ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

PREDICTION OF SEDIMENT INFLOW FOR LEGEDADI RESERVOIR (USING SWAT WATERSHED AND CCHE1D SEDIMENT TRANSPORT MODELS)

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Degree of Masters of Science in Hydraulics Engineering

By

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Addis Ababa,

Ethiopia.

May 2008

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Approval by Board of Examiners

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Chairman (department of graduate committee) signature

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Advisor Signature

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Internal Examiner Signature

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External Examiner Signature

DECLARATION

I, the undersigned, hereby declare that this thesis is my original work performed under the supervision of Dr-Ing. Yonas Michael has not been presented as a thesis for a degree program in any other university and all sources of materials used for the thesis are duly acknowledged.

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Place: Addis Ababa

Date of submission: ---------------------

This thesis has been submitted for examination with our approval as university advisor.

Dr-Ing Yonas Michael

Signature----------------------

Addis Ababa,

Ethiopia.

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ACRONYMS

AAWSA	Addis Ababa Water and Sewerage Authority
CCHE	Centre for Computational Hydro since and Engineering
CSA	Critical Source Area
DBF	Data base file
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
EMA	Ethiopian Mapping Authority
GIS	Geographic Information Systems
GSE	Geological Survey of Ethiopia
GUI	Graphical User Interface
HRU	Hydrologic Response Unit
MUSLE	Modified Universal Soil Loss Equation
MCE	Metaferia Consulting Engineers
MoWR	Ministry of Water Resources
MSCL	Minimum Source Channel Length
NMA	National Meteorological Agency
RH	Relative Humidity
SWAT	Soil and Water Analysis Tool
Tmax	Maximum Temperature
Tmin	Minimum Temperature
ToPAZ	Topographic PArametriZation
USLE	Universal Soil Loss Equation

ABSTRACT

Reservoirs, especially which are formed by dams on natural water courses are subject to some degree of sediment inflow and deposition. Because of this, they are exposed to sediment-related problems.

Legedadi, the main water supply resource of Addis Ababa city, is loosing its capacity due to sedimentation. Bathymetric surveys in 1979 and 1998 have been undertaken to estimate the extent of the sediment in the reservoir and shows that sediments are accumulating at a rate of $0.11Mm^3$/year for the intervening period.

This paper presents the attempts made to assess the amount of sediment inflow and the total quantity which is accommodated to date on Legedadi reservoir using SWAT watershed and CCHE1D sediment transport models. These two models were applied to a variety of sediment studies in different countries like Wyoming East Fork river, Danjangkon reservoir, Mississippi Goodwin Creek water shade, Taiwan Pa-chang…and a good agreement between measured and computed yields is illustrated.

Key Words

CCHE1D, SWAT, Bathymetric Map, DEM, Sedimentation, Legedadi, TOPAZ, Watershed, Digitizing, Simulation, Calibration, Validation

1. INTRODUCTION

1.1. Background

An understanding of the quantity of sediment deposition in a reservoir is necessary for effective reservoir and basin management. Sedimentation affects both the useful life of a reservoir for such important purposes as water supply and flood control as well as its aesthetic quality.

Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earths crust. Such particles vary in size from large boulders to small colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition, the predominant materials being quartz mineral and clay minerals (kaolinites, illite, montmorillonite, and chlorite).

Reservoirs are loosing their capacity due to sedimentation processes, and are therefore seriously threatened in their performance. It is apparent that for mastering the reservoir-sedimentation issues the use of strategies for controlling reservoir sedimentation becomes increasingly important. Obviously a good prediction of the processes and the endeavour to better understanding of the reservoir problem is essential.

The Metropolitan Area of Addis Ababa is supplied with water from three main sources: Legedadi and Dire reservoirs, constructed in 1967 and 1998, respectively, and located east of the city; and Geffersa reservoir, constructed in 1943, and located west of the city. Silt deposits in Legedadi and Geffersa reservoirs have reduced live storage capacity, while the buildup of suspended solids in Legedadi reservoir has affected raw water quality, increasing treatment costs.

