ASSESSMENT OF SURFACE WATER POTENTIAL AND DEMANDS OF WABISHEBELE BASIN IN ETHIOPIA

BY

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Assessment on Surface Water Potential and Demands of Wabishebele Basin in Ethiopia

A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Civil Engineering (Hydraulic Engineering)

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Date defended--------------------

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CERTIFICATION

The undersigned certify that he has read the thesis entitled**: Assessment on Surface water potential and Demands of Wabishebele River Basin in Ethiopia** and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

Water is, like the air we breathe, a basic requirement for all life on Earth. It is vital for many aspects of economic and social development, e.g., for energy production, agriculture, domestic and industrial water supply, and it is a critical component of the global environment. There is growing awareness that development, including development of water resources, must be sustainable, which implies that the world's natural resources must be managed and conserved in such a way as to meet the needs of present and future generations.

An output of this study is readily available to assist planners and managers to make decision on water resource availability in a catchment and also is to assess and forecast water demand in the basin. The soil and water assessment tool (SWAT) and water evaluation and planning system (WEAP) were used for the prediction of surface water potential and demands of Wabishebele River basin respectively.

The objective of this study is to quantify the surface water resources within the basin and assessing the demands in the basin using rainfall-run-off and water resource modeling.

The model was successfully calibrated and validated for measured stream flow at Gode gauging station.

Flow calibration gives coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (ENS) 0.70 and 0.82 respectively. Flow validation gives 0.70 and 0.87 for R^2 and ENS values respectively. The calibration and validation result showed that model performance evaluation statistics (coefficient of determination (R^2) and Nash-Sutcliffe model efficiency (ENS)) were in the acceptable range.

The demand was computed based on three (3) scenarios – Scenario 1: Irrigation projection, Scenario 2: Dam construction and Scenario 3: Increase water demand scenario. The study found that the catchment is relatively sensitive to the Increase water demand scenario and Irrigation projection, suggesting that the slight changes will alter the present and future water availability. Results indicate a general trend of declining water supply and increasing unmet demand in the basin.

In this study the SWAT model yields average annual run off of 3.76B m^3at Gode and an annual demand of 512.6Mm^3 (2000) , 3615.52Mm^3 (2030).

Keywords: Water Evaluation and Planning, SWAT, Water Demand, surface water, Wabishebele Basin, calibration validation.

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List of acronyms and nomenclatures

AAiT	Addis Ababa Institute of Technology
Alpha__Bf	Alpha base factor
NGO	Non governmental organization
CN	Curve Number
Ch__N	Main canal Roughness Coefficient
Cn2	Moisture Condition Curve Number
DEM	Digital Elevation Model
EFA	Environmental flow assessment
ET	Evapotranspiration(mm)
Esco	Soil Evaporation Compensation Factor
FAO	Food and Agriculture Organization
GIS	Geographical Information Systems
GWQMN	Threshold Water Depth in the Shallow Aquifer for Flow
GW_Delay	Groundwater Delay Time
GW_Revap	Groundwater Revap Coefficient
HRU	Hydrologic Response Unit
HYMO	Hydrologic Model
Km2	Kilometer square
Kc	crop coefficient
Pe	Effective precipitation
Ge	Graound water
LR	Leaching requirment

IR	Irrigation requirment
Kcb	Basal crop coeffiecient
Rn	Net radation
G	Soil heat flux
U2	Wind speed at 2 m hieght
ed	Saturated vapour pressure
ea	Actual vapour pressure
∇	Slope vapoure pressure
MCM	Million meter Cube
MIWE	Ministry of Irrigation Water and Energy
MUSLE	Modified Universal Soil Loss Equation
Masl	Meter above Sea Levels
Mm3	Million Meter Cube
NSE	Nash-Sutcliffe Efficiency
Obs	Observed
PET	Potential Evapo transpiration
RCH	Reach number.
SCS	Soil Conservation Service
SEI	Stockholm Environment Institute
SNNP	South nation nationalities and people of Ethiopia
SWAT	Soil and Water Assessment Tool
Sol_Awc	Soil Available Water Content
Sol_K	Soil Saturated Hydraulic Conductivity
US	United states

USDA	United States Department of Agriculture
USLE	Universal Soil Lose Equation
WEAP	Water Evaluation And planning
WWDSE	Water Work Design and Supervision Enterprise
EF	Environmental flow
SDM	Spill demand method
WYIM	water year idex method
RAW	Readily available soil water
SUB	Sub basin

1 Introduction

1.1 Background

Water is the most complex natural resource correlating its availability from the atmosphere to lithosphere through hydrosphere. The availability of water is highly uneven in space and time. Improper assessment of water resources is potentially disastrous. For instance, under estimation of flood can lead to overtopping of dam and consequent failure of its structure. On the other hand, for projects where water potential is overestimated, the system may not come to a position to fill up to the full reservoir level.

Many countries in both the developed and developing world face significant problems in maintaining reliable water supplies, and this is expected to continue in future years due in part to the impacts of global climate change. Growing population demands for increased domestic water supplies and at the same time, results with a higher consumption of water due to expansion in agriculture and industry will further increase the demand for water, and there are limited cost-effective water supply augmentation options. Mismanagement and lack of knowledge about existing water resources and the changing climatic conditions have as consequences an imbalance of supply and demand of water. The problem is prominent in semi-arid and arid areas where the resources are strongly limited(Fekadu,1999).

Water-resources information useful for regional and national assessments of water availability and use requires a continuing process of coordination and collaboration with water demand scenario. Assessing water resource potential and demand will improve water facts today and in the future, what variables or indicators would be useful, what spatial and temporal scales would be appropriate, how to build on existing efforts, and where to expand collaborative opportunities(Paul,2002)

Therefore collection and analysis of long term hydrological and meteorological data like rainfall, runoff, infiltration characteristics, temperature, humidity, wind-speed and others for the area are essential. In developing countries, in general, there is lack of financial, human and technical resources for developing and maintaining hydrometric stations in proper networks to provide data for sustainable water resource planning, design, and management. A systematic assessment of water resources availability with high spatial and temporal resolution is essential in basin for strategic decision-making on water resource related development projects; a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system. As a result mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses. And also; there is a need to develop method for predicting flow at un-gauged sites. One of the most common approaches that is used for estimating flow of un-gagged catchments is the use of rainfall-runoff models whose parameters is going to be regionalized, as catchments with similar characteristics show similar hydrological behavior (Woinishet,2009).

There is an increasing in population growth in our country; the country is also in a range of fastly growing the government has a plan to emerge middle income country with in short period of time. Due to this reason the water demand pattern of the country will be changed in the future. Therefore it is necessary to study the country's current as well as future water potential and its demand in order to manage the water resource potential.

This thesis is intended to provide a basis for future scenario analysis of water resource management of Wabishebele River Basin and also to evaluate the SWAT model capability to predict the runoff River basin

1.2 Statement of problem

Wabishebele River Basin is the largest basin in Ethiopia' with low water resources' potential, very little of which has been developed for agriculture, hydro power, industry, water supply and other purposes. The problems in the basin is that, there has not been any in-depth study done to address surface water potential and demand assessment in the basin with updated information and suitable methods. River flow data are limited to the upstream and rarely available to downstream part of the basin as there are no evenly distributed hydrometric stations, large areas lack gauging stations, and only a few years of data are available.

The basin water resources is under pressure by increasing population, new infrastructure and new large scale irrigation projects development.Therfore, determination of the surface water potential and water demands of the basin are fundamental to sustainable water allocation and conflict management.

1.3 Objective

1.3.1 General Objective

The overall objective of the study is to come up with better estimates of available surface water and water demands which are key to sustainable water management.

1.3.2 Specific objectives

a. To determine the surface water potential of the basin

b. To identify and quantify the major water demands of the basin

c. To assess the impact of suggested water development scenarios in basin.

1.4 Research Questions

1. What is the trend of supply and demand in the catchment?

2. What water demands are expected under different scenarios?

3. What is the significance of assessing surface water potential and water demand in the area?

1.5 Scope of the study

The scope of this research is limited to assessing surface water potential and demands in Wabishebele River Basin. This study considers large water demands which modify the natural hydrological regime of the river and the stream flow in an environment of increasing demands in the basin at main flow gauging stations in the main stream of Wabishebele. Although clusters of small reservoirs store and small scale irrigation significant quantities of water and affect on assessment of the basin, they are ignored in the system. The developed water resources assessment is subject to change in the future, as research and available data improve and a better knowledge of future needs are known

General scope of this paper covers the following:

- Quantification of the surface water resource potential within the basin using rainfall-run-off model for the catchment.
- Estimation of major water demands for different scenarios

- Assessment of impacts of water demands on stream flow.
- Identification of data deficiencies and recommendations on future monitoring requirements.

1.6 Conceptual Framework

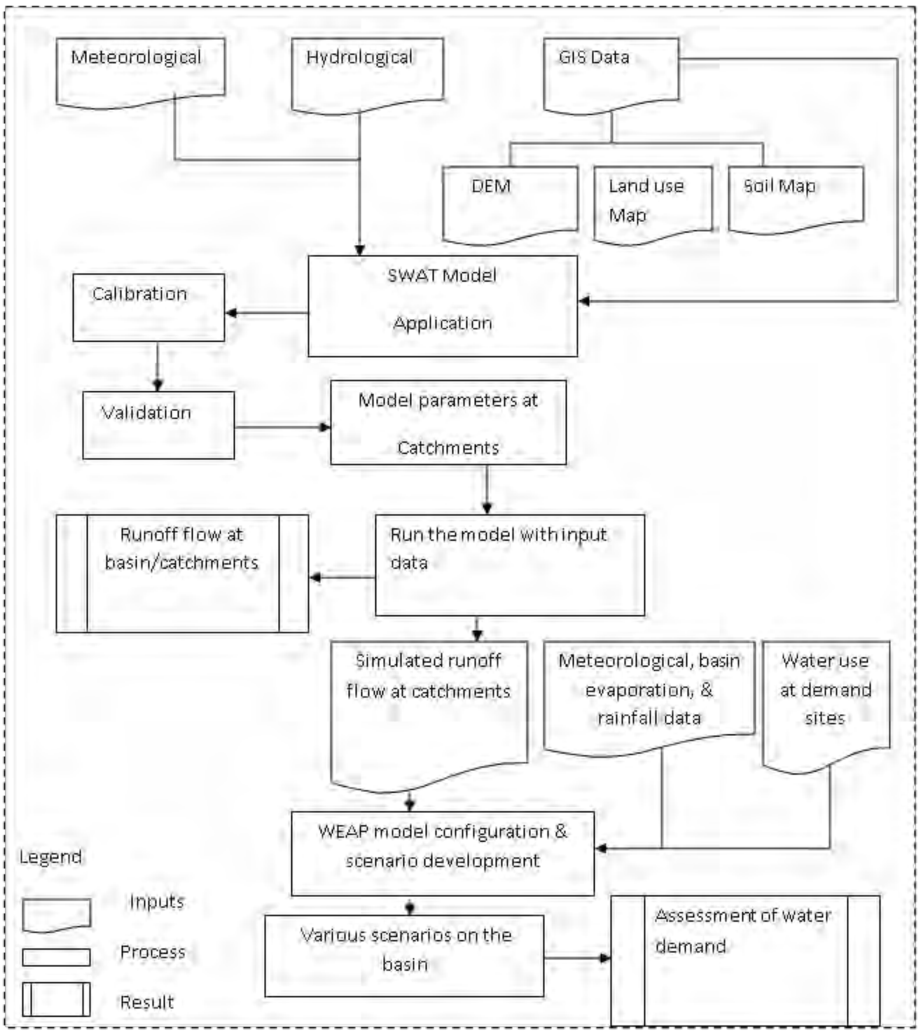


Figure 1-1 General framework of the study

1.7 Outline of the Research

The thesis was divided in to six chapters. Chapter one provides the brief introduction of the study, statement of the problem and objective of the research. Chapter two presents literature review, previous study in related topics .Detail descriptions of the study area are included in chapter three Chapter four deals with data collection, parameter derivation, model input preparation and methodology, model in general, classification of hydrological models, and its setup. The fifth chapter presents model output and result discussions. Conclusions and recommendations are included in chapter six.

2 Literature review

A variety of relevant publications has been used for this thesis paper and information is mainly based on governmental reports from the Ethiopian Ministry of Water, Irrigation & Energy and Substantial efforts are done in terms of publications, but literature on the specific area was the main challenge and information available is partially outdated.

A water resources assessment is created and different demand scenario with the objective of using it in a bigger scheme.

2.1 Water availability and demand

Water is the most important resource of a country, and of the entire society as a whole, since no life is possible without water. The availability of water largely determines the spatial pattern of the Earth's terrestrial biomes (forest, grasslands and deserts): it covers 71% of the Earth's surface providing habitat for fresh and saltwater ecosystems; water is a major controlling element of the Earth's climate, and it is water that is largely responsible for sculpting the Earth's surface into the" infinitely complex associations of erosion and depositional landforms (Garg,2005).

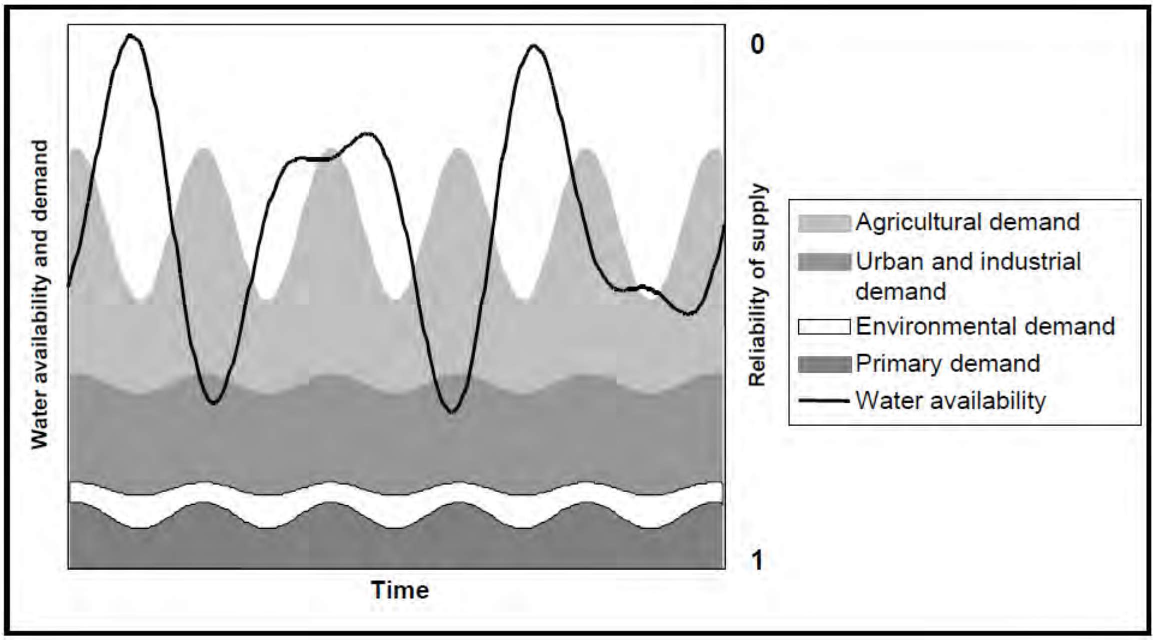
In this new century the world will be challenged to provide sufficient quantities of high-quality water to its growing population. Water is a limiting resource for human well-being and social development, and projections of population growth as well as changing social values suggest that demands for this resource will increase significantly. These projections have fueled concerns among the public and water resources professionals alike about the adequacy of future water supplies, the sustainability and restoration of aquatic ecosystems, and the viability of our current water resource research programs and our institutional and physical water resource infrastructure (Charles,2002).

Water availability and demands are a function of the total flow of water through a basin, its quality, and the structures, laws, regulations, and economic factors that control its use. Because water availability and water demand are closely linked.

Surface water is water that is on the Earth's surface, such as in a stream, river, lake, or reservoir. Surface water is a valuable resource which can be used for public, industrial and agricultural supply purposes. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation.

The geographical location of Ethiopia and its endowment with favorable climate provides relatively higher amount of rainfall in the region. Much of the water, however, flows across the borders being carried away by the transboundary Rivers to the neighboring countries. Although we cannot be definite due to lack of researched data as yet, preliminary studies and professional estimates indicate that the country has an annual surface runoff of close to 122 billion cubic meters of water excluding groundwater. Even thought Ethiopia's water resource is large, very little of it has been developed for agriculture, hydropower, industry, water supply and other purposes. To date only about 160000 ha (about 4%) other potential irrigable land has been developed. National coverage of potable water supply stood at 26% by 1992 while coverage of sanitation services is only 7%. , which is low by even the Sub-Sahara standards. There is also a wide divergence in the water supply coverage between urban (76%) and rural (18.8%) areas. A Wabishebele River Basin water resource is under pressure by increasing population, new infrastructure and new large scale irrigation projects development. Therefore, proper assessment and development of the precious and scarce water resource is absolutely necessary for our country in order to insure over all prosperity of the nation (Nata,2006).

Figure 2-1 shows the variation of supply and demand in an imaginary case. It shows that, in general, primary (domestic) and industrial demands, with the highest ability and willingness to pay, require a high reliability of supply, which is normally achieved through relatively large storage provision. Environmental demands are also not the most demanding on the resource. Agricultural water requirements tend to be much higher, fluctuate strongly but also accept a lower reliability of supply.



(Wallingford,2003)

Figure 2-1 Variation of water availability and demand, and reliability of supply

Water demand scenario are a set of different future water use pattern for all water users and followed by the analysis their impact on water availability. The scenarios addressed a broad range of "what if" questions such as: what if population growth and economic development patterns change? What if reservoir-operating rules altered? What if a water- recycling program is implemented? What if a more efficient irrigation technique is implemented? What if climate change alters the hydrology?

These scenarios will be viewed simultaneously in the result for easy comparison of their effect on the water system

2.2 Hydrological and Water resource models

Watershed models simulate natural processes of the flow of water, sediment, chemicals, nutrients and microbial organisms within watersheds, as well as quantify the impact of human activities on these processes. Simulation of these processes plays a fundamental role in addressing a range of water resources, environmental, and social problems. The current generation of watershed models is quite diverse and varies significant in sophistication and data and computational requirements. Newly emerging technologies are being increasingly integrated into watershed models (Vijay,2006).

2.2.1 Water resource model

2.2.1.1 *Water evaluation and planning system (WEAP)*

WEAP is comprehensive, straightforward, and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (SEI,2013).

Operating on the basic principle of a water balance, WEAP is applicable to municipal and agricultural systems, single catchments or complex transboundary river systems. Moreover, WEAP can address a wide range of issues, e.g.sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and stream flow simulations, reservoir operations, hydropower operating on the basic principle of a water balance.

The analyst represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, reservoirs, and desalination plants); withdrawal, transmission and wastewater treatment facilities, ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts, which can be viewed as a calibration step in the development of an application, provide a snapshot of actual water demand pollution loads, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. Scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

WEAP, in contrast to many other tools, is not optimization oriented in the sense that the optimal water allocation will be presented. The entire approach is based on scenarios (alternatives) to ensure that stakeholders, water managers and policy makers are actively involved in the entire process of planning in order to guarantee the ownership feeling of the final decisions taken

WEAP has two primary functions on basic principle of water balance constraint

- Simulation of natural hydrological processes (e.g.evapotranspiration, runoff and infiltration) to enable assessment of the availability of water within a catchment.
- Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e.consumptive and non- consumptive water demands) to enable evaluation of the impact of human.

WEAP consists of five main views: Schematic, Data, Results, Overviews and Notes. A typical stepwise approach will be followed to develop WEAP for a particular area: (i) create a geographic representation of the area, (ii) enter the data for the different supply and demand sites, (iii) compare results with observations and if required update data, (iv)define scenarios and (v) compare and present the results of different scenarios. In general, the first three steps will be done by technical experts like hydrologists, while for the last two steps input and exchange with stakeholders, water managers and policy makers is essential.

2.2.1.2 Urban Water Demand

The water furnished to a city can be classified according to its ultimate use or end. The uses are:

Domestic, Commercial & Industrial, Public use and Loss and waste

A. Domestic

This includes water furnished to houses, hotels, etc, for sanitary, culinary, drinking, washing, batching, and other purposes. It varies according to the living conditions of consumers, the range usually being considered as 75 to 380 liters per capita per day, averaging 190 to 340 per capita (Wallingford,2003). These figures include:

- Air conditioning of residences
- Irrigation or sprinkling of privately owned gardens and lawns

The domestic consumption may be expected to be about 50% of the total in the average city, but where the total consumption in small, the proportion will be much greater.

B. Commercial and Industrial

Water so classified is that furnished to industrial and commercial plants. Its importance will depend up on local conditions, such as the existence of large industries and whether or not the industries patronize (utilize) the public water works. Self supplied industrial water requirements are estimated to be more than 20 percent of municipal water supply demand (Wallingford,2003).

Industrial water use includes water used for the following:

- Industrial processes such as fabrication, processing, washing and cooling;
- Mining;
- Hydropower generation;
- Thermal electric power generation.

Urban industries tend to be metered, usually according to the volume of water used, through an average charge or a variable marginal charge based on block rates. Where larger commercial and industrial users tend to be metered, determining demands can be facilitated through analyzing meter records. Alternatively, they may have their own source, especially if they are outside urban centers. Monitoring records may exist or there may be some indication as to the energy consumption of pumps or other references to demand and use.

The major factors common to the industrial and commercial sectors in determining water demand are:

- ✓ Economic activity at a local, national and international level;
- ✓ Population;
- ✓ Industrial composition;
- ✓ Price of water;
- ✓ Access to supply and alternative supplies;
- ✓ Access to technology;
- ✓ Working practices.

Industrial water requirements are estimated to be 20% percent of municipal water supply demand for this study.

C. Public Use

Public Buildings, such as:

City halls, Jails, Schools

As well as public services:

- Flushing streets &
- Fire protection

Require much water for which, usually, the city is not paid. Such water amounts to 50 to 75 liters per capita. The actual amount of water used for extinguishing fires does not figure greatly in the average consumption, but very large fires will cause the rate of use to be higher for short periods.

D. Losses and Waste

This water is sometimes classified as "**un accounted for**", although some of the loss and waste may be accounted for in the sense that its cause and amount are approximately known. Un-accounted for water is due to:

- Meter and pump slippage
- Unauthorized water connections and
- Leaks in mains

It is apparent that the unaccountegd for water, also waste by consumers, can be reduced by careful maintenance of the water system and by universal metering of all water services. In a system 100 percent metered and moderately well maintained the unaccounted for water, exclusive of pump slippage, will be about 10 percent.

Taking in to account the potential of development industries in the basin and the purpose of planning it is proposed to use a percentage of domestic demand .Therefore a flat rate of 20% is adopted for all towns, no provision is made for rural areas

Water loss are normally calculated as a percentage of the sum of the domestic demand .For this thesis it is assumed to use a flat range of 15% for urban areas and 5% for rural areas

2.2.1.3 Rural water demand

Rural water demand encompasses all domestic-type water requirements outside of urban areas.

The first term accounts for the domestic water use (including also subsistence irrigation and other economic activities and computed as the product of the population times a per capita usage) and a second term to account for the livestock watering (computed as the product of the number of livestock times a per capita usage).

Estimating domestic water demand and use at a catchment level for rural areas in Ethiopia is problematic owing to the lack of measured data available. Estimates of rural domestic water demand and use are further complicated by the lack of definitions of the terms used. Hence in the context of assessing rural water demand and use it is important that various terms are clarified

There are two main methods of assessing rural domestic demand. These are:

1. Indirect methods, where the quantity of water consumed is calculated from population levels and estimated demand levels in terms of per capita consumption
2. Direct methods where socio-economic surveys and participatory techniques involving the relevant stakeholders are used to estimate the current and future water demand.

In general estimation of rural water demand and use is difficult because:

- The majority of rural domestic water supply systems are unmetered;
- Data concerning domestic rural water demand and use is often expensive and time consuming to collect;
- The level of service provided by the water supply system is often unknown. For catchment management purposes indirect methods are the most appropriate for establishing rural domestic water demand and use.

Many water supply schemes in rural areas are fairly basic; however, the patterns of use and demand are more complicated and tend to be dependent on many factors. Such factors include:

Population, Household occupancy rate, Level of service of the water supply for each household, Tariff levels, Willingness and ability to pay, Local knowledge and indigenous practices, Cultural values, traditions and religious beliefs, Climate and Water quality.

For this study indirect methods for estimating rural demand was used which are relatively straight forward to use and are the most practical method for the estimation of water demand on a sub catchment and catchment basis.

The following information is required:

i. Population data;
ii. Per capita water demand;
iii. Unaccounted for water levels i.e. the difference between the total quantities of water abstracted and the quantity of water consumed.

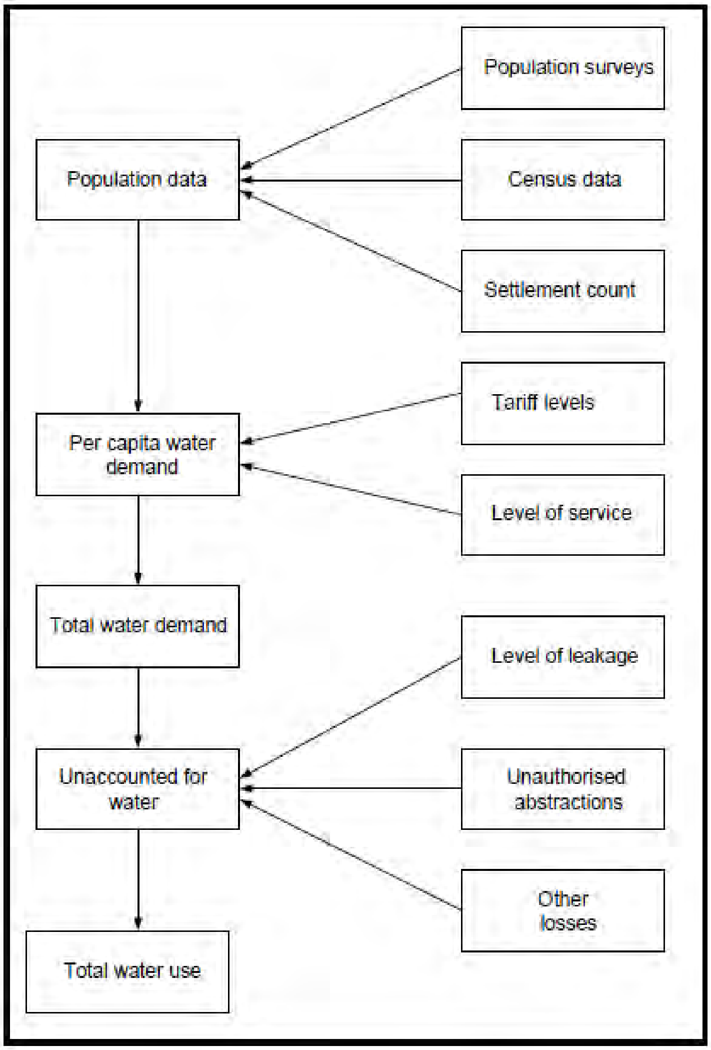


Figure 2-2 Indirect method of calculating total rural water demand

The water requirements of livestock are influenced by several factors, including
Type of livestock, Pregnancy; Lactation; Type of diet; Feed intake and Temperature
Estimating total livestock consumption is relatively simple.

