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Addis Ababa, Ethiopia

Flood Hazard and Risk Assessment
in
Fogera Woreda using GIS & Remote Sensing

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in the Partial Fulfillment of the Requirements for the Degree of Masters of Science in GIS and Remote Sensing

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Declaration

I, the undersigned declare that this thesis is my original work and has not been presented for a degree in any other university and that all sources of material used for this thesis have been dully acknowledged.

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This Thesis has been submitted for examination with my approval as university advisor.

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Abstract

Flood is a natural disaster. However human activities in many circumstances change flood behavior. Activities in the catchment such as land clearing for agriculture may increase the magnitude of flood which increases the damage to the properties and life. Fogera Woreda is one of the most severally flood affected areas in Northwest Ethiopia in general and Ribb-Gumara Catchment in particular. It is situated in the downstream part of Ribb and Gumara Rivers. Relatively dense population and different landuses are found in this area, which are vulnerable to flood hazard. Intensive agricultural activities on steep slope areas of the catchment and its expansion decrease the abstraction of rain water and there by changed quickly to flood water. The high magnitude of water that enters in to Ribb and Gumara rivers overflows these rivers. For a number of reasons the most frequent choice should be protection from the flooding by revilagizing the people to the safe ground, but there is also a need for a broader and comprehensive program for managing flood hazard in the study area. Flood protection has been helpful and must be continued. Side by side other preventive tools like effective landuse planning, creation of a computerized GIS database for the flood prone areas and a detailed flood risk assessment and mapping are required to minimize the harmful effects of flood hazard.

Therefore, an attempt has been made to apply modern techniques like GIS and Remote Sensing for the assessment of flood hazard and flood risk in Fogera Woreda. The flood causative factors were developed in the GIS and Remote Sensing environment and weighted and overplayed in the principle of pair wise comparison and MCE technique in order to arrive at flood hazard and flood risk mapping. Landuse/landcover change detection was done for the catchment using the 1985 and 1999 Landsat images and shrub lands, grass lands and open wood lands were found to be decreased in areal extent while agricultural lands and swamps were increased. Comparison between long year (1974-2006) annual maximum daily rainfall and annual maximum daily gauge levels (1971-2005) data of Ribb and Gumara rivers showed that rainfall slightly decreases while gauge level increases, and this can be attributed to landcover removal especially in the upper catchment. Flood frequency analysis was done using Ribb and Gumara rivers annual daily maximum gauge levels and the likely flood levels in different return periods were found. DEM and the 100 year return period base flood were combined in the GIS environment in order to produce flood inundation maps. Results from the overlay analysis and from the flood frequency analysis soundly agree to each other. The major findings of the study revealed that most of the PAs in the down stream part of the catchment and the different landuses in these areas are within high to very high flood hazard and flood risk level. The presence of risk assessment mapping will help the concerned authorities to formulate their development strategies according to the available risk to the area.

Key words: Flood, Hazard, Risk, GIS, Remote Sensing, MCE, Flood Frequency Analysis, Landuse/Landcover Dynamics, Fogera Woreda, Ribb-Gumara Catchment.

Acronyms

AAU	Addis Ababa University
CETAA	Canadian Education and Training Awards for Africa
DEM	Digital Elevation Model
DPPA	Disaster Preparedness and Prevention Agency
DPPC	Disaster Preparedness and Prevention Commission
DSS	Decision Support System
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental System Research Institute
ETM	Enhanced Thematic Mapper
FAO	Food and Agricultural Organization
FCC	False Color Composite
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
IR	Infra Red
MCE	Multi Criteria Evaluation
MoWR	Ministry of Water Resource
MSS	Multi Spectral Scanning
NMA	National Meteorological Agency
RGB	Red, Green, Blue
SDSS	Spatial Decision Support System
TIN	Triangulated Irregular Network
TM	Thematic Mapper
UNEP	United Nation Environmental Program
UNOCHA	United Nation Office for the Coordination of Humanitarian Affaires
UTM	Universal Transverse Mercator
WLC	Weighted Linear Combination

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1. Introduction

1.1 Background

Topographically, Ethiopia is both a highland/mountainous and lowland country. It is composed of nine major river basins, the drainage systems of which originate from the centrally situated highlands and make their way down to the peripheral or outlying lowlands. Especially during the rainy season (June-September), the major perennial rivers as well as their numerous tributaries forming the country's drainage systems carry their peak discharges.

The country experiences two types of floods: flash floods and river floods. Flash floods are the ones formed from excess rains falling on upstream watersheds and gush downstream with massive concentration, speed and force. Often, they are sudden and appear unnoticed. Therefore, such floods often result in a considerable toll; and the damage becomes especially pronounced and devastating when they pass across or along human settlements and infrastructure concentration. The recent incident that the Dire Dawa City experienced is typical of flash flood.

On the other hand, much of the flood disasters in Ethiopia are attributed to rivers that overflow or burst their banks and inundate downstream plain lands. The flood that has recently assaulted Southern Omo Zone and South Gondar (mainly Fogera Woreda) Zone is a typical manifestation of river floods.

Therefore, owing to its topographic and altitudinal characteristics, flooding, as a natural phenomenon, is not new to Ethiopia. They have been occurring at different places and times with varying magnitude. Some parts of the country do face major flooding. Most prominent ones include: extensive plain fields surrounding Lake Tana and Gumara and Rib Rivers in Amhara Regional State; areas in Oromia and Afar Regional States that constitute the mid and downstream plains of the Awash River; places in Somali Regional State that fall mainly along downstream of the Wabishebelle, Genalle and Dawa Rivers; low-lying areas falling along Baro, Gilo and Akobo Rivers in Gambella Regional State; downstream areas of Omo River in the Southern Nations, Nationalities and Peoples Regional State (DPPA, 2006).

Fogera Woreda, which is located between $11^0 57'$ and $12^0 30'$ North latitude & $37^0 35'$ and $37^0 58'$ East longitude, is traditionally identified as one of flood prone areas of Ethiopia. This

Woreda has an aerial extent of 1110 square kilometer and a total population of about 246541 of which over 90% has rural setting. Elevation in the study area ranges from 1780 m to 2510 m and it has an average elevation of 1937 meter above mean sea level. The Woreda is drained by two major rivers, namely Ribb and Gumara. It totally lays in Ribb-Gumara Catchment, which is part of the Blue Nile Basin. This Catchment encloses big flat to gently sloping plains located in the administrative Zone of South Gondar, east side of Lake Tana. Fogera Woreda is particularly found in the downstream part of the above mentioned catchment.

1.2 Statement of the Problem and Justification

Flood is probably the most devastating, widespread and frequent natural hazard of the world. This problem is more acute in highland areas like Ethiopia under strong environmental degradation due to population pressure. According to UNEP (2002), the major environmental disasters in Africa are recurrent droughts and floods. Their socio-economic and ecological impacts are devastating to African countries, because most of them do not have real time forecasting technology or resources for post-disaster rehabilitation. Although flood events are not new to Ethiopia, the country, in its current main rainy season, has been threatened by quite unprecedented flooding of abnormal magnitude and damage. Apparently, this is, for the large part, due to torrential or heavy rains falling for long days on the upstream highlands. The rains have caused most rivers to swell and overflow or breach their courses, submerging the surrounding ‘flat' fields or floodplains, which are mostly located in the outlying pastoralist regions of the country. It is evident that the problem of river flooding in Ethiopia is getting more and more acute due to human intervention in the fragile highland areas at an ever-increasing scale. According to United Nation Office for the Coordination of Humanitarian Affaires (UNOCHA) (2006), across Ethiopia, the number of people affected by the floods of this year has reached 357,000, including 136,528 forced to abandon their homes. Ethiopia's northern Amhara region was the worst hit in the giant Horn of Africa nation, with 97,000 people affected, of which 37,000 lost their homes. The floods swamp large areas of cropped land in this region. Another survey conducted by the Joint Government and Humanitarian Partners Flash Appeal for the 2006 Flood Disaster in Ethiopia showed that in Amhara Region 40500 people are vulnerable, 47100 affected, and 5 are died by this year flood.

Geographic information system (GIS) is a computer-based system that provides the capabilities for input, data management (data storage and retrieval), manipulation and analysis, and output to handle georeferenced data (Aronoff, 1995). GIS provides a broad range of tools for determining area affected by floods and for forecasting areas that are likely to be flooded due to high water level in a river. GIS will be extensively used to assemble information from different maps, aerial photographs, satellite images and digital elevation models (DEM). Census data and other relevant statistical abstract will also be used to make the risk map more oriented to need of the local inhabitants.

Remote sensing is the science and art of acquiring information (spectral, spatial, and temporal) about material objects, or area, without coming in to physical contact with the objects or areas, under investigation (Lillesand, 2004). Remote sensing technology along with GIS has become the key tool for flood monitoring in recent years. The central focus in this field revolves around delineation of flood zones and preparation of flood hazard and flood risk maps for the vulnerable areas. River flooding in the developing countries of Africa is very acute because of their heavy dependence on agriculture but any flood estimation or hazard mapping attempt in this region is handicapped by poor availability of high resolution DEMs. Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily read, rapidly accessible charts and maps, which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation/response efforts.

Overflow of Ribb and Gumara Rivers and backflow of Lake Tana has affected and displaced 43127 and 8728 people respectively in Fogera Woreda in this summer (UNOCHA, 2006). Some people said that several months of excessive rain has flooded rivers and stranded families in low-lying areas. While others said it is severe environmental degradation of specially the highlands that cause floods of this Woreda. This issue needs research in order to design long-lasting solutions for the safety of the population and the natural environment as well.

The regulation of flood hazard areas coupled with enactment and enforcement of flood hazard zoning could prevent damage of life and property from flooding in short term as well as in long term. Flood management and control are necessary not only because floods impose a curse on the society, but the optimal exploitation of the land and proper management and control of water resources are of vital importance for bringing prosperity in the predominantly agricultural based economy of this highly populated Woreda. This cannot become technically feasible without effective flood hazard and flood risk maps. Flood risk mapping is the vital component in flood mitigation measures and land use planning. This thesis research attempts to synthesize the relevant database in a spatial framework to evolve a flood risk map for Fogera Woreda in particular and flood hazard map of Ribb and Gumara Catchment in general. Basic aim of this effort is to identify the area chronically suffering from flooding and create a flood hazard and flood risk maps based on topographical, meteorological, and socioeconomic data. The study has also focused on the identification of factors controlling flood hazard in the study area. A flood rick map based on administrative units is particularly handy for the planners and administrators for formulating remedial strategy. It also makes the process of resource allocation simple resulting in a smooth and effective implementation of the adopted flood management strategy.

1.3 Objective

1.3.1 General Objective

This thesis research is mainly aimed at assessing the flood risk in Fogera Woreda with the application of Multi Criteria Evaluation (MCE) technique.

1.3.2 Specific Objectives

In connection with the above general objective the following specific objectives are outlined.

