SURFACE IRRIGATION SUITABILITY ANALYSIS OF SOUTHERN ABBAY BASIN BY IMPLEMENTING GIS TECHNIQUES

(A CASE STUDY IN DEDESSA SUB-BASIN)

BY

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A THESIS PRESENTED TO GRADUATE SCHOOL OF ADDIS ABABA UNIVERSITY TECHNOLOGY FACULTY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

FEBRUARY 2007

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ABBREVIATIONS

CWR	Crop Water Requirement
DEM	Digital Elevation Models
ENMSA	Ethiopian Meteorological Service Agency
FAO	Food and Agricultural Organization
FDC	Flow Duration Curve
GIS	Geographical Information System
MOWR	Ministry of Water Resource
ARBIDMPP	Abbay River Basin Development Integrated Master Plan Project
NASA	National Aeronautics and Space Administration
USGS	US Geological Survey
SRTM	Shuttle Radar Topographic Mission
CGIAR	Consultant Group for International Agriculture Research
CSI	Consortium for Spatial Information
LUPRD	Land Use Planning Regulatory Department
WBISPP	Woody Biomass Inventory and Strategy Planning Project

ABSTRACT

The study aims at evaluating physical suitability (land and water resource) for surface irrigation development using GIS techniques. The Dedessa sub-basin was selected as a case study for this thesis work. The Dedessa sub-basin located at the Southern part of the Abbay River Basin. The study area covers an area of about 1.96 M hectares.

The evaluation of land in terms of the suitability classes for surface irrigation was based on the method as described in FAO guideline for land evaluation. The essence of land evaluation is to compare or match the requirement of each potential land use with the characteristics of each kind of land. (*FAO, Land Evaluation for Development. Soil bulletin*)

A land unit is obtained by the overlaying of selected theme layers, which has unique information of land qualities for which the suitability is based on. The selected theme layers for this study include soil types, with their corresponding physical and chemical characteristics that affect irrigation agriculture, land cover, and slope layer, which is derived from the Digital Elevation Model of the study area. As its being the most limiting factor for the realization of, especially for surface irrigation method, the slope layer was used as the base map for the overlaying analysis.

The suitable land identified categorized according to the different climatic zones along the Dedessa River in the sub-basin. They are mostly concentrated in the central and Eastern part of the sub-basin along the Dedessa and Wama River valleys.

The 95, 90, 85, and 80 percentage time exceedence flow of the available surface water in the respective climatic zones was estimated and the area that can be irrigated with this flow was computed using the selected climatic station data and estimated ETo.

1. INTRODUCTION

1.1 GENERAL

For any development to take place or for it to be recognized as such, the available data and those that can be collected must be put together in a form that can be easily accessed and understood by users and decision makers. In a developing country such as Ethiopia, the need to put in place spatial databases that assist in planning and management of development programs, such as irrigation, is not only crucial but also a good investment.

Irrigation is a science of planning and designing a water supply system for the agricultural land to protect the crops from bad effects of drought or low rainfall [32]. Accordingly, irrigation agriculture development, which permits greater control of production factor than any other system of farming, revolves round the development of water resources.

The major challenge facing planners and managers is that the physical availability of water and land is fixed; yet their demand is growing [33]. Due to this, the problem is how to balance demand and supply under this increasingly complex and difficult conditions. For many countries, the only solution, therefore, is to manage the available land and water resource in the country in an efficient and sustainable manner. To achieve this reliable information base is necessary, which can identify the resources available, their allocation, use or misuse, the components involved, their abilities and limitations and the infrastructure on hand. Such a database calls for a Geographic Information Systems, in which the information can be easily analyzed and displayed on a map for spatial reference.

1.2 IRRIGATION DEVELOPMENT IN ETHIOPIA

1.2.1 Water Resources and Irrigation Potentials

Ethiopia possesses a substantial amount of water resources that could play significant role in the Socio-economic development of the country. Based on the drainage condition the country's total area is divided in to 12 major basins, namely, Abbay, Wabishabele, Awash, Tekeze, Baro-Akobo, Mereb, Rift-Valley Lakes, Geneale-Dawa, Omo-Ghibe, Danakil, Ogaden, and Aysha. Of the twelve basins identified, seven discharge water across an international boarder while five is restricted within the country. Those drainage basins, which drain internally, include Awash, Ogaden, Danakil, Rift-Valley Lakes & Aysha basins contribute less to the water resources of the country as compared to basins, which drain across the boundary towards the neighboring countries.

The total annual surface runoff (from the river basins) regardless of its distribution is estimated to be in the order of 122 billion m^3 . There is also an estimated 2.6 billion m^3 of usable ground water Ethiopia's irrigation potential has been estimated to be around 3.7 million hectares not taking into account physical, financial & organizational constraints.

In Ethiopia irrigation projects are classified as large projects with a command area greater than 3,000 ha medium projects with a command area between 200-3,000ha and small projects with a command area less than 200ha.They can be further classified in terms of their water source storage, run-of river or pump schemes.

1.2.2. Present Status

As 2004/2005, the aggregate irrigated area in the Country is 262, 177 hectares. The details are shown as follows and also given in table1.1.

Traditional Irrigation

Traditional schemes are built by farmers with government technical and material support. These irrigated schemes are managed by associations or a committee established by the user's themselves and the ranges of such irrigated schemes are estimated from 70 to 90 hectares on average Presently land area under traditional irrigation is estimated to be about 138, 339 hectares.

Small Scale Irrigation: Modern Communal Schemes.

Such schemes are constructed by the Government with farmers' participation for areas extending from 20 to 200 hectares. Modern communal schemes were developed after the 1983 drought so as to improve food security and peasant livelihoods by providing cash income through production and marketing of crops. Currently a total of approximately 56, 367 hectares is being developed.

ACKNOWLEDGEMENT

I wish to thank my advisor Dr.-Ing. Dereje Hailu for his constructive guidance and advice throughout this thesis work.

A lot of thanks go to the Metadata base Department, Hydrology Department and the Library of the Ministry of Water Resources for providing me the necessary data for the study.

The credibility of this work has been greatly enhanced by the contribution of Robel Waktola, Frehiwot G/Mariam, and Simenesh Kidane for their support and care in all respect during the study period.

I also wish to extend my special thanks to my friends and family who have helped me in several ways for the realization of the thesis work.

Medium and large Scale Irrigation: Private and Public Schemes

Presently the size of irrigated land under medium and large-scale irrigation is estimated at 62,057 hectares. Medium scale irrigation is mainly located in the Oromiya, Southern Nations nationalities and Peoples regions and Afar regions whereas most of the irrigated land under large-scale irrigation is concentrated or located in the Awash River Basin (Oromiya and Afar regions). Large scale schemes are being operated by public enterprises.

Private Investors

Private investors have developed a total of 5,414 hectares of land until year 2000/2001. All the developed schemes were found in Oromiya, Afar and Southern Nations Nationalities and peoples regions. No data are available with regard to investors land area under irrigations since 2001.

Irrigation Development under Implementation

One top of the above mentioned irrigation developments, the following projects are under implementation:

- Study and design of two large-scale irrigation projects i.e. Kesem and Tendaho have been started in the Awash River basin. The total area of these projects is estimated to be about 90,000 hectares. The construction work of these projects has also been started.

- Construction of 3,000 hectares of irrigation land will be carried out in the near future at Gode, Somali Regional State.

- Koga irrigation development and Watershed Management Project, which is planned to irrigate 7,200 hectares, has been started in the Abbay river basin. In addition to the irrigation development, multi social development programs aimed at poverty alleviation are also incorporated within the project. So far the study and design works of the project including the dam and canal design have been completed. Construction of the dam has also been started.

- Under the Nile basin initiative Program, study and design works of Large-scale irrigation development projects have been resumed for 100,000 hectares of land.
- Preparation works for the study and design of the Humera (42,965ha.), Arjo Dedessa (14,280ha), and Lake Tana area (52,384ha.) irrigation projects have been completed. Besides, study and design works of the three projects have also been started.

- With the plan of expansion of the existing sugar factories:
    - The Metehara Sugar Factory has developed 200 hectares out of the planed irrigable land (6800 ha.).
    - The Wonji/Shoa Sugar Factory has started construction of 2,753 hectares out of the 8,400 hectares studied for expansion at feasibility level.
    - More over, 225 hectares of land has been constructed under the expansion of the Finchaa Sugar factory.

Ser. No.	Region	Size of irrigated land			
		Traditional	Modern irrigation		Private investors
			Small	Medium & Large	
1	Tigray	2,607	12,621		
2	Afar	2,440	0	21,000	2,000
3	Amhara	64,035	6,737		
4	Oromiya	56,807	22,032	31,981	2,614
5	Somali	8,200	1,800	3,000	
6	Benishangul-Gumuz	400	200		
7	SNNPR	2,000	11,622	6,076	800
8	Gambella	46	70		
9	Harari	812	265		
10	Dire Dawa	640	1,020		
11	Addis Ababa	352			
	Sub-total	**138,339**	**56,367**	**62,057**	**5,414**
	Grand total	**262,177**			

Table 1.1 Status of Regional Irrigation Development (2004/2005)

Source: - Reports from Regional governments concerned bureaus/offices and MOWR

1.3 OBJECTIVE AND SCOPE OF THE STUDY

Irrespective of Ethiopia's endowment with potentially huge irrigable land and ample water resources Ethiopia suffers from frequent drought problem due to rising population pressure, uneven spatial and temporal occurrence, and distribution of the water resources and land degradation.

Consequently, production of sufficient food and food security in the country currently becomes unattainable. If the country is to achieve its stated aims of food self-sufficiency and food security, the current production shortfalls call for drastic measure to improve productivity of irrigated agriculture and rain fed agriculture. Since agriculture remains the engine of the economic development of the country, all future trends of development will highly depend on how we manage the sector and all other related resources.

Obviously this calls knowing the total irrigation potential of the country and corresponding suitable physical natural resources (water and land) in various basins and sub basins, so that planned irrigation development, that significantly contribute to the overall socio-economic development is realized.

The main objective of this thesis work is to identify suitable area for surface irrigation using GIS techniques, so that the available land and water resource of the study area can be utilized with better efficiency.

Specific Objectives:

- Establishing GIS database for better visualization and understanding of the study area from the irrigation point of view

- Investigating and estimating potentially suitable physical resources for irrigation.

- Providing maps based on the suitability parameters for the analyzed irrigable lands

- Estimating the dependable flow for irrigation

2. LITERATURE REVIEW

2.1 SIGNIFICANCE OF IRRIGATION IN AGRICULTURE

There are still arguments about the definition of irrigation. The more traditional view is that it refers only to the provision of additional water to satisfy the crop water requirements. But taking a broader view, irrigated agriculture can be seen as a special case off intensive agriculture, in which technology intervenes to provide control for the soil-moisture regime in the crop root zone. The aim is to achieve a high standard of year-round agriculture, irrespective of rainfall availability. [25]

The early story of irrigation developments is buried in the oblivion of ancient unrecorded history. The first use of irrigation as an aid to agriculture must have been made about the same time as man adapted himself to a social way of life. Under the climatic conditions prevalent in some parts of the world, it is clear that irrigation must have been a pre- requisite to organized society.

History is replete with references to the practice of irrigation from wells, tanks, and canals. Even today, there are some striking examples of irrigation works built hundreds, and in some cases thousands, of years ago in continental China, Egypt, India, Israel, and some other countries.

Li Ping built a multi purpose scheme for flood control and irrigation on Minkiang River 2200 years ago. Egypt claims to have had the world's oldest dam more than 100 meters long and 12 meters high, built 5000years ago, to store water for drinking and irrigation. Basin irrigation introduced on the Nile about 3300 BC still has until very recently played an important role in Egyptian agriculture. Irrigation works in the valley of the Euphrates and Tigris must have supported several ancient civilizations in Mesopotamia. Wells, tanks and inundation canals from rivers were well-known sources of irrigation water in India thousands of years ago [23].

Irrigation is a process that uses more than two-thirds of the Earth's renewable water resources and feeds one-third of the Earth's population. [36] Although water resources are still ample on a global scale, serious water shortages are developing in the arid and semi-arid regions. [24] The World Food Summit of November 1996 drew attention to the importance of water as a vital resource for future development. [22] A major part of the developed global water resource is used for food production.

The estimated minimum water requirement per capita is 1,200 m^3 annually (50m^3 for domestic use and 1,150m3 for food production. [22]

Sustainable food production depends on judicious use of water resources as fresh water for human consumption and agriculture become increasingly scarce. To meet future food demands and growing competition for clean water, a more effective use of water in both irrigation and rain fed agriculture would be essential. [35]

Irrigation is an obvious option to increase and stabilize crop production. Major investments have been made in irrigation over the past 30 years by diverting surface water and extracting groundwater. The irrigated areas in the world have, over a period of accelerated growth in the 1970s and early 1980s. [21]

Irrigation development programs are not possible unless appropriate institutions exist to plan and execute them. They therefore require the creation of an institution after at ministerial level responsible for planning land and water development and use. This institution can then coordinate the activity of other agencies involved in irrigation development and can also prepare long-term irrigation plans.

Plans such as these need an adequate database. The first planning requirements are therefore knowledge of the physical, social and manpower resources that are available. Such an inventory is critically important as a planning tool. In the past considerable attention was focused on inadequacies in the physical resource database, such as information on soils and their extents, water availability, and salinity. Experience shows that knowledge of the nature and expectations of the societies to be affected by irrigation development is just as important. [20]

2.2 SUITABILITY EVALUATION

Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. [48] Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. [19]

2.2.1 Structure of the Suitability Classification

In FAO's *Framework for Land Evaluation*, the structure of the suitability classification is described recognizing qualitative, quantitative and of current or potential suitability in four categories of decreasing generalization. Each category retains its basic meaning within the context of the different classifications and as applied it different kinds of land use.

1. Land Suitability Orders

Land Suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders Suitable and Not suitable represented in maps, tables, etc. by the symbols S and N respectively.

> ***Order S suitable***: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.
>
> ***Order N not suitable***: Land which has qualities that appear to preclude sustained use of the kind under consideration.

2. Land Suitability Classes

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic number, in sequence of decreasing degrees of suitability within the Order.

> ***Class S1 Highly Suitable***: Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
>
> ***Class S2 Moderately Suitable***: Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.

Class S3 Marginally Suitable: Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increases required inputs, that this expenditure will be only marginally justified.

With the order Not Suitable, there are normally two classes:

Class N1 Currently Not Suitable: Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.

Class N2 Permanently Not suitable: Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

3. Land Suitability Subclasses

Land suitability subclasses reflect kinds of limitations, e.g. moisture deficiency, erosion hazard. Subclasses are indicated by lower-case letters. The number of subclasses recognized and the limitations chosen to distinguish them will differ in classifications for different purposes.

Subclasses are indicated by lower-case letters e.g.S2m, S2e, S3me. There are no subclasses in Class S1.

4. Land Suitability Units

Land suitability units are subdivision of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. Suitability units are distinguished by Arabic numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

Depending on the purpose, scale and intensity of the study, either the full range of suitability orders, classes, subclasses and units may be distinguished, or the classification may be restricted to the higher two or three categories.

The process of suitability classification is often easier than it might appear. Although theoretically there are an almost unlimited number of land-use requirements and land qualities, in practice only a few have a major influence on suitability. These factors change from place to place and depend, of course, on the nature of the land used and this means that a sharp eye must be kept open for unusual local factors on requirements. Each land use has requirements and limitations that relate separately to its objectives, its management needs and to environmental issues. The first step in classifying suitability is to decide which factors should be used to define each suitability classes. Upper and lower limits for each relevant land characteristic or quality are then set for each class. The final assessment of suitability is usually based on one of three principles. [48]

1- The limiting condition principle: the most unfavorable quality determines the suitability classification

2- The subjective assessment principle: suitability classes are raised or lowered on the basis of judgments of the importance of different factors. Because subjective assessments are risky, the relevant factors are weighted, and account is taken of special limitations that may occur if two or more negative factors occur together.

3- The principle of arithmetic modeling: the fact that each land quality has an independent influence on suitability means that land qualities can be assigned values and manipulated arithmetically to provide a numerical assessment of overall suitability. In practice a combination of their approaches is often employed.

2.2.2 Irrigation Suitability

The basic physical factors in determining the suitability of land for irrigation are soil, topography, drainage, water quality and quantity, and climate. Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated [36].

I. Soil

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

The most desirable soil qualities for diversified crop production under sustained irrigation includes; 1) a water-holding capacity adequate to retain and provide optimum moisture for crops between irrigations with the proposed irrigation system; (2) an internal drainage adequate to maintain an aerated root zone and an acceptable salt level; (3) an infiltration rate adequate to replenish soil moisture depleted from evapotranspiration without excessive losses with the proposed irrigation system; (4) an adequate depth to allow optimum root development; (5) a tillable surface; (6) non injurious amounts of exchangeable sodium, or soluble phytotoxic substances; and (7) amendable by an adequate supply of plant nutrients.

Several soil characteristics must be evaluated to determine soil suitability for irrigation. The primary factors are soil-moisture relationships, toxicity, fertility, depth to gravel and cobble, depth to soil horizons that restrict root development or water movement and the erosion hazard.

II. Topography

The principal topographic characteristics determining suitability of land for irrigation are slope, relief, and cover. These factors may influence method of irrigation, land development, design of onfarm irrigation systems, erosion hazard, drainage requirements, water use practices, crop, and other management and production costs.

The topographic characteristics most favorable for sustained irrigation may vary with a number of factors, including the type of irrigation system selected for use. The best features for a gravity system are: (1) a gradient that facilitates uniform water distribution, allows optimum length of runs, and permits adequate control; (2) relief that is economically feasible to correct without permanent damage to the land and that will permit uniform water distribution for optimum production, salinity control, minimal drainage problems, and water conservation; (3) relief that allows field size and shape to be tilled efficiently, permits water conservation and, when irrigated, results in a minimal nonproductive area; and (4) no rock or vegetative cover, or cover that can be removed readily without permanent damage to the land within limitations imposed by prevailing economic conditions.

Selection of the proper irrigation system may minimize or eliminate many of the limitations imposed by topography. The trend is to more automated irrigation systems (such as sprinkler or drip irrigation systems) to conserve water and reduce labor requirements. These systems minimize the effects of steep gradient, reduce or eliminate the need for most land grading, and usually eliminate restrictions on field size. Where there is a choice of irrigation systems, land characteristics may be the major factor in selecting a particular system.

Topographic Characteristics

Land classification factors most affected by topographic qualities are gradient, land grading, field size and shape, and cover. They greatly influence the suitability of land for irrigation. Position of the land is a more important factor for irrigable area determination.

III. Drainage

Drainage can be defined as the removal of excess water and salt from the soil at a rate and to a depth that will permit normal plant growth. Prediction of the drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production. Arable land must be drainable land. The selection of arable lands will, therefore, encompass drainability evaluations. These evaluations include investigating the substrata as well as the root zone. Some lands are endowed with adequate natural drainage to sustain irrigation. However, this must be confirmed by investigations. Adequate 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. Because of the difference in the quality and volume of water applied through irrigation when compared to a natural rainfall situation, the current drainage condition often is not a valid indication of what the drainage conditions will be under project irrigation conditions.

IV. Water Supply

The quality and quantity of the water supply are equally as important as land and other factors to the success of an irrigation project.

1-Water Quality

Irrigation water should perform the necessary function without any adverse effects on the fertility of the soil or on the proper growth of plants. The suitability or otherwise of water for irrigation purposes is determined on the following considerations [34].

1- Presence of soluble salt harmful to plants.
2- Chemicals present in water which react with the soil to produce unsatisfactory conditions of permeability of soil
3- Bacteria in water injurious to plants and their consumers
4- Nature of soil to be irrigated
5- Type of crop grown

Whatever may be the source of irrigation water, river, canal, tank, open well or tube well, some soluble salts are always dissolved in it. However, the nature and quality of dissolved salts depend upon the source of water and its course before use. The main soluble constituents in water are calcium, magnesium, sodium and sometimes potassium as cations and chloride, sulphate, bicarbonate and sometimes carbonate as anions. Factors like texture, structure of soil, its drainage characteristics, nature of the crop grown and climatological conditions are equally important in determining the suitability of irrigation water in agriculture.

With poor water quality, various soil and cropping problems can be expected to develop. Special management practices may then be required to maintain full crop productivity.

2-Water Requirement

Water requirement is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field conditions at a place [1].

Water requirement includes the losses due to evapotranspiration (ET) or consumptive use (CU) plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc.

$$WR = ET\ (CU) + \text{Application Losses} + \text{Special Needs}$$

The combination of two processes whereby liquid water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration.

Consumptive use (CU) is the evapotranspiration from a vegetative area plus the water used directly by plants in the metabolic process of building the plant tissues. As the water used in the metabolic process is negligibly small (usually, less than 1% of the total loss), it is the usual practice to neglect the difference between evapotranspiration and consumptive use and the two terms are generally used synonymously.

Water requirement is, therefore a 'demand' and the 'supply' would consist of contributions from any of the source of water, the major source being the irrigation water (IR) and effective rainfall (ER) and soil profile contribution (S) including that from shallow water tables.

$$WR = IR + ER + S$$

The field irrigation requirement of a crop therefore, refers to the water requirement of crops, exclusive of effective rainfall and contribution from soil profile, and given as:

$$IR = WR - (ER + S)$$

Evapotranspiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the top soil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop developed and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

The evapotranspiration rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in unites of water depth. The time unit can be an hour, day, decade, month, or even an entire growing period of year.

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application.

Factors affecting evapotranspiration

Weather parameters, crop characteristics, management and environmental aspects are factors affecting evaporation and transpiration.

Weather parameters

The principal weather parameters affecting evapotranspiration are radiation, air temperature, humidity, and wind speed.

Crop factors

The crop type, variety, and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions.

Management and environmental conditions

Factors such as soil salinity, poor land fertility, limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration.

When assessing the ET rate, additional consideration should be given to the range of management practices that act on the climatic and crop factors affecting the ET process. Cultivation practices and the type of irrigation method can alter the microclimate, affect the crop characteristics, or affect the wetting of the soil and crop surface.

The related evapotranspiration concepts due to the above factors are as follows.

Reference crop evapotranspiration (ETo)

The evapotranspiration rate from a reference surface, not short of water, is called the Reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions.

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related.

The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is recommended as the sole method for determining ETo.. Moreover, procedures have been developed for estimating missing climatic parameters.

$$ETo = \frac{0.408\Delta(R_n - G) + \frac{\gamma 900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where

- ET_o reference evapotranspiration [mm/day]
- R_n net radiation at the crop surface [MJ/day m2]
- G soil heat flux density [MJ/day m2]
- T mean daily air temperature at 2m height [^{O}C]
- u_2 wind speed at 2m height [m/s]
- e_s saturation vapour pressure [k Pa]
- e_a actual vapour pressure [k Pa]
- $e_s - e_a$ saturation vapour pressure deficit [k Pa]
- Δ slope vapour pressure curve [k Pa/^{O}C]
- γ psychrometric constant [k Pa/^{O}C]

Crop evapotranspiration under standard conditions (ETc)

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate ETc to ETo or ETc = Kc ETo.

Differences in leaf anatomy, stomatal characteristics, aerodynamic properties, and even albedo cause the crop evapotranspiration to differ from the reference crop evapotranspiration under the same climatic conditions. Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest.

Crop evapotranspiration under non-standard conditions (ETc adj)

The crop evapotranspiration under non-standard conditions (ETc adj) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. When cultivating crops in fields, the real crop evapotranspiration may deviate from ETc due to non-optimal conditions such as the presence of pests and diseases, soil salinity, low soil fertility, water shortage or water logging. This may result in scanty plant growth, low plant density and may reduce the evapotranspiration rate below ETc.

The crop evapotranspiration under non-standard conditions is calculated by using a water stress coefficient Ks and/or by adjusting Kc for all kinds of other stresses and environmental constraints on crop evapotranspiration.

ETo can be computed from meteorological data. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the sole standard method for the definition and computation of the reference evapotranspiration. The FAO Penman-Monteith method requires radiation, air temperature, air humidity, and wind speed data.

The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m-1 and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed. The method overcomes shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide.

V. 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. To a lesser extent, climate also influences the relief of the land surface.

Although climate has had 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. Land classes and the lower limit for arable land are dependent on the net income. Some of the most important climatic features that influence irrigation suitability are: (1) length of growing season; (2) temperature; (3) amount, intensity, and distribution of precipitation; (4) wind velocities; (5) hail and windstorms; (6) humidity; and (7) daylight hours.

2.3 GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

The success of planning for developmental activities depends on the quality and quantity of information available on both natural and socio-economic resources. It is, therefore essential to use computerized means of organizing information systems capable of handling vast amount of data collected by modern techniques which could be derived from space borne multispectral data and produce up-to-date reliable information.

Geographic Information System (GIS) is computer based information system used to digitally represent and analyze the geographic features present on the Earth's surface and the events (non-spatial attributes linked to the geography under study) that taking place on it. "Every object present on the Earth can be geo-referenced", is the fundamental key of associating any database to GIS. [52]

Work on GIS began in late 1950s, but first GIS software came only in late 1970s from the lab of the Environmental System Research Institute ESRI. Canada was the pioneer in the development of GIS as a result of innovations dating back to early 1960s. Much of the credit for the early development of GIS goes to Roger Tomlinson. Evolution of GIS has transformed and revolutionized the ways in which planners, engineers, managers etc. conduct the database management and analysis.

GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. It may also be considered as a higher order map. Hence GIS is looked upon as a tool to assist in decision-making and management of attributes that needs to be analyzed spatially.

The GIS technology is rapidly becoming a standard tool for management of natural resources and used to assist decision-makers by indicating various alternatives in development and conservation planning and by modeling the potential outcomes of a series of scenarios.