The assessment of livestock consumption should be carried out as follows.

- Determine types of livestock;
- Use typical water consumption figures per head for each type of livestock;
- Determine number of each type of livestock in the area being assessed

2.2.1.4Agricultural water demand

Agriculture is an important activity thought the world in terms of food security, economic activity and water use. Irrigated agriculture, moreover, plays a disproportionately important role because it is generally two to three times more productive than rain-fed agriculture.

Irrigation demand for water is a function of acreage, crop type, growing cycles (and their corresponding crop coefficients), reference evapotranspiration, and effective precipitation within the irrigated area. Using the "cropwat" demand model the model first calculates the crop requirements. Irrigated agricultural demand encompassed the irrigation of large plots and formal irrigation schemes. It was assumed that therefore only commercial irrigation was represented in this sector Within WEAP the irrigation water demand varied inter annually based on annual rainfall; during wet years the irrigation demand would decrease and during dry years it would increase accordingly (McCartney,005).

The irrigation water demand can be established from:

- Estimates using empirical formula;
- Measurements of water consumption from flow gauging devices;
- Field measurements of the consumptive use of crops

Field measurements of water use by crops are complex, time consuming and expensive. Generally irrigation water demands is estimated from empirical equations

In order to carry out a detailed estimate of irrigation water demand and use, using empirical formulae, the following information is required:

- Reference crop evapotranspiration;
- Crop type and crop evapotranspiration;
- Cropped area;
- Effective rainfall;
- Soil type and leaching requirements;
- Irrigation efficiencies.

A. Methods of estimating reference crop evapotranspiration

The reference crop evaporation is based on a hypothetical, well-watered grass reference crop with specific characteristics. There are four main methods of estimating reference crop evapotranspiration (ETO).

These are:

1) Blaney-Criddle method
2) Radiation method;
3) Pan evaporation method;
4) Penman-Monteith method.

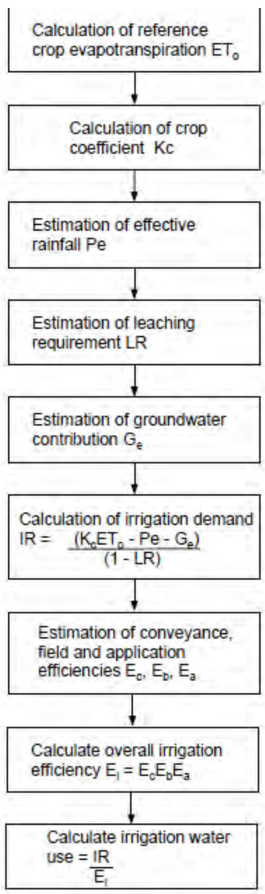


Figure 2-3 Detailed method for estimating irrigation water demand

It should be noted that often the greatest uncertainty in determining irrigation water use is the estimation of irrigation efficiency. The overall irrigation efficiency is defined as the ratio of water consumed by crops to the water diverted from the source. The overall irrigation efficiency can vary from 10% to 90% and is heavily dependent on the irrigation technology used, and the operation and maintenance of the irrigation scheme.

The FAO recommends the Penman-Monteith method as the sole method standard method for the computation of ETO. The use of the Penman-Monteith method does require a reasonable quantity of climatic data. However, advice on the infilling of missing data and the setting up of climate stations is given in FAO Irrigation and Drainage Papers Nos. 56 and 27 respectively. Climate data for over 3000 climate stations in 144 counties is available in a digital format as part of FAO Irrigation and Drainage Paper No. 49. There are also a number of software packages that use the Penman-Monteith method equation to assess reference crop evaporation. The FAO computer program CROPWAT utilizes the Penman-Monteith method and a spreadsheet is also available from the FAO to calculate reference crop evaporation.

This method is recommended for use wherever possible, providing there is sufficient meteorological data. The reference crop evapotranspiration is calculated from the following equation

$$ET_O = \frac{0.408\nabla(R_n - G) + \gamma\frac{900}{T+273}U_2(e_{a-}e_d)}{\Delta + \gamma(1 + 0.34U_2)} \quad \ldots\ldots 2.1$$

Where: Rn is the net radiation at crop surface;

G is the soil heat flux;

T is the average temperature;

U2 is the wind speed measured at 2 m height;

(ea-ed) is the vapour pressure deficit;

∇ is the slope vapour pressure curve;

The crop evapotranspiration ETcrop in mm/day is calculated by multiplying the reference crop evapotranspiration ETO in mm/day by a dimensionless crop coefficient Kc:

$$ET_{crop} = K_c ET_o \quad \ldots\ldots 2.2$$

The crop coefficient is dependent upon the following factors:

Crop type; Climate; Soil evaporation; Crop growth stage.

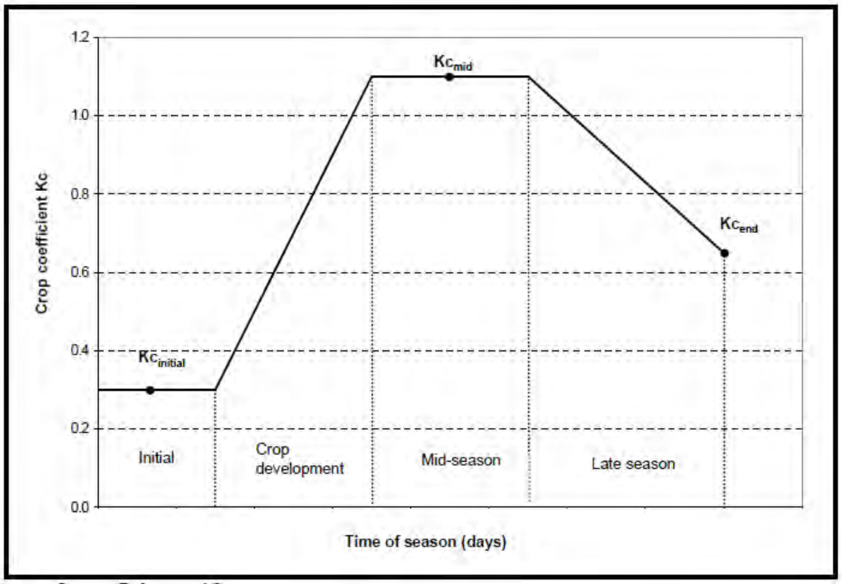


Figure 2-4 Typical crop coefficient curve

As Figure 2-4 illustrates, the crop coefficient varies over the growing period of the crop. As the crop develops the ground cover, crop height and the leaf area change. As a consequence the evapotranspiration of a crop will change during its growing period. The majority of crops have four growth stages:

- **Initial stage** when the leaf area is small and the majority of the evapotranspiration is due to soil evaporation;
- **Crop development stage** when leaf area grows from approximately 10% to full ground cover;
- **Mid-season stage** when the crop is reaching maturity;
- **Late season** runs from the start of maturity to the harvest.

  Typical ranges of crop coefficient Kc together with the factors that affect the Kc during the life of a crop.

The Penman-Monteith method has the following advantages:

- ✓ The Food and Agriculture Organization (FAO) of the United Nations recommend the use of the Penman-Monteith equation as the sole method for the estimation of reference crop evapotranspiration;
- ✓ Climatic data and tools to assist with the calculation of ETo using the Penman-Monteithmethod are available from the FAO;
- ✓ The method can be used to estimate ETo on a daily basis.

B. Estimation of effective precipitation

Crop water requirements may be fully or partly met by precipitation. However, it should be noted that not all rainfall is effective as some may be lost to surface runoff, deep percolation or evaporation. There are several factors that affect effective rainfall including:

Rainfall characteristics, Soil type, Groundwater characteristics and Management practices

C. Groundwater contribution

The contribution from groundwater to the crop water requirement is a factor of the following:

- Depth of the groundwater below the root zone;
- Capillary properties of the soil;
- Soil capillary capacities.

For heavy soils the distance of the movement of the groundwater is high and the rate low, and for coarse soils the distance of movement of the groundwater is small and the rate is high. It should be noted that detailed field experiments are usually needed to ascertain the groundwater contribution to the crop water requirement. For most catchment planning purposes it is unlikely that it is necessary to calculate groundwater contributions.

D. Stored soil water

Stored soil water at the start of the growing season resulting from rain can mean that the soil is close to or at its field capacity. This stored soil water at the start of the growing season can be deducted from the crop water requirement. However, for the purposes of catchment planning it is usually not necessary to take account of stored soil water as it will vary significantly on a seasonal basis.

E. Irrigation efficiencies

The net irrigation requirements can be calculated from the crop water requirements, effective rainfall, the ground water contributions and the stored soil water. However, in order to calculate the total irrigation requirements the quantity of water required for leaching together with the irrigation efficiency should be taken into account. The irrigation efficiency is defined as the ratio of water consumed by crops to the water diverted from the source . The irrigation efficiency can be calculated from the equation:

$$E_i = \frac{V_c}{V_w}$$

Where: Ei is the irrigation efficiency;

Vc is the water consumed by the crops;

Vw is the water diverted from the source (e.g. a river or reservoir).

The irrigation water demands for an irrigation scheme with n different crops being grown on it can be calculated as follows:

$$\textbf{Irrigatioin water demand} = \sum_{i=1}^{n}\left[\frac{A(ET_{crop} - p_e - G_e)}{1 - LR}\right] \quad \text{2.3}$$

In many parts of the world the growing season is long enough that double and sometimes triple cropping can take place on the same irrigated area. In these cases the irrigated area should reflect the number of crops grown in a year.

2.2.1.5 Hydropower water demand

Two methods were used to define demand for hydropower. The first method, called the Water Year Index method (WYIM), is based on energy demand and is used to simulate historical reservoir releases to hydropower plants. The WYIM uses historical observations to approximate operating rules. The second method, called the "spill demand" method (SDM), is based on water demand rather than energy demand and is used to simulate the operating goal of operators to minimize spill, which usually represents lost revenue. Energy demand is modeled explicitly (WYIM) only for powerhouses that receive water directly from a large reservoir; all reservoirs, however, use the spill demand method (SDM).

To prevent hydropower demand at less than capacity when a reservoir is spilling, another hydropower operating rule is introduced, called the spill demand method (SDM). The SDM simply requires that any inflow in excess of existing demands be diverted to generate hydropower. This ensures that hydropower plants use, as much as possible, water that cannot be stored and that would otherwise spill.

Hydropower will only be generated for flows up to the **Maximum Turbine Flow**. **Tail water Elevation** defines the working water head on the turbine. The power generated in a given month depends on the head available, which is computed as the drop from the reservoir elevation (as computed by WEAP, using the Volume Elevation Curve and the storage volume at the beginning of the month) to the tail water elevation. The **Plant Factor** specifies the percentage of each month that the plant is running. The plant **Generating Efficiency** defines the generator's overall operation effectiveness in converting the energy of the falling water into electricity.

2.2.1.6 Environmental flow water demand

The environment is increasingly being considered a legitimate water user in many world countries. As a consequence the water requirement of the environment needs to be estimated.

The amount of water that will be allocated to the environment is a decision made by society, and is to some extent arbitrary. The quantity of water allocated to the environment will always be less than what the environment ideally would require, namely the natural, undisturbed, flow regime of a river. Society, therefore has to weight the potential costs and benefits to the environment and to all other water users, of allocating (or not) a certain amount of water to the environment. In so doing, society accepts a certain modification of the natural environment. This accepted level of modification may differ from river to river, and is sometimes defined in terms of "ecological management classes".

The environmental or Instream flow requirement is often defined as how much of the original flow regime of a river should continue to flow down it in order to maintain the riverine ecosystem in a prescribed state. However, an environmental Instream flow often fulfils a number of different functions

Despite the simplicity of the concept, difficulties arise in the actual estimation of EF values. This is primarily due to the inherent lack of both the understanding of and quantitative data on relationships between river flows and multiple components of river ecology.

There is a range of methods available for assessing Instream flow requirements based on:

- Simple hydrological indices;
- Hydrological simulations;
- Consensus and discussion based approaches;
- Historical data analysis;
- Biological response simulation techniques often referred to as habitat simulation methods

Hydrological index methods are the simplest type of environmental flow assessment, least data intense and rely on the use of historical hydrological data for making flow recommendations. These data are usually in the form of long-term, historical monthly or daily discharge records.

In flow duration curve analysis naturalized or present-day historical flow records are analyzed over specific durations to produce curves displaying the relationship between the range of discharges and the percentage of time each of them is equalled or exceeded.

Assuming a comparably low reserve flow of 95% exceedence(with corresponding discharge3.25m^3/s) for the River basin just for the sake of not neglecting this sector, by using low flow analysis concepts

In order to maintain the ecological services as well as the natural channel habitat associated to the historic flow regimes of the Wabishebele River, a certain reserve flow has to be maintained and could be considered as a sectoral demand on its own.

2.2.1.7 Limitation of WEAP

WEAP is not intended for use in the design of new water systems. It is a tool to aid in the ongoing analysis and management of existing water systems and water resources. It offers the user an opportunity to see the potential effects of different changes made to a system, and to optimize the decision making process. If the goal is to redesign a system or do 3-D modeling of watershed infiltration and runoff WEAP may not be the best choice.

2.2.2 Hydrological model

Hydrological models are characterizations of the real world system. Modeling of the rainfall runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beveb,1985). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to un-gauged catchments and into the future to assess the likely impact of future hydrological changes. A wide range of hydrological models are used by the researchers. However, the applications of those models are highly dependent on the purposes for which the modeling is made Stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Hydrological models are commonly divided into two main categories: Physical and abstract models.

Physical models include scale models such as hydraulic models of a spillway, and analog models which use another physical system having properties similar to those of the real system.

Abstract models represent the system in mathematical form. The system operation is described by a set of equations and logical statements (Aillingteit,1995).

The models are classified according to three main criteria;

- Randomness (deterministic or stochastic)
- Spatial variation (lumped or distributed)
- Time variability (time-dependent, time-independent)

In total, a number of different model classes are classified in this system. The simplest type of model will be a deterministic lumped time-independent model. The most complex type of model would be a stochastic model with space variation in three dimensions and with time variation (Aillingteit, 1995)

There are quite a number of hydrological models. Some available model covers many possible applications (with varying degree of availability). Some make approximate estimate from limited information, and others require a great deal of descriptive data and use large amount of computer time and detailed computations.

There are numerous criteria which can be used for choosing the suitable hydrologic model. These criteria are always project-dependent, since every project has its' own specific requirements and needs, furthermore, some criteria are also user-dependent and subjective.

The following criteria are most commonly applied for comparison and selection of an appropriate hydrological model:

a. Temporal scale: The time step used in the model.

b. Spatial scale: For what basin size is the model developed or recommended to be used

c. Cost: Price of the model.

d. Set-up time: Approximate time needed to set the model into operational use.

e. Expertise: What scientific expertise is required to use the model adequately?

f. Documentation: What documentation is available about the model, such as user‘s guides, reference manuals, web pages, newsletters, etc…?

g. Ease-of-use: Describes computer-related user-friendliness of the model, taking into account , input-output (I/O) operations, and visualization options.

h. Operating System: Computer operation system required for the model

An attempt was made to select hydrological model that addresses the stated objectives of the study based on the above criterion.

Thus, the lumped conceptual model selected for use in this study is SWAT. It is chosen because it suites the objectives of the study,data availability, low set up time,Ease of use and it is recommended for giving good results in predicting model parameters that are used to estimate surface potentialof the basin (Mesgna,2013).

2.2.3 Soil and Water Assessment Tool (SWAT) Model

The Soil and Water Assessment Tool (SWAT) model (Neitsch,2005) is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the response to natural inputs as well as the manmade interventions on water and sediment yields in un-gauged catchments.

The SWAT model

(a) is physically based;

(b) uses readily available inputs;

(c) is computationally efficient to operate and

(d) is continuous time and capable of simulating long periods for computing the effects of management changes.

The SWAT model is a long-term, continuous model for watershed simulation. It operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. The model has been validated for several watersheds. In SWAT, a watershed is divided into multiple sub-water sheds, which are then further subdivided into unique soil/land-use characteristics called hydrologic response units (HRUs). The water balance of each HRU in SWAT is represented by four storage volumes: snow, soil profile, shallow aquifer and deep aquifer. Flow generation, sediment yield, and non-point-source loadings from each HRU in a sub watershed are summed, and the resulting loads are routed through channels, ponds, and or reservoirs to the watershed outlet. The SWAT model is available with various interfaces, such as arc View, and Arc GIS. The most versatile is arc SWAT interface on Arc GIS.

2.2.3.1 Benefits of SWAT Model

- Watersheds with no monitoring data (e.g., stream gage or water quality data) can be modeled.
- SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration and therefore can be used on ungauged watersheds (in fact the usual situation)
- The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, or land use) on water quality or another variable of interest can be quantified.
- The model uses readily available inputs. While SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to run the model are commonly available from government agencies.
- SWAT is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment.
- SWAT explicitly incorporates elevation or topographic effects on precipitation and temperature.
- SWAT was developed for and has been widely applied to simulation of watersheds in arid regions.
- SWAT explicitly incorporates routines for agricultural diversions and irrigation

2.2.3.2 Limitation of SWAT

The following are some of the limitations using SWAT for hydrological modeling

1) SWAT is a long term water and sediment yield model that operates on a daily time steep. Daily precipitation is in put to the model and an empirical (curve number) equation is applied to daily without accounting for intensity
2) Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to represent the spatial variation in the hydrometeorological characteristics in the area. The lack of adequate number of observation stations affects the model output.

3) In order to calibrate the model for the historic land use scenarios, the corresponding land use maps are needed. In order to get the real time picture of the land use pattern,this information can be extracted from the remote sensing satellite imageries by using digital image processing technique. However, acquisition of satellite imageries is expensive and also the expertise required for the image interpretation is another major limitation.
4) Though SWAT is a free software tool, in order to represent the spatial variation in the catchments characteristics, GIS software is the prerequisite to run the model.

2.2.3.3 Runoff generation

Surface runoff will occur when the precipitation rate exceeds both infiltration capacity and surface detention capacity. It is partly governed by factors such as precipitation intensity and duration that are external to the slope system.

However, the most important determining factors are those of the slope system itself such as soil type, the amount and type of vegetation, slope form and angle, and relative position on the slope. When the rainfall intensity is greater than infiltration capacity overland flow will occur and will move down slope increasing in volume as it moves. There are empirically (SCS,1972) and physically based infiltration models (Green and Ampt, 1911).

Physically based infiltration models can be transferred to other regions but they need boundary conditions and high computation time. Empirical Hydrological methods are transferable through calibration on another scale and climate region (Dilnessaw, 2006).

It was the product of more than 20 years of studies involving rainfall-runoff relationships from small rural watersheds across the U.S. The equation was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Evans,1988)

The hydrologic cycle is simulated by the water balance equation:

$$SW_t = SW_o \sum_{t=1}^{t} (R + Q_i + ET_i + P_i + QR_l) \qquad 2.4$$

Where, SWt and SW_0 are the final and initial soil water content respectively (mm).

R = daily rainfall (mm), Q = daily surface runoff (mm), ET = daily evapotranspiration (mm),

P = daily percolation (mm) and QR = daily lateral flow (mm).

Surface runoff is predicted by:SCS curve number equation is (SCS, 1972):

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S} 2 \qquad \text{2.5}$$

for R > 0.2S Q=0 for R<0.2S

$$S = 254\left(\frac{100}{CN} - 1\right) \qquad \text{2.6}$$

Where, Q = daily surface runoff (mm): R = daily rainfall (mm), S = retention parameter (mm); CN = curve number.A complete description of the SCS curve number method is explained by(Neitsch , 2005). The SCS curve number is a measure of the infiltration characteristics of a soil.

In general, soils are divided into four major classes of infiltration and runoff characteristics:

1) Low runoff potential and high infiltration rate even when thoroughly wetted. These soils mainly consist of excessively drained sand and gravel.These soils have a high water transmission rate.
2) Moderate infiltration rate when thoroughly wetted. These soils mainly consist of well-drained fine-to-moderately fine textures. They have a moderate water transmission rate.
3) These soils have a slow infiltration rate when thoroughly wetted. These soils mainly have a layer that impedes downward movement of water and have a slow water transmission rate.
4) These soils have a high runoff potential and very slow to no infiltration when thoroughly wetted. They mainly consist of clay soils that have high swelling potential, soils that have a permanent water table, and soils that have a clay-pan or a clay layer near the surface. These soils have a very slow water transmission rate (Neitsch,2005).

2.2.3.4 Antecedent soil moisture

SCS defines three antecedent moisture conditions: I-dry (wilting Point), II-average moisture and III-wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry condition. The curve numbers for moisture conditions I all III are calculated with the equations.

$$CN_1 = \frac{20(100 - CN_2)}{(100 - CN_2 + exp^{[2.553 - 0.0636*(100 - CN_2)]})} \quad \text{.....} 2.7$$

$$CN_3 = CN_2 * exp^{[0.00673*(100 - CN_2)]} \quad \text{.....} 2.8$$

Where

CN_1 is the moisture condition curve number I, CN_2 is the moisture condition curve number II, and CN_3 is the moisture condition curve number III.

The retention parameter varies with soil profile water content according to the following equation:

$$S = S_{max} * (1 - \frac{SW}{SW + exp^{(W_1} - w_2 * SW} \quad \text{.....} 2.9$$

Where S is the retention parameter for a given moisture content (mm),S_{max} is the maximum value the retention parameter can achieve on any given day (mm), SW is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point mm H_2O ,

and w_1 and w_2 are shape coefficients.

Assuming that

1) The retention parameter for moisture condition curve number I corresponds to wilting point soil profile water content,
2) The retention parameter for moisture condition curve number III corresponds to field capacity soil profile water content, and
3) The soil has a curve number of 99 (S=2.54) when completely saturated.

$$W_1 = \ln\left[\frac{FC}{1 - S_3 * S_{max^{-1}}} - FC\right] + W_2 * FC \ldots\ldots 2.10$$

$$W_2 = \frac{\ln\left[\frac{FC}{1-S_3*S_{max^{-1}}} - FC\right] - \ln\left[\frac{SAT}{1-2.5S_{max^{-1}}} - SAT\right]}{SAT - FC} \ldots\ldots 2.11$$

where

w_1 is the first shape coefficient, w_2 is the second shape coefficient, FC is the amount of water in the soil profile at field capacity mm H_2O , S_3 is the retention parameter for the moisture condition III curve number, Smax is the retention parameter for the moisture condition I curve number, SAT is the amount of water in the soil profile when completely saturated mm H_2O , and 2.54 is the retention parameter value for a curve number of 99 (Tensay, 2011).

2.2.3.5 Equation of water routing

Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. Both the variable storage and Muskingum routing methods are variations of the kinematic wave model.

2.2.3.6Flow rate and velocity

Mannings equation for uniform flow in a channel is used to calculate the rate and velocity of flow in reach segment for a given time step:

$$Q = \frac{A * R^{2/3} S^{1/2}}{n} \ldots\ldots 2.12.$$

$$V = \frac{R^{2/3} S^{1/2}}{n} \ldots\ldots 2.13$$

where Q is rate of flow in the channel(m^3/s),A is cross-sectional area of flow in the channel(m^2),R is the hydraulic radius for a given depth of flow(m),S is the slope along the channel length(m/m),n is the mannings coefficient for the channel,and V is the flow velocity(m/s).

2.2.3.7 Muskingum routing method

The Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages in a reach segment (Chow,1988) When a flood wave advances into a reach segment, in flow exceeds out flow and a wedge of storage is produced. As the flood wave recedes, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length.

As defined by Manning's equation the cross-sectional area of flow is assumed to be directly proportional to be discharge for a given reach segment. Using this assumption, the volume of prism storage can be expressed as a function of the discharge, $k*q_{out}$ where K is the ratio of storage to discharge and has the dimension of time. In a similar manner, the volume of wedge storage can be expressed as in

$K* X (q_{in}-q_{out})$.

Where

X is a weighting factor that controls the relative importance of in flow and outflow in determining the storage in a reach. Summing these terms gives a value for total storage

$$q_{out,2} = C_1 q_{in,2} + C_2 q_{in,1} + C_3 q_{out,1} \cdots\cdots 2.14$$

$$C_1 = \frac{\Delta t - 2KX}{2K(1-X) + \Delta t}$$

$$C_2 = \frac{\Delta t + 2KX}{2K(1-X) + \Delta t}$$

$$C_3 = \frac{2K(1-X) - \Delta t}{2K(1-X) + \Delta t}$$

where

$q_{in,1}$ is the inflow rate at the beginning of the time step (m^3/s), q_{in2} is the inflow rate at the end of the time step (m^3/s) , $q_{out,1}$ is the outflow rate at the beginning of the time step (m^3/s), $q_{out,2}$ is the outflow rate at the end of the time step (m^3/s).

2.2.4 Model efficiency evaluation

The performance of SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (ENS) are the goodness of fit measures used to evaluate model predict ion.