- To assess factors controlling flood hazard in the study area
- To find out flood levels (Gauge) for different return periods by frequency analysis of available gauge data
- To create area inundation map of Ribb-Gumara catchment with a particular return period flood levels computed from frequency analysis and using the DEM, in case of embankment failure
- To develop flood hazard map of the Catchment
- To develop flood risk maps of the study area
- To analyze landuse/landcover change in Ribb-Gumara Catchment
- To recommend some mitigation measures for the recurrent flood risks

1.4 Research Questions

- ✓ What are the main flood causative factors in Ribb-Gumara Catchment?
- ✓ Which parts of Ribb-Gumara Catchment suffer from more flood hazard?
- ✓ To What extent are Fogera Woreda Population and Landuses exposed to flood risk?

- ✓ Is there any LU/LC change in Ribb-Gumara Catchment for the last 15 years? If so, what the general pattern looks like, and to what extent the change undergoes?

1.5 Outline of the Remaining Chapters

Chapter two reviews related literatures. Chapter three presents the general description of the study area while chapter four assesses the materials and methods used in this study. Chapter five focuses on the data processing and analysis made, and chapter six presents the results of the study and discussion about them. It also tries to compare the results of the different approaches in this study. Chapter seven finally focuses on the conclusion and recommendations of the study.

2. Literature Review

2.1 Historical Background of Flood Risk in Ethiopia

Risk assessment of the flood prone areas in Ethiopia is not an easy task. There is a big shortage of adequate and reliable water and soil data. More over, the absence of stream flow data and the secrecy about survey reports of some major rivers, classified as "International Rivers", effectively block any thorough study of the topic.

However, there are some studies, particularly done by the then DPPC (now DPPA) and also by some other organizations and individuals, on flood risk in Ethiopia. In the past, there have been floods which have taken both human lives and destroyed properties. According to DPPC, 1978, the following areas have been recognized as flood-prone areas.

- In Gondar Administrative Region immediately east of Lake Tana where River Ribb and Gumara enter the Lake.
- In Hararghe Administrative Region on the Wabe Shebele River from Imi to Mustahil.
- In Illubabor Administrative Region on the Baro River from the town of Gambela to the border town of Jakao.
- In Wollo Administrative Region on the Awash River around Assayita.
- In Shewa Administrative Region around Tefki in the Teji Depression.

Maps that show geographical distribution of these areas, and other relevant information on flood occurrence years and flood risk are incorporated on the above mentioned document. However, the study is to general to show flood hazard and risks at a lower grass-root kebele level.

Another study conducted again by DPPC, 1996, showed areas that suffer from flood risk at a national scale.

Table 1: Summary of Causes of Flooding, Flood Risk, and duration by Region

Regions	Causes of flooding	Flood Risk			Duration
		No of affected population	*No of affected livestock*	*Property damaged in Birr*	
Tigray	Flash flood,	112	15	13835	1987
Afar	River Flooding	445700	-	-	1985/87
Amhara	River flooding, flash flooding	165363	2693	1504745	1985-88
Oromia	River flooding, flash flooding	63359	359	9882811	1985-87
SNNP	Flash flooding, River flooding	252713	79781	4708683	1981/86/87

Gambela	River flooding	224828	-	-	1985/87
Fourteen	Flash flooding	10572	29	16400718	1986/87
Grand Total		1162647	82877	32510792	

(Source: Compiled from DPPC, 1996)

Although flood events are not new to Ethiopia, the country, in 2006 main rainy season, has been threatened by quite unprecedented flooding of abnormal magnitude and damage. Apparently, this is, for the large part, due to torrential or heavy rains falling for long days on the upstream highlands. The rains have caused most rivers to swell and overflow or breach their courses, submerging the surrounding 'flat' fields or floodplains, which are mostly located in the outlying pastoralist regions of the country.

As a result of the extended and widespread heavy rainfall as of the beginning of 2006 main rainy season, many areas have already experienced devastating damage. According to DPPA, 2006, altogether some 635 people have died (364 in South Omo, 256 in Dire Dawa and 19 in various other parts of the country). Thousands have lost their property and means of livelihood. The soil in most areas is saturated and rivers are full.

In this summer, a total of some 524,400 people were vulnerable to flood disaster through out the country. Out of this population, 199,900 people are actually affected by flood disaster in various areas (Table 2).

Table 2: Areas and Population Affected/under Threat by Flood Disaster in the 2006 main Rainy Season

No	**Region**	**Vulnerable**	**Affected***
1	Afar	28000	4600
2	SNNP	106300	44000
3	Amhara	47100	47100
4	Oromia	61300	21900
5	Tigray	122300	2600
6	Diredawa	10400	10400
7	Somalia	87000	43200
8	Gambela	62000	26100
	Total	**524400**	**199900**

**The affected number of population includes 15 % contingency*

Source: DPPA, 2006

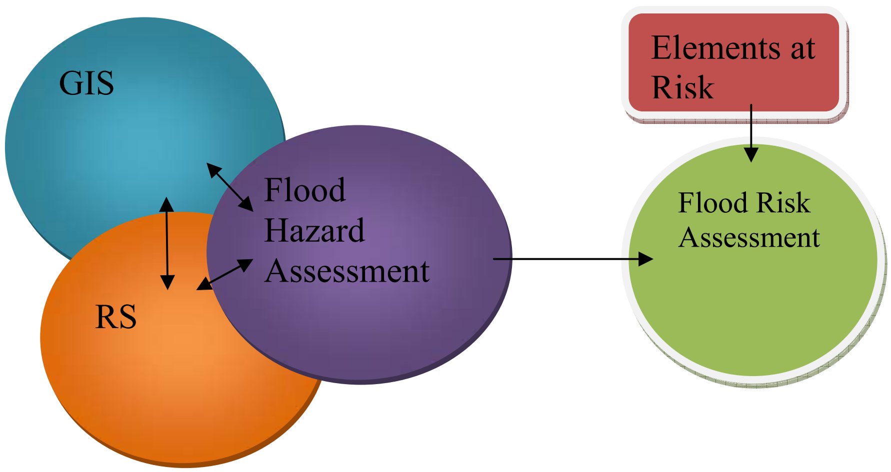
The above document also shows the geographical distribution of flood affected Woredas in Ethiopia as of August 2006.

2.2 Role of GIS and Remote Sensing for Flood Hazard and Risk Assessment

Nowadays GIS is emerging as a powerful tool for the assessment of risk and management of Natural Hazards. Due to these techniques, natural hazard mapping can be prepared now to delineate flood prone areas on the map. Such kind of maps will help the civil authorities for quick assessment of potential impact of a natural hazard and initiation of appropriate measures for reducing the impact. Such data will help the planners and decision-makers to take positive and in time steps during pre disaster situation. It will also help them during post disaster activities for the assessment of damages and losses occur due to flooding. Moreover, GIS provides a broad range of tool for determining areas affected by floods or forecasting areas likely to be flooded due to high discharge of the river. When spatial data are used in an information system, one tends to speak of a spatial information system. Spatial data has a physical dimension and geographic location. With the help of sequential images of certain area, we can find out the behavior of the flood routing and damages.

Spatial data stored in the digital data base of the GIS, such as a digital elevation model (DEM), can be used to predict the future flood events. The GIS data base may also contain agriculture, socio-economic, communication, population and infrastructural data. This can be used, in conjunction with the flooding data to adopt an evacuation strategy, rehabilitation planning and damage assessment in case of a critical flood situation.

Flood risk assessment requires up-to-date and accurate information on the terrain topography and the use of the land. Remotely sensed images from satellites and aircrafts are often the only source that can provide this information for large areas at acceptable costs. Digital Elevation Models can be constructed quickly or can be improved by using e.g. the Aster images. Furthermore all kinds of parameters that are important for hydrological modeling is related to the land cover, e.g. permeability, interception, evapo-transpiration, surface roughness, etc. And since land cover mapping using satellite images is already common practice, the spatial distribution of these values can be easily estimated. However satellite imagery is not only useful to derive input data for the hydrologic models, but offers also good possibilities to validate the output of the models when a flooding disaster has struck. The observed extent of the flood can then be compared with the modeled prediction. Perhaps the most promising application of RS is its use for elements at risk analysis. High resolution images offer great opportunities to identify individual structures. Recognition of the function of these structures is important for the assessment of their vulnerability and their importance and value. Especially for cities that experience fast and uncontrolled expansion into hazardous areas like floodplains, this offers an opportunity to monitor the increasing risks and impacts and to use it in their decision making process.



2.3 Approaches of flood Hazard and Risk Assessment

Flooding occurs when the amount of water reaching the drainage network exceeds the amount of water which can be contained by the drainage channels and overflows out onto the floodplain. Several factors influence whether or not a flood occur:

- the total amount of rainfall falling over the catchment;
- the geographical spread and concentration of rainfall over the catchment, i.e. the spatial variation;
- rainfall intensity and duration, i.e. the temporal variation;
- antecedent catchment and weather conditions;
- ground cover; and,
- the capacity of the drainage system to contain the water.

The causes of flooding are highly variable and a complex set of factors influence whether or not flooding occurs in a catchment. Localized and/or flash flooding typically occurs where there is intense rainfall over a small sub catchment which responds to rainfall in six hours or less. In urban or rural areas where drainage is poor, the risk of localized flooding is high under such circumstances. Widespread flooding and/or non-flash flooding (lasting for more than 24 hours), occurs following rainfall of high intensity or long duration over the whole or a large proportion of the catchment (Ken Granger, 2002). Runoff is typically low in areas where the percentage of vegetation cover is high, as vegetated areas allow high infiltration until the earth is saturated. Where the ground is pre-saturated, such as following a long wet period, medium rainfall events can cause flooding as runoff begins almost immediately. Flood levels in urban areas quickly rise where the percentage of impermeable surfaces on the floodplain, such as buildings, roads and car parks, is high. On sloping concrete and bitumen surfaces, for example, runoff is immediate.

The flood hazard can be assessed by two major approaches: (1) The statistical or hydrological and (2) Geomorphological. Alexander (1993) stated that the hydrological approach comprises methods of calculating or analyzing mainly, variables like discharge, recurrence intervals, flood hydrographs, water yield from the drainage basin and hydraulic geometry. On the other hand, the geomorphological approach consists of geomorphological analysis of the land forms and the fluvial system, to be supported where ever possible by information on the past floods and detailed topographic information (Manuela da Gloria Muianga, 2004). In this thesis, hydrological data was used to do flood frequency analysis. This yielded the return periods of each major peak discharges and the magnitude and probability of occurrence of flood peaks of specified return periods so as to help preparedness to cope with such peaks. Flood hazard and flood risk mapping was accomplished from topographical, land cover, geomorphic, meteorological and population related data. Multi-criteria decision-making technique, which provides a systematic approach for assessing and integrating the impact of various factors, involving several levels of dependent and independent, qualitative and quantitative information, was used. All data are finally integrated in a GIS environment to prepare a final Flood Hazard and flood risk map.

2.4 Multi-Criteria Spatial Decision Support Systems

A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different classifications, and so on. Broadly speaking a Decision Support System (DSS) is simply a computer system that helps you make a decision. DSS provide a means for decision-makers to make decisions on the basis of more complete information and analysis. Decision makers historically have indicated that inaccessibility of required geographic data and difficulties in synthesizing various recommendations are primary obstacles to spatial problem solving. Studies have shown that the quality of decisions (i.e., the ability to produce meaningful solutions) can be improved if these obstacles are lessened or removed through an integrated systems approach, such as a spatial decision support system (SDSS), particular and important types of DSS.

