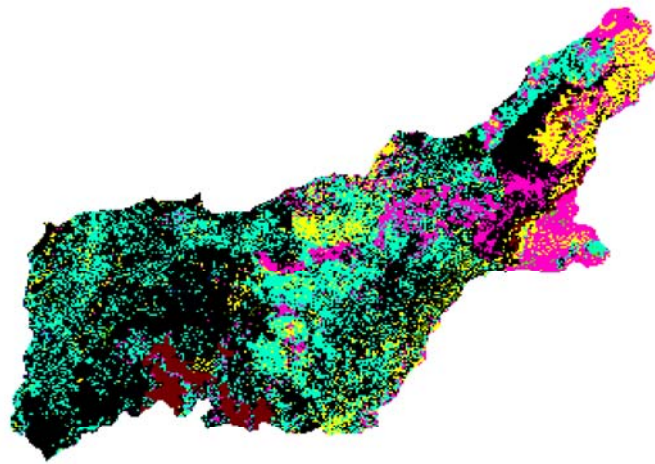




**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
DEPARTMENT OF EARTH SCIENCES**



**IRRIGATION POTENTIAL EVALUATION AND CROP SUITABILITY  
ANALYSIS USING GIS AND REMOTE SENSING TECHNIQUE IN  
BELES SUB BASIN, BENESHANGUL GUMEZ REGION.**

By

HAILEGEBRIEL SHIFERAW

Mar 2007

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IN PARTIAL FULFILLMENT OF THE REQUIREMENT  
FOR THE DEGREE OF MASTER OF SCIENCE IN GEOGRAPHIC  
INFORMATION SYSTEMS AND REMOTE SENSING

By

HAILEGEBRIEL SHIFERAW

Mar 2007

## **ACKNOWLEDGMENT**

I am greatly indebted to my Advisor Dr. Syed Ahmad Ali for his guidance and instructive advice that I needed to accomplish my study. His review and comments on the manuscript are highly appreciated. In addition to, the discussion I made with him on the results of this thesis was very important. I duly acknowledge his contribution to realize this study.

I would like also to thank the staff of Earth Sciences Department of Addis Ababa University who helped me in various ways, especially, the Department head, Dr. Dereje Ayalew, who assisted me when I need and Dr. Dagnachew Legesse, the department advisor, who helped me to use the computer laboratory and materials at any time.

Special thanks to my brother, Dereje Shiferaw, who has been the source of my strength and motivation starting from the beginning to the end of the research. He gave his advice and financial support. I would also like to extend this special thanks to my parents, brothers and sisters who gave me all the encouragement to accomplish my study.

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## ABSTRACT

The study aims at evaluation of land use suitability for surface irrigation by using GIS. The evaluation of land in terms of the suitability classes was based on the method as described in FAO guideline for land evaluation. Multi-criteria decision evaluation method was used to evaluate the physical land characteristics of the study area for surface irrigation. There are techniques, which were used to weight and standardized the factors, which are used to evaluate the land in the study area. These include pairwise combination and weighted linear combination. The factors that were considered for evaluation of the land for surface irrigation is slope, soil drainage, soil texture, soil depth, soil type and land use. After evaluating the physical land capability for surface irrigation, irrigation suitability map was developed. This map was classified in to five suitability classes based on FAO guideline. The result that obtained are 41,650 ha (26.9%) very suitable, 24,100 ha (15.6%) suitable, 44,350 ha (28.7%) marginally suitable, 11,000ha (7.3%) marginally not suitable and 33, 2500ha (21.5%) permanently not suitable. The land in the study area was evaluated for suitability of crops. Temperature and rainfall amount of the study area were the factors in addition to the factors mentioned above used for surface irrigation evaluation. Maize and Cotton were selected to evaluate the land of the Beles sub Basin. Suitability maps for both maize and cotton were developed. The suitability crops maps were classified in to five suitability classes. Regarding maize 12,450ha (8.2%) very suitable, 23,140ha (14.9%) suitable, 54,600ha (35.3%) marginally suitable, 16,200ha (10.6%) marginally not suitable and 46,130ha (30.4%) permanently not suitable of the total Beles Sub basin. Suitability classes for Cotton were 16, 150ha (10.7%) very suitable, 22,540ha (15.1%) suitable, 49,020ha (32.6%) marginally, 17,200ha (11.5%) marginally not suitable and 46,130ha (30.1%) permanently not suitable

# 1. INTRODUCTION

## 1.1 Background

By the year 2025, 83 % of the expected global population of 8.5 billion is expected to be live in developing countries. Yet the capacity of available resources and technologies to satisfy the demands of this growing population for food and other agricultural commodities remains uncertain. The world's food production depends on the availability of water, a precious but finite resource. The role of water as a social, economic, and life sustaining good should be reflected in demand management mechanisms and be implemented through resource assessment, water conservation and reuse (FAO, 1996). Water demands are increasing rapidly and thereby, available water for agriculture is getting limited.

The land, which has great potential for irrigation, is very needed at the demand of this growing population. Evaluation of land suitability which has great physical and chemical land qualities is very needed to contribute to the world's food production in general and the country, Ethiopia in particular to improve food security through more efficient and effective use of water.

In 1987, FAO conducted a study to assess the land and water resources potential for irrigation for Africa on the basis of river basins and countries. It was one of the first GIS-based studies of its kind at continental level. It proposed natural resources based approach to assessing irrigation potential. Its main limitation was in the sensitivity of the criteria for defining land suitability for irrigation and in the water allocation scenarios needed for the computation of the potential (FAO, 1978).

A research was also conducted by FAO in 1995 to know irrigation potential for different countries in Africa based on water resources and land suitability. To study irrigation potential for a country, water, soil and plant are most important things to be considered. However, different factors like investment, technology and political choices are also necessary (FAO, 1995). The area that can potentially be irrigated depends on the physical resources, soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate (FAO, 2003).

Global estimates indicate that irrigated agriculture produces nearly 40 % of food and agriculture commodities on 17% of agricultural land. At present in Africa, about 12.2 million ha benefit from irrigation, which is equal to only about 8.5% of the cultivated land. FAO also evaluated that in sub-Saharan Africa; only about 10% of the agricultural production comes from irrigated land. Trends in irrigated land expansion over the last 30 years show that, on average, irrigation in Africa increased at a rate of 1.2% per year. However, this rate began to fall in the mid-1980s and is now below 1% per year, but varies widely from country to country (FAO, 2003). Africa's river systems have been the target of development planners since the 1960s, and many of the major rivers of the continent have been dammed for irrigation, for power generation and flood control. Indeed, river basin development planning has been widely adopted in Africa, and often enough water resource development has come to be synonymous with river basin development (FAO, 1995).

Until recently, the water potential in Ethiopia was not accurately known, and even today this is still a controversial area. There have been different estimates of the irrigation potential of the country, and the issue has not been satisfactorily resolved. One of the earliest estimations was made by the (World Bank (1993) which suggested a figure of between 1.0 and 1.5 million ha (World Bank, 1993).Recent estimates, however, place the figure somewhat higher. According to the Ministry of Agriculture (1986), the total irrigable land in the country measures 2.3 million hectares.

Different studies were conducted on the Abbay (Blue Nile), Awash and Wabe Shebelle river basins. In 1962, a German engineering team, and in 1964, the U.S. Bureau of Reclamation undertook extensive studies of the water resource potential of the Abbay River basin, the largest basin in the country. Both reports irrigated agriculture in the basin.

There is growing concern about food security in Africa and especially in sub-Saharan Africa. While the aggregate global food supply/demand picture is relatively good, there will be a worsening in food security in sub-Saharan Africa (FAO, 1996). Agricultural productivity in Ethiopia has not kept pace with population increase, and the region is now in a worse position nutritionally than it was 30 years ago: food production has achieved a growth of about 2.5% per year, while population has risen at a rate of over 3% per year.

Both rain-fed and irrigated agriculture will need to be intensified, but irrigated agriculture has a higher potential for intensification. In many of the drought prone countries, the concentration of the human population is relatively high and cannot be adequately supported by rain-fed agriculture alone. Thus, where rainfall is insufficient or unreliable and rain-fed agriculture cannot fully support food production, water management schemes have been considered to be sound investments. Such investments, it is argued, will help stabilise agricultural production and promote food security.

In this paper only the physical characteristics of the land of the study area were given more emphasis to evaluate the irrigation potential of the sub-basin. To enable careful planning of the development of the water resources, especially for agriculture, which is by far the largest water user, a good knowledge of the irrigation potential for the country is necessary. However, environmental and socioeconomic constraints also have to be taken into consideration in order to guarantee a sustainable use of the available physical resources.

There are different types of irrigation (sprinkler, dip, surface etc). But this study only focused on the evaluation of performance of surface (gravity) irrigation and crop suitability analysis on the study area.

## **1.2 Objectives of the study**

### **General objective**

- To evaluate the physical land characteristics and its quality of the study area for suitability of surface irrigation potential and crops in GIS environment using multi-criteria decision evolution (MCDE) method.

### **Specific Objectives**

- To evaluate the slope gradient of the land for surface irrigation.
- To examine the physical properties of the soil i.e. soil texture, soil depth, and soil type found in the Beles sub basin for irrigation.
- To evaluate the soil drainage properties of the basin
- To study land use type of the basin.
- To study the climate of the study area.
- To develop physical land suitability map for irrigation of the Beles basin

- To study major kinds of crops which are suitable for the land and develop suitability maps for them

### **1.3 Significance of the study**

Irrigation is the most common means of ensuring sustainable agriculture and coping with periods of inadequate rainfall and drought. However about 85 % of the people of the country is engaged in agriculture; the activity still depends on rain-fed. As a result the growth of production crops does not much with the growth of population of the country. Rainfall distribution in Ethiopia is seasonal and variable and suffers from the most unstable rainfall regime. Irrigation, applying water to assure sufficient soil moisture is available for good plant growth, because it is used to enhance the rainfall that occurs during the growing season. Irrigation is used on full season agronomic crops to provide a reliable yield every year. It is also used on crops where water stress affects the quality of the yield. Hence irrigation is very needed for the country. Many people in Ethiopia suffer from drought and famine from year to year due to shortage of rain. Irrigation will contribute significantly to poverty alleviation, food security, and improving the quality of life for the country in general and rural population in particular if the irrigation potential of the basin is known.

### **1.4 Limitation of the Study**

Shortage of data of the study area was encountered in order to conduct the study. The chemical properties of soil of the study area were not evaluated for surface irrigation potential and crops suitability due to shortage of data. Only the physical characteristics of the land under the study area were evaluated for determining for the suitability of irrigation and crops.

## **2. LITERATURE REVIEW**

### **2.1 Definition of irrigation potential**

Irrigation can be referred as the process by which water is diverted from a river or pumped from a well and used for the purpose of agricultural production (FAO, 1986). The area, which can potentially be irrigated, depends on the physical resources, soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate.

### **2.2 Irrigation potential in Ethiopia**

The Ethiopian plateau is the source of the Abay, Awash, Tekeze, Mereb, Baro, Akobo and Omo rivers that flow to the west and southwest. The Baro/Akobo basin has potentially the largest possible irrigable area (~489,000 ha) although negligible area has been developed in Awash River basin. The Rift valley is the only river basin that is extensively used for commercial plantations with industrial and horticultural crops. From the total irrigated land of about 161,125 hectares, over 43 % is found in the Awash River basin. The remaining potential for irrigated agriculture using Awash River is estimated at 136,220 hectares (World Bank, 1993)

According to recent Minister of Water Resource data (FAO,1995), some 30 large and medium-scale irrigation projects with a combined command area of over 600,000 hectares have been identified in various parts of the country for development by the state since the 1980s. Of these, about 15 percent have already been completed. The largest water project to be constructed since the 1970s is the Alwero dam in the Gambella region, which has an irrigation potential of over 10,000 hectares, but which remains unutilised two years after completion.

The surface drainage systems need a design that combines erosion control and water conservation functions. In addition, new subsurface drainage systems are needed on irrigated areas where water logging and salinity already occur.

## **2.3 Factors contributing for the Evaluation of Irrigation Potential and Crop Suitability**

### **2.3.1 Topography of the Field**

Topography has a large impact on whether a field can be irrigated. The difference in height between the hills and depressions in the field is one of component of topography of the land, which is referred as relief. The topographic relief will affect the type of irrigation system to be used, the water transportation system (ditches or pipes), drainage requirements and water erosion control practices. The shape and arrangement of topographic landforms and the type of surface waterway network will also influence irrigation management (D.W Thorne and H.B Peterson, 1949).

### **2.3.2 Physical soil properties**

Physical soil properties are the most dominant factors that determine the land suitability for irrigation. These physical soil properties include soil depth, soil texture etc.

The water content in the soil (soil moisture) also determines the irrigation potential by affecting plant growth (FAO, 1995). It is also stated that there are four important levels of soil moisture content that reflect the availability of water in the soil. These levels are commonly referred to as saturation, field capacity, wilting point and oven dry.

### **2.3.3 Water resources**

In 1995 FAO has conducted a review of the annual renewable water resources of the African countries based on detailed information on the variation in water discharges in space and time. This information was compared with surface runoff estimates, calculated for each of total basic units (in GIS) and based on the surface runoff map of Africa. All calculations were based on renewable water resources, and mainly on surface water resources, except for arid countries where renewable groundwater already plays an important role in irrigation development (FAO, 1995). Non-renewable groundwater resources (fossil water) were not taken into consideration. For arid countries, this may result in a relatively low irrigation potential, sometimes even lower than the area already under irrigation.

## **2.4 Parameters used for evaluation of crop suitability**

### **2.4.1 Soil**

The evaluation of soil qualities to predict the performance for specific crops is an essential part of a land evaluation and land use planning exercise applied to agriculture. According to D.W Thorne and H. B. Peterson soil suitability for crops should be evaluated by examining soil properties for a given area. Because not all soils can be irrigated due to various physical problems, such as low infiltration rates and poor internal drainage, which may cause salt buildup (D.W Thorne and H. B. Peterson, 1949).

### **2.4.2 Climate**

Climate has a distinct effect on land characteristics; its most important influence on irrigation suitability is the range and type of crops permitted by the climate in a specific project. These effects greatly influence the net income from land under an irrigation regime (D.W Thorne and H. B. Peterson, 1949).

## **2.5 The Role of GIS and Remote Sensing in Crop Suitability and Irrigation Potential Evaluation**

It has long been recognized that land suitability is assessed as part of a 'rational' cropping system (FAO, 1976) and optimizing the use of a piece of land for a specified use should be based upon its attributes. Furthermore, land may be considered either in its present condition, or after specified improvements. Although criteria may vary, they are essentially based on climate, soil, topography and water availability, which are the most important categories of environmental information required for judging land suitability. Assessing the suitability of an area for crop production requires a considerable effort in terms of information collection that presents both opportunities and limitations to decision-makers. A GIS is used to match the suitability for crops based on the requirements of the crop and the quality and characteristics of land.

To delineate the suitability areas for each important crop in the basin using Multi-Criteria Decision Evaluation (MCDE) method overlay different layers. These layers may differ according to the objectives specified and parameters used.

### 3. GENERAL OVERVIEW OF THE STUDY AREA

#### 3.1 Location and Accessibility

The study area, Beles sub basin, is found in the North West of Ethiopia, in Benshangul Gumz region. It is situated about 560 km from Addis Ababa. Astronomically, the area is located between  $10^{\circ} 05'N$ -  $11^{\circ}47'N$  latitude and  $35^{\circ}07'E$ -  $37^{\circ}00'E$  longitude (Fig.3.1). This sub basin is found in Abbay basin. The study area covers  $1543 \text{ km}^2$ .

Regarding the road networks with in the study area, the area is accessible by a main road that goes from Addis Ababa to the North Western part of the country joining other towns such as Mandura, Mambuk, chagni, pawe. All roads are all weather roads that connect one wereda to others (Fig.3.1).



FIG 3.1 LOCATION MAP OF THE STUDY AREA

#### 3.2 Physiography and Drainage

Beles sub basin is located in between the Northern and partly in Western Ethiopia high land plateau. The morphology of the study area is the direct reflection of the different

volcanic strategic successions, tectonic activities and the action of erosion between successive lava flows. The general elevation of the study area is below 1875 meter above sea level. For instance, pawe and Mandura are found at 1073 and 1192 meter above sea level respectively.

Beles sub basin is found with in the Abbay basin. The Abbay basin is included in the Nile basin. The total area of Ethiopia found in the Nile basin is 365,117 km<sup>2</sup> which is 33.2%of the country. Among the total area of the Nile basin, 11.7% is found in Ethiopia (FAO, 1997). The main rivers found in the study area are Upper Beles, Lower Beles, Dura and other tributaries join to the main rivers (Fig.3.2). The area is characterized by dendrite and parallel pattern. The main Beles River divides the sub basin in to two, i.e. the upper and lower Beles.