The city with its ever-increasing population, has reached a state of critical water shortage. To satisfy the rapidly increasing water demands of the city, the Addis Ababa Water and Sewerage Authority (AAWSA) has done major expansions of the water treatment plant, transmission and distribution facilities in the past, while successive works are continuing. Major water sources or combination of sources must have been urgently developed in order to overcome the current shortage as well as to meet the requirements of the growing population.

A 20 years bathymetric survey (1978 to 1998) of the Legedadi reservoir, for instance, shows an average silt accumulation of 26,000m^3/year (AAWSA, 2000). Siltation of water reservoirs has a considerable impact on the reservoir functions. First, it caused reduced storage capacity and

quantity of water harvested that in return caused water shortage for the rapidly increasing Addis Ababa city residents (over 4 million people).
Secondly, the suspended solids in the eroded material increase turbidity of the raw water (i.e., water becomes muddy and physically dirty), which increased water treatment costs. According to AWSSA reports the cost of water treatment increased from 7.7 million in 1993 to 21.4 million in 2001 due to the increasing rate of reservoir sedimentation. On the average the state incurs water treatment cost of 12.6 million birr/year (AAWSSA, 2001).

Thirdly, chemical compounds in the eroded clay minerals such as nitrates (NO_3), phosphates (PO_4) and ammonium (NH_4) induced growth of undesirable aquatic organisms (phytoplankton) such as algae. The blooming of algae leads to high organic matter content of the reservoir, which causes offensive smell and change in color and taste of the drinking water.

1.2. Previous studies

The sole responsibility of studying the sedimentation problem of the reservoir is vested in its owner Addis Ababa Water and Sewerage Authority (AAWSA). Accordingly different activities were performed in order to identify and quantify the above problem and propose suitable solutions:

In 1979 Bathymetric survey of Legedadi reservoir (capacity 43.8 MCM) is done with the most advanced technology. Echo sounding depth measurements were combined with x, y position data taken by the Differential Global Positioning System (DGPS) to produce bathymetric maps and area-volume curves.

In 1998 Tahal Consulting Engineers (TAHAL) in association with Metaferia Consulting Engineers (MCE) carried out the Bathymetric survey of the reservoir and the results of a bathymetric survey conducted in 1979 were reconstructed by scanning the plans to produce images, which were then digitized using the tracing technique with "rubber sheet" adjustment. A comparison of this result for Legedadi reservoir with those from the previous survey indicated an average silt accumulation of 110,000m^3/year, representing a loss of 0.25% of live storage capacity per year. In terms of soil loss from the catchment area, this amounts to an average of 760tons/km^2/year. (1999 Bathymetric map Report)

1.3. Objectives

The overall objectives of the research are:

- To determine the extent of the sediment accumulated on the reservoir to date.

- To determine the rate of sediment accumulation annually.

- To forward recommendations to any measures that can be taken in order to reduce the amount of sediment inflow.

1.4. Methods of the Study

The study demonstrates the estimation of sediment inflow for Legedadi reservoir using SWAT water shade and CCHE1D which calculate the transport of non-uniform sediment in rivers and streams using the non-equilibrium transport model. Therefore, an effort is made to utilize the models requirements in every step of the research as possible.

The application of the models for sediment inflow simulation requires a well defined methodology to analyze the required data with the assumptions and methodologies employed in the models.

The methodology adopted in the research study is designed to integrate the modern techniques of Arc-View, and ArcGIS in the delineation, digitizing and DEM creation of the catchment and the reservoir areas.

Primarily the problem has been identified and the scope of the research study and the extent of the study area have been defined. Water as a scarce resource in the world, is the prime need for the Addis Ababa community. One of the area main problems is scarcity of clear water; as a result proper follow up for the existing water resources is mandatory.

Terrains topography, rock type, soil type, land cover, slope and geological structures influence the amount of sediment in the study area. After setting the criterion of the factors for sedimentation occurrence in the area, different types of data had been collected and entered into the SWAT and CCHE1D models through scanning, digitizing, and Key-board entering. See table 1.1

for the type and sources of different data collected and used for the research study.