SDSS refers to those support systems that combine the use of GIS technology with software packages for selection of alternatives of location for different activities. In addition, multi-criteria decision making (MCDM) and a wide range of related methodologies offer a variety of techniques and practices to uncover and integrate decision makers' preferences in order to solve "real-world" GIS-based planning and management problems. However, because of conceptual difficulties (i.e., dynamic preference structures and large decision alternative and evaluation criteria sets) involved in formulating and solving spatial decision problems, researchers have developed multi-criteria-spatial decision support systems (MC-SDSS).

2.4.1 Single Objective Multi-Criteria Decision Making in GIS

Spatial Multi-criteria decision problems typically involve a set of geographically defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Malczewski, 1996). To meet a specific objective, it is frequently the case that several criteria will need to be evaluated. Such a procedure is called *Multi-Criteria Evaluation*. A *criterion* is some basis for a decision that can be measured and evaluated. It is the evidence upon which an individual can be assigned to a decision set. Criteria can be of two kinds: factors and constraints. A *factor* is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. But a *constraint* serves to limit the alternatives under consideration. In many cases, constraints will be expressed in the form of a Boolean (logical) map: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1.

Multi-criteria evaluation (MCE) is most commonly achieved by one of two procedures. Each method is characterized by different levels of control over tradeoff between factors and the level of risk assumed in the combination procedure. The first involves *Boolean overlay*, most simplistic type of aggregation, whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). The second is known as *weighted linear combination* (WLC) wherein continuous criteria (*factors*) are standardized to a common numeric range, and then combined by means of a weighted average. The result is a continuous mapping of suitability that may then be masked by one or more Boolean *constraints* to accommodate qualitative criteria, and finally thresholded to yield a final decision. The weighted linear combination (WLC) aggregation method multiplies each standardized factor map (i.e., each raster cell within each map) by its factor weight and then sums the results. Since the set of factor weights for an evaluation must sum to one, the resulting suitability map will have the same range of values as the standardized factor maps that were used. This result is then multiplied by each of the constraints in turn to "mask out" unsuitable areas. All these steps could be done using either a combination of SCALAR and OVERLAY, or by using the Image Calculator. In this thesis, WLC, which give us continuous level of hazard and risk maps in contrast to the Boolean sharp break two class values (hazard- risk/safe), is used. The constraints here are considered during the reclassification process by giving zero (0) scale so that these areas are masked out in the raster calculation and in tern in the final hazard/risk map.

Breaking the information down into simple pair wise comparisons in which only two criteria need be considered at a time can greatly facilitate the weighting process, and will likely produce a more robust set of criteria weights. A pair wise comparison method has the added advantages of providing an organized structure for group discussions, and helping the decision making group sharpen in on areas of agreement and disagreement in setting criterion weights.

The technique used in this thesis and implemented in IDRISI GIS software is that of pair wise comparisons developed by Saaty's (1977) in the context of a decision-making process known as the Analytical Hierarchy Process (AHP) (J. Ronald Eastman, 2001). It is one of the multi-criteria decision-making techniques. In the procedure for Multi-Criteria Evaluation using a weighted linear combination, it is necessary that the weights sum to one. In Saaty's technique, weights of this nature can be derived by taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved in determining suitability for the stated objective. Ratings are provided on a 9-point continuous scale (Table 3).

Table 3: *Ratings on a 9-point continues scale*

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
Less Important					More Important			

Spatial multi-criteria analysis is vastly different from conventional MCDM techniques due to inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, spatial multicriteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria. This means analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two considerations are of paramount importance for spatial Multicriteria decision analysis: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives). The major elements involved in spatial Multicriteria analysis are shown in Figure 1 [Malczewski, 1999].

MC-SDSS offer a flexible, problem solving environment where the decision problem can be explored, understood and redefined; tradeoffs between multiple and conflicting objectives investigated; and priority actions set. In addition, MC-SDSS should have the ability to support both single-user and group decision-making processes. Systems in this category are termed MC-Group SDSS, and usually provide multiple-user/single-model and multiple-user/ multiple-model support.

To summarize, MC-SDSS tools offer unique capabilities for automating, managing, and analyzing single-user and collaborative spatial decision problems with large sets of feasible alternatives and multiple conflicting and incommensurate evaluation criteria.

3. Description of the Study Area and Flood Related Facts

3.1 Gumara-Ribb Catchment Overview

Ribb-Gumara Catchment, drained by Ribb and Gumara Rivers, is located between $11^{0}43'$N & $11^{0}53'$N Latitude and $37^{0}47'$ E &$37^{0}54'$ E Longitude. This catchment is part of the Nile Basin and more particularly part of that of Tana Basin located on the North Eastern side of Lake Tana. It has an areal extent of about 3320 km^2. Fogera Woreda, which has an area of 1110 km^2 totally lies in this Catchment. This Woreda is found in the down stream part of the Catchment where Ribb and Gumara Rivers join to Lake Tana. Overflow of these rivers and back flow of Lake Tana frequently flooded this Woreda than other woredas in the Catchment, and therefore selected for detailed flood risk study.

Gumara River, which is found at 13 km from Woreta Town (headquarter of Fogera Woreda), has its source in Mogishe Kidane Mihiret kebele, Farta Woreda. Guna Mountain in Farta Woreda is the source of Ribb River which crosses the main Bahir Dar-Gondar road at 10 km from Woreta Town. As explained above, in their lower reaches, these rivers flow through a large flat to very gentle sloping plain which is exposed to serious floods.

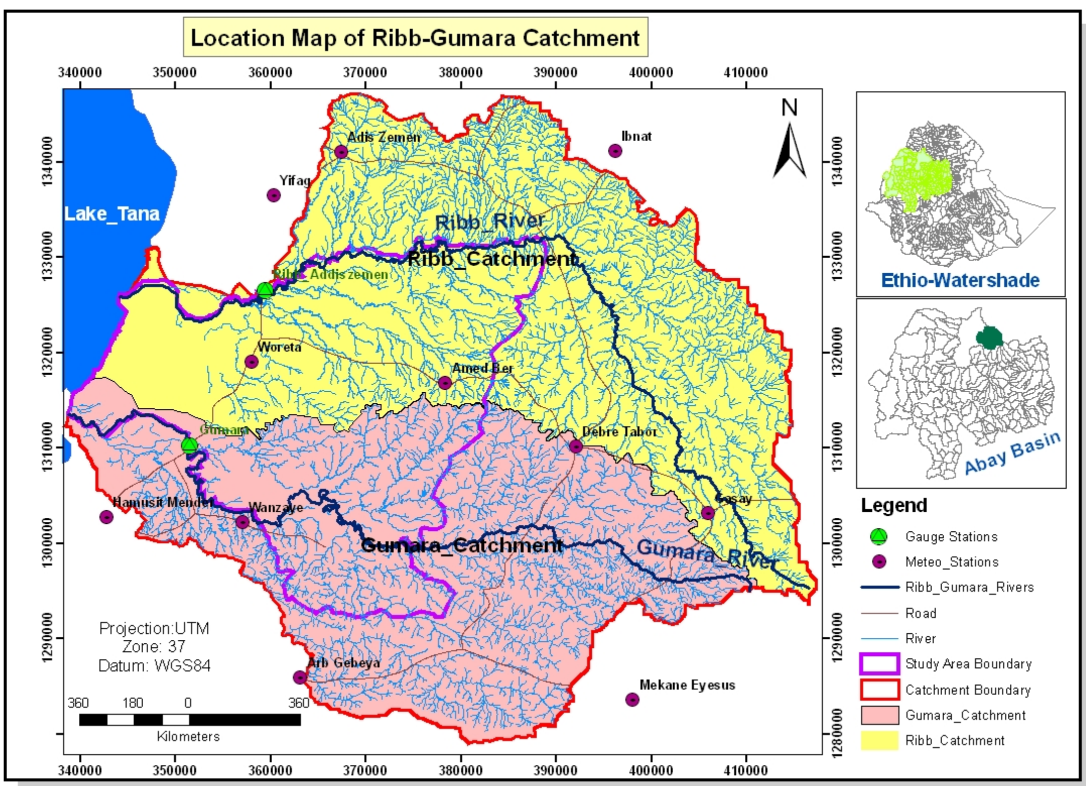


Figure 1: Location Map of Ribb-Gumara Catchment

3.2 General Description of the Study area

3.2.1 Bio-Physical Setting

3.2.1.1 Location

Fogera Woreda lies to the south-eastern shore of Lake Tana on the road from Bahir Dar to Gondar, 625 km from Addis Ababa and 55 km north of the Regional capital of Bahir Dar. It is one of the 105 woredas in the Amhara National Regional State of Ethiopia and located at its center. Part of the Debub Gondar Zone, Fogera is bordered to the south by Dera Woreda, to the west by Lake Tana, to the north by Libo Kemkem Woreda, and to the east by Farata Woreda. The major towns in Fogera Woreda are Woreta and Amed Ber, the former being the head quarter of the head quarter of the Woreda and it has twenty-five Peasant Associations (PAs) or kebeles and 2 urban Kebeles (figure 2). The area is located between 11° 57' and $12^0$30’ N latitude and 37° 35’ E and $37^0$58’ E longitude.

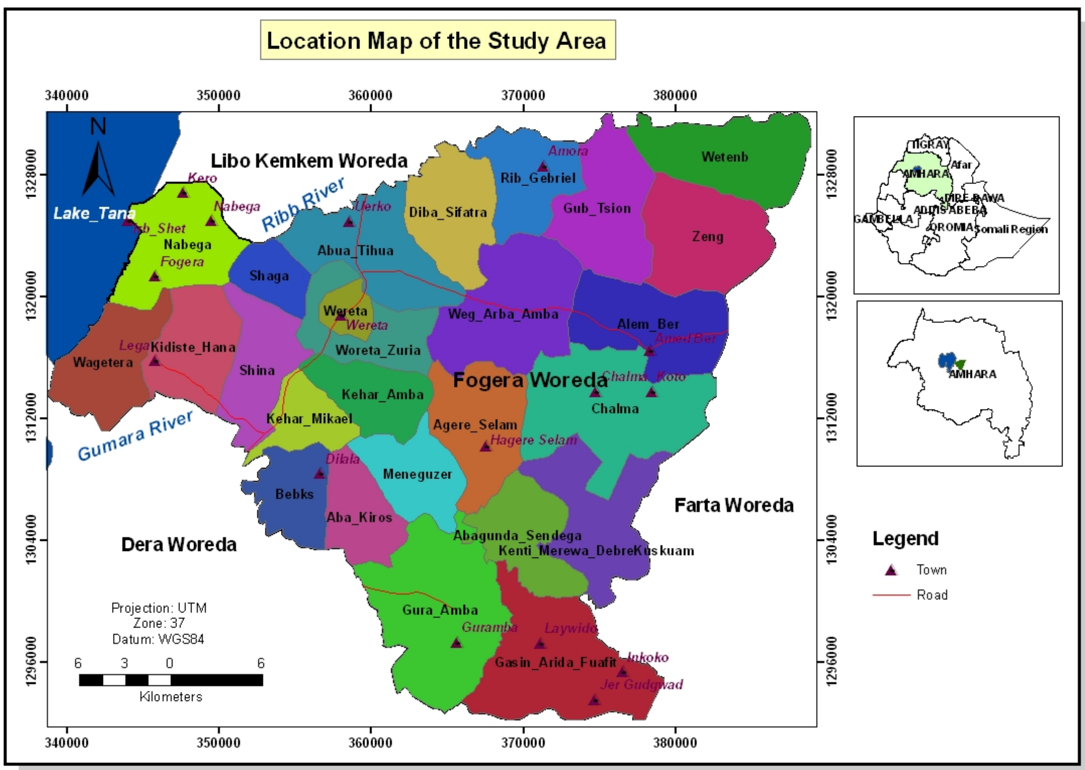


Figure 2: Location Map of the Study Area

3.2.1.2 Topography

The study area has a very flat land, which is known by the Fogera plane, adjacent to the eastern coast of Lake Tana. However, proceeding to eastward there is a rugged topography as shown in figure 3. Altitude ranges from 1780m to 2510 m.