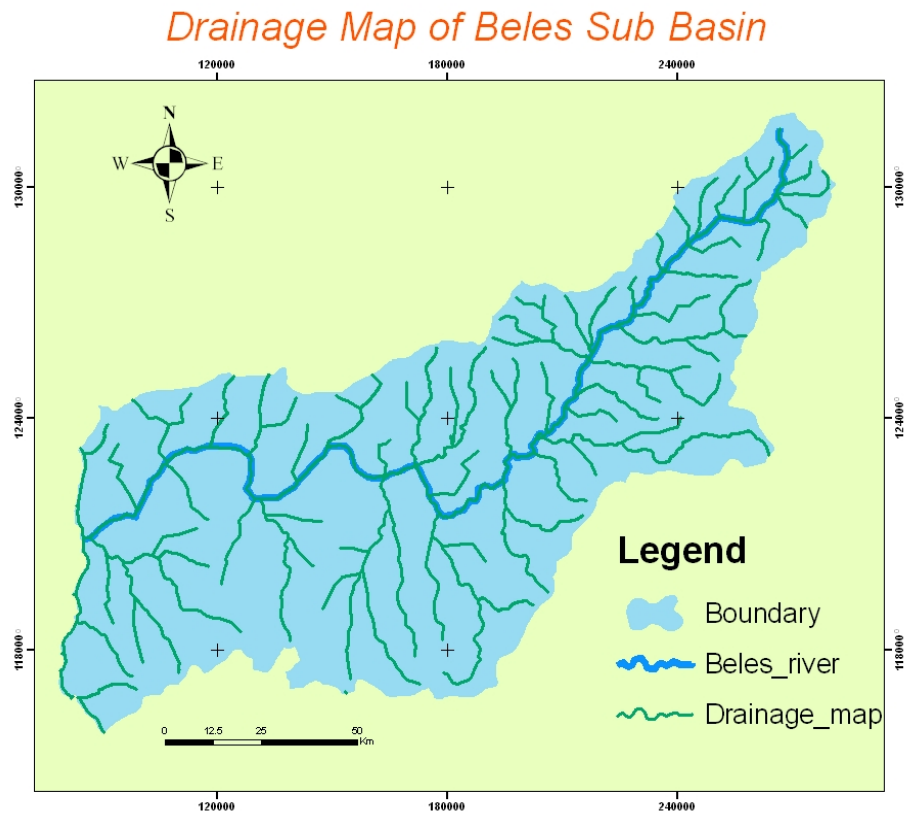


FIG.3.2 SURFACE DRAINAGE OF BELES BASIN

### 3.3 Climate

Ethiopia is situated with in the tropics and there fore is subject to comparatively small seasonal variations in temperature, but experiences considerable diurnal fluctuations in temperature. However, the present study area shows great seasonal variation in rainfall and humidity. Most of the annual rainfall occurs between late June and mid September. During this period, the large low pressure zone located over the Indian Ocean and the Arabian Sea dominates the airflow and there is a strong movement of moist air from Southeast to Northeast, i.e. from the high pressure center over the Gulf of Guinea Atlantic Ocean) towards the low pressure center of Arabia. This movement carries warm, moist, unstable air masses from the Congo basin to Ethiopia and is the largest source of rainwater. The driest time of the year is usually the months of November to January.

#### Temperature and Rainfall:

Temperature data was taken from two stations, Pawe and Chagni, from 1996 to 2005. The study area is grouped under semi arid region. The mean annual temperature for Pawe is 24.52c<sup>0</sup>. The mean annual temperature of Chagni is 21.4c<sup>0</sup>. Generally, months of February, March, and April have the highest temperature while June July, August and September have the lowest temperature (Fig.3.5).

TABLE 3.1 MEAN ANNUAL TEMPERATURE OF PAWE STATION FROM 1996-2005

| Temp.(c <sup>0</sup> ) | Jan   | Feb    | Mar  | Apr  | May   | Jun  | Jul  | Aug  | Sep   | Oct   | Nov   | Dec   |
|------------------------|-------|--------|------|------|-------|------|------|------|-------|-------|-------|-------|
| Max. Av.               | 34.37 | 36.1   | 36.7 | 37.2 | 34.9  | 29.8 | 27.7 | 27.8 | 29.09 | 31.2  | 32.4  | 33.7  |
| Min. Av.               | 12.14 | 15.03  | 18.1 | 19.2 | 19.6  | 18   | 17.9 | 17.6 | 17.03 | 16.9  | 13.9  | 12.2  |
| Mean                   | 23.26 | 25.565 | 27.4 | 28.2 | 27.25 | 23.9 | 22.8 | 22.7 | 23.06 | 24.05 | 23.15 | 22.95 |

Source: Ethiopian Meteorological Agency

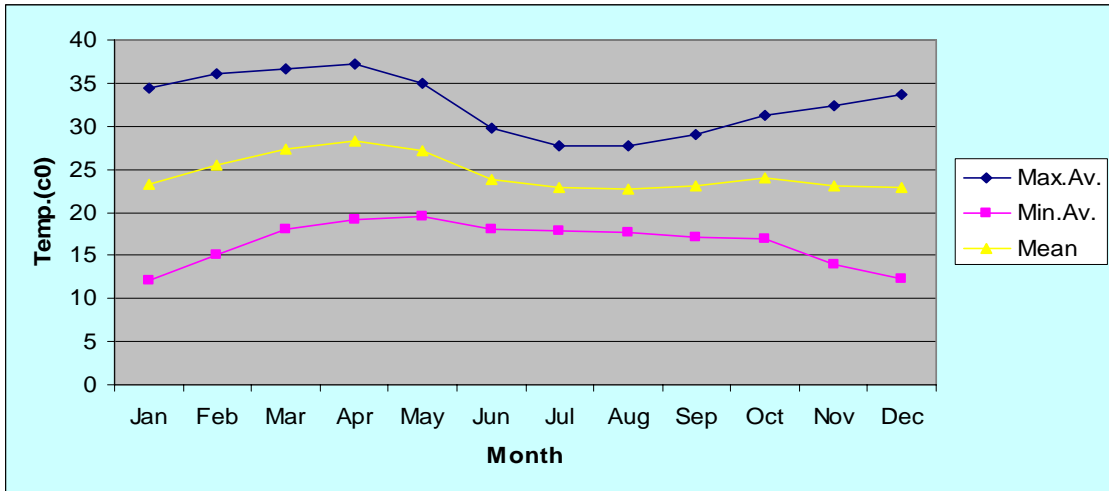
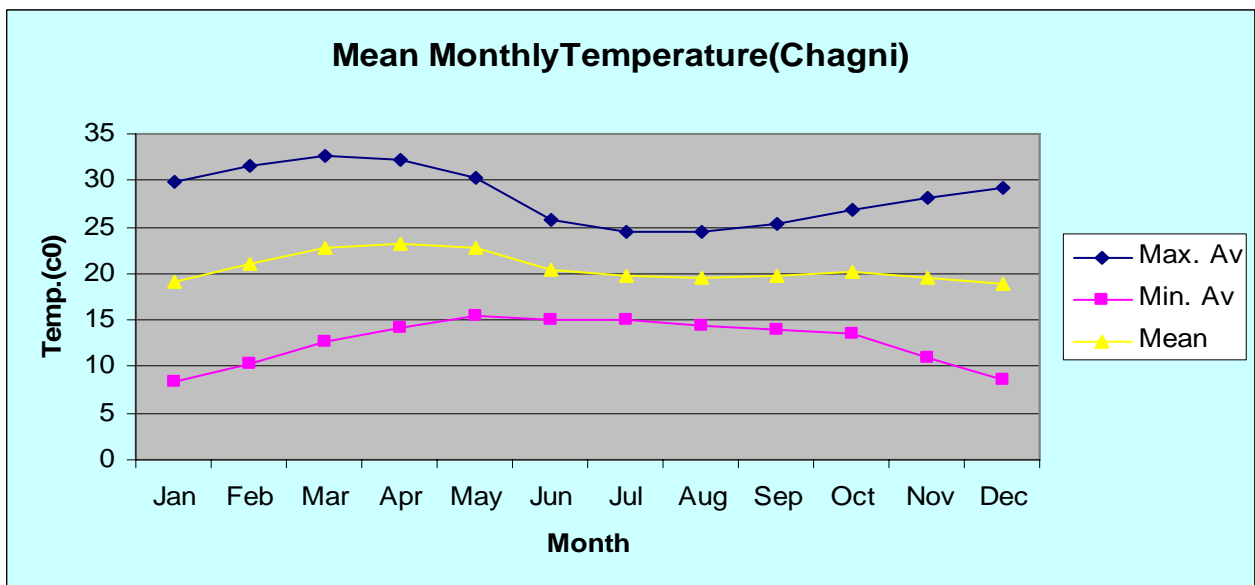


FIG 3.3 TEMPERATURE DISTRIBUTION AT PAWE STATION

TABLE 3.2 MEAN ANNUAL TEMPERATURE AT CHAGNI STATION FROM 1996-2005

| Temp.(c0) | Jan   | Feb    | Mar   | Apr   | May    | Jun  | Jul    | Aug   | Sep   | Oct   | Nov   | Dec   |
|-----------|-------|--------|-------|-------|--------|------|--------|-------|-------|-------|-------|-------|
| Max. Av   | 29.89 | 31.62  | 32.62 | 32.16 | 30.23  | 25.8 | 24.42  | 24.51 | 25.38 | 26.78 | 28.16 | 29.28 |
| Min. Av   | 8.33  | 10.35  | 12.74 | 14.14 | 15.48  | 15.1 | 14.93  | 14.45 | 13.96 | 13.46 | 10.92 | 8.64  |
| Mean      | 19.11 | 20.985 | 22.68 | 23.15 | 22.855 | 20.5 | 19.675 | 19.48 | 19.67 | 20.12 | 19.54 | 18.96 |

FIG.3.4 MEAN ANNUAL TEMPERATURE DISTRIBUTION FROM CHAGNI STATION.



## Rainfall

Rainfall is one of the most important elements in characterizing the climate of the region. In North Western the main dry season is from November to February and the main rainy season from May to September. The study area is characterized by one rainy season. Rainfall data is available from 1996 to 2005 and recorded from three stations, i.e. from Pawe, chagni and Mambik.

Annual Average rainfall for Pawe, Chagni and Mambuik are 1773mm, 1549mm and 1231mm respectively. However, there is low variation of rainfall distribution in the study area at Pawe station than at Chagni station; the total rainfall is between 1500mm 2000mm per year (Fig.3.5 and Fig.3.7).

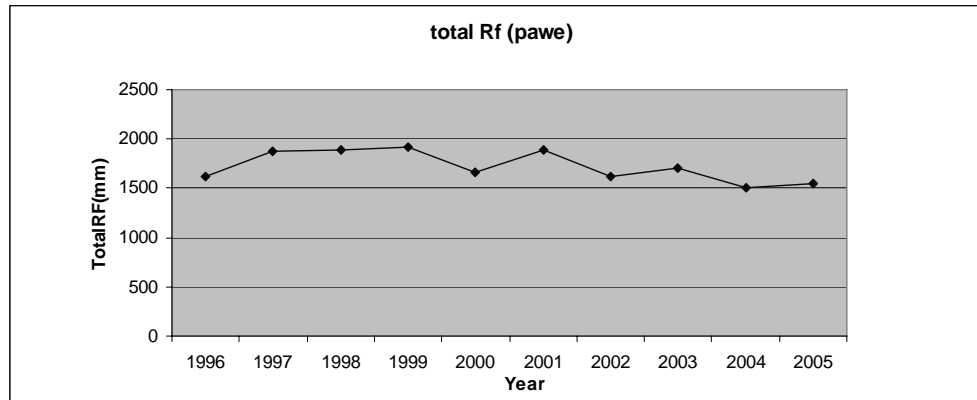


FIG.3.6 TOTAL ANNUAL RAINFALL VARIATION FROM PAWE STATION

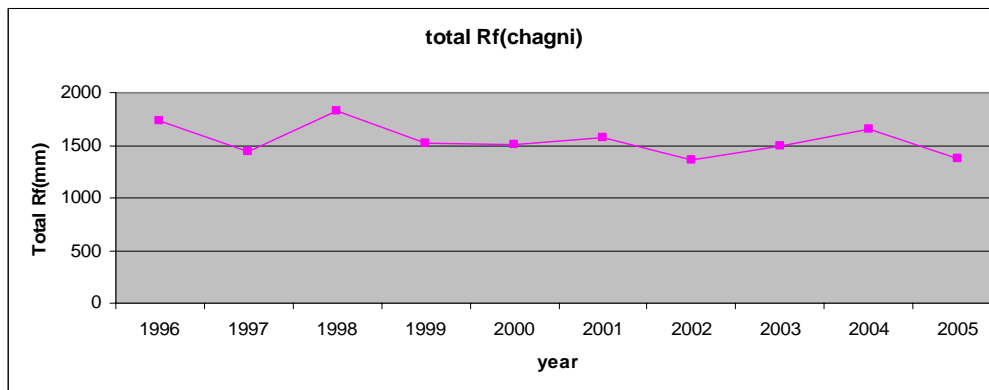


Fig 3.7 Rainfall distribution from Chagni station

### 3.4 Soil

The types of soil found in the study area are Chromic Luvisols, Eutric cambisols Eutric Fluvisols, Eutric Leptosols, Eutric Regosols, Eutric Vertisols, Haptic Acrisols, Haptic Luvisols, Haptic Nitols, and Rhodic Nitols. The study area is dominantly characterized by Vertisols with other types of soils. According to FAO (1988) Vertisols type soils are characterized by their high clay content. They are often dark colored. Due to their semitite clay mineralogy, they are very hard and crack when dry, but becomes sticky and plastic (often impassible) when wet. These are chemically rich soils, but they may develop on an undulating micro relief, which hampers mechanization. Vertisols have great agricultural potential, but special management practices are required.

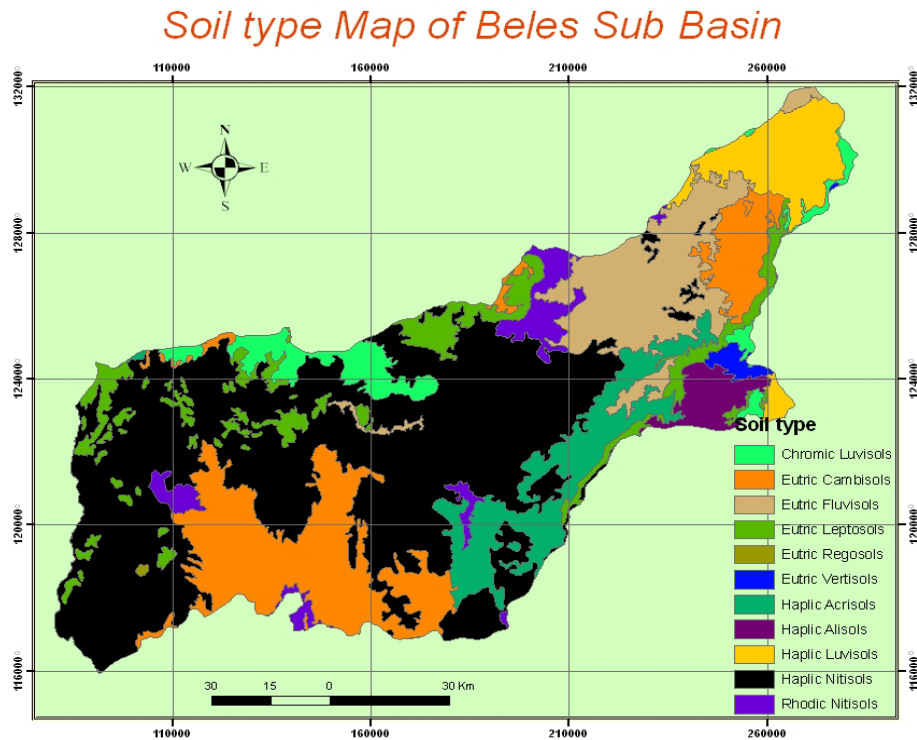


FIG.3.8- SOIL TYPE MAP OF THE STUDY AREA

## 4. DATA, MATERIALS AND METHODS

### 4.1 Data Sources

The most important thing in making research is source of data. Data help to reach the final result, which was designed earlier in the objectives. Different types of data were utilized to attain the objectives in this paper. These include satellite image which was taken in September 2000 by Land sat ETM+ satellite, soil data taken from Ethiopian Ministry of Water Resource, meteorological data from National Meteorological Agency and other data, which described the study area from the Region Bureau.

### 4.2 Material Used

In order to attain the objectives stated earlier the following materials were employed

- ❖ Topographic map 1:50,000
- ❖ Satellite image was used to develop land use / land cover map for the basin.

| Types of Image | Data acquisition date | Bands       |
|----------------|-----------------------|-------------|
| ETM+5          | Sep-2000              | 1,2,3,4,5,7 |

TABLE 1: DESCRIPTION OF SATELLITE IMAGE OF THE STUDY

#### ❖ Software's used:

- ERDAS IMAGINE 8.6 was used for image processing to develop land use map.
  - ArcGIS 9.0 was used for creating different map layers.
  - IDRIS 32 was used for weighting the parameters used for MCDE (Multi-criteria decision evaluation).
- ❖ The data regarding soil texture, soil depth was obtained by Ministry of Water Resource, Ethiopia.

## **4.3 Methodology**

### **4.3.1 Digital image processing techniques**

In order to conduct this study image was processed using different techniques. The techniques used were:

#### **I. Image rectification and restoration**

In their raw form, as received from imaging sensors mounted on satellite platforms, remotely sensed data generally contain flaws or deficiencies (Lillesand and Kiefer, 2000). Some of them are radiometric distortions, geometric distortion and noise. Such errors can be corrected by using preprocessing techniques like radiometric correction, geometric correction and noise removal, which should be applied on the raw image. The image that was used in this study is found in two paths and rows and has distortions like mentioned above. Therefore the image was corrected by averaging neighboring pixel values in a raw format of the image to remove the missing scan lines. The image was also georeferenced.