The Coefficient of determination R^2 value is an indicator of strength of relationship between the observed and simulated values. It indicates how well the dispersion of the measured data is predicted by the model. Its value ranges between 0 and 1 with the zero being no correlation at all and the value of one indicates perfect match, and computed by equation

$$R^2 = \left| \frac{\sum_{i=0}^{n}\left[\left(Q_{sim} - \overline{Q}_{sim}\right)\left(Q_{obs} - \overline{Q}_{obs}\right)\right]^2}{\sum_{i=0}^{n}\left[\left(Q_{obe} - \overline{Q}_{obs}\right)^2 \sum_{i=0}^{n}\left(Q_{sim} - \overline{Q}_{sim}\right)^2\right]} \right| \cdots\cdots 2.15$$

The Nash-Sutcliffe simulation efficiency (ENS) indicates how well the plot of observed versus simulated value fits the line (Nash,1970) . If the measured value is the same as all predictions. ENS is 1. If the ENS is between 0 and 1, it indicates deviations between measured and predicted values. If ENS is negative, predictions are very poor, but the accepted range is greater than 0.5 and the average value of output is a better estimate than the model prediction (Nash , 1970). This coefficient is calculated by equation given below.

$$NSE = 1 - \left| \frac{\sum_{i=0}^{n}\left(Q_{obs} - Q_{sim}\right)^2}{\sum_{i=0}^{n}\left(Q_{obs} - \overline{Q}_{obs}\right)^2} \right| \cdots\cdots 1.16$$

Where:

n is the number of observations during the simulation period, Q_{obs} is the Observed flow data; Q_{sim} is the simulated flow value with the respected time; Q^{-}_{obs} and Q^{-}_{sim} are the arithmetic means of the observed and simulated values

3 Study Area Descriptions

3.1 Location and coverage

The area of investigation in this research is the WabiShebelle River Basin in Ethiopia. In this topic main features of the study area are explained. It describes the location of the study area, its topographic characteristics, the geology, the land use/land cover and the hydro climatic Features and the socio economics of the study area is also briefly discussed.

Ethiopia has 12 river basins, the total mean flow from the 12 river basin is estimated to be 122BCM (Awulachew, 2007). The Wabishebele River Basin is situated between4^{0}45'N to 9^{0}45'N latitude and 38°45'E to 45°30'E longitude. Wabishebele River Basin has an area of 188320 square kilometer, covering parts of the Somalia, Oromia, Harari and a small area at the source of the Wabi River in SNNPE. It springs from the Bale mountain ranges of the Galama and the Ahmar about 4216 m above mean sea level and drains into Indian Ocean crossing Somalia. The basin covers about 19% of the area of the country. It is bounded by Genale basin in the South West, rift valley in the West and North West, Awash basin in the North, Aysha Dewele in the North East, and Ogden in the East and Somalia in the South.

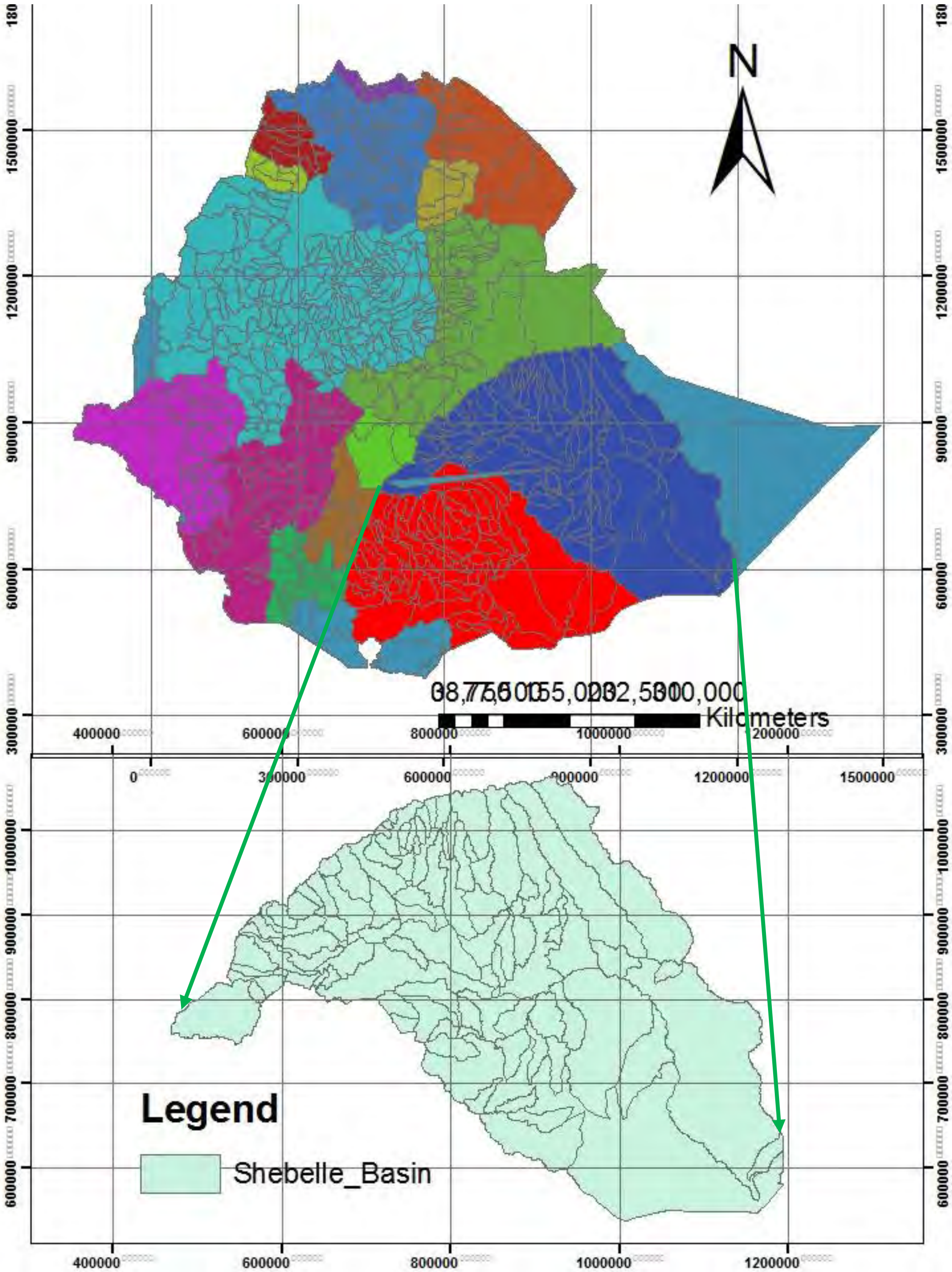


Figure 3-1 Location of Wabishebele rivers in Ethiopia

3.1.1 Topographic Feature

The Wabi Shebelle River emerges from the mountainous areas of the North Western borders of the river basin near a place called Hebeno.The altitude varies from 166 m above mean sea level (msl) north of Mustahil in Somali region to about 4216 mm on the highlands of Bale. From its source, the Wabi River flows eastward until it meets with another major component of the main river joining from Hareri region where most of the left bank tributaries originated and then and it changes its course to flow southwards .Downstream of Melka wakena hydropower dam site the river flows through a deep gorge up to north of Lmi and emerges in its lower valley .The lower valley is a vast alluvial plain stretching up to Somalia border with a very gentle slope of 0.25 to 0.35m/km,most of the tributaries after this portion do not add a substantial flow to the main water. The Ferer and Jerer watersheds are closed watershed.

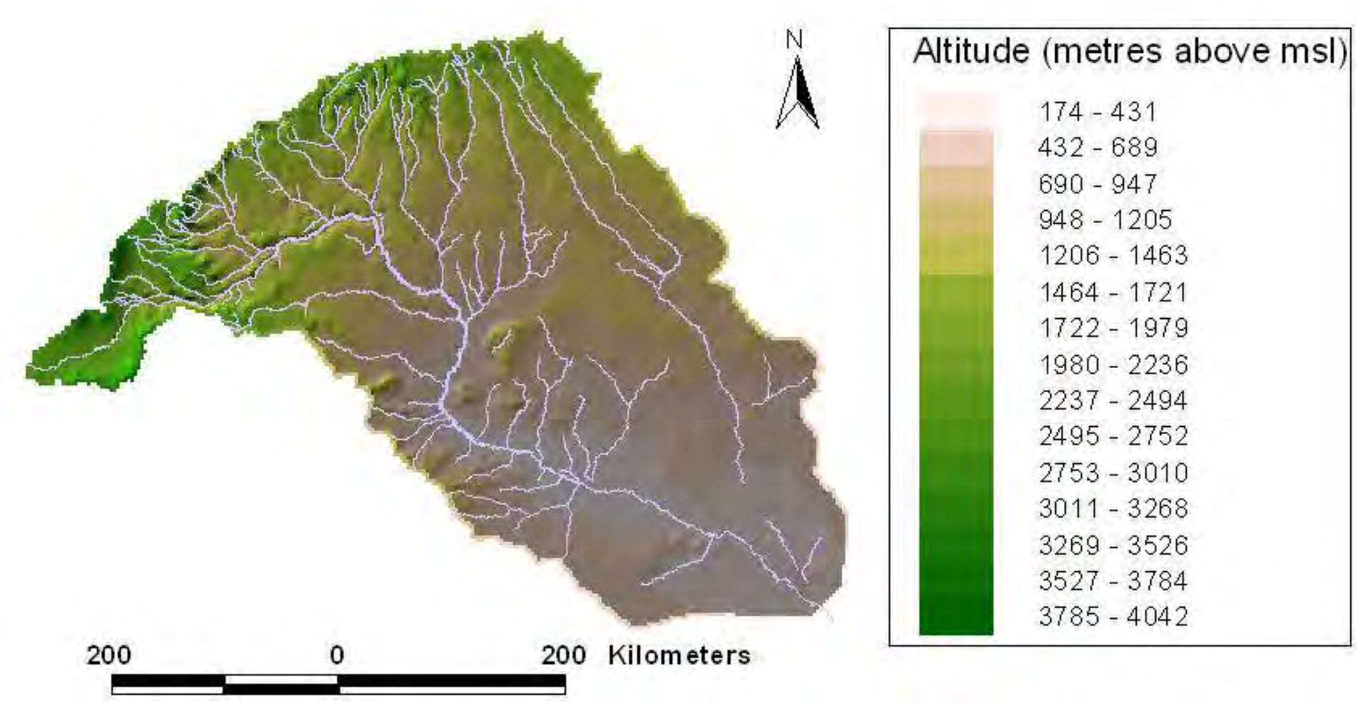


Figure 3-2 Digital model elevation of wabishebele river basin

3.1.2 Geologic feature

The area is dominated by Mesozoic sedimentary formations, to some extent there are also volcanic rocks at the North West of the basin and isolated ridges and hills within the sedimentary basin. Metamorphic rocks outcrops in a small extent at the northern part of the study area. Alluvial deposits are also distributed linearly along the Wabi Shebelle Jerer and Fafen rivers and fan deposits of seasonal floods and stream beds .The volcanic rocks of Arsi-Bale basalt bordering the rift valley are highly fractured .Numerous springs outcrops along faults and fractures in this area and form substantial part s of the base flow of Wabi Shebelle River. The Southern part of the basin is over laid by thick gypsum and limestone.

The water level monitoring for one hydro logic cycle on two wells at Gode showed that the water level is deep always lower than the river bed and the phreatic water level is practically the same during the hydrologic cycle and no interaction with Wabi Shebelle River water indicating the permeability is very low. On the other hand at Kelafo there is interaction of the alluvial ground water with Wabi Shebelle River. At Muslahil there is infiltration of the river flood waters in to the alluvial ground water(Adane,2009)

3.1.3 Land use /Land cover

A small dense forest is found at the North Western portion of the basin. Dense shrub land is the predominant land cover in the basin. The shrub land occurs mainly on the semi- arid parts and often consists of patches of shrubs interspersing grasslands with some scattered low trees. Patches of exposed rock or sand surface are found in parts of Bale and Hararghe lowlands in the southeast. Parts of central Arsi and northern Bale have afro-alpine and sub-afro alpine vegetation.

These consist mostly of short shrub and heath vegetation used partly for sedentary grazing and browsing. Riparian woodland and bush land occur along the river banks and on floodplain sand are important in the semi-arid and arid parts of the basin where they are used for grazing and browsing and scattered seasonal crop cultivation on some of the flood plains.

The land use consists of large part of silvipastoral type. Areas of intensively cultivated land are found on the highlands of Arsi and parts of highland Harerge, and northern Bale. The major seasonal crops in the basin include maize, barley, wheat and sorghum while the perennial crops include coffee, chat and fruit trees.

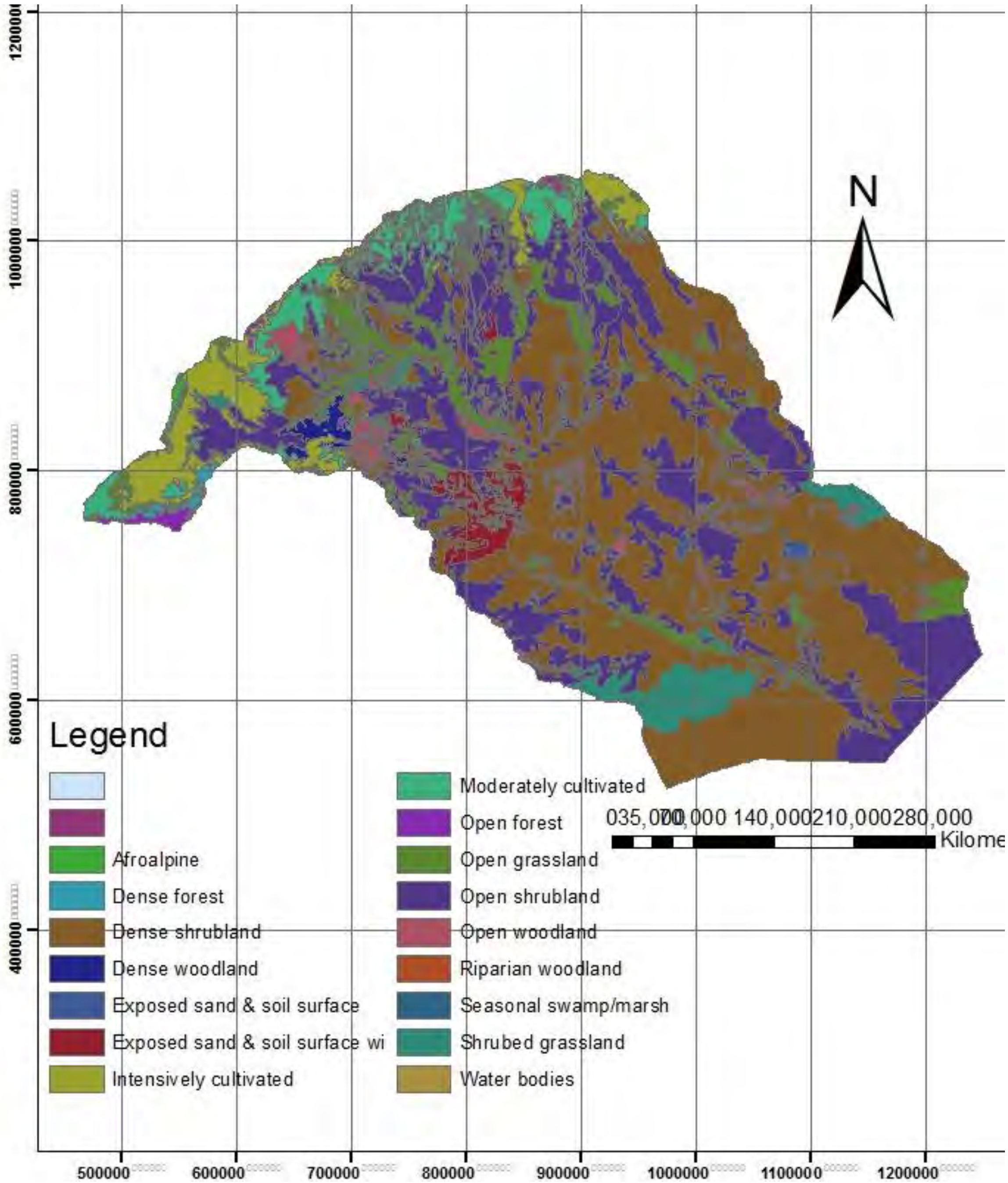


Figure 3-3 Distribution of land cover

3.1.4 Soils

The major soils of the basin are Cambisols (34.7%), Phaeozems (19.7%). Leptosols (12%),Regosols (11,6%),Luvisols (11.2%),Vertisols (4.53%),and Nitsol (3.5%) .Cambisols are distributed in the upper most parts of the watershed, especially areas on hills where the land is too steep. They are inevitably highrisk soils and occur wherever conditions are not favorable for other soil processes than weathering to take place. They are brown in color and shallow to moderately deep soil, phaeozems comprises 19.7% of the basin covering significant areas of the middle belt and downstream of the basin. Luvisols soil formed in the north to middle through south-west (large bell crossing from north-east west and west-north) of the watershed from the basaltic rock cap are deep, well structured, inherently well drained and relatively productive agricultural soil. Leplosols on the southern reach with some at the middle and very small on the northern part. This soil is common on mountainous region partly on continued hard rocks and partly gravels, the soil is limited in depth having calcareous material or cemented layer within 30 to 40cm depth. There are small pockets of vertisols particularly on southern part of basin and Fluvisols in valleys along rivers and streams.

3.1.5 Hydro Climate Condition

3.1.5.1Climate situation

The climate is dependent on the altitude. The highlands are cool and densely populated while the lowlands are arid and sparsely populated. There are some attribute of meteorological stations in and around the basin. Most of them are clustered in or near urban centers of the upper portion of the basin.

The mean annual precipitation is about 468.3mm with the minimum monthly rainfall of 5.83mm in December and maximum 73.22mm in April.

The rainfall is bimodal taking place March-May and June - September. The average annual potential evaporation in the basin is about 1503.1 mm. The low rainfall amount coupled with its erratic nature makes crop growth unreliable even during the main rains.

3.1.5.2Hydrological situation

The Wabi Shebelle River Basin is one of the water scarce basins in the country. While having the largest area coverage, its annual runoff and water availability are one of the lowest among the major river basins. The available hydrological data in the basin are very sparse. There are some stream gauging stations in the basin and fewer are operational at present. A significant portion of which have operated intermittently, the distribution of the meteorological and hydrological gauging stations is not well integrated reducing the plausibility of such data.

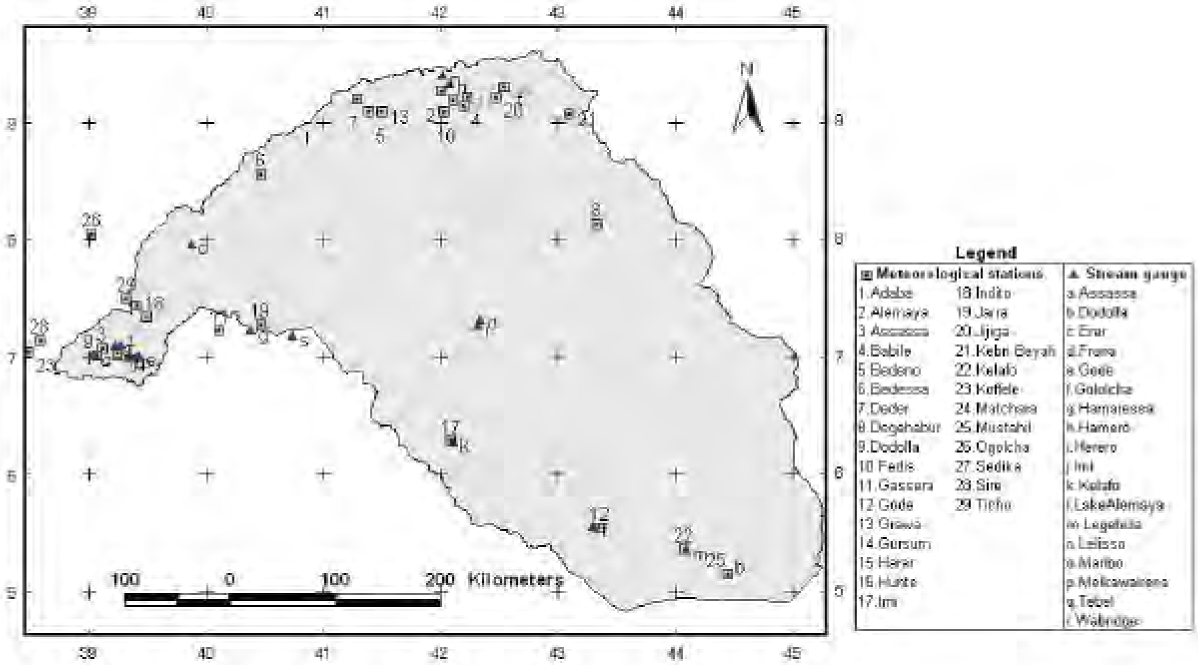


Figure 3-4 Location of some of hydrological gauging station

3.1.5.3 Socio economics

There are about 76 administrative woredas that lie within the basin. About 12% of the population is urban. The major accesses to the basin are a gravel and asphalt road along the highlands of the Bale Mountains and Addis Ababa respectively.

Irrigation has developed in the eastern highlands of the basin since long time. This includes schemes developed by the peasants, government and NGOs. In East and West Hararge zones a number of modern and traditional irrigation schemes were constructed. As it is known the most irrigation practicing area in Ethiopia is East and West Hararge Zones. The farmers are well familiar diverting water from streams and pumping from lakes, marshy area and wells and construction of canals. In most cases people irrigate their land by constructing contour canals negotiating difficult terrains.

In Zones like Bale, there is a neither modern nor traditional irrigation scheme of any size. In Arsi zone small-scale irrigation schemes are constructed by the government but they are not sufficient compared to the resources available in the area and considerable numbers of traditional schemes are found in the western part of the basin.

In Somali region, three modern medium scale (Elbayeh, Bio and Chinakson) and one large scale (Gode irrigation project) schemes were implemented by the Government, but due to various reasons none of these are functional. But, traditional irrigation development along Wabi Shebelle River banks is increasing in recent years.

Generally in the basin, traditional irrigation practice is higher in the lowland area. The construction of modern irrigation schemes in the high land is very small compared to the potential of irrigation site and the requirements of irrigation development in the area.

Traditional irrigation schemes covering an estimated area of 9,739 ha benefiting about 27,057 households exist in the basin. Maximum area developed in these schemes is 450 ha in Mada Dabala scheme in Eastern Harangue Zone. Maximum number of beneficiaries per scheme is 1917 households in Alifif scheme having an area of 119 ha in the above Zone as per the information from Zonal Offices.

The different governments in the last three decades have recognized the need for irrigation development. Accordingly about 75 modern schemes have been constructed. These cover 5,630 ha benefiting 21,246 households as per the data collected from Zonal offices in Phase I study excluding sites which do not have such details. The average size developed per scheme is about 100 ha.

The deficiency of sufficient water for hydropower generation has inclined some consultants to contemplate interbasin water transfer for regulation of a proposed hydropower production scheme at Kuldash from Weyib River

3.1.5.4Population settlement

As per the projected population for the year 2000, the total population of the basin is 6,429,210. Out of this, 69.6 % of the population belongs to parts of four Zones of Oromiya Region while about 27.8 % are that of Somali Region. The rest 2.5% is in Harari and 0.10% in SNNP Regions. Out of the total population of the basin 955.309 are living in Urban and 5,423,901 in rural areas. Population density is the highest in Arsi (86.9 person / km2); whereas it is the lowest in Afder zone i.e. 5.1 persons / km^2. Large percentage of the population lives in the highlands and depends on agriculture while the lowlanders in general are pastoralists.

4 Methodology

4.1 Data Collection

Reliability of the collected raw meteorological and hydrological data significantly affects quality of the model input data. Long-term data are required for any meaningful analysis of the flow regime in area of high variability flow. Absence of recorded long time stream flow data all over the area requires determination of runoff from rainfall. Analysis of raw data was made for data quality checking and filling of missing records.

The hydrology of the basin was characterized by slope, land use, rainfall, temperature, evapotranspiration, and runoff.

The data source were Ministry of Water, Irrigation & Energy, Ethiopian Mapping Agency, National Meteorological Agency, and Water Works Construction Enterprise and literature

The following basic primary and secondary data sets are necessary for the modeling work:-

- Meteorological data (rainfall,temperature,relative humidity and solar radiation)
- Hydrological data (stream flow)
- Spatial data(topographic map, soil data, land use/land cover data, Digital model (DEM)
- Water demand data for each of the sectors which was obtained from the master plan of thebasin,

(See appendix 6 for all available data)

4.1.1 Meteorological Data

The metrological data required were: precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity on daily basis. If any of these data was not available, which is very likely, SWAT can generate data using weather generator.

Precipitation-and-temperature: The daily time sries from Kebridahar, Sofomor, Kulubi, Kora, Sedika, Ogolcha, Koffele, Hunte, Grawa, Alemaya, Bedessa, Degahabur, Dredawa, Gode, Harer and Robe stations were prepared in dbf format.

Solar radiation, relative humidity, and wind speed: data were available only for principal stations Robe and Gode. These data for the rest of the stations were generated by SWAT. They were required to apply Penman Montheith equation is used to evaluate potential evapotranspiration.

Weather simulation data: These data consists of monthly average values of all the values required by the SWAT model in order to generate daily values

4.1.2 Hydrological data

Monthly data is required for SWAT simulated result calibration and validation. This data was obtained from Ministry of Water and Energy Hydrological Department for the period 1976- 2005. Flow data was collected and arranged as per the requirements of SWAT model. The selected gauging station were Assassa, Furna, Gode, Herero, Eeliso Adaba, Maribo Adaba, Unkuma and Wabi below Bridge.

4.1.3 Digital Elevation Model (DEM) Data

The digital elevation model (DEM) is any digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input data for SWAT hydrological model. The Wabishebele River Watershed was delineated and River networks were generated from DEM that has resolution of 90m x 90 m.