The Woreda consists mainly of flat land (76%), while the mountain slopes and valley bottoms account for 24%.

3.2.1.3 Climate

- **Rainfall**

The study area has a diverse altitudinal difference which ranges from 1780 to 2510 masl. The agro climatic zone of the Fogera Woreda based on the agro climatic classification method (altitude and rainfall) is classified as Moist Dega (2300-3200masl) and Weyna-Dega (1500-2300m). Total annual rainfall ranges from about 1100 mm to 1530 mm/year. The spatial distribution of rainfall (Fig. 5) showed that Eastern and Central part of the Woreda receive highest rainfall while the northern portion receives the lowest.

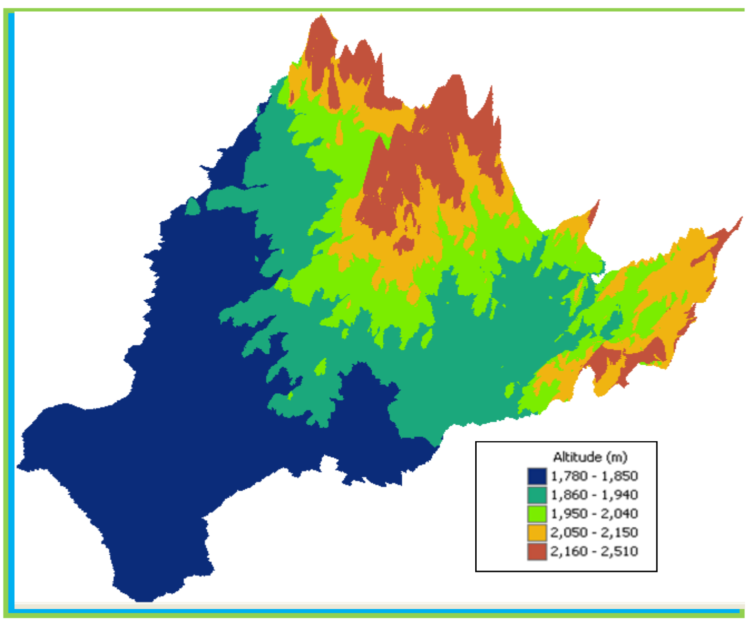
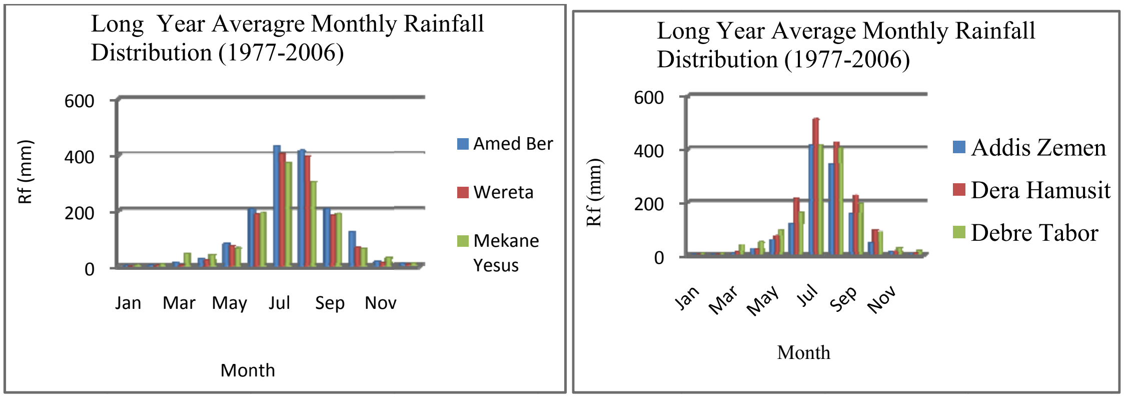


Figure 3: The Three Dimensional Image of the Study Area

The seasonal rainfall has a Unimodal distribution with peak in July. This is the 'Meher' season and it receives about 70% of the annual rainfall. The mean annual rainfall is 1430 mm and mean monthly values varies between 0.6 mm (January) and 415.8 mm (July), which indicate poor temporal distribution of rainfall.



(a) (b)

Figure 4: (a) and (b) Long Year Average Monthly Rainfall at Stations of the Catchment

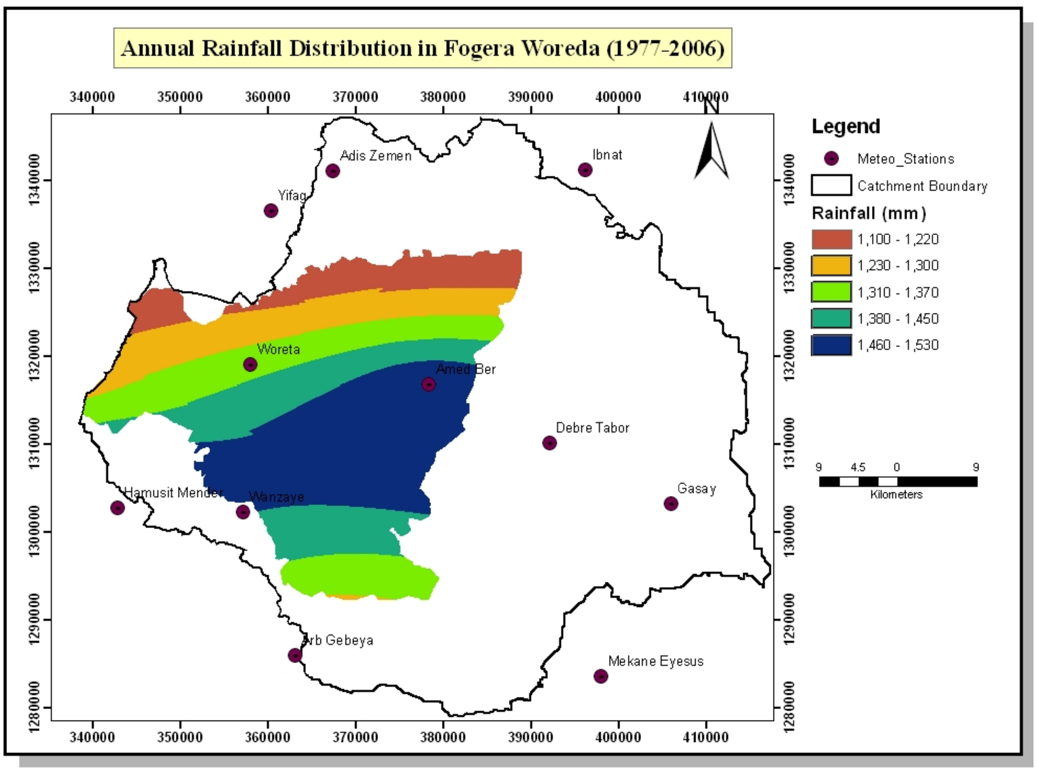


Figure 5: Long Year (1977-2006) Average Annual Rainfall Distribution in Fogera Woreda

Temperature

The mean monthly temperature of the area is about 19 ^{0}C, monthly mean maximum temperature is about 27.3 ^{0}C, and monthly mean minimum temperature is 11.5 ^{0}C. Diurnal range of temperature is higher (16.7 ^{0}C) at Woreta compared to that of Amed Ber (14.9 ^{0}C) (Fig. 6).

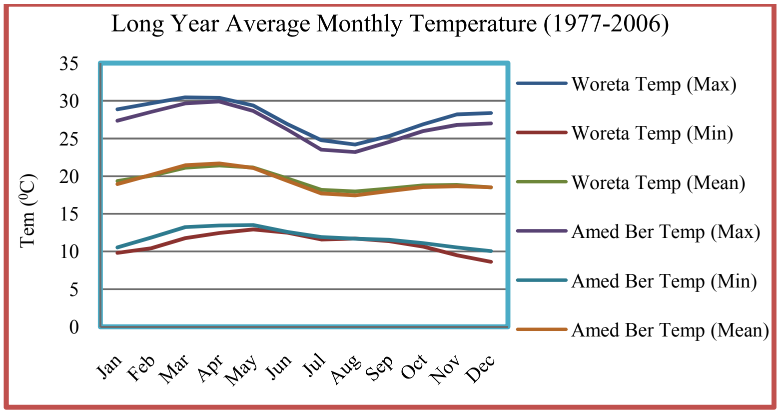


Figure 6: *Long Year (1977-2006) Temperature at Woreta and Amed Ber Stations*

3.2.1.4 Soils

The major soil types in Fogera Woreda exhibit a general relationship with altitude and slopes. Vertisols and Fluvisols are generally dominating the Woreda and particularly the lowland flat plains, valley bottoms and river terraces (Fig. 7). Texturally these soils are sandy clay and sandy loam respectively. Shallow Leptisols are the dominant soil types found in the mountain and hills of the study area. Luvisols dominate the southern and central part of the Woreda.

