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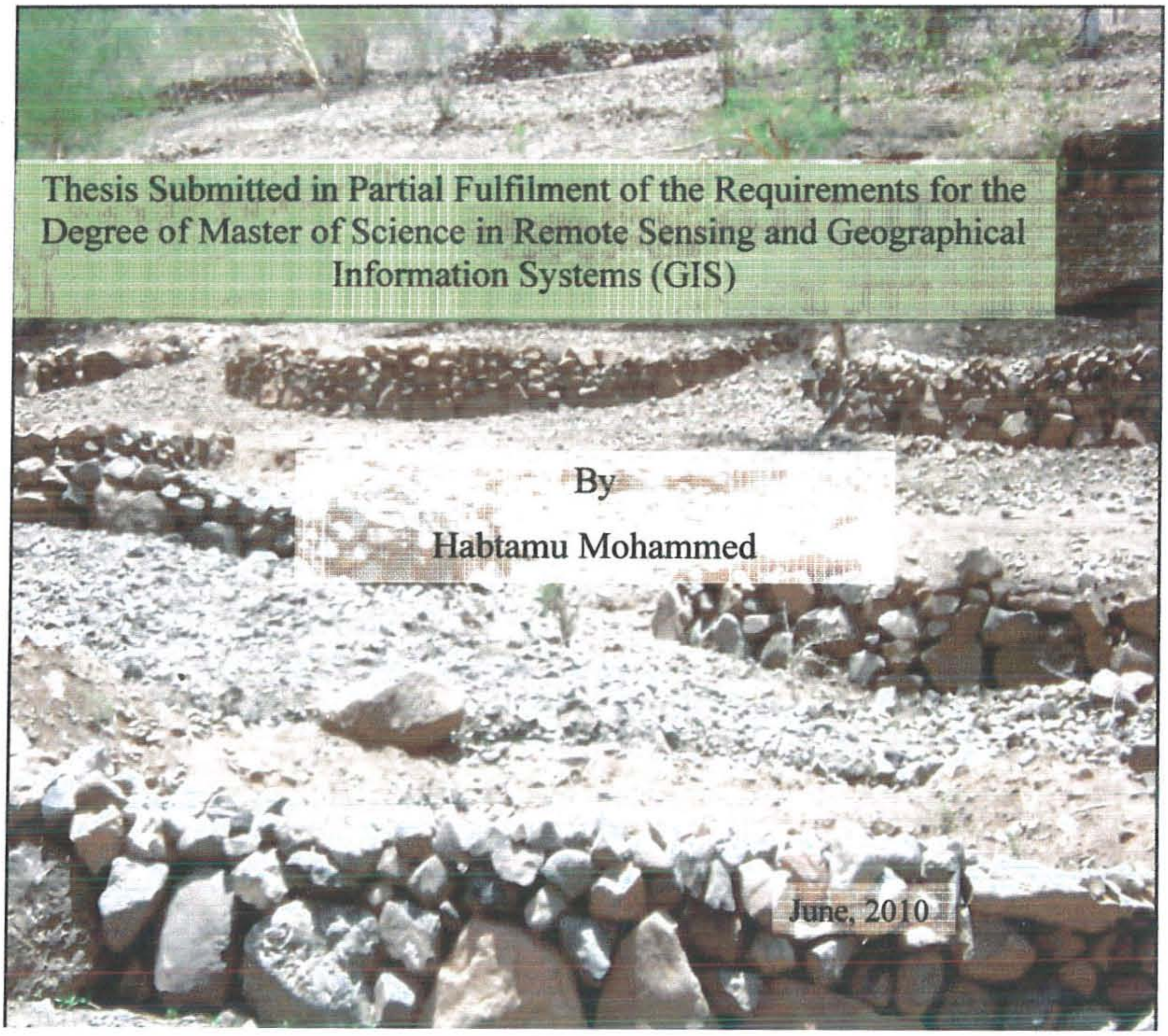
LANDUSE/COVER DYNAMICS AND SELECTION OF SUITABLE SITE FOR WATER HARVESTING STRUCTURE: THE CASE OF ZIQUALA WATERSHED, WAG HIMRA ZONE



Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Remote Sensing and Geographical Information Systems (GIS)

By

Habtamu Mohammed

June, 2010

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Under the Guidance of

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Acronyms

GIS -	Geographical Information Systems
RS -	Remote Sensing
ZWARDO -	Ziquala Woreda Agricultural and Rural Development Office
WFEDO -	Woreda Finance and Economic Development Office
ETM+ -	Enhanced Thematic Mapper Plus
TM -	Thematic Mapper
FCC -	False Colour Composite
MoA -	Ministry of Agriculture
MoWR -	Ministry of Water Resources
NGOs -	Non-Governmental Organizations
GO -	Governmental Organization
UTM -	Universal Transverse Mercator
MCE -	Multi-criteria Evaluation
SDSS -	Spatial Decision Support System
ERDAS -	Earth Resources Data Analysis System
ENVI -	Environment for Visualizing Images
WHSs -	Water Harvesting Structures
SWC -	Soil and Water Conservation
RWH -	Rain Water Harvesting
SCS -	Soil Conservation Services
CN -	Curve Number
USDA -	United States Department of Agriculture
LULCC -	Landuse/landcover Change
LULC -	Landuse/landcover
WLC -	Weighted Linear Combination
MCDM -	Multi-criteria Decision Making
MCDA -	Multi-criteria Decision Analysis
GIS- MCDA -	Geographical Information Systems based Multi-criteria Decision Analysis
m.a.s.l -	meter above sea level
FAO -	Food and Agricultural Organization of the United Nations
COOPI -	Cooperazion Intertnazionale
UK -	United Kingdom
GLCF -	Global Land Cover Facilities

SRTM -	Shuttle Radar Topographic Mission
DEM -	Digital Elevation Model
EIGS -	Ethiopian Institute of Geological Survey
NMSA -	National Meteorological Services Agency
GPS -	Geographic Positioning System
SLC -	Scan Line Corrector
AEZ -	Agro Ecological Zone
HRU -	Hydrologic Response Unit
CI -	Consistency Index
CR -	Consistency Ratio

Abstract

The study area Ziquala Watershed located at a distance of about 760 km from the capital Addis Ababa city covers an area of about 759 km^2. It is one of the drought prone areas in the country. It is found in drought prone areas of the Wag Himra Zone. The area is characterized by scarcity of water even during the rainy seasons. Agriculture predominantly animal rearing is the main stay of the area. Water harvesting structures are extremely important to conserve precious natural resource like, soil and water, which is depleting day by day at an alarming rate. GIS offers a powerful tool for mapping potential sites for rainfall harvesting. Selection of suitable sites for artificial recharge and water harvesting structures needs a large volume of multidisciplinary data from various sources. Remote sensing is of immense use for natural resources mapping and generating necessary spatial database required as input for GIS analysis. The most affecting factors on mapping the potential sites: landuse, soil, geological formation, drainage density and slope respectively. The main objective of this study is to evaluate the landuse/cover change and select and map suitable sites for different water harvesting structures for Ziquala watershed. Landuse/cover was prepared using supervised classification of Landsat imageries of three different years. Post classification analysis was used to reveal the change in landuse/cover during the study periods. During 1988-1999 period more change occur on bareland decreasing by -32.63% and bush land/shrub land increasing by 28.53%. The water harvesting structures considered for this study area are check dam, farm pond, semi-circular bund and contour bund. Multi-criteria evaluation (MCE) method was used to identify suitable sites for WHSs. Weight was given based on their relative importance for individual WHS. Check dam with 48.33% has higher coverage followed by contour bund, semi-circular bund and farm pond having 2.8%, 1% and 1% coverage respectively. The remote sensing and GIS technique proved to be effective for generating thematic layers, facilitating, analysing and derivation of database management and results.

Key word: *GIS, Landuse/cover change, MCE, Remote sensing, suitability, Water harvesting*

1. Introduction

1.1. Background and Justification

Landuse/cover change is a very crucial aspect of change in an area. This is because it is often induced by changes in population trends and economic environments, other human activities and natural phenomena. It can be intimately linked to other forms of change, including changes in climate, biological diversity, and accelerated land degradation. In one way or the other, landuse/cover change will have a profound effect on the availability and extent of both surface and groundwater. Hence, information on the distribution of landuse/cover and its change over time is very important for planning, management and monitoring programs at all administrative levels (Paul and Mascarenhas, 1981). The capability of GIS to integrate and analyse temporal and spatial data helps in quantifying the land-use changes. In areas of rugged topography and poor accessibility, remote sensing is a valuable tool for monitoring the spatial and temporal changes in landuse, as well as its impacts.

Water is the scarcest natural resource in the dry areas. It is the most limiting factor for agricultural development. It is essential for all life. It is also one of the prime requirements for agriculture, industrial production and domestic uses. Components of precipitation, resolved into soil moisture and groundwater, are the prerequisites for biomass production and social development in dry areas. Lack of water resources is generally a function of large inter-annual and annual fluctuations of rainfall, poor infiltration, low hydraulic conductivity, storitivity and high evaporative demand (Ramakrishnan *et al.*, 2007).

Now a day's most of the rural development works in Ethiopia are watershed based. Watershed development and management implies an optimum development of water, land and hence biomass so as to meet the people's basic needs in a sustained manner. This calls for reducing the runoff, soil loss and augmentation of infiltration. A reduction in surface runoff can be achieved by constructing suitable structures or by changes in land management, which in turn will increase infiltration and aid water conservation (Ramakrishnan *et al.*, 2007).

Groundwater resources are being overexploited and both surface and groundwater resources are affected by quality degradation. In order to prevent the fast depletion of ground water levels, artificial recharge is required. Various artificial recharge and water harvesting structures are required to allow the movement of rainwater from the catchment surface into the under ground formations. Selection of suitable sites for artificial recharge and water harvesting structures needs a large volume of multidisciplinary data from various sources.

Water harvesting structures are extremely important to conserve precious natural resource like, soil and water, which is depleting day by day at an alarming rate. Water harvesting has to be done on watershed basis, as watersheds are natural hydrologic units. Management of water resource done in this way is more effective. Watershed is characterized by many parameters like landuse, soil, geomorphology, morphometric characteristics etc. With a suitable structure it is possible to harness maximum amount of water from the watershed. Location and type of structures depend upon soil, landuse/ cover, drainage pattern, geomorphology etc.

Remote sensing is of immense use for natural resources mapping and generating necessary spatial database required as input for GIS analysis. This is because GIS is an ideal tool for collecting, storing and analyzing spatial and non - spatial data, and developing a model based on existing factors to arrive at a suitable natural resources development and management action plans. Both these techniques in conjunction with each other are the most efficient tools for selecting suitable sites for artificial recharge structures and water harvesting structures. In the present study, an integrated remote sensing and GIS based methodology is adopted for identifying the suitable sites for artificial recharge structures and water harvesting structures in the study area located in Ziquala Woreda.

This problem can be alleviated to some extent by artificially recharging the potential aquifer and efficient harvesting of the rainwater. Remote sensing and Geographic Information System (GIS) methods permit rapid and cost effective natural resources survey and management. Moreover remote sensing and GIS are playing a rapidly increasing role in the field of hydrology and water resources development. GIS, in the context of land suitability, helps the user determine what locations are most/least suitable for development. In this way, the results of GIS analysis can provide support for decision-making. This study has unveiled the landuse/cover change during the last 21 years and illustrates the power of remote sensing and GIS in selecting and mapping suitable site for some selected water harvesting structures.

1.2. Statement of the Problem

Ziquala Woreda is found in drought prone areas of the Wag Himra Zone. The area is characterized by scarcity of water even during the rainy seasons. The erratic seasonal rainfall, coupled with the steep slopes and the bare plains with little or no plant cover have led to low retention of ground water and high run-off, which in turn led to extensive soil erosion in the Woreda. In order to mitigate droughts which occur frequently in several parts of the country especially in dry land areas the Ministry of Agriculture (MoA) in co-operation with NGOs has launched an integrated watershed program using easy, simple and affordable local technologies. Watershed approach has been the single most important landmark in the direction of bringing in visible benefits in rural areas and attracting people's participation in watershed programs (Sarangi *et al.*, 2005). Besides, rainwater harvesting has recently been promoted to solve water problem for agricultural and domestic uses.

The programmes under watershed approach broadly fall into soil and water conservation, dry land and rain fed farming, gully reclamation, control of shifting cultivation and improvement in the vegetative cover. The basic objective is to increase production and availability of food, fodder and fuel; restore ecological balance. The Woreda administration has intended to implement projects on harvesting rain water for the sustainable development of the area. Most of the project activities, involved constructing water harvesting structures on watershed basis, failed first due to the fact that they are undertaken with the regular food for work activities and secondly and most importantly due to problems in proper site selection.

For years, NGOs, faith-based groups and the government have been advocating the use of rainwater harvesting with slow progress. Various technologies to harvest rainwater have been in use for those times and new ones are being developed all the time. They include macro-catchment technologies that handle large runoff flows diverted from surfaces such as roads, hillsides, pastures, as well as micro-catchment technologies that collect runoff close to the growing crop and replenish the soil moisture.

One of the problems has been lack of tangible scientifically verified information which can be used to demonstrate the areas where water harvesting can be applied. 'Water harvesting' is here defined as the collection of surface runoff mainly for agricultural, domestic and groundwater recharge purposes. The need for information in user friendly formats and which is easy to update, query, manage and utilize, has popularized the use of Geographic Information systems (GIS).

Besides, watershed management is an iterative process of integrated decision making regarding uses and modification of lands and waters within a watershed. Thus, micro watershed development calls for a detailed understanding and analysis of various interrelated parameters such as landuse, soil, soil moisture, slope, rainfall and lithology (Prasad *et al.*, 1993). The present study is an attempt using Remote Sensing and GIS techniques to propose various water harvesting and soil conservation measures in order to suggest integrated land and water resource development plan for Ziquala watershed covering 759 square kilometres in Ziquala Woreda.

1.3. Objectives

1.3.1. General Objective

The general objective of this study is to evaluate the landuse/cover change and select and map suitable sites for different water harvesting structures for Ziquala watershed.

1.3.2. Specific Objectives

The specific objectives of this study are

- To illustrate the efficiency of remote sensing and GIS tools for identifying suitable site for the selected water harvesting structures
- To provide information for decision makers and practitioners about the landuse/cover change and potential suitability of the watershed for different water harvesting structures.
- To develop multi-criteria approaches in evaluating suitability of a land for a given type of water harvesting structure

2. Literature Review

2.1. Remote Sensing and GIS

The success of planning for developmental activities depends on the quality and quantity of information available on both natural and socio-economic resources. It is, therefore, essential to devise the ways and means of organizing computerized information system. Remote Sensing (RS) data and Geographical Information System (GIS) play a rapidly increasing role in the field of land and water resources development. One of the greatest advantages of using Remote Sensing data for natural resource management is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation.

Historically, remote sensing in the form of aerial photography has been an important source of landcover and landuse information. However, the cost of aerial photography acquisition and interpretation of cover types is prohibitively expensive for large geographic areas. An alternative is to acquire the needed information from digital satellite imagery such as Landsat TM and ETM+. According to Bauer *et al.*, (2003) this approach has several advantages: (1) the synoptic view of the sensor provides coverage of large geographic areas, (2) the digital form of the data lends itself to more efficient analysis and the classified data are compatible with geographic information systems, eliminating the need to digitize interpreted information, and (3) land cover maps can be generated at considerably less cost than by other methods.

Geographic data have been traditionally presented in map form (Dayawansa and Ekanayake, 2003). Land analysis is commonly done with map overlay and it used to be done manually. McHarg (1969) describes how using manual map overlaying can do systematic landuse planning. As the use of computer technology has grown, the more efficient digital form has progressively replaced manual map preparation. This rapidly evolving technology is known as Geographic Information System (GIS). This technology has developed so rapidly over the past two decades and it is now accepted as an essential tool for the effective use of geographic information.

With the increasingly widespread, combined implementation of remote sensing and GIS technology, more natural resource professionals have been provided with efficient and accurate tools for mapping and maintaining management information on forests and other natural resources in regional areas. GIS technology is expanding, allowing for greater integration of remote sensing with digital cartography, thus providing the means to produce more accurate landuse and land cover maps (Berhanu, 2005).

GIS have the ability to perform numerous tasks utilizing spatial and attribute data. Such functions distinguish GIS from other management information systems. Furthermore, GIS as an integrated technology allows for integration of a variety of geographical technologies (such as remote sensing, global positioning systems, computer-aided design, automated mapping and facilities management) that can be in turn integrated with analytical and decision-making techniques (Drobne and Lisec, 2009).

In general, remote sensing and Geographic Information Systems (GIS) are providing new tools for advanced environmental management. The collection of remotely sensed data facilitates the synoptic analyses of earth-system function, patterning, and change at local, regional, and global scales over time. Other factors such as rainfall intensity (erosivity), soil erodibility and slope gradient and length can also be identified and analyzed by GIS techniques.

2.2. Data Models used in GIS

The two possible data models that can be used in a GIS are vector and raster. Vector data consist of discrete points, lines, and polygons. These feature shapes are defined by x and y coordinates. There can be multiple attributes associated with each feature, for example road name and pavement type for a given road segment. The raster data model represents features as a matrix of cells (pixels) in continuous space. Each layer represents one attribute (although other attributes can be attached to a cell) and most analysis occurs by combining the layers to create new layers with new cell values (NC DCM- NCCGIA, 2005).

2.3. Landuse/cover change detection

To meet the demands of large population means the need for more food production, more requirement of energy, more water requirement, better civic amenities for a reasonable quality of urban life, more infrastructure development to sustain increasing pressure and increased per-capita expenditure for maintaining quality of life. This requires cautious use of landuse/cover in the area.

According to Meyer (1995) every parcel of land on the Earth's surface is unique in the cover it possesses. Landuse affects land cover and changes in land cover affect landuse. A change in either, however, is not necessarily the product of the other. Changes in land cover by landuse do not necessarily imply degradation of the land. However, many shifting landuse patterns driven by a variety of social causes, result in land cover changes that affects biodiversity, water and radiation budgets, trace gas emissions and other processes that come together to affect climate and biosphere (Riebsame *et al.*, 1994). Landuse/landcover is, therefore, seen as an interface between the natural conditions of the land and the human influence that provides a framework for linking socioeconomic developments with the consequent environmental impacts (Petit and Lambin, 2002 as sited in Mekuria, 2005). Thus, analyzing the changes in Landuse/landcover is a fundamental step in order to capture the impacts of socioeconomic developments.

When considering the sustainable development of land, landuse change is an important phenomenon. Keeping information up-to-date is important for management and planning of land resources. Planners and resource managers need reliable techniques for accurately detecting, monitoring and analysing landuse/cover changes quickly and efficiently. The digital nature of satellite data makes the change detection process easily amenable for computer aided analysis.

Remote sensing provides a good source of data from which updated landuse/landcover information can be extracted efficiently and economically in order to have inventory and monitor changes effectively (Donnay *et al.*, 2001). Satellite Remote sensed data and GIS for landuse/landcover and its changes is a key to many diverse applications such as Environment, Forestry, Hydrology, Agriculture and Geology. Natural Resource Management, Planning and Monitoring programs depend on accurate information about the land cover in a region. Satellite remote sensing is an evolving technology with the potential for contributing to studies for land cover and change detection by making globally comprehensive evaluations of many environmental and human actions possible. These changes, in turn, influence management and policy decision making (Tanmoy, 2009).

Landuse/cover change (LUCC) reflects the impacts of human activities on natural environment and ecosystem (Zhou *et al.*, 2008). Among various types of LUCC, changes in urban (or built-up areas) and agricultural lands have long been mostly focused research areas in the LUCC studies. The expansion of urban and agricultural areas may generate some significant impacts on the environment, such as lost of wildlife habitat, changes of surface and subsoil hydrology that may lead to accelerated soil erosion and land degradation, and air pollution.

Landuse/cover (LU/C) change detection has become a central component in current strategies for managing natural resources and monitoring environmental changes (Brandon and

Bottomley, 1998). Time series analysis of landuse/cover (LUC) change and the identification of the driving forces responsible for these changes are needed for the sustainable management of natural resources and also for projecting future LUC trajectories (Giri *et al.*, 2003). Change detection and monitoring involve the use of several multi-date images to evaluate the differences in LUC due to various environmental conditions and human actions between the acquisition dates of images (Singh, 1989).

Land cover can be altered by forces other than anthropogenic. Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem dynamics may also initiate modifications upon land cover. Globally, land cover today is altered principally (Meyer, 1995) by direct human use: agriculture and livestock raising, forest harvesting and management and urban and suburban construction and development.

Due to technological advancements, changes of the earth's surface have become visible by satellite imagery as a result remote sensing has become the most effective tool for assessing and monitoring all these transitions (Deer, 1995). Therefore, satellite remote sensing has become a major data source for different change detection applications, because of the repetitive data acquisition capabilities, digital format suitability for computer processing and lower cost than those associated with traditional methods (Coppin *et al.* 2002; Lu *et al.* 2004).

2.4. Methods of Change Detection

Change detection analysis comprises a wide range of methods to identify, describe and quantify changes between images of the same scene at different times (Markham and Barker, 1985). These techniques can be divided into two distinctive categories of digital change detection (Cakir *et al.*, 2006). The first approach, post-classification method, involves the comparative analysis of independently produced thematic labelling or classification of imagery from different dates. The second approach is the simultaneous analysis of multi-temporal data.