#### **II. Image enhancement**

These techniques are applied to images in order to more effectively display or record the data for subsequent visual interpretation. Contrast stretching is a technique to expand the narrow range of brightness values typically present in an output image over a wider range of gray value (Lillesand and Kiefer, 2000). The visual interpretability of the images used in this study is enhanced by using histogram equalization stretch, in this type of contrast enhancement image values are assigned to the display levels on the basis of their frequency of occurrence.

#### **III. Color composite**

For the color composition many combination were checked to identify different land cover/land use of the study area. False color composite that is red 4, green 3 and blue 2 was used to develop the land use/cover map of the study area.

### **4.3.2 Image Classification**

Image classification is the process of creating thematic maps from satellite imagery. A thematic map is an information representation of an image that shows the spatial distribution of particular theme (Lillesand and kiefer, 2000). There are two main

spectrally oriented classification procedures for land cover mapping: unsupervised and supervised.

**I.** Unsupervised classification is more computer-automated. It enables user to satisfy some parameters that the computer uses to uncover statically patterns that are inherent in the data. These patterns are simply clusters of pixels with similar spectral characteristics. In some cases, it may be mere important to identify group of pixels with similar spectral characteristics than it is to sort pixels into recognizable categories (Lillesand and Kiefer, 2000).

**II.** In supervised classification the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene. To do this, representative sample sites of known cover type, called training areas are used to create the parametric signatures of each class. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it 'looks like most like' ( Lillesand and Kiefer, 2000 ). In this study the different land cover classes in image were classified based on field work data.

### **4.3.3 Method of land suitability Evaluation**

In this paper the method which was used to evaluate the land suitability for surface irrigation and crops was based on FAO guideline (FAO, 1976). This guideline is standard and is also accepted by many researches. This guideline has procedures to evaluate the suitability of the land for intended land use. Because land cannot be graded from "best" to "worst" irrespective of the kind of use and management practiced, since each kind of use has a special requirement.

Evaluation of land suitability is the most central part of land evaluation. Therefore in order to attain the objectives of the study in this paper, procedure was set which is derived from FAO guideline. Generally the procedure answers the following questions:

- For any specified kind of land use, which areas of land are best suited?
- For any given area of land, for which kind of use is it best suited?

In simplified form, the procedures used were as follows:

## **I. Description of land-use types**

A land-use type is a kind of land use described in terms of its products and management practices. Such descriptions serve two purposes. First, they are the basis for determining the requirements of a use. Second, the management specifications can be used as a basis for extension services and for planning necessary inputs. The land-use types for this paper were for the selection of the land for surface irrigation and suitable crops within the study area.

## **II. Selection of land qualities and land characteristics**

Land-use requirements are described by the land qualities needed for sustained production. A land quality is a complex attribute of land that has a direct effect on land use. For example, the availability of water (drainage), the soil depth and slope gradient greatly affect surface irrigation. Most land qualities are determined by the interaction of several land characteristics, measurable attributes of the land. For example, the soil texture is determined by the requirement of crops.

In any particular project, only a limited number of land qualities need to be selected for use in evaluation. Criteria for selection should be:

- The quality must have a substantial effect either on performance or on the costs of production.
- Critical values of the quality must occur in the planning area. For example, if the slope gradient of the land is greater than 8% it is not recommended for surface irrigation.

## **III. Mapping of land units and their characteristics**

After land units were identified in the above procedures (Step 2) as a basis for the diagnosis of problems. These units have to be mapped in more detail using GIS. Then Compare the requirements of the land-use types with the properties of the land units to arrive at a land suitability classification using pairwise comparison rating scale technique in IDRIS software. This technique is used to compare the factors in order to give the weight for the factors that determine the land use types

based on their requirements. Accordingly based on their weight given the suitability map of the land can be developed based on the requirements of the specified land use using spatial analyst in ArcGIS 9.0 by the technique called Weighted Linear Combination (WLC).

The suitability map of the land must be classified based on their land use quality priority for specified land use requirements. According to FAO (1976), generally land suitability map is classified in to two classes i.e. Suitable and not suitable. These suitable and not suitable classes are further classified based on their benefits and limitations (Table 3.1).

TABLE 3.1 STRUCTURE OF THE LAND SUITABILITY CLASSIFICATION

|    |                          |   |
|----|--------------------------|---|
| S  | Suitable                 | The land can support the land use indefinitely and benefits justify inputs  |
| S1 | Highly suitable          | Land without significant limitations. Include the best 20-30% of suitable land as S1. This land is not perfect but is the best that can be hoped for                                |
| S2 | Moderately suitable      | Land that is clearly suitable but which has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land |
| S3 | Marginally suitable      | Land with limitations so severe that benefits are reduced and/or the inputs needed to sustain production are increased so that this cost is only marginally justified               |
| N  | Not suitable             | Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs   |
| N1 | Permanently not suitable | Land with limitations to sustained use that cannot be overcome  |

Source: A framework for land evaluation, 1976

#### **IV. Setting limiting values for land-use requirements**

Finally set the limiting values for the land use requirements. Limiting values are the values of a land quality or land characteristic that determine the class limits of land suitability for a certain use. The first and most important decision is to separate land that is suitable from that which is not important criteria for deciding on the suitability of land for a specific use are sustainability and ratio of benefits to costs.

The following flow charts were used by which the processes involved and the out put produced.

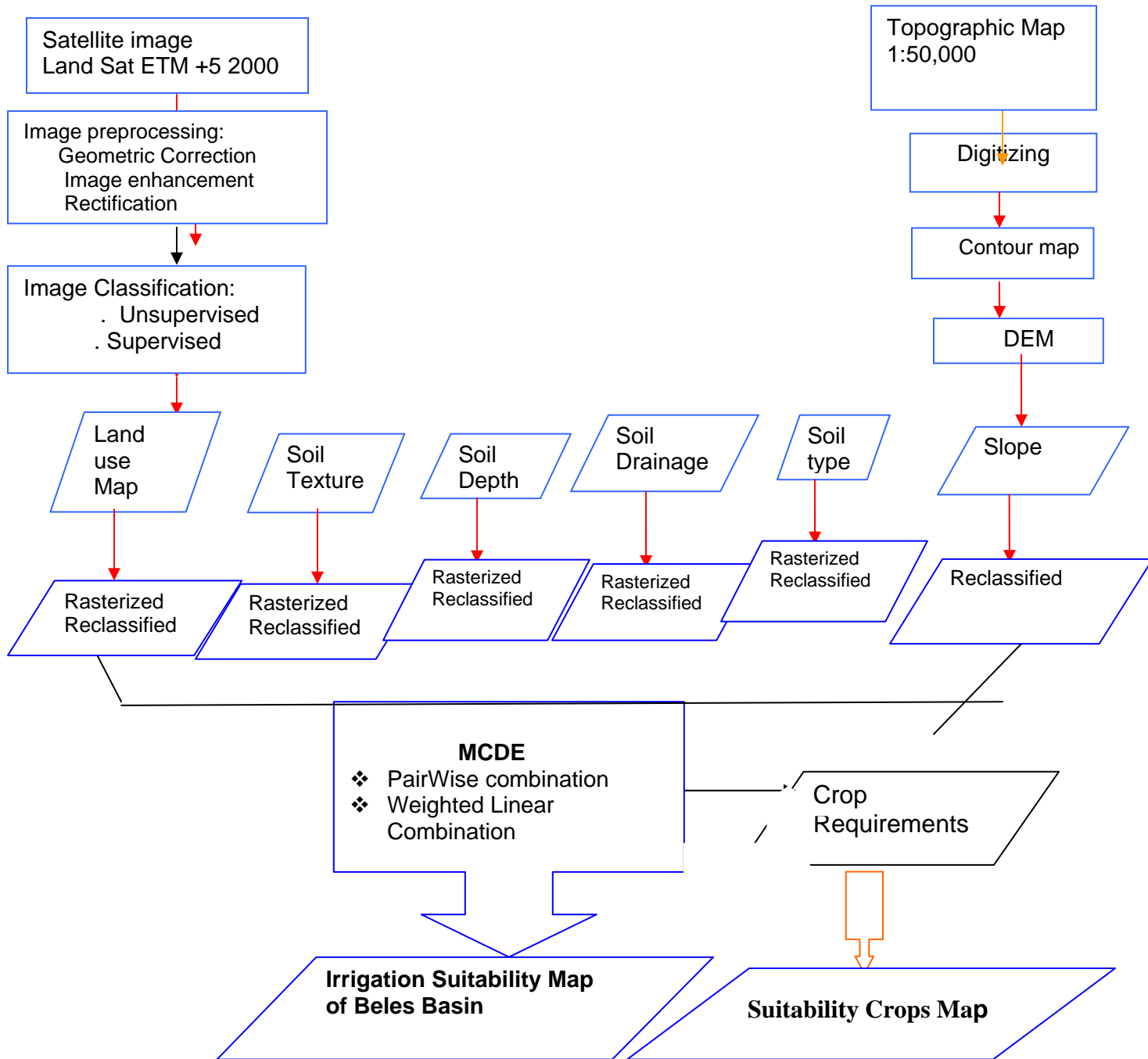


FIG 4.1 FLOWCHART SHOWING THE PROCESSES INVOLVED AND THE OUTPUT PRODUCED

## **5. ANALYSIS AND RESULTS**

### **5.1 Introduction**

One of the major factors that determine the irrigation potential evaluation is physical land resource. These physical land resources include the terrain of land (topography), soil, and water resource. Therefore, in order to determine the suitability of land for irrigation a detail evaluation of the topography of the land within the field, soil properties and the water resource of an area must be done. Because this helps to understand the interaction between soil, water and plant. As a result irrigators can obtain the information about the land characteristics of the land to manage efficiently their crops, soil, irrigation systems and water supplies.

The land use types, which were analyzed in this paper, are surface irrigation potential evaluation and crops suitability in the study area. In order to determine the selection of the suitability of land use described here i.e. surface irrigation potential and crops suitability with in the study area, the physical land qualities and their characteristics of the Beles basin were evaluated based on the land use requirements.

### **5.2 Factors Determining Surface irrigation potential**

Physical and chemical factors of the land as well as climate are the major factors that determine irrigation potential of a given land (FAO. 1987). However the factors, which were evaluated to analyze suitability of the land for surface irrigation under the study area, are only physical land factors (slope, soil depth, soil texture, and soil drainage and soil type), water resource and climate. Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated. However there is a small difference between places in temperature and rainfall. All these are factors which help to evaluate the physical land capability of the study area.

#### **5.2.1 Topographic Characteristics**

Topography indicates an area whether a field can be irrigated or not. The selection of surface irrigation potential is highly influenced by the slope gradient of the land. The topographic relief affects the type of irrigation system to be used, the water conveyance system (ditches or pipes), drainage requirements and water erosion control practices.

The land classification factors, which were evaluated by topographic qualities, are slope gradient, and land grading. They greatly influence the suitability of land for irrigation. Position of the land is a more important factor for irrigable area determination. As it has been reviewed from different literatures, one of the components of topography is relief, which is the difference in height between the steep and gentle area. This difference helps to show the slope difference of the land.

#### **5.2.1.1 Slope Gradient**

Slope is the incline or gradient of a surface and is commonly expressed in percent. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of crops.

The slope gradient of the land has great influence on the length of the irrigation run, crop adaptability, erosion control practices and irrigation method. With surface irrigation, the following adverse effects occur as the gradient increases: erosion hazard increases, water control becomes more difficult, the practical length of irrigation runs decreases, and crop selection becomes more limited. Slope also order the irrigation method used. These factors intensify as the gradient increases. Steep gradients usually result in lower productivity and higher costs of production.

The digitized contour map of the study area is used to derive DEM of the study area. This is used again to derive slope map of the area. Slope derived from the DEM was classified based on the classification system by FAO, 1990 after some modification based on the purpose of the study. According to FAO standard guidelines for the evaluation of slope gradient, slopes, which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999).

The slope of study area was given in percent. The result obtained after the evaluation of the Beles basin was that 45.3% of the basin was less than 2%, 10.3% of the basin between 2-5%, 17.1 % between 5 and 8% and 33.3% of the basin greater than 8%. This indicated that 67.7% of the study area was found to be suitable for surface irrigation in terms of work efficiency and erosion control (Table 5.1 and Fig 5.1).

| Slope gradient (in percent) | Area (in percent) |
|-----------------------------|-------------------|
| <2                          | 40.3              |
| 2-5                         | 10.3              |
| 5-8                         | 17.1              |
| >8                          | 33.3              |

TABLE 5.1 SOURCE SLOPE CLASSIFICATION (FAO, 1990)

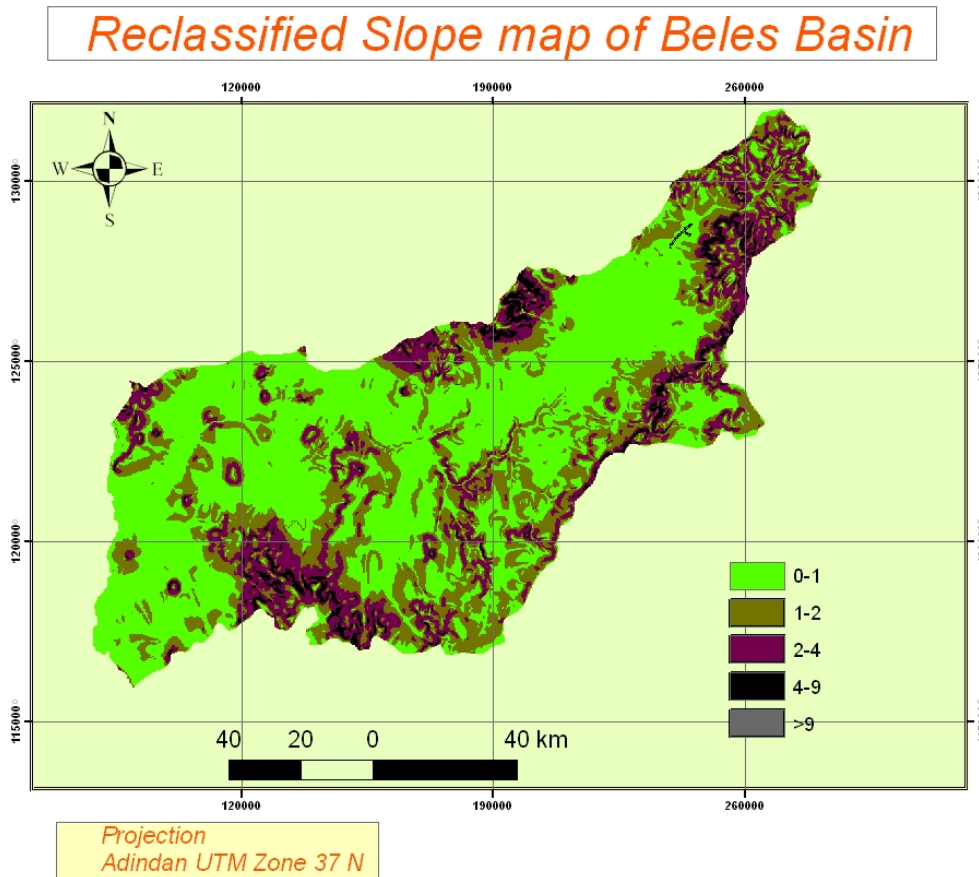


FIG.5.1 MAP SHOWING SLOPE MAP OF THE BELES BASIN

### 5.2.1.2 Slope suitability

As it was mentioned earlier, slope gradient has great impact on work efficiency, erosion control practices and crop adaptability. First Rating factors were given for each slope gradient of the study area based on literature review and FAO guidelines (Table 5.2). Using this rating the basin was reclassified in to four classes according to its land qualities and characteristics of the slope for the selection of the land for suitability of surface irrigation potential. The classes include very suitable (S1), suitable (S2), marginally suitable (S3), and marginally not suitable (N). This type of land classification

is very common and widely used in many researches and also recommended by FAO guidelines (FAO, 1976).

TABLE 5.2 TABLE SHOWING FACTOR RATING OF THE SLOPE GRADIENT OF THE BELES BASIN.

| Factor         | Land quality   | Unit    | Factor rating |     |     |    |
|----------------|--|---------|---------------|-----|-----|----|
|                |  |         | S1            | S2  | S3  | N  |
| Slope gradient | Workefficiency,<br>erosioncontrol and crop<br>adaptability | Percent | <2            | 2-4 | 4-8 | >8 |
|                |  |         |               |     |     |    |

After the reclassification of the slope gradient of the basin, slope suitability map of the basin was developed for surface irrigation (Fig. 5.2). Surface irrigation is highly influenced by slope gradient. The land having slope gradient below 2 percent is very suitable for surface irrigation with out any limitation with respect to slope. This type of land does not need much cost for construction of canals for waterway. Surface irrigation follows the slope gradient, which does not need great energy for distribution of water with in the irrigation field. In addition it is known that most of the time gentle land is suitable for crops production.