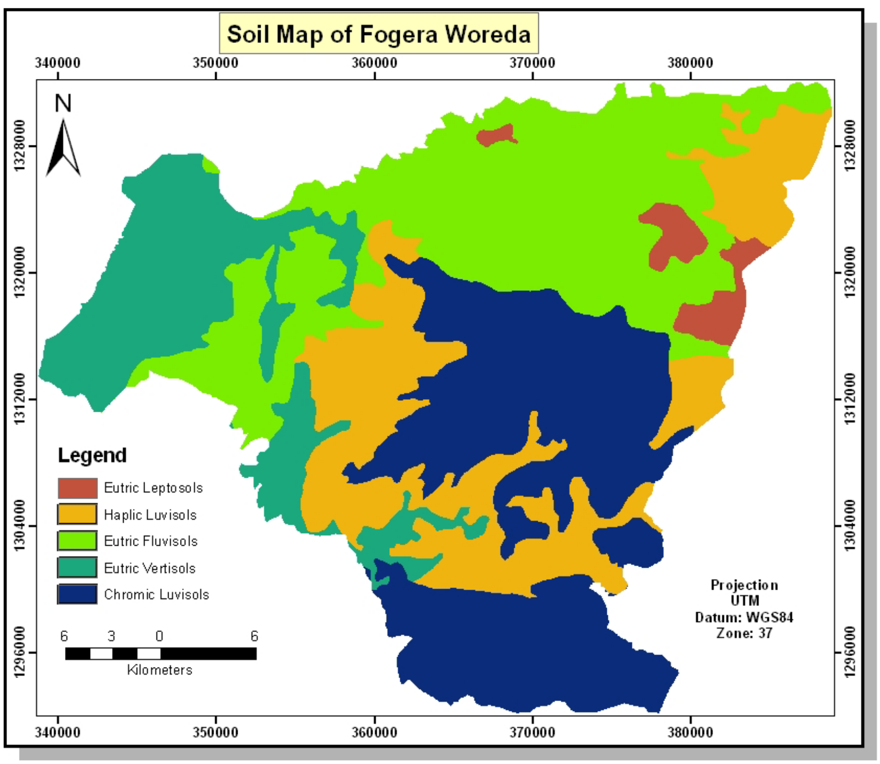


Figure 7: Soil Taxonomy Map

(Source: Endaweke, 2007)

The Woreda is dominated by Termaber basalts, especially in the upper eastern and southern parts (Fig. 8). While the western part adjacent to Lake Tana is occupied by lacustrine deposits.

3.2.1.5 Drainage System

Fogera Woreda mainly consists of a flat, open plain across which the Rib River flows into Lake Tana (Fig. 9). It passes through Wetemb, Addis Betekerstian, Reb Gebriel, Debasi Fatra, Abua Thua, Shaga, Naber and Shina PAs. The Gumara River forms the southern boundary of the study area and it passes through Fuafuat Gajera, Kinti Merewa, Abagunde Sendega, Aba Kiros, Bebeks, Quahr Michiel, Shena Kidist Hanna, Wagatera and Guramba PAs.

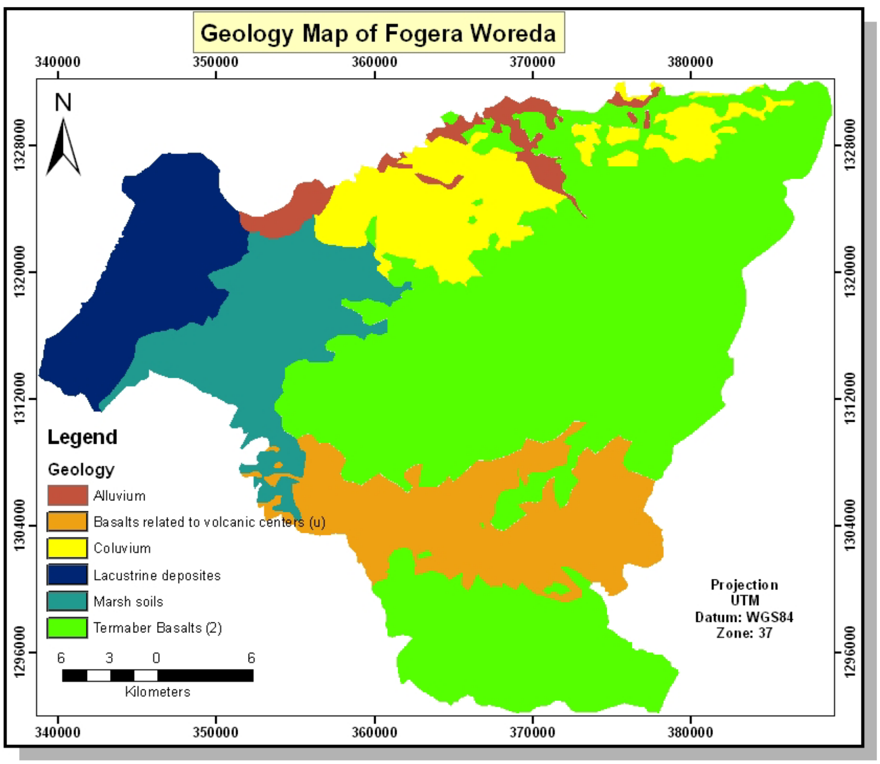


Figure 8: Geological Map of the Study Area

(Source: Ministry of Water Resources)

Both rivers originate on the high plateau to the east, and as they reach the plains the gradient decreases and they form meanders. During and after the rainy season, as the Rib River approaches the level of Lake Tana, water overflows its banks and floods the surrounding area. The perennial Gumara River also overflows its banks as it approaches the lake, but causes less flooding than the Rib. A perennial swamp has been formed around the mouths of these rivers. Lake Tana, which forms the western boundary of this area, also floods up to 1.5 km inland during the rainy season (Shiferaw and Wondafrash, 2006).

3.2.1.6 Vegetation

The shoreline of Lake Tana supports well-established papyrus beds 4 m tall. Further inland the vegetation is dominated by sedges, reed grasses and bulrushes, along with swamp grasses such as *Echinochloa* spp. and *Cynodon aethiopicus* that make very good grazing in the dry season. Patches of mixed small- and broadleaved trees and bushes are found around churches on small, rocky hills near the lake shore. These patches contain trees such as *Albizia* spp., *Croton macrostachyus*, *Cordia africana*, *Olea europaea cuspidata*, figs and *Phoenix reclinata*. The more shrubby areas comprise species typical of degraded forest, with *Carissa edulis*, small *Acacia* spp., *Rosa abyssinica* and *Dodonea angustifolia*. A variety of plants are found in and around homesteads, including *Arundo donax*, *Guizotia scabra*, *Solanum* spp. and other broadleaved plants. Papyrus is essential for making the local reed boats called 'tankwas'. Other reeds and bulrushes are used for matting, fencing and roofing, but as soon as farmers can afford it they use corrugated iron or aluminium sheets for roofing.

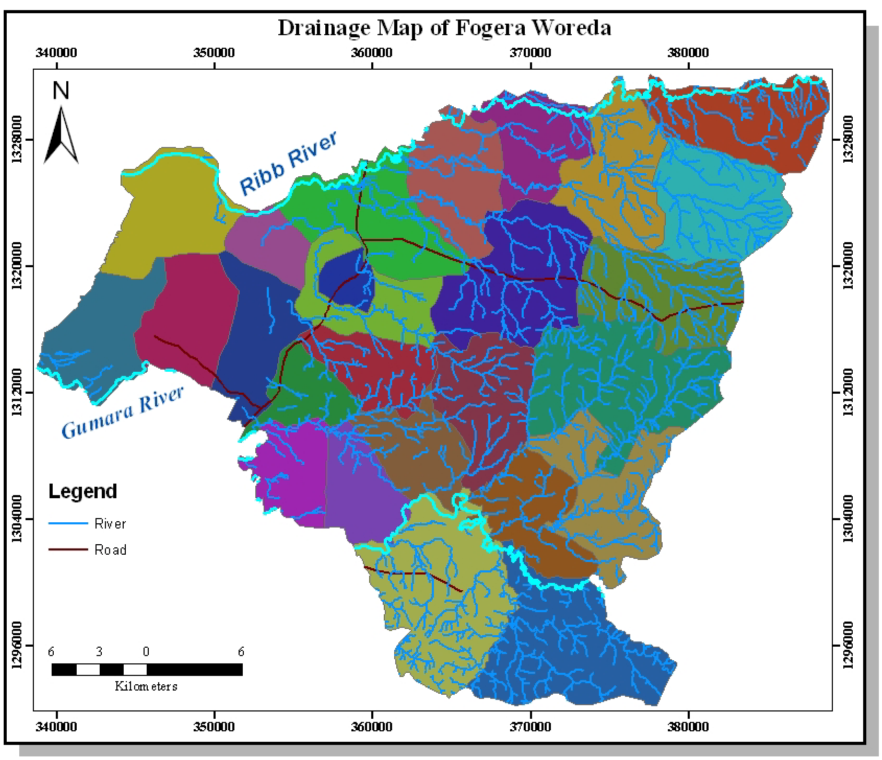


Figure 9: Drainage Map of the Study Area

3.2.1.7 Land Use/Land Cover

There are eight different types of land use/cover types in Fogera Woreda, namely agricultural land, shrub land, grassland, swampy area, plantation forest, wood land, Urban, and Water body. Form these land use/land cover classes the dominant one is agricultural land. It covers about 78.7 % of the total land area (Fig. 10). Table 4 shows the land use land cover of the study area.

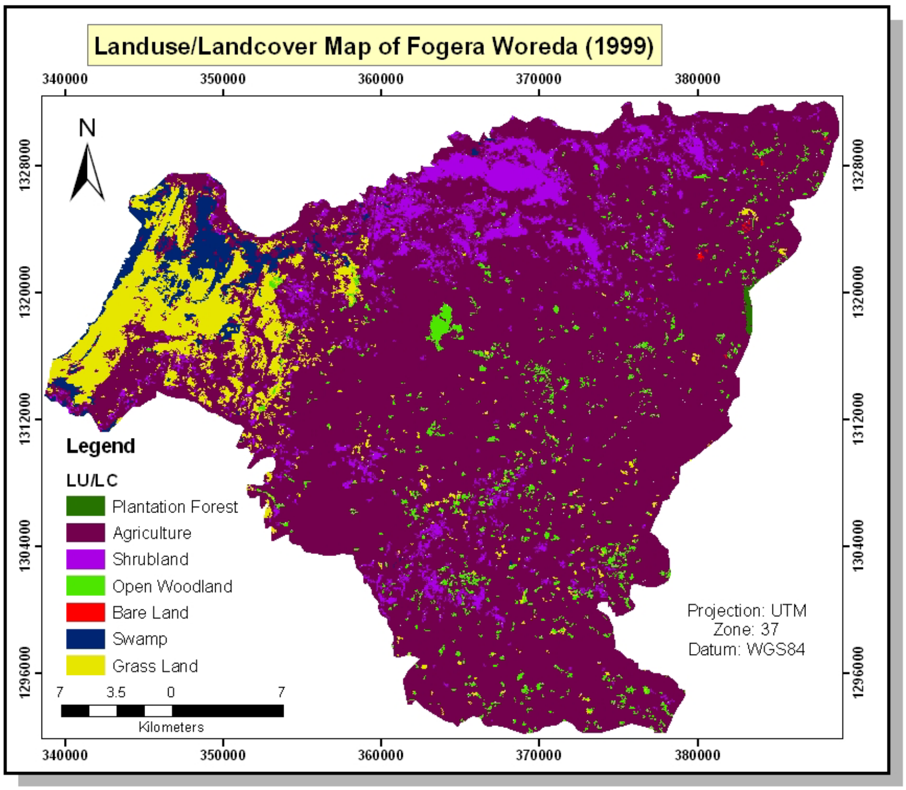


Figure 10: Land Use/Land Cover Map of the Study Area (1999)

Table 4: Land Use/Land Cover of Fogera Woreda

S.N	Land Use/Land Cover Type	Area (Km^2)	Percentage
1	Agricultural Land	873.4	78.7
2	Shrub Land	76.2	6..9
3	Wood Land	43.2	3.9
4	Plantation Forest	1.3	2.3
5	Grass Land	84.9	7.7
6	Swamp	29.9	2.7
7	Bare Land	0.5	3.9

3.2.2 Socio-Economic Setting

3.2.2.1 Population

The total human population of the Woreda is 246541 (Table 5). The rural population is estimated at 216511. Rural sex ratio is higher (108) than the Urban (85). The number of agricultural households is 42,230.