Data Type	Method of Input	Data Source
The Site Topographic Map	Digitized from Topographic Map	Addis Ababa Water and Sewerage Authority
National Topographic Map	Digitized from Topographic Map	Ethiopian Mapping Agency
1979 Bathymetric Map	Used for Calibration of the Model	Addis Ababa Water and Sewerage Authority
1998 Bathymetric Map	Used for Calibration of the Model	Addis Ababa Water and Sewerage Authority
Rainfall Data	Daily Rainfall through keyboard entry	National Metrological Agency
Temperature Data	Daily Tmax and Tmin through keyboard entry	National Metrological Agency
Relative Humidity	Daily RH through keyboard entry	National Metrological Agency
Wind Speed At 2m height	Wind Speed through keyboard entry	National Metrological Agency
Land Cover	Classified from Satellite Imageries	Ministry of Water Resources

Table 1.1: Identified data types and possible sources

Since two Bathymetric Surveys and original topographic map of the area are available it was possible to calibrate the model with one Bathymetric map and validate it with the other.

The original area contour map of 5m intervals and the topographic with 20m contour intervals were digitized using ArcGIS and DEMs which are the main input data of SWAT and CCHE1D models, are generated.

1.5. Thesis Layout

The thesis has comprised six separate chapters. The first chapter gives general introduction on the background of the problem, objectives of the research study, the methodology utilized and layout of the thesis.

The general characteristic of the study area including its location and accessibility is well described in the second chapter. Chapter three covers literatures on the concepts of sedimentation problems of reservoirs and application of models for the prediction of sediments. Different international experiences of using CCHE1D model, SWAT, and TOPAZ in integration for sediment assessment and previous works in the study area are also reviewed in this chapter.

The main part of the research study, data analysis and model simulations are presented in the fourth chapter while the model results calibration and validations are discussed in chapter five. Finally conclusion and recommendation measures to decrease the amount of sediment inflow to the reservoir are given in the sixth chapter. Different tables and additional information are collected in the annexes.

2. STUDY AREA DESCRIPTION

2.1. Location and Accessibility

2.1.1. Location

The research area is located about 25 km from Addis Ababa in the east direction. The reservoir catchment area exists in Oromia Regional State under the administration of North Western Shoa Zone in Aleltu Bereh district administration. Sendafa town, the capital of Aleltu Bereh district and a little part of Addis Ababa city also belongs to the catchment area.

The catchment is bounded by latitude 9°01' N – 9°13' N and longitude 38°60' E - 39°07' E. In general, the catchment area has a total area of 234km^2. Legedadi dam is administrated by Addis Ababa Water and Sewerage Authority.