2.4.1. Post-classification methods

Post classification comparison is a common method used for change detection. This method involves independently produced spectral classification results from each end of time interval of interest, followed by a pixel by pixel or segment by segment comparison to detect changes in cover type. It is a method in which *from* and *to* classes can be quantified for each changed pixel. The major advantage of these methods is the capability of providing a matrix of change information and reducing external impact from atmospheric and environmental differences between the multi-temporal images (Lu *et al.*, 2004).

The accuracy of this method is totally dependent on the accuracy of the initial classifications. By coding the classification results properly, a complete matrix is obtained and change classes can be defined (Lillisand *et al.*, 2004). However, the difficulty rests in securing completely consistent, comparable and highly accurate target identifications for each period (Coppin *et al.*, 2002; Deer, 1995). Examples of the post classification technique can be seen in, Chen (2002); Yang and Lo (2002). They have concluded that post-classification techniques with GIS allowed for further spatial analysis of data derived from remotely sensed images and the impact of landuse land cover dynamic.

2.4.2. Simultaneous analysis of multi-temporal data

This approach is based on a single classification performed on a combined data set for two dates. The success of this approach depends upon the extent to which "change classes" are significantly different spectrally from the "non change classes", which makes the nature of change difficult to detect (Deer, 1995; Lillesand *et al.*, 2004). The critical step for these methods is identifying the threshold boundaries used to distinguish change form no change (Lillesand *et al.*, 2004; Lu *et al.*, 2004).

2.5. Water harvesting

The economy of Ethiopia is agrarian, and mainly relying on household labour. Agriculture production is aimed at self-subsistence and dependent on forces of nature. As such, success in production in the lowland agro-ecology is severely affected by climatic variability (Mitiku and Sorssa, 2002). The total annual rainfall is inadequate for crop production; since often the rainfall distribution is erratic. The most common shock to which mainly the lowland inhabitants are exposed is insufficient agricultural production resulting from moisture stress. Techniques to improve soil moisture retention or water harvesting is not known to most farmers or not commonly practiced.

Only a small fraction of the rainfall falling in arid and semi-arid areas percolates into deeper soil or rock layers to recharge an aquifer. Another small fraction is used for transpiration of vegetation or of agricultural crops. The majority of the precipitation evaporates from the often bare soil or from surface depressions (Prinz *et al.*, 1998). Continuous overexploitation of natural resources like land, water and forest has caused serious threat to the local population of the semiarid region. Thus, problems like little scope for soil moisture storage, high rate of soil erosion, declining ground water level and shortage of drinking water prevail.

2.5.1. Classification and techniques of water harvesting

Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term rainwater harvesting while all systems which collect discharges from watercourses are grouped under the term floodwater harvesting.

There are two main techniques of rain water harvestings. These include storage of rainwater on surface for future use and recharge to ground water (www.oppapers.com/essays/Rain-Water-Harvesting-Ajay-Mishra/194694). The storage of rain water on surface is a traditional technique and structures used were underground tanks, ponds, weirs etc. Recharge to ground water is a new concept of rain water harvesting and the structures generally used are infiltration pits, trenches, dug wells, percolation pond etc. Most of the structures used for ground water recharge are constructed along with the regular soil and water conservation activities.

The difference between soil and water conservation (SWC) and rainwater harvesting (RWH) technologies for crop production is very small. SWC can be described as activities that reduce water losses by runoff and evaporation, while maximizing in-soil moisture storage for crop production, but the same could be said of RWH. The two are differentiated by the fact that under soil and water conservation, rainwater is conserved *in-situ* wherever it falls, whereas under water harvesting, a deliberate effort is made to transfer runoff water from a "catchment" to the desired area or storage structure (Critchley and Siegert 1991). The important thing is that both systems complement each other, and under rain-fed agriculture in dry areas, both are necessary nearly all the time (Mati, 2005).

Semi-circular bunds

Semi-circular bunds (also known as crescent-shaped bunds) are earth embankments (Critchley and Siegert, 1991) in the shape of a semi-circle with the tips of the bunds on the contour. Semi-circular bunds, of varying dimensions, are used mainly for rangeland rehabilitation or fodder production. This technique is also useful for growing trees and shrubs and, in some cases, has been used for growing crops. When used for growing of trees, the runoff water is collected in an infiltration pit at the lowest point of the bund, where the tree-seedlings are also planted.

Farm Ponds

Traditional ponds have been used in Ethiopia for millennium; some estimates it as early as 560 BC (Fattovich, 1990). They are used to harvest rainwater for both human and livestock watering, particularly in the arid and semi arid rural areas where annual rainfall is less than 700 mm. The most common type of pond is the excavated type. The size of the ponds range from 650 M^3 to several thousands, and they serve for 3 to 6 months and largely during the rainy season (www.ucowr.siu.edu/proceedings/2003%20Proceedings/W8D.pdf).

The main objectives (Rao *et al.*, 2003) of constructing farm pond are:

- To provide water storage for life saving irrigation in a limited area.
- To provide drinking water for livestock and human beings in arid areas.
- To serve as water storage for providing critical irrigation to a limited number of fruit plants for establishment purpose and

Check dams

A check dam is a small barrier constructed of rock, gravel bags, sandbags, fibre rolls, or reusable products, placed across a constructed swale or drainage ditch. Check dams reduce the effective slope of the channel, thereby reducing the velocity of flowing water, allowing sediment to settle and reducing erosion. The most important decision to be taken when building a check dam is its location. This decision is crucial, as the effectiveness of the dam depends on this.

Contour bunds

Contour bunds are a simplified form of micro-catchments. Contour Bunds are effective method to conserve soil moisture in watershed for long duration (http://sites.google.com/site/projectjhabua/Reading-List-Resources). This system consists of small trash, earth or stone embankments, constructed along the contour lines. The embankments trap the water flow behind the bunds allowing deeper infiltration into the soil. The water is stored in the soil profile and above ground to the elevation of the bund or overflow structure. This is a versatile system for crop production in a variety of situations. As with other forms of micro-catchment water harvesting techniques, the yield of runoff is high, and when designed correctly, there is no loss of runoff out of the system.

2.6. The Soil Conservation Service (SCS) runoff estimation method

Landuse/cover has several impacts on the hydrological cycle such as floods, droughts, runoff and water-quality (www.isprs.org/proceedings/XXXV/congress/comm7/papers/52.pdf). Rainfall-Runoff model play an important role to understand hydrological condition of watershed areas and predict their behaviour over time. Accurate process for predicting runoff volumes is used to flood warning, navigation, water quality management and many water resource applications. Land surface characteristics are important to generate rainfall-runoff model. Such models need remote sensing and GIS technologies to produce more accurate spatial data which play an important role to derive input data such as landuse/cover and soil type.

In conventional hydrological model, to estimate runoff, input parameters have to be determined through ground truth measurement which still needs huge economic and time–labour consuming. Therefore, remote sensing can also provide information about runoff input data most cost-effectively and with large-land coverage. Moreover, these data are suitable to enter into GIS. All kinds of data can be stored as different layers by using GIS techniques. In this study, soil conservation service (SCS) curve number (CN) method was used to determine runoff depth with the aid of remote sensing and GIS technologies.

There are several techniques available to estimate runoff amount. One technique is the use of SCS CN method. The CN procedure was developed in the 1950s by the (then) Soil Conservation Service (SCS) as a simple procedure for estimating stream flow volume (exclusive of base flow) generated by large rain storms (Garen and Moore, 2005).

SCS CN Method employs a number to calculate runoff depth. This number is dependent on soil characteristics, soil cover and landuse. The CN is between 0 and 100 which is related to the amount of runoff generated from a watershed. In this method, a CN is assigned to each watershed or portion of watershed based on soil type, landuse and treatment, and antecedent moisture condition (www.isprs.org/proceedings/XXXV/congress/comm7/papers/52.pdf).

The Soil Conservation Service model developed by United States Department of Agriculture (USDA) computes direct runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs. For a given precipitation event, the CN method partitions a given uniform depth of precipitation into a runoff component and an infiltration/initial abstraction component through the following equations (Weissling *et al.*, 2009).

$$\frac{F}{S} = \frac{Q}{P-I} \quad \ldots\ldots (1)$$

where F, actual retention (mm); S, watershed storage (mm); Q, actual direct runoff (mm); P total rainfall (mm); I, initial abstraction (mm). From the continuity principle,

$$F = (P - I) - Q \quad \ldots\ldots (2)$$

The SCS method defined the value of the initial abstraction *I* to be approximately equal to 20% of the watershed storage S,

$$I = 0.2S \quad \ldots\ldots (3)$$

Solving equation 1 and 2 simultaneously,

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \quad (P \geq 0.2S) \ldots\ldots (4)$$

The watershed storage, *S, and* the curve number CN are related by,

$$S = \frac{25400}{CN} - 254 \ldots\ldots (5)$$

2.7. Remote Sensing and GIS in Land Suitability Analysis

Traditionally, spatial data has been acquired and rendered into pictorial form to accomplish variety of activities related to land resource management. With the introduction and dissemination of high speed computers and of data capture and display devices, the importance of developing a computer based system of efficient and cost effective land resource data management was emphasized. As a result, database systems for spatial data, commonly named as Geographical Information system (GIS) were designed and developed enabling the acquisition, compilations analysing and displaying topological interrelations. Therefore, it is apparent that the accomplishment of almost any project aimed at land resources planning may be greatly facilitated by the use of and efficient GIS. The surface and overlay analysis capabilities in GIS can effectively facilitate in handling this vast amount of spatial information. Today, remote sensing and GIS are playing a very significant role in land evaluation systems such as production of land suitability maps (Perera and Tateishi, 1994).

The land suitability analysis problem involves classification of the units of observations according to their suitability for a particular activity. The analysis defines an area in which a good site might exist. Landuse suitability is a generic term associating a combination of factors and their impacts with respect to potential landuses. Land allocation, on the other hand, involves the process of designing an optimal mix of landuses based on their estimated suitability and perceived management objective.

More interactive modelling techniques that are built upon map algebra concepts and tools are becoming available within GIS. For example, methods that combine data layers within an explicit decision-making/modelling environment are increasingly integrated into GIS software (e.g. the Idrisi software). Data layers are thought of as criteria for decision-making and can be developed, standardized, weighted relative to each other, and, finally, aggregated in a number of ways so as to manage the level of trade-off between criteria and the overall level of risk (Malczewski, 1996).

An integrated GIS-based multi-criteria approach to land suitability analysis and allocation offers significant advantages. The GIS environment enables the spatially explicit evaluation of site suitability and the assignment of various measures of suitabilities to specific sites or geographic areas. The integration also allows area allocations at specific spatial or geographic locations. Hence, the integrated GIS-based model combines the spatial capabilities of GIS, with the analytical power of multi-criteria analyses. That is, the GIS-based integrated model permits both analytical planning and optimization of landuse decisions at different levels, namely; 1) site suitability assessments based on different factors and specific landuses; 2) generation of suitability indices based on combinations of different factors (i.e. composite index/measure of site suitability); and 3) generation of an optimal landuse plan that simultaneously considers the individual site suitabilities, and the optimal allocation to the most suitable landuse (i.e., mix of landuses that yields the "highest" overall cumulative suitability.

Site suitability assessment is inherently a multi-criteria problem. That is, land suitability analysis is an evaluation/decision problem involving several factors. In general, a generic model of site/land suitability can be described as:

$$S = f(x1, x2, \ldots, xn) \qquad (6)$$

where S = suitability measure; x1., x2, ..., xn = are the factors affecting the suitability of the site/land.

Central to the map algebra approach for handling land-use suitability problems is overlay analysis. The map overlay approach has been typically applied to landuse suitability in the form of Boolean operations and weighed linear combination (WLC). The most prevalent procedure for multicriteria evaluation is WLC (Eastman, 2006). With WLC factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map, i.e.,

$$S=\sum w_i x_i \qquad (7)$$

where S is suitability, w_i is the weight of factor i, x_i is the criterion score of factor i (Eastman, 2006).

2.8. Spatial Decision Support System (SDSS)

Spatial decision support systems (SDSS) are a class of computer systems in which the technologies of both GIS and DSS are applied to aid decision makers with problems that have a spatial dimension (Manoli *et al.*, 2001). Spatial multi-criteria decision analysis can be thought of as a process that combines and transforms geographical data (input) into a resultant decision (output) (Drobne and Lisec, 2009). It is based on multiple attribute decision analysis techniques and combines multi-criteria evaluation methods and spatio-temporal analysis performed in a GIS environment (Malczewski, 1999). Decision making is a sequence of activities starting with decision problem recognition and ending with a recommendation, and eventually with a final choice of alternative (Drobne and Lisec, 2009).

Decision support methods in geographic information systems (GIS) go beyond simple querying in that they enable users to evaluate and rank decision alternatives based on multiple criteria. GIS-based multi-criteria evaluation is commonly used in applications such as site suitability analysis (Malczewski, 1999).

2.9. GIS-based Multicriteria Decision Analysis

One of the most useful features of GIS is the ability to overlay different layers or maps. However, the overlay procedure does not enable us to take into account that the underlying variables are not equally important. One approach that can help overcome such limitations is MCE (Carver, 1991), which has received renewed attention within the context of GIS-based decision-making (Pereira and Duckstein, 1993). The objective of using MCE models is to find solutions to decision-making problems characterized by multiple alternatives, which can be evaluated by means of decision criteria (Jankowski *et al.*, 2001).

GIS and MCDM are currently the two most common decision support tools employed to solve spatial decision-making problems (Khalid *et al.*, 2005). GIS-based multicriteria decision analysis (GIS-MCDA) can be defined as a process that transforms and combines geographical data (map criteria) and value judgments (decision-makers' preferences) to obtain relevant information for decision-making. The main rationale behind integrating GIS and MCDA is that these two distinct areas of research can complement each other. While GIS is commonly recognized as a powerful and integrated tool with unique capabilities for storing, manipulating, analyzing and visualizing spatial data for decision-making, MCDA provides a rich collection of procedures and algorithms for structuring decision problems, designing, evaluating and prioritizing alternative decisions. It is in the context of synergetic capabilities of GIS and MCDA that one can see the benefits for advancing theoretical and applied researches on the integration of GIS and MCDA (Malczewski, 1999, 2006a).

The effort to integrate GIS and MCDA can be associated with the current proliferation stage of GIS development (Malczewski, 2006a). During this phase, the systems have been evolving from a 'close' or expert-oriented to an 'open' user-oriented technology. This has stimulated a movement in the GIS community towards using this technology to increase the democratization of the decision-making process via public participation and collaboration. Malczewski (2006a) suggested that it is in the context of the debate on the interrelationship between "GIS and society" (Pickles, 1995) that one can see the potential for constructing GIS-MCDA systems to enhance and facilitate collaborative decision-making.

It has been argued that GIS-MCDA systems can potentially enhance collaborative decision-making process by providing a flexible problem-solving framework where participants can explore, understand and redefine a decision problem (Feick and Hall, 1999; Jankowski and Nyerges, 2001). MCDA approaches can integrate multiple views of decision problems. They improve communication and facilitate the process of building a consensus and reaching compromise solutions. GIS-MCDA can support the collaborative process by providing a tool for structuring decision problems and facilitating communication among decision-makers (Malczewski, 2006a).

MCDM techniques coupled with GIS have been used to solve various site selection problems. A GIS is used to perform the spatial analysis required in the screening phase of candidate sites, and the Analytic Hierarchy Process (AHP), a MCDM method, is used to identify the most suitable site in the site evaluation phase. Saaty (1980) has shown that weighing activities in multi-criteria decision making can be effectively dealt with via hierarchical structuring and pairwise comparisons. Pairwise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements.

2.10. Site Suitability Studies for WHSs using MCE

The land suitability analysis problem involves classification of the units of observations according to their suitability for a particular activity. The analysis defines an area in which a good site might exist. Water harvesting has to be done on watershed basis, as watersheds are natural hydrologic units. Management of water resource done in this way is more effective. Watershed is characterized by many parameters like landuse, soil, hydrogeomorphology etc... Output from similar watershed is often similar. With a suitable structure it is possible to harness maximum amount of water from the watershed. Location and type of structures depend upon soil, landuse/landcover, drainage pattern, geomorphology, lithology etc. (Ramakrishnan *et al*, 2007; Kumar *et al*, 2008; Singh *et al*, 2009; Girma, 2009).

Most suitability analyses for water harvesting structures involve multi-criteria multiple objectives. Ahmedou *et al*, (2007) used multi-objective multi-criteria method to identify sites for water harvesting structures predominantly check dams. Girma (2009) used multi-objective multi-criteria method to identify sites for ponds and in-situ rain water harvesting structures. Singh *et al*, (2009) used multi-objective multi-criteria method to identify sites for check dams and percolation tanks. Kumar *et al*, (2008) used multi-objective multi-criteria method to identify sites for check dam, contour bund, contour trenching, and recharge pit and wells.

3. The Study Area

3.1. Location

Ziquala it is located between 13°8'34" and 12°32'31" north latitudes, and 38°41'54" and 38°46'53" east longitudes. It has an area of 1726.12 km^2. The Woreda is found in the western part of Wag Himra Administrative zone, and shares borders with Sekota Woreda (in the east), Dehana Woreda (in the south), Sehala Seyemt Woreda (in the southwest), and Abergele Woreda (in the east). It is the home of dominantly Agew ethnic group. The study watershed is found in this Woreda covering an area of 761.35 km^2 and located between 12°54'32.074" and 12°33'33.136" north latitudes and 38°39'40.366" and 38°45'11.302" east longitudes (Figure 3.1). It is found in the Tekeze basin.

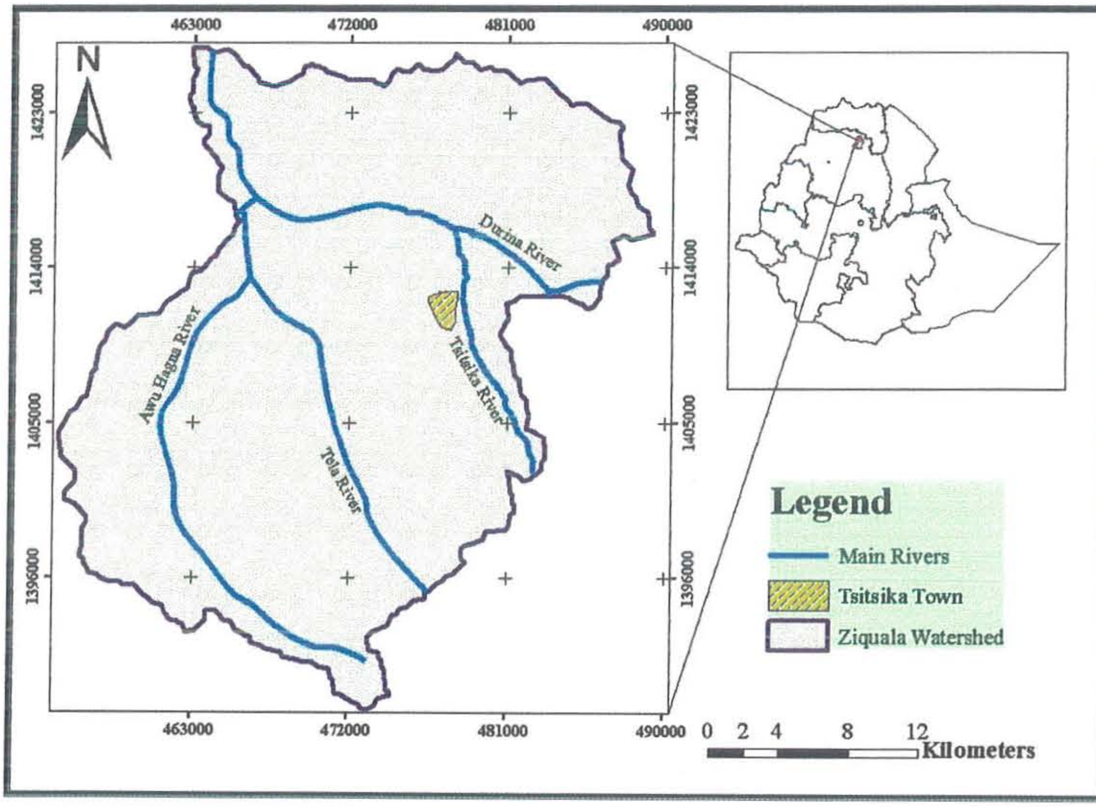


Figure 3.1: Map of the Study Area

3.2. Population

According to the Woreda Finance and Economic Development Office, the total population at the Woreda is estimated to be 43964 comprising 21500 females (49%) and 22464 males (51%). There are 8739 households out of which 10% are female headed.

3.3. Climate

Based on the traditional climatic classification, Ziquala is divided into two agro-climatic zones: *kola* and *weina-dega*, with most parts of the Woreda (about 89 percent) falling in *kola* AEZ. As is the characteristics of *kola* areas in central and northern parts of Ethiopia, drought is a major hazard in Ziquala because of the high variability of rainfall compared to its low average as well as because of the size of population affected by low levels of rainfall in any one year.

There is one meteorological station in Ziquala, which is recently established. But there no detailed information on the climate is available. The available scant information from Agriculture and Rural Development Office of the Woreda show that the range of annual rainfall in the Woreda varies from time to time and it ranges between 200 to 350 mm. According to the above source the annual temperature ranges from 27^0c to 39^0c. This indicates that the low and erratic rainfall make the Woreda unsuitable for crop cultivation. Over the period 1982 –1999, Ziquala belonged to the top 20 Woredas with the highest coefficient of variation of rainfall (SERA Project, 2000).