Table 5: Population Data of Fogera Woreda (1999)

	Male	Female	Total
Rural	112664	103847	216511
Urban	13814	16216	30030
Total	126478	120063	246541

(Source: FWOARD, 2006)

3.2.2.2 Agriculture

The farming system in the north and western section of the Woreda, encompassing the area known as the Fogera plains, and which gets flooded during the rainy season, is mainly rice, fish, horticulture and livestock. The farming system in the south and eastern section, which varies from lowlands to highlands, is cereals, oil crops, horticulture, livestock and apiculture.

The plains support a large population of an indigenous breed of cattle, Fogera, named after the area. Cattle-farming is still a major activity, but crop cultivation has become increasingly important. What makes Fogera unique from other Woredas is that it grows rice with in the Fogera Plain and also recognized for the unique Fogera Cattle breed.

3.2.2.3 Infrastructure

Woreta and Amed Ber are two major towns in the Woreda. Both towns have supplies of potable water and electric power. Woreta town has also telephone service. The Woreda has 17 Km of asphalt road that crosses the town. There are also 38 Km of all weather roads and 67 Km of dry weather road.

There is one high school (grade 9-10), 4 junior secondary schools (grade 5-8) and 28 elementary schools in the Woreda. One health center, 7 clinics and 2 health posts are found in the Woreda. Health posts are located in the rural areas.

3.3 Flood Related Facts in Fogera Woreda

3.3.1 The Situation of Flooding in the Study Area

There have been many destructive floods in Fogera Woreda, including very severe floods of 1996, 1998, 1999, 2000, 2001, 2003 and 2006 (Shiferaw and Wondafrash, 2006). The 1996 flood set a new record for flooded area, while 2006 flood was unprecedented with its long duration and damage. In 1996, the total area inundated was over 5000 ha. In addition, about 2500-2600 ha area of land was inundated at the eastern shore of Lake Tana as the level of the Lake rose. The 1996 flood affected eight PAs, namely, Wagtera, Nabega, kidiste Hana, Shaga, Shina, Woreta Zuria, Kuhar Michael and Abatihua (Shiferaw and Wondafrash, 2006).

Flooding regularly occurs in the particular areas of Nabega, Wagtera, Shaga, Shina and other PAs of Fogera Woreda. The aforementioned PAs have been suffering from flooding. According to MoWR (1999), the main cause of flooding in the area particularly east of Lake Tana was the rise in the Lake level. It stated that "Lake levels (Lake Tana) vary between +1784 and + 1787.5 and especially during flood flows and high lake levels the area in the lower reaches of the plain face drainage problem." But, WMO/GWP (2003) argues that such a natural tendency of rise or fall in the lake level was not a regular cause of flooding in the area. It actually related the flooding of the area to the construction of a low weir at the outlet of Lake Tana at a spot known as Chera Chera. Thus, it explains that, after the completion of the weir the level of the Lake rose above the intended level and caused sever flooding along its shores especially on the eastern and southern parts." In one way or another, flooding has been a serious problem in the flat downstream areas of Ribb-Gumara Catchment. From 1996 onwards, flooding has a regular incidence in some areas especially the Lake Tana adjacent PAs such as Nabega, Wagtera and Kidiste Hana.

3.3.2 The 2006 Flood Event

The 2006 flood affected over 7473 households compared to that of the 1996 flood which affected about 6206 households (Shiferaw and Wondafrash, 2006). This year flood was the most sever of all the flood events experienced in the area so far. Due to the flood, 43,127 people (12% of the Woreda population) were affected (UNOCHA, 2006). This figure accounts 50% of the affected population in Amhara Administrative Regional State (UNOCHA, 2006). The following plates show the devastating 2006 flood events from its occurrence to the month when it gradually dries up.

Plate 3.1: The 2006 Flood in Woreta Zuzia PA *Plate 3.2: Gumara Bridge (Along Bahir Dar to Woreta)*

The figure above shows how sever is flooding in the study area. Water overflows on the settlement areas and the agricultural and grazing lands around them.

Over all, compared with the earlier years, the 2006 summer flood was so severe in terms of area coverage and property damage, but the causalities to human life is minimal. Fore example, in 1996 the flood taken away 40 people life in which, 32 were children, 5 and 3 were women and men respectively. Depending up on different flood causative factors the number of households displaced by its impact varies from year to year (Fig. 11).

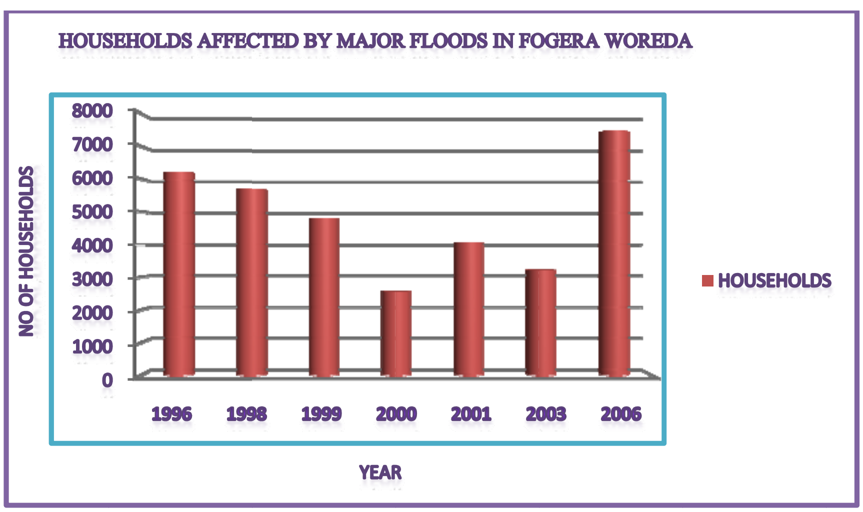


Figure 11: Households Affected by Major Floods in Fogera Woreda

(Source: Shiferaw and Wondafrash, 2006)

According to FWOARD, the 2006 flood severely affects six PAs adjacent to Lake Tana. About 35692 people were affected and 9080 of were displaced from their homes (Table 6).

Table 6: Affected and Displaced Population of Fogera Woreda by the 2006 Flood

S.N	PA Name	Total Population			Affected Population			Displaced Population		
		M	F	Total	M	F	Total	M	F	Total
1	Nabega	5393	5120	10513	5393	5120	10513	2752	1470	4222
2	Kidiste Hana	3122	3438	7060	3122	3438	7060	1382	706	2088
3	Wagtera	4721	4721	4482	4521	4021	3819	665	441	1106
4	Shina	4813	4569	9382	1532	1454	2986	183	235	418
5	Shaga	3629	3445	7074	2054	1948	4002	541	646	1187
6	Abua Thua	2834	2690	5524	1765	1525	3290	19	40	59
Total		**24512**	**24512**	**48756**	**18387**	**17305**	**35692**	**5542**	**3538**	**9080**

(Source: FWOARD, 2006)

The flood of 2006 has also caused a physical damage on women and children. The reason behind such impacts on this group of the society is that, this group does not trained swimming.

Plate 3.3: Evacuation from Flooding

Plate 3.4: Journey to the Temporary Shelter

Plate 3.5: Flood Damage around Woreta Zuria PA

Plate 3.6: Displaced people in the Temporary Shelter

The flood has created a Post-traumatic stress disorder, including anxiety, depression, and psychosocial problems on the community (Shiferaw and Wondafrash, 2006). Direct health effects (heart attacks and injuries) occurred during the flood occurrence and indirect health effects like diarrhea were also happened later on. Large number of people is expected to be victims of malaria since the flood will be a good ground for mosquito breeding. This may indirectly affect the hospital treatment cost, the labor force, productivity and so on.

Plate 3.7: Post health effects of flooding *Plate 3.8: Cattle on available small grassing Land*

Besides such bad events and expected effects, the flood has killed 9 cows and 1 sheep. Moreover, 322 bee hives were also destroyed. Most of the hats have been drowned by the flood. Cattle have been evacuated from the area. As a result environmental degradation because of overgrazing occurred in areas where the animals concentrated. Grains, which have been inside traditional containers, were spoiled by the flood. As a result of this, people from the impact areas are forced to depend on food aid. In which, the food aid might bring long term impacts on our working power, creativity potential, culture and on agricultural development activity.

Plate 3.9: Food aid to the Displaced People *Plate 3.10: Struggle for survival*

The flood has frequently devastated agricultural crops. A total of 6673ha of land, which were covered by different types of agricultural crops were drowned by the flood in the year 2006 (Table 1). The expected crop productions, which lost was 148005 quintals. The reduction in agricultural production because of flooding may elevate prices in agricultural crops in the coming year, which in turn may lead to poverty that forces people into a vulnerable position causing great loss of life and damage. From 1988-1997, in different years time, the country has lost 69929760 Birr due to loss of agricultural crops caused by flooding in Fogera Woreda.

Plate 3.11: Complete crop damage by Flooding

Table 7: Agricultural crops damaged by the flood in the year 2006.

No	Type of crop that were damaged by the flood	Area covered (ha)	Expected production that is lost (Quintals)
1	Rice	4482	121014
2	Millet	608	6810
3	Maize	567	13608
4	Pepper	263	2038
5	Niger seed	209	836
6	Teff	544	3699
	Total	6673	148005

(Source: FWOARD, 2006)

Table 8: Agricultural crops damaged by flooding in different years in Fogera Woreda.

No	year	Damaged crop land (ha)	Expected production that was lost (quintals)	Loss in terms of Birr	Number of PAs affected by the flood
1	1996	4557	21722	3258300	8
3	1998	4516	36519	5477850	6
4	1999	3583	12754	1658020	5
5	2000	1566	14562	21843000	5
6	2001	3697	21617	2594040	7
8	2003	1155	22937	34980550	3
10	2005	39	590	118000	2
11	2006	6673	148005		6

(Source: Shiferaw and Wondafrash, 2006)

Flooding has also aggravated riling, gulling and other forms of accelerated soil erosion on agricultural lands in Fogera Woreda. Therefore most of the agricultural lands have been wasted. Because of sedimentation problem most of the tributary rivers flow channels has been chocked and this tributaries form a new trench line. Transported sediments and dissolved substances deposited in the river channel, Lake Tana, on adjacent flood plains and wetlands. The transported sediments diminished the rivers water holding capacity and the rivers depth, and its aesthetic value. The sediments also damaged the rivers fauna and flora. The dissolved substances (particularly phosphorous and nitrogen fertilizers leached from the upland sites), will create eutrophication problem, which intern affect the lake, rivers and wetlands fauna and flora. Information from the Woreda agricultural office indicated that the wetlands found in Fogera plain support lots of migratory birds which came from Israel. This year (2006) the flood affected the breeding ground and season of these migratory birds.