4.1.4 Soil Map Data

The soil textural and physicochemical properties required by the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. These data were obtained from (FAO,2003) and the Ministry of Water ,Irrigation and Energy of Ethiopia. The shape file which describes the distribution of soil in the study area was obtained from the available basin maps (figure 4.1). It was observed that Chromic Cambisol, Leptosols ,Eutric Vertisols, Vetric ,Fuvisols,EutricNitisols,Euric Regosols,Haplic Phaeozems are the most dominant soils in the basin

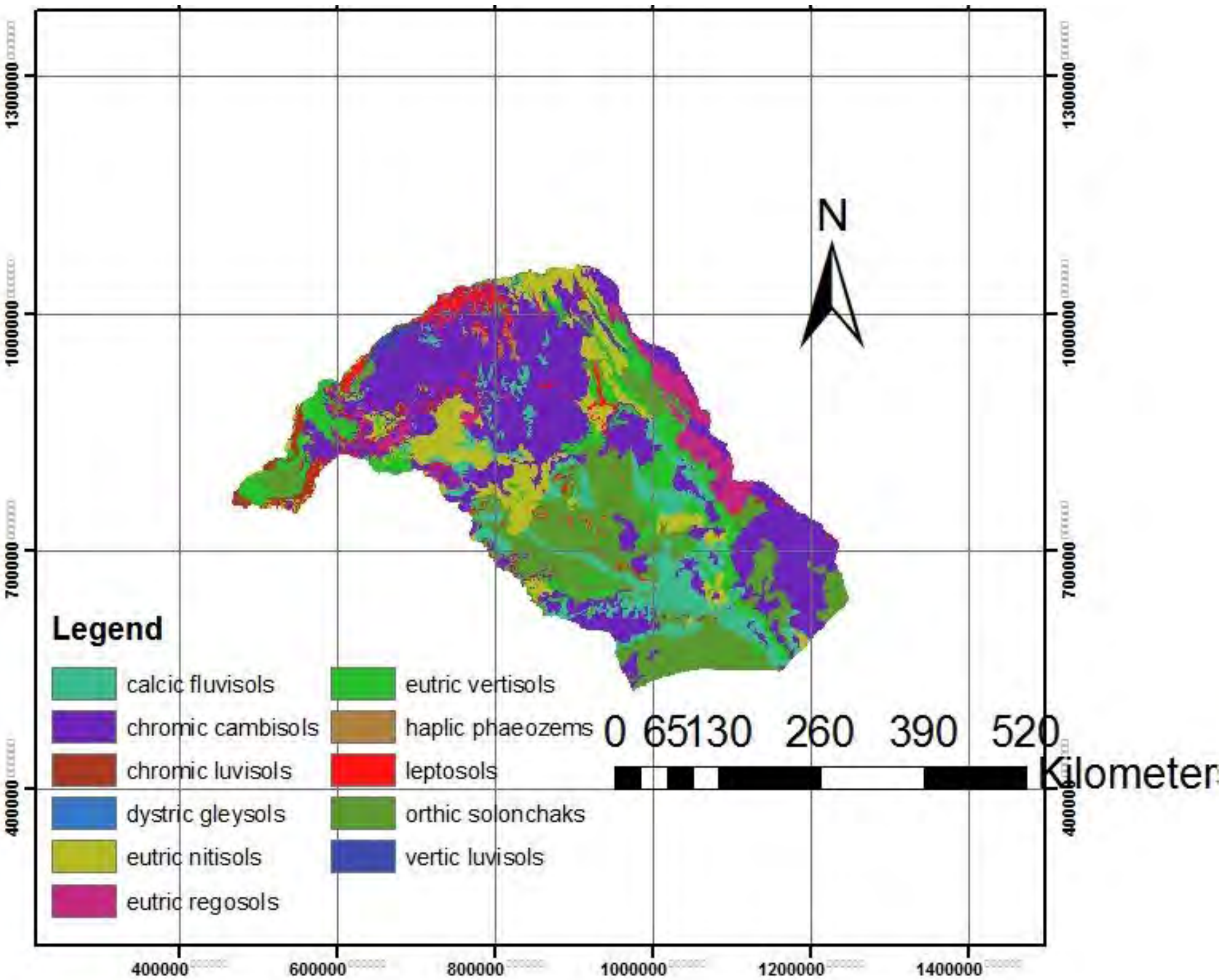


Figure 4-1 Distribution of different soil type in Wabishebele Basin

4.1.5 Land use/land cover

Spatial distribution and specific land use parameters were required for modeling. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Hence the classified land use map and its attribute were adjusted to the SWAT model requirement format and database. Silivipasture is the dominant land use in the catchment

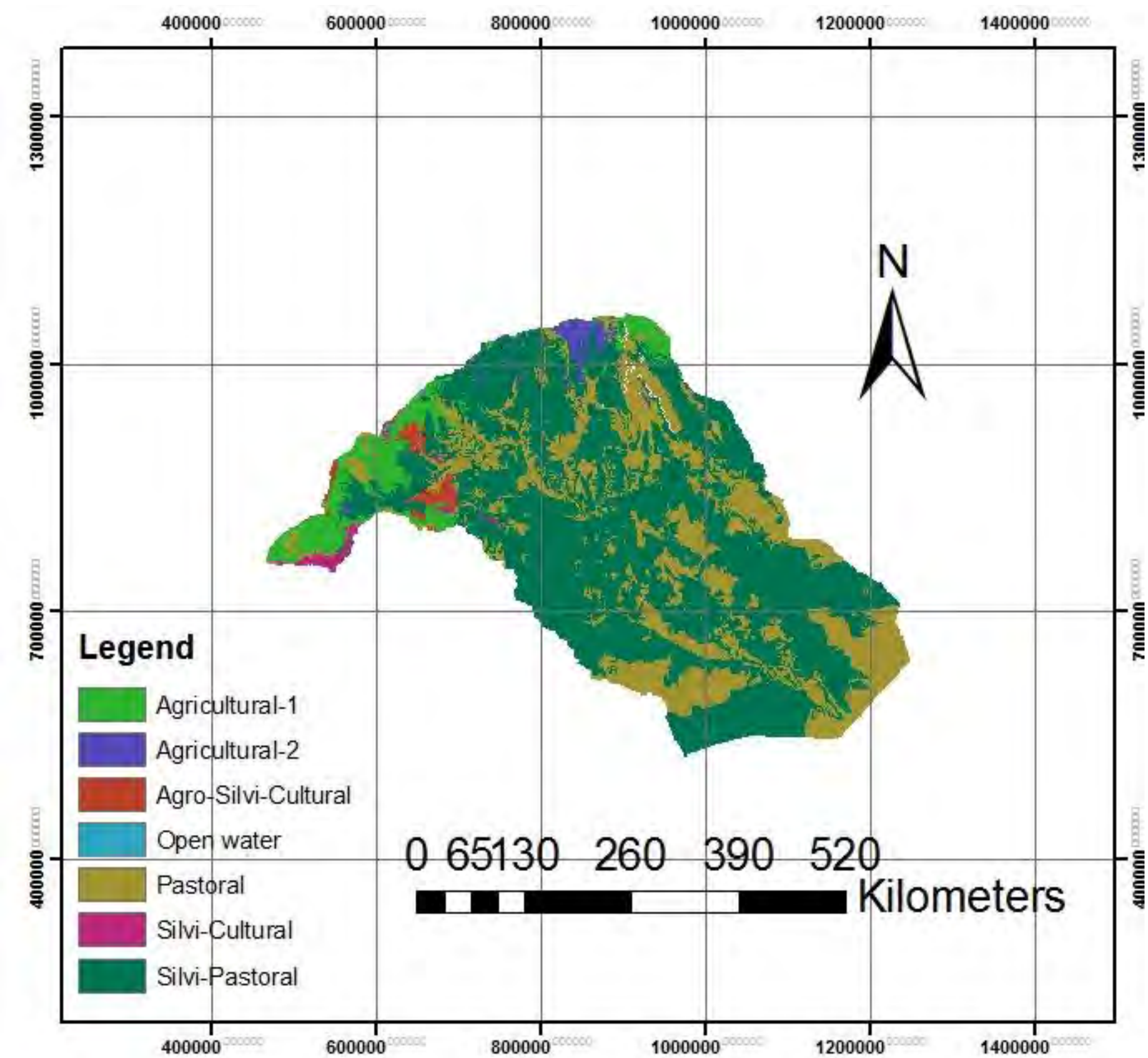


Figure 4-2 Land use /Land cover of the study area

4.2 Hydro-Meteorological Data analysis

4.2.1 Data screening

4.2.1.1 Checking homogeneity of selected rainfall station

Homogeneity is an important issue to detect the variability of the data. In general when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environmental characteristics and structures, and location of stations.

One of the methods to check homogeneity of the selected stations in the watershed is the non-dimensional rainfall records and plotted to compare the stations with each other

Non-dimensional values of the monthly precipitation of each station can be computed by

$$\boldsymbol{P_i = \frac{P_{i,av}}{P_{av}} * 100} \qquad \ldots 4.1$$

Where

Pi is non - dimensional value of precipitation for the month in station i. Pi,av is over years averaged monthly precipitation for the station i and Pav is over year’s averaged yearly precipitation of the station

When the rainfall patterns are spatially identical or vary with in a range, they could considered as homogeneous.

The stations that were used for this study have a rainfall pattern of bi- modal with high rainfall season in March to September

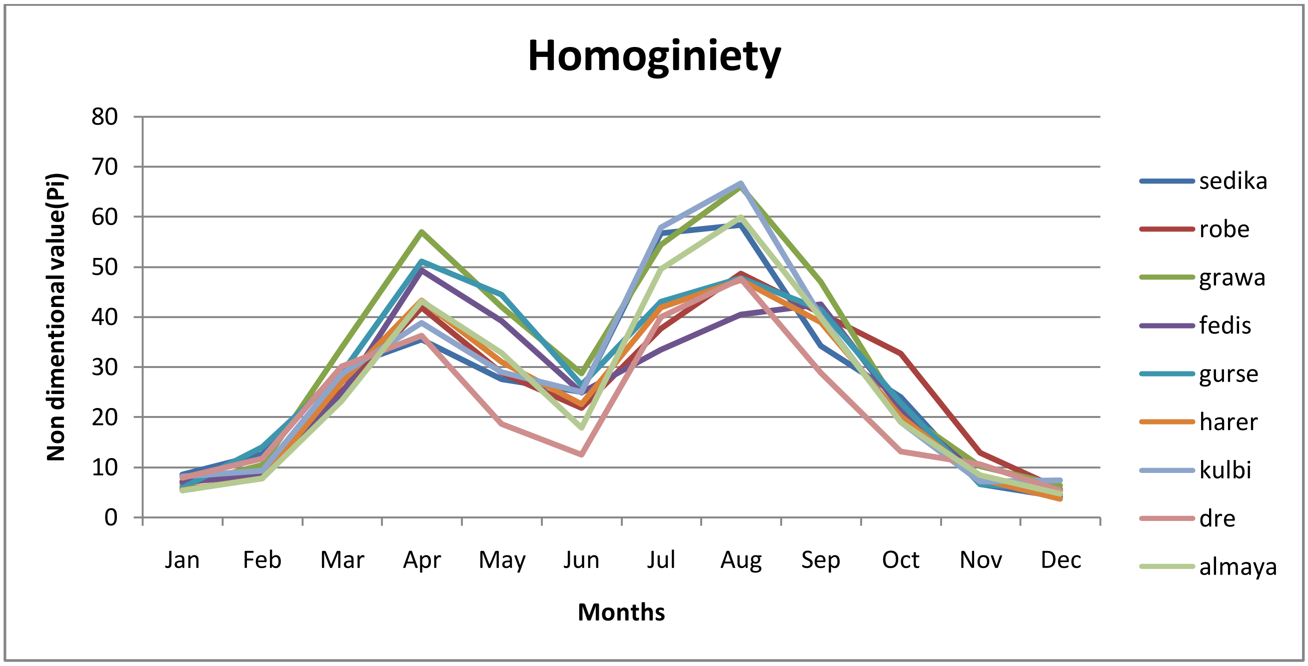


Figure 4-3 Non-dimensional plot of selected stations within and around the Wabishebele River Basin

4.2.1.2 Checking consistency and adjustment of rainfall data

A consistent record is the one where the characteristic of the record has not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value.

The consistency of rainfall records on selected stations is commonly checked by double mass curve analysis. Double mass curve is a graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations. If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time significant change took place. If significant change in the regime of the curve is observed, it should be corrected by using Equation 4.2. The stations used in this study have not undergone significant changes during the base line period (R-squre value is greater than 0.98) of the study.

$$P_{CX} = P_x * \frac{M_c}{M_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

Where: Pcx is corrected precipitation at any time period, Px is original recorded precipitation at time period,Mc is corrected slope of the double mass curve and Ma is original slope of the double mass curve(see appendix 3 double mass curve).

4.2.2 Missing data Completion

4.2.2.1Filling missing rainfall data

Failure of any rain gauge or absence of observer from a station causes short break in the record of rainfall at the station. These gaps should be filled before using the rainfall data for analysis. The surrounding stations located within the basin help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations

A number of methods have been proposed to estimate missing rainfall data

- **Arithmetic Mean Method**
- **Normal Ratio Method**
- **Regression Method**
- **Inverse Distance Method**

Normal Ratio Method: This method is used when the normal annual precipitation of the index stations differ by more than 10% of the missing station. The rainfall of the surrounding index stations are weighed by the ratio of normal annual rainfalls using the following equation

$$P_m = {}^{1}\!/_{n}\left[\sum_{i=1}^{n}\left(\frac{N_m}{N_i}\right)P_i\right] \quad \text{......} \quad 4.7$$

Where,

Nm = Average annual rain at rain gauge for which data are missing,

Ni = Average annual rain at gauge i.

Because the normal-ratio method is more advanced than station average method and simple,it was used for filling the missing rainfall data

4.2.2.2 Filling of missing stream flow

In the analysis of hydrological data, the stations were required to have daily records for the required period of simulation (1990-2000) years. It may so happen that a particular flow-gauge was not functional for a part of a month or year .It then becomes necessary to fill missing records. In this thesis, arithmetic mean value of the entire period was used to fill the missed records for the stations with less than 10 percent missed records while for the stations having greater than 10 percent of missed records normal-ratio method was used

4.2.3 Estimation of Areal rainfall

Rain gauges represent only point measurements. In practice however,hydrological analysis requires knowledge of the precipitation over an area.

Several approaches have been devised for estimating areal precipitation from point measurements.

- Isohyetal method: - isohyets are line joining places of equal rainfall intensities over a basin. An Isohyetal map represents an accurate picture of the rainfall distribution over the basin. If the net work rainfall stations within the storm area are sufficiently dense, the Isohyetal map will give a reasonably accurate indication of the rainfall distribution zones.
- Arithmetic average method:-When the rainfall is uniformly distributed over the area, the average rainfall may be taken as the arithmetic average of the recorded rainfall.
- Thiessen polygon method: - Rainfall varies in intensity and duration from place to place. Hence the rainfall recorded by each rain gauge station should be weighted according to the area it is assumed to represent. In this thesis Thiessen polygon method was used to determine the average areal precipitation over the whole basin from rain gauge measurements.

Average rainfall over the catchment was calculated by

$$\boldsymbol{P_{av}} = \frac{\boldsymbol{P_1A_1 + P_2A_2 + P_3A_3 ---------- + P_nA_n}}{\boldsymbol{A_1 + A_2 + A_3 ---------------- + A_n}} \quad \ldots\ldots \mathbf{4.8}$$

Where

P_{av} average areal rainfall (mm),p_1,p_2,p_3……P_n precipitation of station 1,2,3…n, respectively and A_1,A_2,A_3…..A_n is area coverage of station 1,2,3…n respectively in the Thiessen polygon

The method weights each gauge in direct proportion to the area it represents from the total basin area. The area of influence of each gauge was obtained by constructing Ttheissen polygons. The Theissen gauge weights developed for catchments of rainfall gauging stations are presented in Table 4.1 and Figure 4.5.

Table 4-1 Theissen gauge weights for the rainfall station

ID	Station name	Area (km^2)	Theissen Weight (%)
1	Sedika	17055	9.06
2	Grawa	11601	6.1
3	Kora	4780.4	2.53
4	Fedis	23901	12.69
5	Bedessa	28614	15.19
6	Degahabur	29611	15.72
7	Gode	46144	24.50
8	Kebridahar	26613	14.1

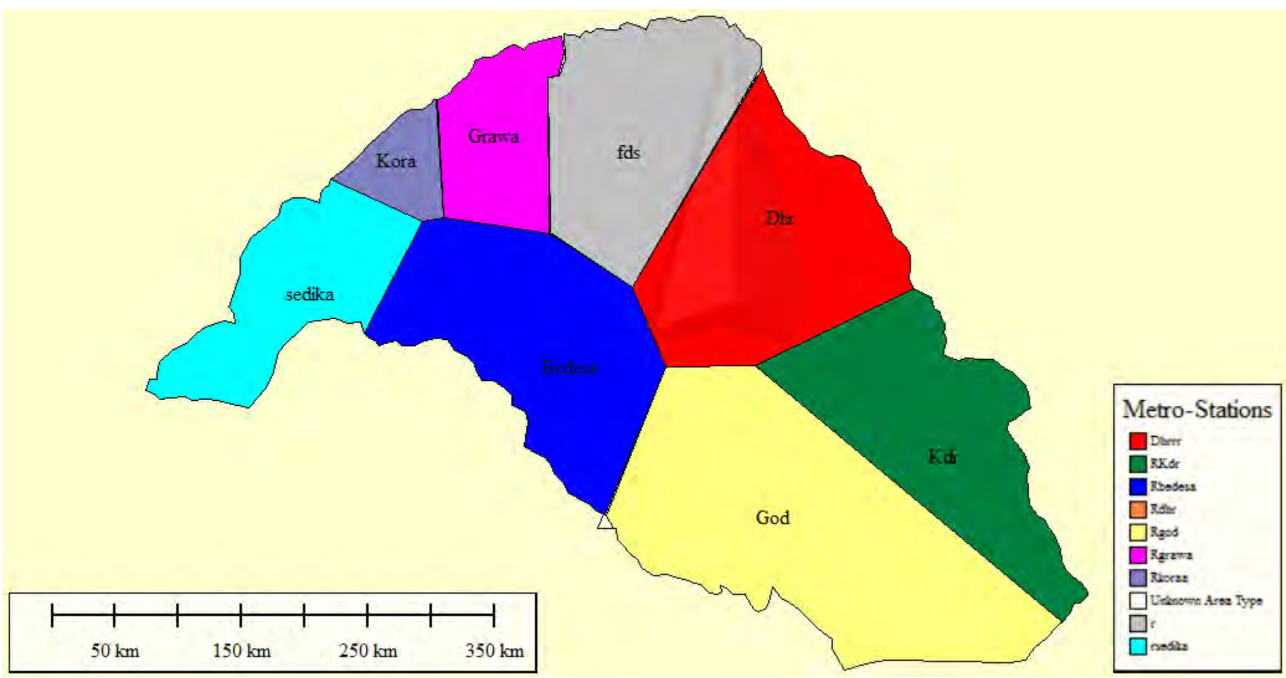


Figure 4-4 Theissen polygons developed for the basin

4.3 Hydrological Modeling in Wabishebele River Basin

4.3.1 SWAT Model parameterization

4.3.1.1 Watershed delineation

The watershed delineation interface in Arc-View is separated into five sections including model Set Up, Stream Definition, Outlet and Inlet Definition, Watershed Outlet(s) Selection and Definition and Calculation of Sub basin parameters. In order to delineate the networks sub basins, a critical threshold value is required to define the minimum drainage area required to form the origin of a stream.

After the initial sub basin delineation, the generated stream network can be edited and refined by the inclusion of an outlet. Adding an outlet at the location of established monitoring stations is useful for the comparison of flow concentrations between the predicted and observed data. Therefore, one sub basin outlet was manually edited into the watershed based on known stream gage location that had sufficient stream flow data available from 1976-2005

4.3.1.2 Hydrologic response unit definition

Hydrologic response units (HRUs) are lumped land areas within the sub - basin that comprised of unique land cover, soil and management combinations. The overlay of land use, soil and slope maps resulted in the definition of 270 HRUs. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff of was estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of inflow prediction and provides a much better physical description of the water balance, the land use and the soil data in a projected shape file format that was loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes. After the land use SWAT code was assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil data base information by loading the soil look- up table and reclassification applied. The DEM data used during the watershed delineation was also used for slope classification. After the reclassification of the land use, soil overlay operation was performed.

The second step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU- definition, a threshold level was used to eliminate minor land uses, soil or slope classes in each sub – basin. Land uses, or soils which cover less than the threshold level were eliminated. After the elimination process, the area of the remaining land use was reapportioned so that 99.93% of the land area in the sub- basin was modeled. The threshold levels set is a function of the project goal and amount of detail required.

4.3.1.3 Weather data definition

Available Meteorological records (i.e. precipitation, relative humidity, minimum and maximum temperature, solar radiation and wind speed) and location of Meteorological station were prepared based on SWAT CN table format and integrated with the model using weather data input wizards. Gode Meteorological station data were used as weather generator because it is a synoptic station.

4.3.1.4 Sensitive analysis, calibration and validation

After the model setup completed, the next step was to run the model and analyze the simulation result. The applicability of the model for intended purpose should be evaluated through the process of sensitivity analysis, calibration and validation (Whit ,2005)

Sensitivity analysis evaluates the influence of different parameters on simulation result, the response of output variable to a change in input parameter. Model users are often faced with the difficult task of determining which parameters to calibrate so that the model response mimics the actual field conditions as closely as possible. In such cases, sensitivity analysis is helpful to identify and rank parameters that have significant impact on specific model outputs of interest. The most sensitive parameter corresponds to greater change in output response. It can also improve simulation result and thus understand the behavior of hydrologic system in Wabishebele River. Sensitivity analyses were conducted using the entire flow parameters. Model calibration involves modification of input parameters and comparison of predicted output with observed values until a defined objective function is achieved. Parameters identified in sensitivity analysis that influence significantly the simulation result were used to calibrate the model. In this research, model sensitivity and calibration were performed using the output of SWA T-CN method.

A SWAT model was calibrated and validated on a monthly basis to estimate the flow using a time series dataset of 10 years from 1990 to 2000. The first year of the modeling period was used for model warm-up". Data for the period 1991 to 1996 were used for calibration and the remaining part of the dataset was reserved for validation. The watershed was subdivided into 15 sub basins based on a chosen threshold area of 700,000 ha.The simulated flow at the outlet of the watershed gauging station was compared with the observed flow.

Stream flows, measured at Gode stream gauges were used for calibrating and validating the model. This stream gauge is not affected by reservoirs, diversions, or return flows that is why it is selected for model calibration and validation

4.3.2 Building WEAP model

Water demand sites and catchment were added and WEAP was run in its water allocation mode using the rainfall-runoff parameters determined from the SWAT model and demand data. This was done in order to assess water uses in the basin. The model was used in this study operates at the WEAP sub catchment scale and on both monthly and daily time- steps.

WEAP software is composed of five different "views" onto the working Area: such as Schematic, Data, Results, Overview and Notes. These views are listed as graphical icons on the View Bar located on the left of the screen. The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. The comparison of these alternative scenarios proves to be a useful guide to development policy for water systems from local to regional scales

WEAP calculates a water quantity for every node and catchment and link in the system on a monthly daily time step. Water is dispatched to meet in stream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints.

Building the area by adding GIS based Raster and Vector maps to the projected area for the purpose of orient and constructs the system and refines the necessary area boundaries.

The background vector data can be added from a shape file format. Once the area is open, the years, Time Steps and Units are set.

In this study, the Current Account is set to be year 2000 with the Last Year Scenario to year 2030. The Time Steps per year was set to be 12 and the Time Step Boundary to "Based on Calendar Month", starting with the month of January. The Current Accounts year is chosen to serve as the base of the model, and all system information (for instance, demand and supply data) is the input into the Current Accounts. The Current Accounts is the dataset from which the scenarios are built. A default scenario, the "Reference Scenario" carries forward the Current Accounts data into the entire project period (2000-2030). River path is drawn in WEAP by clicking on the "River" symbol in the element window. The direction of the flowing river is built from the headwater (upstream) of the main river.

4.3.3 Water demand for different sectors

The water demand is the total amount of water required to meet domestic, commercial, agricultural, institutional, hydropower, environmental and industrial uses. Different water-use sectors were modeled within fifteen sub-catchments. The current water demand for domestic use of the basin was estimated at about 15-35 liter per day.

Wabishebele River Basin has an estimated total population of 6 million (2000).Over the last time, the population growth rate of the study area has been increasing at 2.9% percent per annum. (MoWIE, 2004)

4.3.3.1Demand site for agriculture

In this study six major irrigation sites were chosen five (from prefeasibility study) (MoWIE,2004) and one from existing irrigation project. Agricultural demand comprises irrigation of large plots and formal schemes. Therefore, only large scale irrigation is represented in this sector. Within the WEAP model the irrigation water demand varied interannually based on rainfall. During wet years the irrigation demand reduces and during dry years it increases(McCartney,2005)

Agricultural irrigation demands has been calculated by simulating demand node and CropWat model of the Food and Agriculture Organization (FAO) was used to simulate the observed seasonal pattern of irrigation with different cropping seasons in the basin. SWAT output stream flow data were used as the main hydrological inputs. Metrological data were used to estimate net evaporation from catchment and interannual variation in irrigation demand.

It is the land area for a catchment or sub catchment, or the share of land area from the branch above. There are different crops on the same piece of land in different years (crop rotation). It can be done with different branches under the catchment

Table 4-2 Location of selected large scale irrigation site

Project Destignation	Location zone	Gross irrigation area	Net Irrigation area	Headwork type	Latitude	Longtude
Gololcha –I	Bale	11500	10000	Dam	7^0 24'	$40^0$46'
Gololcha –IV		9200	8000	Dam	$7^0$32'	$41^0$16'
Erer	E.Hararghe	4600	4000	Dam	$9^0$16'	$42^0$05’
Gode -West	Gode	10000	8300	DW	6°08'	43°08'
Gode south	Gode	23,000	18,800	Syphon	6°08'	43°08'
Robe2	Arsi	98100	97000	Dam	7° 53'	39° 37'
Bludohe	Kelafo	57000	52150	Dw	5°35'	44°14'
Umcho	W.Hararghe	4600	4000	Dam	8° 46'	40° 53’

4.3.3.2 Domestic water demand

All domestic demands drawing water from the Wabishebele River Basin are captured in WEAP as aggregate as urban, rural, public and industrial demands

Each node represents the respective population multiplied by the average per capita water demand an area. Ahypothetical per capita water demand of about 30 and 15 m3 per year were used respectively for urban and rural areas.This is lower than the WHO recommendation of 130L per person per day (or 47.3 m3 per person per year).(David,1998)

4.3.3.3 Hydropower demand

The WEAP model utilizes required energy production and the characteristics of each reservoir to determine the flows necessary for meeting specified hydropower demand.