3.4. Topography

The topography of the study area is rugged and altitude ranges from about 1102 m.a.s.l in the northern bottomlands to about 2368 m.a.s.l on the tip of the mountain. As a result of the topography soil erosion, gully formation on the slopes and bottomlands and flooding on the bottomlands is a common phenomenon. Ziquala Woreda is characterized by 78% undulating and rolling, 2% flat and 20% mountainous topography (Figure 3.2).

3.5. Geology

According to the National Geological Map (Mengesh *et al.*, 1996) the study area is underlain by Adigrat Formation consisting mainly of sandstone and minor lenses of siltstone, Ashangi Basalt which consists of predominantly mild alkaline basalts with interbedded pyroclastics and rare rhyolites and commonly injected by dolerite sills and dykes, and Aiba Basalts which are generally aphyric, compact rocks, in place, showing stratification and contain rare interbedded basic tuffs (Figure 3.3).

3.6. Soil

Soils in the study area are classified by the FAO soil classification system (1997). The soils do not show extensive variation, and are limited to the two main classes of Leptosols (Lithosols), and Luvisols (Figure 3.4). Leptosols having sandy clay loam texture are by far the dominant soil class accounting for 64.36% of the study area. Where as Luvisols having silty-clay and clay textures cover 35.64% of the study area.

3.7. Drainage and Water Sources

The slope, landform and the configuration of the hills and peaks surrounding the study area have created a drainage network, which takes the surface flow towards Tekeze River. There are more than ten seasonal and few annual rivers and streams that spring out from the southern highlands of the Tekeze Basin. The major streamlines in this study area are Aku Hağńa, Tela, Tsitsika, and Durina. All except the first one are annual streams and most of them are fourth order. These streams are supplied by, gully lines, ephemeral streams, and road channels and sometimes directly from overland flows of adjacent farmlands.

In some localities of the watershed, water for both human and livestock is not easily available. In most instances the water sources are either unclean running water, where at times, both human and livestock share the same water together. In few cases, farmers use water from deep wells and springs which were dug and developed by Non-governmental Organizations (e.g. Cooperazion Internazionale/ COOPI and Save the Children UK).

3.8. Landuse/cover

Ziquala watershed is characterized by a diverse landuse/ landcover types. The major landuse /cover are, open agricultural land, mixed shrub and agricultural land, shrub land (e.g. consists of some Acacia species and Balanites aegyptica) with exposed rock, open forest land, and settlement. According to the Woreda Agricultural and Rural Development Office only 4.84 % of the Woreda is covered by agricultural land while grazing land cover 47.12% of the Woreda which is the most dominant landuse in the area. The middle part is dominated by cultivated land and the lower part is covered by open shrub land and grass land. Exposed rock covered some areas along the Tsitsika and Goskew Rivers and in the north western part of the watershed. Pockets of land in the south western part of the watershed are covered by open Boswelia papyrifera forest. Some of the other types of vegetation in the area include species like Ziziphus mucronata, Acacia decurrens, Euclea racemosa subsp. Schimperi (bush) etc...

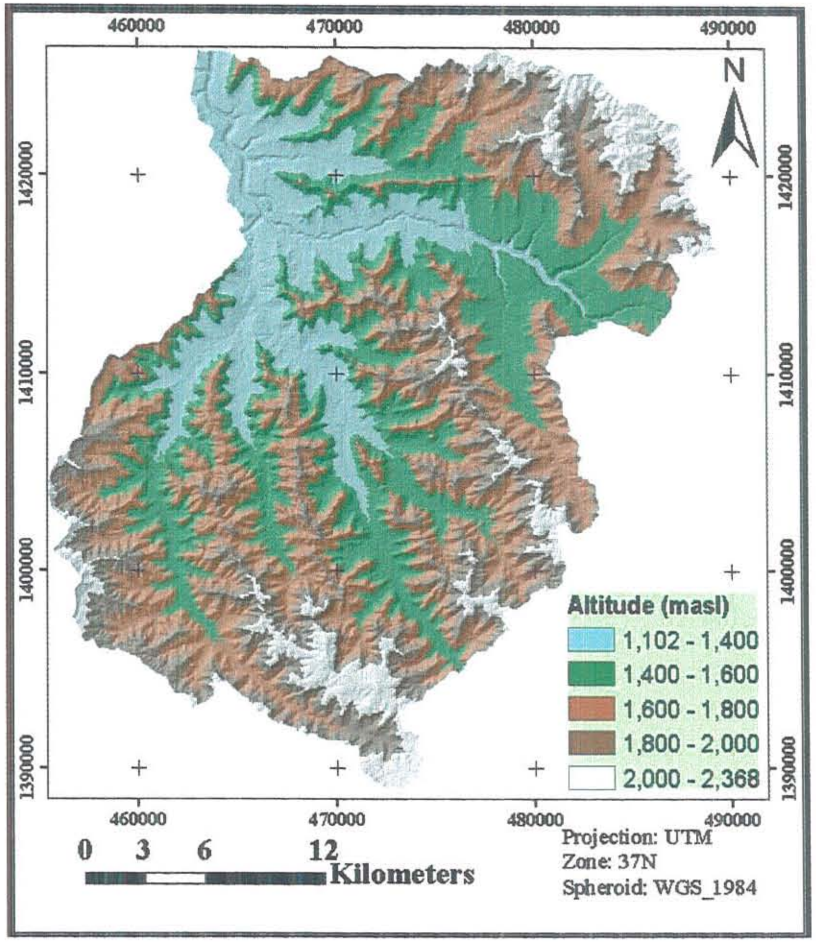
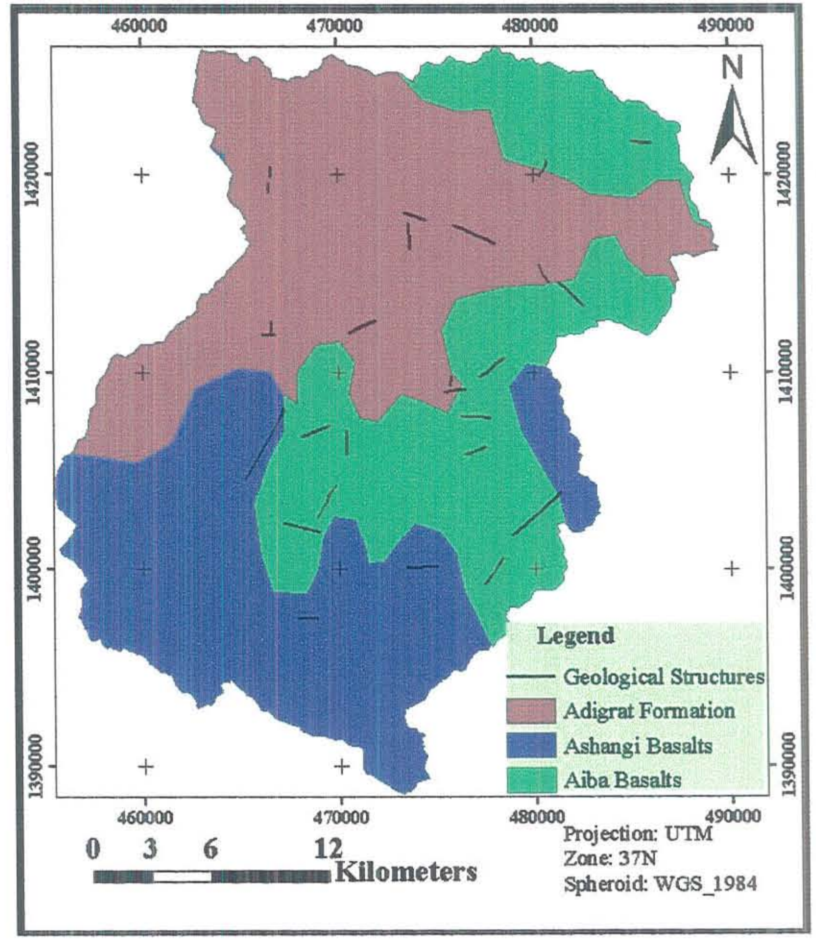
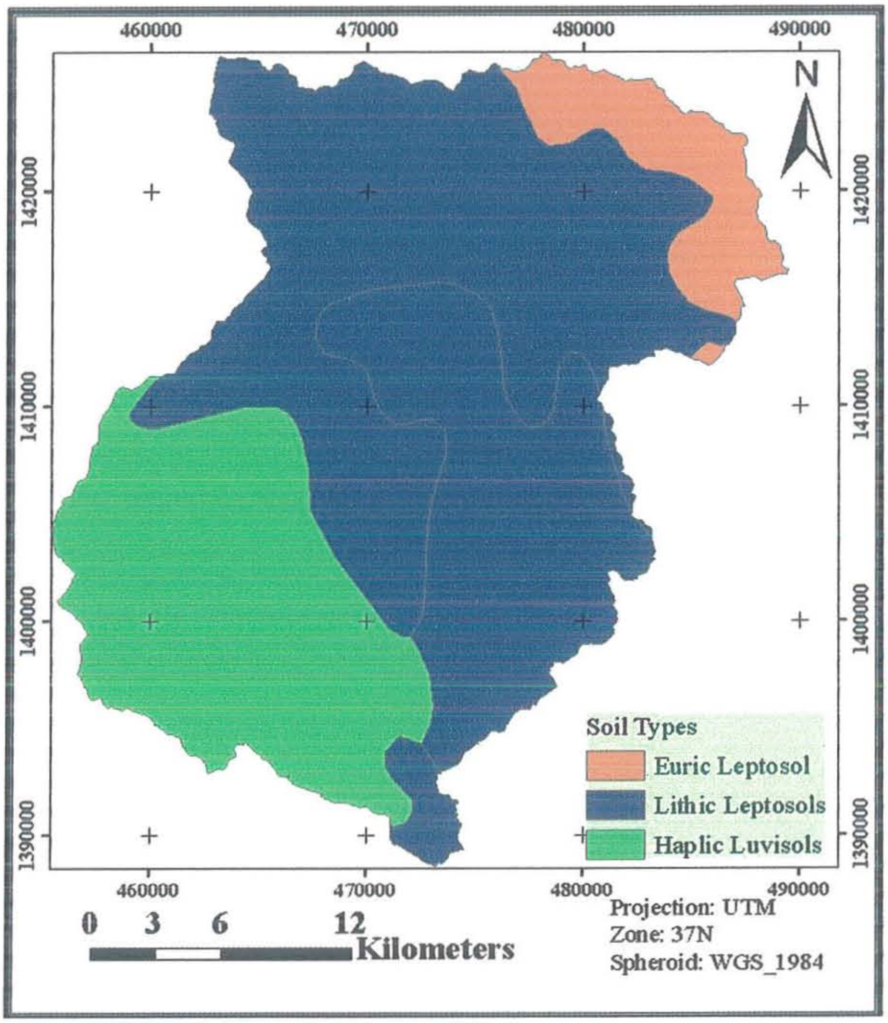


Figure 3.2: Map of Topographic Structure and Elevation



Source: Ethiopian Institute of Geological Survey (EIGS), 1996

Figure 3.3: Geological Formations Map



Source: FAO, 1997

Figure 3.4: Map of Soil Types

3.9. Agricultural production

According to SERA Project (2000) about 99 % of the population in Ziquala Woreda lives in rural areas and earn living from agriculture (i.e. crop cultivation and animal rearing). Agriculture, the main economic activity of the people, involves livestock rearing and subsistence crop production. In actual terms the former is increasing its importance over time as the out come from the latter is declining due to natural calamities, like rain fall variability, environmental degradation and back ward farming technology. Moreover, crop production is restricted to some pocket area with more fertile soil and moderate moisture. The major crops grown in the Woreda are *teff, wheat, sorghum, barley, peas*, and *chickpeas*. *Sorghum* is the major crop produced since the Woreda is predominantly *kola*. Due to the uni-modal nature of the rainfall crop production is only once per year i.e., during the *meher* season. Because of the recurrent drought and limited agricultural production the area is dependent on food aid.

Livestock rearing plays a vital role in the livelihood economy and is a prominent coping mechanism to off set impacts of disaster. According to the Woreda Agricultural and Rural Development Office goat is the predominant animal constituting 45.77% of the total livestock. The average household livestock holding is 5.9 cattle (oxen and cow), 0.7 equines, 13.3 goats and sheep, 1.3 bee hives and 2.4 chickens.

4. Material and Method

4.1. Data used

Satellite Data: Cloud free images of Landsat TM path/row, 169/051 acquired on 11/02/1988, ETM+ path/row 169/051 acquired on 24/11/1999 and ETM+ path/row 169/051 acquired on 08/03/2009 satellite image data have been used for the preparation of landuse/cover map. These images have 80m, 60m and 30m spatial resolution, respectively. The image was obtained from Ministry of Water Resources archive and Global Land Cover Facilities (GLCF) archive.

Collateral Data: A 30 m SRTM was used for preparation of digital elevation model (DEM), out of which the slope map, the watershed boundary, and drainage map were derived. In addition, soil map prepared by Land and Water Development Division, FAO at a scale of 1:1 million and geological and lineament maps prepared by Ethiopian Institute of Geological Survey (EIGS) at a scale of 1:2 million were also used. Meteorological data (monthly rainfall and temperature of one meteorological station, recently established) obtained from National Meteorological Services Agency (NMSA) were used to compute the direct runoff.

Field Data: Two dimensional position of each landuse/cover and existing water harvesting structures in the field is located using GPS, and this positional data is integrated in to the GIS for the verification of the image classification and evaluation of the suitable areas.

Software used: ArcGIS 9.2, ERDAS Imagine 9.1, ENVI 4.5, EDRISI Andes and 3DEM were used for the analysis of the digital data. In addition, MS-Word and MS-Excel were used for further statistical analysis and presentation.

4.2. Methodology

The adopted methodology (Figure 4.1) includes a three stage approach:

1. Generation of thematic layers using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) and collateral data;
2. Data integration and analysis; and
3. Development of decision rules and field validation.

The boundary of Ziquala watershed was delineated using 30 m SRTM data. Area of interest was prepared for the scene of each time using this shape file. Landuse/cover maps for the years February 1988, November 1999 and March 2009 were generated following standard procedures (maximum likelihood classifier) using ERDAS Imagine software. An existing database on lithology and soil was used to generate the geological formations, soil and hydrologic soil group map of the study area.

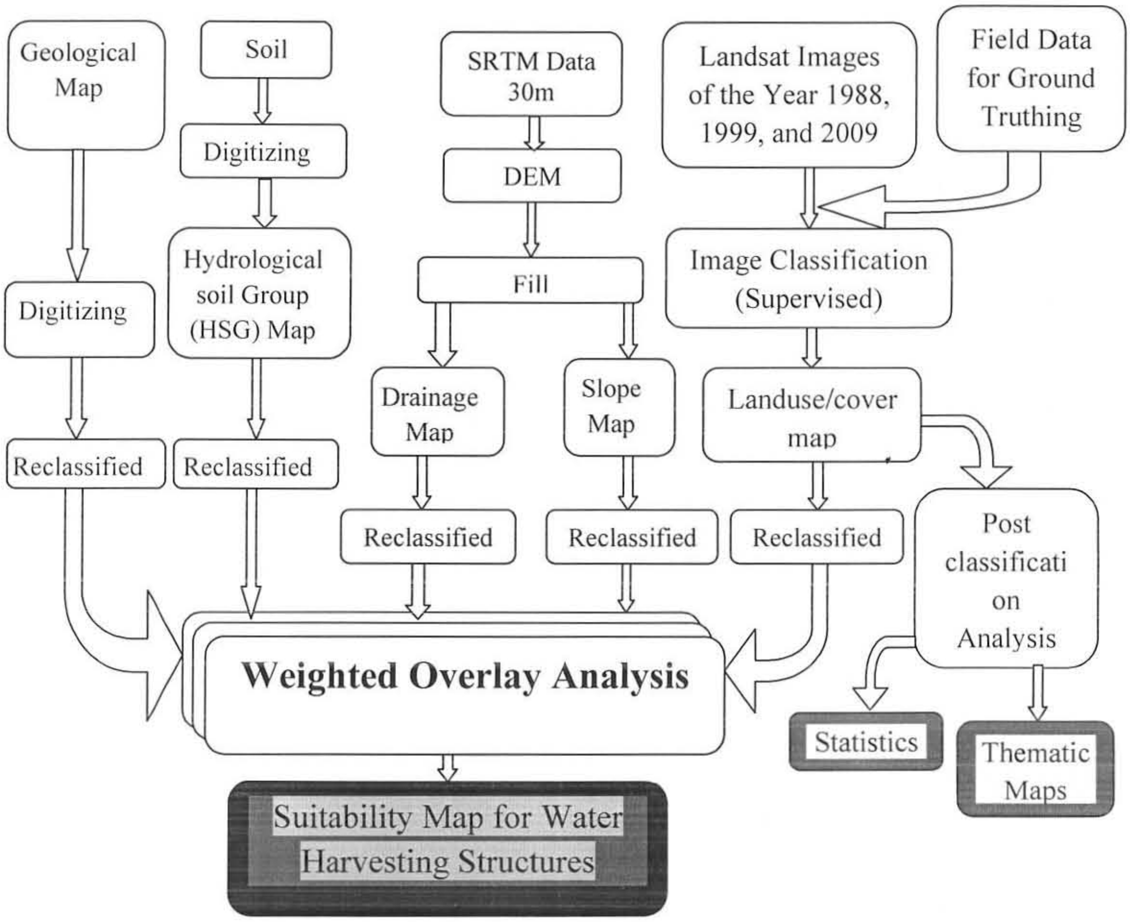


Figure 4.1: Schematic diagram showing the methodology

The landuse/cover dynamics was analysed using digital image analysing tools (ERDAS Imagine and ENVI). The stepwise method for change detection and suitability analyses is presented through the flowchart below. The integration of vector data and collateral data was carried out using ArcGIS software. An analytical hierarchy process (Saaty, 1980) was adopted to assign weight to parameters that govern the site suitability for water harvesting/recharging structures. Specifications prescribed by the Community Based Participatory Watershed Development: A Guideline (Lakew *et al.*, 2005) and the Food and Agriculture Organization (FAO, 1977) were adhered for site selection.

4.2.1. Image Pre-processing

Pre-processing of satellite images prior to image classification and change detection is essential. Pre-processing functions involve those operations that are required prior to the main data analysis and extraction of information. In this study, the imagery of 1988 (TM), 1999(ETM+), and 2005 and 2009 (ETM+) used for the analysis are already geometrically corrected and geo-referenced to the UTM coordinate system, zone 37 North (Figure 4.2a-d). But Landsat images from 2003 onwards are SLC-off (Scan Line Corrector off). They have a problem of gaps. Gap-filling of the Landsat ETM+ image of 2009 was computed using Landsat ETM+ image of 2005. The algorithm works on band to band basis. In this case spatial model maker (Figure 4.2) of ERDAS Imagine was employed (Landsat Update, 2008). Indeed, histogram matching was done to remove the speckles on the resulting gap-filled image.