4. Data Source, Materials and Methods

4.1 Data Source

Reliable data is necessary to realize the designed objectives. The study was based on both primary and secondary data. In addition to this, frequent field observation was used together with the GPS readings to generate primary information.

In order to accomplish this work the following data (Table 9) were used.

Table 9: Data and their Sources

Areas	Data	Data Type	Scale	Data Sources
Ribb-Gumara Catchment	1. Boundary, Contour	Topographic map	1: 50,000	EMA
	2. Hydrologic Data	Gauge level	Daily Max	MoWR
	2. Landuse/Landcover	Landsat image (TM & ETM)	Landsat (28.5m)	Internet
	3. Daily Max Rainfall	Rainfall records	Daily Max, Monthly Average	NMA
	4. Monthly Temperature	Temperature records	Monthly Average	NMA
	5. Drainage Net Work	Topographic map	1: 50,000	EMA
	6. Slope & Elevation	Topographic map	1: 50,000	EMA
	7. Soil	Soil Type Shape File	-	Endaweke
Fogera Woreda	1. Boundary	Woreda shape file	-	ELRI
	3. Population	Population records of 1999	Tot Pop by PA	FWOARD
	4. Landuse/Landcover	Landsat image	Landsat (28.5m)	Internet
	3. Ground Truth and Accuracy Assessment Points	Point data	-	Field survey

4.2 Materials and Software

Software used in this study was selected based on the capability to work on the existing problems in achieving the predetermined objectives. First and for most, Arc Hydro 9 soft ware, which works as extension on ArcGIS 9.0 and above version, was used to delineate the watershed for which flood hazard analysis was done. MS Excel is used for flood frequency analysis. ERDAS 8.7 was used for image processing activities on satellite images. ENVI 4.2 was used to compute change detection analysis on Landuse/Landcover map of classified images and to do accuracy assessment. The factor map development was carried out using ArcGIS9.1 software package. The factors that are input to for multi-criteria analysis should be preprocessed in accordance to the criteria set to develop flood hazard analysis. So using

Spatial Analyst and 3D Analyst extension, some relevant GIS analyses were undertaken to convert the collected shape files. Eigen vector for the selected factor was computed using Weight module in IDRISI 32 software.

GPS was used to collect information on structures critically affected by the 2006 flood. It was also used to collect information on training sites for landuse/landcover classification.

4.3 Methodology

Flood Risk assessment requires an understanding of the causes of a potential disaster which includes both the natural hazard of a flood, and the vulnerability of the element at risk. According to Ken Granger*, 2002, t*he terms hazard, vulnerability, element at risk, and risk are defined as follows:

• H***azard (H)*** *means the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon.*
• ***Vulnerability (V)*** *means the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude…*
• ***Elements at risk (E)*** *mean the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk in a given area.*
• ***Risk (R)*** *means the expected degree of loss due to a particular natural phenomenon*

Risk analysis can be defined as "*a systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences" (*Ken Granger*, 2002).*

Flood risk of the Woreda was analyzed from the following general risk equation (Shook, 1997).
Risk = (Elements at risk)*(Hazard*Vulnerability)...…………..……………………Equation 1.1

Flood frequency analysis is one of the important studies of river hydrology. It is essential to interpret the past record of flood events in order to evaluate future possibilities of such occurrences. The estimation of the frequencies of flood is essential for the quantitative assessment of the flood problem. The knowledge of magnitude and probable frequency of such recurrence is also required for proper design and location of hydraulic structures and for other allied studies. The gauge data which are random variable follow the law of statistical distribution. After a detailed study of the distribution of the random variables and its parameters such as standard deviation, skewness etc. and applying probability theory, one can reasonably predict the probability of occurrence of any major flood events in terms of discharge or water level for a specified return period.

Flood frequency analysis is done in this study by selecting annual maximum gauge levels at Ribb-Addiszemen and Gumara gauge site located in the catchment area. Two methods of statistical distribution i.e. Gumbel's extreme value distribution and Log Pearson type III distribution were attempted by selecting peak gauge level data for 35 years (1971-2005) at the two catchments above.

Gumbel's Method:

This extreme value distribution was introduced by Gumbel (1954) and is commonly known as Gumbel's distribution (R. Suresh, 2005). It is one of the most widely used probability analysis for extreme values in hydrologic and meteorological studies for prediction of flood, rainfall etc.

Gumbel defined a flood as the largest of the 365 daily flows and the annul series of flood flows constitute a series of largest values of flows. This study attempt to find out water levels at different return period using the Gumbel's equation:

$x_T = x + k * SDV$, where,

x_T = Value of variate with a return period 'T'

x_{avg} = Mean of the variate

SDV = Standard deviation of the sample

k = Frequency factor expressed as
$k = (y_T – 0.577) / 1.2825$

y_T=Reduced variate expressed by

$(y_T) / (T - 1) = - (LN * LN)$

T =Return period

Log Pearson Type - III Method:

This method is extensively used in USA for project sponsored by US Government. In this method, the variate is first transformed into logarithmic form (base10) and the transformed data is then analyzed (Chow, 1988). If 'X' is the variate of a random hydrologic series, then the series of ‘Z’ variates where z = log x are first obtained. For this ‘z’ series, for any recurrence interval "T’, the equation is

$z_T = z_{avg} + Kz * SDV$

Where,

K_z = Frequency factor taken from table with values of coefficient of skew "Cs" and recurrence interval ‘T’.

SDV = Standard deviation of the ‘Z’ variate sample.

Cs = Co-efficient of skew of variate ‘Z’

$=\{ N \Sigma (z - z_{avg})3 \} / \{ (N - 1) (N - 2) (SDV)3 \}$

z_{avg} = Mean of the ‘z’ values

N = Sample size = Number of years of record

After finding ‘z_T’ with the equation above, the corresponding value of ‘x_T’ is obtained by

x_T=Antilog (z_T)

After obtaining gauge levels by above two methods for different return period flood, Chi Square test was carried out for "goodness of fit".

Recurrence Interval can be calculated as (n+1)/m,

where

n is number as of samples (years), and

m-rank of a given gauge level.

The flood hazard analysis was computed using multi criteria evaluation (MCE). To run MCE, the selected flood causative factors such as soil type, elevation, slope, drainage density, land-use, and rain fall were developed and weighted. Then weighted overlay technique was computed in ArcGIS 9.1 Model Builder to generate flood hazard map. Considering the degree of loss to be total for the study area, the vulnerability is assumed to be one. Finally to generate flood risk map of the Woreda, elements at risk layer (population density and land use) and the flood hazard map were overlaid using weighted overlay analysis technique in ArcGIS 9.1 environment.

Landcover mapping methodology should be governed by the attributes of the land cover types. Since landcover types usually have significantly different interpretation characteristics, they should be mapped separately according to the methodology suitable to their particular attributes.

Landcover mapping requires the use of other interpretation elements than just reflectance, particularly positioned in the landscape, with size and association. In addition, knowledge of the landuse systems and their extent is essential for attributing spectral reflectance curves to landcover types.

Since the same spectral reflectance curve can represent a variety of landcover types, ground information is essential. Ground information is also needed to determine other landcover characteristics (interpretation elements) such as associations, landscape position, etc. Field visits were consequently undertaken as early as possible in the mapping of the study sites. The principal aim of the field visit was to understand the image representation of the ground information; to learn what all the image and patterns represent, although areas of uncertainty will always be discovered later. This method was previously used to interpret aerial photography – rather than the black box approach whereby ground information is only recognized from specific training areas. Fig. 13 shows the schematic flow chart of landuse/landcover mapping.