Remote sensing has shown greater potential in agricultural mapping and monitoring due to its advantages over traditional procedures in terms of cost effectiveness and timeliness in the availability of information over larger areas. Remote sensing is the technique of obtaining information about an object, area, or phenomenon through the analysis or data acquired by a device that is not indirect contact with the object, area, or phenomenon under investigation.

The use of RS technology involves large amount of spatial data management and requires an efficient system to handle such data. The GIS technology provides suitable alternatives for efficient management of large and complex databases. It has evolved as a highly sophisticated data management system to put together and store the voluminous data typically required for these purpose.

Environmental Systems Research Institute (ESRI) is well-known for its ARC/INFO geographic information system. The United Nation Food and Agriculture Organization (FAO), in 1987 contracted ESRI to develop a spatial database and resulting out put products for estimating irrigation potentials for the African continent. The project was designed to identify areas that had sufficient water for irrigation, and those areas that would support agriculture if irrigated. The final map products were designed to support planning activities to try and avoid a repeat of the African drought and famine.

The water availability and irrigation potential data were derived from a water balance model that was written by FAO hydrologists and programmed by ESRI. The water requirement of each country and each watershed were determined from soil, slope, and texture factors. Based on this data, the volume of water required for irrigation could be estimated. The next step was to estimate water resources. Surface-water resources were estimated from rainfall data, and ground water resources were estimated from geological and aquifer data. The model was then used to identify irrigable areas with a water surplus for each country and watershed [26].

Remote sensing is a technology that has close ties to GIS. Remote sensing can provide timely data at scales appropriate to a variety of applications. As such many researchers feel that the use of GIS and RS can lead to important advances in research and operational applications. Merging these two technologies can result in a tremendous increase in information for many kinds of users.

2.4. PREVIOUS GIS BASED STUDIES

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 a 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.

In 1995, another study was conducted by FAO as part of the AQUASTAT program, which is a program of collection of secondary information on water resources and irrigation by country. A survey was carried out for all African countries, in which information on irrigation potential was systematically collected from master plans and sectoral studies. Such an approach integrates many more considerations than a simple physical approach to assessing irrigation potential. However, it cannot account for the possible double counting of water resources shared by several countries.

The study has taken the above limitations into consideration. It concentrates mainly on a qualitative assessment based on physical criteria (land and water), but relies heavily on information collected from the countries. A river basin approach has been used to ensure consistency at river basin level. Where country information was unavailable or incomplete, potential was assessed on the basis of available information on land and water resources at regional level. The FAO Geographic Information System (GIS) facilities were extensively used for this purpose. [15]

PREVIOUS STUDIES IN THE ABBAY RIVER BASIN

USBR (United State Bureau for Reclamation) Study

The study was made by the United States department of the Interior Bureau of Reclamation (USBR) between 1957, and 1964. The repot was issued in June 1964.The main objectives were:

- To conduct an investigation of the land and water resources of the Blue Nile River Basin.
- To assist in the establishment of an appropriate administrative and engineering organization within the Ethiopian Government to continue investigations and undertake similar projects in other regions.
- To train Ethiopian personnel.

ARBMPP (Abbay River Basin master plan project) Study

The study was made by the French Engineering Consultants (BECOM) in association with ISL and BRGM between 1994 and 1998. The main objectives were:

- The preparation of the River Basin Development Master Plan that will guide the development of the resource of the basin particularly with respect to the occurrence , distribution, quality and quantity of the water resources for the coming 30 to 50 years.
- To prepare water allocation and utilization plan(s) under alternative development scenarios and to generate data, information and knowledge that will contribute to the future water allocation negotiations with the downstream countries.

3 DESCRIPTION OF THE STUDY AREA

3.1 BASINS AND SUB BASINS

3.1.1 Nile River basin

The Nile River, with an estimated length of over 6,800 km, is the longest river flowing from South to North over 35 degrees of latitude. It is fed by two main river systems the White Nile, with its source on the Equatorial Lake Plateau (Burundi, Rwanda, Tanzania, Kenya, Democratic republic of Congo and Uganda), and the Blue Nile, with its sources in Ethiopian highlands. The sources are located in humid regions, with an average rainfall of over 1000 mm per year. The arid region starts in Sudan, the largest country of Africa, which can be divided in to three rainfall zones: the extreme south of the country where rainfall ranger from 1200 to 1500mm per year; the fertile clay-plains where 400 to 800 mm rainfalls annually; and the desert northern third of the country where rainfall averages only 20 mm per year. Further North, in Egypt precipitation falls to less than 20 mm per year.

The total area of the Nile basin represents 10.3% of the area of the continent and spreads over ten countries. For some countries, like Democratic republic of Congo, the Nile basin forms only a very small part of their territory. Other countries, like Burundi, Rwanda, Uganda, Sudan & Egypt, are almost completely within the Nile Basin. However, all the waters in Burundi & Rwanda and more than half the water in Uganda are produced internally, while most of the water resources of Sudan & Egypt originate outside their boundaries: 77% of Sudan's & more than 97% Egypt's Water resources.

The Blue Nile and its main tributaries, the Dinder & the Rahad, rise in the Ethiopian mountains and around Lake Tana. The confluence of the White Nile and the Blue Nile is at Khartoum. Further downstream is the Atbara tributary, the last important tributary of the Nile system again deriving from the Ethiopian Plateau North – East of Lake Tana and forming the border between Ethiopia & Eritrea before entering Sudan. There are no important tributaries further down stream in Egypt.

The contributions of the rivers of Ethiopian catchment area (Blue Nile System) to the Nile is about twice the contribution of the rivers of the equatorial lake Plateau catchment area (white Nile System), but it is characterized by the extreme range in discharger between the peak and low periods, while the flow from the Equatorial Lakes plateau is more uniform. At its peak the former provides nearly 90% of all water reaching Egypt, the latter only 5% during the months with low flow the contributions are nearer 30% and 70% respectively.

The irrigation potential in the Nile basin in Ethiopia has been estimated at more than 2.2 million hectares. The irrigated area was about 23,000 ha in 1989.

The seasonality of the flows in Ethiopia is very high. This means that very considerable regulation would be necessary for their full utilization. The risk of rapid siltation of the reservoirs because of the steep slopes is a real problem. Construction of dam would augment the quantity of water available, because of a loss of only 3% by evaporation or against a loss of almost 16% in the Aswan reservoir [15].

Nile Sub - Basin	Annual Surface runoff (km^3)	Irrigation Potential (ha)	Irrigated area in 1989 (ha)
Baro – Akobo	13.4	905,500	350
Blue Nile (Abbay)	54.7	1,001,500	21,010
Setit –Tekeze/Atbara	12.0	312,700	1,800
Total Nile Basin	80.1	2, 219,700	23,160

Table 3.1 Water resources, irrigation Potential and areas under irrigation in the different Nile Sub-basins in Ethiopia

3.1.2 Abbay River Basin

The Abbay river (Blue Nile) basin lies in the west of Ethiopia between latitude7^o 45’ and 12^o 46’N, and longitude 34^{0}06’and 40^{0}00’E. The basin is approximately rectangular in shape, and extends about 400km from north to south, plus an extension in the south formed by the Dedessa, valley; and about 550 km from east to west it drains towards Sudan on its western border and shares common boundaries with the Tekeze basin to the north, the Awash basin to the east and southeast, the Omo-Gibe basin to the south, and the Baro-Akobo basin to the southwest. The drainage basin area of the Abbay River at the boarder with Sudan plus the drainages within Ethiopia of the Rahad, Galegu and Dindir rivers which join the Blue Nile River below the Rosaries dam in Sudan Course 199812km^2

The three regional states sharing the Abbay river basin area are Amhara (about 46% of the basin area), Benishangul-Gumuz (22% of the basin area) and Oromia (31% of the basin area). The administrative hierarchy comprises zones, woredas and peasant associations. As per the administrative hierarchy Amhara region has a total of 76 woredas (23 woredas are partly with in the basin), Oromia has 67 woredas (of which 34 woredas are partly found) & Benishangul-Gumuz has 19 woredas (5 of them are partly found). The total numbers of peasant association estimated being within the basin are 6,300.

Water resources of the basin

The water resources of the basin dominated by the Abbay, which rises in the center of the catchments and develops its course in the north direction and turning clockwise to the west up to the Sudan border. It collects tributaries all along its 992km length before reaching the Sudan border above Rosaries dam. The Abbay River itself has an average annual run-off of about 49 Billion cubic meters. Including the flow of Galengu, Dindir and Rahad rivers which join the Abbay (Blue Nile) downstream in Sudan becomes 54 Billion cubic meters at the boarder.

Irrigation development and potential of the basin

In the Abbay river basin through the development of modern small and medium scale irrigation schemes identified 9, 3,11,8 hectares of land under irrigation as of June 2004. The existing traditional irrigation inventory data is not available during the compilation work of specific projects within the basin. But, according to the estimate of master plan study undertaken in 1998, a total area of about 28,035 ha has been developed through irrigated agriculture. Hence, the completed inventory of these and others schemes if any shall be conducted in order to come up with complete data.

With in the basin through the development of 20 proposed small and medium scale irrigation schemes, 90 small scale water control projects, and 69 medium scale irrigation projects a total of 719,088 hectares of land area could be under irrigation. Even though, the basin is endowed with large irrigation potential area the currently irrigated does not exceed 4% of the total potential irrigable area.

3.2 NATURAL FEATURES OF THE STUDY AREA

3.2.1 Location

According to the Abbay River Basin Integrated Development Master Plan Project (ARBIDMPP), the Abbay river basin in Ethiopia is divided in to 16 reasonably homogeneous areas named basin units or sub basins, representing each the catchment of one tributary or of several minor ones with similar behavior. The Dedessa sub basin is one of these in the Abbay basin.

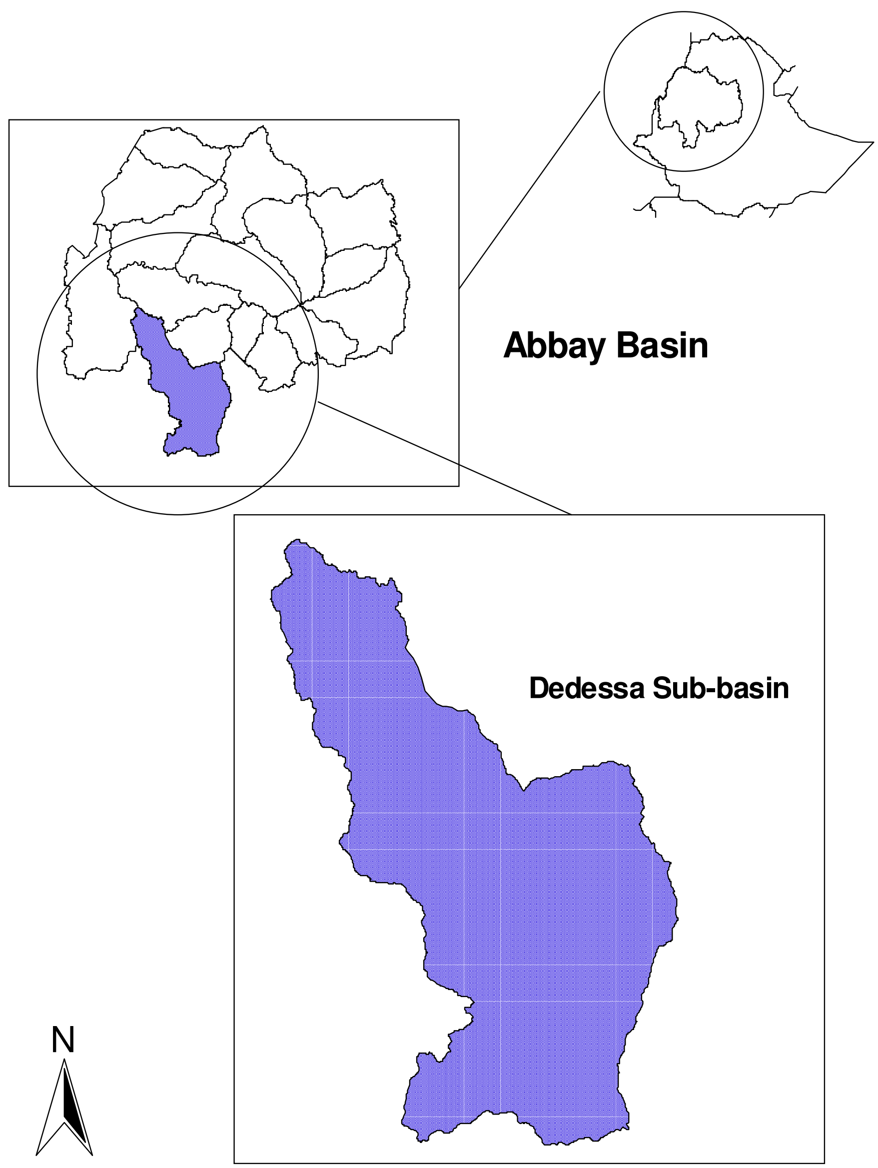


Figure 3.1 Dedessa Sub-basin Location

The Dedessa sub-basin covers a catchment area of 19,630 km^2 with a more or less rectangular shape. The sub-basin mainly located in East and West Welega zone, Illubabor zone, Jimma (special zone of Oromiya region) and some part in Kamashi zone of Benishangul-Gumuz. Geographically the sub-basin is located between $7^0$45'-$0^0$00'N and $35^0$30'-$37^0$15'E latitude and longitude respectively in western part of Ethiopia.

3.2.2 Topography

The topography of the project area is characterized by a lengthy valley, formed by erosive action of the Dedessa River and its numerous tributaries, which frequently dissect the plains. The surrounding highland plateau elevations averages 2000 meters or more while the valley floor elevations range from 630 to 1500 m asl.

On the northern part of the area, the elevation decreases gradually from the midlands towards the river except for some scattered hills. In this area the average elevation is 1200m and reaches as low as 630m asl. On the southern side there is a complicated system of higher and lower hills bordering and interrupting the plains, which gently slope towards the Dedessa River. In some places, small hills are found very close to the river. In the western section of the southern part, the steep mountainous landscape initiates the river. Generally the land elevations vary from 3100meters down to 630 meters above sea level and averages about 2000m asl.

3.2.3 Climate

The classical empirical classification of Koppen has been used to classify the climate of Ethiopia [4]. Although the method has some limitations, it has been adapted by National Meteorological Service Agency (NMSA) due to its simplicity with some minor modifications. In defining the climate, rainfall and temperature have been used as imputes. The climatological data made available to the study come from the NMSA of Ethiopia.

The NMSA classify the Abbay River basin in to five types of climates according to the modified Koppen system (Trewartha 1954, and Lema 1985). Out of these five types of climate the Dedessa sub basin is dominated by four of them. These are tropical climate II, Tropical climate III, Warm temperate climate I and Warm temperate climate II, as their general characteristics described below.

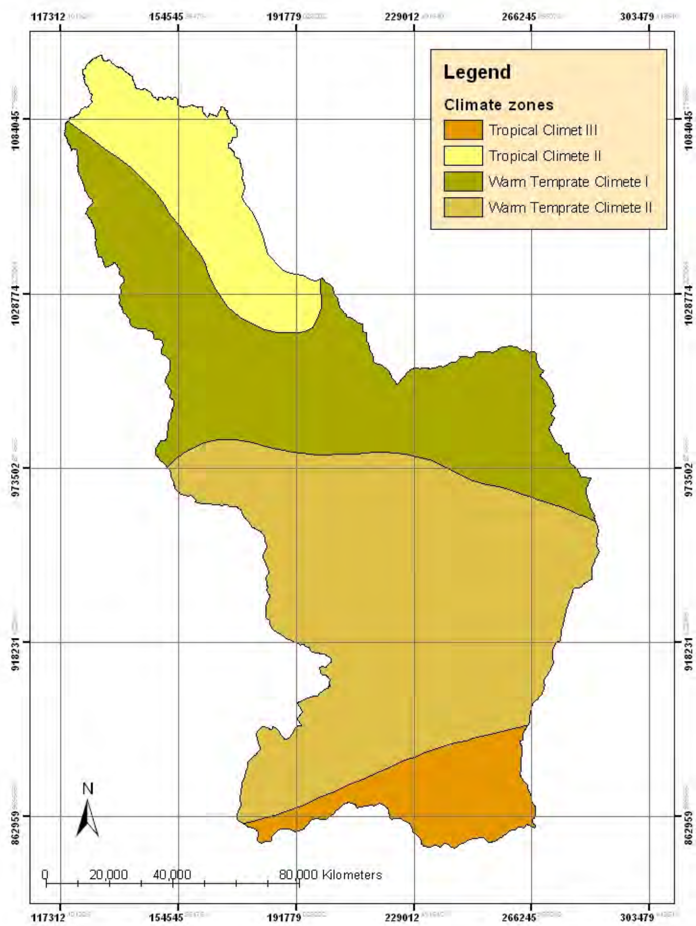


Figure 3.2 Climatic Zones of the Dedessa Sub-Basin.

Tropical climate II

The dry months are in winter. The mean temperature of the coldest month is > 18^0C and the mean annual rainfall is 680-1200 mm. This type of climate prevails up to an elevation of 1750 meters above mean sea level. The length of dry and wet periods vary considerably from the western part to the northern and eastern part of the country. This climate is characterized by tall grass usually grass and trees are intermingled.

This type is prevailed by the downstream northern part of the basin at the confluence of the Dedessa River with Abbay, mostly in the Kamashi zone which covers around 12% of the total sub basin area. The mean annual rainfall reaches 1400mm and the mean annual maximum temperature is 35 ^{0}C in the warmest month February with an average relative humidity of 58 %.

Tropical climate III

This is referred as tropical rain-forest climate. The temperature of the coldest month is > 18^0C and the mean annual rainfalls 1,200-2,800 mm. This climate differs from climate II by the total amount of rainfall and the amount that falls during the driest month. This climate supports an evergreen rain forest and prevails up to an elevation of 1,750m above mean sea level.

This type is found near Jimma in the very upstream part of the basin, which covers 8% of the total area. The maximum and minimum temperatures are 31^0C and 8^0C respectively with mean annual rainfall of 1500mm. In the very rainy month July the sunshine duration decreases up to 5hr with a relative humidity of 70%.

Warm temperate climate I

This climate has distinct dry months in winter. The mean temperature of the coldest month is < 18 ^{0}C and for four months the mean temperature is > 10 ^{0}C with the mean annual rainfall (mm) > 20 x (T+14), where t is the mean annual temperature in ^{0}C. The rainfall distribution and amount varies considered from areas to area. Forests are predominant in areas of heavy rainfall while grass is covered in areas of moderate rainfall. This climate prevails over areas with altitude of 1,750-3,200 m above mean sea level.

This type is prevailing in the lower part of the basin covering about 33% of the total area around Nekemt, Ghimbi and Nejo towns. This part of the sub basin includes one of the highest rainfall region in the country found around Nekemt town with a mean annual rainfall of 2000mm. The mean annual maximum and minimum temperature are 28^0C and 11^0C in the warmest and coldest month respectively. The average annual sunshine duration and relative humidity are 7hr and 60% respectively.

Warm temperate climate II

This climate has more soil moisture than in climate I. This is a humid temperate climate with more or less all months having some amount of rainfall. The mean temperature of the coldest month is < 18^0C. The rainfall of the driest summer month is more than one third of rainfall of the wettest winter month and the rainfall of the driest winter month is more than one tenth of the rainfall of the wettest summer month. It experiences adequate rainfall during all the seasons and thus suitable for abundant forest cover.

This type of climate, which is not shown in any other part of the Abbay basin, prevailed by the largest middle part of the Dedessa basin covering 47% of the total area. The mean annual rainfall reaches 1900 mm, which is also the highest rainfall region in the country. The mean annual maximum and minimum temperature are 30 ^{0}C and 12^{0}C in the warmest and coldest months respectively with an average annual sunshine duration of 7hrs.

The sub basin is characterized by two season types, wet and dry, where the wet periods runs from April/May to October/November and from June/July to August/September for the lower and upper reach of the sub basin respectively.

3.2.4 Hydrology

The Dedessa River is one of the largest left bank tributary of Abbay River in terms of volume of water, contributing 8.5% of the annual average flow measured at the Sudan border.

The Dedessa River originates in Mt. Vennio and Mt. Wache ranges, flowing in an easterly direction collecting many small seasonal streams and main rivers like Yebu, Temsa and Urgessa for about 75 Km, then turning rather sharply to the north until it reaches the Abbay River.

The major tributaries of the Dedessa River are the Dabena entering from the west, the Wama with Sifa, Idris, and Tato from the east and, the Anger also from the east. According to the ARBIDMPP the Anger sub basin, which hydrograph is dominated by the Anger River is considered as a separate sub basin from the Dedessa sub basin. This leaves the boundary between the two sub basins to be the Dedessa River down stream of their confluence point up to the Abbay River unlike other sub basin boundary demarcation, which focus on the drainage area contributing to the main river that joins the Abbay River.

This study work adopts the sub basin classification by the ARBIDMPP for the Dedessa sub basin excluding the Anger River contribution.

The hydrological data used are received from the hydrology department of the Ministry of Water Resource. The hydrometric stations in the sub basin are not evenly distributed; on the contrary, they are mainly concentrated along the main roads while points with large drainage areas and significant importance lack gauging stations.

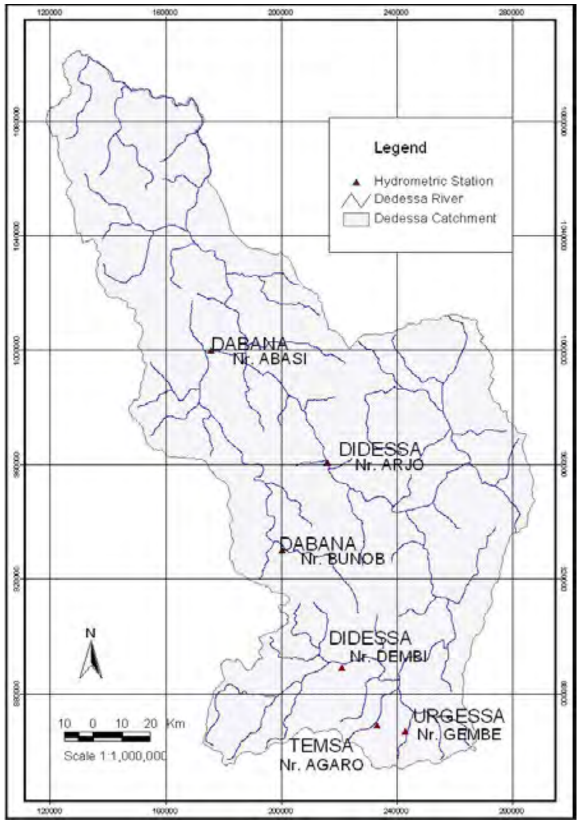


Figure 3.3 Hydrological Stations in Dedessa Sub-Basin

Stream runoff has been observed since 1960 at a station known as “the Dedessa River near Arjo” installed in April 1959 with a drainage area of 9,981 Km^2. The average annual flow of the Dedessa River at this station is 117m^3/s. This includes all the upstream catchment areas drained by the Urgessa and Temsa rivers with average annual flow of 0.8 and 1.3 m^3/s draining an area of 19 and 47.5 Km^2 respectively and also the Yebu River with a drainage area of 47 Km^2.

Another station on the Dedessa River is the one at the extreme upstream of the river, which drains the mountainous area of the sub basin eastward before joined by the Urgessa, Yebu and Temsa rivers and turns to the north. This station named “Dedessa River near Dembi/Toba” drains a catchment area of 1806 Km^2 with a recorded mean annual flow of 46m^3/s. The maximum flow at this station reaches up to 226m^3/s following the rainy season in August.

The average annual discharge of the Dabena River which drains a catchment area of 2881 Km^2 before joining the Dedessa River from the west is 56m^3/s at the station "Dabena near Abasina".

3.2.5 Soil

Soil survey is regarded as a necessary prerequisite for all agricultural developments, particularly where irrigation is concerned. Explanatory or reconnaissance surveys, covering large areas at small scale, are necessary for national or regional development strategy. The information collected is a general nature, suitable for decision on the initiation or more detailed studies for specific developments.

In 1998, the reconnaissance soils survey at 1:250,000 scales carried out within Abbay basin as part of the Abbay River basin integrated development master plan project. It was the third of its kind to be executed in the country. The first survey at this scale was carried out in Omo-Gibe basin, and the second in the Baro-Akobo basin.

The reconnaissance soils survey has enable the identification of eleven soil units. It has also determined the geographic distribution of the soils within the basin on a map of scale 1:250,000 scale. The description of the soils was accomplished using the FAO-ISRIC Guidelines for soils description (1990) and the soils were classified using the FAO-UNESCO-ISRIC legend to the soil map of the world (1988).

The major soils in the Abbay basin were found to be Leptosols, Alisols, Nitisols, Vertisols, Cambisols, and Luvisols in order of decreasing aerial coverage. Others found in relatively lesser aerial coverage are Arenosols, Acrisols, Fluvisols, Phaeozons, and Regosols.

From the identified eleven major soil groups in Abbay basin, the Dedessa sub basin is covered by seven of them. These are Alisols, Nitisols, Acrisols, Vertisols, Leptosols, Cambisols and Fluvisols. Out of these, Alisols, Nitisols, Acrisols, and Vertisols covered more than 95% of the area.