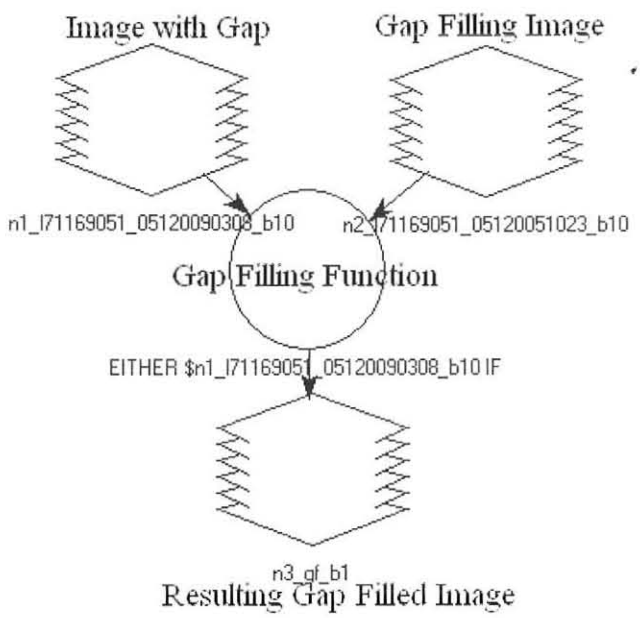


Figure 4.2: Spatial model for Gap-Filling of SLC-Off Landsat images

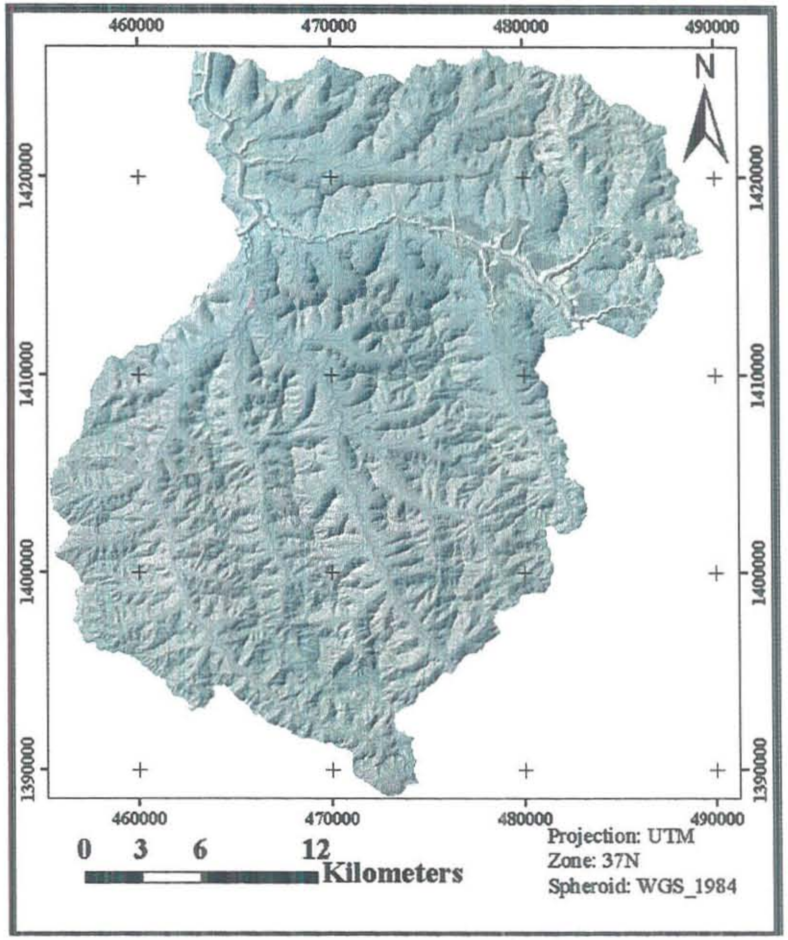


Figure 4.3: FCC of Landsat TM 1988

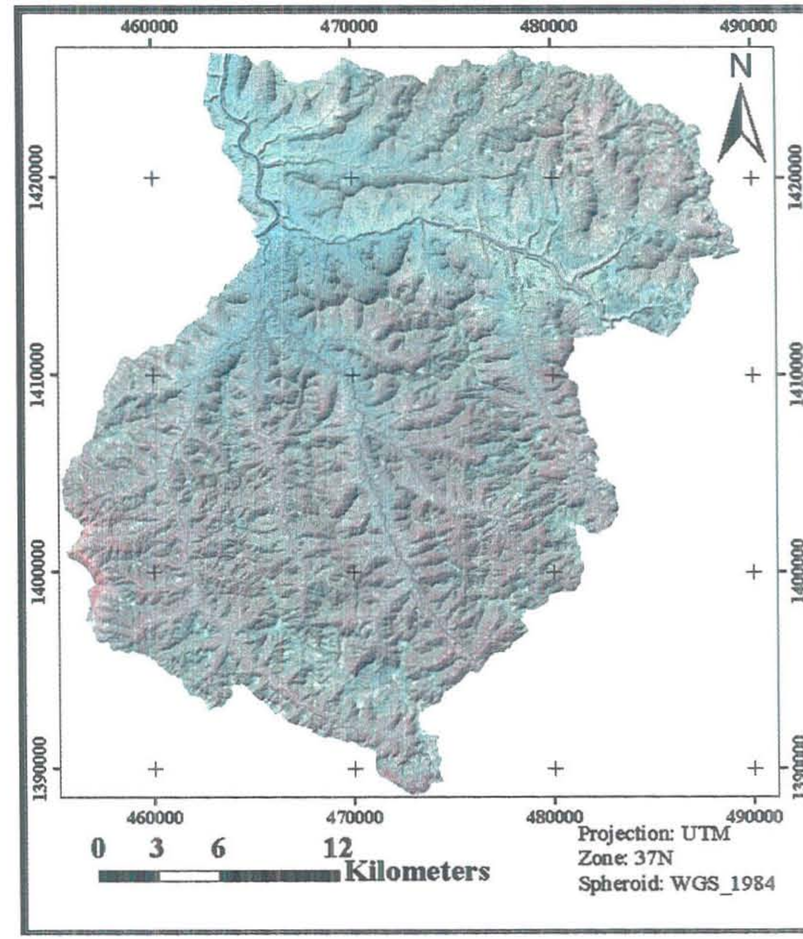


Figure 4.4: FCC of Landsat TM 1999

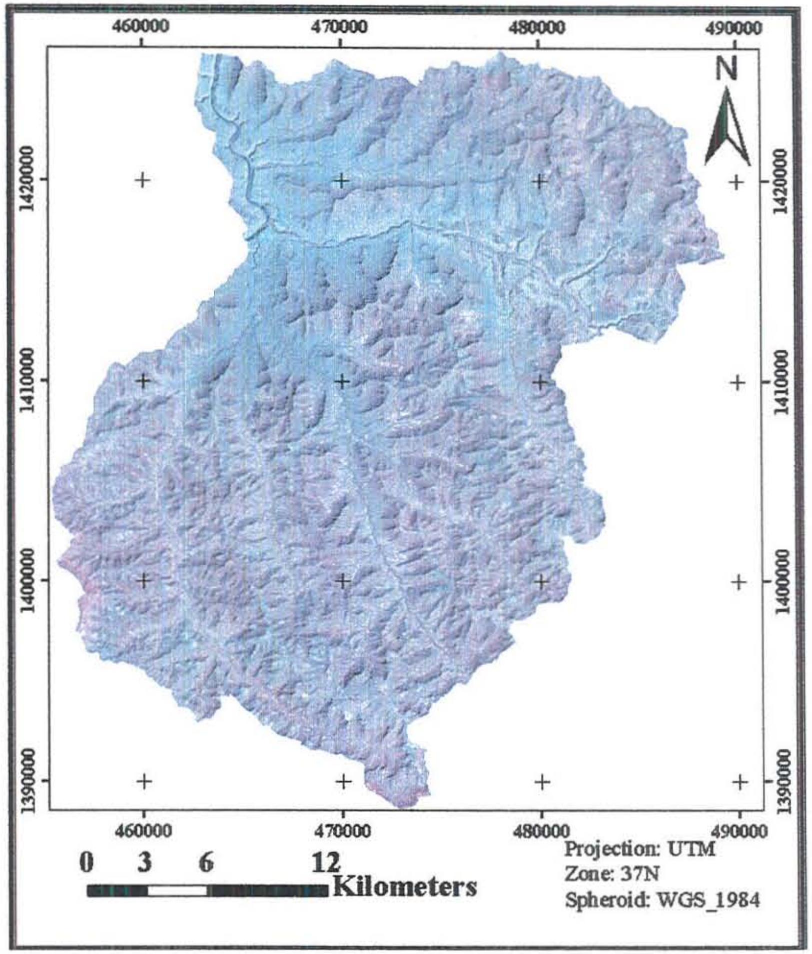


Figure 4.5: FCC of Landsat TM 2005

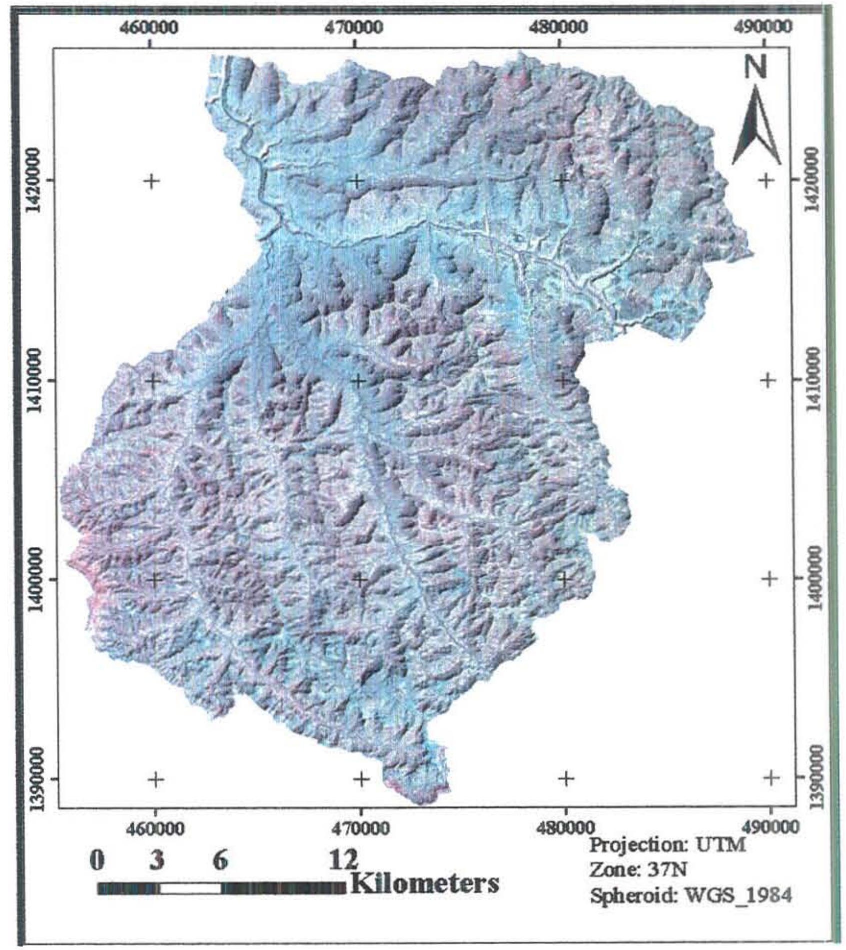


Figure 4.6: FCC of Landsat TM 2009

4.2.2. Image Classification

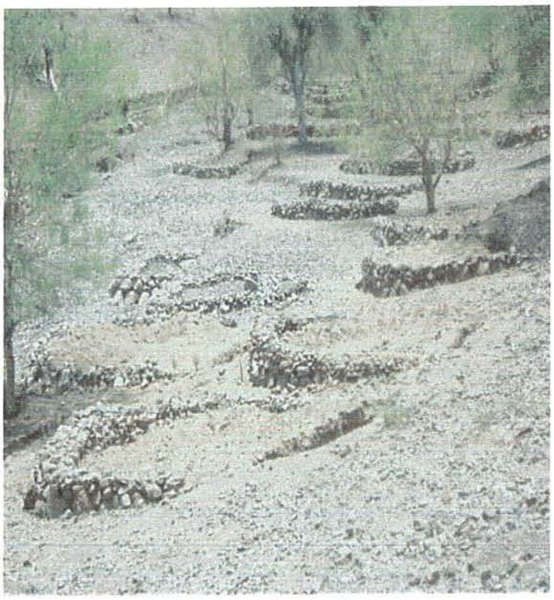
In order to look at the changes in different LU/C between images of different times each scene was classified into six (1988) and seven (1999 & 2009) landuse/cover classes (Table 4.1). Some of the landuse/cover units are presented in Plate 4.1. Ground reference data was obtained from more than 20 ground data points as signatures for each satellite image. Training classes were created from the images using the supervised classification method and they were then classified using maximum likelihood classifier and filtered using 3×3 fuzzy convolution method to reduce the sand and paper look. The classified maps were verified through the 1:50 000 topographic map, and Google Earth Imageries. Classified images for each scene are shown in the result and discussion section.

Table 4.1: Description of Landcover classes

Land cover classes	Descriptions
Settlements/Built up Areas	This classes includes urban fabric, commercial, transport units and other related built up (Artificial) surfaces of non agricultural and vegetated areas
Agricultural areas	Crop, pasture, irrigated land and heterogeneous agricultural areas and agro-forestry areas
Scrublands	It sparsely vegetated land of low quality
Bareland	Open spaces with little or no vegetation, dunes sands, and bare rocks,
Water bodies	Rivers and reservoirs
Bush land/shrub land	Land supporting an assemblage of small trees and shrubs and herbaceous vegetation associations
Forest land	This land use includes natural fully grown trees of species like Boswelia papyrifera

4.2.3. Accuracy Assessment

Land cover maps derived from classification of images usually contain some sort of errors due to several factors that range from classification techniques to methods of satellite data capture. Hence, evaluation of classification results is an important process in the classification procedure. In so doing among the common measures used for measuring the accuracy of thematic maps derived from multispectral imagery, error/confusion matrix was used. The landuse/cover classification accuracy assessment was based on 250 random sampling points, comparison between each classified images, and comparison with Google Earth Imageries and existing landcover maps.

a) b)


c) d)

Plate 4.1: a) check dam b) semi-circular bund c) shrub land and d) bareland

4.2.4. Post Classification Change Detection

Following classification of imagery from the individual years, a post-classification comparison change detection algorithm was applied to determine changes in landuse/cover from 1988 to

1999, from 1999 to 2009 and 1988 to 2009. The post-classification was carried out in ENVI 4.5 using classified images of the periods 1988, 1999 and 2009.

4.2.5. GIS Data analysis and modelling

After accuracy assessment, the classified image was vectorized into polygons. This polygon coverage was then pre-processed to eliminate areas less than 1 ha as a minimum mapping unit for spatial landscape analysis. The true strength of GIS lies in its functionality of spatial analysis and modelling. Model based-raster data were utilized in this study. According to David (2002) raster is grid cells with a fixed number of row and columns that have several tables associated with them. Raster is different from vector data model because they may represent a continuous surface instead of a discrete feature. GIS data within raster model have several advantages relative to the vector GIS data.

Raster allows for faster analysis and operation, especially for any overlay and buffer type analysis (Dangermond, 1990). Raster also allows for modelling continuous surfaces such as determining optimal path through a surface. For this reason the raster data model was primarily utilised in this study. Then all the thematic maps of important factors were prepared using ArcGIS 9.2. These maps were rasterized for further analysis. The raster grid cells were defined with a cell size of 30m. The data layers of criteria that affect the suitability of sites for water harvesting structures were then reclassified so that they could be used as the rating maps required in this process.

Then these reclassified factor maps were taken to IDRISI Andes by converting to the appropriate file format for computing weights. The weight values were computed using pair-wise comparison method. The calculated weight values were then transferred to the ArcGIS, to create a suitability maps with a value range per cell matching that of the standardised criteria map using a range 1-5. Finally, the resulting raster maps were then vectorized. The final maps of suitability area are illustrated in the results and discussion section.

4.2.6. Direct Runoff Estimation

In this study the SCS CN method was used to estimate the direct runoff. The hydrologic group designation for any soil type can be either A, B, C, or D, where the runoff potential increases from A to D. The watershed was represented by 7 individual land cover classes in 4 categories. Soil hydrologic group types were predominately C and D (soil types with low infiltration and high runoff potential), representing 64.4% and 35.6% of the total watershed area, respectively.

Geographic Information Systems (GIS) allow for merging vector-based soil map units with the vector-based landuse/cover (LULC). The resultant product is a vector map of each soil map unit and LULC classification, commonly referred to as a hydrologic response unit (HRU) (Weissling *et al.*, 2009). CNs for each LULC and soil type combination are readily available in lookup tables found in various hydrology handbooks and manuals. This tabular CN values were taken to populate to the hydrologic response units. The specific area of each HRU was used to calculate a spatially weighted composite CN (CN_{comp}) for the watershed according to the following Equation:

$$CN_{comp} = \frac{\sum A_i CN_i}{\sum A_i} \qquad (8)$$

with A_i and CN_i being the area and curve number for each HRU within the watershed, respectively.

5. Suitability Analysis

Land suitability evaluation is an important step to detect the environmental limit in sustainable landuse planning. It deals with the assessment of land performances for a specific use. The identification of suitable areas for water harvesting structures is a multi-objective multi-criteria problem. The field survey indicated that most RWH interventions in and around the study area focused on surface runoff collection i) for groundwater recharge (check dam, semi-circular bund) ii) for domestic use (farm pond) and iii) for storage in the soil profile for tree and crop production (trenches and percolation pits).

This multi-objective multi-criteria methodology involved the following major steps: (i) Selection of criteria; (ii) assessment of suitability level for the criterion maps (standardization); (iii) assignments of weights to these criteria; (iv) collection of spatial data for generating maps for each criteria using GIS tools; (v) developing a GIS-based suitability model which combines maps through MCE process; and (vi) generating suitability maps.

5.1. Criteria selection and assessment of suitability level

In a vector-based GIS context, attributes of geographic features may serve as decision criteria while in a raster-based system, different raster datasets (maps) would represent the decision criteria (Heywood *et al.*, 2002). In the present study, a land suitability evaluation in a watershed has been carried out through examination of the indicators of land suitability especially for water harvesting. Based on the information obtained from field survey supported by expert judgment, five criteria were selected for the identification of potential areas for selected water harvesting structures, i.e. hydrologic soil group, drainage density, slope, geology, and land cover. The criteria used in the GIS analysis are presented and discussed below.

Each criterion was evaluated using a different set of data, at an appropriate scale, and with a specific model. For all of the criteria, spatial analysis procedures using a raster GIS were an important part of the evaluation process. Spatial maps created by using GIS-based methodology are illustrated in Figures 5.1-5.5.

5.1.1. Landuse/cover

Since landuse is the key component for controlling runoff and evapotranspiration, landuse maps of March 2009 (Figure 5.1) was considered for subsequent analysis. It was prepared by the classification of Landsat ETM^+ 2009 satellite image using supervised method with a standard procedure (Maximum Likelihood Classifier). The map was prepared with a scale of 30 meter. In the map, seven major landuse classes, namely bush land/shrub land (490 km^2) forest (37.63 km^2), agricultural land (145.14 km^2), scrubland (24.44 km^2), bareland (54.73 km^2), water bodies (6.61 km^2) and built-up area (2.36 km^2) were observed.

5.1.2. Hydrologic soil group

The suitability of a certain area either as catchment or as cropping area in RWH depends strongly on its soils characteristics. The infiltration rate of the soil determines the type of structure to be located and the surface runoff potential also depends on the soil texture of the area. The hydrologic soil group map (Figure 5.2) was derived from the FAO soil map. The soil map of the study area consists of two texture classes namely texture class 4 (Sandy, silty-clay and clay) and texture class 3 (sandy-clay-loam) covering 269.94 km^2 and 489.26 km^2 areas, respectively.

5.1.3. Slope

The ground slope is the main limiting factor for water harvesting. The slope map was generated from (Figure 5.3) the 30m Digital Elevation Model (DEM) obtained from Shuttle Radar Topographic Mission (SRTM). Subsequently the slope map was classified in to the following five broad classes; Level: 0 - 8%, Gentle: 8 - 15%, Moderate: 15 - 30%, Steep slope: 30 - 50% and Very Steep slope: > 50%.

5.1.4. Geology

Geology of the study area consists of Adigrat Formation (Ja), Ashangi Basalts (P_2a) and Aiba Basalts (P_3a). Geological map (Figure 3.3) of the study area was prepared by on screen digitizing of the geological map of Ethiopia using Arc/INFO as topological vector data. The data were cleaned and edited to polygon coverage and lithological attributes updated.

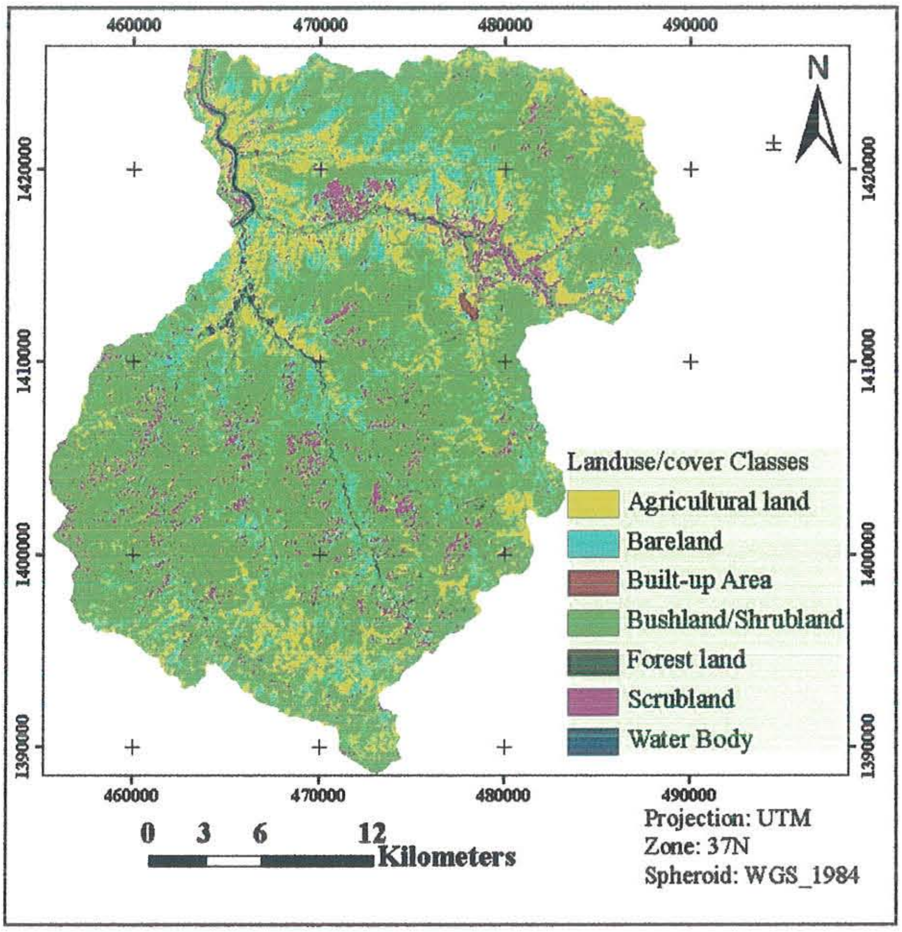


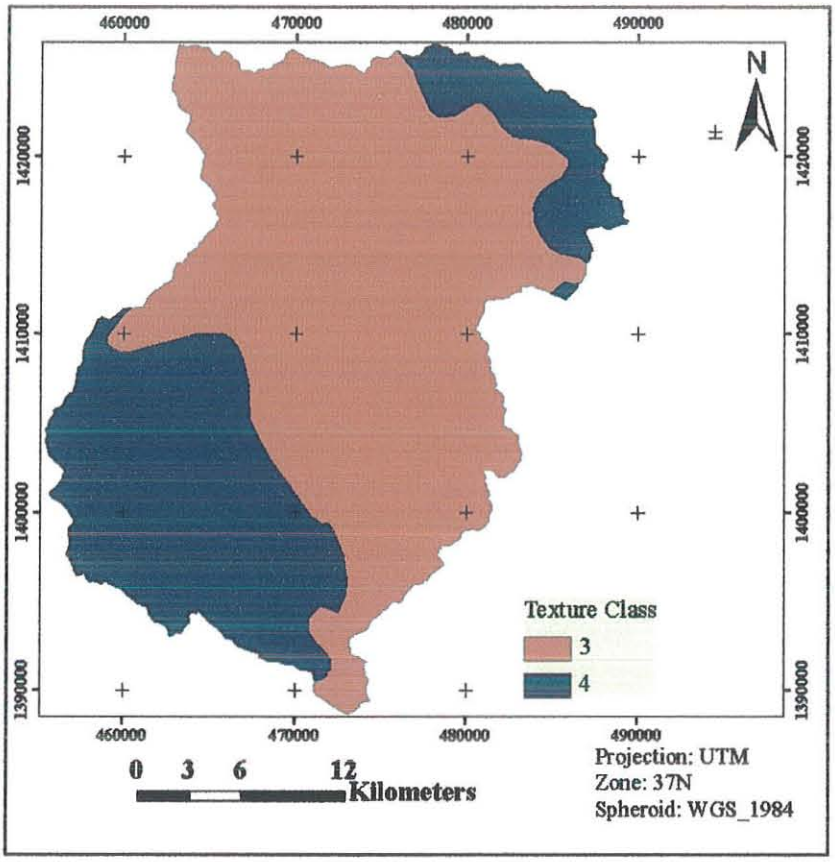
Figure 5.1: Landuse/cover map of the study Area

5.1.5. Drainage Density

The availability of the total quantity of surface water is proportional to the drainage order and some particular structure are suitable at a particular drainage order only for example, check dams should be constructed at lower order streams only. Drainage density map (Figure 5.4) of the study area has been prepared from 30m DEM.