Note that both plants on sub catchments are treated as one reservoir hydropower plant, with combined energy demand for Melkawakena and WS18, for practical reasons.

Maximum turbine flow is a key parameter in WEAP, and must be specified for the model to allow electricity generation. Turbine flow should correspond to the rated capacity of the plant, taking into consideration the net head, efficiency and availability of the plant .For this study average turbine discharge was 94.4 cms, tail water elevation was approximately 484.5 m- amsl, generation efficiency of 100%, Plant Factor of 71% and combined energy demand for Melka wakena and WS18 was 927GJ

Hydropower demand was computed based on water demand rather than energy demand by converting the energy demand into an equivalent volume of water that must be released from the reservoir that month to satisfy that demand.

Table 4-3 Reservoir volume elevation relationship for dam site WS18

Elevation(m.a.s.l)	Area(km2)	Volume(Mm3)
480	0.1	
520	25.64	364.55
560	61.76	1695.91
600	103.56	3375.54

4.3.3.4 Public and Industrial water demand

The water requirement for schools hospitals, hotels, public facilities, parks, offices, commercial establishments etc. is classified as public demand. Public demand is usually expressed as a percentage of average domestic. For this study an average 5% has been taken for all towns at the current account year This is expected to increase to 15% for towns at the end of the scenario period. For the rural areas, a flat rate of 5% has been considered

Industrial firms use water for several purposes: cooling intermediate inputs, producing high-pressure steam, moving inter-mediate inputs, sanitation, and as a direct input (e.g., in beer production)

Taking in to account the potential of industrial development in the basin a flat rate of 20% is adopted for all towns, and no provision was made for rural areas

Water loss is normally calculated as a percentage of the domestic demand .In this thesis water loss of 15% for urban areas and 5% for rural areas were used.

4.3.3.5 Livestock demand

The total water requirment for the basin livstock was calculated based on the average daily drinking water reqirment of each livestock.

Table 4-4 Estimated daily drinking water requirement of livestock under African condition (liters)

Animal	Weight(kg)	Mean	Maximum	For plannig purpose
Cattel	350	16.4	56.1	25
Sheep	35	1.9	5.2	5
Goat	30	2	5.4	5
Equine	-	-	-	12
Camel	500	18.4	34	30

Table 4-5 Annual water requirement for livestock in the basin

Animal	Average water requirment (lt/hd/day)	Annual water requirment (cu.mt/hd/yr)	Total Livestock(hd)	Total water requirment (Mm^3/yr)	%share
Cattel	25	9.13	5891100	53.78	64.88
Sheep	5	1.83	5744900	10.51	12.68
Goats	5	1.83	4616300	8.45	10.19
Equine	12	4.38	595300	2.61	3.15
Camel	30	10.95	688800	7.54	9.10
Total		28.11	17536400	492.95	100

(MoWIE,2004)

4.3.3.6 Environmental flow demand

An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated.

In order to maintain the ecological services as well as the natural channel habitat associated to the historic flow regimes of the WabiShebelle River, a certain reserve flow has to be maintained and could be considered as a sectoral demand on its own

An environmental flow that corresponds to low flow of 95% exceedence has been used in this study.

5 Results and discussion

5.1 Sensitivity analysis

Sensitivity analysis was carried out to identify which model parameter is most important or sensitive. From this analysis tewenty seven parameters were identified (Table 5-1). Curve number (CNII) , soil evaporation compensation (ESCO),soil depth (SOL_Z) and channel hydraulic conductivity (CH-K2) were the most sensitive parameters that significantly affect surface run off .

Table 5-1 Sensitive Parameters and range of optimum value

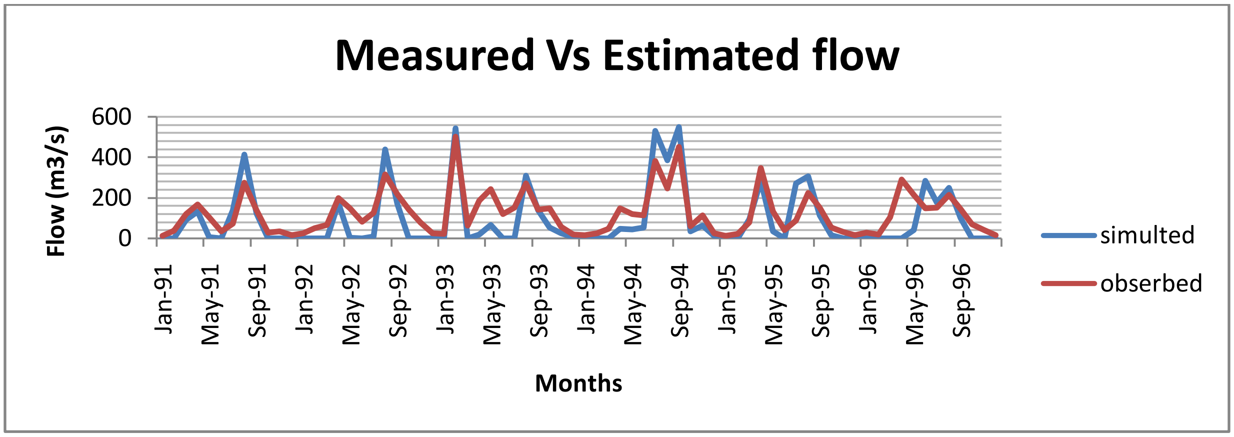
Name	Discription	Relative sensivity	Rank	Min	Max
cn2	SCS runoff CN for moisture condition II	1.57	1	35	98
Esco	soil evaporation componsation factor	0.606	2	0	1
Sol_Z	soil depth	0.445	3	0	3000
Ch_K2	hydraulic conductivity in main channel (mm/hrs)	0.341	4	0	150
Revapmn	Threshold depth of water in the shallow aquifer for revap‘ t o occur (mm)	0.329	5	0	500
Sol_Awc	Available water capacity of the soil layer (mm/mm soil)	0.265	6	0	1
Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.221	7	0	5000
Alpha_Bf	Baseflow alpha factor (days)	0.204	8	0	1
Blai	Maximum potential leaf area index	0.106	9	0.5	1.5
Gw_Revap	Groundwater revap‘ coefficient.	0.0944	10	0.02	0.2
Canmx	Maximum canopy storage [mm];	0.083	11	0	1
Epco	lant evaporation compensation factor	0.0167	12	0	1
Sol_K	Soil conductivity (mm/hrs)	0.0147	13	0	100

5.2 Stream flow calibration and validation

Model calibration involves adjustment of parameter values of models to reproduce the observed response of the Wabishebele Basin within the range of accuracy specified in the performance criteria. After the sensitive parameters were identified using sensitivity analyses, a combination of manual and automatic calibration methods were used to calibrate the model using the observed monthly stream flow for a period (1991 -1996) .Calibration resulted in Nash-Sut cliffe simulation efficiency (ENS) of 0.81 and correlation coefficient (R^2) of 0.70 showing a good agreement between measured and simulated monthly flows. The calibration result demonstrated the SWAT's ability to predict realistic flow.

Table 5-2 Calibrated and default SWAT parameter value

s.no	Parameter	Initial value	Calibrated value
1	Alpha_Bf	0	0
2	Biomix	0.2	0.2
3	Canmx	0	0
4	Ch_K2	0	0
5	Cn2	94	57
6	Epco	0	0
7	Esco	0.9	0.31
8	Gw_Delay	31	31
8	Gw_Revap	0.02	0.02
9	Gwqmn	0	5000
10	Revapmn	1	1
11	Sol_Alb	0.13	0.13
12	Sol_Awc	0.15	0.1



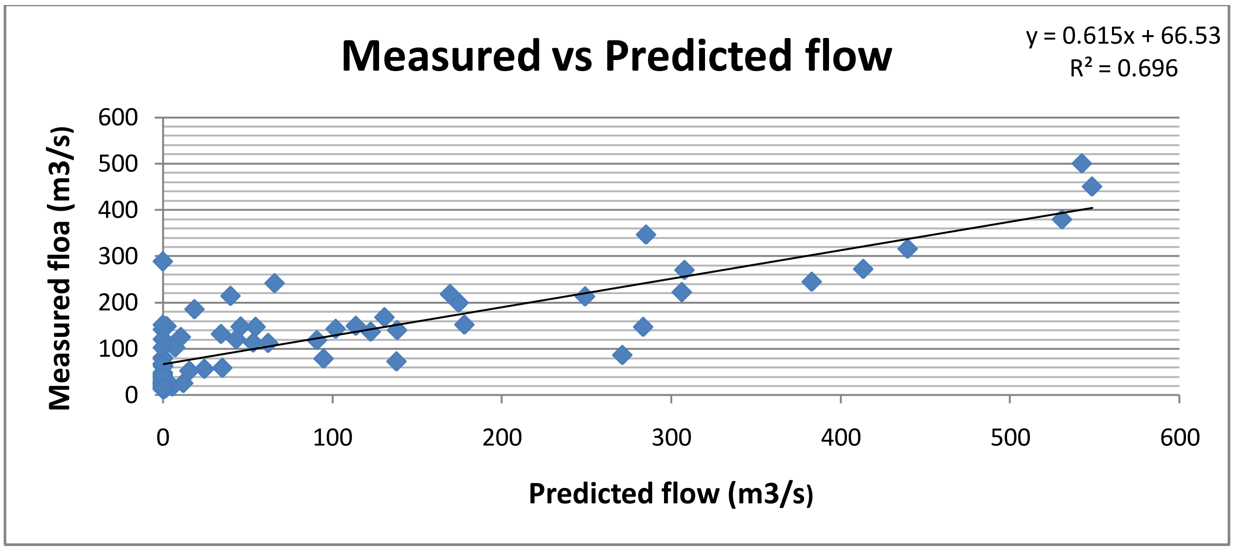
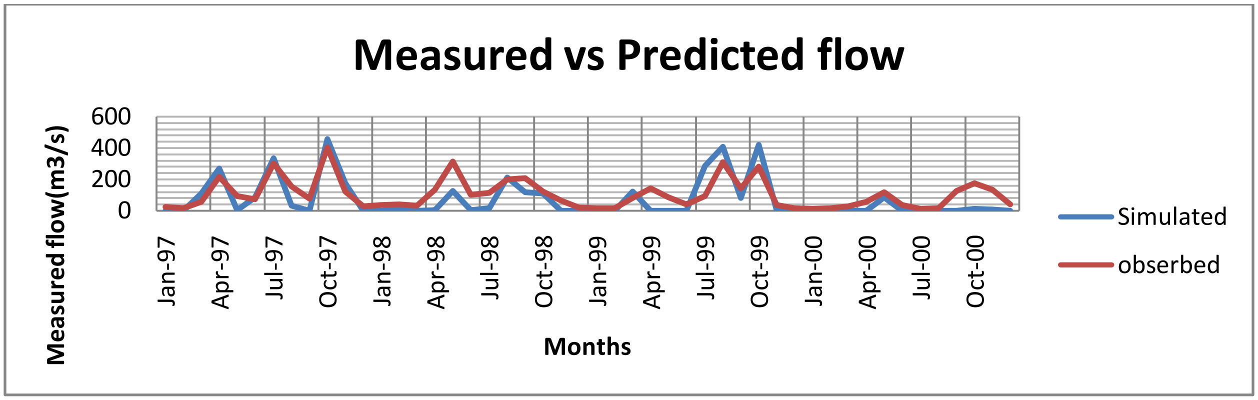


Figure 5-1 Monthly measured vs. estimated flow, calibration

In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set perform reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in both the calibration and validation phase .the model can be used with some confidence for future predictions under somewhat different management scenarios (Kassa,2009).

Calibrated parameters were validated for the period of (1997-2000) and the model results were then compared with observed stream flow values measured at Gode gauging station.

Validation resulted in Nash-Sut cliffe simulation efficiency (ENS) of 0.87 and correlation coefficient (R^2) of 0.66 showing a good agreement between measured and simulated monthly flows.



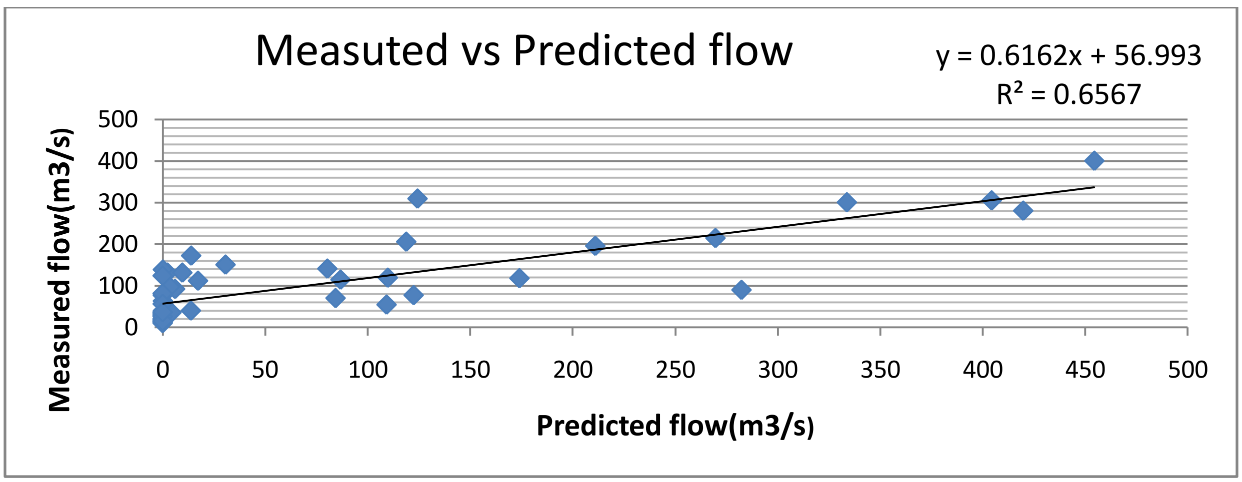


Figure 5-2 Monthly measured vs. estimated flow, validation

After compiling all data, several simulations were carried out. The model computes the surface flow of theWabishebel River Basin, the flow rate, the peak runoff rate, potential and actual evapotranspiration,and the water yield, some of them were compared with measurements carried out by master plan of Wabishebele River Basin at Gode station.

5.3 Comparison of result with previous study

Table 5-3 Comparison between model annul output and previous study

Water balance component	This study	Master plan study
Surface runn off(BM³)	3.763	3.49
Rainfall(mm)	468.1	425
Actual evaporation(mm)	374.2	-
Potential evapotraspiration(mm)	1503.1	1500
Water yield (BM³)	3.154	-
Area (km²)	188818.89	200000

Evapotranspiration is the combination of evaporation from the soil surface and transpiration from vegetation and was estimated by standard Penman- monteith method

The following figure presents the monthly actual evapotraspiration and potential evapotranspiration for the basin

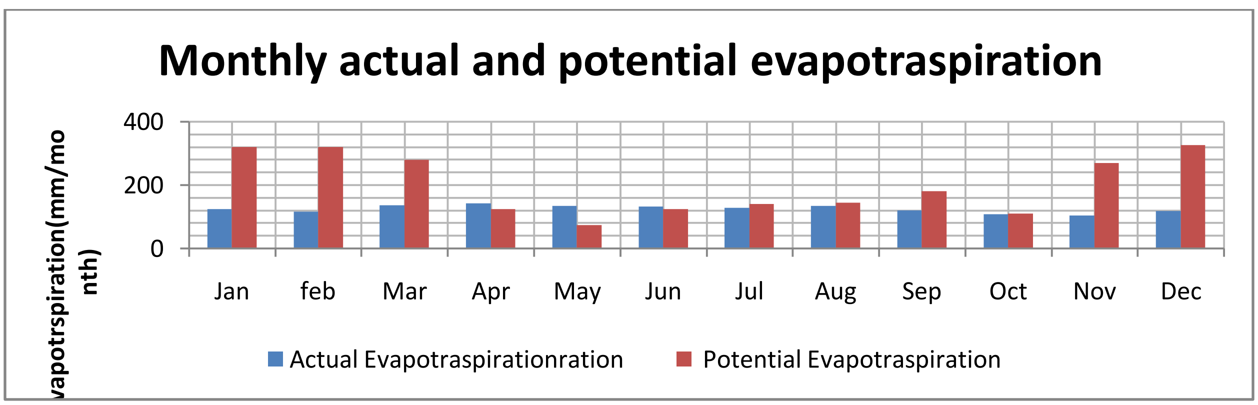


Figure 5-3 Monthly evaporation and potential evapotranspiration

The mean annual precipitation is about 468.3mm with the minimum monthly rainfall of 5.83mm in December and maximum 73.22mm in April.

The rainfall is bimodal taking place in March-May and June - September. The low rainfall amount coupled with its erratic nature makes crop growth unreliable even during the main rainy season.

Surface runoff contribution of each sub basin spatially clearly is shown in the following figure 5.4

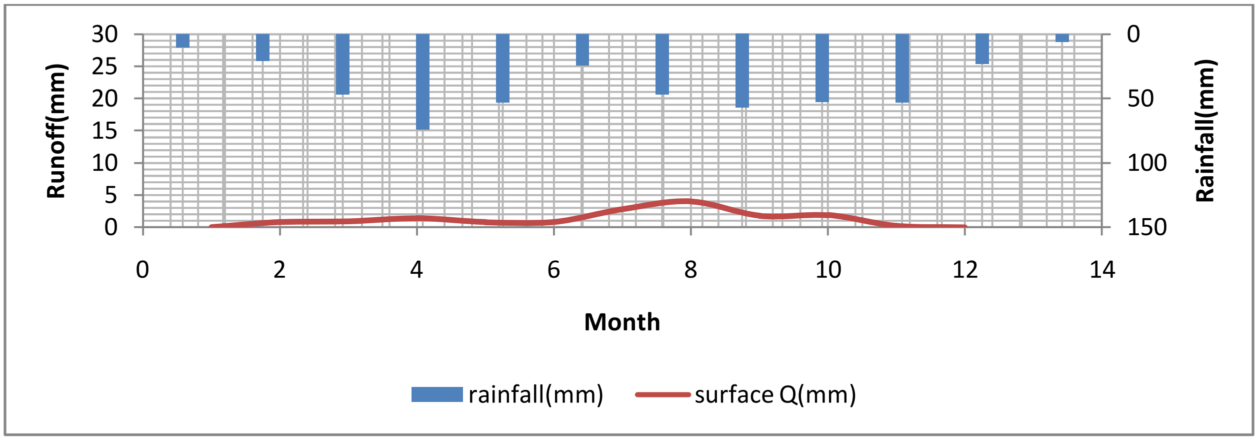


Figure 5-4 Monthly rainfall and run off of the basin

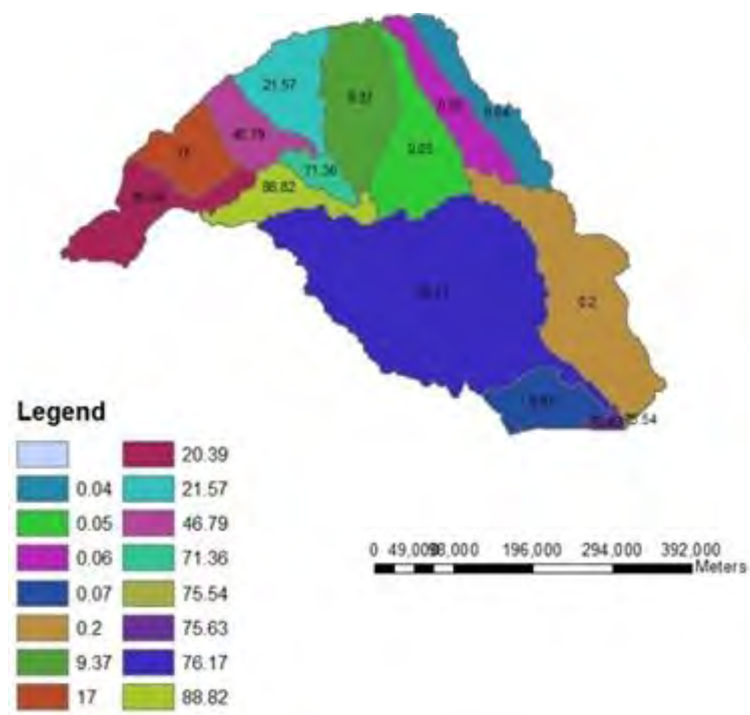


Figure 5-5 surface runoff result for each sub basin

5.4 Analysis of WEAP scenarios

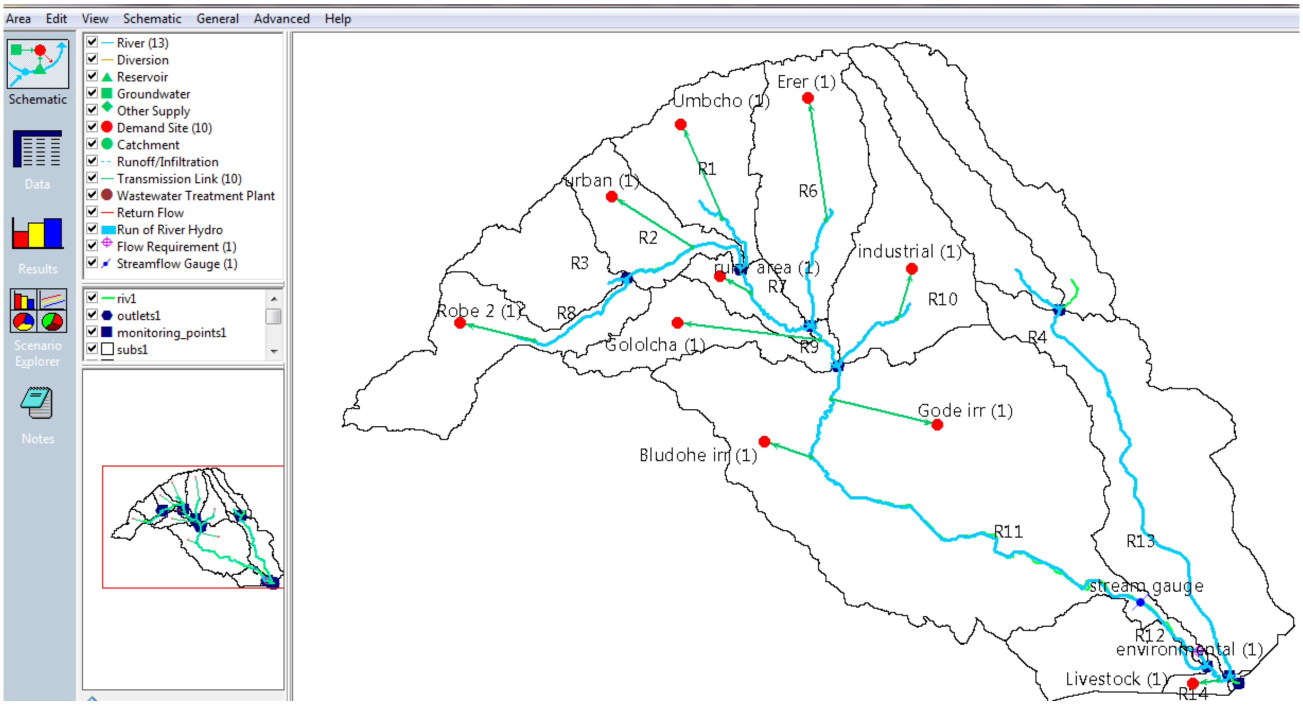


Figure 5-6 Schematic area of the basin

In this section, the outputs of the WEAP model for the Wabishebele Basin and the different scenarios are presented .

The modeling was done for the Reference Scenario, that was generaterd using Current Accounts information for the specified project (2000 to 2030).

In WEAP, the typical scenario modelling effort consists of three steps:-

i. Current Accounts year is chosen to serve as the base year of the model. In this study year 2000 was selected to be the base year;

ii. Reference scenario is established from the Current Accounts to simulate likely evolution of the system without intervention; and

iii. What-if scenarios can be created to alter the "Reference" scenario and evaluate the effects of changes in policies and/or technologies.

The following results for Wabishebele River Basin were made based on three (3) scenarios :

i. Baseline water demand
ii. Reference Scenario
iii. Scenario 1: Irrigation projection
iv. Scenario 2: WS18 Dam construction
v. Scenario 3 :Increased water demand scenario

5.4.1 Baseline water demand

The WEAP model was set up for the 2000 baseline water demand Under this condition, domestic,and livestock demand site data were identified based on Annual Water Use Rate . The total agricultural demand was estimated using cropwat cosidering the land use,climate and soil of the area.

Hydropower generation was computed from the flow passing through the turbine,based on the reservoir release stream flow, and constrained by the turbine's maximum flow capacity.

Environmental flow was determined from the flow duration curve corresponding to 95% exceedence of discharge ,which was gained from SWAT output .This flow is required along a river to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements. The flow duration curve with 95% exceedence, which is 3.25m^3/s, is shown in the figure 5.7.

Environmental flow demands stay the same annually 104.4 MCM for the Shebelle River.