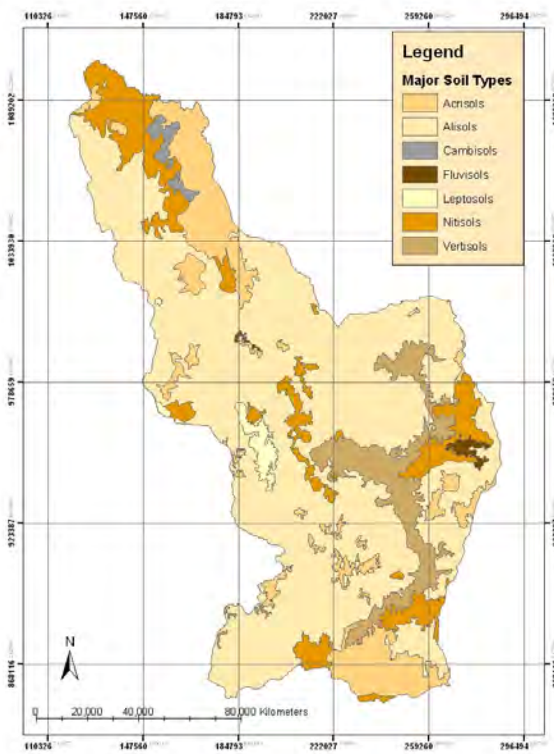


Figure 3.4 Types of Soil in Dedessa Sub-Basin

Alisols

Alisols are the most important soils covering 60% of the sub basin in terms of aerial coverage. They are distributed all over the sub basin except in the southern mountainous parts and the upstream valley of the Dedessa River with the inclusion of the easterly Wama river area.

These soils are reddish brown in color and have deep profiles; usually exceeding 100cm. Alisols are mainly derived from basalts, granites and granodiorites and possess favorable drainage, structure and workability. Alisols are acid soils (with pH values of 5.3 and 5.2 for the top soil and sub-soil, respectively) and thus may be prone to Aluminum toxicity.

Nitisols

Nitisols are the second most important soil group within the basin in terms of aerial coverage. They are mostly found in the central, highland areas in the South, Northern part around the confluence of the Dedessa River with Abbay and in the east around the Wama river valley.

Nitisols are derived from basalts/tuffs and granites/associated felsic materials. The soils are reddish brown in color, clay-to-clay loam in texture, well-drained and very deep. They also have good permeability, a favorable structure, and high water holding capacity. Moreover, they are characterized by a more or less uniform clay distribution within the upper 150cm, and gradual to diffused boundaries between the A and B-horizons.

Acrisols

Acrisols are one of the significant soils of the sub basin making up 15% of the total aerial coverage. They are found in the northern lowland part of the basin near the Anger sub basin and in the south in the highland part of the Jimma zone.

Acrisols are mature soils that have developed on old land surfaces characterized by seasonally wet and dry humid tropical climates. They exhibit strongly weathered profiles and may be affected by aluminum toxicity and high phosphorus fixation.

Vertisols

The aerial coverage of the Vertisols is less as compared to the other soil groups. They are strictly concentrated in the upstream southern Dedessa river valley and Wama River valleys.

They are mostly imperfectly to poorly drained, dark gray soils, formed on flat to almost flat plains. The clay fraction of these soils is dominated by expandable 2:1 lattice clays. They commonly display clay texture throughout the profile.
These soils develop deep and wide cracks in the dry season, which close on wetting in the rainy season. Another particular characteristic of these soils is a micro-relief known as gilgai, which is manifested as a series of hollows and mounds.

Vertisols are very to extremely hard when dry and very sticky and plastic when wet which is reflected in their poor workability. When dry and hard, traditional cultivation, and even under mechanized cultivation traction is poor and the soil tends to smear and compress. There is thus only a limited window of opportunity for cultivating Vertisols, after the soil has been dampened (softened) and before it is wet. Clearly, mechanized cultivation offers the greatest potential for working these soils, although they are popular for traditional rainfed cultivation.

4. METHODOLOGIES AND DETAILED APPROACH

4.1 SURFACE WATER RESOURCE ASSESSMENT

4.1.1 Hydrological Analysis

Performance of any water resource project depends on the correct prediction of future hydrologic events. Information on the past observed records helps to derive statistical parameters based on which the future occurrences are predicted. Laws of probability help to arrive at the desired objective. Observed records called historical data are the outcome of complex natural hydrologic phenomena. A hydrologic process is a change of this natural hydrologic phenomenon with time [15].

4.1.1.1 Data Availability and Review

The quality, quantity and characteristics of hydrological parameters should be carefully assessed in order to make a sound decision on water resource allocation and utilization. The hydrological analysis under taken during the study required the collection and review of hydrometric data associated with the Dedessa River. The main purpose of the hydrological investigation was to:

- Fill the missing gap of the data series
- Checking data for possible errors (data quality)
- Generating synthetic time-series which relay on historical records for the desired period
- Deriving Flow Duration Curves and calculating low flow statistics

Hydrometric discharge measuring stations within the Dedessa river basin are 11 in number. Out of these, due to their poor data quality, very short time series record and longer missing record data, only six of them used for the analysis of available water resource investigation.

These stations are the Urgessa station on Urgessa River, the Temssa station on Temssa River, the Dabena-Bunobedelle and Dabena-Abasina stations both on the Dabena river upstream and downstream respectively and the Dedessa- Dembi/Toba and Dedessa-Arjo station also both on the Dedessa river upstream and downstream respectively. [Figure: 3.3]

The station with the longest record time is the "Dedessa near Arjo" since 1960, on the Dedessa River. The downstream station "Dedessa near Dembi/Toba", also on Dedessa River is functional since 1985. The "Dabena near Abasina" station on the main tributary Dabena River, installed in 1962 was abandoned since 1984 and the downstream station "Dabana near Bunobedelle "installed in 1984.The other stations "Temssa near Agaro" and "Urgessa near Gembe" are functional since 1989 and 1979 respectively. All the other stations had either very short record or very erroneous data with very small catchement area not to be included in this analysis.

Station No.	**River**	**Site**	**Location**		**Installation Date**	**Drainage area (Km^2)**
			Latitude	**Longitude**		
114001	Dedessa	Nr. Arjo	$8^0$41' N	$36^0$25' E	1-4-59	9981
114005	Dabena	Nr. Abasina	$9^0$02' N	$36^0$03' E	10-4-61	2881
114009	Urgessa	Nr. Gembe	$7^0$50'08'' N	$36^0$40'31''E	29-3-79	19
114013	Dabena	Nr. Bunobedele	$8^0$24'11'' N	$36^0$17'17''E	19-2-83	47
114014	Dedessa	Nr. Dembi	$8^0$02'29'' N	$36^0$28'13''E	23-2-83	1806
114019	Temsa	Nr. Agaro	$7^0$51'8'' N	$36^0$35'37''E	2-3-89	47.5

Table 4.1 Hydrological stations and their drainage area in Dedessa Sub-basin

4.1.1.2 Analysis Approach

As a first priority, for the purpose of analysis all discharge measurements for the study area made available from the Hydrology department of the Ministry of Water Resource. This discharge series were first carefully checked for homogeneity in order to prepare discharge series as long and reliable as possible for the necessary low flow analysis.

The most representative stations are selected based on the following criteria:

- The station with longest record
- Station on the main river

- Station on the main tributaries, and
- Stations with long and reliable records with reasonable drainage area for small rivers

Based on this criteria six stations are selected as mentioned in the previous section, to represent the whole area. Visual judgment from their corresponding hydrographs was part of the selection process.

Observation from the data series show missing gaps ranging from one day to in some instances more than a year. It was necessary to fill the missing periods with synthetic values.

Estimating Missing Data

The goal of any infilling technique is the production of a complete data set, which may then be analyzed using complete data inferential methods. For example, it may be useful to apply data generation techniques to synthesize or generate hydrological data in cases where 1) there are gaps in the series of observed data 2) the observation period is short and 3) data are not available at the site of interest but in the neighboring region. [27]

A variety of methods exist in the literature for filling missing hydrological data, ranging from the simple to the complex. For longer and continuous data establishment, correlation method with the neighboring stations having longer data was used.

The degree of association between variables is known as correlation and the statistical parameter determining their relation is known as *correlation coefficient*. Correlation coefficient is an important parameter, which signifies the association between two variables. Square of the correlation coefficient is called coefficient of determination which shows the degree of explainable and unexplainable association between the two variables. In hydrology, the value of correlation coefficient should be greater than 0.6. [27]

Infilling missing data was carried out according to the gap length, which is followed by the hydrology department of the Ministry of Water Resource:

- For one day gap the average value between the previous and next data was taken
- For very short gaps (up to 3 days) mean ten day values for the same time period was used
- For medium gaps (less than two months) correlation within the station itself from known data series in different years considering seasonal trend was followed
- For longer gaps (two month or more) daily data were correlated with neighboring station or stations with similar hydrological characteristics

For the selected six stations, a complete record of daily data for a longer period, optimally 1960-2004 (44 years), established.

Data consistency

The runoff data needs to be analyzed and checked for errors before it is applied in any engineering applications. Errors in the data series can be detected graphically by differential series technique. This technique is very simple and errors can be detected easily. It is easier to detect errors when the time resolution is small. So it is he time resolution is small. So it is recommended to use the smallest possible time e time resolution is small. So it is recommended to use the smallest possible time resolution when this method is applied.

A double mass plot is drawn by plotting cumulative data from one station against corresponding data from another. The time interval must be the same for both data series.

Double mass curves are a useful indicator of consistency, both within the database itself and in the outside world. This is due to the fact that, stations in the same vicinity should experience comparable hydrological phenomena.

For example, wet and dry periods will be monitored by all stations (flow and rainfall). This will be true over seasons rather than days. The double mass plot, if plotted over several years, should therefore produce a line of approximately constant slope. However if something were to upset data collected at one station, such as upstream abstraction of flow, the slope of the line on the double mass plot would show a change.

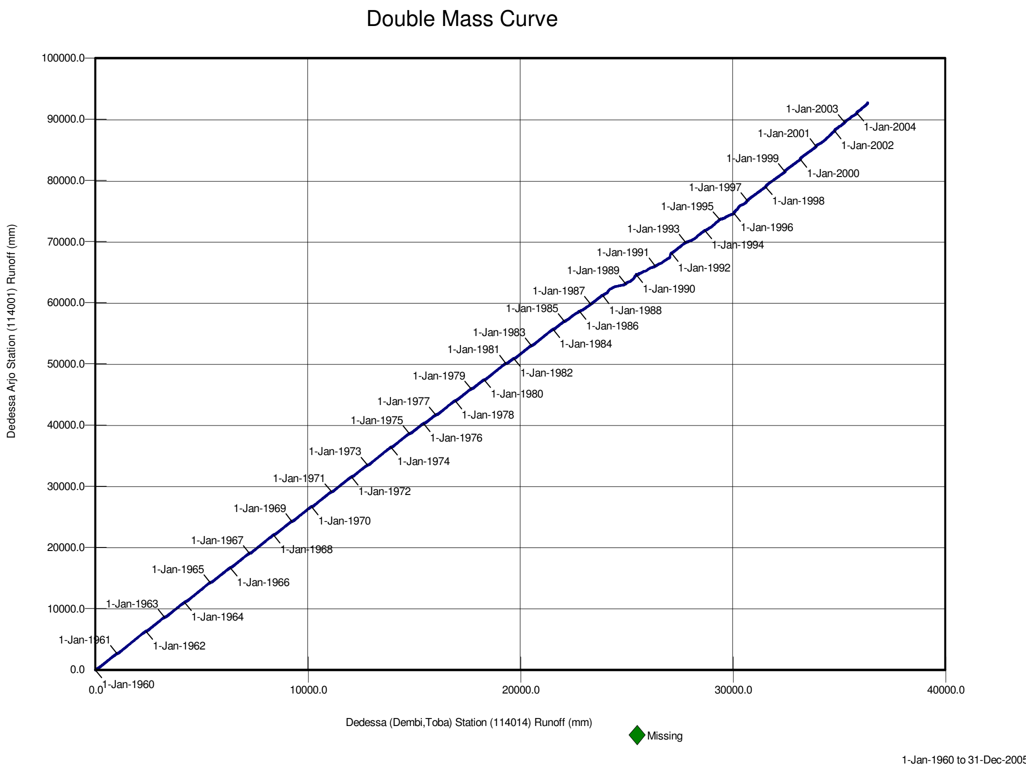


Figure 4.1 Double mass curve of station Dedessa near Arjo Vs Dedessa near Dembi/Toba.

4.1.1.3. Method of Analysis

In Ethiopia a British Software, Windows HYDATA, acquired by the Hydrology Department of the Ministry of Water Resource in 1994, is used as the national hydrological database.

HYDATA (Hydrological Database and Analysis Software) is a purpose-built, Windows-based database and analysis system for processing the hydro meteorological data that is essential for planning and operating water-related schemes. This software is used entirely for this study work.

Overview of the Software

HYDATA is designed to store the types of data most commonly required in water resources studies, including river levels and flows, reservoir, lake and tank levels and storages, rainfall and other meteorological data. It includes facilities for developing rating curves relating river levels to flows, and reservoir, lake and tank levels to storages. Output is provided in the form of "yearbook" style tabulations and graphs, and there are also data transfer facilities.

HYDATA can import ASCII files containing columns or row of data that are in a simple and clearly definable format, such as CSV (comma separated values). Also it can export files in a very simple format which can be read by almost any word-processing software or spreadsheet application.

HYDATA can perform several types of data conversion:

- Generic conversion of data to different time periods (e.g. daily discharge to monthly discharge) with the option of applying simple statistical analysis
- Conversion of stage data to flow data through the use of rating curve equation
- Conversion of reservoir or lake level to storage through the use of rating equation.

The system is suited with a number of standard conversion types, but also allows user-defined types of time series data conversion.

Options are provided for routine hydrological analyses, including derivating flow duration curves and calculating low flow statistics. HYDATA meets the need for a modern digital data archiving and retrieval system, which can be used by staff with little experience of computers, and yet is powerful enough to hold national records and to be used for advanced hydrological analysis. [42]

4.1.1.4 Flow Duration Curve Derivation

A flow duration curve represents the relationship between the magnitude and frequency of daily, weekly, monthly (or some other time interval of) stream flow for a particular river, providing an estimate of the percentage of time a given stream flow was equaled or exceeded over a historical period. FDC provides a simple, yet comprehensive, graphical view of the overall historical variability associated with stream flow in a river basin. [38]

A flow duration curve for a particular point on a river shows the proportion of time during which the discharge there equals or exceeds certain values. Flow duration curves for long periods of runoff are useful for deciding what proportion of flow should be used for particular purposes, since the area under a curve represents volume. Storage upstream of the gauging point in the forms of lakes or reservoirs will modify the FDC of a river that has been previously without such storage.

The slope of FDC gives an indication of the character of a river. A gentle slope indicates a river with few floods that is extensively supplied from ground water, while a steeply sloping curve indicates a river with frequent floods and low flow periods, having little ground water flow and being supplied mainly from runoff. [11]

The purpose of flow duration curve analysis is for evaluating dependable flow of various percentages for surface irrigation. The flow duration curve gives the duration of occurrence of the whole range of flows in the river.

HYDATA has the facility to produce flow duration curves and flow duration tables for daily mean flow time series.

Figure 4.2 FDC of Urgessa River at the station Urgessa near Gembe

4.1.2 Climatic Data Analysis

4.1.2.1 Data Availability and Review

The climatic data used in this project was collected from the National Metrological Service Agency (NMSA). There are about twenty climatologically stations in and around the study basin ranging form only rainfall recording order four stations up to order one stations with many data types. According to the NMSA climatic stations are ordered based on the number of data types they can record.

- Class-1 Principal or Indicative stations
- Class-2 Synoptic stations
- Class-3 Ordinary stations and,
- Class-4 Rainfall stations.

The selection of stations for this project focus on the required data types in order to estimate reference evapotranspiration using FAO Penman-Monteith method and their distribution in the existing different climatic regions. These selection criteria lead to Class 1 and, when not available Class 2 stations mainly.

Based on these criteria the climatic data available for this study comes from five different weather stations, representing each climatic region, as classified by NMSA, in the basin. The spatial distribution is not dense, but there is at least one weather station in each of the climatic zone of the Dedessa sub basin.

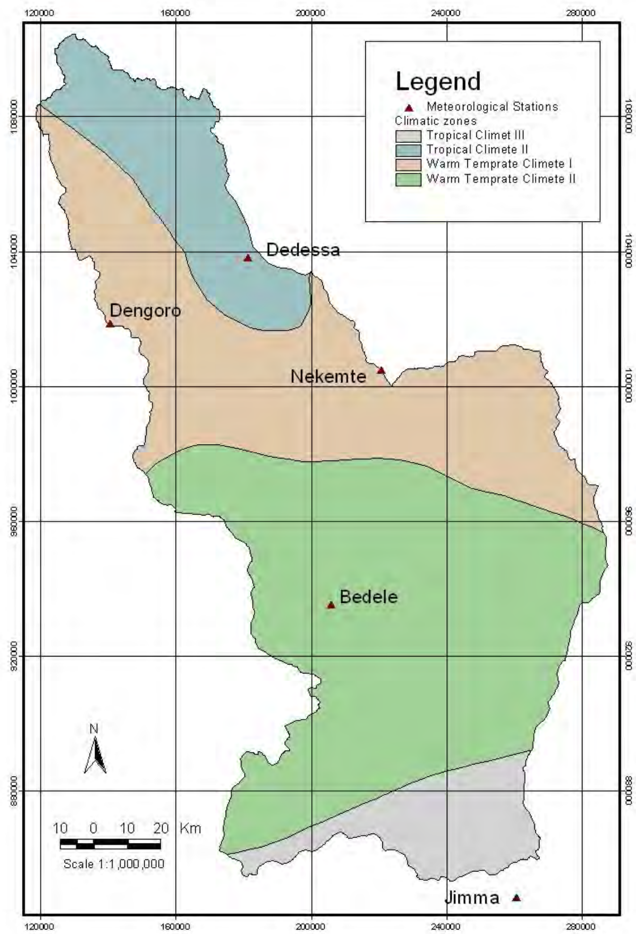


Figure 4.3 Meteorological stations in Dedessa Sub-Basin corresponding to each Climatic zones

These are Bedelle (representing Warm Temperate climate II), Nekemt and Dongoro (representing Warm Temperate climate I), Dedessa station (representing Tropical climate II) and Jimma which is the near by station not exactly in basin (representing Tropical climate III).

For this evaluation work mean monthly data of 10 years (1996-2005) are used. The data types collected include:

- Rainfall, in (mm)
- Maximum and minimum air temperature, in (^{O}C)
- Relative humidity, in (%)
- Wind speed, in (m/s)
- Sunshine duration, in (hours)

Month	Data Type					
	Rain Fall (mm)	Max Temp. (°C)	Min Temp.(°C)	Relative Humidity (%)	Wind Speed (m/s)	Sunshine Hour (hrs)
Jan	17.64	27.32	12.52	46.10	0.43	8.05
Feb	16.04	29.47	12.97	40.99	0.50	8.58
Mar	75.55	28.58	14.09	49.79	0.61	7.68
Apr	100.68	28.44	14.49	51.84	0.69	7.60
May	235.76	26.51	13.85	59.83	0.64	7.67
Jun	355.37	23.95	13.10	70.65	0.49	6.15
Jul	298.58	22.39	13.05	78.37	0.49	4.43
Aug	270.39	22.82	13.00	76.83	0.51	4.54
Sep	285.19	24.29	12.76	72.53	0.52	6.12
Oct	171.48	24.90	12.26	63.96	0.49	7.65
Nov	47.18	25.72	11.66	56.68	0.44	8.24
Dec	21.08	26.60	11.53	51.60	0.42	8.35

Table 4.2: Mean monthly recorded data of Bedelle station

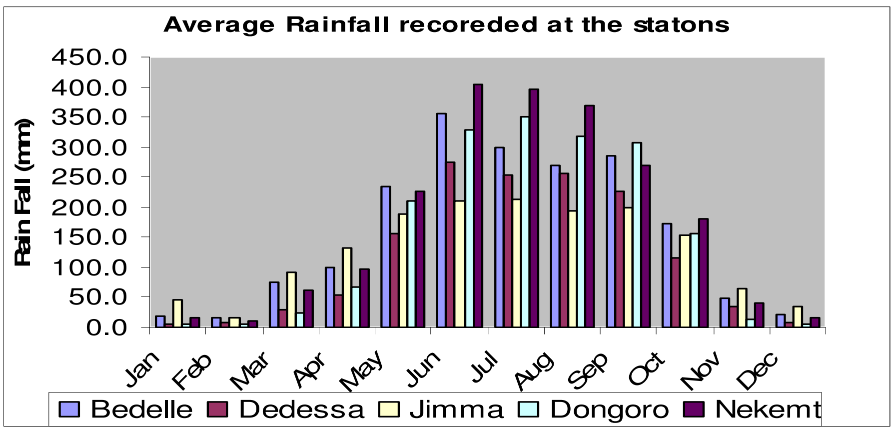


Figure 4.4: Average rainfall recorded at the stations

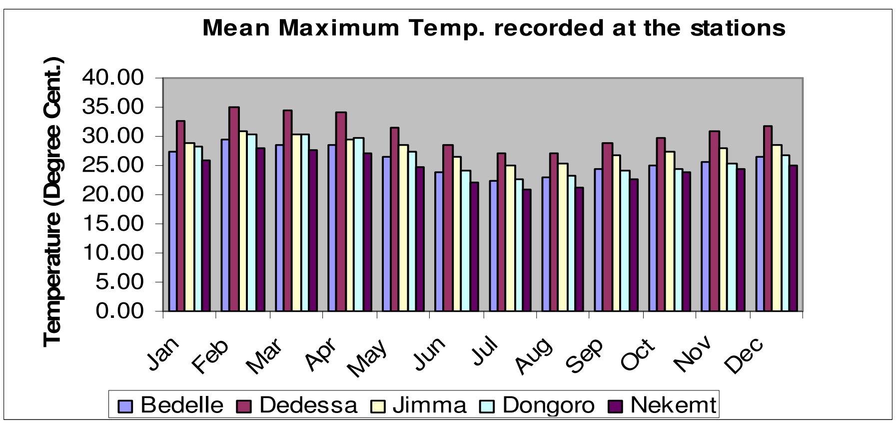


Figure 4.5: Mean Maximum Temperature recorded at the stations

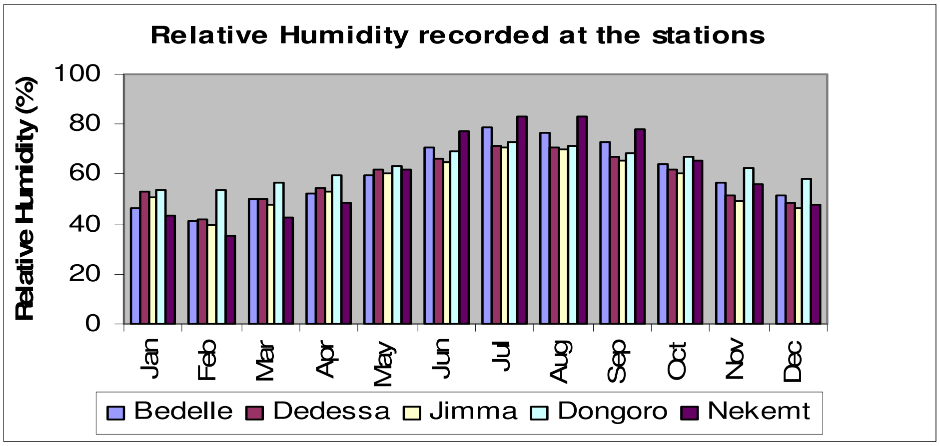


Figure 4.6: Relative Humidity recorded at the stations

4.1.2.2 Analysis Approach

For the purpose of analysis the Dedessa catchment was sub divided in to four parts along the main river Dedessa in accordance to each climatic region. In addition of limited years of data, all the stations, representative of each climatic region, have some missing data for different periods of time. Because of this missing data several method to fill these gaps were analyzed.

Estimating missing climatic data

The determination of irrigation water requirement needs the knowledge of water contributed by the effective rainfall, which in turn needs the rainfall data over the area. All the stations that are selected for this study have rainfall data without any missing gap in the analysis period selected.

The calculation of the reference evapotranspiration (ET_o) with the Penman-Monteith method requires mean daily, ten-day or monthly maximum and minimum air temperature (T_{max} and T_{min}), actual vapor pressure (e_a), net radiation, and wind speed measured at 2 m. If some of the required weather data are missing or cannot be calculated, it is strongly recommended for the estimation of the climatic data with one of the procedures briefly discussed in FAO Irrigation and Drainage paper 56.
Many of the estimation procedures rely upon maximum and minimum air temperature measurements. Unfortunately, there is no dependable way to estimate air temperature when it is missing. Therefore, maximum and minimum daily air temperature data are the minimum data requirements necessary to apply the FAO

Penman-Monteith method. Also it is used as a criteria in the selection of stations used for this study work.

To fill the missing meteorological data the following methods were followed:

- For short missing gap length (one up to two months) the mean value of data in available years was simply taken
- For longer missing gap length (more than two months) correlation was carried out with another station having data in the missing period.
- In the case of correlations with their correlation coefficient less than 0.6 with the available stations, the FAO recommended procedures in filling missing data were used.

4.1.2.3 Methods of Analysis

The irrigation water requirement of selected areas in each climatically classified regions of the basin, are quantified from the knowledge of crop water requirement demand. The estimation of crop water requirement needs the selection of appropriate crops that are likely to be grown in the specific climatic condition with their appropriate crop coefficients and the corresponding reference evapotranspiration. The estimation of reference evapotranspiration (ETo) for the selected climatic stations is made using CROPWAT 4 Windows model.

CROPWAT

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation practice in water resource development. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation.

Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 "Crop water requirements" and No. 33 "Yield response to water". The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions.

Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. For the estimation crop water requirements (CWR) the model requires:

- ***Reference Crop Evapotranspiration*** (ETo) values measured or calculated using the FAO Penman-Montieth equation based on decade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed;

- ***Rainfall*** data (daily/decade/monthly data); monthly rainfall is divided into a number of rain storm each month;

- A ***Cropping Pattern*** consisting of the planting date, crop coefficient data files (including K c values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area); a set of typical crop coefficient data files are provided in the program.

Once all the data is entered, CropWat 4 Windows automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly.

Crop Type Used for Analysis
The crop type selected for this analysis is sugarcane. Sugarcane does not require a special type of soil. Best soils are those that are more than 1m deep rooting to a depth of up to 5m is possible. The soil should preferably be well-aerated and have a total available water content of 15 percent or more. [14]

4.2 LAND AND SOIL RESOURCE ASSESSMENT

4.2.1 Topography

Topography is a major factor affecting irrigation, particularly surface irrigation. It influences drainage, erosion, irrigation efficiency, cost of land development, size and shape of fields' labors requirements, range of possible crops, etc. Topographic knowledge is basic to many earth surface process analyses, as a means of explaining processes and of predicting them through modeling. Our capacity to understand and model these processes depends on the quality of the topographic data that are available. In general terms, a model is a representation of reality. Due to the inherent complexity of the world and the interactions in it, models are created as simplified, manageable view of reality. Models help in understanding, describing, or predicting how things work in the real world.

Recording spot elevation values at significant points and intervals on the land surface is an approach in the production of a digital elevation model (DEM) for an area. A DEM is the representation of the elevation of the land at regularly spaced intervals, used for various applications, most notably for the production of topographic maps and three- dimensional visualization of the Earth's surface.

4.2.1.1 Data Availability

Under an agreement with the National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial Intelligence Agency (NGA), the US Geological Survey (USGS) distribute elevation data from the Shuttle Radar Topographic Mission (SRTM). SRTM is a joint project between NASA and NGA to map the Earth's land surface in three dimensions.

The 90m resolution SRTM DEM produced using radar images gathered from NASA's shuttle is provided by the CGIAR-CSI. The Consortium for Spatial Information (CSI) is an initiative of the many geospatial scientists within the Consultative Group for International Agriculture Research (CGIAR) linking the effort of CGIAR scientists, national and international partners, and others working to apply and advance geospatial Science for international sustainable agriculture development, national resource management, biodiversity conservation, and poverty alleviation in developing countries. It provides a major advance in the accessibility of high quality elevation data for large portion of the tropics and other areas of the developing world.

This data is provided in an effort to promote the use of geospatial science and applications for sustainable development and resource conservation in the developing countries. This data, which is used by this project, is currently distributed free of charge by USGS and is available for download from the USGS ftp site. The Dedessa sub-basin DEM shown in the figure below.

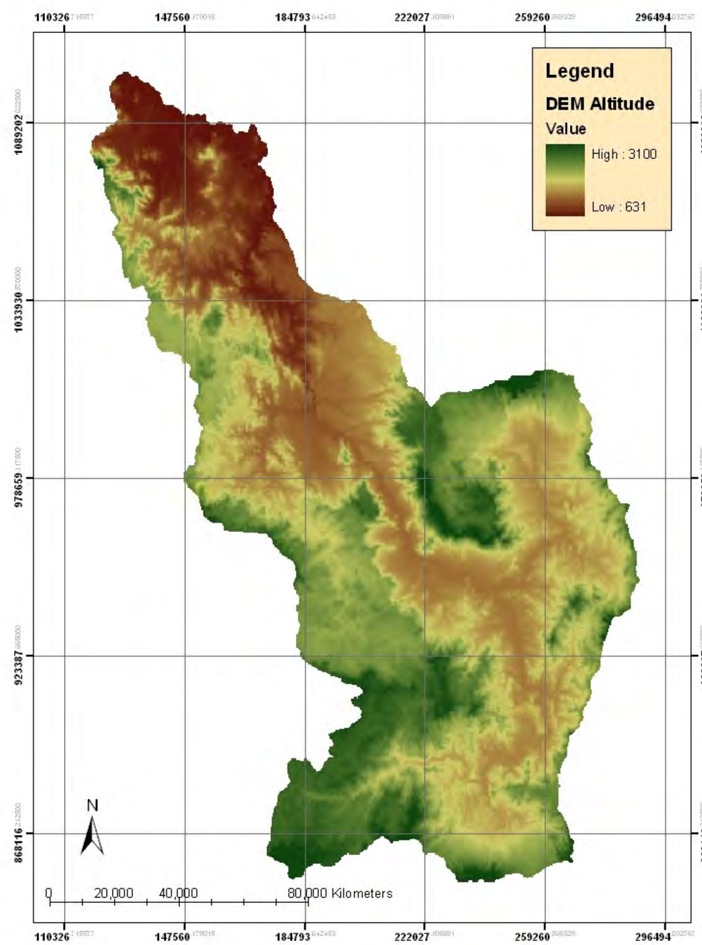


Figure 4.7: DEM of the Dedessa Sub-basin

4.2.1.2 Analysis Approach and Slope Map Derivation

Land slope and its uniformity are two of the most important topographical factors influencing land evaluation for irrigation suitability. Slope is clearly an important agro-ecological parameter. It has direct implication on cultivation; steeper slope are more difficult to cultivate than gentler slopes. FAO guidelines suggest that slopes above 30% should not be cultivated, although such slopes are frequently cultivated in Ethiopia. Soil conservation methods directly related to slope. On slope <15%, agronomic and biological conservation methods should normally be sufficient. Above 15%, conservation structures become increasingly important. In general, the steeper the slope the greater the runoff, and the lower the supplied water or rainfall infiltration.

The slope map of the Dedessa sub basin is derived from the available DEM using the Spatial Analysis tool in raster form. In Arc GIS Spatial Analysis tool slope identifies the steepest downhill gradient for a location on a surface. It is the maximum rate of change in elevation over each raster cell and its eight neighbors. This raster data was converted to vector shape file, with its slope rages, to simplify slope map for the evaluation purpose.

There are many literatures on suitable land slope for different types of irrigation method. The land slope ranges used for this project is the one followed by FAO in land and water bulletin (*Irrigation potential in Africa A basin approach,* 1994). The suitable order is divided in two classes Highly Suitable (S1) for slope up to 5% and Moderately Suitable (S2) for slope range between 5%and 8%. Land slope >8% is classified in general as not suitable for surface irrigation.

This slope map is the basic map for all other land evaluation due to its being the critical limiting factor for irrigation implementation even if other evaluation parameters namely water availability, land cover, suitable soil and agro-climatic conditions are suitable.

The slope variation in the study area rages up to 160% as shown in the figure below. this slope map was drived from the DEM layer using the spatial analysis in ArcGIS.

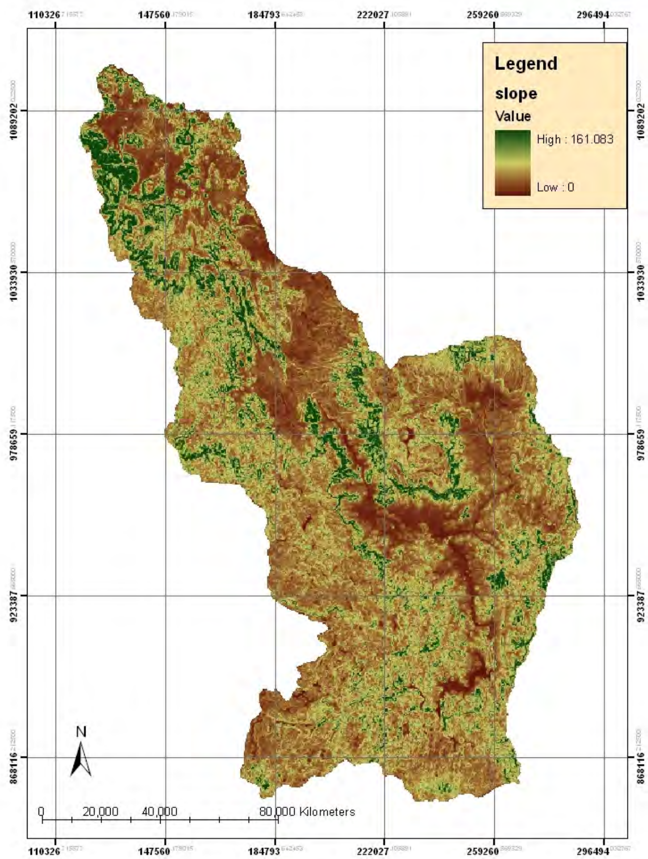


Figure 4.8: Land Slope of the Sub-basin derived from the DEM

4.2.2 Land Cover/ Land Use

These two terms, land cover and land use, are often used interchangeably, but the distinction between land use and land cover is an important one. Land use refers to the actual economic activity for which the land is used i.e. food production, commercial forestry, etc. land cove refers to the cover of the earth's surface i.e. vegetation (by type), bare soil, urban development, etc. without reference to how that cover is used.

In many cases, land cover and land use are directly related; for example, grass (land cover) may generally be used for livestock grazing (land use). However, such close relationships may not always be true. Thus land could have a land cover of forest: the land use could be commercial forestry, watershed protection/conservation, National Park, wild life, recreation, etc. similarly, grass land (land cover) could be used (land use) for wildlife grazing and the land use may be tourism. Land areas may often have multiple uses.

This separation is important in mapping, especially when using remotely sensed imagery as a mapping base. Remotely sensed data can only provide information on land cover; interpolations can be made from the land cover for probable use but land use can only be confirmed through detailed field investigation.

People use of the land is not random; it reflects the complex interaction between biophysical potential of the land, the socio-economic condition of the people (the land users), and the institutional and policy environment within which the land is used.

4.2.2.1 Data Availability and Review

Several studies on land cover and land use, at different scales, have been undertaken in Ethiopia. These include land use planning project, assisted by FAO, the Land Use Planning and Regulatory Department (LUPRD) at 1:1,000,000 scale for the whole of Ethiopia, Ministry of Mines and Woody Biomass Inventory and Strategy Planning Project (WBISPP). The 1:250,000 scale land cover map for this project is adapted from the ARBIDMPP, which used the Land Sat imagery as the base data for the land cover mapping.

Land cover in Ethiopia is very complex and may vary remarkably over short distances, and it is almost impossible to identify 'homogeneous' areas at the 1:250,000 scale of mapping. Thus most mapping units are complexes (or associations) of land covers.

A land cover classification was prepared by ARBIDMPP, using the LUPRD and WBISPP legends with some modifications for the entire Abbay River basin. The legend contains twelve main classes, with sub-divisions as necessary.

In the Dedessa sub basin eight classified main land cover types exist, which shows that the basin has a diversified land cover. They are described with their aerial coverage (in percentage) as follows:

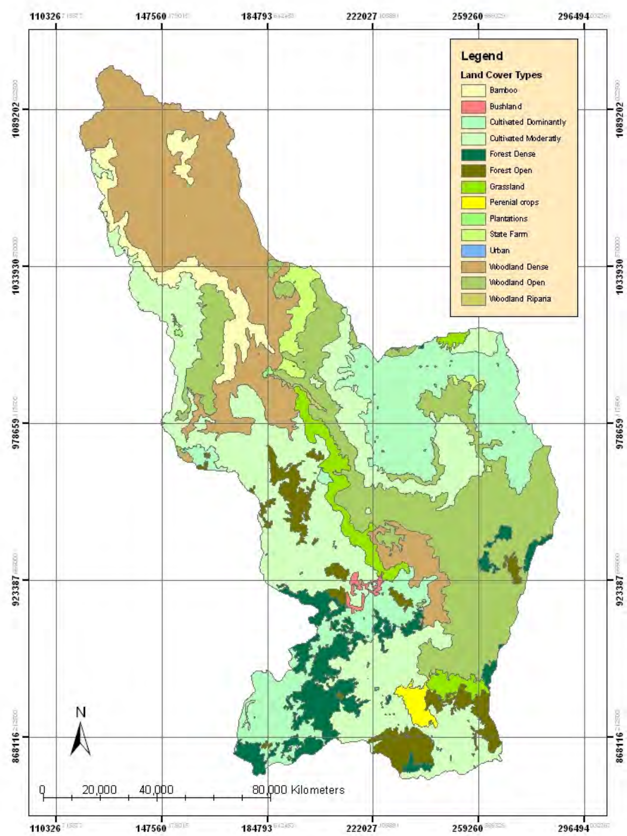


Figure 4.9: Land cover map of the Dedessa basin

Land cover Types	Arial Coverage (%)
Cultivated	45.6
Woodland	34
Forest	10.7
Bamboo	3.7
Grassland	2.8
State Farm	2
Perennial Crops	0.6
Bush land	0.3
Urban	0.2

Table 4.3: Arial coverage (%) of the land cover types

Description

Cultivation

Cultivation is in a sense self-explanatory, being that land which is being cultivated. Sub divisions of the cultivated class included

- ***Rainfed***: This refers to rainfed smallholder cultivation, which can be subdivided based on the intensity of cultivation.
- ***State farm***: This category refers only to rainfed state farms.
- ***Perennial crop***: The main perennial crop is coffee grown under shade trees. Enset and Chat also are perennial crops, mainly grown around homesteads.
- ***Irrigated land:*** Within the basin, most irrigated land is small scale and localized, and cannot be either identified o the images nor mapped at the scale of mapping.

Woodland

Woodland is a single story tree cover underlain by grass. When the canopy covers more than 50% of the area it was considered as dense woodland. Otherwise it was classed as open woodland.

Forest

Forest consists of a multi storied tree community, and is described by the major type (deciduous or coniferous) and degree of disturbance.

Bamboo

This category is self explanatory. Within the study area, the bamboo occurrence is lowland bamboo, in the lowland northern part mostly in Kamashi zone.

Grassland

This category is subdivided further for better understanding. Open grassland is defined where the area is dominated by grass with very few shrubs or bushes. Bushed/Shrubed grassland consists of grassland with frequent patches of shrubs and/or bushes. Wooded grassland has, in addition, dispersed trees throughout the unit.

Bush land
This consists of multi stemmed wood y species with a height of more than 2m. It was defined as dense or open, depending on the assessed degree of ground cover.
Urban
Again, this is self explanatory. This land cover type is the least in the study area as compared to other land cover types.

4.2.2.2 Analysis Approach and Suitable Land Identification

The method followed in identifying the availability of land, as rated by its cover, for irrigation agriculture is based on the most limiting factors. The eight mentioned (section 4.2.2.1) main land cover classes in the project area used in rating the land cover for suitable and not suitable orders based on the most limiting factors. This limiting factors includes, lands that are already irrigated, dense forest, bamboo, and woodlands, and urban areas. For each suitable order there are two classes that reflect the limitation that restrict the suitability of that land mapping unit for the irrigation purpose due to its environmental, social or economical cost, unless some important measures are taken. These two classes are Highly suitable (S1) and moderately suitable (S2).

Category	Name	Description of Land Cover types
S1	Highly Suitable	Cultivated---Dominantly, Moderately Grassland--- Open, Bushed, Shrubed Bush land--- Open, Riparian
S2	Moderately Suitable	Woodland ----Open, Riparian Bush land ----- Dense Forest --------- Open
N	Not suitable	Cultivated ----- Irrigation, state farm Wood land ---- Dense Bamboo Urban area

Table 4.4: Land Cover evaluation criteria description

The selection of rainfed and perennial cultivated land in the suitable order is to use the chance of improved and reliable crop yields in the rainless seasons as well. No definite line can be drawn between areas where irrigation is essential and areas where it is not needed. Often irrigation in humid area is called supplemental however, all irrigation is supplemental to natural rainfall, and the quantity of irrigation water needed is inversely proportional to the rainfall available in the rainy seasons.

4.2.3 Soil

Agricultural land is of value only because of its ability to grow crops. Most evaluations are based on factors that affect this ability. Assessment of land resource, with particular regard to soil survey is a necessary prerequisite for all agricultural developments, particularly where irrigation is concerned.

Soil act, as a storehouse of water, supplying plant needs during dry periods when rain is inadequate. Soil with their included water help to regulate temperatures, becoming neither so cold nor so hot as the air above. They even help greatly in moderating air-temperature. Soils also contain air and supply oxygen to plant roots. Soils store minerals nutrients for plant use and commonly give mechanical support to the plants.

In addition to there positive factors, soils should not contain factors injurious to plants, such as:

- Excessive amount of soluble salts
- Toxic quantities of special elements like boron, arsenic, or aluminum
- Extreme acid or alkaline reactions
- Presence of plant disease causing organisms or harmful insects.

Soil maps and reports are generally technical documents prepared by and for soil specialists. As such the incorporate technical terms and forms of presentation, which are often not easily understood by planners and decision makers.
Land evaluation is one approach to interpreting this technical soil information to provide understandable and readily useable information for use in the planning process. It involves evaluation of land units, usually based on soil mapping units, for defined potential uses.

4.2.3.1 Data Availability

A number of studies have been conducted within the Dedessa river basin, chief among which are the Land and Water Resource Study of the Blue Nile Basin by the United States Bureau of Reclamation (USBR), in 1964, named Arjo-Dedessa, Dabena, Wama river area, and Nekemt projects, and the Geomorphology/Soil map of Ethiopia by the Land Use Planning and Regulatory Department (LUPRD) of the Ministry of Agriculture. The LUPRD of the Ministry of Agriculture made an effort in producing nation-wide soil association and geomorphology/soil maps at scale 1:2,000,000 and 1:1,000,000, respectively. The study was based on interpretations made from LANDSAT imagery and consequent field checks of an exploratory nature.

The soil map used in this study work is adapted from the ARBIDMPP. It is made available from the Metadata Base Department of the Ministry of Water Resource in soft copy form that can be easily manipulated using the Arc GIS environment.

4.2.3.2 Analysis Approach and Suitable soil Identification

In rating land for irrigation agriculture, the soil properties, which affect the inherent productivity, are to be considered. Physical and chemical properties of soil influence land suitability for irrigation in several different land and soil qualities. For example, soil texture (physical property) has an influence on 14 different land qualities (FAO 1983) including moisture availability, nutrient retention, workability, and erosion. The influence of texture on land suitability is thus impossible to define; a sand texture may be good for workability and drainage but poor for moisture and nutrient retention.

The assessment of soil suitability for irrigation in this project is based on a mixture of soil qualities (physical and chemical), measured and estimated by means of different soil survey methods conducted by ARBIDMPP studies. The essential feature of a land quality is that it influences land in a particular manner, as compared to general soil characteristics, which may influence in several different ways apart from the required specific purpose.

The land qualities and their corresponding soil characteristics used in identifying this qualities, used in this project are described briefly as follows.

Land Quality	Soil characteristics used in assessment of land qualities
Physical	
Texture	Clay, Silt, and Sand
Drainage Condition	Oxygen (O2) Availability
Rooting Condition	Soil depth
Chemical	
Nutrient Status/ Availability	Organic carbon (OC) Available Phosphorus (P) Acidity and Alkalinity (PH)
Nutrient Retention Capacity	Cataion Exchange Capacity (CEC)

Table 4.5: Soil physical and chemical qualities considered for the evaluation

Soil Physical Properties

Texture

The proportion of sand, silt and clay are used to determine the textural classes of the soil. Particle size distribution is a function of parent materials and degree of weathering. Basalts weather into clays while granites/grandiorities tends to weather into sands. The proportion of sand, silt and clay are used to determine the textural classes of the soil. Particle size distribution is a function of parent materials and degree of weathering. Basalts weather into clays while granites/grandiorities tend to weather into sands.

The particle size limits used by USDA/FAO are as follows;

1.0 - 2.0mm	Very coarse Sand
0.5 - 1.0mm	Coarse sand
0.25 - 0.5mm	Medium sand
0.1 - 0.25mm	Fine sand
0.05 - 0.1mm	Very fine sand
0.002 - 0.05mm	Silt
< 0.002mm	Clay

Soil of all textural classes, except perhaps Cores sand, are irrigable by an appropriate method when there is an economic incentive and no impedance to root growth. Those at the extremes of the textural range require good management and perhaps additional inputs. The extremes of texture acceptable within a specific project requires considerable judgment backed by the performance of similar soils (local or elsewhere) under comparable conditions, taking in to account climate, water quality, method of irrigation, cropping pattern and erosion hazard.

Drainage Condition

Drainage is the removal of excess surface and subsurface water. Soil drainage refers to the flow of water through the soil, and the frequency and duration of periods when the soil is free of saturation under natural conditions. Soil drainability refers to the ability of soil and substrata to respond to subsurface drains. It is useful term since it enables predictions to be made of soil drainage under project irrigation conditions.

Internal soil drainage is defined as the quality of a soil that permits the downward flow of excess water through it. It is determined by the texture, structure, and other characteristics of the soil profile and underlying layers and by the height of the water table, either permanent or perched, in relation to water added to the soil.

The classes of internal soil drainage used are the following:

Excessively drained
Well drained
Moderately well drained
Imperfectly drained
Poorly drained

Soil Depth

The depth of soil that can be effectively exploited by plant roots is an important criterion in selection land for irrigation. Root penetration, however, is often inhibited by mechanical factors (land or impermeable horizons), chemical factors (zone of high line or gypsum content) or poor drainage.

While a depth of 150cm is ideal in well drained friable soil, experience has shown that many irrigated annual and perennial crops produce excellent yields with a well drained effective root zone depth of 90cm.

The soil depth categories used in this report are the following:

< 30cm	very shallow
30 - 50	shallow
50 - 100	moderately deep
100 - 150	deep
>150	very deep

Chemical properties

Soil reaction (pH)

The degree of acidity or alkalinity of a soil is usually expressed as a pH value which is defined as the negative logarithm of the hydrogen ion activity. pH determination on soil samples is made to make some generalizations regarding the availability of nutrients. A suitable range for most crops is between about 6.3 and 7.5 (1:2.5 soil: water suspension).Under low pH values (<5.5) phosphorous becomes unavailable and aluminum ions are established on the clay complex causing toxicity. On the other hand, high pH values can indicate a sodicity hazard and reduction in the availability of micro-nutrients.

Organic Carbon

Organic carbon measurements are often made as a measure of the quality of organic mater in a soil, which in turn is taken as a crude measure of fertility status. The organic carbon content invariably decreases with depth, the decrease at times being more than 50%. The OC values are in general low to very low in the study area therefore organic matter does not contribute much to soil fertility.

Available Phosphorus

Phosphorous is present in soils in both organic and inorganic forms. The inorganic form is usually more important as a plant nutrient. The phosphorus availability to plants therefore, differs between different forms of phosphorus in soils. Available phosphorus refers to the plant readily available form.

Cataion Exchange Capacity (CEC)

Cataion Exchange Capacity (CEC) is a measure of the soil's ability to retain and supply plant nutrients. CEC measurements are commonly made as part of the overall assessment of the potential fertility of a soil, and possible response to fertilizer application. The CEC results can also be used as a rough guide to the type of clay minerals present and its value critically depend on pH.

The following suitability rating for land quality and characteristic are used to distinguish different soil types suitable in this project adapted from the ARBIDMPP study, *FAO Guideline for soil evaluation for irrigation agriculture 1979, and FAO land and water bulletin No4 Irrigation potential in Africa a basin approach.*

Criteria	Category	Condition
Drainage	S1 S2 N	Well drained Moderately well – Imperfectly drained Imperfectly – Poorly drained
Soil depth (cm)	S1 S2 N	> 150 150 – 50 < 50
Organic Carbon (OC)%	S1 S2 N	> 10% 2 - 10% <2%
Available Phosphorus (P) ppm	S1 S2 N	>15% 15 – 5% < 5%
Acidity and Alkalinity (pH)	S1 S2 N	5.5 – 7.0 5.5 – 4.5 7.0 – 8.5 < 4.5 >8.5
Cation Exchange Capacity (CEC) meq/100g soil	S1 S2 N	35 – 70 35 – 16 < 16

Table 4.6: Soil evaluation criteria description

4.3 GIS ANALYSIS

Geographic Information System (GIS) technology is about 30 years old. However for the most part, it is still often used just to make maps. However, GIS can do much more. Using GIS databases, more up- to-date information can be obtained or information that was unavailable before can be estimated and complex analyses performed. This information can result in a better understanding of a place, can help to make the best choices, or prepare for future events and conditions (Mitchell 1999).

The most common geographic analyses that can be done with a GIS are:

- Mapping where things are
- Mapping the maximum and minimum values
- Mapping density
- Finding what is inside (intersection analysis)
- Finding what is nearby (proximity analysis)
- Mapping change (overlay analysis)

The steps for a good geographic information system analysis are:

- **Stating the problem.** Stating the problem defines what information is needed, and it is often in the form of a question. Being as specific as possible about this statement will help when trying to decide how to approach the analysis, which method to use, and how to present the results. Other factors that influence the analysis are how it will be used and who will use it.

- **Understanding the data.** The type of data and features to be used in the project will help in determining the specific method to be used.

- **Choosing a method.** There are almost always two or three ways of getting the information that is needed. Often one method is quicker and gives more general information. Others may require more detailed data and more processing time and effort, but provide more precise results. To decide which method to use the level of precision to answer the problem has to be again evaluated.

- **Processing the data.** Once the method has been selected, the necessary steps in the GIS have to be performed.

