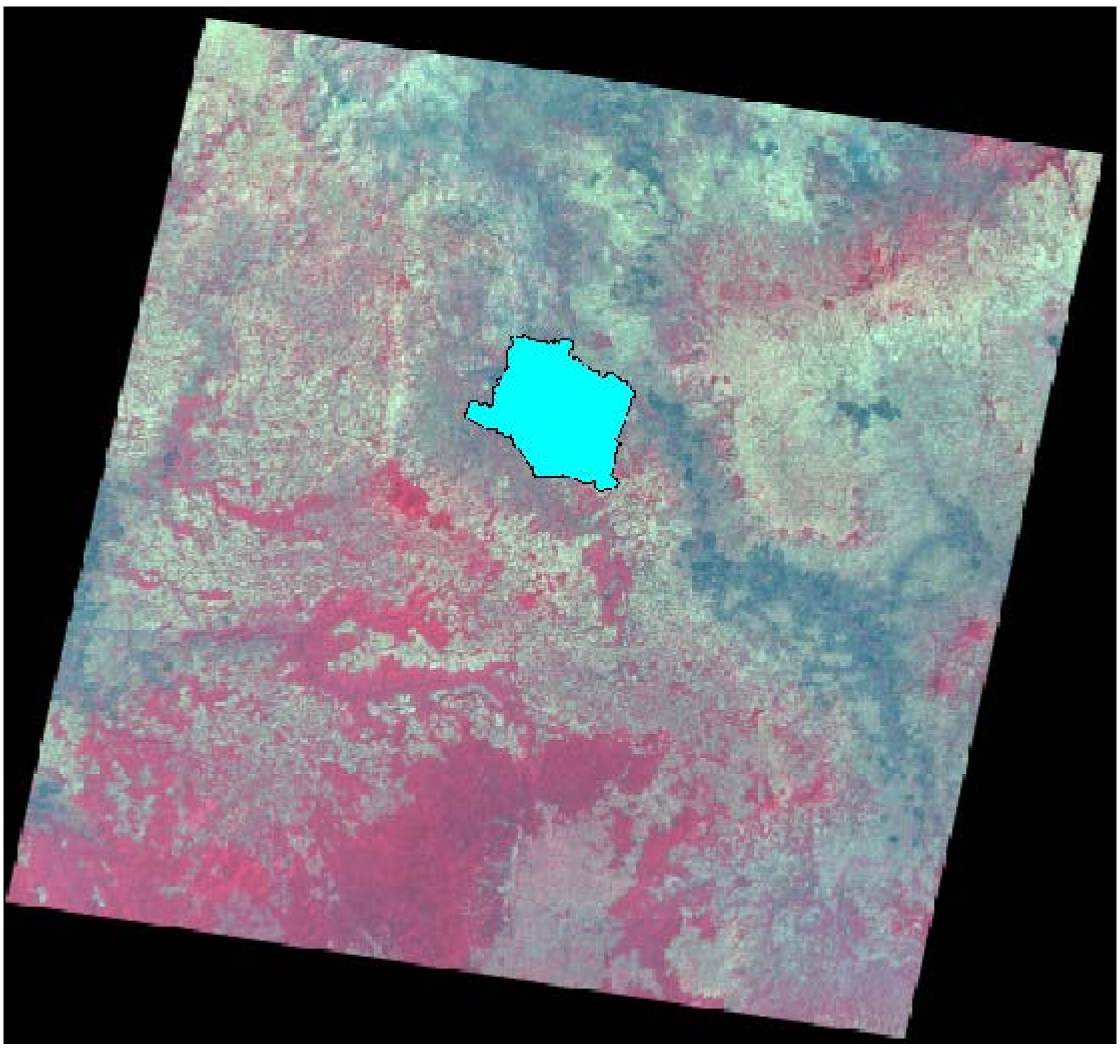
Annex 1

Table 13: The average annual rainfall during the last 41 Years (1969 – 2009 GC) in mm

Year	Arjo	Bedelle	Dhidhessa	Gimbi	Nakamte	Annual Average
1969	1806	1954	1579	1544	2050	1787
1970	2172	1891	1612	1550	2064	1858
1971	2255	2017	1545	1543	2054	1883
1972	2224	1954	1679	1539	2033	1886
1973	2860	2079	1426	1547	2074	1997
1974	2631	1829	1612	1531	2085	1938
1975	1804	2348	1566	1562	2044	1865
1976	1756	1805	1367	1584	2127	1728
1977	2694	2272	1345	1499	1960	1954
1978	2104	2028	1424	1500	2155	1842
1979	1731	1898	1278	1541	1836	1657
1980	1813	1945	1342	1458	1960	1704
1981	1270	1719	1336	1541	2038	1581
1982	1871	1949	1345	1559	1777	1700
1983	1700	2340	1992	1628	1988	1930
1984	1663	1682	1286	1490	1650	1554
1985	1815	1792	1695	1584	1923	1762
1986	1706	1420	1283	1522	1576	1501
1987	1825	1971	1691	1830	2026	1868
1988	2110	2135	2097	1980	1741	2013
1989	1855	1683	1872	2097	1928	1887
1990	1635	1710	1216	1709	1890	1632
1991	1600	1837	1251	1574	2035	1660
1992	2001	1880	1178	2049	2479	1918
1993	1899	1844	1382	1757	2518	1880
1994	1654	1550	1410	1624	2090	1666
1995	1339	1825	1031	1376	2072	1528
1996	1807	1727	1936	1576	2321	1873
1997	1933	1998	1379	1857	2190	1872
1998	1668	2005	1717	1837	2551	1956
1999	1884	2291	1494	1981	1929	1916
2000	1930	1847	1842	2029	2172	1964
2001	1873	2184	1292	1604	1942	1779
2002	1354	1406	865	1651	1706	1396
2003	1781	1458	533	1946	1838	1511

2004	2361	1876	1470	1873	1792	1874
2005	2143	2180	1549	1847	2249	1994
2006	2085	1900	1653	2191	2139	1994
2007	2196	1988	2263	1741	2163	2070
2008	2141	2000	1822	2114	2441	2104
2009	2169	1957	1913	2015	1897	1990

Annex 2. Row satellite Image used for Environmental Suitability Analysis: Landsat ETM+, the path and row is 170 & 054 taken at January 2005



Annex 3. GPS readings recorded for representative land use/land cover categories

Waypoints	UTM Coordinate		Land use/land cover category
	Easting (X)	Northing (Y)	
486	183453	995752	Grass land
542	191342	972408	Grass land
057	191804	970596	Grass land
351	187209	985906	Built up Area
312	186976	986623	Built up Area
320	187370	986222	Built up Area
322	187199	986248	Built up Area
334	187011	986275	Built up Area
360	185924	989670	Dense Forest
362	191378	971200	Dense Forest
362	192394	969679	Dense Forest
354	186226	987061	Dense Forest
245	184445	990345	Bush and Shrub
256	192188	976038	Bush and Shrub
012	185650	990299	Cultivated Agricultural land
021	186653	188824	Cultivated Agricultural land
032	186954	986043	Cultivated Agricultural land
079	184786	983354	Cultivated Agricultural land
202	182531	994911	Cultivated Agricultural land
212	191946	977559	Cultivated Agricultural land

Annex 4. Partial view of different land use/land cover in the study area: A=resettled and built up area, B, C, and D are cultivated areas, E= bush and Shrub land, and F= Grass Land (Photographs taken during field work)