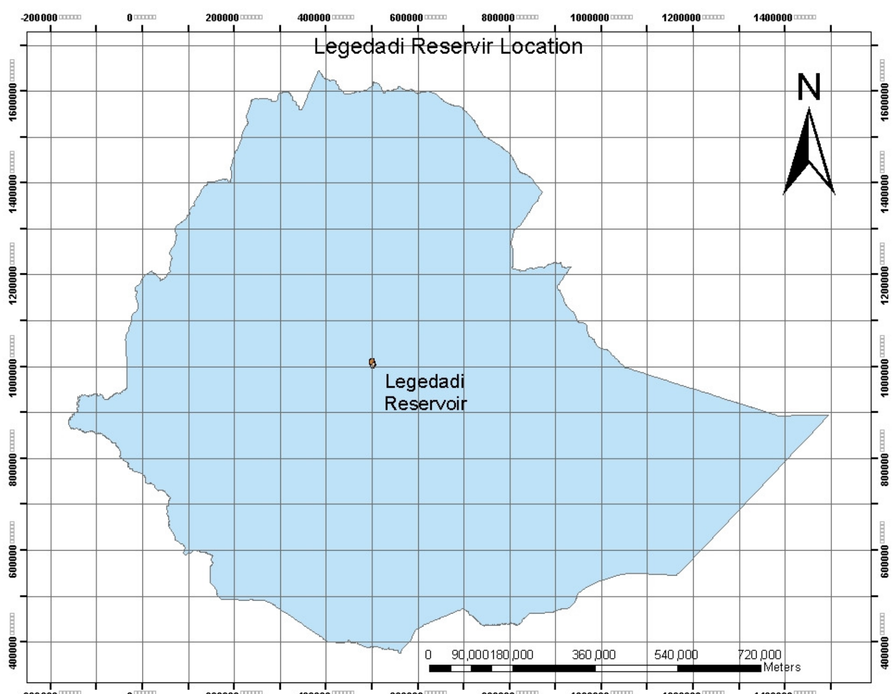

Figure 2.1 Location of Legedadi reservoir

2.1.2. Accessibility

Except the eastern part, which is mountanies, the rest of the reservoir area is accessible by four-wheel drive vehicles. The Addis Ababa-Dessie main asphalt road runs west east across the central part of the reservoir catchment area. Dry weather road, which runs between Legedadi and Dire reservoirs, crosses the catchment area from south to north. Besides these, there are footpaths from different villages that join Addis Ababa-Dessie road on the catchment area boundary.