- **Reviewing the results.** The results of the analysis can be displayed as a map, values in a table, or a chart. It has to be decided which information to include in the maps, and how to group the values to best present the information. Looking at the results will help in the decision making process, deciding what information is valid or useful, or whether the analysis should be rerun using different parameters or even a different method. GIS makes it relatively easy to make these changes and create new output. The results using different methods can be compared to decide which one presents the most needed information and produces it in an efficient way

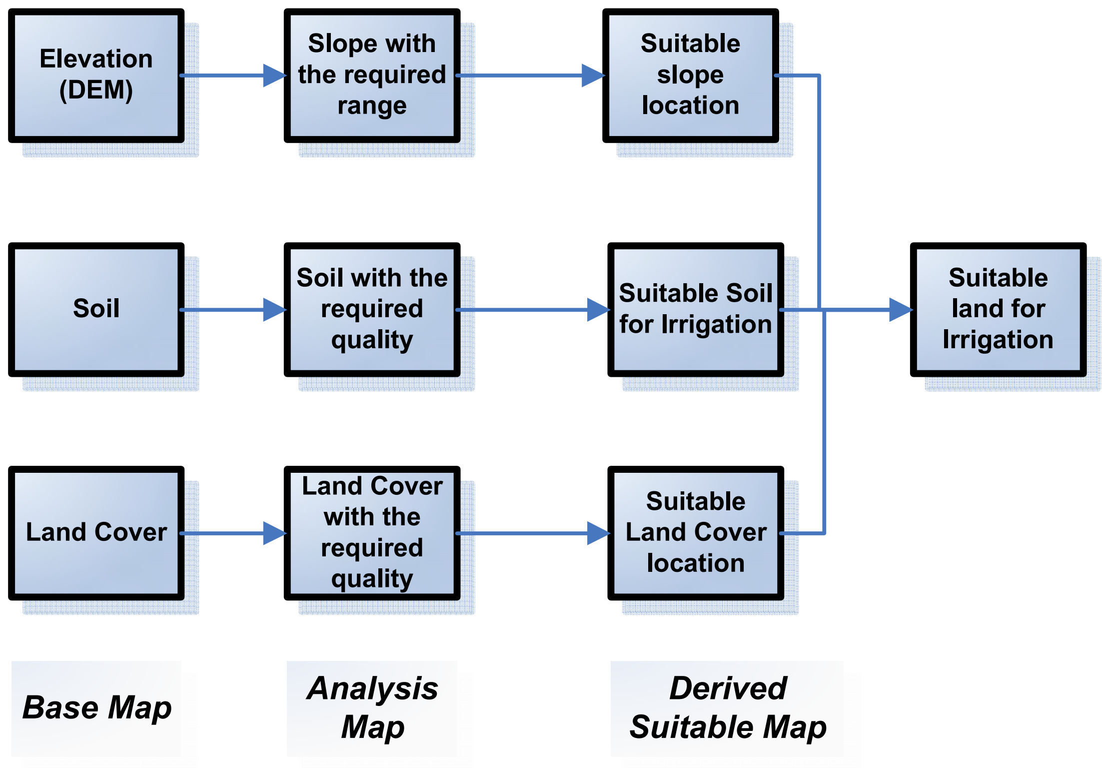
4.3.1 Data Organization for Analysis

The integration of data provides the ability to ask complex spatial questions that could not be answered otherwise. Often, these are inventory or locational questions such as how much? or where? Answers to locational and quantitative questions require the combination of several different data layers to be able to provide a more complete and realistic answer. The ability to combine and integrate data is the backbone of GIS.

Land use suitability evaluation needs the integration of data layers to create and derive themes or layers that represent the result depending on the required purpose. These data layers are commonly defined based on the needs of the analysis and the availability of data.

In this study work the different data layer that are required for the analysis are identified and organized, (both spatial and attribute), in a form which permits them to be quickly retrieved for updating, quarrying and analysis and for easy visual understanding.

The GIS model that is used can be expressed as a flowchart of processing steps as follows:



Each box in the flowchart represents a map while each line indicates a GIS operation.

4.3.2 Map Projection

This functionality concerns the transformation of data in geographic coordinates for an existing map projection to another map projection. ArcGIS/ ArcView software requires that data layers must be in the same map projection for analysis. Accordingly, if data is acquired in a different projection than the other data layers it must be transformed.

The digital maps of Dedessa sub basin were in different projection or did not have any stated projection sometimes; however this is not something different to correct. ArcGIS contains a feature that allows setting the derived coordinate system for a map. Typically twenty or more different map projections are supported in ArcGIS software. The coordinate system selected for the maps of the Dedessa sub basin was the Universal Transverse Mercator (UTM) zone 37 North. It is important to note that bad metadata can be a source of spatial error, especially when trying to overlay different layers.

4.3.3 GIS Layers Created or Edited For the Project From The Original Maps

Slope

The original raster data (DEM) for the Dedessa sub basin obtained using the "mask tool" of the Geoprocessing wizard in ArcGIS by the basin area. [Fig 4.4] The slope map of the sub basin derived using the Spatial Analysis "Slope" tool. [Fig 4.5]

Using the "Reclassification" tool, which is an attribute generalization technique in ArcGIS, the three suitability ranges (S1, S2, N) are classified.

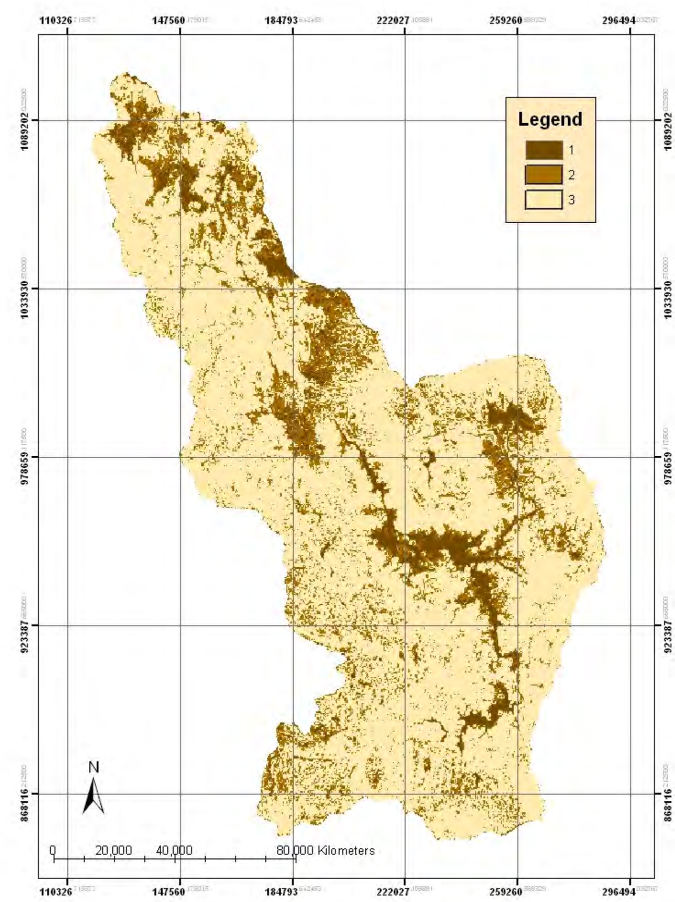


Figure 4.10: The classified Slope raster layer derived from the slope map.

To make a clearer map the "Neighborhood" command is used in slope raster data, which results a new data layer. Then this classified raster data layer converted to feature (vector) data layer for the overlaying analysis.

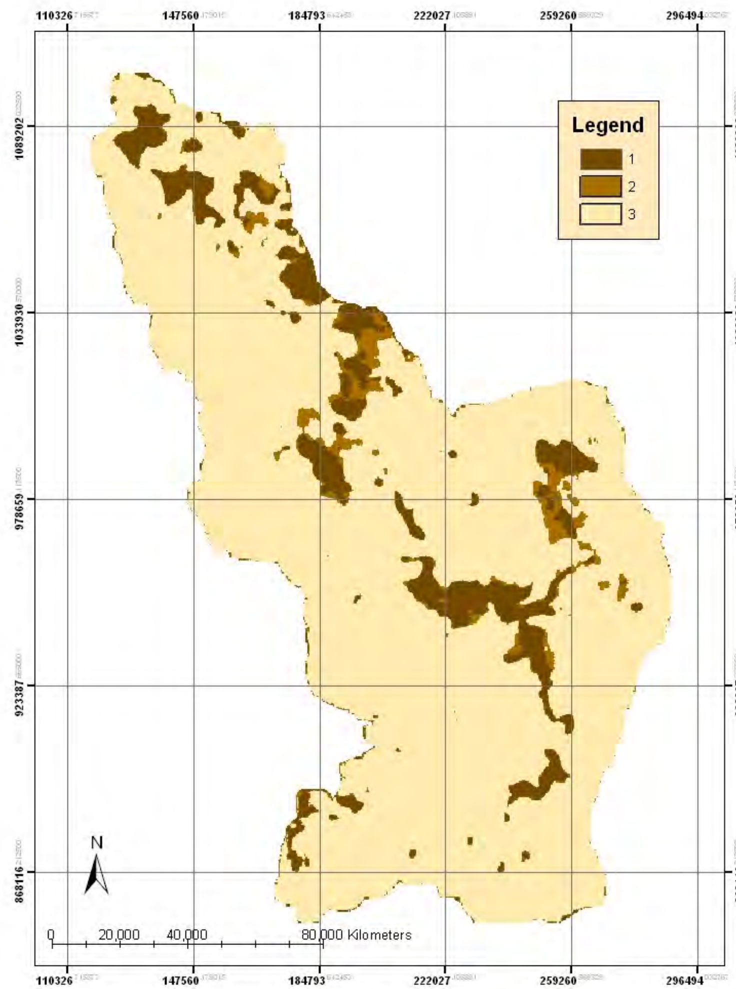


Figure 4.11: Slope categorized based on the suitability class

Legend	Slope (%)	Category
1	0 - 5	Highly Suitable (S1)
2	5 - 8	Moderately Suitable (S2)
3	> 8	Not Suitable (N)

Table 4.7: Slope evaluation criteria category

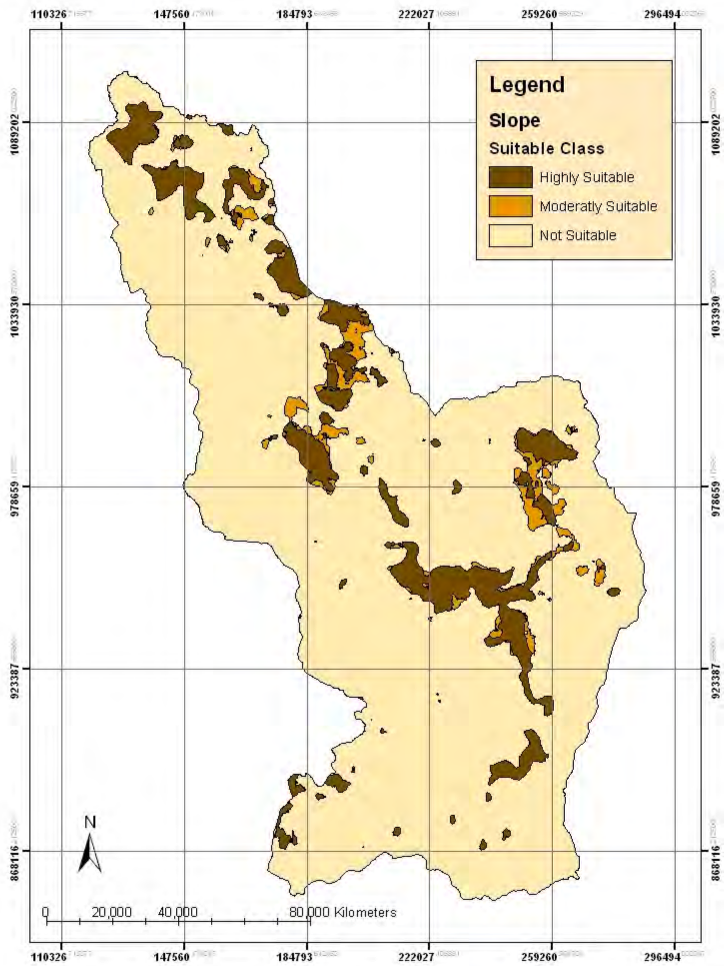


Figure 4.12: Suitable land for Surface Irrigation from the slope analysis

The suitable land from the parameter 'slope' point of view is not seen in the highland areas they are mainly concentrated in the Dedessa and Wama river valleys and at the northern lowland parts. It is apparent that the basin shows an overall slope from South to North.

Soil

The original soil map of the Dedessa sub basin contains various types of soils that are too complex to use in this suitability analysis.

The "dissolve" tool in the "geoprocessing" wizard of ArcView was used to simplify this layer. The new soil map divides all the soils in to the major groups (Acrisols, Alisols, Nitisols, Vertisols, Leptosols Cambisols, and Fluvisols). The distribution of these soils within the sub basin is presented in [Fig 3.4].

Having undertaken the preceding preliminary steps, the evaluation proceed by matching the requirements for irrigation with the qualities of each soil type, to provide an overall soil suitability for each soil unit. The suitability rating for each mapping unit is labeled based on the required quality criteria explained in section [4.2.3.2]

Matching proceeds initially for each soil quality for each soil type. This produces a series of suitability (S1, S2, N) for irrigation based on the defined soil quality. These individual ratings are then combined into an overall suitability through the method of most limiting condition. Thus, for each soil type, the soil quality, which is most limiting, defines the overall suitability of the land unit.

The FAO (1983) offers four alternatives for combining the individual suitability ratings, subjective, arithmetic, modeling, and limiting conditions. The most common method, recommended by FAO, and that used here, is that of limiting conditions.

The logic of this procedure is that it is of little use having excellent conditions with respect to temperature regime, moisture availability, absence of salts and toxicities, etc., if rooting conditions are limited by a soil depth of 10cm. This procedure is a broadening of the well-known 'law of the minimum' in agriculture, which states that crop yield will be determined by the plant nutrient in lowest supply. The method of limiting conditions should always be followed where there is an assessment on N Not suitable. The advantages of the procedure of limiting conditions are its simplicity, and the fact that it will lead in most cases to an overall assessment which lies on the cautious side. (FAO, 1983)

Soil type	Texture	Depth (m)	Drainage Condition	OC (%)	P (ppm)	pH	CEC (meq/100 g soil)	Irrigation Suitability
Alisols	Clay/Clay Loam/Silty clay	Deep to Very Deep	Well	3.24	15.44	5.3	35.28	**S1**
		S1	S1	S2	S1	S2	S1	
Nitisols	Clay/ Clay loam/ Silty clay loam	Deep to Very Deep	Well	2.12	25.23	5.5	35.72	**S1**
		S1	S1	S2	S1	S1	S1	
Acrisols	Clay	Deep to Very Deep	Well	4.06	8.57	5.8	36.43	**S1**
		S1	S1	S2	S2	S1	S1	
Vertisols	Clay	Deep to Very Deep	Imperfect to Poor	2.09	12.22	6	65.39	**S2**
		S1	N	S2	S2	S1	S1	
Leptosols	Loam/Clay	Shallow to Very Shallow	Well	1.12	38.9	6.6	50.29	**N**
		N	S1	S2	S1	S1	S1	
Cambisols	Silty clay	Moderately Deep	Well	2.44	24.84	5.8	39.70	**S2**
		S2	S1	S2	S1	S1	S1	
Fluvisos	Clay/Silty Clay loam/Clay loam/ Clay	Deep to Very Deep	Well	3.70	54.5	7.5	61.0	**S1**
		S1	S1	S2	S1	S2	S1	

Table 4.8: Soil suitability evaluation for Irrigation

According to Table: 4.8, Leptosols only categorized as not suitable for their shallow depth. Vertisols and Cambisols are categorized as moderately suitable for their poor drainability and moderate soil depth respectively. Fluvisols, Acrisols, Nitisols, and Alisols, which cover most part of the sub basin [Fig. 3.4], are categorized to highly suitable classes.

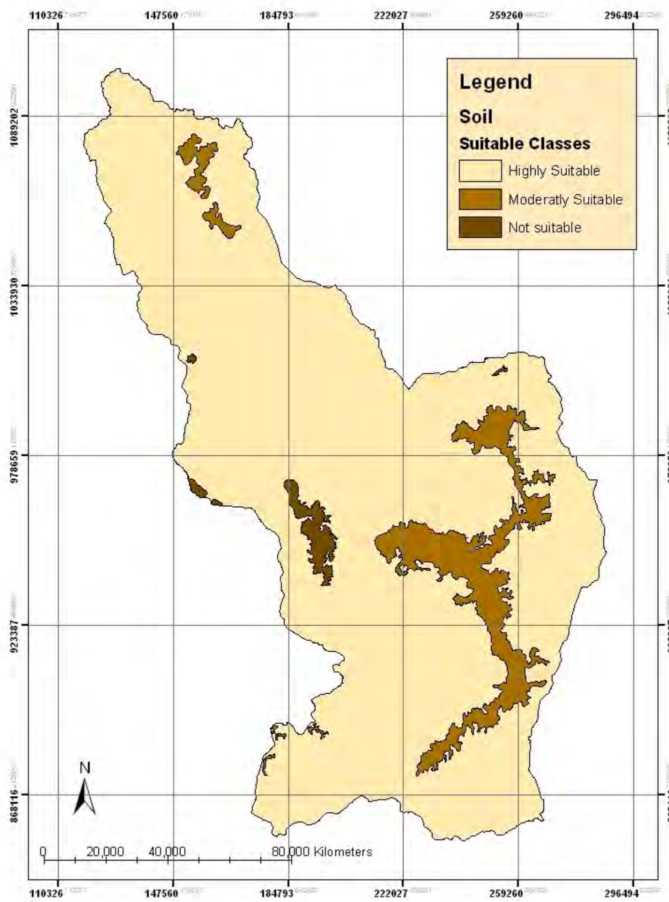


Figure 4.13: Suitable land for Irrigation from Soil analysis

Land Cover

This layer was created from the Abbay River basin land cover map by using the "clip" tool of ArcView. The original land cover map adapted from the ARBIDMPP was simplified to the major classes of land cover only by implementing the "dissolve" command. Using the suitability rating criteria explained in section 4.2.2.2, the land cover layer created.

Highly suitable class includes, grass land, cultivated land and bush land. Moderately suitable includes open wood land bush land and open forest land. Not suitable category includes irrigated land, state farm, dense wood land and urban areas as explained briefly in section [4.2.2.2.].

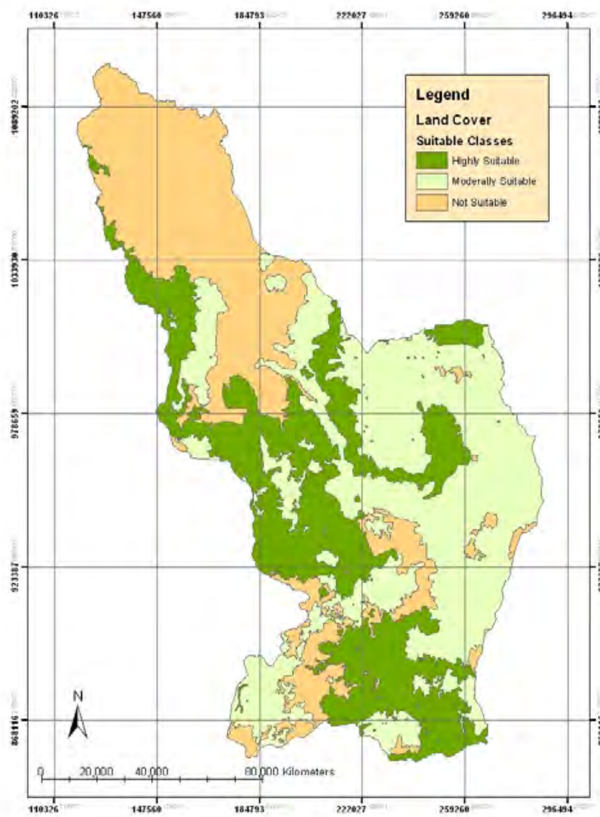


Figure 4.14: Suitable land for Irrigation from Land cover analysis

5. SUITABLE LAND FOR SURFACE IRRIGATION

The three layers slope, soil and land cover overlaid in order to find the suitable land. The slope layer was taken to be the base map for overlaying due to its being the most limiting factor in practicing surface irrigation agriculture. Following this procedure, suitable land for surface irrigation, which is totally in the Moderately Suitable class is obtained.

The general suitability analysis followed by this study work shown by the flow chart in [Fig 5.1

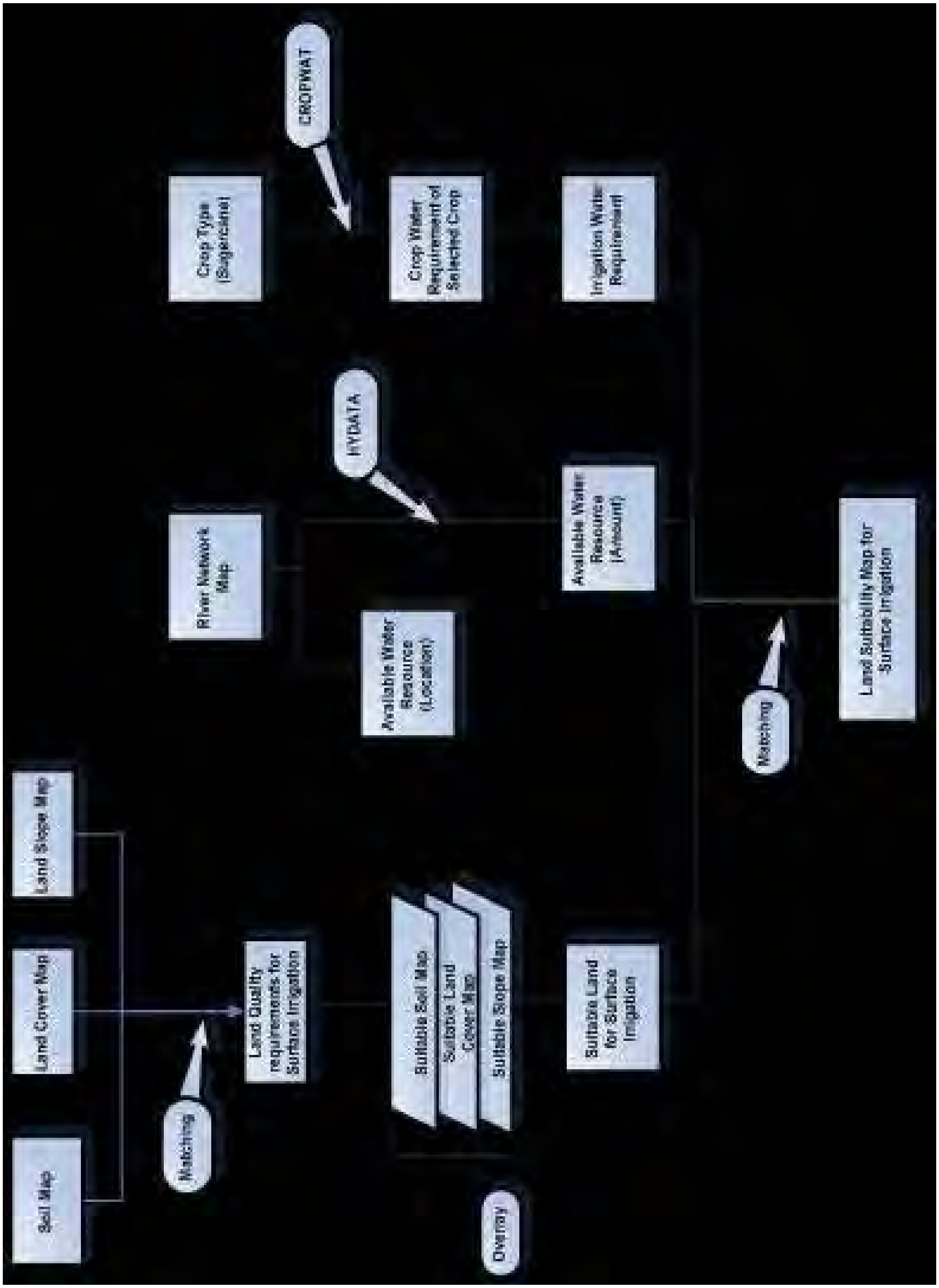


Figure 5.1: Flow chart of the total suitability analysis carried out.