5.2. Standardizing Criteria Maps

The first step in multi-criteria evaluations is to identify the relevant criteria that will allow, for each piece of land, a determination of suitability for that objective. Because of the different scales on which the criteria are measured, MCE requires that the values contained in the criterion map are standardized (Eastman, 2006) or transformed into units that can subsequently be compared (Malczewski, 1999). Therefore, the criteria maps were re-classified into standard coding.



Source: FAO, 1997

Figure 5.2: Map of Hydrologic Soil Group

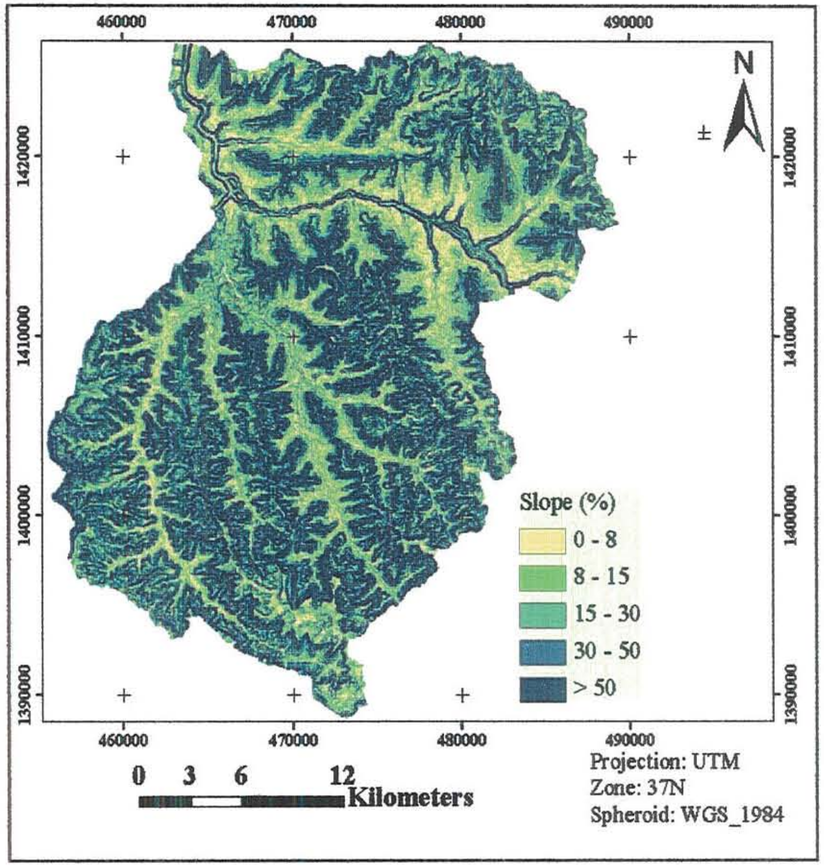


Figure 5.3: Slope map of the study Area

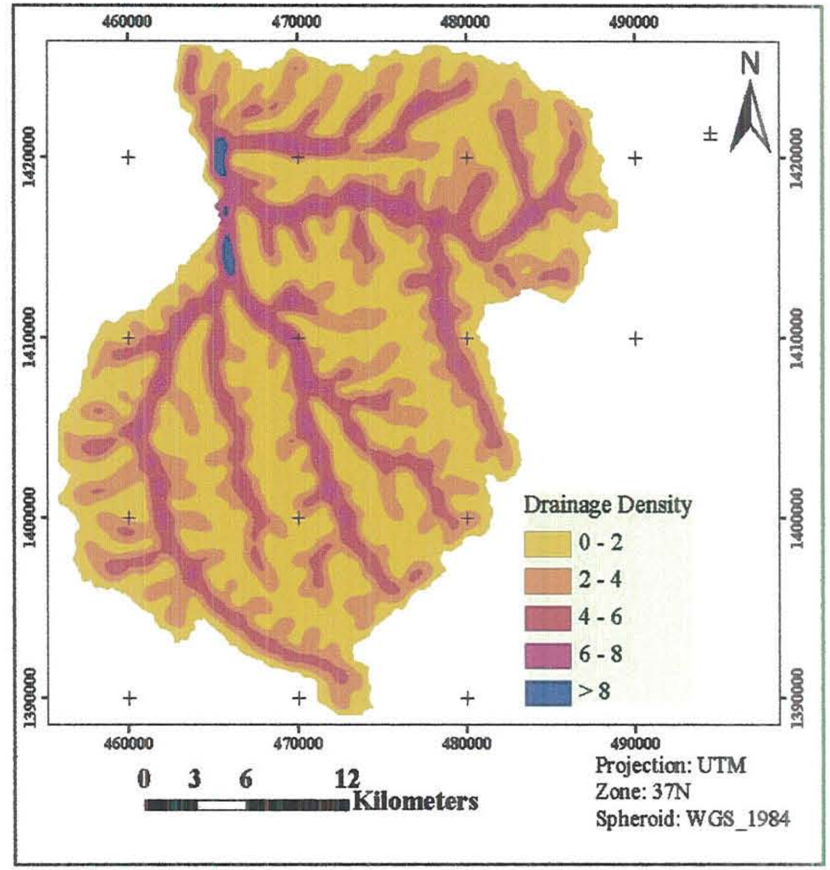


Figure 5.4: Map of Drainage Density

5.3. Decision rules in Selecting Suitable Sites for Water Harvesting Structures

Decision rules for selecting suitable sites for conserving water depends on many variables like slope, landuse, soils, geology, drainage, etc... These rules are used as an expert knowledge in the developed expert classifier shell and discussed in the following sections.

Check Dams:

Check dams are constructed at lower order streams (first to third order). The slope of the terrain should be flat to gentle so as to retain maximum quantity of water with less height of check dam. They are proposed where water table fluctuations are very high and the stream is influent and/or internally effluent. It should be located nearer to agricultural areas and settlement to convey the water. Check dams have greater importance than other structures since it has got a complimentary benefit of controlling soil erosion (Rao *et al.*, 2003). The soils should be less to medium permeable (i.e., sandy clay loam.) to allow some recharge to the downstream side of the dam if necessary (Singh, 2009).

Farm Ponds:

Farm ponds are made either by constructing an embankment across a watercourse or by excavating a pit or the combination of both. Normally, such structures are provided within individual farms. Farm ponds are created by excavating pits in areas having flat topography, low permeable rock formation underneath and should be free from any faults. Preferably these ponds should be nearer to agricultural areas (Rao *et al.*, 2003). Ponds fed by surface runoff must have impermeable soils beneath the pond basin to prevent excess downward seepage. The lope should be less than 10 per cent (Singh, 2009).

Semi circular bund:

These structures are generally constructed on active aquifer and on scrub or barren land. Slope of the area should not be more than 5% and soil should be highly permeable. It should be constructed on area having highly permeable lithology underneath with low drainage density (www.fao.org/documents/u3160e03.htm).

Contour bund:

Contour bund can be easily constructed but it is limited to availability of human power (for earth moving) and stones. It is useful where ground slope ranges from 1- 5%. It is mostly constructed on farm land (www.fao.org/documents/u3160e03.htm).

5.4. Assigning weight of factors and Multi Criteria Evaluation (MCE)

The purpose of weighting is to express the importance or preference of each factor relative to other factor on the effectiveness of the WHSs. Factors established in this phase are not unique, but they are the most relevant. The more important the factor and variable is, the higher the weight. Criterion weighting is performed using expert judgments to compare each criterion to each water harvesting structure based on experts' preferences. Expert opinion of specialization in water harvesting or soil and water conservation was very crucial in this phase. These experts from the Agriculture and rural development line offices have identified the following variables as relevant to suitable WHSs areas: soil texture, drainage density, geology, slope, and landuse/cover.

Although a variety of techniques exist for the development of weight, one of the most promising techniques is the Pairwise Comparison Matrix (PWCM) developed by Saaty (1980) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (Eastman *et al.*, 1995). Using the above mentioned factors/variables as criteria, a pairwise comparison matrix was constructed (Table 5.2 - 5.5). The comparison concerns the relative importance of the two criteria involved in determining the suitability of the stated objective.

Ratings were provided on a nine-point continuous scale, which ranges from 1 to 9 (Table 5.1). This method has been tested theoretically and empirically for a variety of decision making situations, including spatial decision making and has been incorporated into a GIS based decision making procedure (Malczewski, 1999). In the procedure for MCE using *Weighted Linear Combination* (WLC), it is necessary that the weights sum to 1.

Table 5.1: Scale of Pair-wise Comparison developed by Saaty (1980)

Preferences in numeric variables	1	3	5	7	9	2,4,6,8
Preferences in linguistic variables	Equal importance	Moderate importance	Strong importance	Very strong importance	Extreme importance	Intermediate values between adjacent scale values

Table 5.2: Pair-wise Comparison Matrix for Semi-circular Bund

	Drainage Density	Geology	Landuse/cover	Slope (%)	Soil Texture
Drainage Density	1				
Geology	3	1			
Landuse/cover	1/4	1/5	1		
Slope (%)	4	3	6	1	
Soil Texture	4	1/2	3	1/3	1

Table 5.3: Pair-wise Comparison Matrix for Check Dam

	Drainage Density	Geology	Landuse/cover	Slope (%)	Soil Texture
Drainage Density	1				
Geology	1/5	1			
Landuse/cover	1/4	1	1		
Slope (%)	1/5	1/2	2	1	
Soil Texture	1/3	1/2	1	1/3	1

Table 5.4: Pair-wise Comparison Matrix for Farm Pond

	Drainage Density	Geology	Landuse/cover	Slope (%)	Soil Texture
Drainage Density	1				
Geology	1/5	1			
Landuse/cover	3	5	1		
Slope (%)	3	5	1	1	
Soil Texture	5	6	1	1	1

Table 5.5: Pair-wise Comparison Matrix for Contour Bund

	Drainage Density	Geology	Landuse/cover	Slope (%)	Soil Texture
Drainage Density	1				
Geology	1/3	1			
Landuse/cover	3	8	1		
Slope (%)	2	5	1/3	1	
Soil Texture	5	5	1	1/2	1

Classes with higher scores are most suitable or preferred. Using Pairwise Comparison Matrix, factor weights were calculated and 5 composite layers were constructed (Table 5.6). The resolution of all the factor maps were not the same, therefore, all the layers were converted to the same output raster cell size as 30 m in order to make an effective weighted overlay.

Table 5.6: Compound Weight Index for the Water harvesting structures

Weight Factor	**Weight in % For**			
	Check Dam	**Farm Pond**	**Semi-circular Bund**	**Contour Bund**
Drainage Density	50.27	10.82	9.65	9.46
Geology	15.56	4.29	23.63	4.05
Landuse/cover	10.19	26.64	4.69	36.25
Slope (%)	14.92	26.64	43.93	23.80
Soil Texture	9.06	31.61	18.11	26.44
Consistency Ratio	0.09	0.05	0.08	0.08

In all the cases, the consistency ratio (CI/CR) was less than 0.1. Hence, weight assigned can be accepted with a high degree of confidence.

5.5. The Overlay Analysis

Once the composite layers and their weights were obtained, the model for the overlay analysis was constructed using the spatial modeller tool (Figure 5.5). Then the model was run to produce the map of suitable areas for each WHSs. The grading scale used in the present study for the suitability index was 1–10, which is, respectively, from the least to the most suitable area. Table 5.7 shows the ratings of classes in the factor maps for each WHS. Then the resulted suitability maps were converted to vector data model for further overlay analysis. Finally, union overlay was carried out to produce a single final suitability map.

Table 5.7: Weights and ratings assigned to variables and classes for Water Harvesting site suitability modelling

No.	Variables	Classes	Ratings			
			Check Dam	Semi-circular Bund	Farm Pond	Contour Bund
1	Drainage Density	0 - 2	10	10	10	10
		2 - 4	9	2	4	2
		4 - 6	7	Res	Res	Res
		6 - 8	5	Res	Res	Res
		> 8	Res	Res	Res	Res
2	Slope (%)	0 - 8	10	10	10	10
		8 - 15	9	1	2	2
		15 - 30	7	Res	Res	Res
		3 - 50	3	Res	Res	Res
		> 50	Res	Res	Res	Res
3	Geology	Adigrat Formation (Ja)	10	10	8	8
		Ashangi Basalts (P_2a)	9	8	9	9
		Aiba Basalts (P_3a)	6	6	10	10
4	Landuse/cover	Agricultural Land	7	Res	10	10
		Bareland	8	8	9	7
		Built-up Area	6	Res	,Res	Res
		Bush land/shrub land	10	10	3	8
		Forest Land	9	9	2	9
		Scrubland	5	7	1	1
		Water body	Res	Res	Res	Res
6	Soil Texture	3	10	10	9	10
		4	9	9	10	9

Note: Res= Restricted

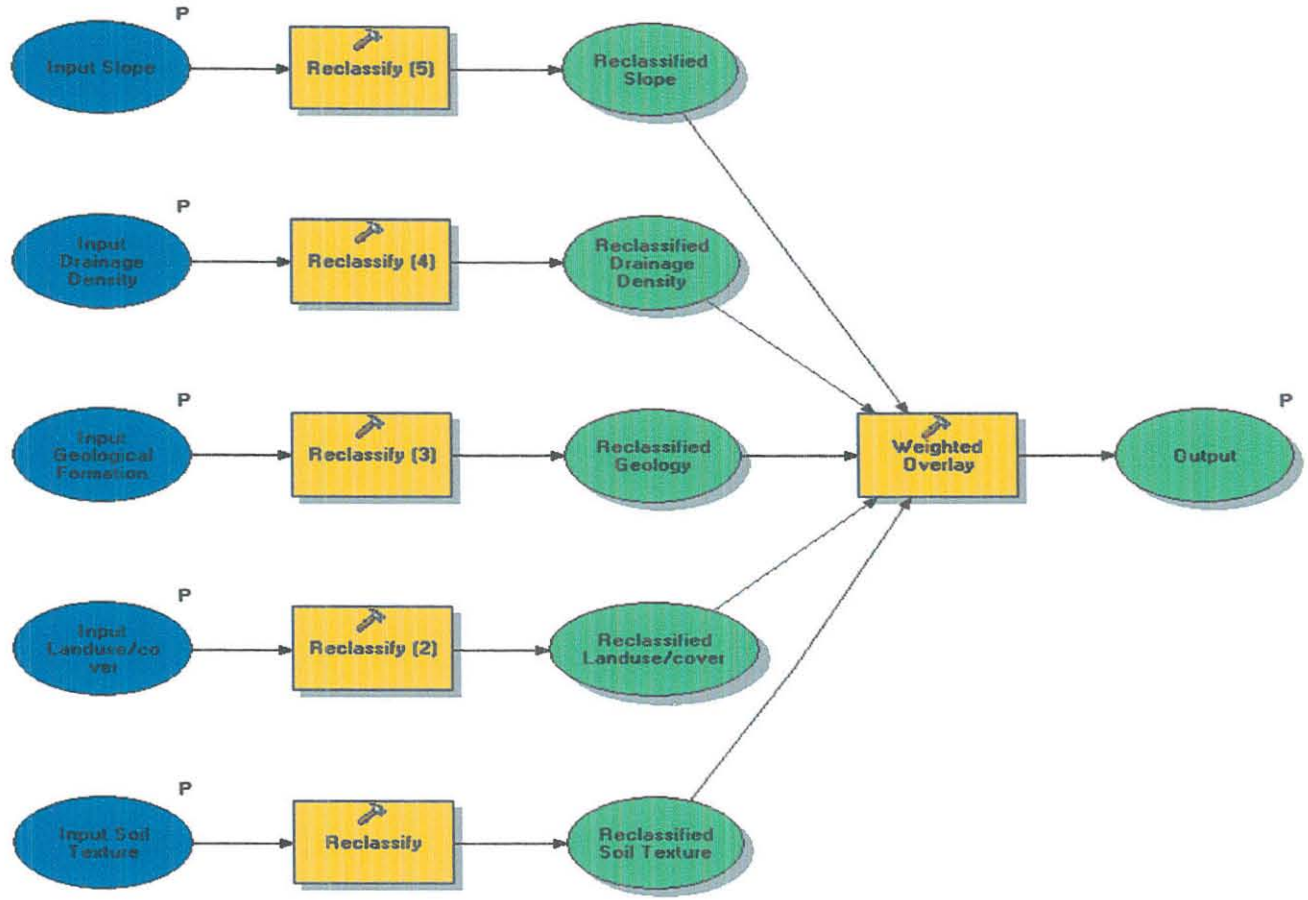


Figure 5.5: The spatial modeller used for raster based weighted overlay

6. Result and Discussion

6.1. Landuse/cover Change Result

Three landuse/cover maps were produced, respectively, for years 1988, 1999 and 2009 using the maximum-likelihood algorithm (Figure 6.1- 6.3). These maps show 6 landuse/cover types for 1988 and 7 landuse/cover types for 1999 and 2009. These maps were produced from the combination of the multi spectral bands corresponding to blue, green, red and near infrared (B, G, R, NIR) which were found to be appropriate to identify the landuse/cover types in the study area. General patterns of landuse/cover identified in all three images were largely dominated by bush land/shrub land, bareland and agricultural land areas.