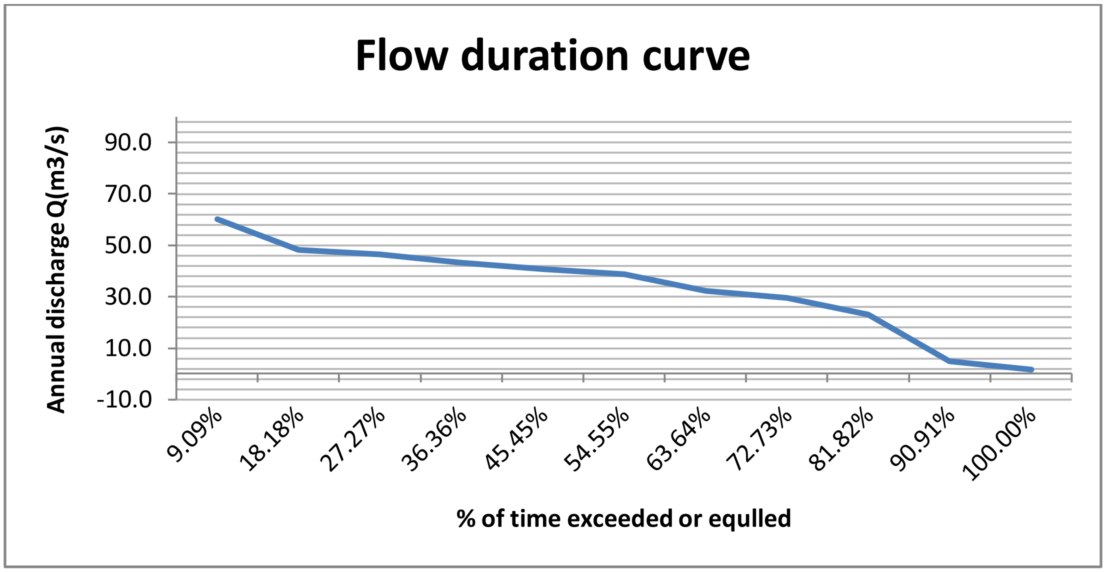


Figure 5-7 Flow duration curve (own source)

Table 5-4 Overall water demand for the year 2000

No	Demand site	Population / Area (ha / number)	Demnd (Million m^3)	Unmet demand (Million m^3)	Remark
1	Bludohe irrigation	52150	44.3	33.13	
2	Erere agricultural area	4000	1.2	1.2	
3	Gode irrigation	27100	23.0	17.22	
4	Gololcha irrigation	18000	5.4	1.36	
6	Industrial and public demand	4000	5.2	5.2	45% urban demad
7	Livestock demand	17536400	131.16	98.1	
8	Rural demand	771505	62.2	24.99	
9	Robe 2 irrigation	97000	25.2	16.49	
10	Umcho irrigation	4000	1.2	1.2	
11	Urban demand	5657705	11.6	0	
12	Environmental demand		104.4	0	
13	WS18 hydropower demand		97.7	0.011	
	Sum		512.56	198.9	

All the above data served were act as the base input to the model in order to project the water demand in the next fifteen (15) years in the Reference Scenario.

The comparison of current annual demands by the different sectors reveals the clear dominance of agricultural water use over livestock, environmental flow, hydropower and domestic demands.

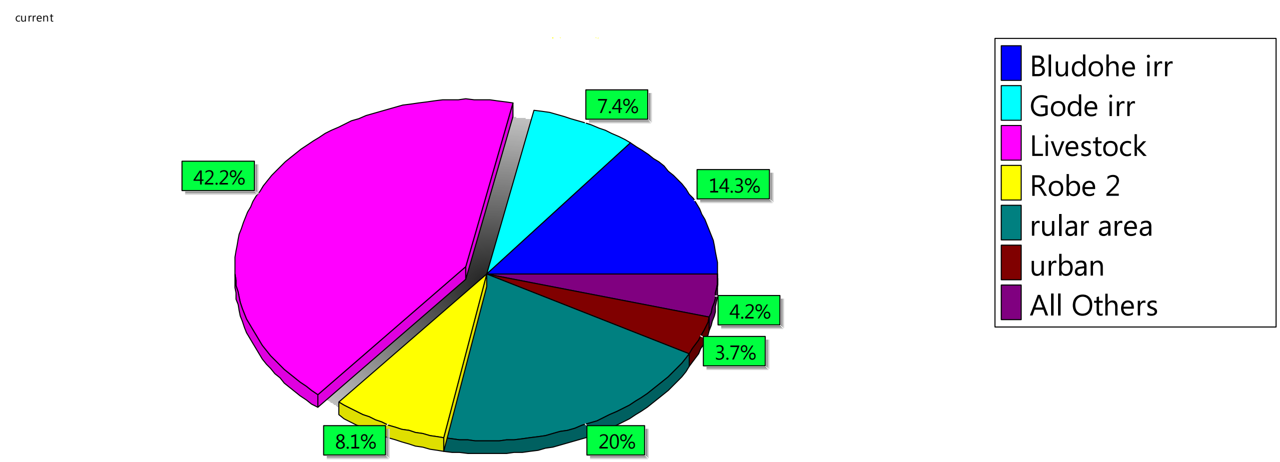


Figure 5-8 Current annual sectoral water demand water in Wabishebele River Basin

5.4.2 Reference scenario

The Reference scenario is the scenario in which the current situation, current account year as 2000 is extended to the future (2001-2030). No major changes are imposed in this Scenario (Akivaga,2010) Alinear population increase was assumed based on the Central Statistics agency of E thiopia report (The population rate increased about 2.9%). The model mimics reality over the period 2000 to 2030, given the constraints of simplification of the model and data limitations.

Increased of Irrigation Water Needs for simulation of agricultural water demands from natural rain fall is cosidered in the model for this scenario.

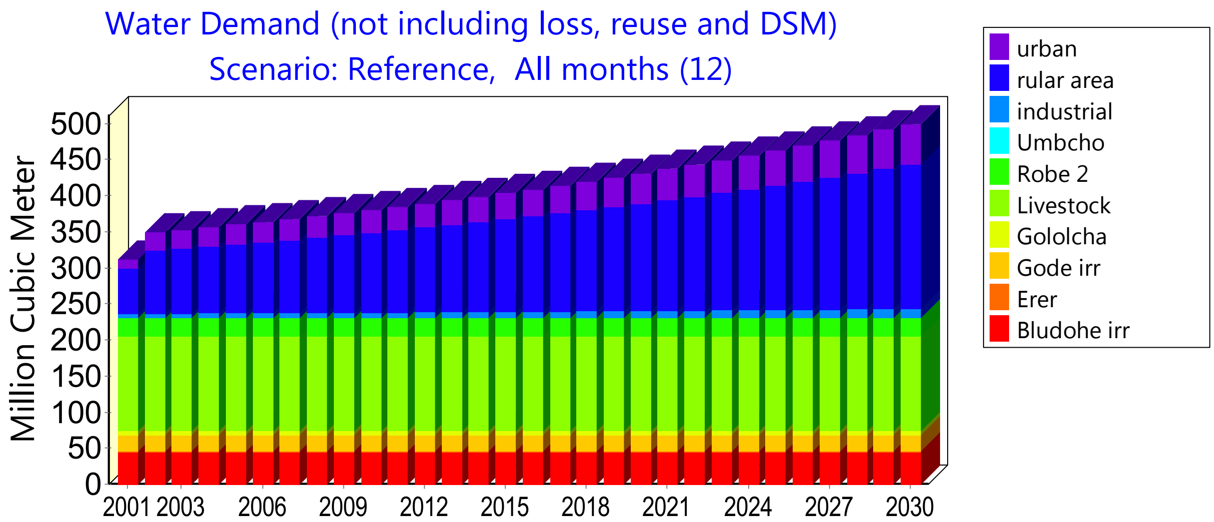


Figure 5-9 Over all reference scenario result

Table 5-5 Overall result for reference scenario

year	2000	2001	2005	2010	2013	2015	2020	2025	2030	Total
Demand(Mm^3)	512.66	562.30	641.42	797.19	937.54	1059.10	1506.06	2276.82	3615.52	10291.81
Unmet demand(Mm^3)	198.90	277.52	65.94	206.25	318.74	268.59	503.41	1374.06	1530.16	4743.57

The reference scenario is overshadowed by the Robe2 ,Gode and Bludohe irrigation schemes,unmet demands Water shortages occur June of most years. Both domestic and agricultural demands are met except for industrial demands in the month of April toJune and October to December

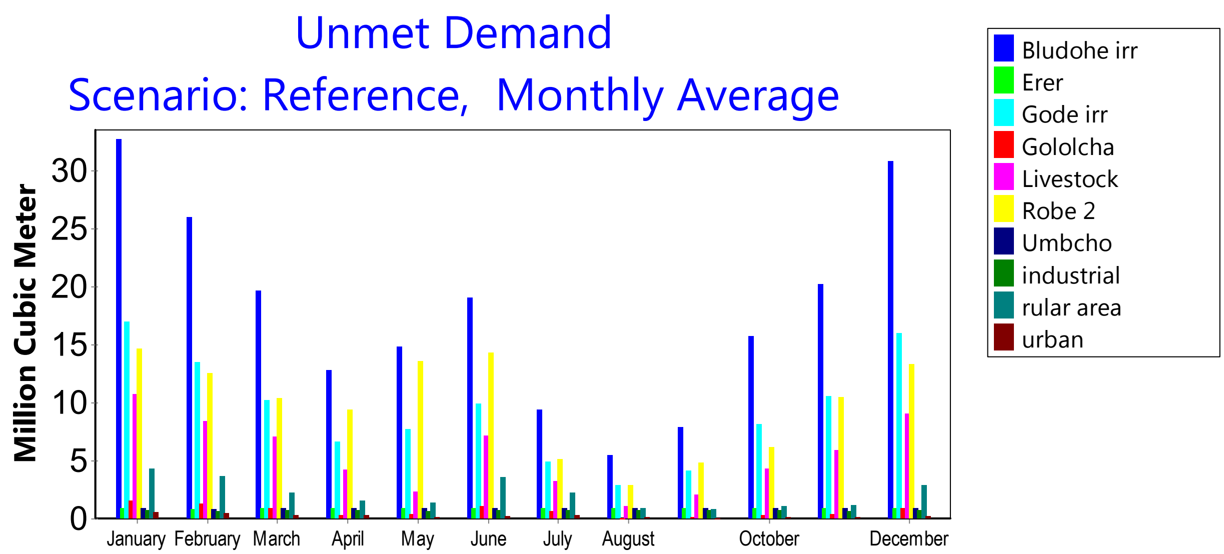


Figure 5-10 Reference scenario monthly unmet demand

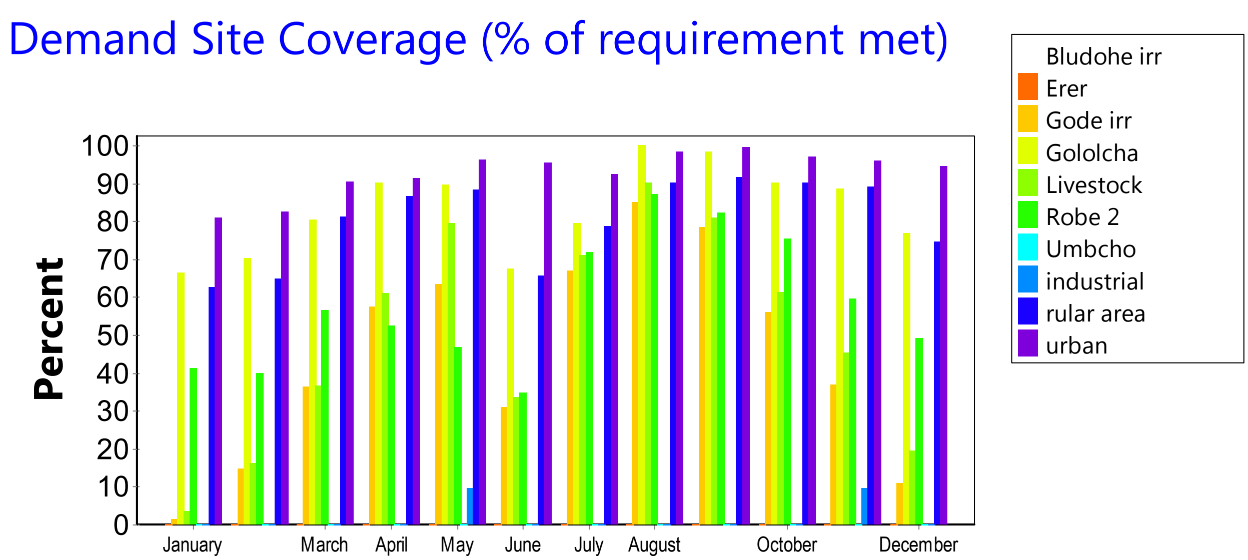


Figure 5-11 Reference scenario mean monthly demand coverage of basin

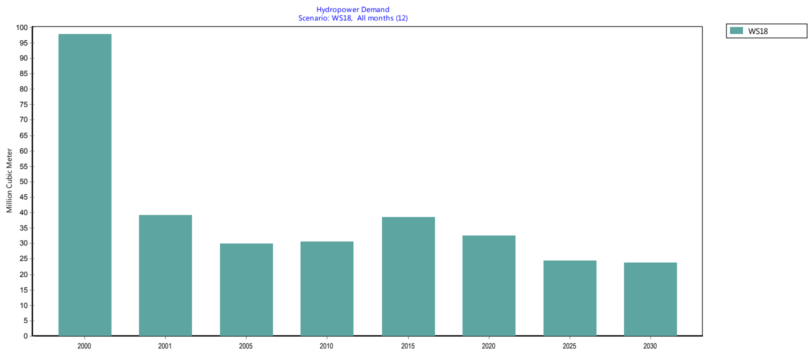


Figure 5-12 hydropower demand of reference scenario

5.4.3 Scenario1 Irrigation projection

In order to foresee the impact of possible condition to the model. Scenario was created to evaluate the impact of irrigation projection for basin higher than current command area for the period 2001-2030 .

Increase the expanition area rate for the whole basin from a value of normal to 5% to all command area.It is noted that the water demand for the case of irrigation projection of command area gives four times of water demand in 2030 compared to 2000 in the irrigation areas. The total water demand for Scenario 1 is indicated to be a total amount of 99.6 million cubic meters for Robe2 Irrigation demand compared to reference scenario, a total amount of 23 million cubic meters.

Unmet Demand for Robe2 irrigation project in year 2030 with the amount of 109 million cubic meters. This indicates that if the command area is increased at a rate of 5 % in 2030, there will be a shortage of water in future

Table 5-6 Overall result of Robe2 agricultural area water demand

Year/demand			2000	2001	2005	2010	2015	2020	2025	2030	Total
Demand (Mm^3)	Robe 2	Reference scenario	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	184.3
		Scenario1	23.0	24.2	29.4	37.5	47.9	61.1	78.0	99.6	400.7

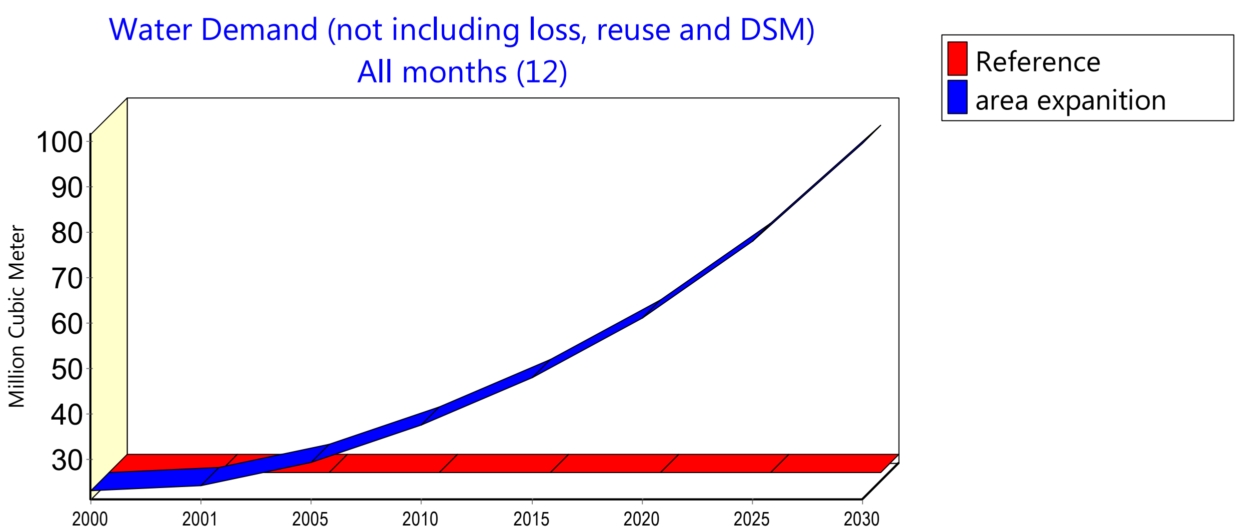


Figure 5-13 Mean annually water demands of irrigation projection

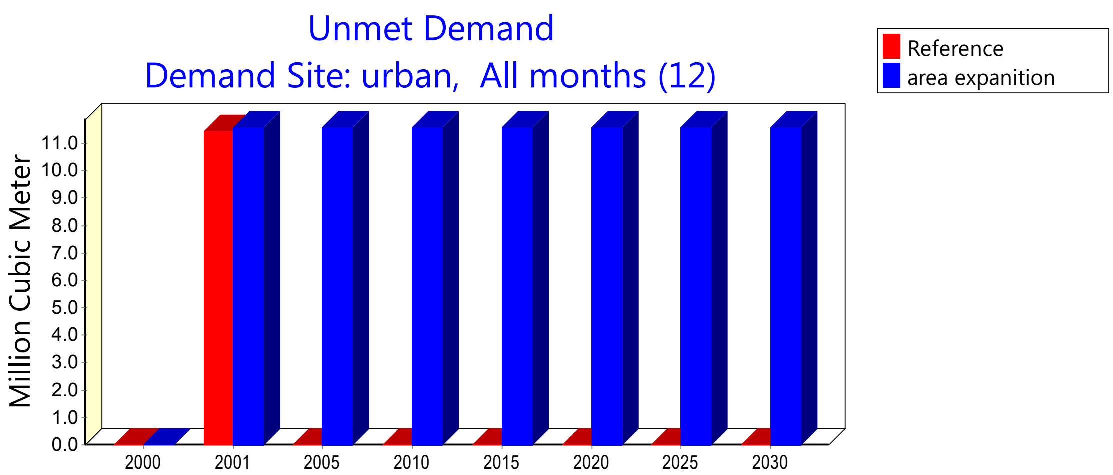


Figure 5-14 Unmet demands of irrigation projection

5.4.4 Scenario 2 WS 18 Dam construction

The government is planning to construct multipurpose dam on Wabishebele River Basin for water supply, hydropower and irrigation.

The proposed WS18 Multipurpose dam with an estimated reservoir volume of 2000 million m^3

This scenario looks at what will happen if the Reservoir has been built on the upstream side of robe irrigation demand node.

The construction of dam in this scenario will impact significantly on the downstream users.

On average, there is a great reduction in monthly average unmet demand in the catchment for the simulated period as compared to the results obtained from the reference scenario

Figure 5.15. The highest amount of unmet demand dropped more than 75%. This indicates that the construction of this dam will reduce water scarcity situations downstream of the catchment.

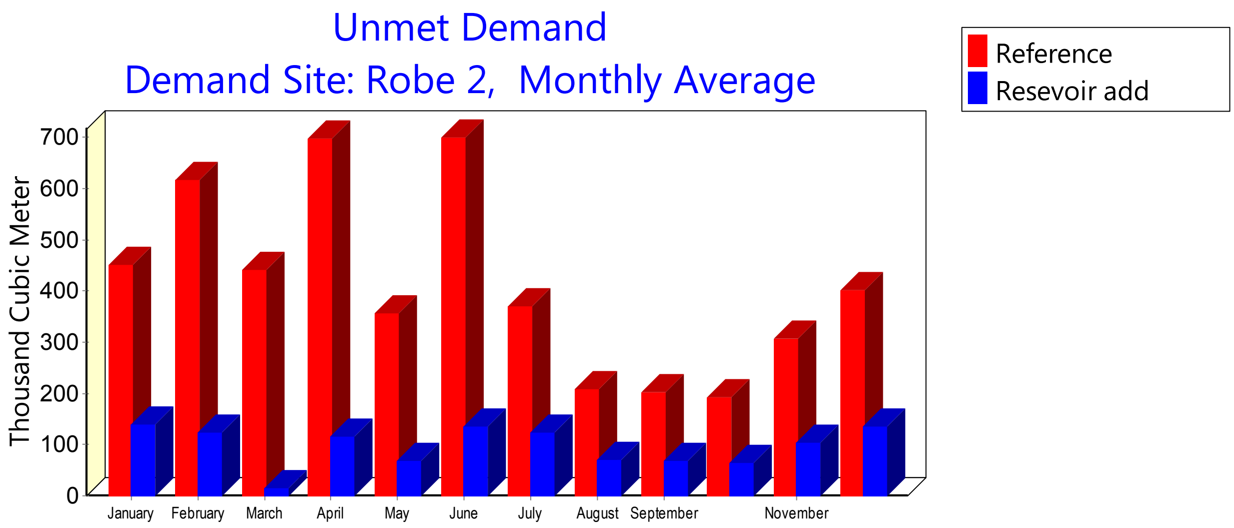


Figure 5-15 Unmet demands of added Reservoir

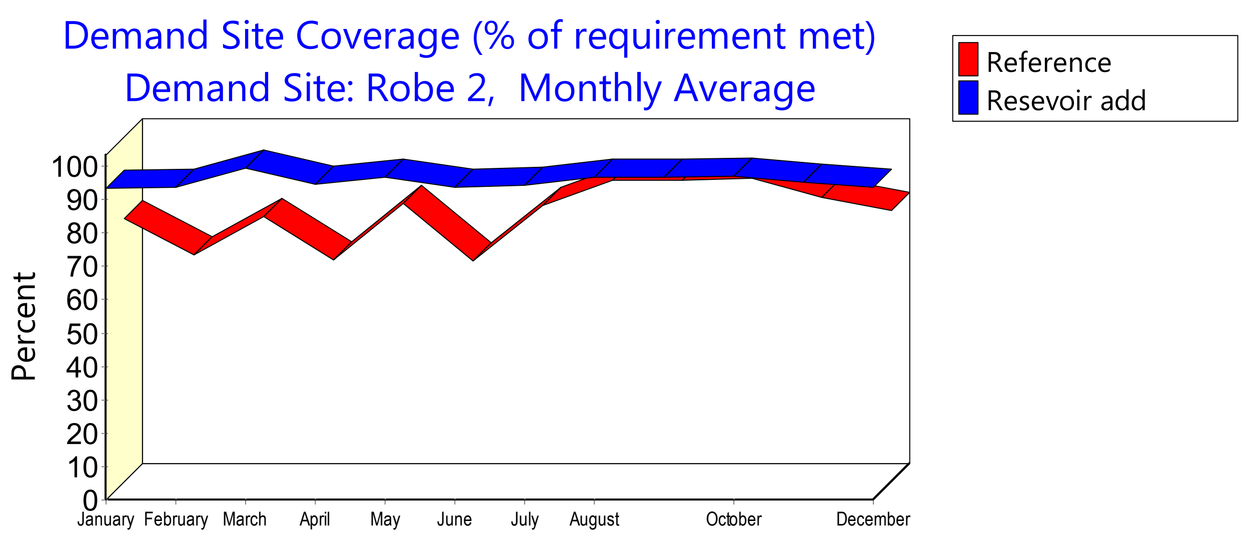


Figure 5-16 Demand coverage of dam

5.4.5 Scenario 3 Increased water demand scenario

It is proposed that for well standard of living the per capita demand should be increased .This scenario was modeled to assess the impact of consuming more water (40l/c/d to 110l/c/d) at rural scheme level.

Demand coverage at rural area Scheme increased on average by 56 %. In the reference scenario, the month of June had the least demand Coverage at only 75.33%. In this scenario, the lowest demand coverage is 15.32% in June.

Table 5-7 Demand and Unmet demands for increase water demand scenario

Year/demand		2000	2005	2010	2015	2020	2025	2030	Total
Demand (Bm3)	Reference scenario	0.06	0.10	0.11	0.13	0.15	0.18	0.21	0.94
	Scenario 3	0.06	0.39	2.42	15.08	94.05	586.36	3655.87	4354.23
Unmet Demand (Mm3)	Reference scenario	24.99	0.00	0.00	17.66	0.00	58.99	6.82	108.46
	Scenario 3	25.0	16.7	1464.7	12055.3	92543.6	583886.6	3652795.3	4342787.1

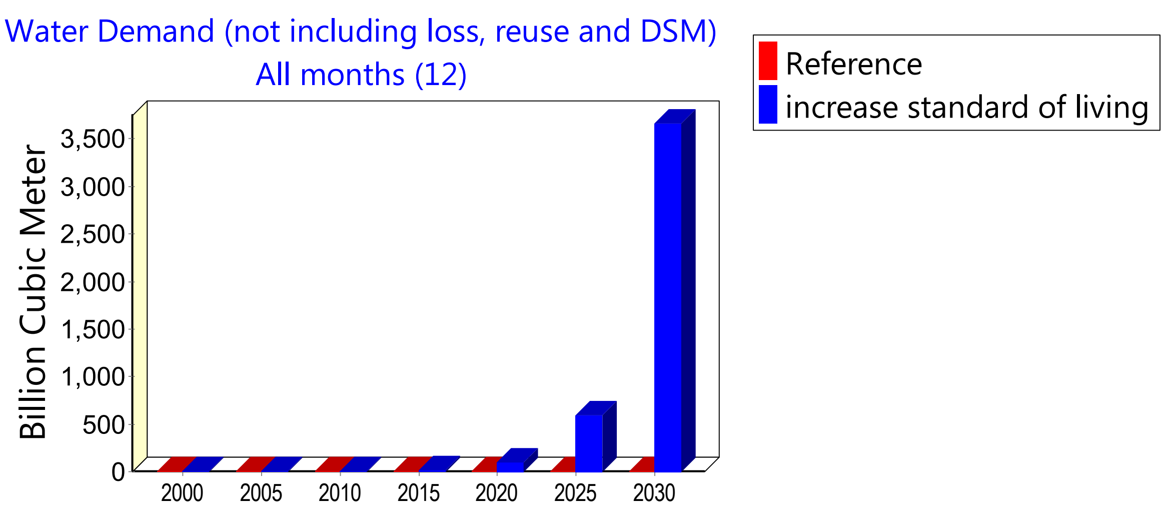


Figure 5-17 Increased water demand scenario

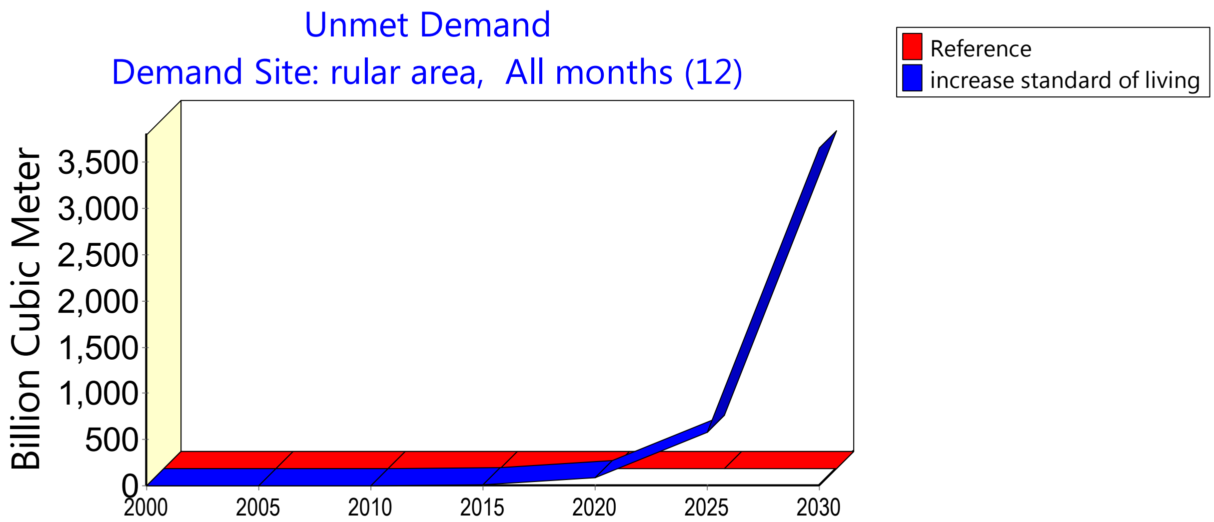


Figure 5-18 Unmet water demands for Increased water demand scenario

6 Conclusion and recommendation

6.1 Conclusion

The main objective of this thesis is to assess surface water potential and major demand of the basin. It should be noted that application of distributed hydrological and water resource models for the aforementioned purpose is challenging when used in areas where there is limited data availablity.