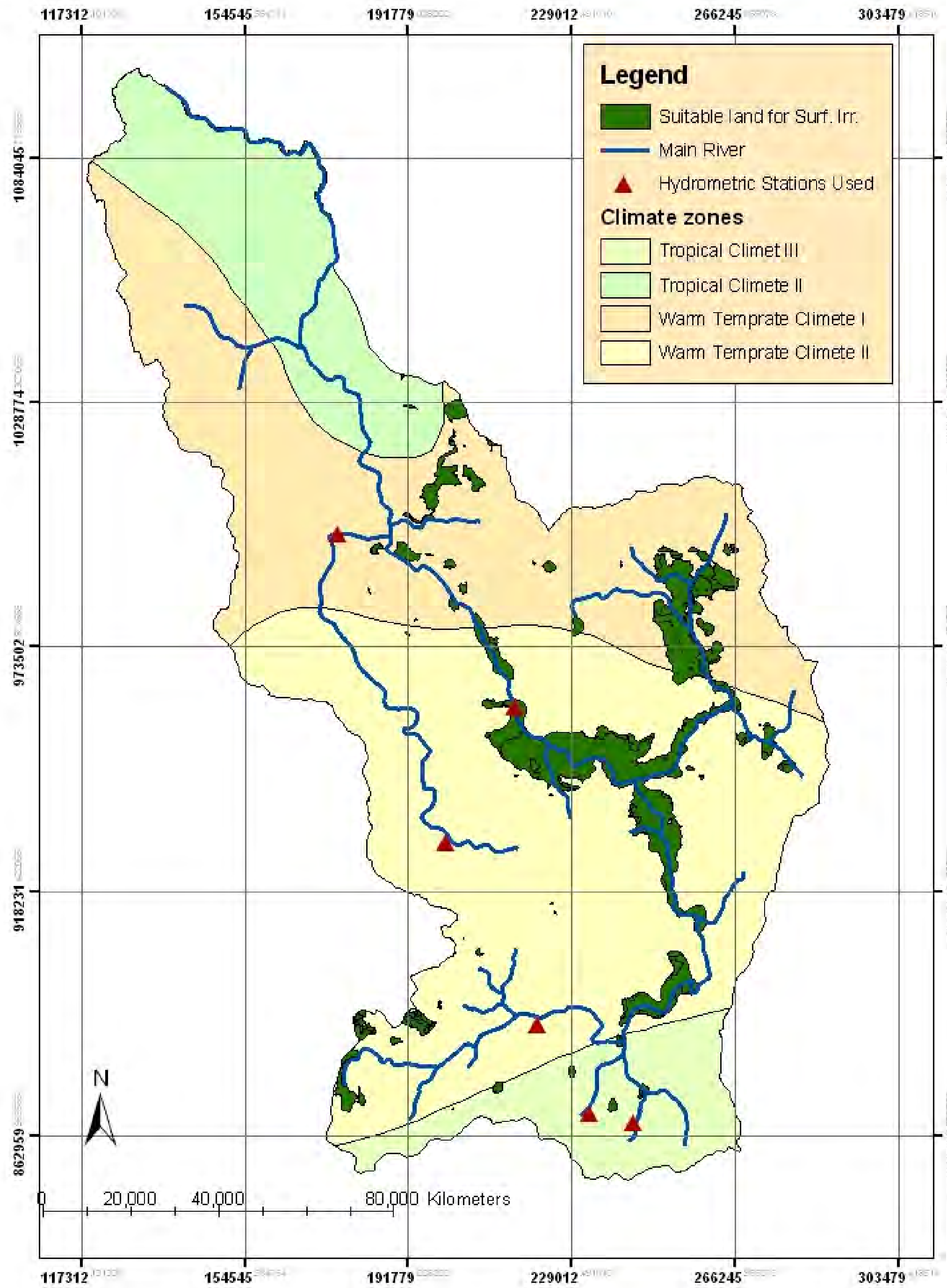


Figure 5.2: Suitable land for Surface Irrigation in Dedessa Sub-basin

Climatic Zone	**Total Area (ha)**	**Area suitable for Irrigation (ha)**
Tropical climate II	247,705	143
Warm Temperate Climate I	638,674	39,536
Warm Temperate Climate II	916,901	89,009
Tropical climate III	159,016	2,017
Total	1,962,296	**130,705**

Table 5.1: Suitable area for Irrigation identified in the Dedessa Sub-basin

The discharge data and the climatic data used for estimating low flow availability with different percentage of exceedence time and Evapotranspiration respectively, selected based on their nearness and being representative of the climatic zone.
Suitable areas in the Tropical Climate II zone is only 143ha even if it is highly suitable from the slope and soil point of view due to its dense wood land cover.

River	**Station Used**	**Climatic Zone**	**Irrigable Area (ha)**
Urgessa	Urgessa Nr. Gembe	Tropical climate III	910
Temssa	Temssa Nr. Agaro	Tropical climate III	1107
Dedessa	Dedessa Nr. Dembi	Warm Temperate Climate II	18,053
		Warm Temperate Climate I	28,820
Dedessa	Dedessa Nr. Arjo	Warm Temperate Climate II	70,956
Dabena	Dabena Nr. Abassina	Warm Temperate Climate I	10,716
Total			**130,562 (ha)**

Table 5.2: Hydrometric stations used for the evaluation of water resource availability

According to the Abbay River Basin Master Plan, total suitable land was estimated to be 617,400ha and the maximum potentially irrigable area reduced to 357,764ha for large scale irrigation agriculture being defined as contiguous areas of greater than 3000ha. This value is almost three times greater than the value found by this study work, which is 130,562ha.

The analyses in the Master Plan consider two parameters only; that is, it considered suitability only in terms of soil and slope. The analysis does no consider the availability of water or the cost of bringing water to the irrigable areas. A maximum slope of 6% was considered suitable for surface irrigation. It is almost certain that the 100m contour interval of the used topographic base map hides large areas of land with slopes greater or less than 6%. However the analysis gives useful insights at a macro level.

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The suitability analysis has been carried out for Dedessa sub-basin to evaluate and estimate irrigable land without considering the social, environmental and economical constraints as evaluation parameters. The evaluation of these constraints is very crucial for the overall suitability results that help in decision making for the implementation of irrigation agriculture.

The hydrological data collected from six stations in the basin were checked using double mass curve analysis for their good quality as the total water resource availability is highly dependent on these data. The missing data encountered filled using different correlation procedures between stations. Flow duration curve analysis was carried out using HYDATA software in order to estimate 95, 90, 85, and 80 percentage flow exceedence.

The suitability of the water resource evaluation focuses on the quantitative availability only, taking the quality being suitable. Because the main river, Dedessa and its tributaries, in the sub basin found in rainy part of the country the availability of water in ample amount is shown, but its nearness or accessibility and infrastructural availability identification needs detail site specific investigation.
The climatic data used for the estimation of crop water requirement collected from five different stations which represent each climatic zones of the basin. Apart from some specific procedures recommended by FAO for the estimation of missing climatic data, the same procedure applied to the hydrological data was carried out. The CROPWAT for Windows software used for the estimation of reference Evapotranspiration and crop water requirement.

The slope, soil, and land cover data layers are used for the GIS analysis. Each layer was categorized in to different class of suitability (Highly, Moderately, and Not suitable) using different criteria considering land qualities required by surface irrigation method from the slope, soil, and land cover aspect. After checking and correcting each layers for their accuracy and reliability the overlaying analysis procedure carried out using the GIS environment. The number of theme layers involved depends on the number of evaluation parameters which inter highly dependent on the degree of detailed information needed for the decision making. The ArcView 3.2 and ArcGIS softwares used in this study.

The implementation of the GIS technique reduces the time and cost of the general evaluation process by narrowing the investigation to areas that are already evaluated by the most limiting factor for irrigation agriculture practices. Further this approach help in gathering and using all information, which demanded economical investment of the country and done by different fields of specific and specialized data collection process through site investigation and data preparation.

Based on the analysis, irrigable land of 130,705ha, which is 6.65% of the total sub basin area, completely in moderately suitable sub-class of the suitable class was found. This suitable area can be further up graded to Highly Suitable sub-class or down graded to Not Suitable class by carrying out evaluations from the above mentioned parameters in addition to this physical resources evaluation only.

6.2 RECOMMENDATIONS

Based on the results of this study the following points are recommended for further consideration

- According to the analysis results the GIS model approach is recommended to be used for detailed planning.

- The water resource requirement and availability evaluation are carried out using hydro-meteorological dada that are not site specific. So it is recommended to reevaluate with independent set of data for better reliability.

- The reliability of the analysis results depends on the GIS data set used for the overlaying process. Recent data layers with the accuracy and smaller resolution results better reliability. So this can be improved by updating the GIS database using new technologies like remotely sensed images interpretation, when it is available.

- The irrigation water requirement is calculated using only one example crop approach. The result of this approach completely ignores detailed suitable crop identification for better yield based on the climatic and soil variation. Hence, it is recommended to select crop types that can be grown in each specific area for their demand of water resource.

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49- http://www.fao.org/icatalog/inter-e.htm
50- http://www.fao.org/landandwater/default.stm
51- http://www.gis.com/whatisgis/index.htm
52- http://www.gisdevelopment.net/tutorials/tuman006a.htm
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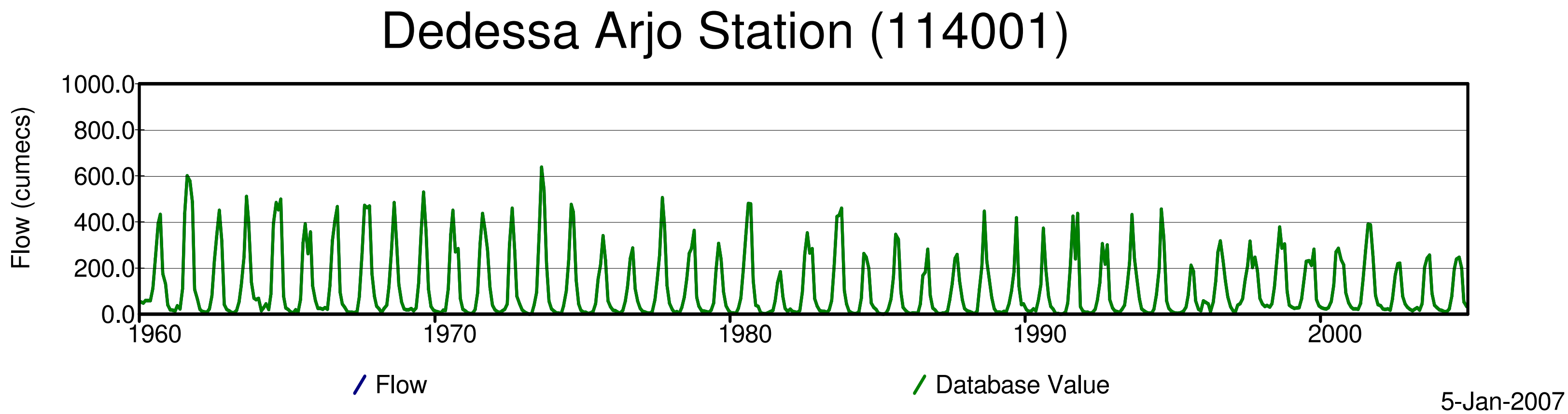
8. APPENDICES

APPENDIX A
(Hydrographs)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Flow (cumecs)
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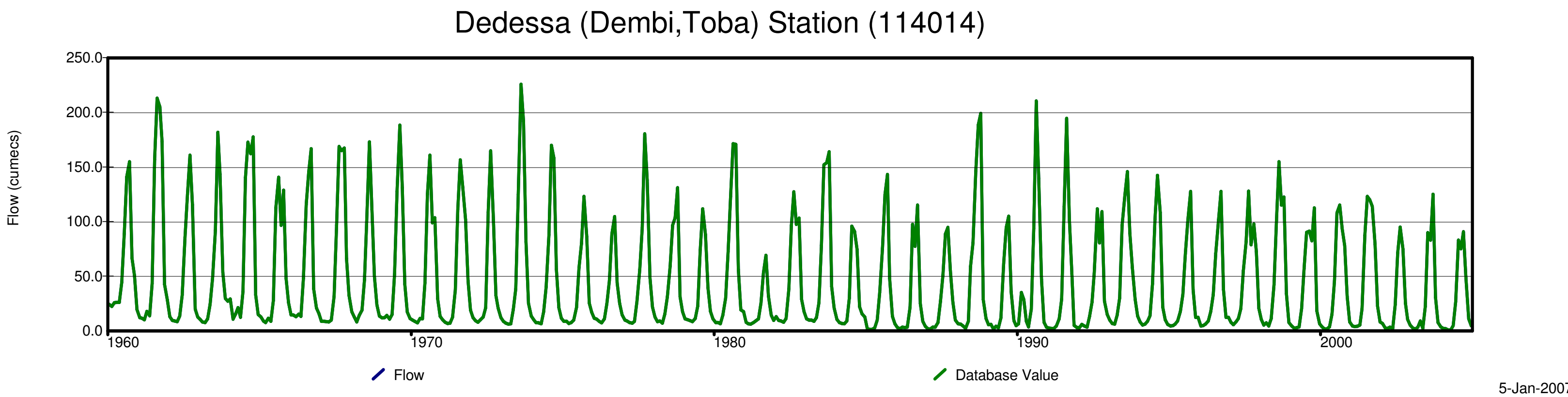
600.0
400.0
200.0
0.0
1960
1970
1980
1990
2000
Flow
Database Value
5-Jan-2007


Dedessa (Dembi,Toba) Station (114014)
Flow (cumecs)
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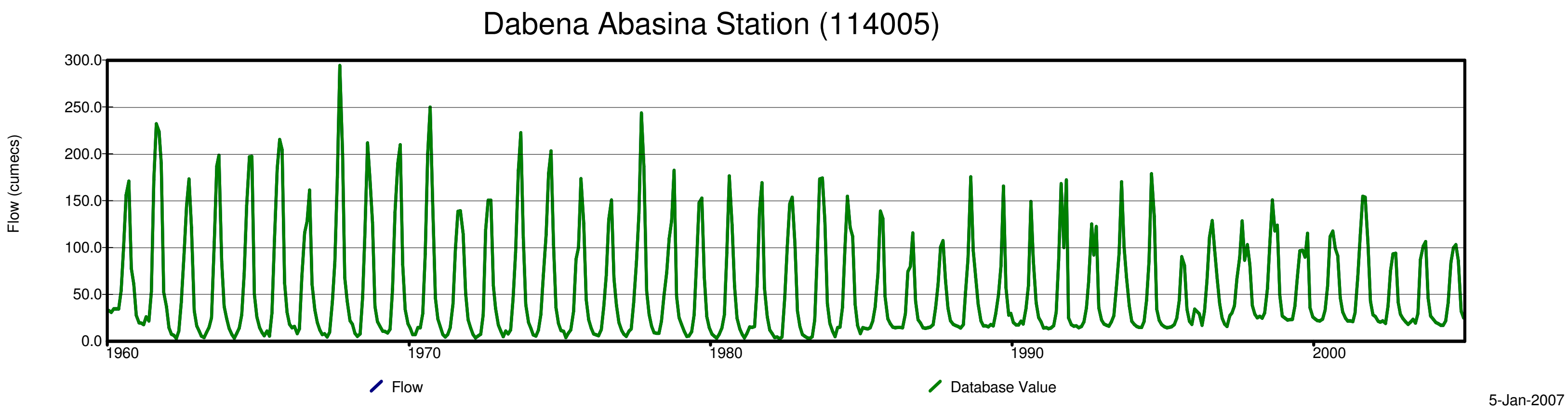
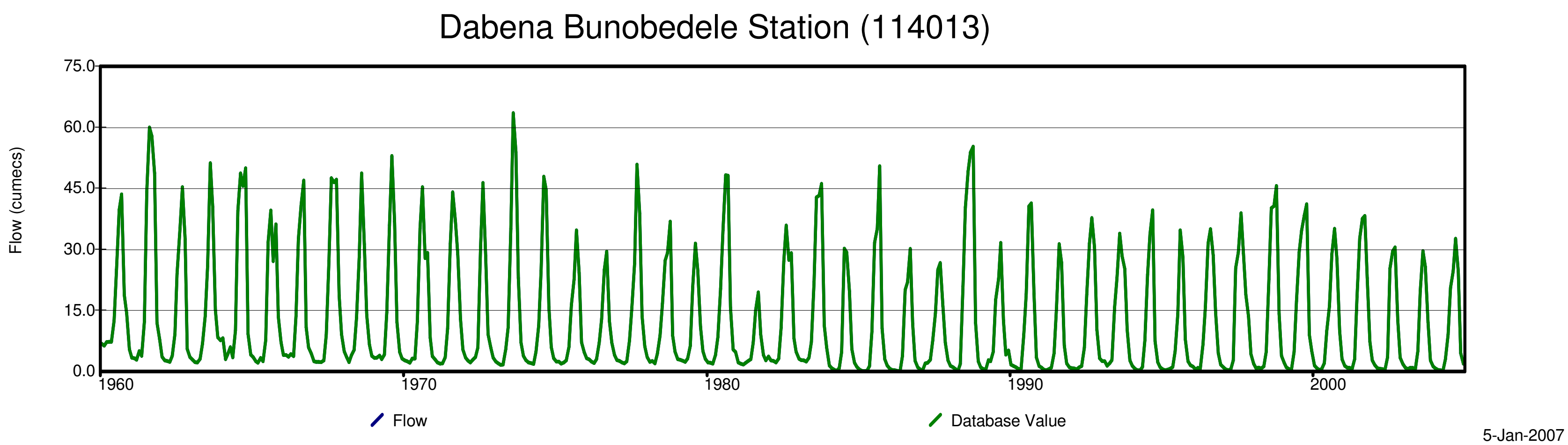
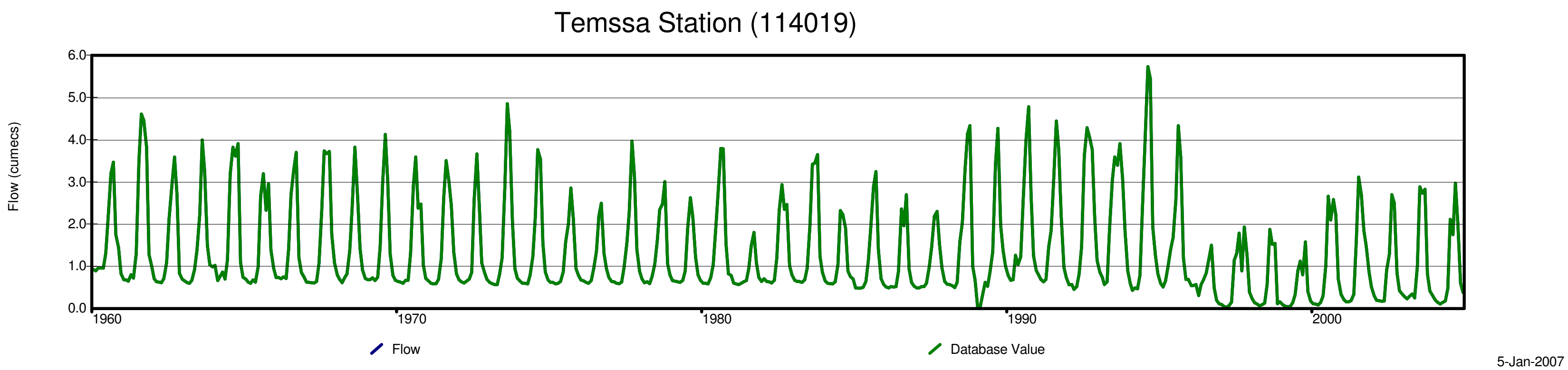
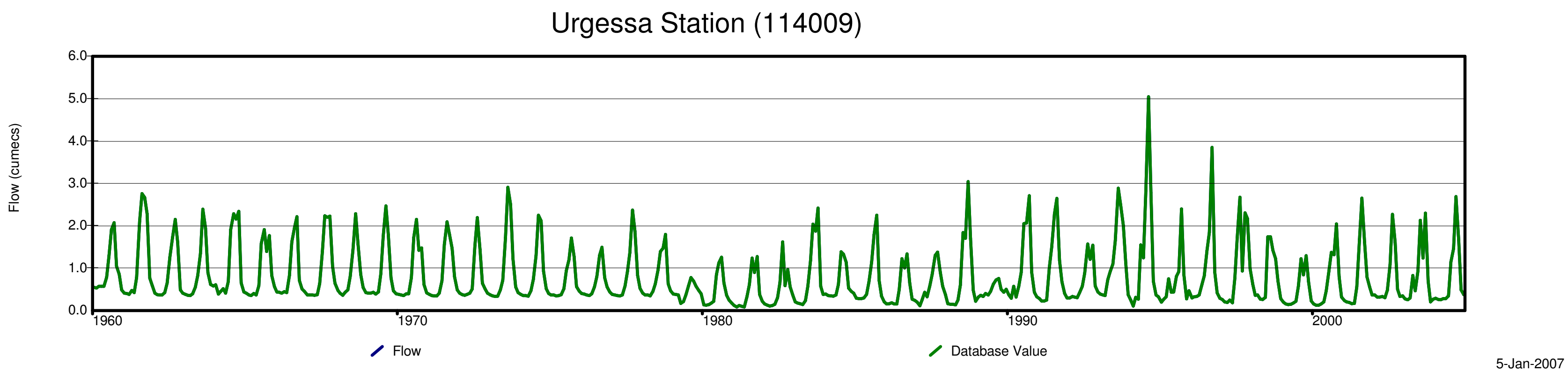
200.0
150.0
100.0
50.0
0.0
1960
1970
1980
1990
2000
Flow
Database Value
5-Jan-2007

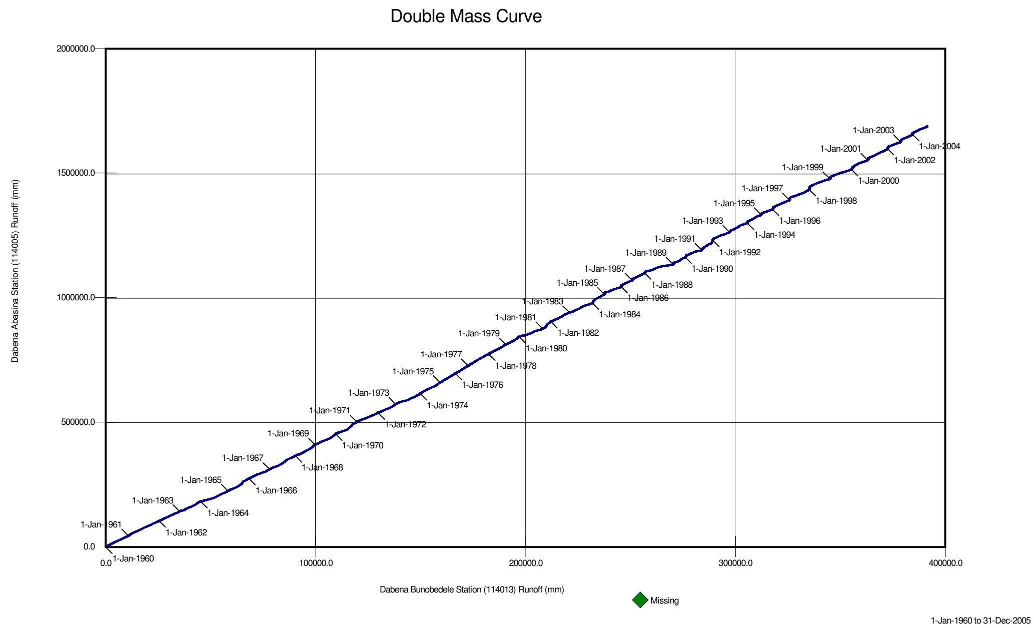

Dabena Abasina Station (114005)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Flow (cumecs)
1960
1970
1980
1990
2000
Flow
Database Value
5-Jan-2007

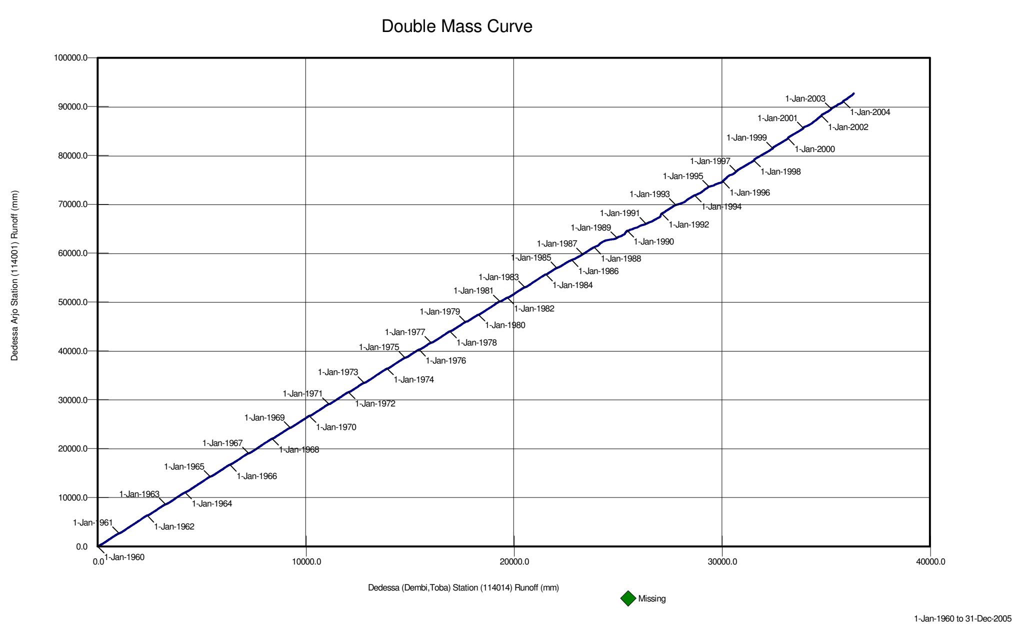

Dabena Bunobedele Station (114013)
75.0
60.0
45.0
30.0
15.0
0.0
Flow (cumecs)
1960
1970
1980
1990
2000
Flow
Database Value
5-Jan-2007

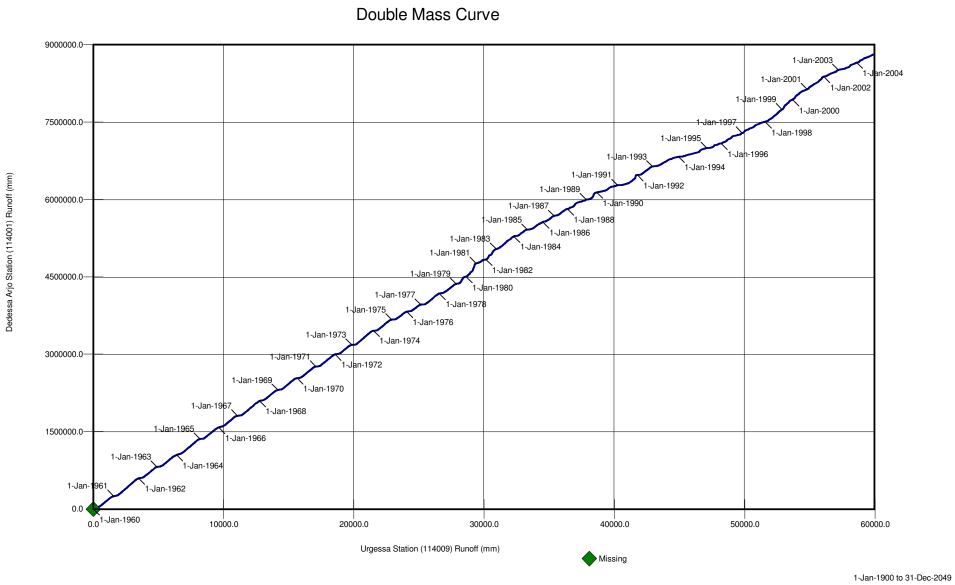

Temssa Station (114019)
Flow (cumecs)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1960
1970
1980
1990
2000
Flow
Database Value
5-Jan-2007