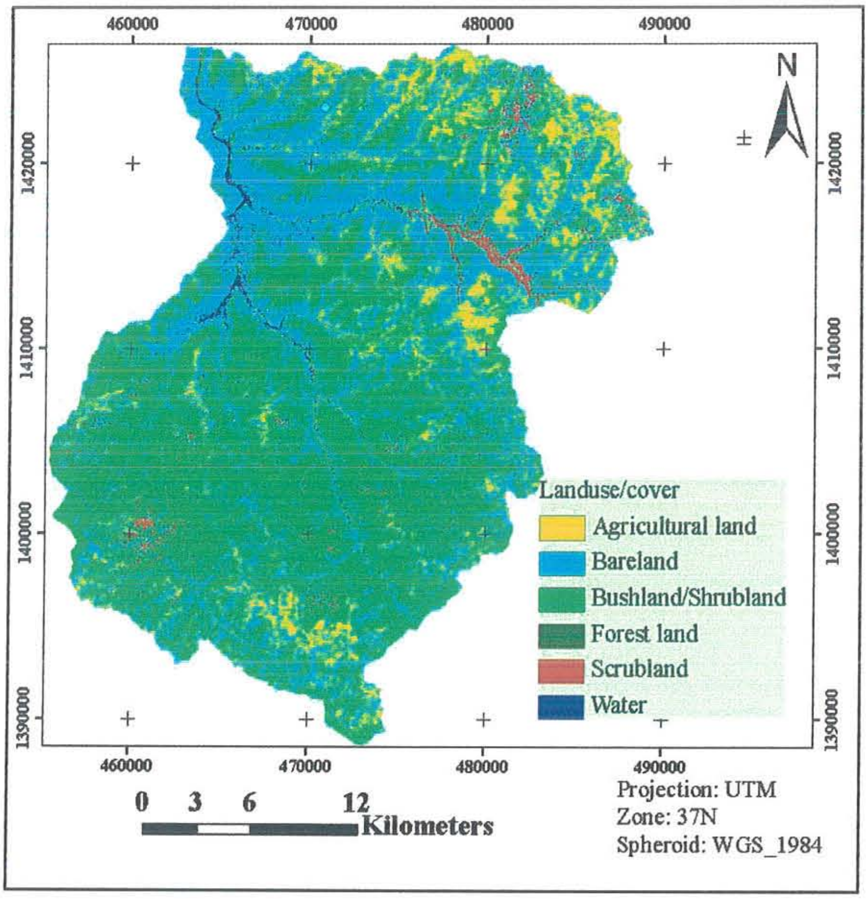


Figure 6.1: Landuse/cover map for year 1988

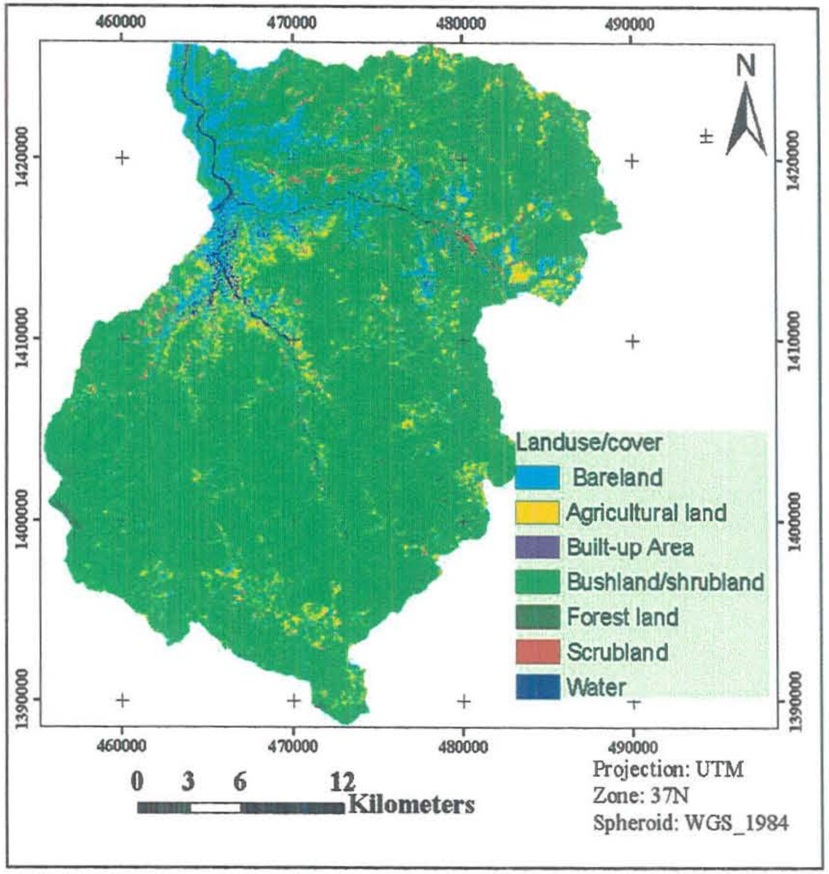


Figure 6.2: Landuse/cover map for year 1999

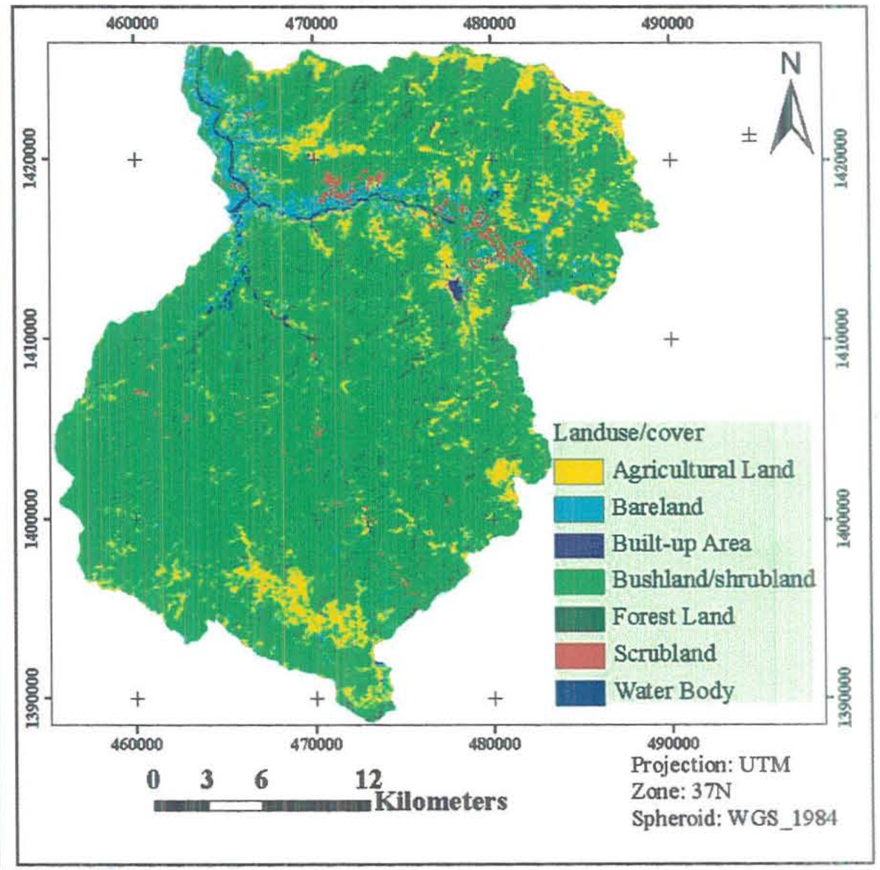
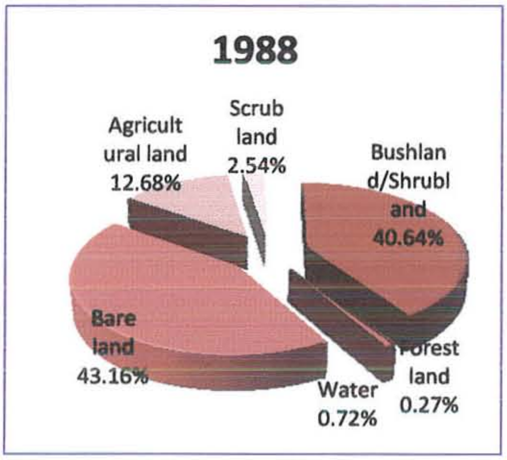
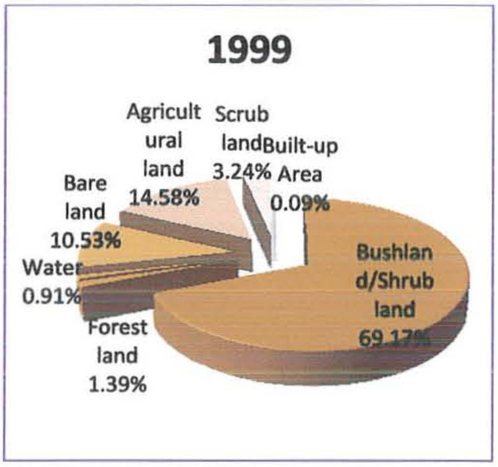


Figure 6.3: Landuse/cover map for year 2009

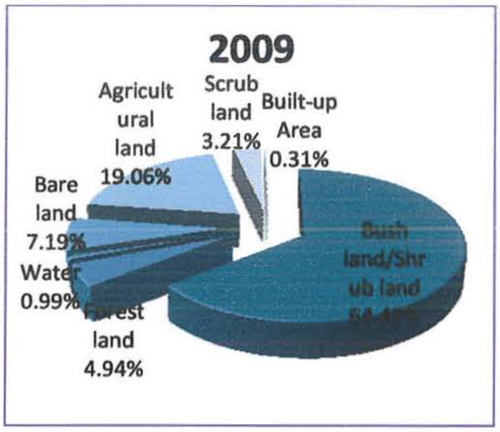
Informal discussion and field visit with the experts of ZWARDO and local farmers were also used as an input for post-classification accuracy assessment. The results indicated that the overall accuracy were 89.20%, 92% and 95.20% with Kappa index 83.31%, 81.49% and 89.82% for the 1988, 1999 and 2009 images respectively (Annex I). User's accuracy of individual classes ranged from 85.84% to 100% and producer's accuracy ranged from 33.33% to 100%. This shows maps have sufficient accuracy for post classification comparison approach (Yuan et al., 2005).



a)



b)



c)

Figure 6.4: The percentage Share of Landuse/cover units in a) 1988, b) 1999 and c) 2009

In 1988, bareland 328.57 km^2 (43.16%) followed by bush land/shrub land 309.44 km^2 (40.64%) were the dominant landcover units, and these were followed by small scale farming with an area coverage of 96.52 km^2 (12.68%) (Figure 6.4a). Scrubland covers 19.31 km^2 (2.54%) of the area. This landcover unit is dominated along the river banks. Ironically there was still some forest standing stock 2.02 km^2 (0.27%) during this period (Table 6.1). This was mainly observed around the south western highlands of the area. These areas receive relatively higher precipitation than the rest of the watershed areas.

Table 6.1: Area coverage of Main Landuse/cover Classes the three periods in km^2 and in %

Landuse/ cover Class	1988		1999		2009		Percentage Change in Landuse/cover	
	Area	%	Area	%	Area	%	$T_2 - T_1$	$T_3 - T_2$
Bushland/ Shrubland	309.44	40.64	526.65	69.17	490.44	64.42	28.53	-4.76
Forest land	2.02	0.27	10.61	1.39	37.63	4.94	1.13	3.55
Water	5.5	0.72	7.54	0.99	6.61	0.87	0.27	-0.12
Bareland	328.57	43.16	80.15	10.53	54.73	7.19	-32.63	-3.34
Agricultural land	96.52	12.68	111.01	14.58	145.14	19.06	1.90	4.48
Scrubland	19.31	2.54	24.68	3.24	24.44	3.21	0.71	-0.03
Built-up Area	0	0.00	0.69	0.09	2.36	0.31	0.09	0.22
Class Total	**761.35**	**100**	**761.35**	**100**	**761.35**	**100**		

Note: T1, T2 and T3 are 1988, 1999 and 2010 respectively.

After eleven years, small-scale farming had increased by 1.90% to reach 111.01 km^2 (14.58%) during 1999 land utilization. Other landcover units gained in the same period including; bush land/shrub land having an area of 526.65 km^2 (69.17%), forest land 10.61 km^2 (1.39%), built-up areas 0.69 km^2 (0.09%), scrubland 24.68 km^2 (3.24%) and water body 7.54 km^2 (0.99%) (Figure 6.4b).

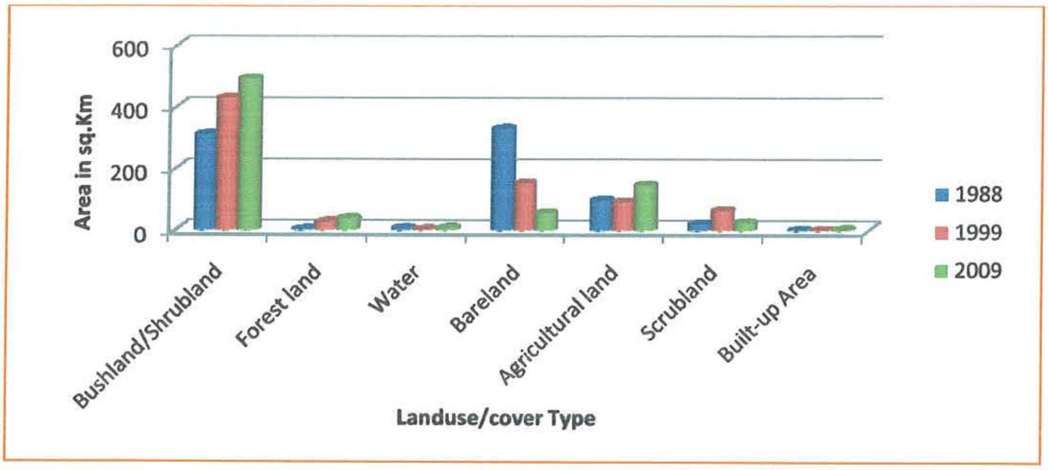


Figure 6.5: Area coverage of Main Landuse/cover Classes during the three years

The major landuse/cover classes of 2009 are the same as that of the 1999. As indicated in the Table 6.1 the greatest share of landuse/cover from all the classes is bush land/shrub land, which covers an area of 490.44 km^2, contributes (64.42%) of the study area. Since the area is dependent on animal husbandry most of the cattle and sheep and goats are left for grazing and browsing in these areas. There is no such isolated grass land left for grazing. Bare land and scrubland have an area of 54.73 km^2 (7.19 %) and 24.44 km^2 (3.21 %), respectively. In this period in contrary to the 1988, forest land has an area of 37.63 km^2 (4.94 %). Whereas water and, built-up area which have only 6.61 km^2 (0.87 %) and 2.36 km^2 (0.31 %), respectively from the total size of the watershed contribute the least coverage.

6.2. Post-classification Change Detection

The prime requisite for better landuse planning is information on existing landuse and their spatial distribution as they are important to determine landuse policy, planning of every development activity in an area. In every corner of the world landuse/cover change is inevitable. For change detection post-classification comparison approach was employed. There are several ways to quantify the land cover change results. One basic method is to tabulate the totals for each landuse cover type and examine the trends between the years.

The change matrix was presented in Tables 6.3 - 6.5, making it easy to identify not only where changes have taken place, but also the class into which the pixels are changed. Values in the table were sorted by area. The overall landuse/cover changes during the 1988–1999 period showed distinct trends as compared to those of the 1999–2009 period. For example, the 'bareland to bush land/shrub land', 'agricultural land to bush land/shrub land' and 'bareland to scrubland' change rates were greater during this period, while the 'forest land to built-up area', 'agricultural land to built-up area' and 'scrubland to water body' change rates were less. On the other hand, 'bare land to agricultural land', 'scrubland to bush land/shrub land' and 'agricultural land to bush land/shrub land' change rates were greater during the 1999-2009 period, while 'water body to forest land', scrubland to water body' and 'water body to built-up area' changes rate were less.

However, in particular, agricultural land has not increased considerably, as the case in other areas. This is because most of the area, as it can be seen from the Table 6.1, is covered by bare land and bush land/shrub land which are in most cases inhospitable for agriculture. The majority of the built-up area, as indicated in the change matrix of both periods, was converted from bareland. According to the Woreda Finance and Economic Development Office

(WFEDO) the centre of the Woreda was established in 1994. It can be seen from the values in the Table 6.2 that the built-up area growing at a rate of 0.11 from 1988-2009 at a cost of other landuse/cover units.

The transition among major landuse types between 1988 and 1999 was also determined based on classified images. According to the classified images, major transition of landuse type between 1988 and 1999 years relates to the 161.24 km^2 vegetation areas created from open areas (Table 6.3). This is probably a result of increase of bush land/shrub land and agricultural land. However, 22.42 km^2 vegetation areas were converted into barelands, that would be explained by land clearing for settlements or some other social pressure would cause the change. However, there was a net area of 138.82 km^2 shift from open areas to vegetation areas. During the same period, water bodies decreased to approximately 2.1 km^2, being replaced by vegetation uses (Table 6.3).

Major landuse/cover conversions during the second period were from bareland to bush land/shrub land, scrubland to bush land/shrub land, bareland to agricultural land, Agriculture to bush land/shrub land and bush land/shrub land to forest with 34.38 %, 60.1%, 30.31% and 35.73%, respectively. During this period the higher conversion rate were those of bareland and bush land/shrub land having -9.71km^2 per year and 6.27 km^2 per year, respectively. During study period (1988-2009) bush land/shrub land had maximum changes between all landuse/cover classes. During this time bareland decreased by a rate of -13.04 km^2 per year, while bush land/shrub land increasing by 8.62 km^2 per year.

Table 6.2: Landuse/cover change rate

Landuse/cover Class	**1988-1999**		**1999 - 2009**		**1988-2009**	
	Area (Km^2)	Change/yr (km^2/yr)	Area (km^2)	Change/yr (km^2/yr)	Area (km^2)	Change/yr (km^2/yr)
Bare land	-176.75	-16.07	-97.08	-9.71	-273.84	-13.04
Agricultural land	118.45	10.77	54.91	5.5	48.62	2.32
Bushland/ Shrubland	-6.29	-0.57	62.55	6.26	181.01	8.62
Forest land	23.63	2.15	11.98	1.2	35.61	1.7
Scrubland	43.9	4.0	-38.77	-3.88	5.13	0.24
Water	-3.41	-0.31	4.52	0.45	1.11	0.05
Built-up Area	0.47	0.04	1.89	0.19	2.36	0.11

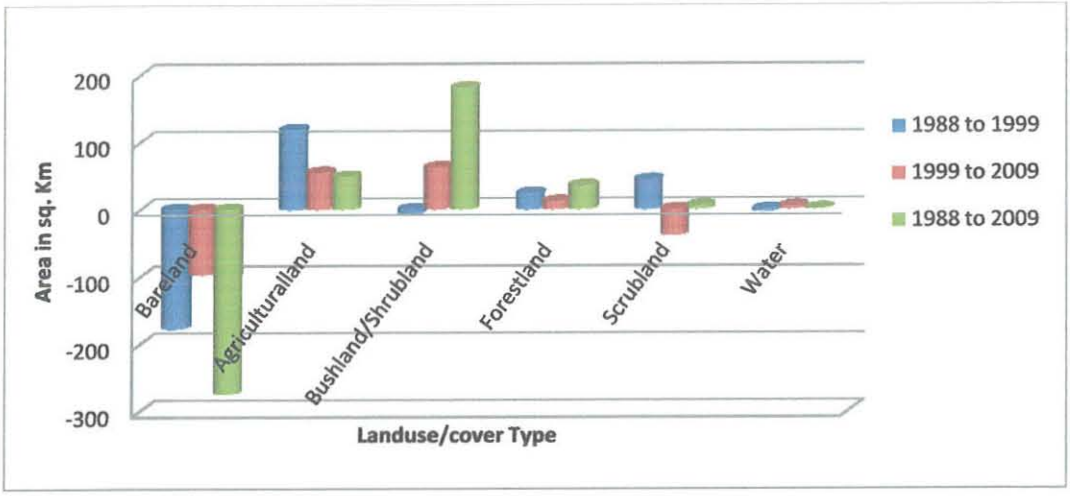


Figure 6.6: Post Classification Difference showing landuse/cover change

6.2.1. Causes of landuse/cover changes

Major landuse/cover changes within the study area (Table 6.2) are a result of 1) the recurrent drought occurred in the northern parts of the country (including the study area) 2) the establishment the town (centre of the Woreda), 3) the domestic war which lasts for nearly two decades and 4) the dynamic nature of agriculture expansion as highlighted by the dominant 'bush land/shrub land to agriculture', 'bareland to agriculture', 'agricultural land to bareland' and 'agricultural land to scrubland' conversions (Table 6.3 - 6.5).

Although it is not quantified the impact of wildfires and droughts on landuse/cover changes, local knowledge suggest that the expansion of scrubland and bareland is not only a consequence of forest land clearing but also due to the impact of occasional wildfires in dry summer season as well as the devastating effects of the 1984/85 famine.

6.2.2. Related studies

Studies elsewhere show different trends in landuse/cover changes. For example, in the Fincha valley areas of East Wolega, Zeleke Kebebew (2005) reported that during the period 1972-1986 most of the bushland, woodland and bush/shrubland have been replaced by crop fields. On the other hand, Woldesemayat, 2007 indicated that rapid expansion of cultivated land in Bonga (43.7 %) during the period 1990-2006 was due to high population pressure/settlement. It was observed that cultivated land increased from 10% in 1973 to 37% in 2003 in Muga watershed was mostly at the expense of shrub land and bush land (Ermias, 2007) and contributes to the land degradation occurred in the area. On the other hand, Zelalem (2007) showed that in 2000 the water body has decreased to 24 % and the forest coverage to 4 % while agricultural lands have tremendously increased to 12 %.

6.2.3. Efforts So far

It is clear that the fragile ecosystem of the area has come under severe pressure because of lack of water. Most of the people in the area are suffering and they are still dependent on food aid for most of the time during the year. This is mostly due to loss of land cover through the dynamics of landuse/cover and because of the aforementioned reasons. GOs and NGOs along with the local people are striving to make the area hospitable for their livelihood. One of their endeavours is to implement soil and water conservation works along with the Productive Safety Net Program.

The result of their effort can be seen at from the findings above. For example, the increase in bush land/shrub land during the 1988-1999 period was because the land was devoid of the people due to the 1984/85 famine. Some of the people were displaced by themselves in search of food and others were taken to other places of the country by the government for settlement. On the other hand, the increase in this landcover unit during 1999-2009 period was due to area closure undertaken by GO and NGOs in collaboration with the local people.

Again there was an increase in bush land/shrub land which was converted from built-up areas during the 1999-2009 period. This was because the people were forced to leave the up-land areas where erosion and degradation were severe. Even though, these areas were being covered by vegetation and under relatively minimum pressure, they were not supported by appropriate physical measures. On one hand, these structures were built on food for work basis; on the other hand they were mostly built as a campaign.

Rain water harvesting is one of the development activities that has been and is being implemented in the area. Even though, it is considered as one activity by itself, most of the time it is implemented as one component of soil and water conservation activities. These activities were implemented for not less than two decades. As it can be seen from the field visit and the change results above the positive changes are not showing up as expected. It needs special attention from the planning stage to its implementation.