This is due to the fact that models use different spatial, temporal, time series data to predict flow components and hydrologic characteristics over the watershed. Both SWAT2005 and WEAP require detailed description of the distribution of physical parameters affecting the water availability and corresponding demand at the land surface. The use of GIS environment provides a powerful platform for processing of DEM, land use and land cover soil data layers and other topographic attributes and displaying model results in a spatial way so that it becomes possible to capture local complexities of a watershed.

Sensitivity analysis was performed to select important model parameters: both manual and automatic calibration were performed for stream flow using measured data at Gode gauging station for the period of 1991 -1996. It is shown that the model performed well with ENS and R^2 0.81and 0.70 respectively. The model was validated for the stream flow for the period of 1997-2000. The model performed well at monthly time step with ENS and R^2. 0.87 and 0.66 respectively.

The assessment using WEAP based on current and future conditions gave the opportunity for user to evaluate how Wabishebele River Basin could respond to various scenarios in terms of supply and demand.

The current water uses in the basin are agriculture, domestic, non-domestic (industrial and public) and livestock demand.

In this study, the assessment model used to operate at the WEAP sub catchment scale and on a monthly time-step. The period of the study was from year 2000 –2030.The computation of the assessment model was done by computing the entire model for the Reference Scenario, a default scenario that was generated using the Current Accounts information for the period of study (2000 – 2030). Current Accounts year is chosen to serve as the base year of the assessment model. In this study, all the data in Current Accounts were base on the year 2000.

The baseline year and future (2030) total surface water demand in the river basin were estimated to be 512.6Mm^3 and 3615.52Mrn^3, which are lower than surface water potential (3.763Bm^3) and in general demand can be satisfied

In general, the SWAT and WEAP models performed well in predicting both the flow and demand from the study watershed and the results were acceptable. They can be considered as good tools for further hydrological analysis of the basin.

6.2 Recommendation

The calibrated model parameter value can be used for further analysis of surface water potential and to investigate the effect of different management scenarios on stream-flows and demand in the watershed.

Data quality and availability should be stressed much more while using distributed hydrological models. The applications SWAT of 2005 and WEAP models were very challenging and a lack of appropriate data was one of the biggest concerns throughout. Without proper data, model implementation is very difficult. The use of new data gathering techniques should be envisaged for developing countries so that local and regional authorities can be involved in integrated and coordinated data compilation.

Few studies of localized nature or basin wide have been carried out in the past. This study is comprehensive study carried out taking the basin as a whole. It is strongly recommend to conduct further water demand assessment for different scenarios.

A complete study should also take into consideration integrating other factors such as existing infrastructure development within Wabishebele basin, industrial growth in the basin, and the groundwater recharge within the basin to produce more realistic water resources / availability scenarios.

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Appendices

Appendix 1 crop parameter

1 AGRL 4

33.50 0.45 3.00 0.15 0.05 0.50 0.95 0.64 1.00 2.00

30.00 11.00 0.0199 0.0032 0.0440 0.0164 0.0128 0.0060 0.0022 0.0018

0.250 0.2000 0.0050 4.00 0.750 8.50 660.00 36.00 0.0500 0.000

0.000 0 0.00 0.650 0.100

2 FRST 7

15.00 0.76 5.00 0.05 0.05 0.40 0.95 0.99 6.00 3.50

30.00 10.00 0.0015 0.0003 0.0060 0.0020 0.0015 0.0007 0.0004 0.0003

0.010 0.0010 0.0020 4.00 0.750 8.00 660.00 16.00 0.0500 0.750

0.300 50 1000.00 0.650 0.100

3 PAST 6

35.00 0.90 4.00 0.05 0.05 0.49 0.95 0.99 0.50 2.00

25.00 12.00 0.0234 0.0033 0.0600 0.0231 0.0134 0.0084 0.0032 0.0019

0.900 0.0030 0.0050 4.00 0.750 10.00 660.00 36.00 0.0500 0.000

0.000 0 0.00 0.650 0.100

4 RNGE 6

34.00 0.90 2.50 0.05 0.10 0.25 0.70 0.35 1.00 2.00

25.00 12.00 0.0160 0.0022 0.0200 0.0120 0.0050 0.0014 0.0010 0.0007

0.900 0.0030 0.0050 4.00 0.750 10.00 660.00 39.00 0.0500 0.000

0.000 0 0.00 0.330 0.100

5 RNGB 6

34.00 0.90 2.00 0.05 0.10 0.25 0.70 0.35 1.00 2.00

25.00 12.00 0.0160 0.0022 0.0200 0.0120 0.0050 0.0014 0.0010 0.0007

0.900 0.0030 0.0050 4.00 0.750 10.00 660.00 39.00 0.0500 0.000

0.000 0 0.00 0.330 0.100

6 WATR 6

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

0.000 0.0000 0.0000 0.00 0.000 0.00 0.00 0.00 0.0000 0.000

0.000 0 0.00 0.000 0.100

7 AGRC 5

30.00 0.40 4.00 0.05 0.05 0.45 0.95 0.50 0.90 1.30

18.00 0.00 0.0250 0.0022 0.0663 0.0255 0.0148 0.0053 0.0020 0.0012

0.200 0.0300 0.0060 4.00 0.750 6.00 660.00 39.00 0.0500 0.000

0.000 0 0.00 0.650 0.100

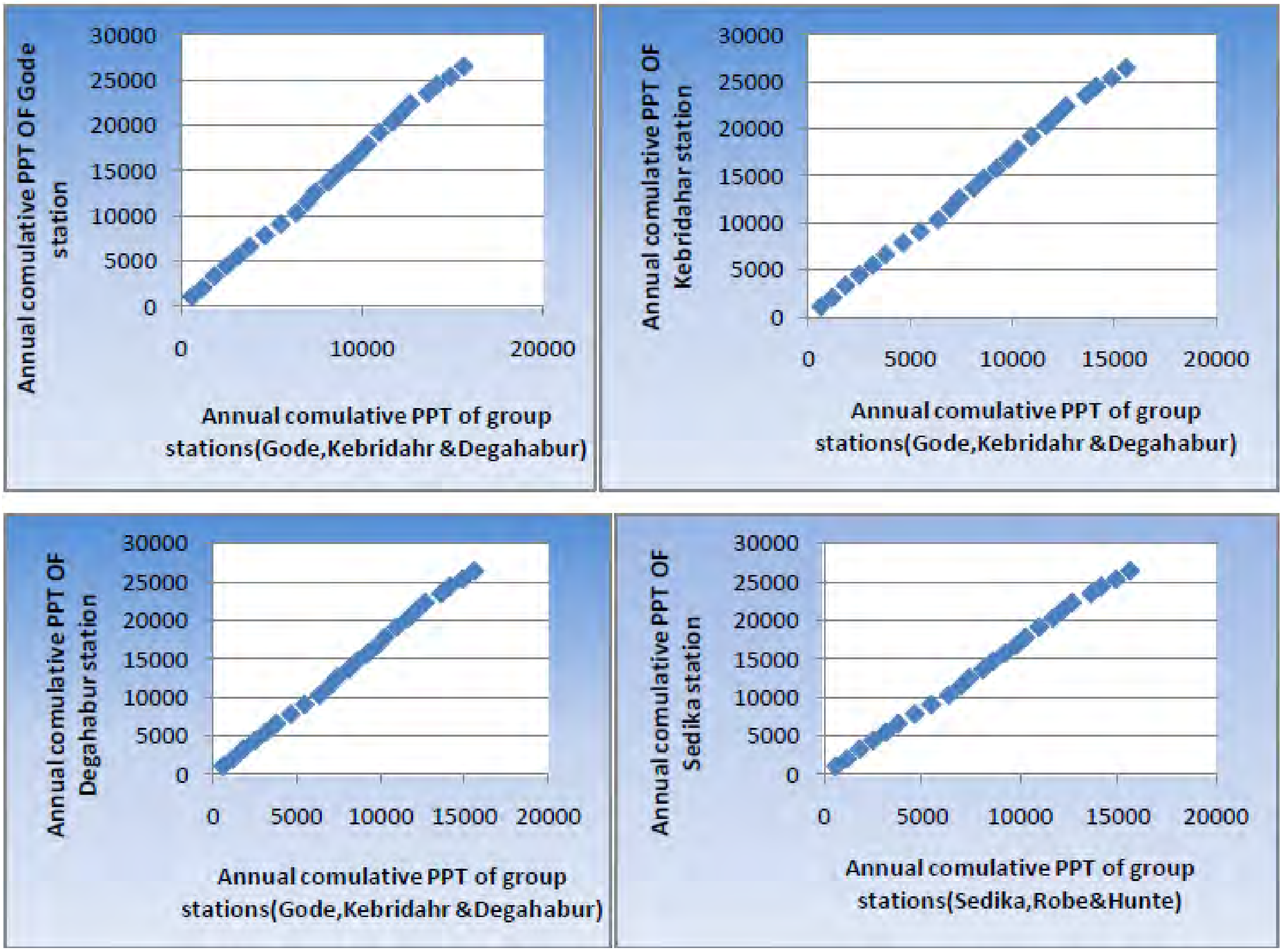
Appendix 2 Weather Generator Statistic and Probability Value

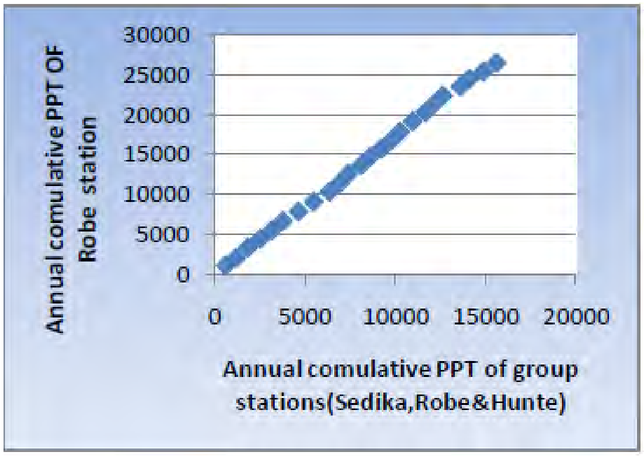
Statistical Analysis of Daily Precipitation Data (1990 - 2013)

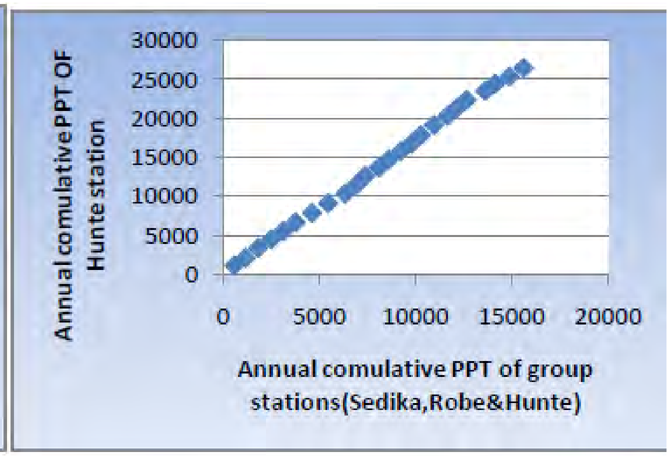
PCP_MM	average monthly precipitation [mm]
PCPSTD	standard deviation
PCPSKW	skew coefficient
PR_W1	probability of a wet day following a dry day
PR_W2	probability of a wet day following a wet day
PCPD	average number of days of precipitation in month
TMP_MAX	average daily maximum temperature in month [°C]
TMP_MIN	average daily minimum temperature in month [°C]
DEWPT	average daily dew point temperature in month [°C]
SOLARAV	Average daily solar radiation for month (MJ/m2/day).
WND AV	Average daily dew point temperature in month (ºC).
HMD	average daily humidity in month [%]

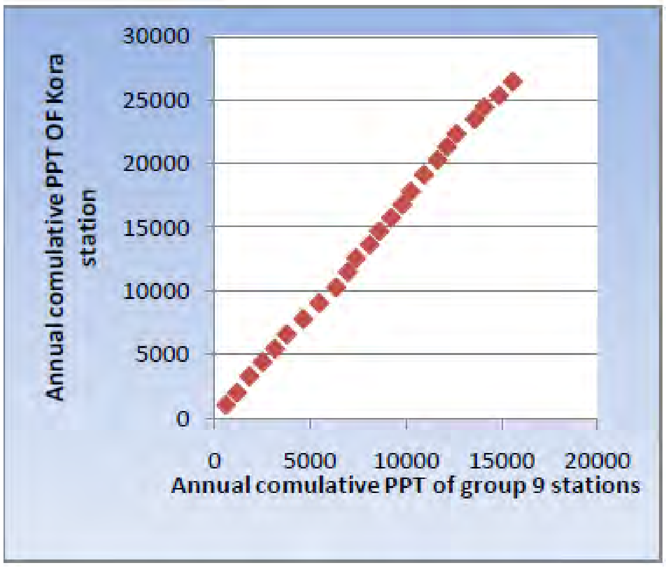
`	Jan	Feb	Mar	Apr	may	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PCP_MM	1.56	4.16	21.19	63.34	31.2	1.09	3.71	0.85	8.22	55.62	37.68	17.79
PCPSTD	0.3	1.34	3.88	6.47	6.94	0.14	1.2	0.06	3.93	6.34	6.45	3.14
PCPSKW	14.57	12.07	7.1	4.16	11.9	10.5	16.04	2.09	17.9	4.84	7.83	7.42
PR_W1	0	0	0.02	0.15	0.06	0.01	0.02	0	0.01	0.15	0.1	0
PR_W2	0.95	0.93	0.91	0.64	0.76	0.94	0.89	0.97	0.92	0.71	0.76	0.95
PCPD	5.82	6.45	8.18	9.27	6.91	5.64	5.73	5.64	5.73	11.27	11.64	11.45
TMP_MAX	32.52	33.61	34.23	33.7	32.7	32.5	32.56	33.07	33.68	32.47	32.2	32.48
TMP_MIN	20	20.96	22.38	23.34	23.2	22.8	22.76	21.98	22.92	22.16	20.41	19.66
DEWPT	18.22	18.82	19.33	20.74	20.8	20.4	20.09	19.9	20.54	19.81	18.71	18.09
SOLARAV	21.35	21.52	21.4	20.89	20.9	20.1	19.5	20.66	21.38	20.68	21.04	21.13
WND AV	2.36	2.37	2.43	2.13	2.34	3.34	3.74	3.56	2.92	2.02	1.85	2.08

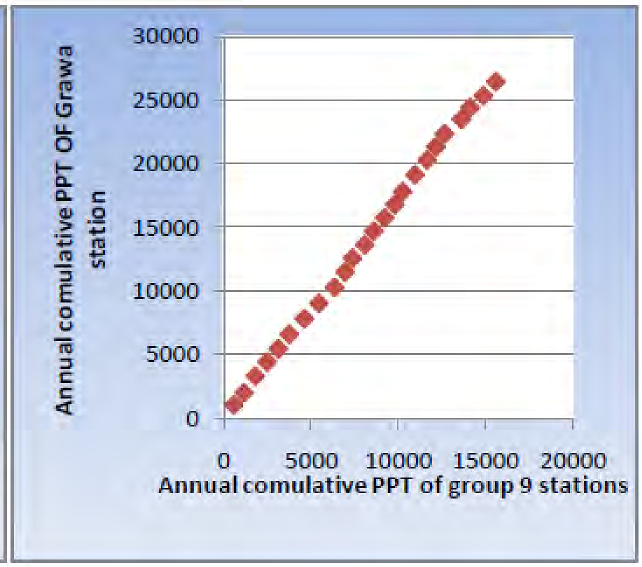
Appendix 3 Consistency test for all stations by using double mass curve

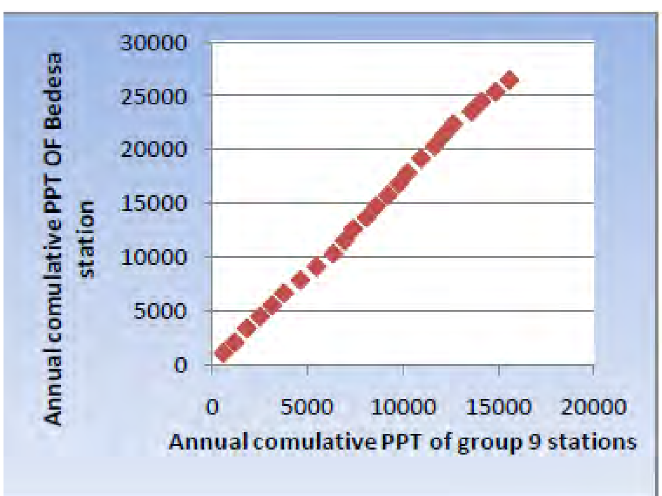


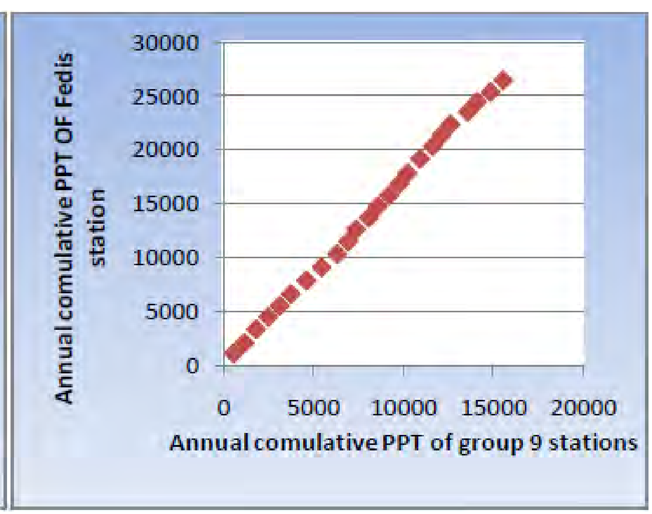

Annual comulative PPT OF Robe station
30000
25000
20000
15000
10000
5000
0
0 5000 10000 15000 20000
Annual comulative PPT of group stations(Sedika,Robe&Hunte)

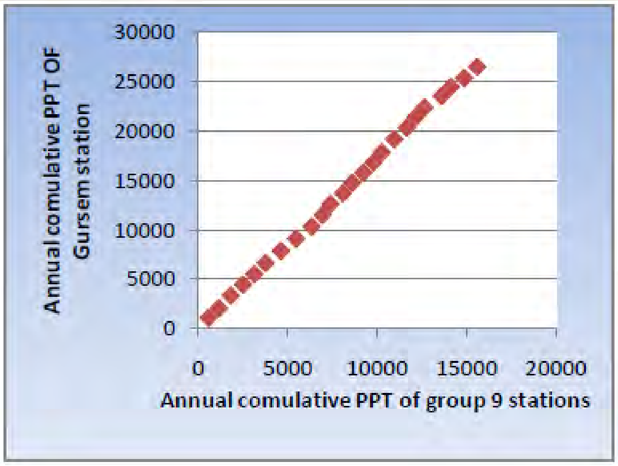

Annual comulative PPT OF Hunte station
30000
25000
20000
15000
10000
5000
0
0 5000 10000 15000 20000
Annual comulative PPT of group stations(Sedika,Robe&Hunte)

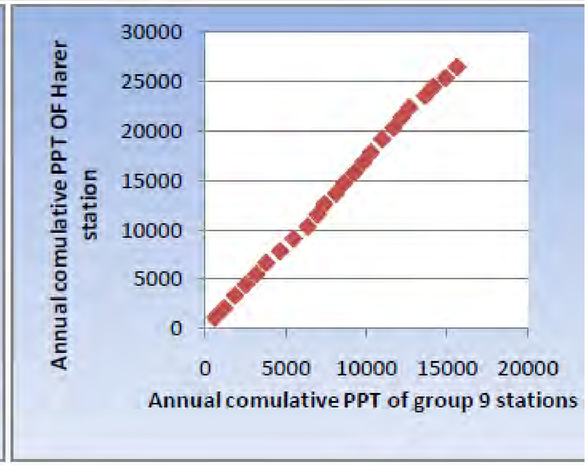

Annual comulative PPT OF Kora station
30000
25000
20000
15000
10000
5000
0
0 5000 10000 15000 20000
Annual comulative PPT of group 9 stations

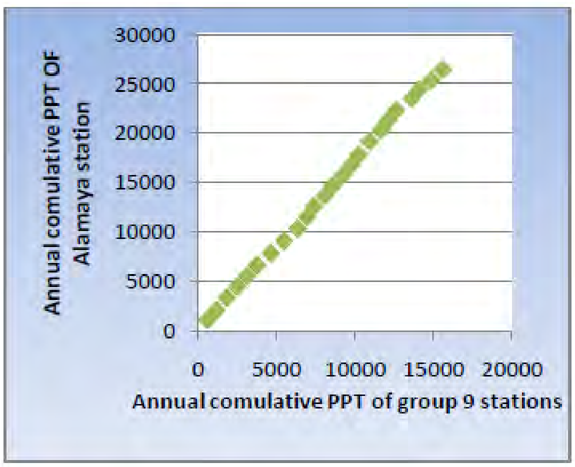

Annual comulative PPT OF Grawa station
30000
25000
20000
15000
10000
5000
0
0 5000 10000 15000 20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Bedesa station
30000
25000
20000
15000
10000
5000
0
0 5000 10000 15000 20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Fedis station
30000
25000
20000
15000
10000
5000
0
0 5000 10000 15000 20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Gursem station
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Harer station
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Alamaya station
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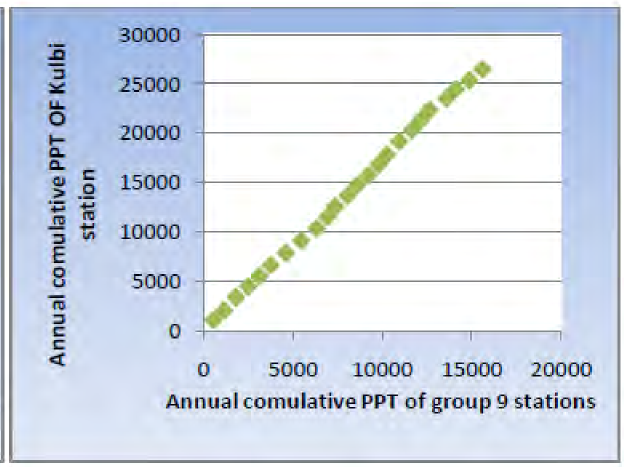
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Kulbi station
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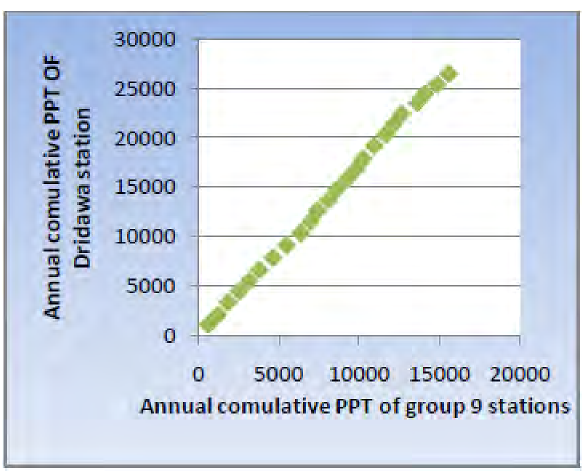
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
Annual comulative PPT of group 9 stations


Annual comulative PPT OF Dridawa station
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
Annual comulative PPT of group 9 stations

Appendix 4 metrological station in and around wabishebele basin

Name	Y	X	Z
Afdem	92748	405958	1056
Agarfa	71600	394900	2550
Alemaya	92400	420200	2020
Arata	75835	390321	1765
AsebeTeferi	90421	405217	1792
Babile	91300	421900	1657
Bedeno	90800	413800	2050
Bedessa	85430	404616	1703
Bekoji SF	73200	391500	2388
Deder	91900	412600	2114
Degahabur	81300	433300	1070
DeloSebro	71500	402800	2200
Dire Dawa	95800	423200	1180
Dodola	65848	391048	3000
DolloOddo	41023	420300	179
Elcare	55008	420619	924
Fedis	90800	420500	1690
Gesera	70800	395600	1680
Ginir	70800	404200	1750
Girawa	90800	415000	2100
Gode Met	55400	433448	290
Gunna	82200	395300	2531
Gursum	92100	422300	1900
Harar Indicative	91800	420500	1977
Hirna	91300	410600	1822
Hunte	70300	392400	2380
Hurso	93700	413800	1250
Imi	62700	420701	
Indento	72024	392924	2480
Jara	101835	395919	1960
Jijiga	92000	424700	1775

KeberBeya	90624	431023	1753
KebriDehar	64400	441800	505
Kelafo	53600	441000	250
Keleta	81912	390712	1500
Kofele	70400	384800	2620
Kora	90617	403130	1239
Kulubi	92500	414100	2436
Kulumsa	80035	390919	2211
Meraro	72700	392200	2940
Metehara (NMSA)	85131	395508	944
Ogolcho	80223	390106	1682
Robe	70800	400300	2480
Sagure	72736	390524	2480
Sedika	73819	394920	2416
Shashemene	71201	383601	1927
Sheneka	71500	400000	2400
Sire	81617	392927	2037
Sofomor	65400	405024	1680
Ticho	74912	393148	

Appendix 5 soil properties in wabishebele river basin

Soil Properties in the River Basin, which are stored in the file Usersoil.dbf and values of each parameters.