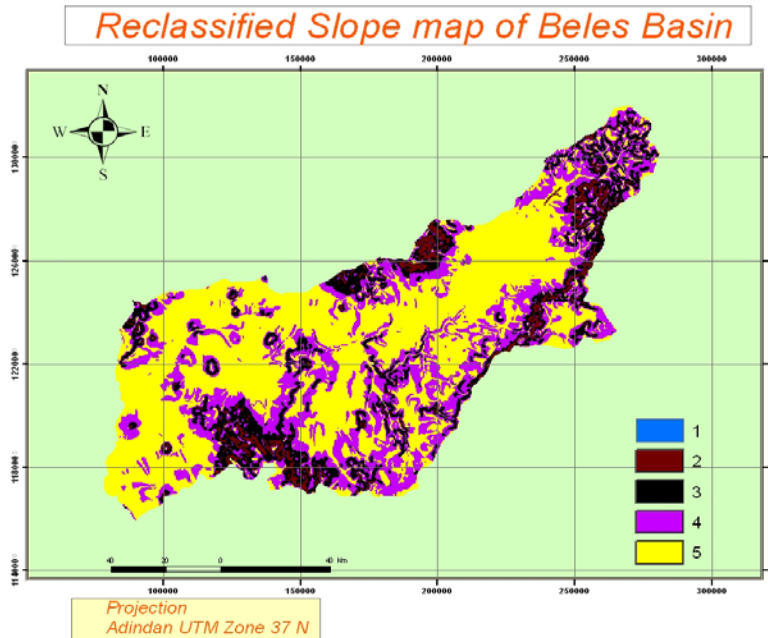


Fig.5.2 Map showing reclassified slope of the Beles basin

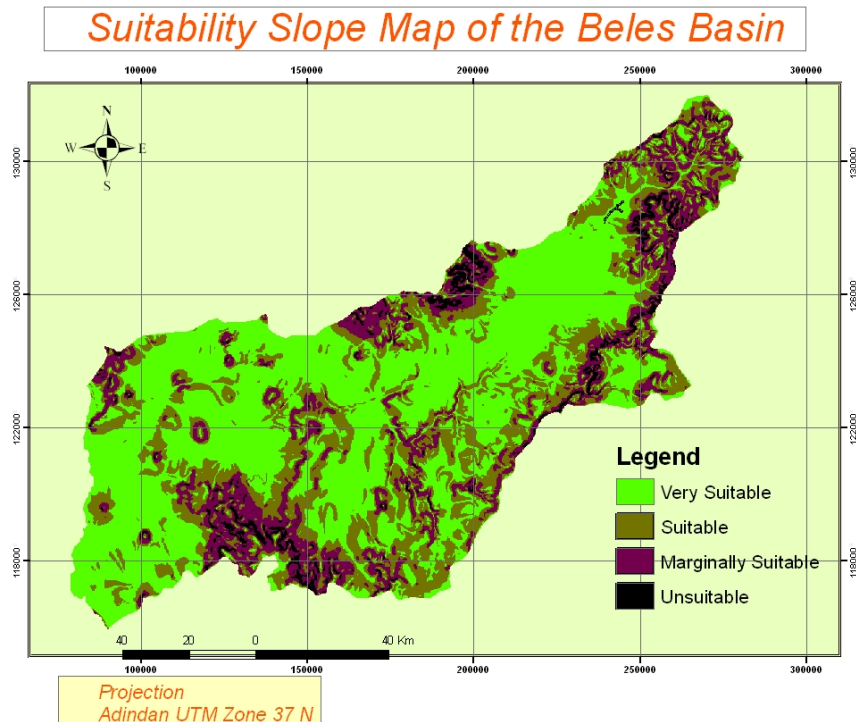


FIG.5.2 MAP SHOWING THE SUITABILITY OF SLOPE OF THE BELES BASIN.

## 5.2.2 Physical properties of Soil

Soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is on the productive capacity, but it also influences production and development costs.

Soil texture, soil drainage, soil depth and soil type are the major physical properties of soil which are very important for evaluation of irrigation potential of the basin. They affect the root growth of plant, infiltration of water in to the soil and the production of crops.

These physical properties of the Beles basin were evaluated independently to determine the irrigation potential of the land. This helps to see the land capability of the basin and determine the suitable area for irrigation.

### 5.2.2.1 Soil Texture

Based on its particles size soils, soils are divided in to three major type soil textures. These include clay, silt and sand soils. These major types have mixtures like silt-clay, clay-loam, sandy loam etc. Generally, clay, clay loam and silty clay loam are classified as

fine-textured soils while sandy clay loam, loam, and silt loam classified as medium-textured soils and the others like sandy soils are classified as coarser-textured soils.

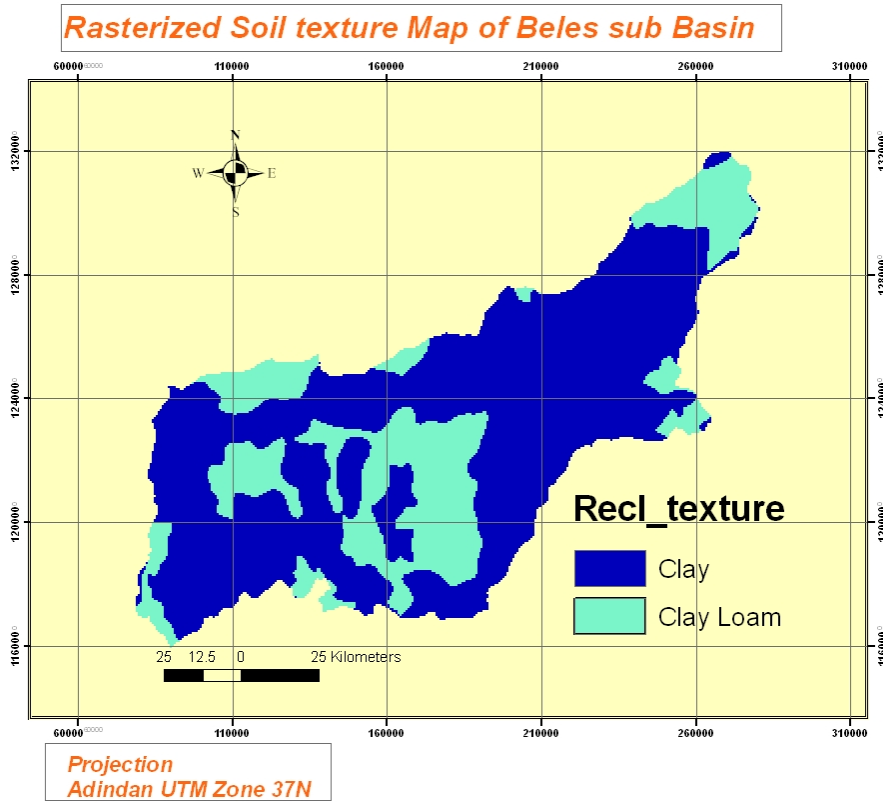
Infiltration (the rate at which water enters the soil) is influenced primarily by characteristics of the surface soil texture. When the infiltration capacity greatly exceeds the permeability of the subsoil, the permeability will greatly influence the basic intake rate of the soil. The infiltration rate may influence selection of the irrigation method, length of irrigation runs, field size, irrigation development costs, and crop selection.

Fine-textured soils will have higher available moisture than coarser-textured soils. However, soils with extremely high clay content may actually have less available water than medium-textured soils.

The soil texture data was obtained from Ministry of Water Resource. The dominant soil textures of the study area were clay loam and clay soil (Fig.5.3). As it can be seen from the figure, clay texture was the dominant type of texture in the study area and the other small area was covered by clay loam. As a result the clay type of the soil under the basin influences permeability, chiefly by its swelling and shrinking qualities with changes in soil moisture. The soils of the basin evaluated under the study area, which were fine-textured, have higher soil moisture.

Soil moisture has great relation ship with rainfall distribution. Thus, the basin has one rainy season, which is from May to August. The soil moisture content is closely related to the rainfall. After the rainy season the soil moisture content is at its maximum in September and October. After this period the soil dries down again. In winter and spring the soil moisture content is very low due to absence of rainfall.

Soil texture of the land is determined by the requirements of crops. Different crops require different types of soil texture.



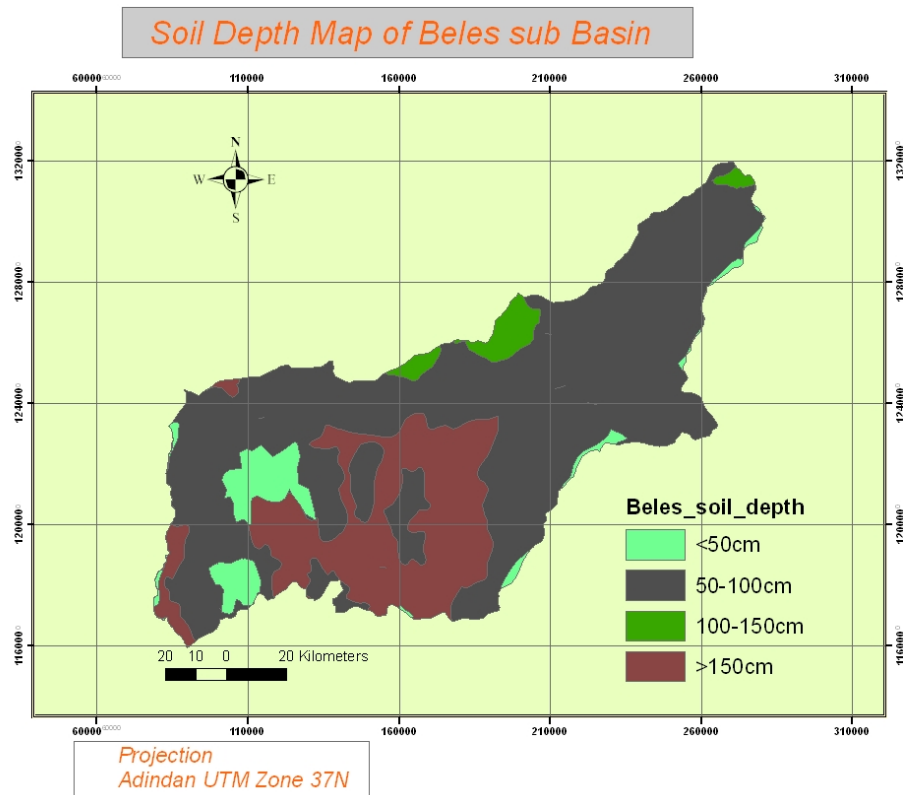
SOURCE: MINISTRY OF WATER RESOURCE.  
 FIG.5.3 TYPE OF SOIL TEXTURE OF THE BELES BASIN

### 5.2.2.2 Soil Depth

Soil depth refers to the thickness of the soil materials. Soil depth provides structural support, nutrients, and water for plants. Soil depth, soil layering, and depth to an estimated water table are also major factors that must be considered when determining the amount of available water a soil profile can hold (Thorn and Peterson, 1949).

The depth to a contrasting soil layer of sand, clay and silt affect irrigation management decisions. If the depth to this layer is less than 10 centimeters, the rooting depth and available soil water for plants require more frequent irrigations. This indicates that soil depth is the major factor that determines plant growth. Plants can extract only the soil water that is in contact with their roots. For most agronomic crops, the root distribution in a deep uniform soil is concentrated near the soil surface (Thomas F. Scherer, 1996). Over the course of a growing season, plants generally extract more water from the upper part of their root zone than from the lower part.

Soil depth was considered as one of the major factors that determine the selection of surface irrigation potential and crops with in the study area. The soil depth data was obtained from Ministry of Water Resource. The soil depth of the study area was varied from place to place. It was ranging from less than 50 centimeters to greater than 150 centimeters (Fig.5.4). Most crops require deep soil depth than shallow.



SOURCE: MINISTRY OF WATER RESOURCE

FIG.5.4 SOIL DEPTH MAP OF THE STUDY AREA

### Soil Depth Suitability

Based on soil depth requirement of most common crops, soil depth of the study area was divided in to suitability classes to select surface irrigation potential. Rating factor was given for the value of soil depth and weighting them to evaluate the suitability of surface (gravity) irrigation potential of the study area. Rating factor was adopted from FAO guidelines (FAO, 1991) (Table 5.3).

TABLE 5.3 FACTOR RATING FOR SUITABILITY OF SOIL DEPTH

| Factor          | Factor Rating |        |       |       |     |
|-----------------|---------------|--------|-------|-------|-----|
|                 | S1            | S2     | S3    | N1    | N2  |
| Soil depth (cm) | >100          | 80-100 | 50-80 | 20-50 | <20 |

Source: FAO guideline for land evaluation, 1991

Based on the given weighting factors for each soil depth of the study area, soil depth suitability map of the study area for surface irrigation potential was developed (Fig 5.5)

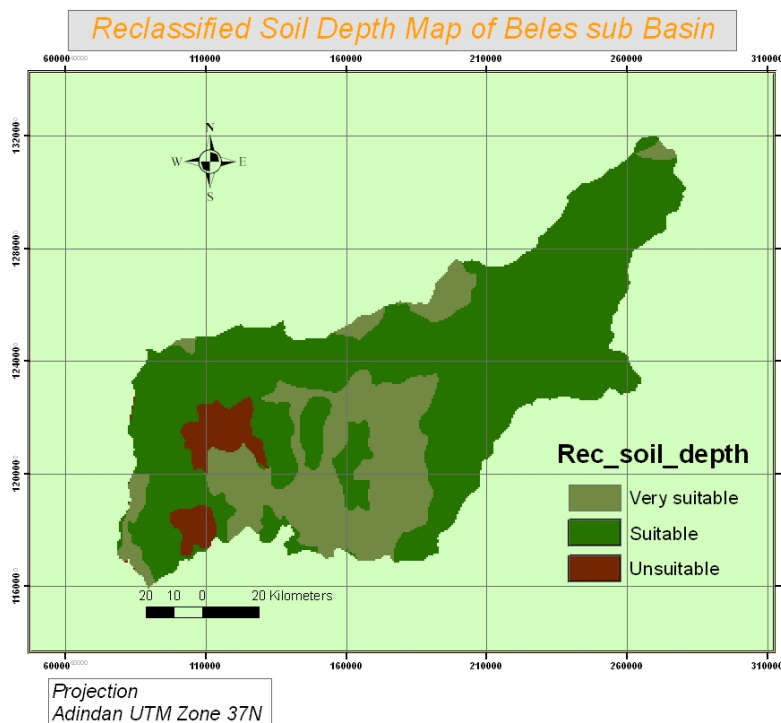


FIG.5.5 MAP SHOWING SOIL DEPTH SUITABILITY OF THE BELES BASIN

### 5.2.2.3 Soil Drainage

Soil drainage permits normal plant growth. Evaluation of the soil drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. Under irrigation, consideration must be given to

additional facilities to permit adequate removal of the excess water and salts added by irrigation.

According to FAO evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage area can be classified as well drained, moderately well drained, imperfectly drained, poorly drained and very poorly drained. The soil texture can determine the permeability of the soil for water in the study area. There fore the soil drainage properties of the study area was classified in to well, moderately well and imperfectly drained (Fig.5.6).

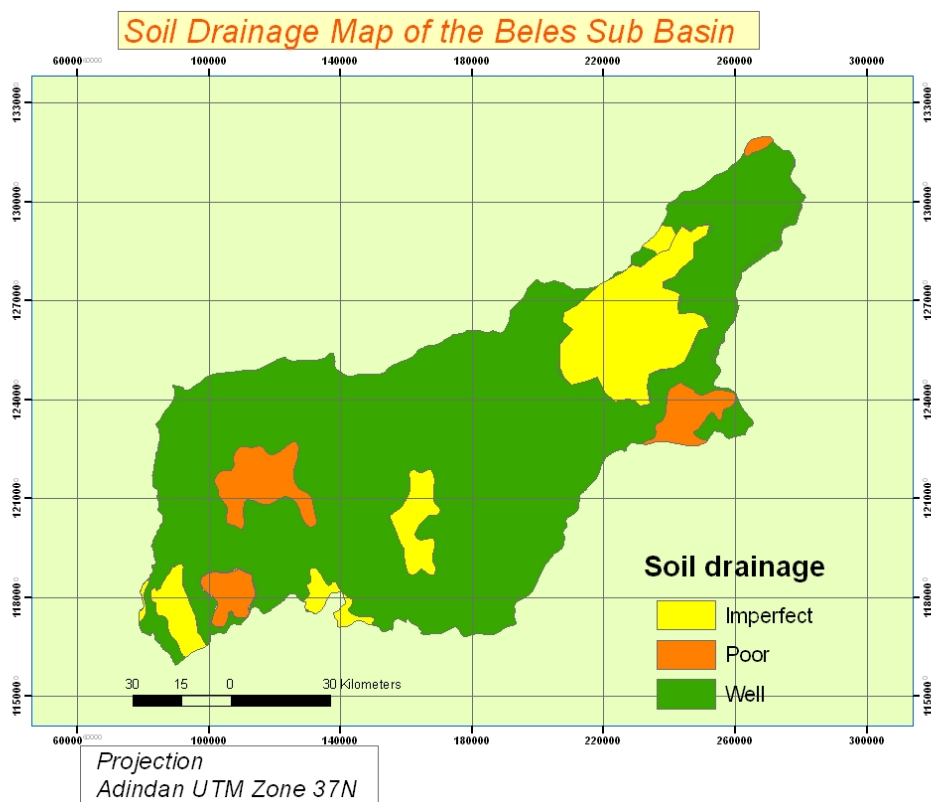
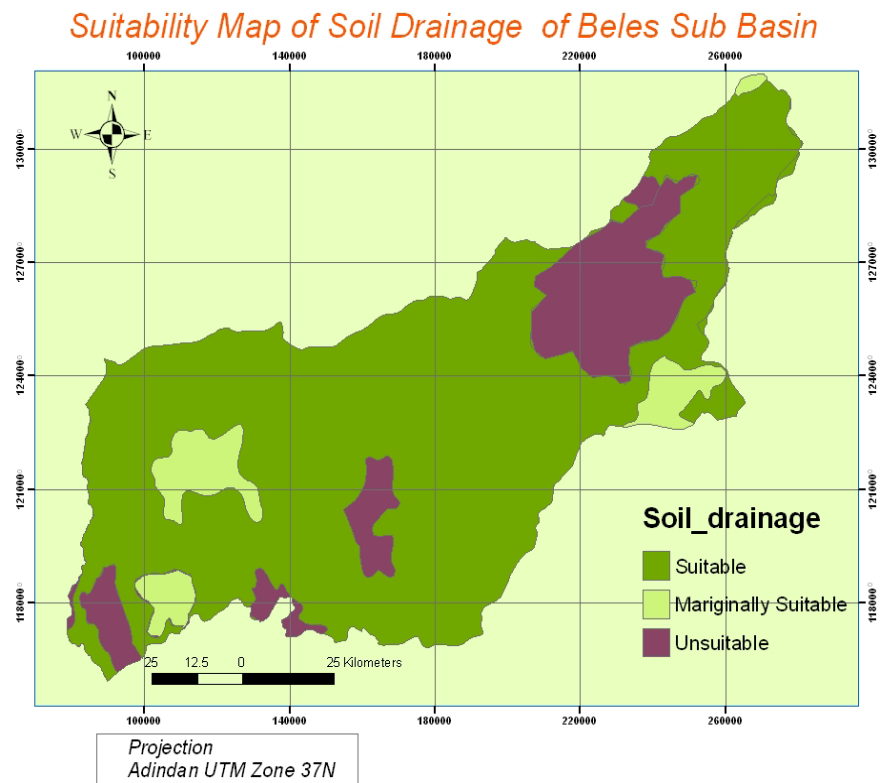


FIG 5.6 SOIL DRAINAGE MAP OF BELES BASIN

After conversion of soil drainage map of the study area in to raster form, the rasterized soil drainage map was reclassified based on the requirements of crops and surface irrigation potential. As a result suitability map of soil drainage with in the study area was developed (Fig 5.7). The value was changed in to suitable classes based on the FAO

guideline (FAO, 1976). The suitability classes were three i. e. very suitable, marginally suitable and unsuitable (Fig.5.8).