Table 6.3: Conversion Matrix from 1988 to 1999; area in km^2

	Landuse/cover Class	Initial Image (1988)							
		Bushland/ Shrubland	Forest land	Water	Bareland	Agricultural land	Scrubland	Built-up Area	Row Total
Final Image (1999)	Bushland/ Shrubland	259.06	1.3	1.02	121.92	32.48	12.11	0	427.89
	Forestland	18.82	0.23	0.01	4.8	0.61	1.18	0	25.65
	Water	0.13	0.1	1.3	0.5	0.06	0	0	2.09
	Bareland	11.75	0.24	2.52	125.16	10.51	1.63	0	151.81
	Agricultural land	10.76	0.11	0.63	39.32	38.56	0.86	0	90.23
	Scrubland	8.9	0.04	0.02	36.43	14.3	3.52	0	63.2
	Built-up Area	0.02	0	0	0.44	0	0.01	0	0.47
	Class Total	309.44	2.02	5.5	328.57	96.52	19.31	0	761.34

Table 6.4: Conversion Matrix from 1999 to 2009; area in km^2

	Landuse/cover Class	Initial Image (1999)							
		Bushland/ Shrubland	Forest land	Water	Bareland	Agricultural land	Scrubland	Built-up Area	Row Total
Final Image (2009)	Bushland/ Shrubland	348.11	19.77	0.1	52.19	32.24	37.98	0.06	490.44
	Forestland	31.8	5.41	0	0.19	0.17	0.06	0	37.63
	Water	1.71	0	1.83	2.56	0.5	0	0	6.61
	Bareland	7.31	0.17	0.1	41.55	2.71	2.58	0.32	54.73
	Agricultural land	29.79	0.13	0.05	46.02	52.99	16.1	0.05	145.14
	Scrubland	8.81	0.16	0	7.64	1.4	6.42	0.01	24.44
	Built-up Area	0.37	0	0.01	1.67	0.22	0.06	0.03	2.36
	Class Total	427.89	25.65	2.09	151.81	90.23	63.2	0.47	761.35

Table 6.5: Conversion Matrix from 1988 to 2009; area in km^2

		Initial Image (1988)							
	Landuse/cover Class	**Bushland/ Shrubland**	**Forest land**	**Water**	**Bareland**	**Agricultural land**	**Scrubland**	**Built-up Area**	**Row Total**
Final Image (2009)	**Bushland/ Shrubland**	251.14	1.33	1.8	180.41	42.21	13.55	0	490.44
	Forestland	34.96	0.28	0.04	1.18	0.97	0.2	0	37.63
	Water	1.33	0.16	2.22	2.12	0.76	0.01	0	6.61
	Bareland	3.74	0.14	0.61	47.47	1.17	1.6	0	54.73
	Agricultural land	13.81	0.08	0.76	79.59	49.86	1.04	0	145.14
	Scrubland	4.21	0.02	0.04	16.04	1.25	2.89	0	24.44
	Built-up Area	0.25	0.01	0.03	1.77	0.29	0.01	0	2.36
	Class Total	309.44	2.02	5.5	328.57	96.52	19.31	0	761.35

6.3. Suitability Results

6.3.1. Suitable site for Check Dam

The suitable areas for check dam, as shown in the Figure 6.7 are located out side the river valleys. The total coverage of suitable site for this water harvesting structure is 48.33%. Out of this 68.1% (Table 6.10) is located on bush land/shrub land cover unit. Most of the suitable sites are situated on the upland areas of the catchments. This is more appropriate as watershed development activities commence from the upper catchments. The conserved water will feed the rivers and some springs down.

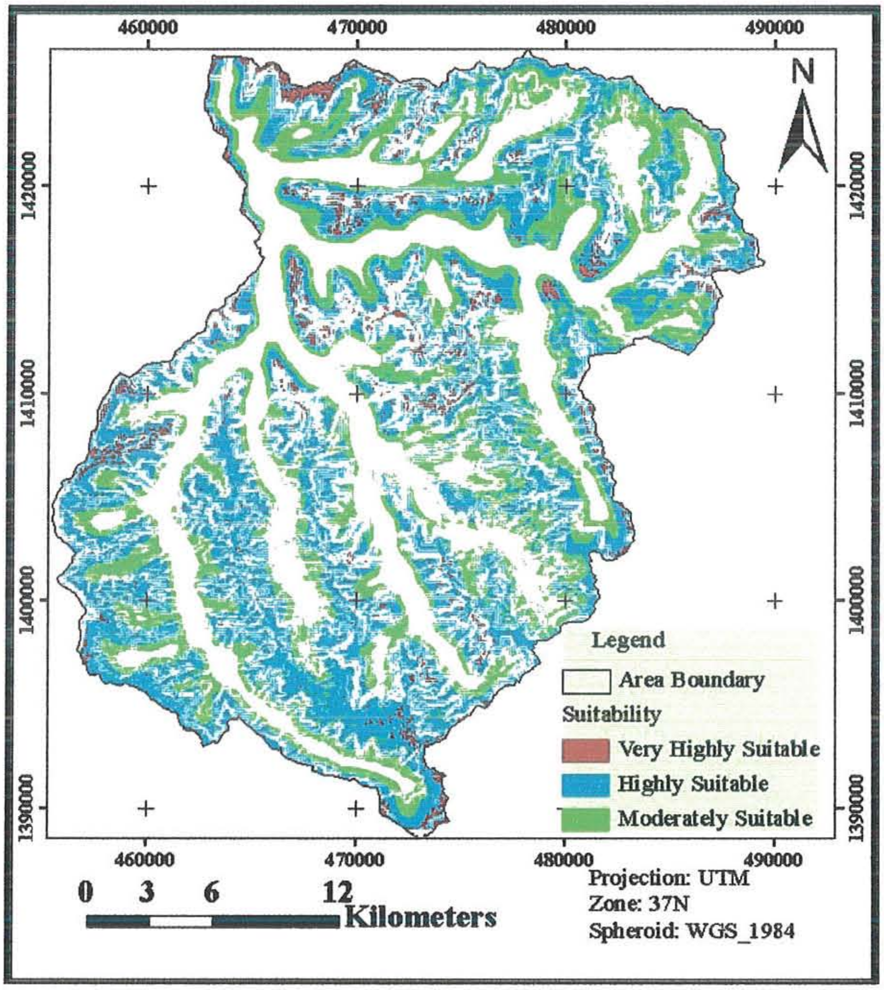


Figure 6.7: Suitability Map for check dam

Overlay analysis of the suitable map with map of drainage order was made to see the distribution of suitable area for check dam with respect to the drainage order (Figure 6.8). The summarized values presented in Table 6.6 showed that large portion (4.9%) of it will be suited on 1st order streams. 62.4% of the area suitable for check dam is on Sandy Clay Loam soil texture class (Table 6.8). 55.5% of this area is suited on slope range 15-30% (Table 6.9).

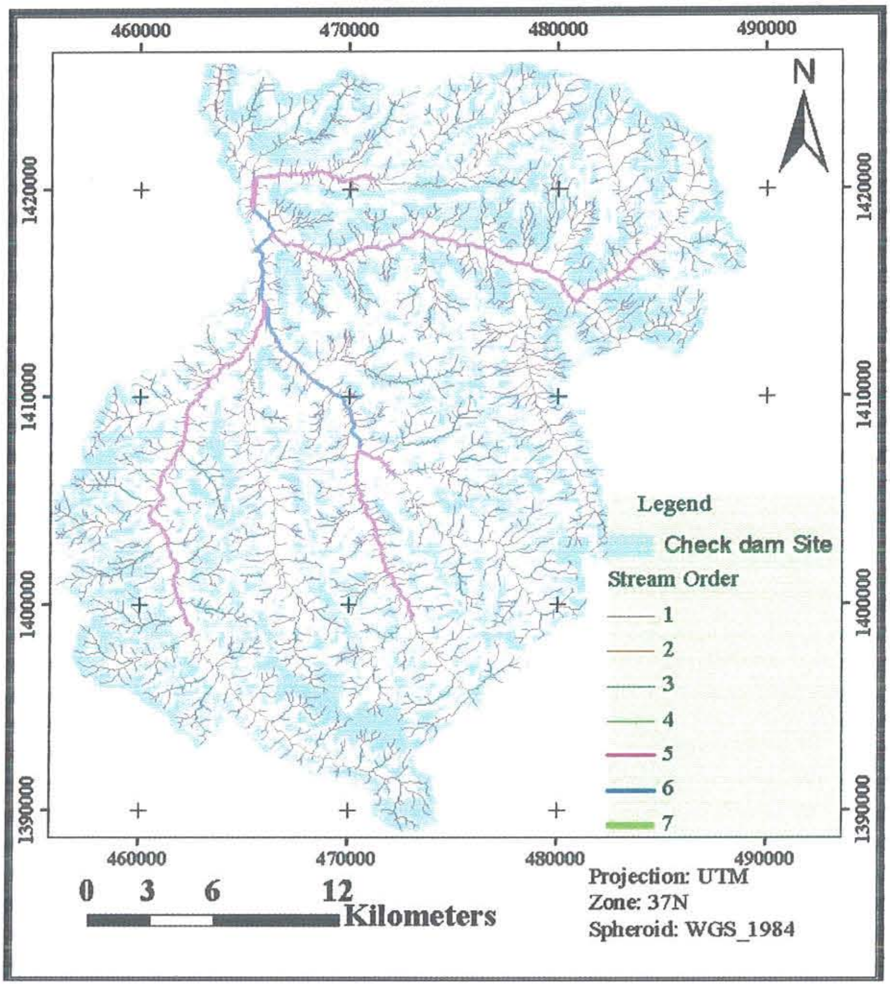


Figure 6.8: Suitable site for check dam Vs Stream order

Table 6.6: Distribution of Check dam per stream order

Stream Order	Area coverage in km^2	Area coverage in %
1	17.84	4.9
2	8.05	2.2
3	2.99	0.8
4	0.35	0.1

6.3.2. Suitable Sites for Farm Pond

Map of suitable sites for farm pond is shown in the Figure 6.9. These are located mostly in the southern and north-eastern and small patches in the central north eastern part of the watershed near the river valleys. The total coverage of suitable site for this water harvesting structure is only 1%. Out of this 83.8% is located on agricultural landcover unit (Table 6.10).

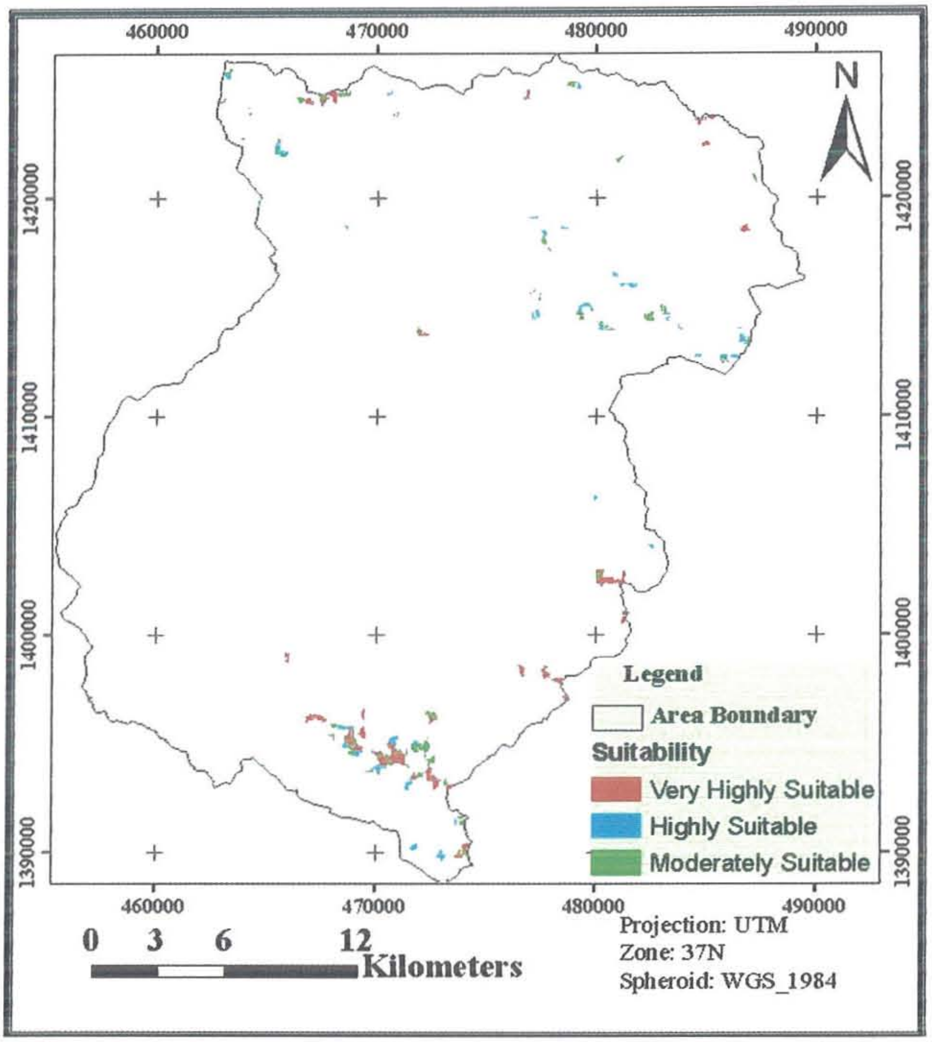


Figure 6.9: Suitability map for Farm Pond

As shown in Table 6.8 58.7% of the area suitable for farm pond is on Sandy Clay Loam soil texture class while the rest 41.3% is on more appropriate Sandy, Silty Clay, Clay. 75.6% of this area is suited on slope range 8-15% (Table 6.9).

Table 6.7: Area coverage of WHSs with suitability classes in km^2

Suitability Rate	Check dam	Contour Bund	Semi-circular Bund	Farm Pond
Very highly suitable	23.82	4.79	1.16	4.76
Highly suitable	211.58	7.74	6.64	5.33
Moderately suitable	141.91	13.6	3.04	12.46

6.3.3. Suitable Sites for Semi-circular Bund

Map of suitable sites for Semi-circular bund governed predominantly by slope, is shown in the Figure 6.10. These are located mostly in the southern tip and central north-eastern and small patches distributed in all parts of the watershed. The total coverage of suitable site for this water harvesting structure is only 1%. Out of this 66.6% is located on bush land/shrub land landcover unit.

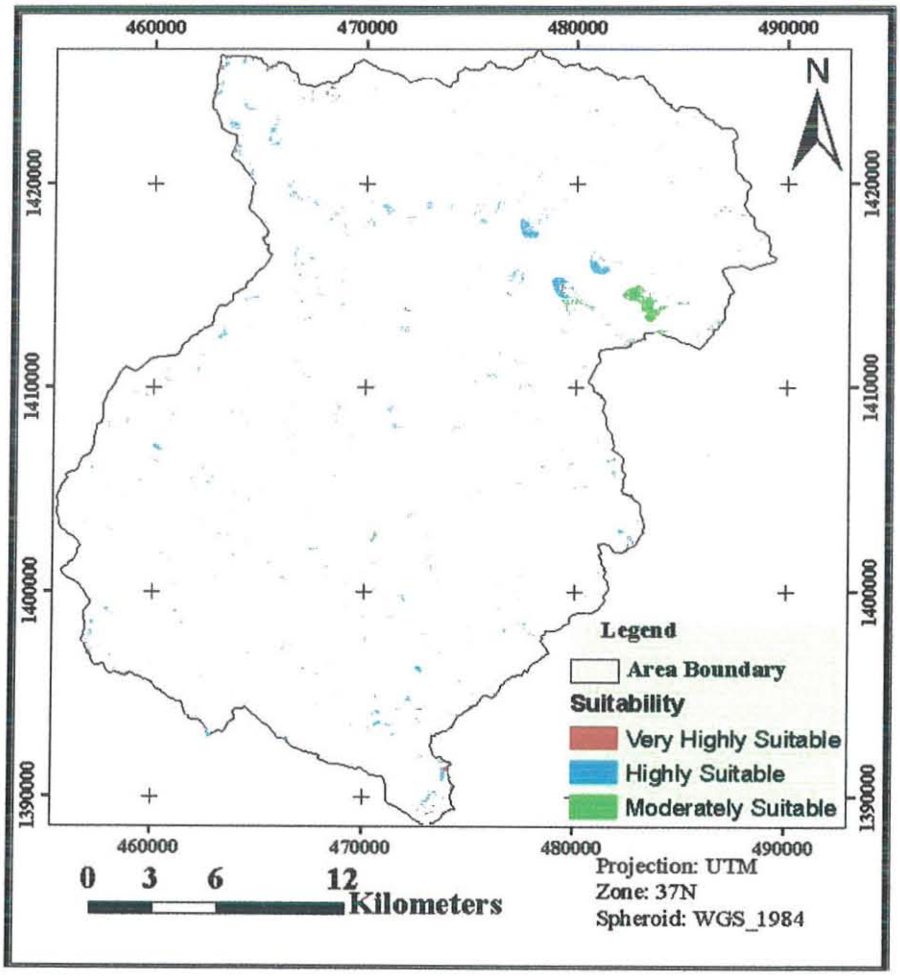


Figure 6.10: Suitability map for Semi-circular Bund

81% of the area suitable for semi-circular bund is on relatively more appropriate Sandy Clay Loam soil texture class (Table 6.8). 79.9% of this area is suited on slope range 15-30% (Table 6.9).

Table 6.8: Distribution of WHSs per Soil texture classes

Soil Texture class	Area coverage in %			
	Check dam	Contour Bund	Semi-circular Bund	Farm Pond
3	62.4	45.3	81.0	58.7
4	37.6	54.7	19.0	41.3

6.3.4. Suitable Sites for Contour Bund

Map of suitable sites for contour bund, is shown in the Figure 6.11. These are located mostly in the southern tip and central north-eastern and small patches distributed in all parts of the watershed. The total coverage of suitable site for contour bund is only 2.8%. Out of this 62.7% is located on bareland landcover unit (Table 6.10).

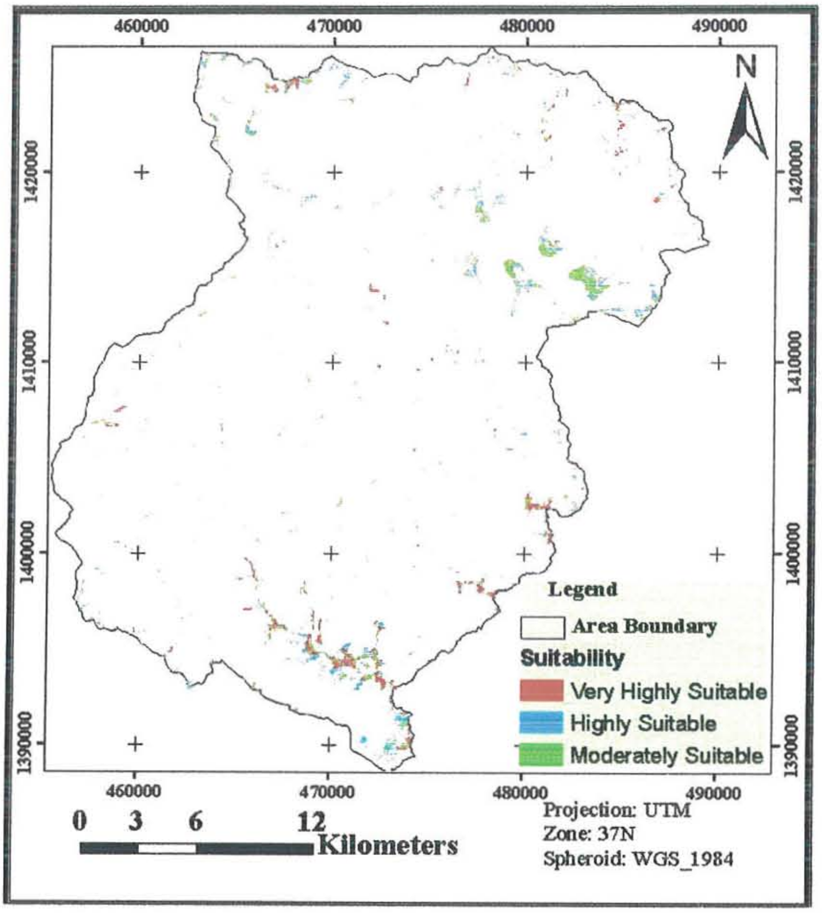


Figure 6.11: Suitability map for Contour Bund

45.3% of the area suitable for contour bund is on relatively more appropriate Sandy Clay Loam soil texture class while the rest 54.7% is on less appropriate Sandy, Silty Clay, Clay (Table 6.8). 81.5% of this area is suited on slope range 8-15% (Table 6.9).