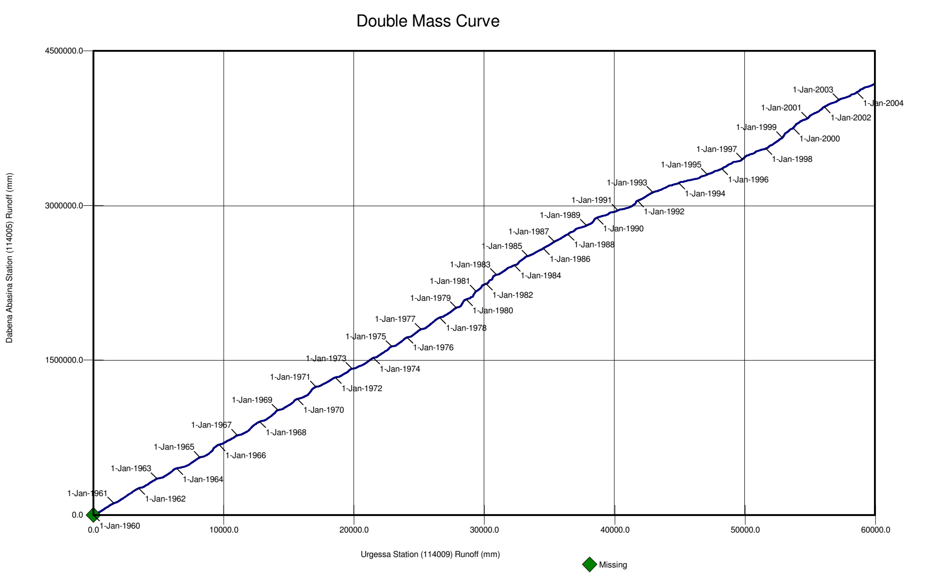

Urgessa Station (114009)
Flow (cumecs)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1960
1970
1980
1990
2000
Flow
Database Value
5-Jan-2007

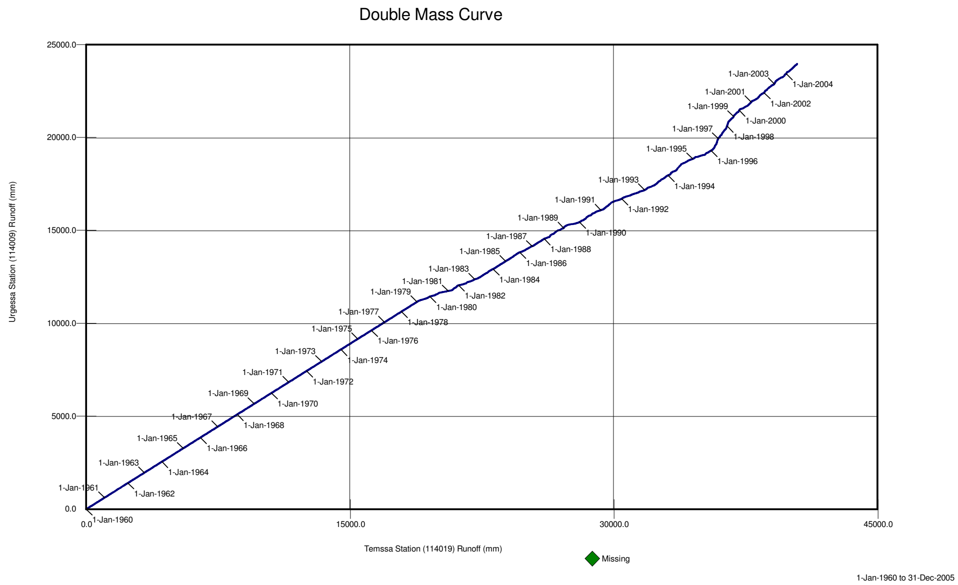
APPENDIX B
(Double Mass Curve Analysis)


Double Mass Curve
Dabena Abasina Station (114005) Runoff (mm)
Dabena Bunobedele Station (114013) Runoff (mm)
Missing
1-Jan-1960 to 31-Dec-2005


Double Mass Curve
Dedessa Arjo Station (114001) Runoff (mm)
Dedessa (Dembi,Toba) Station (114014) Runoff (mm)
Missing
1-Jan-1960 to 31-Dec-2005


Double Mass Curve
Dedessa Arjo Station (114001) Runoff (mm)
9000000.0
7500000.0
6000000.0
4500000.0
3000000.0
1500000.0
0.0
0.0
10000.0
20000.0
30000.0
40000.0
50000.0
60000.0
Urgessa Station (114009) Runoff (mm)
Missing
1-Jan-1900 to 31-Dec-2049


Double Mass Curve
Dabena Abasina Station (114005) Runoff (mm)
4500000.0
3000000.0
1500000.0
0.0
0.0
10000.0
20000.0
30000.0
40000.0
50000.0
60000.0
Urgessa Station (114009) Runoff (mm)
Missing
1-Jan-1900 to 31-Dec-2049


Double Mass Curve
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
Urgessa Station (114009) Runoff (mm)
0.0
15000.0
30000.0
45000.0
Temssa Station (114019) Runoff (mm)
Missing
1-Jan-1960 to 31-Dec-2005
1-Jan-1960
1-Jan-1961
1-Jan-1962
1-Jan-1963
1-Jan-1964
1-Jan-1965
1-Jan-1966
1-Jan-1967
1-Jan-1968
1-Jan-1969
1-Jan-1970
1-Jan-1971
1-Jan-1972
1-Jan-1973
1-Jan-1974
1-Jan-1975
1-Jan-1976
1-Jan-1977
1-Jan-1978
1-Jan-1979
1-Jan-1980
1-Jan-1981
1-Jan-1982
1-Jan-1983
1-Jan-1984
1-Jan-1985
1-Jan-1986
1-Jan-1987
1-Jan-1988
1-Jan-1989
1-Jan-1990
1-Jan-1991
1-Jan-1992
1-Jan-1993
1-Jan-1994
1-Jan-1995
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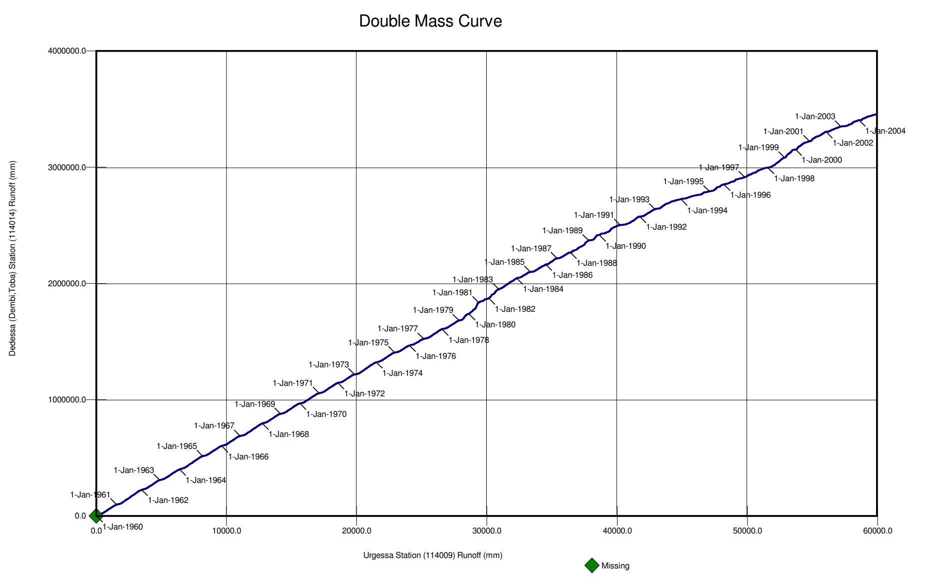
1-Jan-2000
1-Jan-2001
1-Jan-2002
1-Jan-2003
1-Jan-2004


Double Mass Curve
4000000.0
3000000.0
2000000.0
1000000.0
0.0
Dedessa (Dembi,Toba) Station (114014) Runoff (mm)
0.0
10000.0
20000.0
30000.0
40000.0
50000.0
60000.0
Urgessa Station (114009) Runoff (mm)
Missing
1-Jan-1900 to 31-Dec-2049
1-Jan-1960
1-Jan-1961
1-Jan-1962
1-Jan-1963
1-Jan-1964
1-Jan-1965
1-Jan-1966
1-Jan-1967
1-Jan-1968
1-Jan-1969
1-Jan-1970
1-Jan-1971
1-Jan-1972
1-Jan-1973
1-Jan-1974
1-Jan-1975
1-Jan-1976
1-Jan-1977
1-Jan-1978
1-Jan-1979
1-Jan-1980
1-Jan-1981
1-Jan-1982
1-Jan-1983
1-Jan-1984
1-Jan-1985
1-Jan-1986
1-Jan-1987
1-Jan-1988
1-Jan-1989
1-Jan-1990
1-Jan-1991
1-Jan-1992
1-Jan-1993
1-Jan-1994
1-Jan-1995
1-Jan-1996
1-Jan-1997
1-Jan-1998
1-Jan-1999
1-Jan-2000
1-Jan-2001
1-Jan-2002
1-Jan-2003
1-Jan-2004

APPENDIX C
(Flow Duration Curves and Tables)

FLOW DURATION TABLE

Station Number:	114005
Name:	Dabena Abasina Station (114005)
Time-Series:	Mean Daily Flow

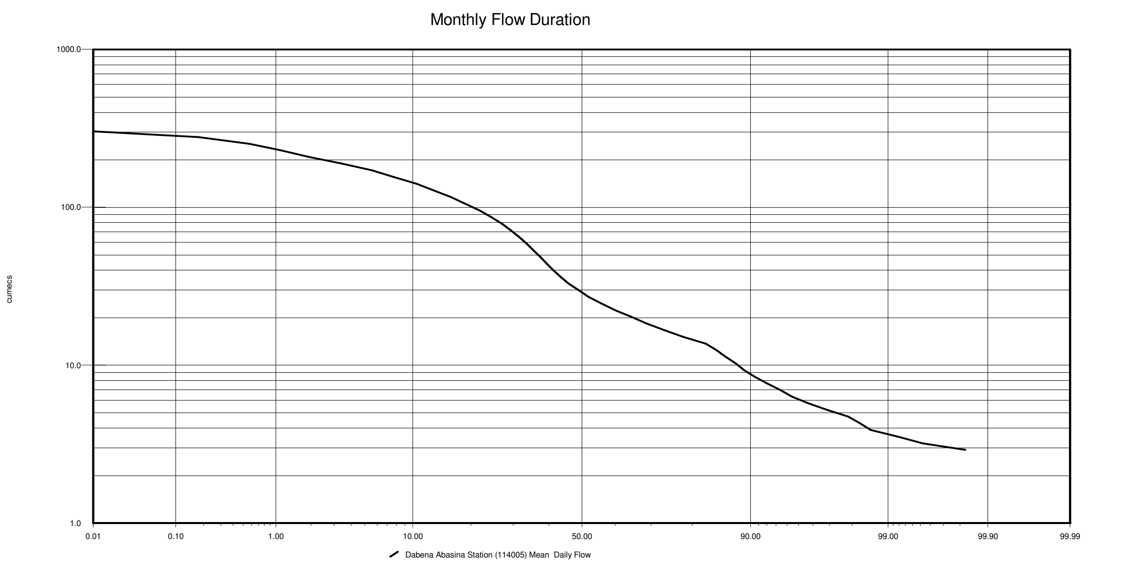
Period of analysis from: 1-Jan-1960 to 31-Dec-2004
Seasonal flow duration analysis from Jan to Dec

Time interval (days) = 30 Intervals in period = 16408
Intervals with data 16408
Intervals missing or out of season 0

Mean daily flow 55.915

95 percentile (Q95)	6.074
90 percentile (Q90)	8.793
85 percentile (Q85)	12.237
80 percentile (Q80)	14.554
75 percentile (Q75)	16.2
50 percentile (Q50)	29.016
25 percentile (Q25)	85.394

Percentiles in cumecs



FLOW DURATION TABLE

Station Number:	114013
Name:	Dabena Bunobedele Station (114013)
Time-Series:	Mean Daily Flow

Period of analysis from: 1-Jan-1960 to 31-Dec-2004
Seasonal flow duration analysis from Jan to Dec

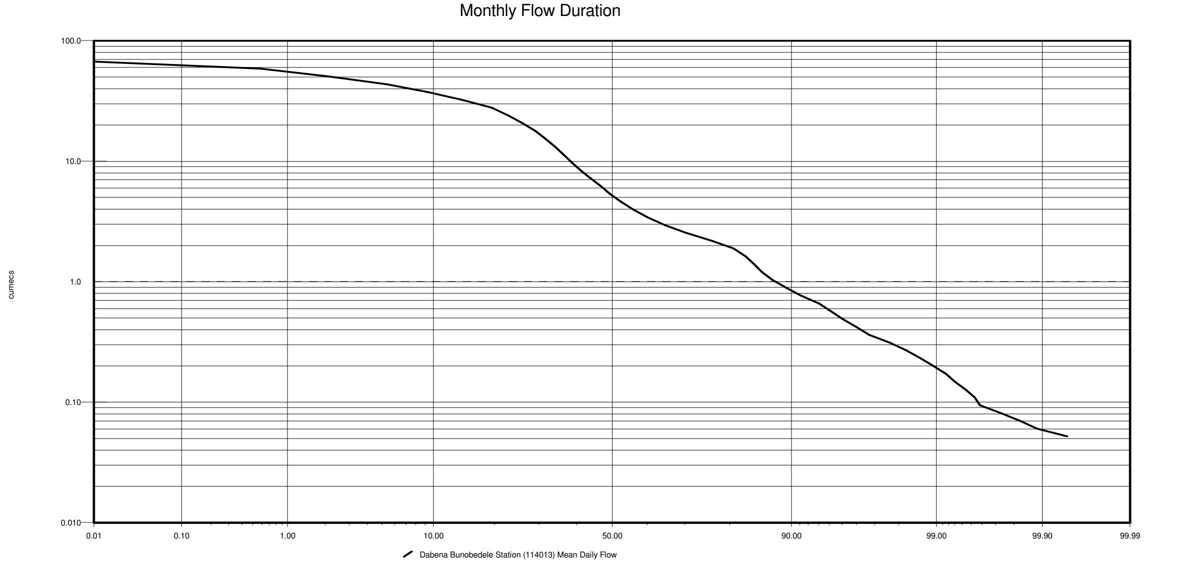
Time interval (days) = 30   Intervals in period = 16408

Intervals with data	16408
Intervals missing or out of season	0
Mean daily flow	12.944

95 percentile (Q95)	0.491
90 percentile (Q90)	0.846
85 percentile (Q85)	1.324
80 percentile (Q80)	1.933
75 percentile (Q75)	2.258
50 percentile (Q50)	5.198
25 percentile (Q25)	21.658

Percentiles in cumecs

Monthly Flow Duration



FLOW DURATION TABLE

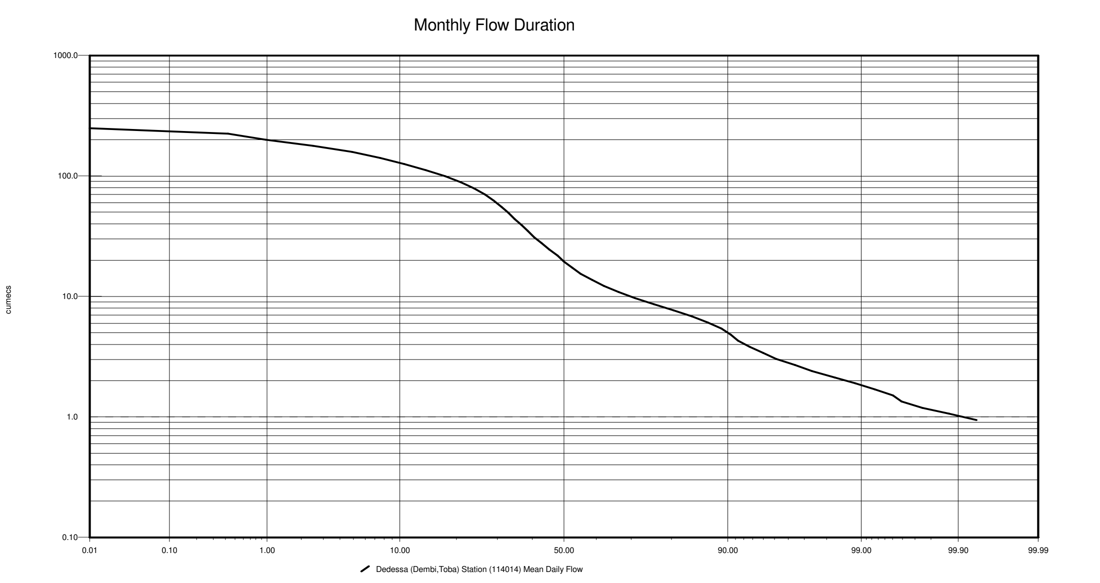
Station Number:	114014
Name:	Dedessa (Dembi,Toba) Station (114014)
Time-Series:	Mean Daily Flow

Period of analysis from: 1-Jan-1960 to 31-Dec-2004
Seasonal flow duration analysis from Jan to Dec

Time interval (days) = 30	Intervals in period = 16408
Intervals with data	16408
Intervals missing or out of season	0
Mean daily flow	46.218

95 percentile (Q95)	3.066
90 percentile (Q90)	4.995
85 percentile (Q85)	6.612
80 percentile (Q80)	7.767
75 percentile (Q75)	8.836
50 percentile (Q50)	19.518
25 percentile (Q25)	75.663

Percentiles in cumecs



FLOW DURATION TABLE

Station Number: 114001

Name: Dedessa Arjo Station (114001)

Time-Series: Mean Daily Flow

Period of analysis from: 1-Jan-1960 to 31-Dec-2004

Seasonal flow duration analysis from Jan to Dec

Time interval (days) = 30 Intervals in period = 16408

Intervals with data 16408

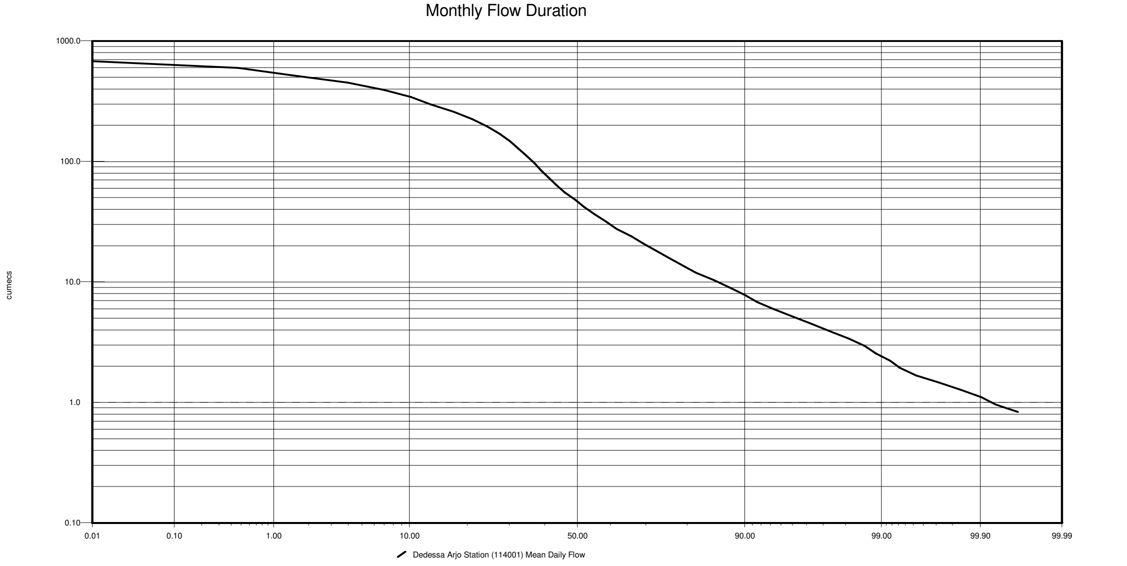
Intervals missing or out of season 0

Mean daily flow 117.898

95 percentile (Q95)	5.171
90 percentile (Q90)	7.788
85 percentile (Q85)	10.416
80 percentile (Q80)	13.027
75 percentile (Q75)	16.521
50 percentile (Q50)	46.574
25 percentile (Q25)	190.79

Percentiles in cumecs

Monthly Flow Duration



FLOW DURATION TABLE
Station Number: 114019
Name: Temssa Station (114019)
Time-Series: Mean Daily Flow

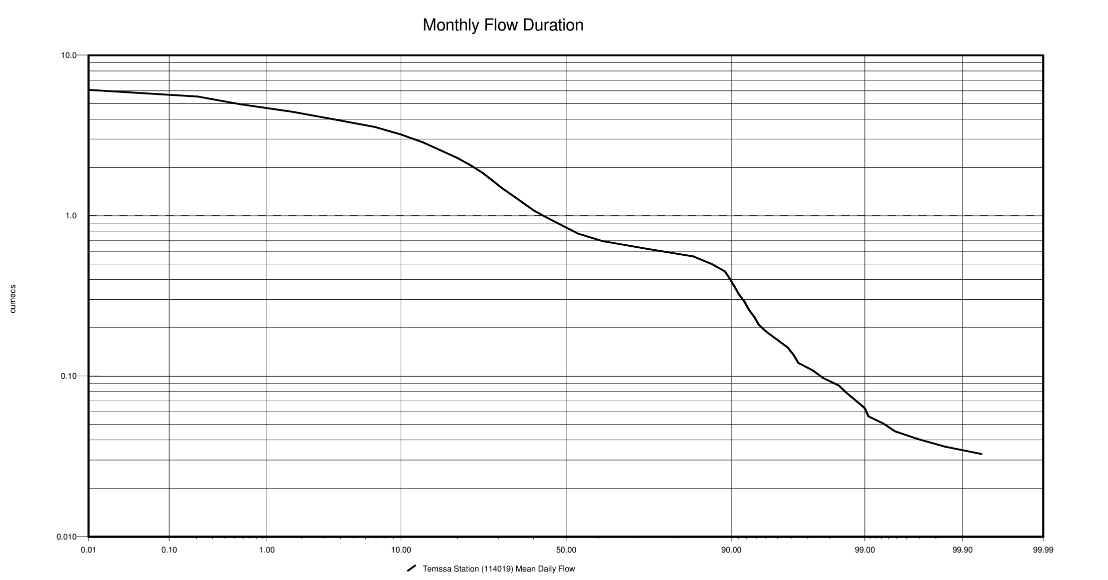
Period of analysis from: 1-Jan-1960 to 31-Dec-2004
Seasonal flow duration analysis from Jan to Dec

Time interval (days) = 30 Intervals in period = 16408
Intervals with data 16408
Intervals missing or out of season 0

Mean daily flow 1.352

95 percentile (Q95)	0.168
90 percentile (Q90)	0.392
85 percentile (Q85)	0.538
80 percentile (Q80)	0.582
75 percentile (Q75)	0.613
50 percentile (Q50)	0.844
25 percentile (Q25)	1.904

Percentiles in cumecs



FLOW DURATION TABLE
Station Number: 114009
Name: Urgessa Station (114009)
Time-Series: Mean Daily Flow

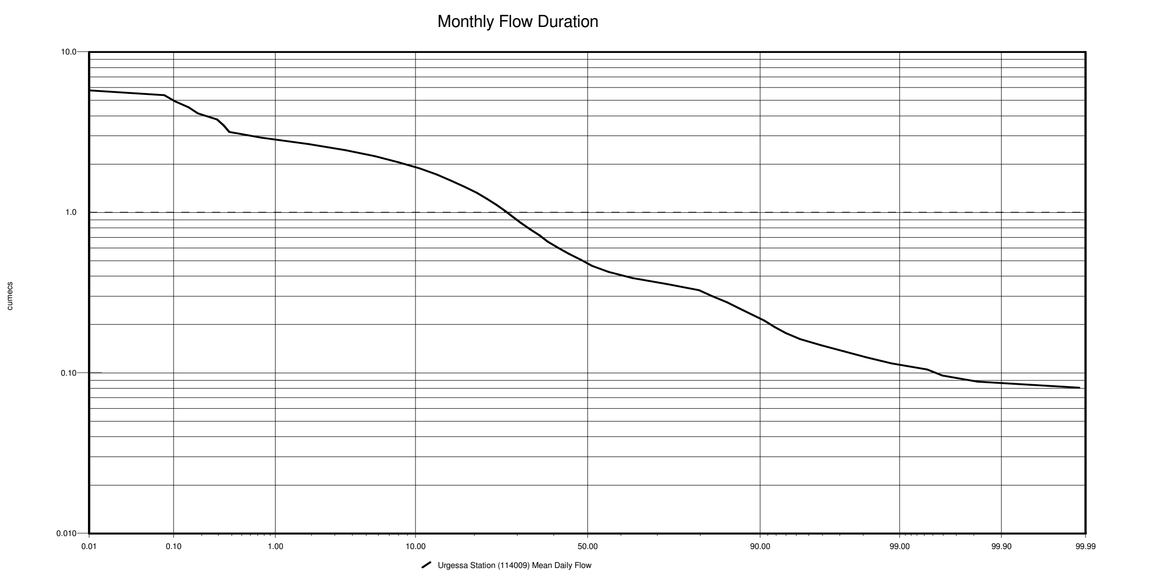
Period of analysis from: 1-Jan-1960 to 31-Dec-2004
Seasonal flow duration analysis from Jan to Dec