#### 5.2.2.4 Soil type of the Beles Basin

Soil is the layer of the earth's surface, which has been changed by physical or biological processes. The five soil-forming factors that control the process of change are parent material, climate, topography, biota (plants and animals) and time. Soils are grouped into categories according to their observed properties. The USDA classification system consists of six categories. The highest category (soil order) contains 11 basic soil groups, each with a very broad range of properties. The lowest category (soil series) contains over 12,000 soils, each defining a very narrow range in soil properties.

The soil type map of the study area was derived from Minister of Water Resource. There are 11 types of soils in the basin. Luvisols, Cambisols, Fluvisols, Leptisols, Regosols, Vertisols, Acrisols, Alisols, and Nit sols were the major ones (Fig 5.9). Soil type of the basin has impacts for determination of irrigation potential. Thus, it was taken as a one

input to develop irrigation suitability map for the basin. Because all types of soils are not suitable for crops in irrigation.

Many soil series do not have a deep, uniform soil profile. Restrictive subsurface layers often interfere with root penetration. In these situations the roots will be concentrated in the upper part of the soil profile. This type of information is important for irrigation. The vector format of soil type map of the study area was rasterized to reclassify it (Fig.5.9).

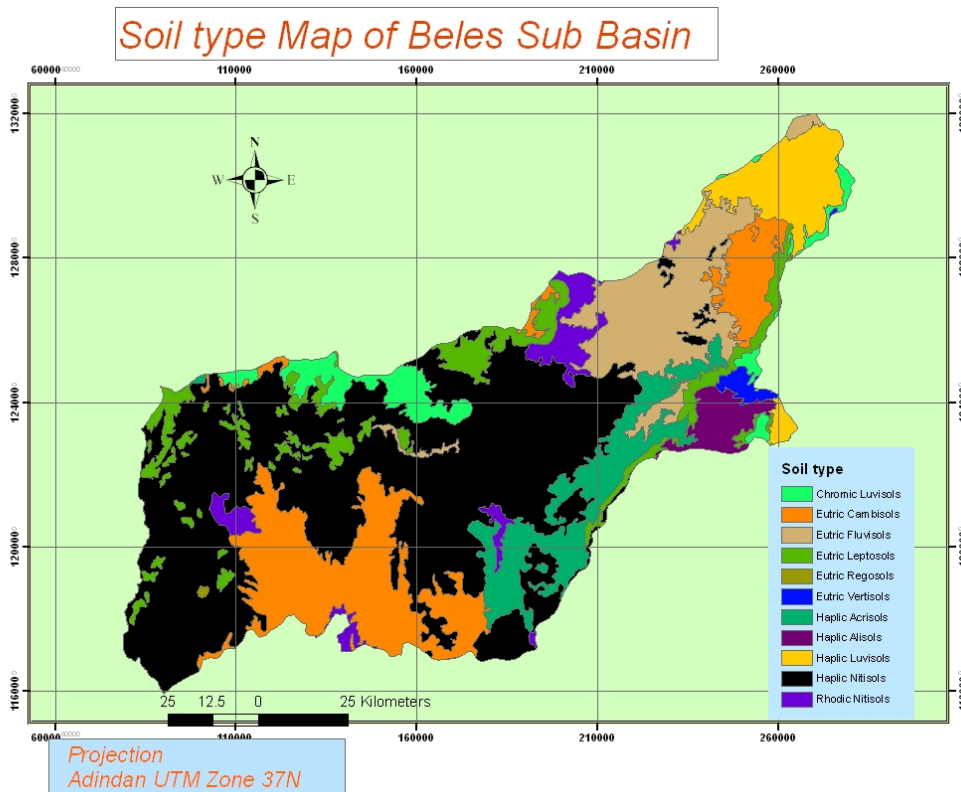


FIG.5.9 SOIL TYPE OF BELES SUB BASIN

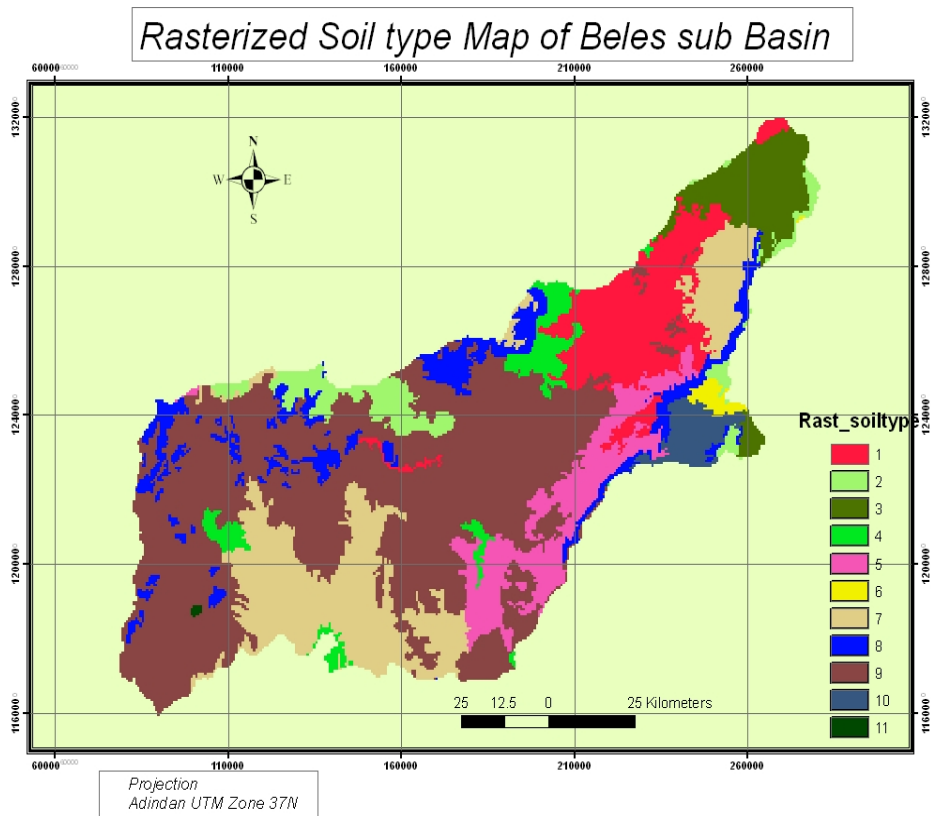


FIG.5.10 RASTERIZED SOIL TYPE OF THE STUDY AREA

The rasterized soil type of the study area was reclassified based on their soil type name found in the basin. The final reclassified map was developed for analysis to determine the suitability of surface irrigation and mapping the final physical land suitability of surface irrigation and crops (Fig 5.11)

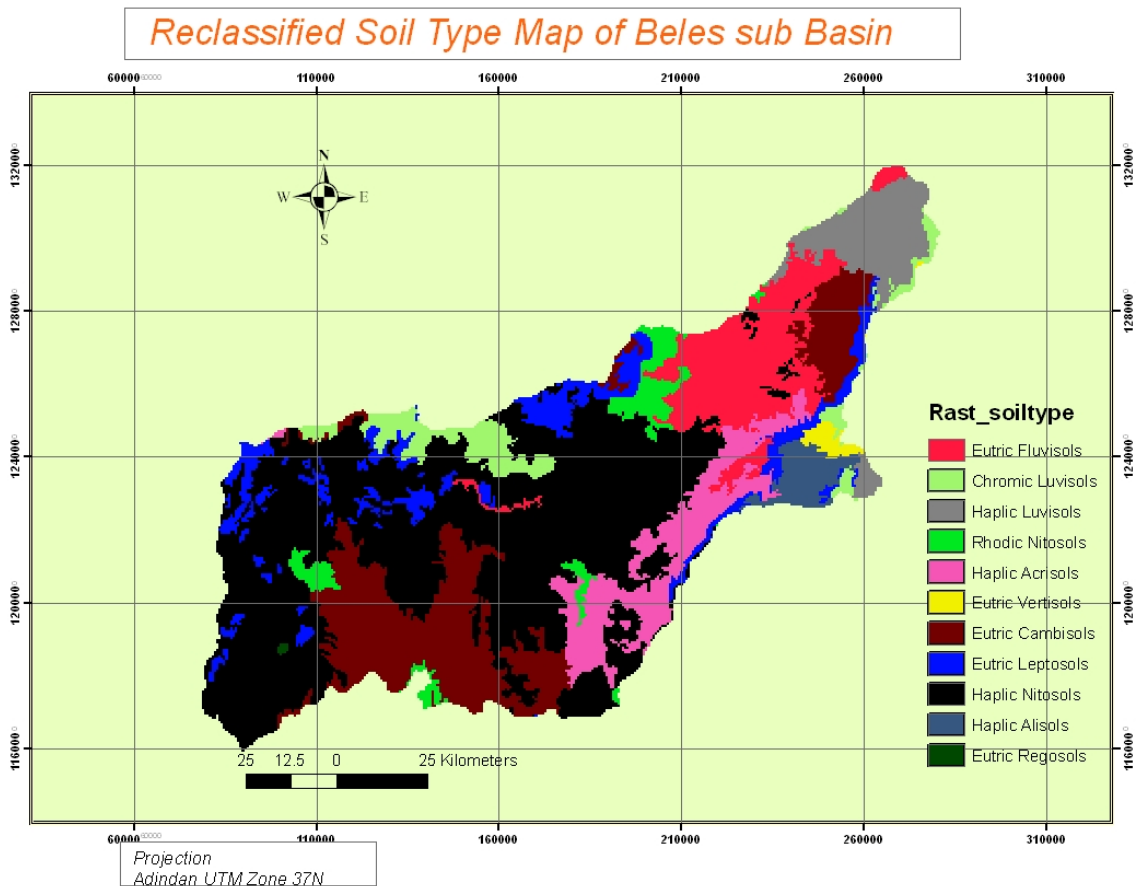


FIG 5.11 MAP SHOWING RECLASSIFIED SOIL TYPE OF THE STUDY AREA

### 5.3 Present land use/ land cover

Land use / land cover study is also the factor, which is used to evaluate the land for irrigation. Land use map of the basin was derived from Land sat ETM+ image taken in 2000 during September. The image was used only to develop the land use map of the Beles basin. Land use/land cover map was made using maximum likelihood classification technique. Land use / land cover influences on the cost of irrigation practice to prepare the land for agriculture. It was taken as one input for the evaluation of land qualities for irrigation for the study area.

Vegetation and rock are the most common cover types that require removal for successful irrigation. Rocks may also be a factor in construction of farm distribution and drainage systems and in land grading operations. Lands with cover, which limit irrigation, can be managed in one of two ways: (1) leave the cover and limit use and productivity of the land, or (2) remove the cover (at a higher development cost) so that normal cultural practices are possible. Because cover primarily affects tillage practices, it may have little effect on the choice of irrigation method for a specific area.

The type of land use/land cover in the study area included grasses, shrubland, cultivation, woodland, bare land, wetland, plantation, natural forest, highland bamboo. Woodland, cultivation land, grassland, shrubland and bare land are the major land use land cover of the study area (Fig5.12).

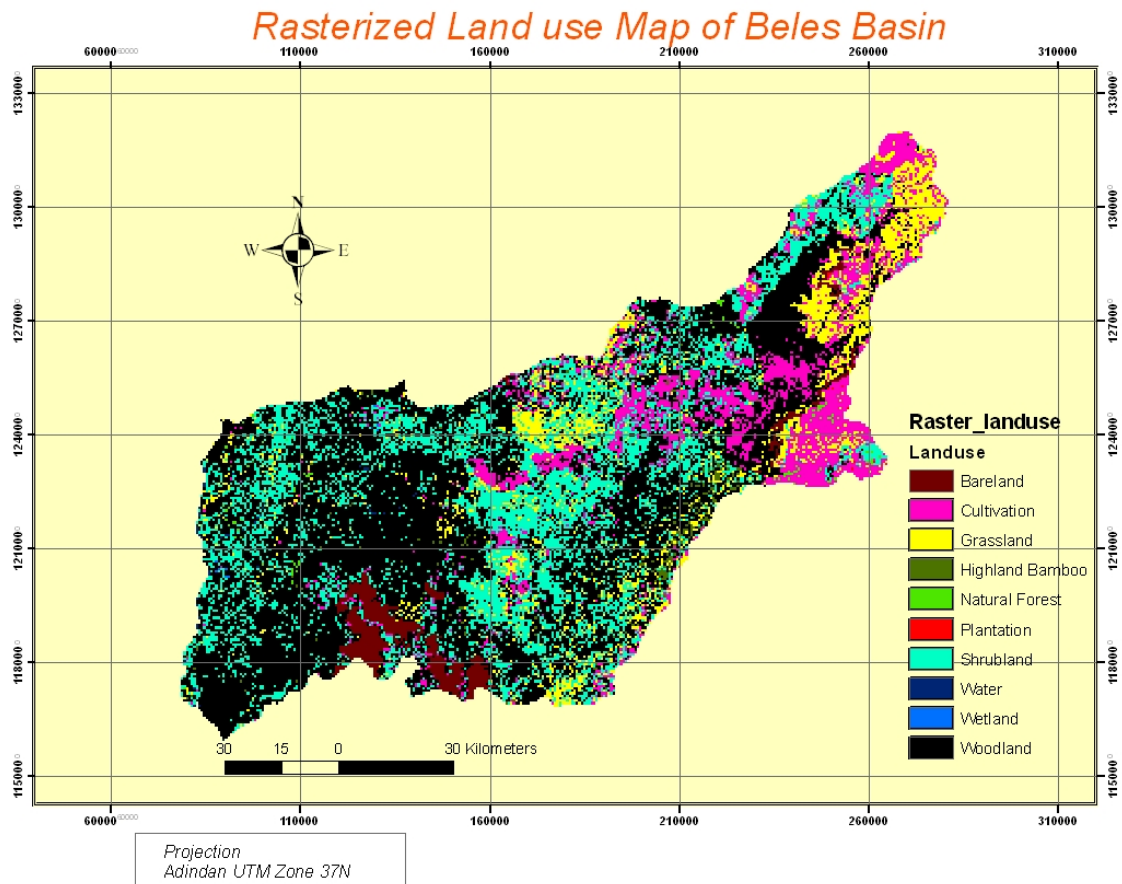


FIG.5.12 LAND USE MAP OF THE STUDY AREA

The types of land use/ cover of the study area were ranked based on their importance for surface irrigation potential, costs to remove or change for cultivation and environmental impacts under the basin. After rank was given for the land use types, reclassified map of the study area was developed (Fig.5.13). The land use type was reclassified in to four suitability classes and given value from 1 to 4. 1 represents very suitable, 2 suitable, 3 marginally suitable and 4 unsuitable.