Table 6.9: Distribution of WHSs per Slope Classes

Slope Classes in %	Area coverage in %			
	Check dam	Contour Bund	Semi-circular Bund	Farm Pond
0-8	2.6	18.5	20.1	24.4
8-15	41.9	81.5	79.9	75.6
15-30	55.5	--	--	--

Table 6.10: Area coverage in Percentage of suitable sites per Landuse/cover

Landuse/cover	Area coverage in %			
	Check dam	Contour Bund	Semi-circular Bund	Farm Pond
Bush land/shrub land	68.1	26.5	66.6	4.7
Agricultural land	22.5	--	--	83.8
Bare land	5.7	62.7	25.6	11.5
Forest land	1.4	10.0	5.8	--
Scrubland	2.2	--	--	--
Built-up area	0.1	--	--	--

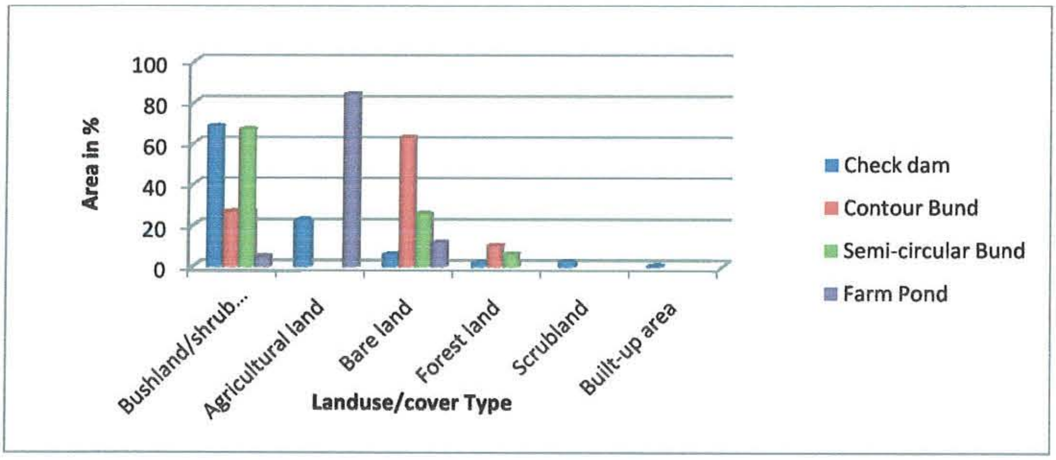


Figure 6.12: Distribution of WHSs over Landuse/cover of the watershed

6.3.5. Result of Suitable Site for WHSs

The overall suitability map for different WHSs is shown in the Figure 6.13 below (*Note: CB= Contour Bund, CD= Check Dam, FP= Farm Pond and ScB= Semi-circular Bund*). This is created by union overlay of the individual suitability map described above. As it can be seen from the Table 6.11 most of the suitable areas are allotted for check dam. Sites are not more suitable for semi-circular bund and farm ponds due to steep slope and poor soil characteristics of the area.

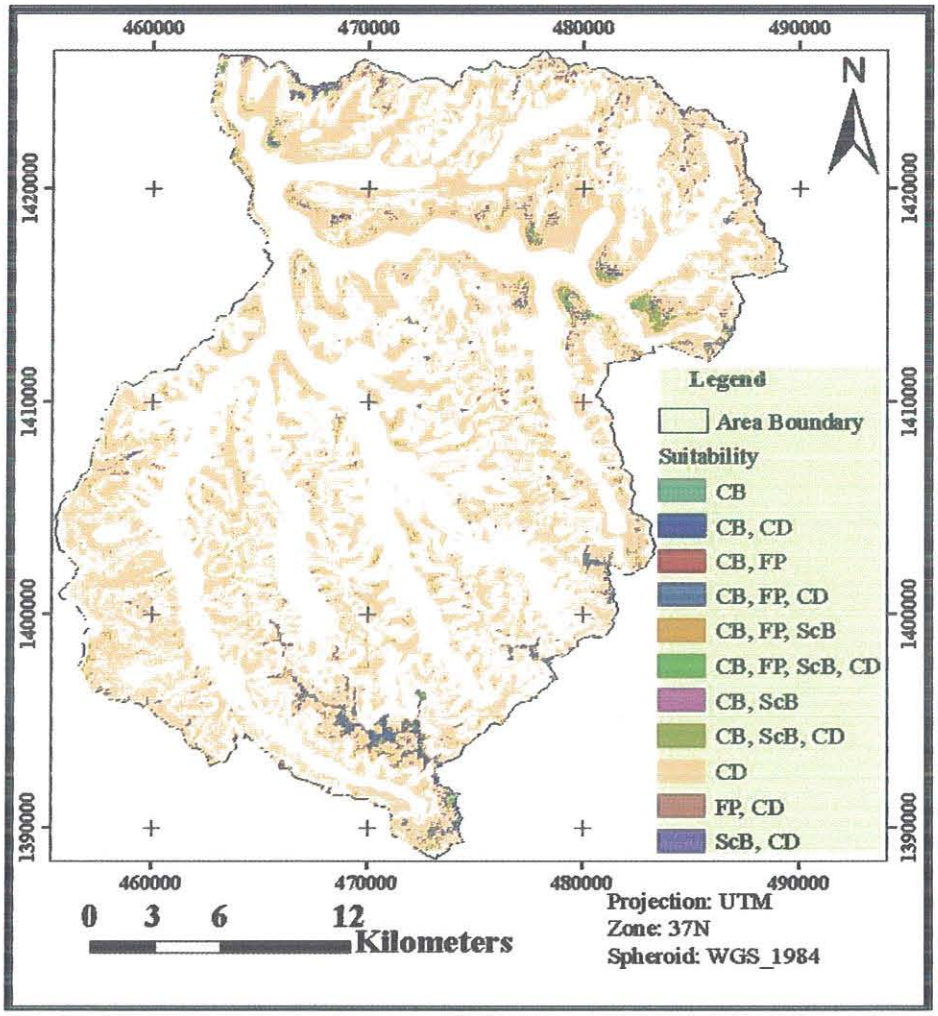


Figure 6.13: Map of Final Suitability for Water harvesting structures

Table 6.11: Area Coverage for Different WHSs

WHS	Area in km^2	Area in %
CB	0.056	0.015%
CB, CD	7.342	2.004%
CB, FP	0.011	0.003%
CB, FP, CD	6.098	1.664%
CB, FP, ScB	0.003	0.001%
CB, FP, ScB, CD	1.157	0.316%
CB, ScB	0.016	0.004%
CB, ScB, CD	5.991	1.635%
CD	344.608	94.049%
FP	0.001	0.000%
FP, CD	0.533	0.145%
FP, ScB, CD	0.001	0.000%
ScB	0.002	0.001%
ScB, CD	0.596	0.163%

6.4. The Direct Runoff Available

Based on the hydrological soil group, the maximum area of Ziquala watershed was observed to be under hydrological soil group C and D (Table 6.12). The watershed has main landuse/cover units like bush land/shrub land, forest land, agricultural land, water body, scrubland, bareland and built-up areas. The land use/ cover and soil maps were used to determine the curve number parameter required by the model. Depending on textural information, soil groups C and D were assigned to the corresponding polygons of the soil map as shown in the Annex III. This map was then crossed with the land use/cover map. The crossed (Annex IV) map gave all possible combinations between landuse/cover and the different soil groups. Based on this CN values were assigned to each combination (Annex II).

Table 6.12: Characteristics of the soil

Hydrologic Soil Group	Soil Type	Character
C	Sandy Clay Loam	Low infiltration rate
D	Sandy, Silty Clay, Clay	High Runoff Potential, Very Low infiltration rate

Table 6.13: Computation of weighted curve number per total area

Landuse/cover	Hydrologic Soil Group	CN	Area (Km^2)	Percentage of Area	$CN_i \times A_i$
Water Body	C	100	4.8791	0.64	487.91
	D	100	0.1159	0.02	11.59
Built-up Area	C	57	1.1054	0.15	63.01
	D	72	0.0517	0.01	3.72
Bush land/shrub land	C	30	346.3131	45.64	10389.39
	D	58	214.5431	28.27	12443.50
Agricultural Land	C	55	136.7549	18.02	7521.52
	D	69	55.011	7.25	3795.76
Sum			**758.77**	**100**	**34716.40**

A composite curve number is then calculated using area-weighted averaging and it is calculated by using the equation (8, section 4.2.6):

$$CN_{comp} = \frac{CN_1 * A_1 + CN_2 * A_2 + \ldots + CN_i\ A_i}{A_{total}}$$

$$CN = \frac{\mathbf{34716.40}}{758.77}$$

$= \underline{45.75}$ and it is rounded to **46**

From equation (5, section 2.6)

$$S = \frac{25400}{CN} - 254$$

$$= \frac{25400}{46} - 254$$

$$= \underline{301.15}$$

From the equation (4, section 2.6)

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \qquad (P \geq 0.2S) \rightarrow 506 \geq (0.2 * 301.15)$$

$$506 \geq 60.23$$

Table 6.14: The average and total runoff of in the last four years

Years	Total Rainfall (mm)	Total Runoff (mm)	Runoff Percentage	Volume (m^3) Runoff × Area
2006	668.2	406.58	60.85	308500707
2007	545.1	299.10	54.87	226948107
2008	394	175.46	44.53	133133784
2009	419.4	195.37	46.58	148240895
Average	506.675	269.13	51.71	204207770

The average curve number and annual runoff for the study area (Table 6.14) are 46 and 269.13mm (51%), respectively. Accordingly the average total runoff of the study area is 204207770m^3. Due to its ease of use this method has gained wide acceptance among a range of users. But the method was developed for small watersheds. For large un-gauged watersheds, hydrologic model accuracy for peak runoff rate estimates should be considered ± 30% at best. However, as watersheds become smaller, such as the typical size modelled for storm water management purposes, the estimate accuracy for hydrologic models decreases (http://www3.villanova.edu/VUSP/Outreach/pasym01/pdffiles/B32.pdf).

7. Conclusion and Recommendations

7.1. Conclusion

Landuse/cover change is a very crucial aspect of change in an area. It will have a profound effect on the availability and extent of both surface and groundwater. Hence, information on the distribution of landuse/cover and its change over time is very important for planning, management and monitoring programs at all administrative levels. The capability of GIS to integrate and analyse temporal and spatial data helps in quantifying the land-use changes.

Water is one of the prime requirements for agriculture, industrial production and domestic uses. But, it is also the scarcest natural resource in the dry areas. Now a day's most of the rural development works in Ethiopia are watershed based. Watershed development and management implies an optimum development of water, land and hence biomass so as to meet the people's basic needs in a sustained manner. This calls for reducing the runoff, soil loss and augmentation of infiltration. A reduction in surface runoff can be achieved by constructing suitable structures or by changes in land management, which in turn will increase infiltration and aid water conservation.

The general objective of this study was to evaluate the landuse/cover change and to select and map suitable sites for different water harvesting structures for Ziquala watershed. Ziquala Woreda is found in drought prone areas of the Wag Himra Zone. The area is characterized by scarcity of water even during the rainy seasons. The erratic seasonal rainfall, coupled with the steep slopes and the bare plains with little or no plant cover have led to low retention of ground water and high run-off, which in turn led to extensive soil erosion in the Woreda. The Woreda is divided into two agro-climatic zones: *kola* and *weina-dega*, with most parts of the Woreda (about 89 percent) falling in kola AEZ.

Depending on the available spatial data, the accuracy and reliability of the result using GIS application could be high. Landsat images of 1988, 1999 and 2009 were used in addition to FAO soil map, SRTM 30cm, and geological formations map prepared by Ethiopian Institute of Geological Survey (EIGS) to identify the landuse/cover change and prepare the factor maps for further analysis. The adopted methodology includes a three stage approach: 1) Generation of of thematic layers using satellite using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) and collateral data, 2) Data integration and analysis and 3) Development of decision rules and field validation.

The landuse/cover dynamics was analysed using digital image analysing tools (ERDAS Imagine and ENVI). Following classification of imagery from the individual years, a post-classification comparison change detection algorithm was applied to determine changes in land use/cover from 1988 to 1999, from 1999 to 2009 and 1988 to 2009.

The integration of vector data and collateral data was carried out using ArcGIS software. An analytical hierarchy process was adopted to assign weight to parameters that govern the site suitability for water harvesting/recharging structures. Specifications prescribed by the Community Based Participatory Watershed Development: A Guideline and the Food and Agriculture Organization (FAO) were followed for site selection. Once the composite layers and their weights were obtained, the overlay was applied using the weighted overlay tool within ArcGIS 9.2 to produce the map of suitable areas for each WHSs.

Three land use/cover maps were produced, respectively, for years 1988, 1999 and 2009 using the maximum-likelihood algorithm. Landuse/cover was produced with the overall classification accuracy 89.20%, 92% and 95.20% and Kappa index 83.31%, 81.49% and 89.82% for the 1988, 1999 and 2009 images, respectively. In 1988, bareland 328.57 km^2 (43.16%) followed by bush land/shrub land 309.44 km^2 (40.64%) were the dominant landcover units. During the year 1999 small scale farming has increased by 1.90% reaching 111.01 km^2 (14.58%). In this year bush land/shrub land and forest land cover an area of 526.65 km^2 (69.17%) and 10.61 km^2 (1.39%), respectively. The major landuse/cover classes of 2009 are the same as that of the 1999. Agricultural land increased by 4.48% and reached 145.14km^2.

Post-classification change detection method was applied using the produced three years landuse/cover maps. The resulting conversion matrix revealed that in the study area there is high landuse/cover dynamics. Major transition of landuse type between 1988 and 1999 years was related to the 161.24 km^2 vegetation areas created from open areas, the majority land cover unit being bush land/shrub land. Major landuse/cover conversions between 1999 and 2009 were from bareland to bush land/shrub land, scrubland to bush land/shrub land, bareland to agricultural land, Agriculture to bush land/shrub land and bush land/shrub land to forest with 34.38 %, 60.1%, 30.31% and 35.73%, respectively. During this period the higher conversion rate were those of bareland and bush land/shrub land having -9.71km^2 per year and 6.27km^2 per year, respectively.

The site suitability analysis for locating water harvesting structures using GIS analysis has added an advantage over the conventional survey. GIS provides a great advantage to analyze multi-layer of data spatially and quantitatively. In this study, a set of criteria was evolved to locate suitable sites for water harvesting/recharging structures. The criteria chosen were comprehensive and sensitive. The remote sensing technique proved to be effective for generating various thematic layers relevant to site suitability. GIS has facilitated in database management, analysis and derivation of results.

Interpretation of thematic layers from remote sensing and GIS data was assigned various classes and rated. The weighted overlaid results were further classified as very highly suitable, highly suitable and moderately suitable for each WHS. Check dam with 48.33% has higher coverage of suitable area. Much of the suitable area falls on lower order streams and agricultural area, i.e., 4.9% and 68%, respectively. Contour bund, semi-circular bund and farm pond having 2.8%, 1% and 1% coverage, respectively. Check dam and semi-circular bund have much of their area under highly suitable while much of farm pond and contour bund fall on moderately suitable sites. Sites are not more suitable for semi-circular bund and farm ponds due to steep slope and poor soil characteristics.

7.2. Recommendations

Thus from the study it is recommended that:

- It is useful to use GIS and remote sensing when dealing with landuse/cover change detection and selecting suitable sites for water harvesting structures
- A close examination of the other factors determining the change in landuse/cover, such as socio-cultural environment and the socioeconomic factors is needed for the development of landuse policy objectives of the area.
- Factors like socioeconomic (infrastructure, population density) and runoff potential which are also necessary for a complete assessment of the suitability of land for RWH were not considered due to lack of readily available data for this large area. It is therefore recommended to include such factors in future studies to improve the suitability assessment.
- Because watershed management needs a multi-disciplinary approach, on one hand selecting sites should consider different factors like soil texture, slope, geological formation, landuse/cover and drainage density especially stream order; on the other hand appropriate decision support system should be followed.

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Annexes

Annex I. Accuracy assessment of the landuse/cover maps of a) 1988, b) 1999 and c) 2009

a) 1988

Classified Data	Water	Bushland/ Shrubland	Agricultural land	Bareland	Forest land	Scrubland	Row Total	User's Accuracy (%)	Kappa
Water	**2**	0	0	0	0	0	2	100.00	1
Bush land/ Shrub land	0	**97**	10	0	6	0	113	85.84	0.764
Agricultural land	0	3	**25**	0	0	1	29	86.21	0.8396
Bare land	0	0	0	**95**	0	7	102	93.14	0.8893
Forest land	0	0	0	0	**0**	0	0	---	0
Scrubland	0	0	0	0	0	**4**	4	100.00	1
Column Total	2	100	35	95	6	12	**250**		
Producer's Accuracy (%)	100	97.00	71.43	100	---	33.33			

b) 1999

Classified Data	Water	Bushland/ shrubland	Agricultural land	Bareland	Built-up Area	Scrubland	Forest land	Row Total	User's Accuracy (%)	Kappa
Water	**5**	0	0	0	0	0	0	5	100.00	1
Bushland/ Shrubland	1	**177**	0	0	0	3	13	194	91.24	0.6999
Agricultural land	0	0	**28**	0	0	0	0	28	100.00	1
Bareland	0	0	0	**16**	2	1	0	19	84.21	0.8313
Built-up Area	0	0	0	0	**0**	0	0	0	---	0
Scrubland	0	0	0	0	0	**3**	0	3	100.00	1
Forest land	0	0	0	0	0	0	**1**	1	100.00	1
Column Total	6	177	28	16	2	7	14	**250**		
Producer's Accuracy (%)	83.33	100.00	100.00	100.00	---	42.86	7.14			

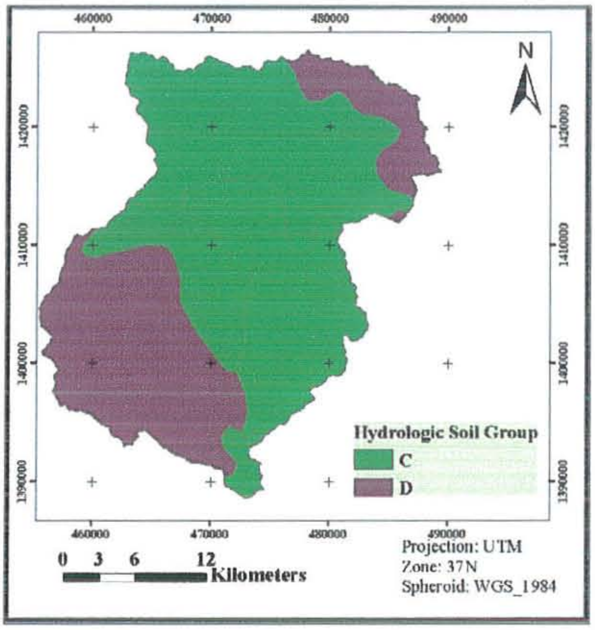
c) 2009

Classified Data	Bushland/ Shrubland	Built-up Area	Water	Bareland	Agricultural land	Scrubland	Forest land	Row Total	User's Accuracy (%)	Kappa
Bushland/ Shrubland	**173**	0	0	0	0	0	7	180	96.11	0.8737
Built-up Area	0	**0**	0	0	0	0	0	0	---	0
Water	0	0	**1**	0	0	0	0	1	100.00	1
Bareland	0	0	0	**13**	0	1	0	14	92.86	0.9247
Agricultural la	0	0	0	0	**37**	4	0	41	90.24	0.8855
Scrubland	0	0	0	0	0	**6**	0	6	100.00	1
Forest land	0	0	0	0	0	0	**8**	8	100.00	1
Column Total	173	0	1	13	37	11	15	**250**		
Producer's Accuracy (%)	100.00	---	100.00	100.00	100.00	54.55	53.33			

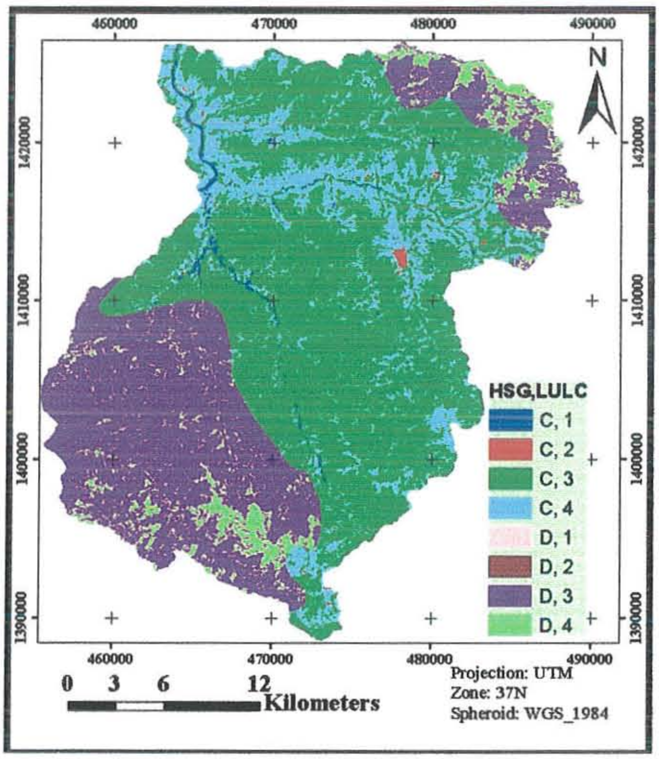
Annex II: Runoff curve numbers

Landuse/cover	Hydrologic condition	Hydrologic Soil Group	
		C	D
Water Body	Poor	100	100
Built-up Area	Poor	57	72
Forest Land	Fair	30	58
Agricultural Land	poor	55	69

Annex III: Map of Hydrologic Soil Group



Annex IV: HSG-LULC combination map



*Note: **C**=Hydrologic Soil Group **'C'**, **D**= Hydrologic Soil Group **'D'***

***1**- Water body, **2**- Built-up Area, **3**- Forest land (included in Bush land/shrub land) and **4**- Agricultural land (including bareland and scrubland)*

DECLARATION

I here by declare that the thesis entitled "**Landuse/Cover Dynamics and Selection of Suitable Site for Water Harvesting Structures: The Case of Ziquala Watershed, Wag Himra Zone**" has been carried out by me under the supervision of Prof. Tenalem Ayenew, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2009-2010 as partial fulfilment of Master of Science degree in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma. All the sources and materials used for the thesis have been duly acknowledged.

Habtamu Mohammed

Sgniture: ____________________

Place: Addis Ababa

Date: June 29, 2010

CERTIFICATE

This is certified that the thesis entitled "**Landuse/Cover Dynamics and Selection of Suitable Site for Water Harvesting Structures: In The Case of Ziquala Watershed, Ziquala Woreda**" is a bona-fide work carried out by Habtamu Mohammed under my guidance and supervision. This is the actual work done by Habtamu Mohammed for the partial fulfilment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University, Addis Ababa.

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