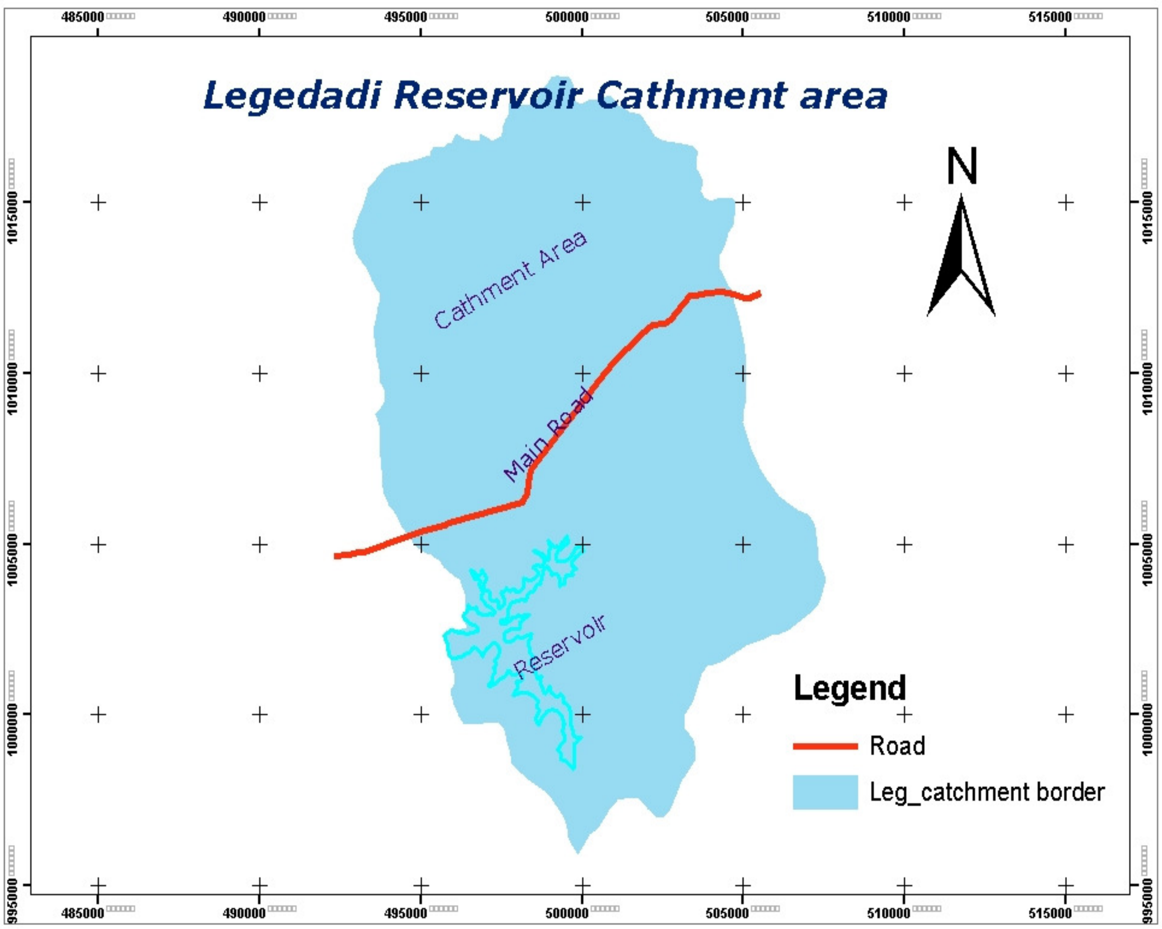

Figure 2.2: Legedadi Reservoir Catchment Area

2.2. Climate and Hydrology

2.2.1. Climate

The area is located in the upper northwestern part of the Awash basin. There are two seasonal patterns in the region of Addis Ababa. The weather is relatively cool in the wet season of July to September when the main rain falls, while the more or less rainless season of October to June has warmer temperatures with easterly winds. Rainfall usually occurs in the form of localized thunderstorms due to convective heating of the air masses during the day and rapid cooling at night.

i) Precipitation/Rainfall

Near to the study area, there are two meteorological stations, which are located in Sendafa ($38^{0}20'E$, $4^{0}05'N$) and Addis Ababa ($39^{0}04'E$, $3^{0}31'N$). 10 years of rainfall data was collected from the National Meteorological Agency for the stations from 1954 to 2006. Summary of the mean rainfall (mm/month) data is given in the table 2.1 and 2.2 below

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	21.5	31.2	59.4	80.1	60.2	110	326.1	324.3	121.4	22.3	5.3	5.6	1167.4

Table 2.1: Summary of mean rainfall data of Sendafa Station, Year 1962-2006

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	17.1	34.1	66.4	86.5	73.1	118.8	245.2	244.6	141.7	32.6	5.68	5.36	1071

Table 2.2: Summary of mean rainfall data of Addis Ababa Station, Year 1963-2006

From the rainfall data of the stations high rainy seasons are observed in July and August. The main cause of the rainfall in this region is the southward migrating Inter Tropical Convergence Zone (ITCZ) and westward propagating disturbance from the Indian Ocean (Zenaw et al, 2000).