Time interval (days) = 30 Intervals in period = 16408
Intervals with data 16408
Intervals missing or out of season 0

Mean daily flow 0.802

95 percentile (Q95)	0.157
90 percentile (Q90)	0.219
85 percentile (Q85)	0.275
80 percentile (Q80)	0.324
75 percentile (Q75)	0.347
50 percentile (Q50)	0.482
25 percentile (Q25)	1.105

Percentiles in cumecs



APPENDIX D
(Climatic Data and Estimated ETo)

Country : Ethiopia Station : Jimma
Altitude: 1725 meter(s) above M.S.L.
Latitude: 7.40 Deg. (North) Longitude: 36.50 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	Eto (mm/d)
Jan	28.7	9.2	50.7	25.9	8.5	20.4	3.33
Feb	30.9	8.6	39.6	25.9	8.9	22.2	3.67
Mar	30.4	12.2	47.6	34.6	7.9	21.6	3.98
Apr	29.5	13.2	52.9	25.9	7.4	20.9	3.83
May	28.6	13.6	60.1	25.9	7.7	20.7	3.77
Jun	26.4	13.7	65	51.8	6.1	17.9	3.45
Jul	25	13.8	70.3	25.9	4.9	16.3	3.02
Aug	25.4	14	69.7	25.9	5.1	17	3.18
Sep	26.8	13.7	65.7	25.9	6.7	19.9	3.58
Oct	27.3	12.4	60.5	25.9	7.6	20.4	3.58
Nov	27.9	9.2	49.4	17.3	8	19.9	3.16
Dec	27.9	9.2	46.4	17.3	9.4	21.2	3.18
Average	27.9	11.9	56.5	27.4	7.4	19.87	3.48

Country : Ethiopia Station : Nekemt
Altitude: 2080 meter(s) above M.S.L.
Latitude: 9.05 Deg. (North) Longitude: 36.27 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	Eto (mm/d)
Jan	26	12.2	43.3	67.4	7.9	19.2	3.53
Feb	28.1	3.5	35	0.8	8.4	21.1	2.94
Mar	27.8	14.3	42.5	70	8	21.6	4.27
Apr	26.9	14.6	48.7	76	7.6	21.3	4.27
May	24.9	13.9	61.8	80.4	7	19.8	3.87
Jun	22.1	12.8	77	64.8	6	17.9	3.24
Jul	20.8	12.6	83.2	0.7	5.2	16.9	2.92
Aug	21.1	12.7	83	0.8	5.2	17.3	3.01
Sep	22.7	12.8	77.8	68.3	6.1	18.7	3.4
Oct	23.7	12.9	65.6	56.2	6.5	18.6	3.38
Nov	24.5	12.6	55.7	56.6	6.9	18	3.27
Dec	25.1	11.3	49.9	0.7	7.8	18.5	2.7
Average	24.5	12.2	60.3	45.2	6.9	19.1	3.4

Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients: a = 0.25 b = 0.5

Country : Ethiopia Station : Dongoro
Altitude: 1900 meter(s) above M.S.L.
Latitude: 9.12 Deg. (North) Longitude: 35.44 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	Eto (mm/d)
Jan	28.1	12.1	54	72.6	9	20.7	3.83
Feb	30.3	13.7	53	71.7	9.4	22.6	4.39
Mar	30.3	14.9	56	69.1	9	23.2	4.61
Apr	29.6	15.4	59	70	8.6	22.8	4.58
May	27.3	14.7	63	74.3	7.9	21.2	4.17
Jun	24.1	14	69	76.9	6.5	18.7	3.57
Jul	22.8	13.9	73	69.1	5.6	17.5	3.28
Aug	23.2	13.8	71	71.7	5.9	18.3	3.46
Sep	24.2	13.6	68	69.1	6.5	19.3	3.46
Oct	24.2	13.4	67	128.7	6.7	18.9	3.8
Nov	24.5	12.9	63	60.5	7.3	18.5	3.36
Dec	50.1	12.4	58	72.6	8.1	18.9	4.89
Average	28.2	13.7	63	75.5	7.5	20.1	3.95

Country : Ethiopia Station : Bedelle
Altitude: 2030 meter(s) above M.S.L.
Latitude: 8.27 Deg. (North) Longitude: 36.17 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	Eto (mm/d)
Jan	27.3	12.5	46.1	34.6	8.1	19.6	3.33
Feb	29.5	13	41	43.2	8.6	21.6	3.89
Mar	28.6	14.1	49.8	51.8	7.7	21.2	4.09
Apr	28.4	14.5	51.8	60.5	7.6	21.2	4.21
May	26.5	13.8	59.8	51.8	7.7	20.8	3.91
Jun	24	13.1	70.7	43.2	6.1	18	3.3
Jul	22.4	13.1	78.4	43.2	4.4	15.6	2.89
Aug	22.8	13	76.8	43.2	4.5	16.2	3.01
Sep	24.3	12.8	72.5	43.2	6.1	18.7	3.43
Oct	24.9	12.3	64	43.2	7.6	20.3	3.58
Nov	25.7	11.7	56.7	34.6	8.2	20	3.35
Dec	26.6	11.5	51.6	34.6	8.4	19.6	3.23
Average	25.9	13.0	59.9	43.9	7.1	19.4	3.52

Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients: a = 0.25 b = 0.5

Country : Ethiopia Station : Dedessa
Altitude: 1200 meter(s) above M.S.L.
Latitude: 9.23 Deg. (North) Longitude: 36.06 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	Eto (mm/d)
Jan	32.6	12.4	53	61.3	10.8	23.2	4.25
Feb	35.1	12.5	42	80.4	11.5	25.7	5.12
Mar	34.5	15.4	50	98.5	10.7	25.8	5.58
Apr	34.1	16.5	50	1.2	10.3	25.4	4.47
May	31.5	16.5	62	99.4	9.2	23.1	4.96
Jun	28.4	16.3	66	82.1	7.7	20.4	4.15
Jul	27	16.3	71	60.5	6.8	19.2	3.74
Aug	27.1	16.4	71	57	6.8	19.7	3.82
Sep	28.9	16	67	0.6	7.9	21.4	3.78
Oct	29.7	15.2	62	49.2	8.5	21.5	4.05
Nov	30.9	13.2	51	46.7	9.7	21.9	3.88
Dec	31.9	12.1	49	0.6	10.5	22.2	3.18
Average	31.0	14.9	58	53.1	9.2	22.5	4.25

APPENDIX E
(Irrigation Water Requirement)

Sugarcane Station : Bedelle
Planting date 1-Jan
Calculation time step = 30 Days
Irrigation Efficiency = 80%

Date	ETo (mm/period)	Area (%)	Crop Kc	ETm (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)
1-Jan	109.64	100	0.4	43.86	0.04	0.04	43.82	0.21
31-Jan	118.47	100	0.62	73.61	14.29	14.29	59.31	0.29
2-Mar	120.88	100	1.04	126.24	70.84	56.8	69.45	0.33
1-Apr	117.48	100	1.25	146.85	150.71	93.44	53.41	0.26
1-May	110.64	100	1.25	138.3	231.4	128.96	9.34	0.05
31-May	103.23	100	1.25	129.03	291.32	155.33	0	0
30-Jun	97.63	100	1.25	122.04	315.21	166.55	0	0
30-Jul	95.21	100	1.25	119.01	297.38	160.09	0	0
29-Aug	95.99	100	1.25	119.98	242.85	137.31	0	0
28-Sep	98.79	100	1.17	115.38	166.13	103.25	12.13	0.06
28-Oct	101.63	100	1.01	102.67	87.96	65.64	37.03	0.18
27-Nov	102.56	100	0.85	87.45	29.71	28.98	58.47	0.28
27-Dec	16.98	100	0.76	12.91	1.61	1.61	11.31	0.33
Total	1289.13			1337.35	1899.44	1112.27	354.28	[0.14]

ETo data is distributed using polynomial curve fitting.
Rainfall data is distributed using polynomial curve fitting.

Crop Sugarcane Station : Dedessa
Planting date 1-Jan
Calculation time step = 30 Days
Irrigation Efficiency = 80%

Date	ETo (mm/period)	Area (%)	Crop Kc	ETm (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)
1-Jan	129.82	100	0.4	51.93	0	0	51.93	0.25
31-Jan	146.78	100	0.62	91.37	2.63	2.4	88.97	0.43
2-Mar	153.5	100	1.04	160.39	15.81	15.81	144.58	0.7
1-Apr	150.55	100	1.25	188.19	75.87	64.78	123.41	0.6
1-May	141.14	100	1.25	176.43	161.06	110.22	66.21	0.32
31-May	129.34	100	1.25	161.68	232.74	139.39	22.28	0.11
30-Jun	118.83	100	1.25	148.54	268.75	153.01	0	0
30-Jul	112.06	100	1.25	140.07	259.87	152.93	0	0
29-Aug	109.82	100	1.25	137.28	208.2	135.9	1.38	0.01
28-Sep	111.32	100	1.17	130.03	127.59	96.86	33.18	0.16
28-Oct	114.61	100	1.01	115.77	45.93	41.58	74.18	0.36
27-Nov	117.48	100	0.85	100.14	3.02	3.02	97.11	0.47
27-Dec	19.75	100	0.76	15.02	0	0	15.02	0.43
Total	1555			1616.83	1401.48	915.91	718.25	[0.28]

ETo data is distributed using polynomial curve fitting.
Rainfall data is distributed using polynomial curve fitting.

Crop Sugarcane Station : Jimma
Planting date 1-Jan
Calculation time step = 30 Days
Irrigation Efficiency = 80%

Date	ETo (mm/period)	Area (%)	Crop Kc	ETm (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)
1-Jan	105.37	100	0.4	42.15	28.27	28.27	13.88	0.07
31-Jan	111.9	100	0.62	69.49	46.37	44.04	25.46	0.12
2-Mar	114.3	100	1.04	119.4	83.39	67.78	51.63	0.25
1-Apr	112.86	100	1.25	141.07	130.34	95.98	45.1	0.22
1-May	109.01	100	1.25	136.26	175.37	122.39	13.87	0.07
31-May	104.51	100	1.25	130.64	207.49	141	0	0
30-Jun	100.86	100	1.25	126.07	219.14	147.7	0	0
30-Jul	98.9	100	1.25	123.63	207.78	141.12	0	0
29-Aug	98.71	100	1.25	123.39	176.34	122.85	0.54	0
28-Sep	99.61	100	1.17	116.37	132.64	97.18	19.2	0.09
28-Oct	100.5	100	1.01	101.55	87.74	70.23	31.33	0.15
27-Nov	100.33	100	0.85	85.56	53.2	48.6	36.96	0.18
27-Dec	16.6	100	0.76	12.63	6.76	6.68	5.94	0.17
Total	1273.46			1328.22	1554.82	1133.79	243.9	[0.10]

ETo data is distributed using polynomial curve fitting.
Rainfall data is distributed using polynomial curve fitting.

Crop Sugarcane Station : Nekemt
Planting date 1-Jan
Calculation time step = 30 Days
Irrigation Efficiency = 80%

Date	ETo	Area	Crop Kc	ETm	Total Rain	Effect. Rain	Net Irrigation Req.	Field Water Supply
	(mm/period)	(%)		(mm/period)	(mm/period)	(mm/period)	(mm/period)	(l/s/ha)
1-Jan	99.33	100	0.4	39.73	2.25	2	37.74	0.18
31-Jan	110.75	100	0.62	68.93	4.92	4.23	64.7	0.31
2-Mar	116.4	100	1.04	121.67	40.32	40.32	81.36	0.39
1-Apr	116.15	100	1.25	145.19	121.7	96.63	48.56	0.23
1-May	111.61	100	1.25	139.51	241.5	133.96	5.55	0.03
31-May	105.06	100	1.25	131.33	348.74	155.42	0	0
30-Jun	98.73	100	1.25	123.42	399.02	164.95	0	0
30-Jul	94.26	100	1.25	117.83	372.47	164.19	0	0
29-Aug	92.42	100	1.25	115.52	280.42	149.32	0	0
28-Sep	93.05	100	1.17	108.7	160.89	114.27	0	0
28-Oct	95.26	100	1.01	96.22	62.82	59.74	36.49	0.18
27-Nov	97.84	100	0.85	83.39	19.03	12.14	71.25	0.34
27-Dec	16.53	100	0.76	12.57	2.33	1.05	11.52	0.33
Total	1247.4			1304.02	2056.4	1098.22	357.16	[0.14]

ETo data is distributed using polynomial curve fitting.
Rainfall data is distributed using polynomial curve fitting.

Crop Sugarcane Station : Dongoro
Planting date 1-Jan
Calculation time step = 30 Days
Irrigation Efficiency = 80%

Date	ETo (mm/period)	Area (%)	Crop Kc	ETm (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)
1-Jan	136.71	100	0.4	54.69	0	0	54.69	0.26
31-Jan	135.92	100	0.62	84.14	1.77	1.49	82.66	0.4
2-Mar	132.39	100	1.04	138.12	15.69	15.69	122.43	0.59
1-Apr	126.35	100	1.25	157.94	88.06	72.05	85.89	0.41
1-May	119.06	100	1.25	148.82	204.63	126.31	22.51	0.11
31-May	112.14	100	1.25	140.17	303.97	155.58	0	0
30-Jun	107.11	100	1.25	133.88	346.23	159.06	0	0
30-Jul	105.02	100	1.25	131.27	330.65	153.37	0	0
29-Aug	106.22	100	1.25	132.77	278.11	150.06	0	0
28-Sep	110.23	100	1.17	128.72	178.58	118.53	10.19	0.05
28-Oct	115.79	100	1.01	116.94	14.75	12.11	104.83	0.51
27-Nov	121.02	100	0.85	103.13	0	0	103.13	0.5
27-Dec	20.53	100	0.76	15.61	0	0	15.61	0.45
Total	1448.49			1486.21	1762.45	964.25	601.93	[0.24]

ETo data is distributed using polynomial curve fitting.
Rainfall data is distributed using polynomial curve fitting.

APPENDIX F
(Irrigable Area)

Climatic Zone: Tropical climate III
River: Urgessa
Hydrology Station used: Urgessa Nr. Gembe
Meteorological Station used: Jimma
Suitable area for Irrigation: 910ha
Total area: 159016ha

Month	Net Irrigation Req. (mm/month)	Field Water Supply (l/s/ha)	Irr.Req over total area (m^3/s)	Area Irrigable (ha) with ---Percent exceedence flow 80% $0.32m^3/s$	85% $0.28m^3/s$	90% $0.22m^3/s$	95% $0.16m^3/s$
1-Jan	13.88	0.07	0.06	4571	4000	3143	2286
31-Jan	25.46	0.12	0.11	2667	2333	1833	1333
2-Mar	51.63	0.25	0.23	1280	1120	880	640
1-Apr	45.1	0.22	0.20	1455	1273	1000	727
1-May	13.87	0.07	0.06	4571	4000	3143	2286
31-May	0	0	0.00				
30-Jun	0	0	0.00				
30-Jul	0	0	0.00				
29-Aug	0.54	0	0.00				
28-Sep	19.2	0.09	0.08	3556	3111	2444	1778
28-Oct	31.33	0.15	0.14	2133	1867	1467	1067
27-Nov	36.96	0.18	0.16	1778	1556	1222	889
27-Dec	5.94	0.17	0.15	1882	1647	1294	941

Climatic Zone: Warm Temperate Climate I
River: Dabena
Hydrology Station used: Dabena Nr. Abasina
Meteorological Station used: Nekemt
Suitable area for Irrigation: 10716ha
Total area: 638674ha

Month	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)	Irr.Req over total area (m^3/s)	Area Irrigable (ha) with ---Percent exceedence flow 80% 13.03m^3/s	85% 10.42m^3/s	90% 7.79m^3/s	95% 5.17m^3/s
1-Jan	37.74	0.18	1.9	72389	57889	43278	28722
31-Jan	64.7	0.31	3.3	42032	33613	25129	16677
2-Mar	81.36	0.39	4.2	33410	26718	19974	13256
1-Apr	48.56	0.23	2.5	56652	45304	33870	22478
1-May	5.55	0.03	0.3	434333	347333	259667	172333
31-May	0	0	0.0				
30-Jun	0	0	0.0				
30-Jul	0	0	0.0				
29-Aug	0	0	0.0				
28-Sep	0	0	0.0				
28-Oct	36.49	0.18	1.9	72389	57889	43278	28722
27-Nov	71.25	0.34	3.6	38324	30647	22912	15206
27-Dec	11.52	0.33	3.5	39485	31576	23606	15667

Climatic Zone: Tropical climate III
River: Temssa
Hydrology Station used: Temssa Nr.Agaro
Meteorological Station used: Jimma
Suitable area for Irrigation: 1107ha
Total area: 159016ha

Month	Net Irrigation Req. (mm/month)	Field Water Supply (l/s/ha)	Irr.Req over total area (m3/s)	Area Irrigable (ha) with ---Percent exceedence flow 80% 0.58m^3/s	85% 0.54m3/s	90% 0.39m3/s	95% 0.17m3/s
1-Jan	13.88	0.07	0.08	8286	7714	5571	2429
31-Jan	25.46	0.12	0.13	4833	4500	3250	1417
2-Mar	51.63	0.25	0.28	2320	2160	1560	680
1-Apr	45.1	0.22	0.24	2636	2455	1773	773
1-May	13.87	0.07	0.08	8286	7714	5571	2429
31-May	0	0	0.00				
30-Jun	0	0	0.00				
30-Jul	0	0	0.00				
29-Aug	0.54	0	0.00				
28-Sep	19.2	0.09	0.10	6444	6000	4333	1889
28-Oct	31.33	0.15	0.17	3867	3600	2600	1133
27-Nov	36.96	0.18	0.20	3222	3000	2167	944
27-Dec	5.94	0.17	0.19	3412	3176	2294	1000

Climatic Zone: Warm Temperate Climate II
River: Dedessa
Hydrology Station used: Dedessa Nr. Dembi/Toba
Meteorological Station used: Bedelle
Suitable area for Irrigation: 18053ha
Total area: 916901ha

Month	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)	Irr.Req over total area (m3/s)	Area Irrigable (ha) with ---Percent exceedence flow 80% 7.77m^3/s	85% 6.61m3/s	90% 4.99m3/s	95% 3.07m3/s
1-Jan	43.82	0.21	3.79	37000	31476	23762	14619
31-Jan	59.31	0.29	5.24	26793	22793	17207	10586
2-Mar	69.45	0.33	5.96	23545	20030	15121	9303
1-Apr	53.41	0.26	4.69	29885	25423	19192	11808
1-May	9.34	0.05	0.90	155400	132200	99800	61400
31-May	0	0	0.00				
30-Jun	0	0	0.00				
30-Jul	0	0	0.00				
29-Aug	0	0	0.00				
28-Sep	12.13	0.06	1.08	129500	110167	83167	51167
28-Oct	37.03	0.18	3.25	43167	36722	27722	17056
27-Nov	58.47	0.28	5.05	27750	23607	17821	10964
27-Dec	11.31	0.33	5.96	23545	20030	15121	9303

Climatic Zone: Warm Temperate Climate II
River: Dedessa
Hydrology Station used: Dedessa Nr. Arjo
Meteorological Station used: Bdelle
Suitable area for Irrigation: 70956ha
Total area: 916901ha

Month	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)	Irr.Req over total area (m3/s)	Area Irrigable (ha) with ---Percent exceedence flow 80% 13.03m^3/s	85% 10.42m3/s	90% 7.79m3/s	95% 5.17m3/s
1-Jan	43.82	0.21	14.90	62048	49619	37095	24619
31-Jan	59.31	0.29	20.58	44931	35931	26862	17828
2-Mar	69.45	0.33	23.42	39485	31576	23606	15667
1-Apr	53.41	0.26	18.45	50115	40077	29962	19885
1-May	9.34	0.05	3.55	260600	208400	155800	103400
31-May	0	0	0.00				
30-Jun	0	0	0.00				
30-Jul	0	0	0.00				
29-Aug	0	0	0.00				
28-Sep	12.13	0.06	4.26				
28-Oct	37.03	0.18	12.77	72389	57889	43278	28722
27-Nov	58.47	0.28	19.87	46536	37214	27821	18464
27-Dec	11.31	0.33	23.42	39485	31576	23606	15667

Climatic Zone: Warm Temperate Climate I
River: Dedessa
Hydrology Station used: Dedessa Nr. Arjo
Meteorological Station used: Nekemt
Suitable area for Irrigation: 28820ha
Total area: 638674ha

Month	Net Irrigation Req. (mm/period)	Field Water Supply (l/s/ha)	Irr.Req over total area (m3/s)	Area Irrigable (ha) with ---Percent exceedence flow 80% $13.03m^3/s$	85% 10.42m3/s	90% 7.79m3/s	95% 5.17m3/s
1-Jan	37.74	0.18	5.19	72389	57889	43278	28722
31-Jan	64.7	0.31	8.93	42032	33613	25129	16677
2-Mar	81.36	0.39	11.24	33410	26718	19974	13256
1-Apr	48.56	0.23	6.63	56652	45304	33870	22478
1-May	5.55	0.03	0.86	434333	347333	259667	172333
31-May	0	0	0.00				
30-Jun	0	0	0.00				
30-Jul	0	0	0.00				
29-Aug	0	0	0.00				
28-Sep	0	0	0.00				
28-Oct	36.49	0.18	5.19	72389	57889	43278	28722
27-Nov	71.25	0.34	9.80	38324	30647	22912	15206
27-Dec	11.52	0.33	9.51	39485	31576	23606	15667

APPENDIX G
(Photo)

Meteorological station at Gembe

River level gauging staff on Urgessa R

Meteorological station at Dedessa.

Dedessa River at Dembi

Meteorological station at Temssa

River level gauging staff on Temssa River

Temssa River fall

Meteorological stations at Bedelle

Dedessa River at Bedelle

Hydrometric station on Dedessa River at the bridge site near Arjo

Landscape of the Dedessa Valley

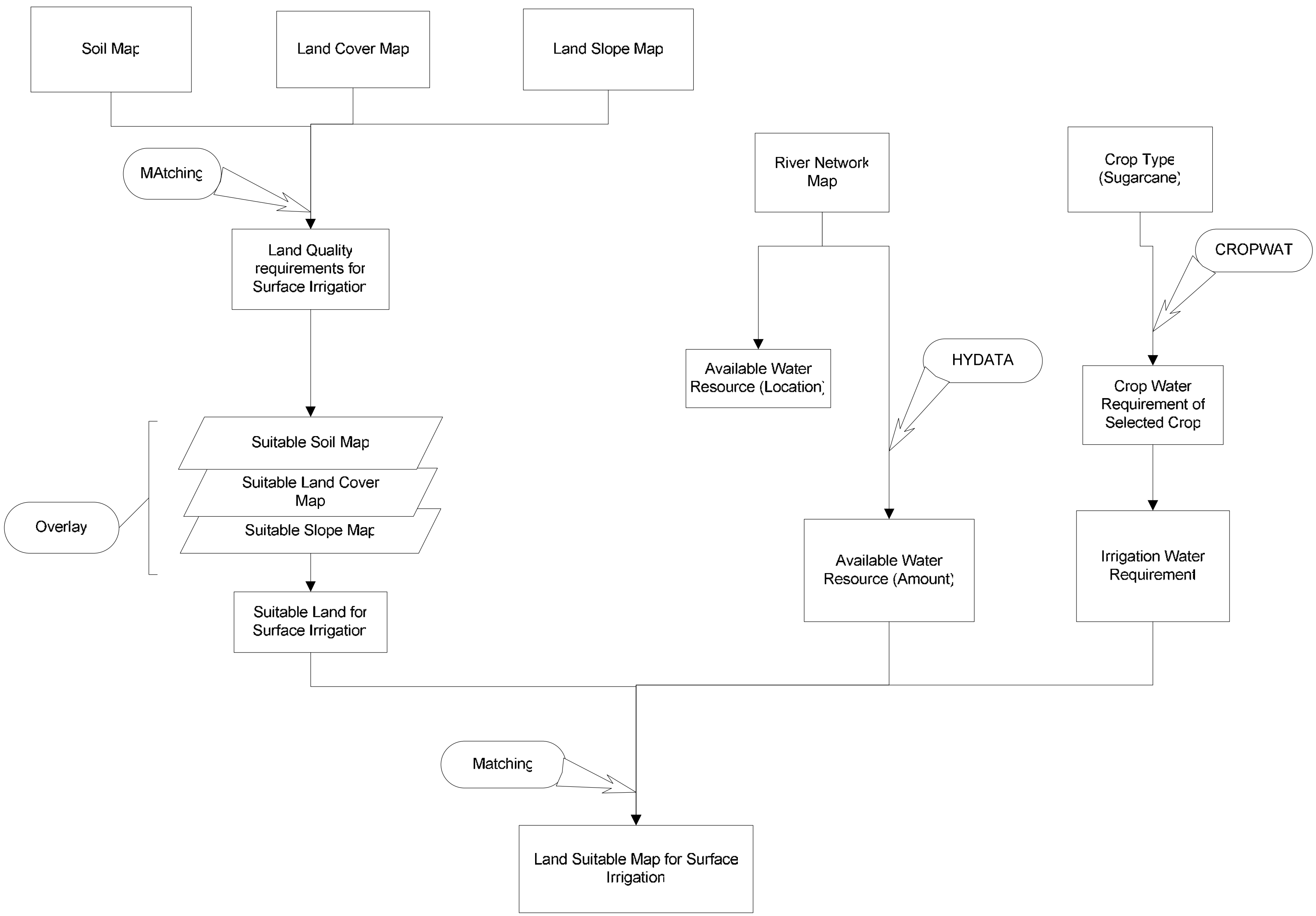


Figure 5.1 Flow chart of the total suitability analysis carried out.