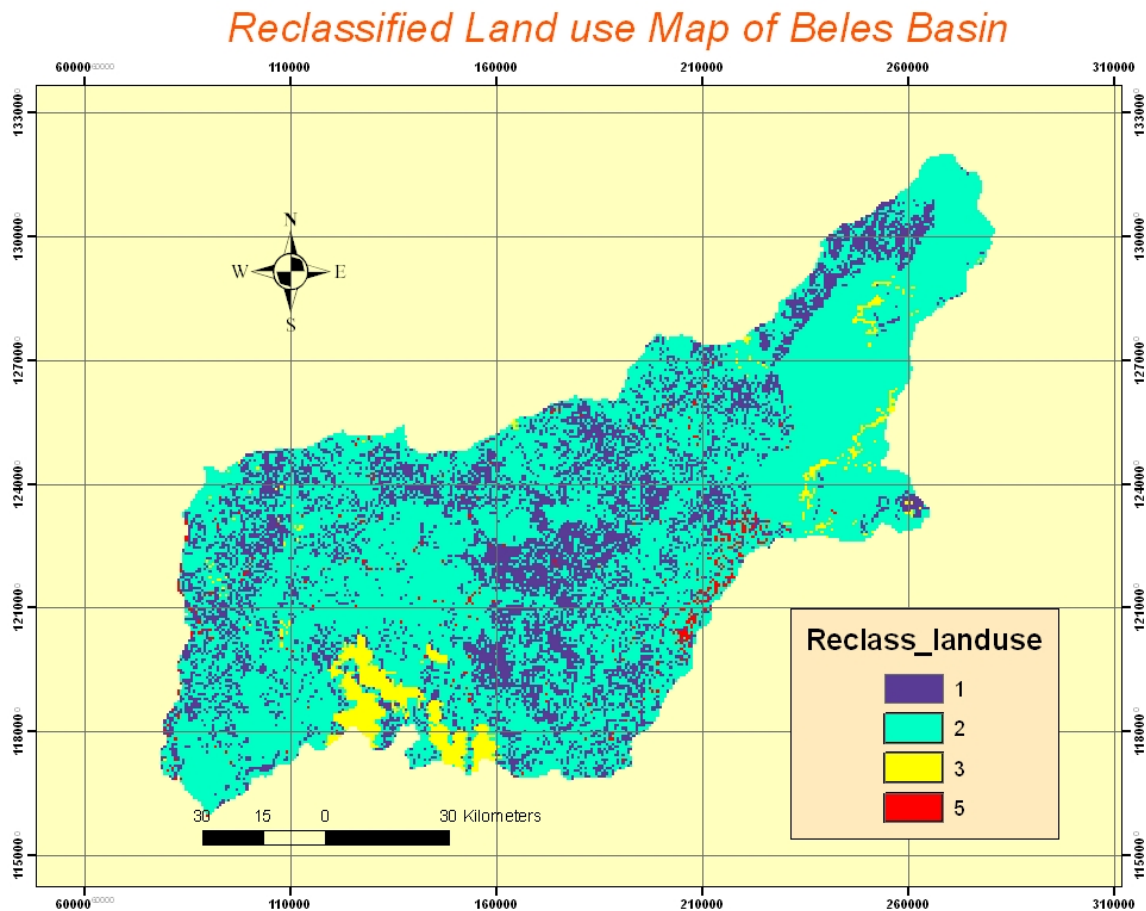


Fig. 5.13 Reclassified land use land cover map of the study area.

#### 5.4 Water Resource

Water resource is one of the major factors, which are needed for irrigation. Plant needs water to grow. Water is essential for plant growth. Without enough water, normal plant functions are disturbed, and the plant gradually wilts, stops growing, and dies. Plants are most susceptible to damage from water deficiency during the vegetative and reproductive

stages of growth. Also, many plants are most sensitive to salinity during the germination and seedling growth stages.

Most of the water that enters the plant roots does not stay in the plant. Less than 1% of the water withdrawn by the plant is actually used in photosynthesis (i.e. assimilated by the plant). The rest of the water moves to the leaf surfaces where it transpires (evaporates) to the atmosphere. The rate at which a plant takes up water is controlled by its physical characteristics, the atmosphere and soil environment.

As water moves from the soil, into the roots, through the stem, into the leaves and through the leaf stomata to the air, it moves from a low water tension to a high water tension. The water tension in the air is related to its relative humidity and is always greater than the water tension in the soil.

Beles River is grouped under the main rivers found in the country. It flows also in plain land of the study area. There are also other large tributaries like Dura, which are perennials and join to main Beles River. The Beles sub basin is characterized by well external drainage.

## **5.5 Climate**

Climate exerts important influences on the suitability of lands for irrigation. The characteristics of the soil, drainage conditions, distribution of native vegetation, and crop adaptation are related to climate. Interactions of climate, land, economic, and social factors operating over time express themselves in broad patterns of irrigation farm types. Thus, the physical environmental factors (including climate) determine what will or will not grow, while economic and social factors determine what is grown. Therefore, fundamental considerations in planning an irrigation project involve deriving a proper set of assumptions regarding the cropping pattern and management systems.

Climate of the study area was characterized by semi arid. Rainfall distribution and temperature amount with in the study area have little variation. Rainfall and temperature map of the study area were developed using Inverse Distance Weighted (IDW) technique. The rainfall and temperature data were obtained from Pawe and Chagni stations(Fig 5.14).

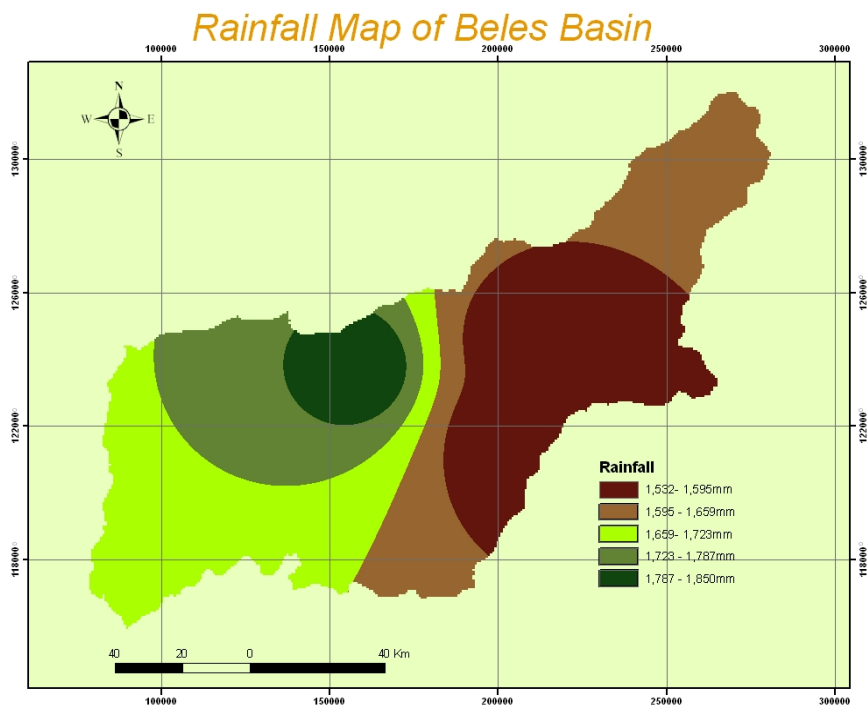


FIG 5.14 RAINFALL MAP OF THE STUDY AREA

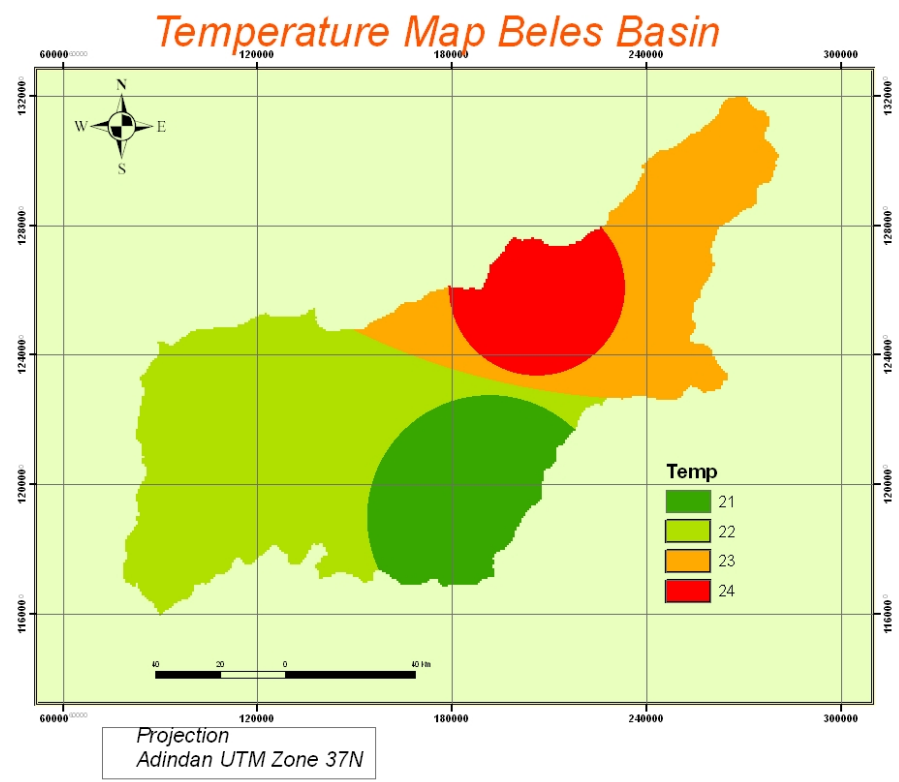


FIG 4.15 TEMPERATURE MAP OF THE STUDY AREA

## 5.6 PHYSICAL LAND SUITABILITY MAPPING FOR IRRIGATION

### 5.6.1 Multi-Criteria Decision Evaluation

MCE is a set of procedures designed to facilitate decision-making. The basic purpose is to investigate a number of choice possibilities in the light of multiple criteria and conflicting objectives.

Decision Theory is concerned with the logic by which one arrives at a choice between alternatives. What those alternatives are varies from problem to problem. They might be alternative actions, alternative hypotheses about a phenomenon, alternative objects to include in a set.

The primary issue in Multi-Criteria Evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation. Weighted Linear Combination (WLC) is most common technique used to create suitability map. Weight is used to develop a set of relative weights for a group of factors in a multi-criteria evaluation. The weights are developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These pairwise comparisons are then analyzed to produce a set of weights that sum to 1. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination. The procedure by which the weights are produced follows the logic developed by T. Saaty under the Analytical Hierarchy Process (AHP) with a weighted linear combination; applying a weight to each followed by a summation of the results to yield a suitability map, i.e., combines factors (Ronald Eastman J., 2001).

$$S = \sum W_i X_i \quad \text{where:}$$

$S$  = suitability  
 $W_i$  = weight of factor  $i$   
 $X_i$  = criterion score of factor  $i$

The above method mentioned was also used in this paper to develop the suitability map of physical land for surface irrigation potential in the study area. In order to develop suitability map there are procedures to be followed when using weighted linear combination technique. The following are the procedures, which were used for developing physical land suitability map for surface irrigation potential in the study area.

## **5.6.2 Establishing the Criteria: Factors and Constraints**

### **A. FACTORS**

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore most commonly measured on a continuous scale.

For the evaluation of physical land suitability of the basin for irrigation, sets of factors that influence the capability of physical land and water resource for surface irrigation in the study area were first established. From these factors, the possibilities and constraints for surface irrigation were analyzed. The following factors, which were discussed before, were considered for the evaluation of the physical land suitability for irrigation:

- Slope gradients
- Soil texture
- Soil depth
- Soil drainage
- Present land use of the basin
- Soil type of the basin

### **B. Constraints**

A constraint serves to limit the alternatives under consideration. In many cases, constraints are areas excluded from consideration should be coded with a 0 and those open for consideration should be also coded with a 1. In this paper road and built up area (town) were considered as constraints for physical land suitability for irrigation (Fig 4.15).

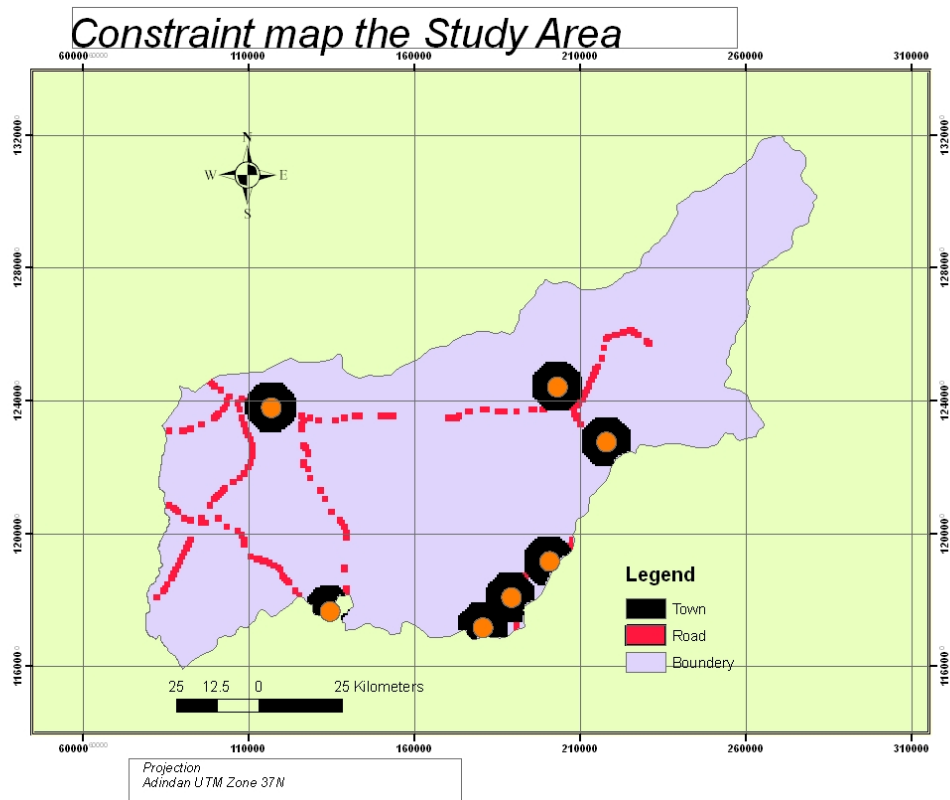


FIG 5.16 CONSTRAINT MAP OF THE STUDY AREA

### 5.6.3 Standardizing the Factors

In this paper, factors, which were selected to evaluate the physical land capability of the Beles basin, were standardized using IDRIS software. Pair wise technique was used for standardizing the factors. Ratings were given for all factors on a 9-point continuous scale (Table 4.4). For example, if one feels that proximity to slope gradient is very strongly more important than soil texture in determining physical land suitability for surface irrigation, one will enter a 7 on this scale. If the inverse is the case (soil texture was very strongly more important than slope gradient), one will enter 1/7. But the value given for the factors was based on requirements of surface (gravity) irrigation and reviewed from different literature.

Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half.

TABLE 5.4 ILLUSTRATES THE STANDARDIZED RESULTS OF ALL SIX FACTORS FOR THE PHYSICAL LAND SUITABILITY FOR IRRIGATION OF THE BELES BASIN.

| Factors       | Slope | Soil drainage | Depth | Texture | Soil type | Land use |
|---------------|-------|---------------|-------|---------|-----------|----------|
| Slope         | 1     |               |       |         |           |          |
| Soil Drainage | 1/3   | 1             |       |         |           |          |
| Depth         | 1/3   | 1/3           | 1     |         |           |          |
| Texture       | 1/5   | 1/3           | 1/5   | 1       |           |          |
| Land use      | 1/5   | 1/3           | 1/3   | 3       | 1         |          |
| Soil type     | 1/5   | 1/5           | 1/3   | 1/3     | 1/3       | 1        |

#### 5.6.4 Establishing the Factor Weights

This is the second step in MCDE to establish a set of weights for each of the factors. The technique described here and implemented in IDRISI is that of pair wise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (Saaty, T.L., 1977). In Saaty's technique, taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria can derive weights of this nature.

In this paper pair wise comparison was used for weighting the factors. All the six factors, which were selected for the evaluation of irrigation potential in the basin, were weighted using pair wise comparison.

After the pair wise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best-fit weights.

The consistency ratio (CR) was 0.04, which was acceptable for weighting the factors to evaluate the physical land capability of the Beles basin for developing irrigation suitability map.

Eigenvector of the pair wise comparison matrix

| Factors        | W <sub>j</sub> |
|----------------|----------------|
| Slope gradient | 0.42           |
| Soil Drainage  | 0.21           |
| Depth          | 0.14           |
| Texture        | 0.10           |
| Land use       | 0.08           |
| Soil type      | 0.05           |
| CR             | 0.04           |

### **5.6.5 Undertaking the Multi-Criteria Evaluation**

After the criteria maps (factors and constraints) had been developed, an evaluation (or aggregation) stage was undertaken to combine the information from the factors and constraints. In this paper, as it is widely used and mostly accepted by many researches, weighted linear combination (WLC) was used to evaluate the factors and constraints maps (Ronald Eastman J., 2001). After the weights were established, the module MCE (for Multi-Criteria Evaluation) was used to combine the factors and constraints in the form of a weighted linear combination (WLC option).