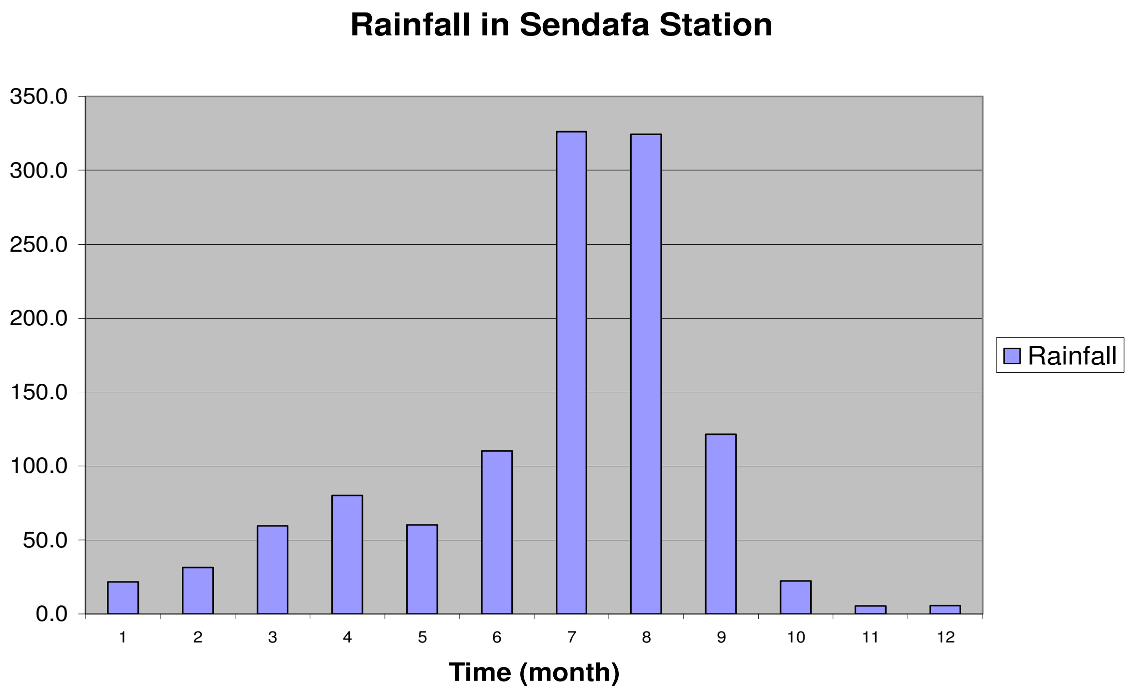

Figure 2.3: Mean Annual Rainfall Chart of Sendafa Station

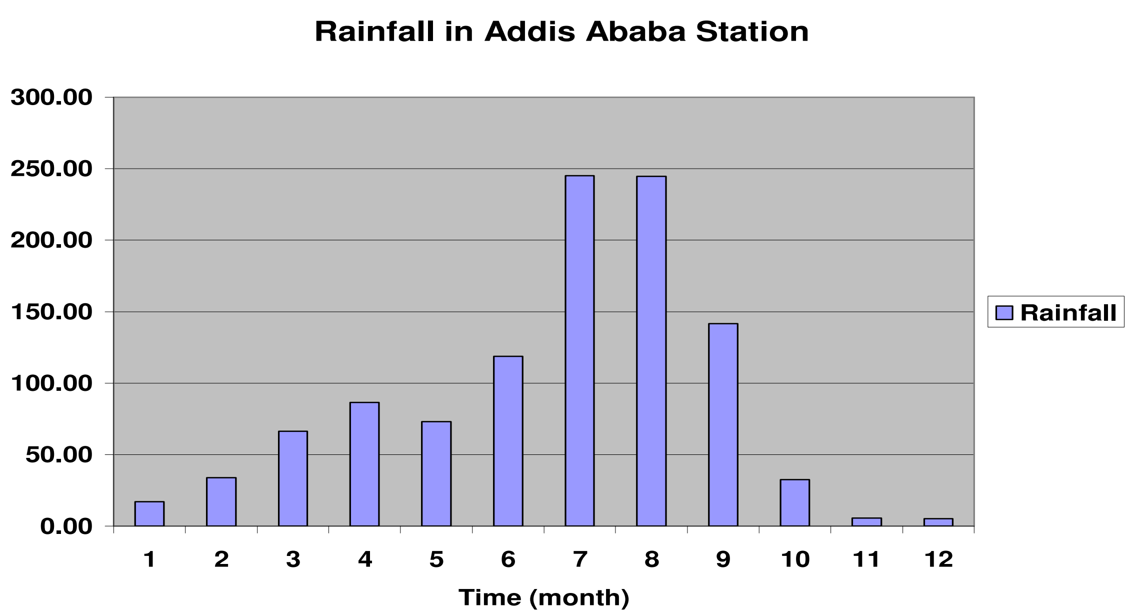

Figure 2.4: Mean Annual Rainfall Chart of Addis Ababa Station

The above charts clearly show that the area has maximum rainfall in July and August. And the minimum rainfall is recorded in November and December.

There is also no significant variation in the mean annual rainfall of the two stations.

ii) Temperature

The mean monthly temperature is between 16°C and 26°C throughout the year. The minimum monthly average temperature registered is 16.1°C in the month of July in Addis Ababa Station and the maximum monthly average temperature is 25.5°C in the month of February in Sendafa Station. The hottest season extends from December to late March.

The summary of mean monthly air temperature of the stations is given below.