Most of the soil parameters derived from the sources which are obtained from FAO database and master plan of the basin but the following parameters were estimated using the indicated methods:

A) Available water capacity oo the soil layer (SOL_AWC(mm/mm)),

B) Organic Carbon content (SOL_CBN (%soil weight) and

C) Saturated hydraulic conductivity (SOL_K(mm/hr)),

D) Moist soil albedo (SOL_ALB (fraction))

E) Soil Erodibility (USLE_K)

Available water capacity of the soil layer (SOL_AWC(mm/mm)),

Soil Texture classes	Available water in mm/m of depth
Coarse sands	20-65
Fine sands	60-85
Loamy sands	65-110
Sandy loams	90-130
Fine sandy loams	100-170
Silt loams	150-230
Silty clay loams	130-160
Silty clay	125-170
Clay	110-150
Peats and Mucks	160-240

Typical available water holding capacities based on soil texture (Adane, 2009)

Soil Organic Carbon content (SOL_CBN (% soil weight))

Textural Classes content	Symbol	Average Organic carbon
sand	S	0.9
loamy sand	LS	1
loamy silt	LU	1.6
sandy loam	SL	1.3
loam	L	1.7
silt loam	UL	1.7
Clay	T	1.9

Average Corbon contents for various soil textures (Adane, 2009)

Saturated hydraulic conductivity Of soil texture

Texture class	Saturated hydraulic conductivity (mm/hr)
sand	210
loamy sand	61.1
Sandy loam	25.9
loam	13.2
Clay loam	2.3
Silty clay loam	1.5
Silty clay	0.9
Silt loam	6.8
clay	0.6
Sandy clay loam	4.3
Sandy clay	1.2

Saturated Soil Hydraulic Conductivity (Rawls, 1982)

Moist soil albedo (SOL_ALB) is based on Taylor and Ashcroft

Soil Color	Albedo
Brown	0.13
red	0.14
black	0.09
gray	0.13
yellow	0.17

(Adane, 2009)

E) Soil Erodibility (USLE_K) were estimated from Hurni (1985)

Soil Colour	Soil Erodibility (K)
Brown	0.2
red	0.25
black	0.15
yellow	0.3

Source: (Adane, 2009)

Soil Name	NLAYERS	HYDGRP	SOL_ZMX	SOIL- Z	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN11	CLAY11	SILT1	SAND1	ROCK	SOIL-A	USLE_K1
Chromic Luvisols	4	D	1800	300	1.5	1.5	0.6	0.4	26	15	59	0	0.14	0.25
				700	1.5	1.5	0.6	0.2	31	15	54	0	0.14	0.25
				1100	1.5	0.23	6.8	0.2	27	55	11	0	0.14	0.25
				1800	1.5	0.15	0.6	0.1	22	23	55	0	0.14	0.25
Chromic Cambisol	3	D	2000	200	1.5	1.5	0.6	1.63	72	21	8	0	0.09	0.15
				600	1.5	1.5	0.6	1.2	73	19	9	0	0.13	0.2
				2000	1.5	1.5	0.6	1.1	75	19	7	0	0.13	0.2
Calcic Fluvisols	3	B	2000	300	1.45	0.17	0.9	0.8	54	41	5	5	0.13	0.2
				700	1.45	0.23	6.8	0.3	11	51	0	0	0.13	0.2
				2000	1.45	0.23	6.8	0.4	19	53	28	0	0.13	0.2
Leptosols	1	C	200	200	1.45	0.16	4.3	2.8	23	19	58	5	0.13	0.22
Eutric	4	D	2000	160	1.45	0.17	0.9	2.4	50	41	9	0	0.09	0.15
				800	1.45	0.15	0.6	2.1	69	26	6	0	0.09	0.15

Vertisols				1300	1.45	0.15	0.6	0.9	79	18	4	0	0.13	0.2
				2000	1.45	0.15	0.6	0.6	77	18	5	0	0.13	0
Vetric Luvisols	3	D	2000	300	1.45	0.17	0.9	0.8	54	41	5	5	0.13	0.2
				700	1.45	0.23	6.8	0.3	11	51	0	0	0.13	0.2
				2000	1.45	0.23	6.8	0.4	19	53	28	0	0.13	0.2
Dystric Gleysals	3	B	2000	200	1.75	0.23	13.2	2.5	14	46	40	0	0.13	0.2
				800	1.75	0.23	13.2	1.7	25	32	43	0	0.13	0.2
				2000	1.75	0.16	2.3	0.3	30	37	33	0	0.13	0.2
Eutric Nitisols	4	D	2000	200	1.45	0.15	0.6	2	61	26	13	0	0.13	0.22
				700	1.45	0.15	0.6	1.5	77	15	8	0	0.13	0.22
				2000	1.45	0.15	0.6	1.3	55	36	9	0	0.13	0.22
Euric Regosols	2	D	1000	300	1.45	1.5	0.6	2.2	30	22	48	0	0.13	0.2
				1000	1.45	1.5	2.3	1.8	25	16	59	0	0.13	0.2
Haplic Phaeozems	4	D	2000	300	1.45	0.15	0.6	1.6	53	24	24	0	0.13	0.2
				600	1.46	0.15	0.6	2	59	23	17	0	0.13	0.2
				1500	1.45	0.15	0.6	0.7	55	25	20	0	0.13	0.2
				2000	1.46	0.15	0.6	0.5	61	24	15	0	0.13	0.2
Orthic Solonchaks	3	D	1000	200	1.45	0.15	2.3	1.5	30	43	27	0	0.13	0.2
				7000	1.45	0.16	2.3	0.4	32	25	43	0	0.09	0.15
				1000	1.45	0.23	13.2	0.2	9	47	45	0	0.17	0.3
Arenosols	1	A	500	500	1.8	0.13	25.9	0.9	15	7	78	0	0.13	0.22
Andosols	1	A	1800	1800	1.75	0.13	25.9	2	24	33	43	0	0.09	0.15
Gypsisols	2	B	500	250	1.6	0.17	25.9	0.3	14	16	70	0	0.13	0.2
				500	1.6	0.17	25.6	0.5	15	15	70	0	0.13	0.2

Appendix 6 proposed crops and cropping pattern

Proposed Crops and Cropping Pattern for different Sites

A. Erer

No.	Crop	Percent coverage	Starting date of planting	Starting date of Harvesting	Cultivation Season
1	Haricot bean	20	April 1	July 15	Wet
2	Maize	20	March.1	July 14	Wet
3	Groundnut	15	April 15	Sept. 1	Dry
4	Sorghum	20	March.1	July 14	Wet
5	onion	10	Sept. 10	Feb. 5	Dry season
6	Watermelon	10	Oct.15	Feb. 15	Dry season
7	Pepper	10	Oct.1	Feb. 8	Dry.
8	Sugarcane	5	June 1	June 1	All round the year.
9	Chat	10	April 15	April 15	All round the year.

(MoWIE, 2004)

B Gode

No.	Crop	Percent coverage	Starting date of planting	Starting date of Harvesting	Cultivation Season
1	Sesame	20	May 15	Aug. 15	Dry
2	Maize	20	March.1	July 14	Wet
3	Groundnut	15	April 15	Sept. 1	Dry
4	Sorghum	20	March.1	July 14	Wet
5	onion	10	Sept. 10	Feb. 5	Dry season
6	Watermelon	10	Oct.15	Feb. 15	Dry season
7	Pepper	10	Oct.1	Feb. 8	Dry.
8	Sgarcane	5	June 1	June 1	All round the year.

C. Gololcha

No.	Crop	Percent coverage	Starting date of planting	Starting date of Harvesting	Cultivation Season
1	Kenaf	5	Feb 1	July 15	Dry
2	Maize	10	May 15	July 28	Wet
3	Groundnut	15	April 10	Aug 28	Dry
4	Sorghum	20	March.1	July 4	Wet
5	onion	15	Aug 15	Dec. 13	Dry season
6	Watermelon	20	Oct.15	Feb. 15	Dry season
7	Pepper	10	Sept.1	Jan. 9	Dry.
8	Sugar cane	5	June 1	June 1	All round the year.
9	Sweet potato	15	Sept 15	March 14	All round the year.
Cropping intensity		170			

Appendix 7 WEAP Data Expressions Report

Current Accounts
Date: 6/27/2015

Key Assumptions			
Urban	(m^3)		11
Rural	(m^3)		5
Population growth urban			
Population growth rural	(% share)		2.9
High population growth urban			
High population growth rural			
Demand Sites and Catchments			
Urban	Water Use	Annual Activity Level (cap)	771505
		Annual Water Use Rate (m^3/cap)	Key\urban [m^3]
	Advanced	Method	Specify yearly demand and monthly variation
Rular	Water Use	Annual Activity Level (cap)	5657705
		Annual Water Use Rate (m^3/cap)	Key\rural[m^3]
	Advanced	Method	Specify yearly demand and monthly variation
Gig	Water Use	Annual Activity Level (cap)	261403
		Annual Water Use Rate (m^3/cap)	11
	Advanced	Method	Specify yearly demand and monthly variation
Harer	Water Use	Annual Activity Level (cap)	96943
		Annual Water Use Rate (m^3/cap)	11
	Advanced	Method	Specify yearly demand and monthly variation
Livstock	Water Use	Annual Activity Level (cap)	17536400
	Advanced	Method	Specify yearly demand and monthly variation
Cattle	Water Use	Annual Activity Level (% share of cap)	64.88
		Annual Water Use Rate (m^3/cap)	9.13
Sheep	Water Use	Annual Activity Level (% share of cap)	12.68
		Annual Water Use Rate (m^3/cap)	1.830
Goat	Water Use	Annual Activity Level (% share of cap)	10.19
		Annual Water Use Rate (m^3/cap)	1.830
Equne	Water Use	Annual Activity Level (% share of cap)	3.15
		Annual Water Use Rate (m^3/cap)	4.380
Camel	Water Use	Annual Activity Level (% share of cap)	9.1
		Annual Water Use Rate (m^3/cap)	10.980
Industrial and public demand	Water Use	Annual Activity Level (cap)	771505
	Advanced	Method	Specify yearly demand and monthly variation
New Branch	Water Use	Annual Activity Level (% share of cap)	45
		Annual Water Use Rate (m^3/cap)	11

Gode irrigation	Land Use	Area (ha)	27100
	Climate	Precipitation (mm)	ReadFromFile (F:\desktop\rgode.csv)
		Min Temperature (C)	ReadFromFile(F:\desktop\tgod.csv, 2)
		Max Temperature (C)	ReadFromFile(F:\desktop\tgod.csv, 1)
		Latitude	6.133
		Altitude (m)	290
	Advanced	Method	MABIA (FAO 56, dual KC, daily)
Maize	Land Use	Area (% share of ha)	20
		Crops	Crop Library ("Maize (grain) (East Africa (alt.))", Mar 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Mar 1, Aug 27, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Sorghum	Land Use	Area (% share of ha)	20
		Crops	Crop Library ("Sorghum (Arid Region)", Mar 1)
		Soil Water Capacity (%)	SoilLibrary (Silty clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Schedule	IrrigationSchedule(1, Mar 1, Jul 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Ground nut	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Groundnut (Peanut) (Mediterranean)", Apr 15)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Apr 15, Sep 1, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
tomato	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Tomato (Arid Region)", Sep 10)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80

	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Sep 10, Mar 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
onion	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Onion (green) (Arid Region)", Sep 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Sep 1, Dec 4, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
water melon	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Watermelons (Near East (desert))", Oct 15)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Oct 15, Jan 2, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
sugarcane	Land Use	Area (% share of ha)	5
		Crops	CropLibrary("Sugarbeet (Arid Regions)", Jun 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Jun 1, Dec 22, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
peper	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Sweet peppers (bell) (Arid Region)", Oct 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80

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                                     Irrigation          Irrigation Schedule                       IrrigationSchedule(1, Oct 1, Apr 28,
% of RAW, 100, % Depletion, 100)
                                                         Fraction Wetted                           0.8
                                                         Irrigation Efficiency (%)                 50
                                                         Loss to Groundwater (%)                   50
                                                         Loss to Runoff (%)                        50
    others                           Land Use            Area (% share of ha)                      Remainder(100)
                                                         Crops                                     CropLibrary("Cotton (Yemen)", Jan 1)
                                                         Soil Water Capacity (%)                   SoilLibrary(Clay)
                                                         Maximum Infiltration Rate (mm/day)        12.5
                                                         Effective Precipitation (%)               80
                                     Irrigation          Irrigation Schedule                       IrrigationSchedule(1, Jan 1, Jul 14,
% of RAW, 100, % Depletion, 100)
                                                         Fraction Wetted                           0.8
                                                         Irrigation Efficiency (%)                 50
                                                         Loss to Groundwater (%)                   50
                                                         Loss to Runoff (%)                        50
  Robe 2                           Land Use            Area (ha)                                 97000
                                   Climate             Precipitation (mm)                        ReadFromFile(F:\desktop\rbedessa.csv)
                                                       Min Temperature (C)
ReadFromFile(F:\desktop\tminbedessa.csv)
                                                       Max Temperature (C)                       ReadFromFile(F:\desktop\tmax

bedesa.csv)
                                                       Latitude                                  7.8833
                                                       Altitude (m)                              1599
                                   Advanced            Method                                    MABIA (FAO 56, dual KC, daily)
    maize1                           Land Use            Area (% share of ha)                      20
                                                         Crops                                     CropLibrary("Maize (grain) (East
Africa (alt.))", Mar 1)
                                                         Soil Water Capacity (%)                   SoilLibrary(Clay)
                                                         Maximum Infiltration Rate (mm/day)        14
                                                         Effective Precipitation (%)               80
                                     Irrigation          Irrigation Schedule                       IrrigationSchedule(1, Mar 1, Aug 27,
% of RAW, 100, % Depletion, 100)
                                                         Fraction Wetted                           0.8
                                                         Irrigation Efficiency (%)                 50
                                                         Loss to Groundwater (%)                   50
                                                         Loss to Runoff (%)                        50
    maize2                           Land Use            Area (% share of ha)                      15
                                                         Crops                                     CropLibrary("Maize (grain) (Arid
Climate)", Oct 1)
                                                         Soil Water Capacity (%)                   SoilLibrary(Clay)
                                                         Maximum Infiltration Rate (mm/day)        14
                                                         Effective Precipitation (%)               80
                                     Irrigation          Irrigation Schedule                       IrrigationSchedule(1, Oct 1, Feb 17,
% of RAW, 100, % Depletion, 100)
                                                         Fraction Wetted                           0.8
                                                         Irrigation Efficiency (%)                 50
                                                         Loss to Groundwater (%)                   50
```

		Loss to Runoff (%)	50
vegetable	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Onion (green) (Arid Region)", Oct 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.0
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Oct 1, Jan 3, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
sorghum	Land Use	Area (% share of ha)	40
		Crops	CropLibrary("Sorghum (Arid Region)", May 5)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.0
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, May 5, Sep 11, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
potato	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Potato (Continental Climate)", Nov 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.0
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Nov 1, Mar 10, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
sweet potato	Land Use	Area (% share of ha)	5
		Crops	CropLibrary("Sweet potato (Mediterranean)", Dec 20)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.0
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Dec 20, May 18, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50

citrus spp	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Citrus, with active ground cover or weeds (70% canopy) (Mediterranean)", Jan 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.0
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Jan 1, Dec 31, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Golch irr	Land Use	Area (ha)	18000
	Climate	Precipitation (mm)	ReadFromFile(F:\desktop\rbedessa.csv)
		Min Temperature (C)	ReadFromFile(F:\desktop\tminbedessa.csv)
		Max Temperature (C)	ReadFromFile(F:\desktop\tmax bedesa.csv)
		Latitude	7.4
		Altitude (m)	1703
	Advanced	Method	MABIA (FAO 56, dual KC, daily)
maize	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Maize (grain) (East Africa (alt.))", Mar 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Mar 1, Aug 27, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
sorghum	Land Use	Area (% share of ha)	20
		Crops	CropLibrary("Sorghum (Arid Region)", Mar 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Mar 1, Jul 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
haricot bean	Land Use	Area (% share of ha)	20
		Crops	CropLibrary("Faba bean, broad bean (Spring) (Mediterranean)", May 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)

		Maximum Infiltration Rate (mm/day)	14.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, May 1, Aug 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
groundnut	Land Use	Area (% share of ha)	15
		Crops	CropLibrary("Groundnut (Peanut) (Mediterranean)", Apr 15)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Apr 15, Sep 1, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
onion	Land Use	Area (% share of ha)	15
		Crops	CropLibrary("Onion (green) (Arid Region)", Aug 15)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Aug 15, Nov 17, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
sweet potato	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Sweet potato (Mediterranean)", Dec 20)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Dec 20, May 18, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
peper	Land Use	Area (% share of ha)	10
		Crops	CropLibrary("Sweet peppers (bell) (Arid Region)", Oct 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	14.50

		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Oct 1, Apr 28, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Bludohe irr	Land Use	Area (ha)	52150
	Climate	Precipitation (mm)	ReadFromFile(F:\desktop\rgode.csv)
		Min Temperature (C)	ReadFromFile(F:\desktop\tgod.csv, 2)
		Max Temperature (C)	ReadFromFile(F:\desktop\tgod.csv, 1)
		Latitude	5.58
		Altitude (m)	471
	Advanced	Method	MABIA (FAO 56, dual KC, daily)
moize	Land Use	Area (% share of ha)	15
		Crops	CropLibrary("Maize (grain) (Arid Climate)", Apr 19)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.5
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	IrrigationSchedule(1, Apr 19, Sep 5, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
sorghom	Land Use	Area (% share of ha)	40
		Crops	CropLibrary("Sorghum (Arid Region)", Mar 1)
		Soil Water Capacity (%)	SoilLibrary(Clay)
		Maximum Infiltration Rate (mm/day)	12.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule(1, Mar 1, Jul 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Vegetables	Land Use	Area (% share of ha)	5
		Crops	Crop Library ("Carrots (Arid climate)", Oct 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	12.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Oct 1, Jan 18, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50

		Loss to Runoff (%)	50
Cotton	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Cotton (Egypt; Pakistan; Calif.)", Apr 20)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	12.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Apr 20, Oct 31, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Citrus spp.	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Citrus, with active ground cover or weeds (70% canopy) (Mediterranean)", Jan 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	12.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Jan 1, Dec 31, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Sugar beet	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Sugar beet (Arid Regions)", Jun 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	12.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Jun 1, Dec 22, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Umcho irrigation	Land Use	Area (ha)	4000
	Climate	Precipitation (mm)	Read From File (F:\desktop\rfedis.csv)
		Min Temperature (C)	Read From File (F:\desktop\talmyamin.csv)
		Max Temperature (C)	Read from File (F:\desktop\tmaxalmaya.csv)
		Latitude	8.766
		Altitude (m)	1030
	Advanced	Method	MABIA (FAO 56, dual KC, daily)
Maize1	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Maize (grain) (Arid Climate)", Oct 1)

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                                        Soil Water Capacity (%)                SoilLibrary (Clay)
                                        Maximum Infiltration Rate (mm/day)     9.5
                                        Effective Precipitation (%)            80
                     Irrigation         Irrigation Schedule                    Irrigation Schedule (1, Oct 1, Feb
17, % of RAW, 100, % Depletion, 100)
                                        Fraction Wetted                        0.8
                                        Irrigation Efficiency (%)              50
                                        Loss to Groundwater (%)                50
                                        Loss to Runoff (%)                     50
   Maize2                Land Use       Area (% share of ha)                   20
                                        Crops                                  Crop Library ("Maize (grain) (East
Africa (alt.))", Apr 4)
                                        Soil Water Capacity (%)                SoilLibrary (Clay)
                                        Maximum Infiltration Rate (mm/day)     9.5
                                        Effective Precipitation (%)            80
                     Irrigation         Irrigation Schedule                    Irrigation Schedule (1, Apr 4, Sep
30, % of RAW, 100, % Depletion, 100)
                                        Fraction Wetted                        0.8
                                        Irrigation Efficiency (%)              50
                                        Loss to Groundwater (%)                50
                                        Loss to Runoff (%)                     50
   Sorghum                Land Use       Area (% share of ha)                   30
                                        Crops                                  Crop Library ("Sorghum (Arid
Region)", May 5)
                                        Soil Water Capacity (%)                SoilLibrary (Clay)
                                        Maximum Infiltration Rate (mm/day)     9.50
                                        Effective Precipitation (%)            80
                     Irrigation         Irrigation Schedule                    Irrigation Schedule (1, May 5, Sep
11, % of RAW, 100, % Depletion, 100)
                                        Fraction Wetted                        0.8
                                        Irrigation Efficiency (%)              50
                                        Loss to Groundwater (%)                50
                                        Loss to Runoff (%)                     50
   Beans green           Land Use       Area (% share of ha)                   5
                                        Crops                                  Crop Library ("Beans (green) (Calif.,
Mediterranean)", Dec 20)
                                        Soil Water Capacity (%)                SoilLibrary (Clay)
                                        Maximum Infiltration Rate (mm/day)     9.50
                                        Effective Precipitation (%)            80
                     Irrigation         Irrigation Schedule                    Irrigation Schedule (1, Dec 20, Mar
19, % of RAW, 100, % Depletion, 100)
                                        Fraction Wetted                        0.8
                                        Irrigation Efficiency (%)              50
                                        Loss to Groundwater (%)                50
                                        Loss to Runoff (%)                     50
   Ground nut            Land Use       Area (% share of ha)                   15
                                        Crops                                  Crop Library ("Groundnut (Peanut)
(Mediterranean)", Apr 15)
                                        Soil Water Capacity (%)                SoilLibrary (Clay)
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                                    Maximum Infiltration Rate (mm/day)      9.50
                                    Effective Precipitation (%)             80
                     Irrigation     Irrigation Schedule                     Irrigation Schedule (1, Apr 15, Sep 
1, % of RAW, 100, % Depletion, 100)
                                    Fraction Wetted                         0.8
                                    Irrigation Efficiency (%)               50
                                    Loss to Groundwater (%)                 50
                                    Loss to Runoff (%)                      50
    Sugarcane        Land Use       Area (% share of ha)                    10
                                    Crops                                   Crop Library ("Sugar beet (Arid 
Regions)", Jun 1)
                                    Soil Water Capacity (%)                 SoilLibrary (Clay)
                                    Maximum Infiltration Rate (mm/day)      9.50
                                    Effective Precipitation (%)             80
                     Irrigation     Irrigation Schedule                     Irrigation Schedule (1, Jun 1, Dec 
22, % of RAW, 100, % Depletion, 100)
                                    Fraction Wetted                         0.8
                                    Irrigation Efficiency (%)               50
                                    Loss to Groundwater (%)                 50
                                    Loss to Runoff (%)                      50
    Citrus spp       Land Use       Area (% share of ha)                    10
                                    Crops                                   Crop Library ("Citrus, with active 
ground cover or weeds (70% canopy) (Mediterranean)", Jan 1)
                                    Soil Water Capacity (%)                 SoilLibrary (Clay)
                                    Maximum Infiltration Rate (mm/day)      9.50
                                    Effective Precipitation (%)             80
                     Irrigation     Irrigation Schedule                     Irrigation Schedule (1, Jan 1, Dec 
31, % of RAW, 100, % Depletion, 100)
                                    Fraction Wetted                         0.8
                                    Irrigation Efficiency (%)               50
                                    Loss to Groundwater (%)                 50
                                    Loss to Runoff (%)                      50
  Erere agriculture       Land Use       Area (ha)                              4000
                     Climate        Precipitation (mm)                      Read From File (F:\desktop\rfedis.csv)
                                    Min Temperature (C)                     Read From File 
(F:\desktop\talmyamin.csv)
                                    Max Temperature (C)                     Read from File 
(F:\desktop\tmaxalmaya.csv)
                                    Latitude                                9.266
                                    Altitude (m)                            1690
                     Advanced       Method                                  MABIA (FAO 56, dual KC, daily)
    Maize            Land Use       Area (% share of ha)                    10
                                    Crops                                   Crop Library ("Maize (grain) (East 
Africa (alt.))", Mar 1)
                                    Soil Water Capacity (%)                 SoilLibrary (Clay)
                                    Maximum Infiltration Rate (mm/day)      9.5
                                    Effective Precipitation (%)             80
                     Irrigation     Irrigation Schedule                     Irrigation Schedule (1, Mar 1, Aug 
27, % of RAW, 100, % Depletion, 100)
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		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Sorghum	Land Use	Area (% share of ha)	20
		Crops	Crop Library ("Sorghum (Arid Region)", Jun 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Jun 1, Oct 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Haricot	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Beans (green) (Calif., Mediterranean)", Dec 20)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Dec 20, Mar 19, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Groundnut	Land Use	Area (% share of ha)	15
		Crops	Crop Library ("Groundnut (Peanut) (Mediterranean)", Apr 15)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Apr 15, Sep 1, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Tomato	Land Use	Area (% share of ha)	5
		Crops	Crop Library ("Tomato (Arid Region)", Sep 10)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Sep 10, Mar 8, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8

		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Onion	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Onion (green) (Arid Region)", Sep 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Sep 1, Dec 4, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Watermelon	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Watermelons (Near East (desert))", Oct 15)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Oct 15, Jan 2, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Pepper	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Sweet peppers (bell) (Arid Region)", Oct 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Oct 1, Apr 28, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50
		Loss to Groundwater (%)	50
		Loss to Runoff (%)	50
Sugarcane	Land Use	Area (% share of ha)	10
		Crops	Crop Library ("Sugar beet (Arid Regions)", Jun 1)
		Soil Water Capacity (%)	SoilLibrary (Clay)
		Maximum Infiltration Rate (mm/day)	9.50
		Effective Precipitation (%)	80
	Irrigation	Irrigation Schedule	Irrigation Schedule (1, Jun 1, Dec 22, % of RAW, 100, % Depletion, 100)
		Fraction Wetted	0.8
		Irrigation Efficiency (%)	50