#### **MCE and Weighted Linear Combination:**

The weighted linear combination (WLC) aggregation method multiplies each standardized factor map (i.e., each raster cell within each map) by its factor weight and then sums the results using spatial analyst in GIS by calculating sum to one, the resulting suitability map will have the same range of values as the standardized factor maps that were used. This result was then multiplied by each of the constraints in turn to "mask out" unsuitable areas (Ronald Eastman J., 2001).

$$S = \sum W_i X_j$$

$$S = 0.42 SP + 0.21SD + 0.14 D + 0.10 T + 0.08 L.U + 0.05 S.T$$

Where:

**S** is the suitability irrigation area

**SP** is the Slope

**SD** is Soil drainage

**D** is the soil depth

**T** is the texture

**L.U** is the land use

**S.T** is the soil type

### 5.6.6 Land Suitability Class Specification

According to FAO standards, which are widely used to classify land suitability for specified objectives of land utilization types, a land can be divided into five classes. These include very suitable (S1), suitable (S2), marginally suitable (S3), marginally not suitable (N1) and permanently not suitable (N2) (FAO, 1976).

Class-determining factors are those factors, which affect the performance of the land utilization types on the land units under the study i.e. the irrigation potential evaluation in the Beles basin. These factors are also called factors maps, which were mentioned above. These factors include slope gradient, soil drainage, soil depth, soil texture, soil type and land use of the basin. The factors were selected based on the requirement of the surface irrigation potential evaluation of the basin.

Multiplying the reclassified factors map based on the given weights and adding them by Raster calculator technique in spatial analyst module in ArcGIS 9.0 software obtained the final physical land suitability map of the basin. The result was given with values in five classes. These classes were changed with suitability classes.

The physical land suitability map was divided into five suitability classes (Fig 5.14). These were very suitable, suitable, marginally suitable, marginally not suitable and

permanently not suitable. From the total land of the basin 41650 hectare (26.9%) was very suitable, 24100 hectare (15.6%) suitable, 44350 hectare (28.7%) marginally suitable, 11000 hectare (7.3%) marginally not suitable and 33250 hectare (21.5%) was permanently not suitable for surface irrigation. This physical land suitability map of the study area for surface irrigation potential was multiplied by 1 and adding the constraints map multiplied by 0 to obtain the final physical land suitability map.

The reclassified factors maps, which were used to evaluate the suitability of physical land for surface irrigation of Beles basin, are listed below.

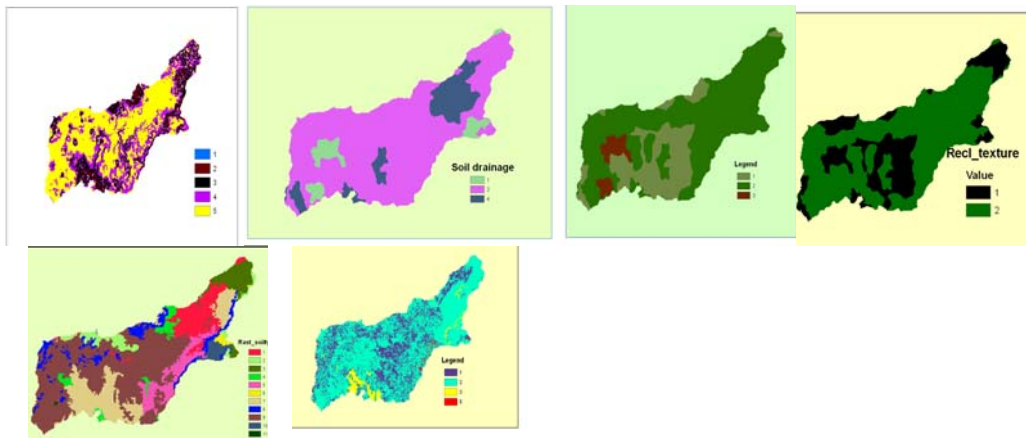


FIG.5.17 RECLASSIFIED FACTORS MAP

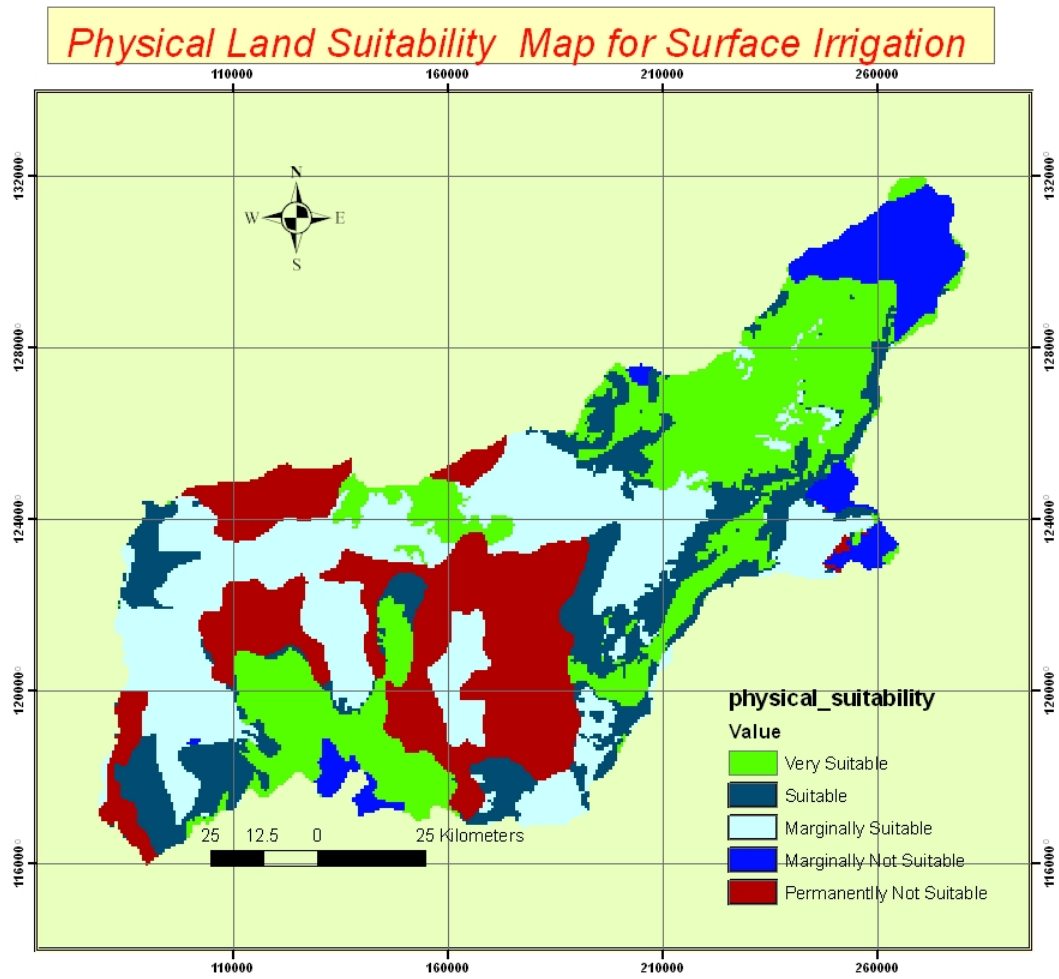


Fig.5.18 Physical Land Suitability Map of the Study Area for Surface Irrigation potential

## **6. CROPS SUITABILITY MAPPING IN THE BELES BASIN**

### **6.1 INTRODUCTION**

After evaluation of the physical land characteristics of the land for surface irrigation, it is very necessary to examine the land capability for crops production in the study area. There fore the study aimed at to evaluate suitable crops in the study area. The base line to select types of crops, which are suitable for the land, was types of crops, which are widely grown in the area and used by many farmers as commercial crops. In addition types of crops, which are very necessary for, export items and can, bring economic growth for the country in general.

Maize and cotton were selected in order to evaluate the capability of the land under the study area. Maize is widely grown in the study area. The farmers are using it. The scale production is carried out in low management and investment level. Water resource used for maize is mainly rain fed. Cotton is not widely used by many farmers like maize, but there are some people who harvest the cotton in the study area. Its production is also good with in small plot of land. There fore if it is widely grown with good management and investment level, it can be one of the major export items for the country.

### **6.2 Evaluation of Physical Land Qualities of the Beles Basin for Crops suitability**

Land evaluation provides information and recommendations for deciding 'Which crops to grow where' and related questions. Land evaluation is the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable. The main product of land evaluation investigations is a land classification that indicates the suitability of various kinds of land for specific land uses, usually depicted on maps with accompanying reports.

The evaluation and suitability classification system described in this paper is based on A Framework for Land Evaluation (FAO 1976).

The evaluation of soil qualities, soil drainage and topographic conditions to predict the performance for maize and cotton is an essential part of a land evaluation applied to agriculture. In this paper, emphasis was placed on the evaluation of physical properties of soils, water resource and slope for developing suitability of land for the crops.

In order to compare soil and terrain conditions with specific crop requirements for optimum growth and production, soil qualities or characteristics and terrain condition were evaluated against specific crop requirements as derived from the Minister of Water Resource and literature review.

### **6.3 Physical Land Characteristics of the Beles basin**

Land characteristics or qualities of the land for specified land use are very important. They greatly affect the land utilization types. There fore they should be studied based on their land utilization types. In this paper physical land properties were evaluated based on the crops requirements. The physical land properties of the basin, which were evaluated, include drainage, slope gradient, soil texture, and soil depth and soil type and land use.

#### **6.3.1 Soil Drainage**

Soil permeability of water is one of the major factors that determine crop production. The soil drainage of the basin was dominantly characterized by well and imperfect drained area. According to FAO standard guidelines, soil drainage of a specified area can be divided in to five classes. These are well drained, moderately drained, imperfectly drained, poor drained and very poorly drained. There fore, based on its soil permeability of water in the study area, the Beles basin was classified in to well, moderately well and imperfect drained (Fig5.6).

#### **6.3.2 Soil Depth**

The thickness of the soil materials, which give structural support, nutrients and water for crops, is referred as soil depth. A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots. Soil depth, which is needed by crops for optimum root growth, is called effective soil depth. The required effective soil depth for crops is varied based on their requirements.

Plants develop extensive root systems, but the depth of rooting and the concentration of roots in a given volume of soil depend on soil conditions as well as on the genetic nature of the plant. Plants root need room to growth (Thorne and Peterson, 1949).

In this paper, the soil depth of Beles basin was classified in to five (Fig.5.4). The depth was given in centimeter. Soil series that have bedrock between 25 and 50 centimeters from the surface were described as shallow. Bedrock between 50 and 100 centimeters was described as moderately deep. Most soil series in the Beles basin have at depths greater than 100 centimeters.

### **6.3.3 Soil Texture**

Soil texture is determined by the size and type of solid particles that make up the soil. Soil particles may be either mineral or organic. In most soils, the largest proportions of particles are mineral and are referred to as "mineral soils." For mineral soils, the texture is based on the relative proportion of the particles below 2 millimeters (mm) or 5/64th of an inch in size. Based on its size soils can be divided in to gravel, sand, silt and clay. These are called the mineral fraction of soil. These gravel and sand are inactive chemically, supplying no appreciable quantities of mineral nutrients for plant use, but they do perform important function by making soils friable and providing larger pore spaces for drainage and root growth (Thorne and Peterson, 1954).

The silt fraction represents mineral particles between 0.05 and 0.002 mm. in diameter. The particles consist largely of primary such as feldspars, mica, and quartz. Silt particles supply only small quantities of nutrients directly to plants (Thorne and Peterson, 1954).

Clay is the most chemically active of the soil minerals. Because of the small size of the particles in relation to its total size, clay has a tremendous surface area per unit of mass. The significant feature of clay particles in relation to plant nutrition is the capacity to retain numerous positively charged ions in an exchangeable state.

Generally, the soil texture of the specified land use is divided in to five classes based on the FAO guidelines (FAO, 1986). These are loam, silty clay loam, clay, sandy loam and clay loam.

According to FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified in to clay and clay loam (Fig.5.3). Clay has important effects on the physical properties of soil. It acts as a binding agent, holding sand, silt and clay together in aggregates. Clay has a high absorption capacity for water. It swells and shrinks with soil moisture changes (Thorne and Peterson, 1949). They also stated that

usually soils with intermediate clay contents (5 to 40 percent) are preferred for agricultural purposes.

#### **6.3.4 Slope gradient**

Slope is important to soil formation and management because of its influence on runoff, soil drainage, erosion, use of machinery, and choice of crops. Slope is the incline or gradient of a surface and is commonly expressed in percent. The topography of the Beles basin was evaluated and classified. The slope gradient of the basin per percent was ranging from less than 2 percent up to greater than 9 percent (Table 5.1). Gentle land is suitable for agriculture than steep land. The supplying of water, flood protection, leaching, and salt accumulation are often problems of land related topography. Some lands occupy a high slope gradient where they are inaccessible for water. Some lands are low-laying and subject to flooding and seepage if lands above them are irrigated. Low-laying lands are also frequently subject to frost drainage (Fig. 5.2).

#### **6.4 Climate**

Crops need specific requirements of temperature and rainfall for growth. The study area of climate was characterized by high amount of average temperature, which is above 24.5c°. However it varies little from year to year. The other major elements of climate, which is very required for crops production is rainfall. As it was discussed earlier the total annual rainfall of the study area is from 1231mm to 1773mm. Generally the climate of the study area was classified under semiarid climate. Temperature and rainfall were considered as factors for analysis of crops suitability in the study area. Crops require specific an average amount of temperature and rainfall. However climate was taken as homogenous for evaluation irrigation suitability analysis earlier.

#### **6.5 Crops Requirements**

The factors, which are mentioned above, are the major physical factors, which were considered to determine the production of crops in a specified area. All these factors have not the same impacts on crops. Some crops need one factor more than the others. However the factors bring different effects on production. Therefore weight given for the two crops were different based on their requirements (Table 6.1).

The physical properties of soils such as depth, texture, soil drainage (permeability) are the important soil characteristics in land evaluation that affect the yields under specific climatic and site conditions. Deep (>100 cm), well drained, gentle sloppy, soils with clay to fine loamy texture are most preferred soil environments for the growth of cottoncrop. Maize require altitude 1000-1800meter above sea level and 500-800 mm rainfall Cotton is mostly concentrated (under rainfed agriculture) in semiarid to dry sub-humid areas with average annual rainfall varying from 700 to 1200mm, with growing season rainfall varying from 650 to 900mm. The mean temperature during the growing season ranges from 21 to 28 C<sup>0</sup> and mean relative humidity during the growing season varies from 45 to 84 per cent. The length of cropping period for cotton is 135 to 180 days (Thorne and Peterson,1954).

TABLE 6.1 CRITERIA USED IN THE EVALUATION OF SOIL AND TERRAIN SUITABILITY FOR CROPS REQUIREMENT ADOPTED FROM FAO GUIDELINES.

| Criteria      | Condition | Maize           | Cotton          |
|---------------|-----------|-----------------|-----------------|
| Slope         | Optimum   | 0-10%           | <2%             |
|               | Marginal  | 10-20%          | 2-8%            |
| Soil drainage | Optimum   | Well            | Well            |
|               | Marginal  | Moderately well | Moderately well |
| Texture       | Optimum   | Loam            | Clay            |
|               | Marginal  | Silty Clay loam | Silty loam      |
| Soil Depth    | Optimum   | >100cm          | >100cm          |
|               | Marginal  | 50-80cm         | <80cm           |

Source: Frame work for land evaluation, FAO,1976

### 6.5 Approaches Used to develop Suitability Map for Crops

The same procedure used to evaluate for surface irrigation potential was used for suitability of crops mapping under the study area. This method was multi-criteria decision evaluation (MCDE). It is not necessary to explain detail about this technique. Since it was already discussed earlier.

Multi-criteria decision evaluation (MCDE) method in GIS environment is the best technique to evaluate different factors for a specific objective. There fore, in this paper, MCDE was also used to evaluate the physical land characteristics and qualities of the

basin for developing suitability map for both Maize and Cotton, based on FAO land evaluation framework (1976, 1983).

In order to develop a set of themes for evaluation and ultimately to produce a suitability map for maize and cotton, the crop requirements in terms of land qualities were reviewed (Sys et al 1993 and FAO 1983)(Table 6.1).

Generally crops production is highly determined by climate, chemical properties of soil and physical characteristics and qualities of land for specified area. These include temperature, rainfall, soil texture, soil depth, slope, Ph, fertility of soil (i.e. nitrogen, phosphors, and potassium). But in this paper, due to shortage of data, as it was discussed earlier only physical characteristics of the land and its quality were evaluated to develop crop suitability map of the Beles basin. These were drainage property, soil depth, soil texture, slope gradient, rainfall, temperature, soil type and land use.

In order to evaluate the factors for the selection of the physical land for suitability of major crops i.e. maize and cotton, the factors were standardized based on the crops requirements. Pair wise technique was used in IDRIS software to standardize the factors to obtain weight.