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
T (°C)	20.6	21.0	20.3	19.5	18.3	16.8	16.1	16.9	18.3	18.9	19.2	19.8

Table 2.3: Mean Monthly temperature of Addis Ababa Station

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
T (°C)	24.9	25.5	25.0	23.0	21.8	20.6	19.9	20.5	21.6	22.0	22.5	24.9

Table 2.4: Mean Monthly temperature of Sendafa Station

2.2.2. Hydrology

The Legedadi catchment area may be sub-divided into six sub-catchment areas as:

The main sub catchments:

- The Lege Beri sub-catchment
- The Lege Sekoru and Lege Fule sub- catchment
- The Lege Bolo sub- catchment
- The Lege Sendafa sub-catchment
- South Eastern Tributary
- Others

Lege Sekoru and Lege Fule streams enter Legedadi reservoir via a common course. Lege Bolo and Lege Sendafa also merge several hundred meters before entering Legedadi reservoir.

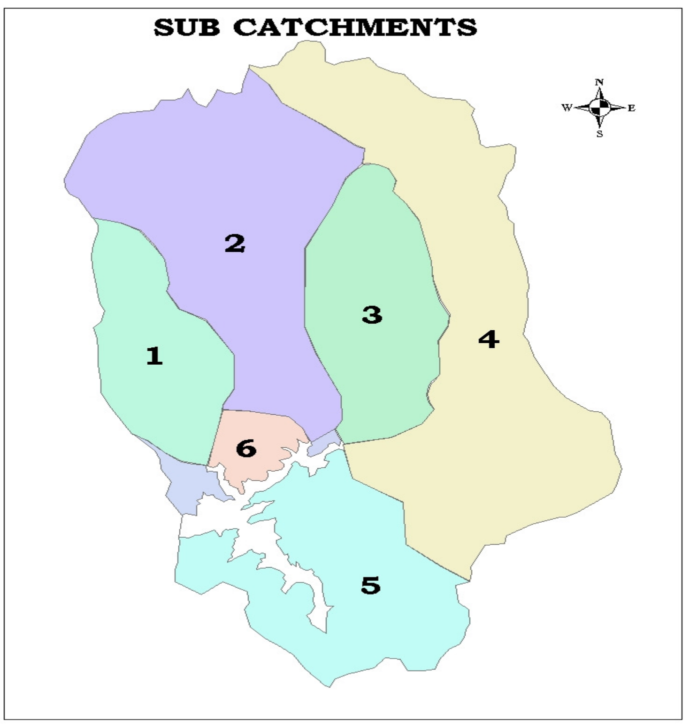

Figure 2.5 Sub catchments of Legedadi Reservoir

2.3. Land use and Soil Type

2.3.1. Land Use

The land use and land cover types in the Legedadi catchment area are distributed by the government and local authorities according to the farmers needs but without there being any regional plan that is necessary to maintain the ecological balance of the reservoir. (Bathymetric Survey, 2002)

The cultivated fields are located in: the mid and lower slopes of the mountains and hills, foot slopes, undulating plains, flat to almost flat plain valley sides, and at part the edge of the perimeter of the reservoir. The cultivated fields situated on the steep and undulating slopes are not protected from water erosion by any soil and conservation measures. The area land use/ land cover is discussed in detail on the methodology chapter. (Chapter 4)

2.3.2. Soil Type

There are four types of soils in the catchment area on which crops are grown annually. Theses soils are Koticha afer (Black vertisol soil), Dalecha afer (Grey soil), Gembore afer (Light soil) and Key afer (Red soil) (Bathymetric Survey, 2002)

The Koticha afer (Black soil) is found on flat to almost flat areas and valley bottoms and is not sensitive to erosion. It gives good yields of crops when fertilizers are applied; teff, wheat, barely, lentile chickpea and rough pea, are grown on these soils. These crops occupy 45%, 30%, 5%, 10%, 5% and 5% respectively of the crops areas situated on the black vertisol soils. (Bathymetric Survey, 2002)

The Dalecha afer(Grey soil) occupies some of the undulating plains and valley sides. According to the farmers this soil has law fertility. Half of the area of these soils has to be left fallow every other year and the residues burned to give good crop yields. These soils are susceptible to erosion. (Bathymetric Survey, 2002)

The Gembore afer (Light soil) and the key afer (Red soil) occupy the hills, mountainsides and the foot slopes. They are susceptible to erosion when ploughed because of their steep slopes. (Bathymetric Survey, 2002)