TABLE 6.2 FACTORS WEIGHTING FOR MAIZE

| Factors       | Soil drainage | Soil depth | Slope | Soil texture | Temperature | Rainfall | Soil type | Land use |
|---------------|---------------|------------|-------|--------------|-------------|----------|-----------|----------|
| Soil drainage | 1             |            |       |              |             |          |           |          |
| Soil depth    | 1/3           | 1          |       |              |             |          |           |          |
| Texture       | 1/3           | 1/3        | 1     |              |             |          |           |          |
| Slope         | 1/3           | 1/3        | 1/3   | 1            |             |          |           |          |
| Temperature   | 1/3           | 1/3        | 1/3   | 1/3          | 1           |          |           |          |
| Rainfall      | 1/3           | 1/3        | 1/3   | 1/3          | 1/3         | 1        |           |          |
| Soil type     | 1/5           | 1/5        | 1/5   | 1/3          | 1/5         | 1/3      | 1         |          |
| Land use      | 1/5           | 1/5        | 1/5   | 1/7          | 1/3         | 1/3      | 1/3       | 1        |

The eigenvector of weights is:

Soil drainage: 0.2786  
 Soil depth: 0.2108  
 Texture: 0.1595  
 Slope: 0.1256  
 Temperature: 0.1153  
 Rainfall: 0.0845  
 Soil type: 0.0488  
 Land use: 0.0269

Consistency ratio = 0.08  
 Consistency is acceptable.

TABLE 6.3 FACTORS WEIGHTING FOR COTTON

| Factors       | Slope | Soil drainage | Soil depth | Soil texture | Temperature | Rainfall | Soil type | Land use |
|---------------|-------|---------------|------------|--------------|-------------|----------|-----------|----------|
| Slope         | 1     |               |            |              |             |          |           |          |
| Soil texture  | 1/3   | 1/3           |            |              |             |          |           |          |
| Soil drainage | 1/3   | 1/3           | 1          |              |             |          |           |          |
| Soil depth    | 1/3   | 1/3           | 1/3        | 1            |             |          |           |          |
| Temperature   | 1/3   | 1/3           | 1/3        | 1/3          | 1           |          |           |          |
| Rainfall      | 1/3   | 1/3           | 1/3        | 1/3          | 1/3         | 1        |           |          |
| Soil type     | 1/5   | 1/5           | 1/5        | 1/3          | 1/5         | 1/3      | 1         |          |
| Land use      | 1/5   | 1/5           | 1/5        | 1/7          | 1/3         | 1/3      | 1/3       | 1        |

The eigenvector of weights is:

Slope: 0.2856  
 Texture: 0.2160  
 Soil drainage: 0.1634  
 Soil depth: 0.1218  
 Temperature: 0.1091  
 Rainfall: 0.0807  
 Soil type: 0.0367  
 Land use: 0.0267

Consistency ratio = 0.06  
 Consistency is acceptable.

The purpose of weighting is to express the importance or preference of each factor relative to other factor affect on crop yield and growth rate. To avoid and reduce the

individual biases of factor weighting, the weights in the study were determined by using a pairwise comparison method as developed by Saaty (1977) in the context of the analytical hierarchy process (AHP) (Saaty, T.L., 1977.). Pairwise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements. A matrix is constructed, where each factor is compared with the other factors, relative to its importance, on a scale from 1 to 9. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons. If the  $CR > 0.10$ , then some pairwise values needs to be reconsidered and the process is repeated till the desired value of  $CR < 0.10$  is reached. The pairwise comparison method showed that the consistency ratios (CR) of Maize and Cotton were less than 0.1 - Maize 0.08 and Cotton 0.06 (Table 6.2 & 6.3). This indicates that the comparisons of each factor were perfectly consistent, and the relative weights were suitable for use in the GIS multi-factor evaluation.

### **6.6 Developing Suitability maps for maize and Cotton**

In this step, Weighted Linear combination method was used to create suitability map (Ronald Eastman J., 2001). In this technique, the eight important factors were mapped and reclassified in to four classes. These were very suitable (S1), suitable (S2), marginally suitable (S3) and unsuitable (N). Each factors map was multiplied by weighting factors and sum together to get the suitability maps for Maize and Cotton. Finally, one and zero respectively to obtain the final result map for suitability of Maize and Cotton multiplied the result map and constraints map.

$$S_m = \sum W_i X_j$$

$$S_c = \sum W_i X_j$$

$$S_m = 0.27D + 0.21SD + 0.12ST + 0.15SP + 0.11TP + 0.08RF + 0.04ST + 0.02LU$$

$$S_c = 0.28SP + 0.21ST + 0.16SD + 0.12D + 0.10TP + 0.07RF + 0.08ST + 0.02LU$$

Where:

**S m** = Suitability map for Maize

**S c** = Suitability map for Cotton

**SD** = soil drainage

**D** = Soil depth

**SP** = Slope

**RF** = Rainfall

**TP** = Temperature

**T** = Soil texture

**ST** = Soil type

**LU** = Land use

## 6.6 Suitability Class Specification

The final crops suitability maps for maize and cotton were developed by multiplying the reclassified factors map using weighted linear combination method in GIS environment and adding them.

The constraint map was multiplied by zero and the result map multiplied by one and adding them to find the final crops suitability maps. Both maize and cotton crops suitability map were divided in to five suitability classes. These were very suitable, suitable, marginally suitable, marginally not suitable and permanently not suitable.

### Suitability classes of Maize

From the total land of the basin 12,450 hectare (8.2%) was very suitable, 23140 hectare (15.2%) suitable, 54600 hectare (35.3%) marginally suitable, 16000 hectare (10.6%) marginally not suitable and 46130 hectare (30.4%) was permanently not suitable for maize crops.

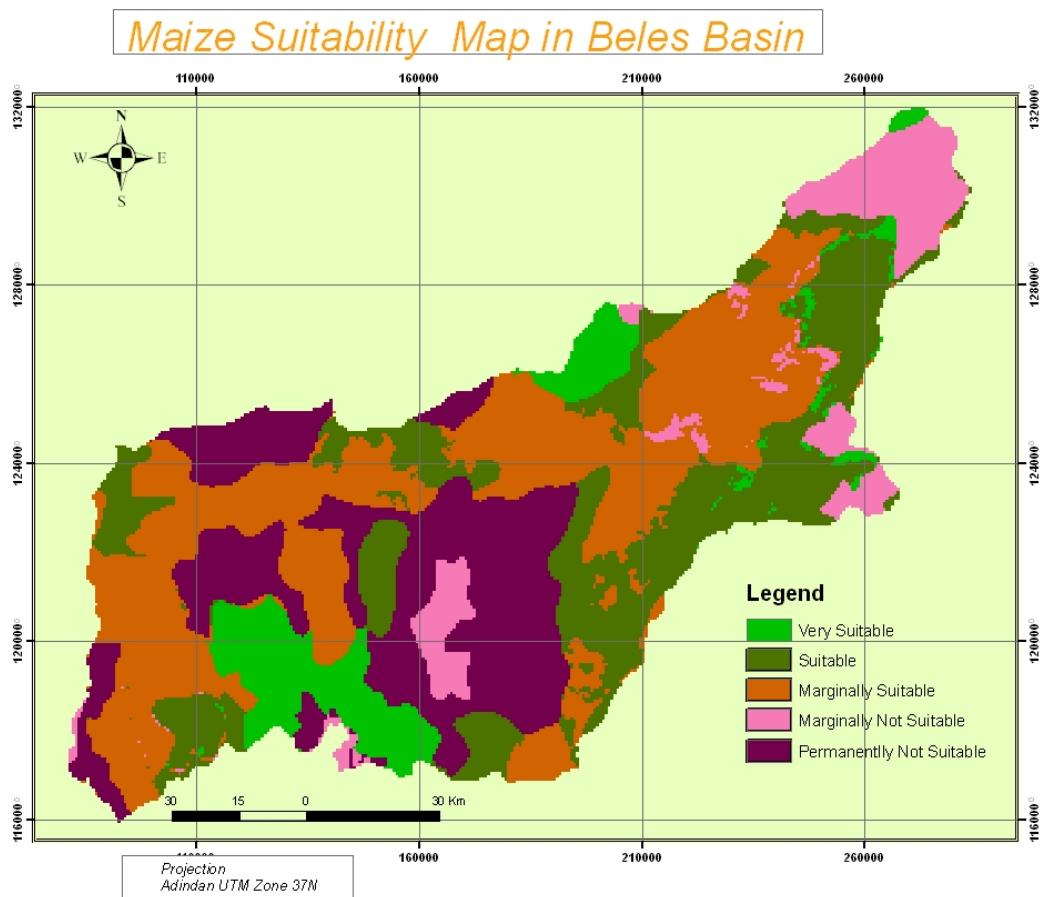


FIG 6.2 MAIZE SUITABILITY MAP IN THE STUDY AREA

### Suitability classes of Cotton

From the total land of the basin 16,150 hectare (10.7%) was very suitable, 22540 hectare (15.1%) suitable, 49020 hectare (32.6%) marginally suitable, 17200 hectare (11.5%) marginally not suitable and 46130hectare (30.1%) was permanently not suitable for cotton crops.

The reclassified factors maps after multiplying the constraint maps by zero are listed here under (Fig.6.3) and (Fig 6.4)

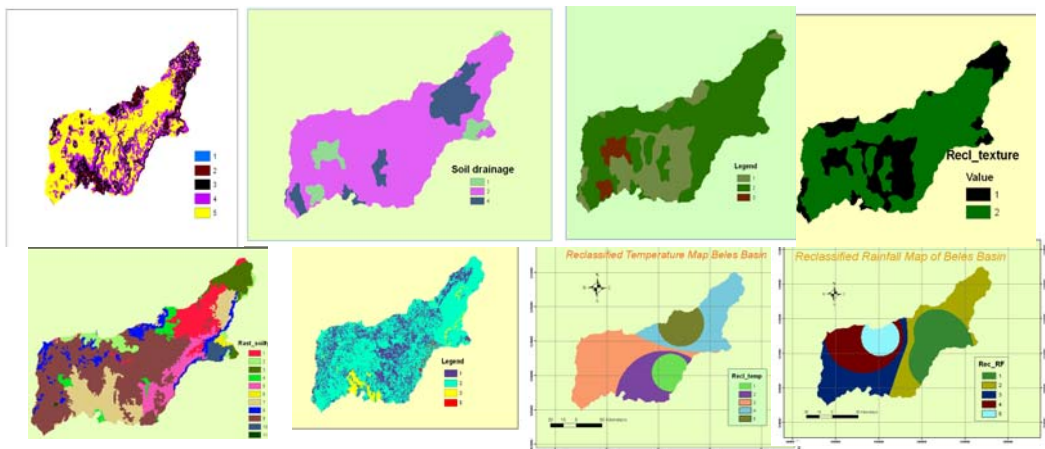


FIG 6.2 FACTORS MAP FOR CROPS SUITABILITY

## Cotton Suitability Map of the Beles Basin

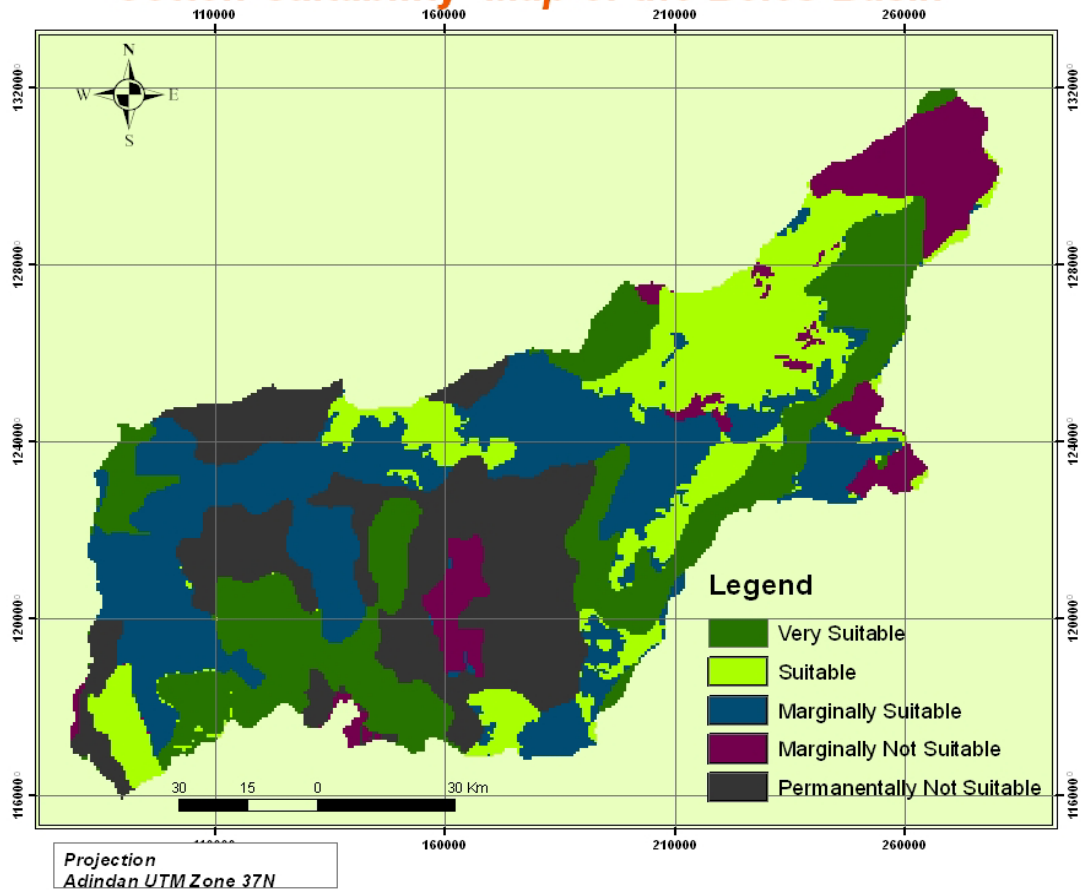


Fig.6.4 Cotton suitability map under the study area

## 6. CONCLUSIONS and RECOMMENDATION

### 6.1 Conclusions

The land evaluation of physical land qualities of the study area indicates that Beles basin has great potential for surface irrigation. The factors which were considered for evaluation of the land for surface irrigation of the study area are slope of the land, soil depth, soil texture, soil type, land use land cover and water resource such as drainage nature and climate. These factors were also used for suitability of crops under the study area. The selected crops for evaluation of physical land characteristics are maize and cotton. The most critical factor that determines gravity (surface) irrigation is slope gradient. Most of the land of the sub basin is characterized by gentle slope, which is less than 8%, which accounts for 65.7% of the total area of the study area. This indicates that 65.7 % of the Beles sub basin is classified under suitable for surface irrigation.

Most types of crops require deep soil depth for their growth. Soil depth of the Beles basin varies from place to place. Its depth is between less than 25cm up to greater than 100cm. Those places having soil depth greater than 100cm is very suitable for crops. However it depends based on the requirements of crops. There is soil depth, which can be classified as very suitable for maize and Cotton, which is above 100cm in the study area. The land having greater than 50cm soil depth in a specified area can be recommended suitable for surface irrigation. Hence, the Beles basin has great potential for irrigation.

Clay texture is the dominant type of soil texture in Beles basin as the physical land characteristics of the basin was evaluated. Soil texture affects the infiltration rate of the soil. Coarse-textured soil type has great infiltration rate than fine-textured soil type. Clay texture soil has great retention (water holding capacity) or less infiltration rate. Therefore, more than half of the land of the Beles basin is characterized by less infiltration rate. The other type of soil texture found in the study areas that determine the physical land suitability of land for surface irrigation and crops suitability is clay loam. This type of soil is suitable for many crops next loam texture soil.

Soil type of the land determines the physical land characteristics of the study area for irrigation and crops suitability. Vertisols is the most dominant soil type in the Beles basin. This type of soil is black in color and reach in chemical properties of soil.

As it was evaluated the physical land for irrigation and crops suitability, the drainage properties of the study area are classified in to well, moderately well and imperfect drained area. The dominant drainage type found in Beles basin is well drained area. Such type of drainage property is suitable for surface irrigation and growth of plants.

The total land under the study area which is suitable for surface irrigation is 110,100 hectare which is 71.2% of the Beles basin. The other 28.8% (44250hectare) is not suitable for surface irrigation due to slope limitation dominantly. However land suitability evaluation was done by combing different factors. The slope gradient found in this unsuitable area is greater than 16%.

## **6.2 Recommendation**

- As the land has been evaluated, the physical land quality of the Beles basin has great potential for irrigation. But irrigation cannot be carried out only based on physical land qualities of the land. Chemical properties of soils are also very necessary for irrigation and crops suitability in a specified area. There fore, a research should be conducted on the evaluation of chemical properties of the soil such as Ph, soil fertility etc. under the study area.
- The evaluation carried out in this paper is in terms of physical suitability for irrigation and crops. But the effects of each alternatives use or classes should be appraised in environmental, economic and social terms.
- It is recommended that environment should be considered in irrigation development. The expansion and intensification of agriculture made possible by irrigation has the potential for causing: increased erosion; pollution of surface water and groundwater from agricultural biocides. The potential negative environmental impacts of irrigation include water logging and salinization of soils, increased incidence of water-borne and water-related diseases.

- Land-use policy must take account of land suitability in relation to the expected future needs and the possibility of meeting demands. The critical importance of land for specified uses should be known either physical or economic suitability. This means not only whether it is important that this specific area of land should be used in particular way but also whether a particular area is physically suitable.
- It is known that one of the major economic activities in Ethiopia is agriculture. One of the agricultural activities practiced in the country is cultivation of crops. But this activity is being done in small plots of land with poor management and investment level. As a result, the growth of production doesn't much with the growth of population. Having great contribution to poverty alleviation, food security, and improving the quality of life for rural populations and economic for the country in general, suitable irrigation land is very necessary.
- Agricultural land use system of the country should meet the demands of food supply for increasing population. Therefore, irrigation should be considered as an important investment for improving rural income through increased agricultural production in the country.

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