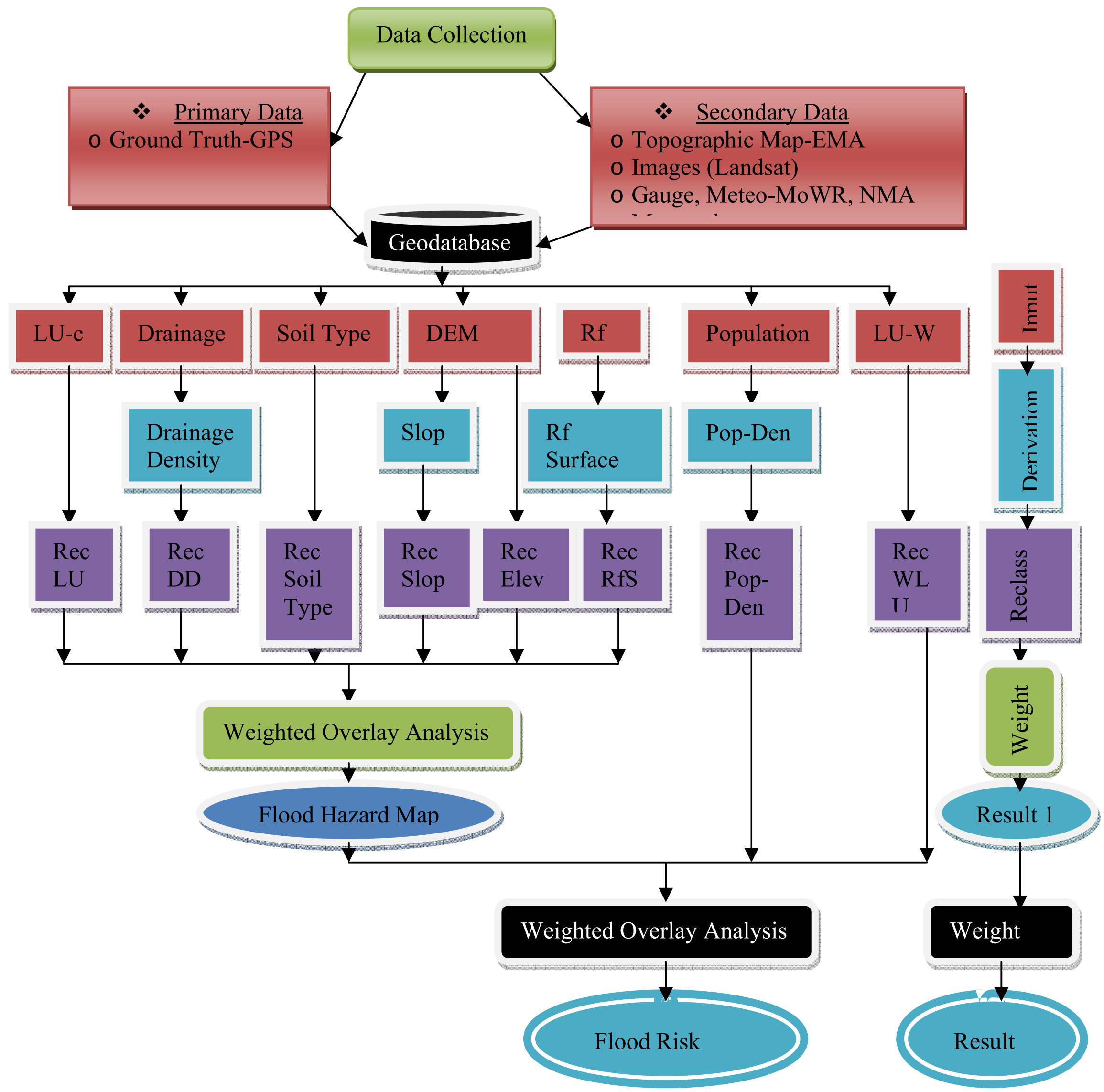


Figure 12: Work Flow of the Study

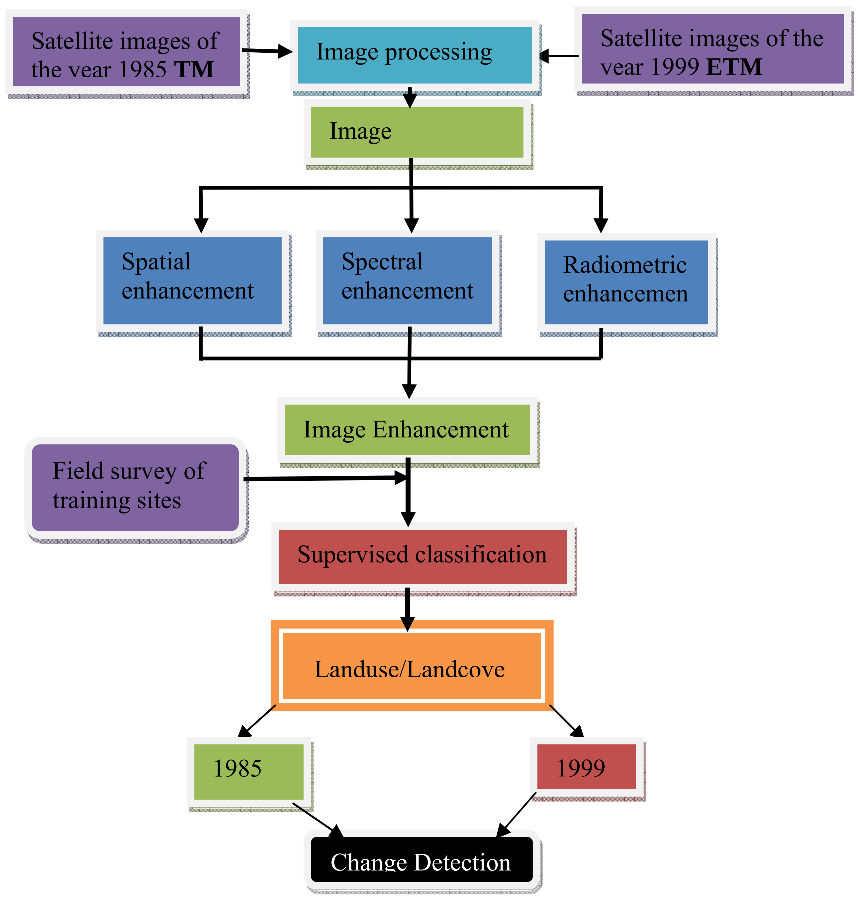


Figure 13: Schematic Flow Chart of Landuse/Landcover Analysis

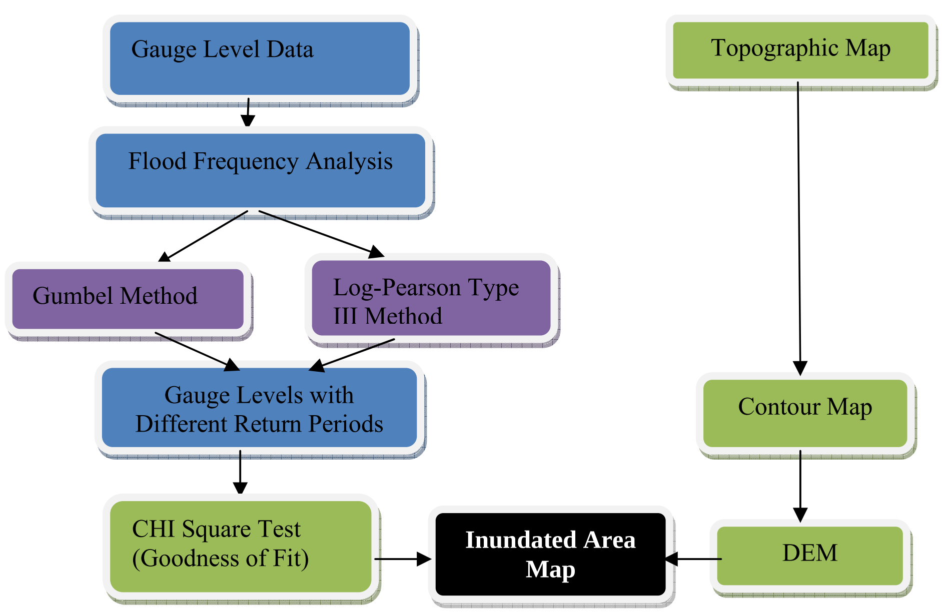


Figure 14: Schematic Flow Chart of Flood Frequency Analysis

5. Data Processing and Analysis

5.1 Data Processing

5.1.1 Database design creation and Field survey

- Personal Geodatabase

The geographic database (geodatabase) is a core geographic information model to organize a spatial data in to thematic layers and spatial representations. Two types of geodatabase architectures are available under ESRI's ArcGIS package: Personal Geodatabase and Multiuser Geodatabase. In this study, personal geodatabase was implemented to store the necessary data that could be applicable to the final analysis for the designed objectives.

- Pre-field Survey

Before the field survey, relevant secondary data has been organized in a GIS environment. The available satellite images of the 1985 TM and 1999 ETM have been geometrically corrected and a supervised classification has been accomplished in order to check and verify the existing situations of the landuse/land cover in the study area.

- Field Survey

During field survey the necessary information have been taken and registered. Ground truths of major damages of the 2006 flood was collected using GPS so as to compare it with the flood hazard and flood risk map generated in this study. In addition, the ground verification for the landuse/land cover map was conducted.

5.1.2 Satellite Image Processing

Satellite images of Landsat 7 sensor of 1985 TM and 1999 ETM, path 169 and row 52, which were acquired on October 23 and November 09 respectively, (with a map projection of UTM_ zone 37, spheroid and datum WGS_ 84) have been used for the landuse/land cover mapping and change detection processes. These images were stacked in the ERDAS IMAGINE 8.7 software and subset by the boundary of the Ribb-Gumara Catchment.

The most common image processing function (digital image processing) in this study consists of four steps:

- Pre-processing

Pre-processing is done before the main data analysis and extraction of information. Pre-processing involves two major processes: geometric correction and radiometric correction or haze correction.

Remote sensing imageries are inherently subjected to geometric distortions. These distortions may be due to the perspective of the sensor optics, the motion of the scanning system, the motion of the platform (the platform altitude, attitude and velocity), the terrain relief, or the curvature and rotation of the earth (Lillesand, 2004). Geometric corrections are done in order to compensate for these distortions so that the geometric representation of the imagery will be as close as possible to the real world. Many of these variations are systematic or predictable in nature and accurate modeling of the sensor and the platform motion and the geometric relationship of the platform with the earth can correct these distortions.

Pre-processing operations, sometimes referred to as image restoration and rectification, are intended to correct for sensor- and platform-specific radiometric and geometric distortions of data. Radiometric corrections may be necessary due to variations in scene illumination and viewing geometry, atmospheric conditions, and sensor noise and response. Each of these will vary depending on the specific sensor and platform used to acquire the data and the conditions during data acquisition. Also, it may be desirable to convert and/or calibrate the data to known (absolute) radiation or reflectance units in order to facilitate comparison between data.

- Haze correction

During recording spectral reflectance, atmospheric effects on energy illumination from ground features or geometric distortion can be built up due to high altitude, etc. So the image should be corrected from these distortions. The images of the Ribb-Gumara Catchment were checked on anomalies caused by this energy interaction in the atmosphere.

- Image Enhancement

Image enhancement is used in order to increase the details of the image by assigning maximum and minimum brightness values to maximum and minimum display values, and it is done on pixel values. This makes visual interpretation easier and assists the human analyst. Histogram equalization is done on the images, where enhancement assigns more display values (or ranges) to the frequently occurring portions of the histogram.

- False color composite (FCC)

When displaying a multi-spectral image in color (Red, Green and Blue) a combination of three bands is selected. By using different TM and ETM bands for (RGB), different color composite were created for the catchment, each with its own characteristics. By comparing the different color composites, a selection was made, which could be used for vegetation and bare soil differentiation. Color composite 742 was found best to be used for water bodies (flooded areas) identification while 432 for vegetation cover and 472 or 471 are used for identifying the shrub lands.

❖ Image Classification

Image classification serves a specific goal: converting image data in to thematic data. In the application context, one is rather interested in thematic characteristics of an area (pixel) rather than in the reflection values. Thematic characteristics such as landuse/land cover can be used for further analysis and input into GIS based models. In addition, image classification can also be considered as data reduction: the *n* multi spectral bands result in a single band raster file.

With a particular application in mind, the information classes of the interest need to be defined and their spatio-temporal characteristics assessed. Based on the characteristics the appropriate image data can be selected. Selection of the adequate data set concerns the type of sensor, the relevant wavelength bands and the date of acquisition. For this study, the 1999 image which was acquired shortly after the main rainy season was selected in order to identify flooded areas. As discussed previously, this year was the major flood year next to 2006 and 2001, which affects about five PAs in Fogera Woreda. And that of the 1985 image is acquired during the relatively non-flooded year.

Before starting to work with the acquired data, a selection of the available bands may be made. Reasons not using all available bands (for example all seven bands of Landsat TM) lie in the problem of band correlation and sometimes, in limitations of hardware and software. Band correlation occurs when the spectral reflection is similar to the two bands. An example is the correlation between the green and the red wavelength bands for vegetation: a low reflectance in green correlates with a low reflectance in red. For classification purposes, correlated bands give redundant information and might disturb the classification process (Lillesand, 2004). The 1999 image was classified and used as a factor map for flood hazard (level of abstraction of rain water) as well as flood risk (element at risk). The 1999 classified image (with the 1985 classified image) was used for landuse/land cover change detection. The processes of this classification and change detection were discussed later in this chapter.

❖ Data Merging and GIS Integration

These procedures are used to combine image data for a given geographic area with other geographically referenced data sets for the same area in the context of a GIS. In this study, the catchment landuse/land cover map of 1999 was overlaid with other factor maps in the GIS environment in order to identify the extent of flood hazard in different areas in the catchment. Moreover, the extracted landuse/land cover map of this catchment by the study area shape file (Fogera Woreda) was overlaid with the flood hazard map and the other element at risk, population density, to derive flood risk map of the study area.

5.2 Hydro-Meteorological Data Analysis

5.2.1 Rainfall Trend Analysis

The long year daily maximum rainfall trend below (Fig. 15) shows that there is a slight decrease in daily maximum rainfall from 1974 to 2006. There were high daily maximum rainfall peaks in the middle of 1970s and around 1990 even though the sever flood in Ribb-Gumara Catchment occur last summer (2006 Ethiopian main rainy season). Here, one can judge that the resent floods in the catchment in general and Fogera Woreda in particular is not caused mainly from rainfall.

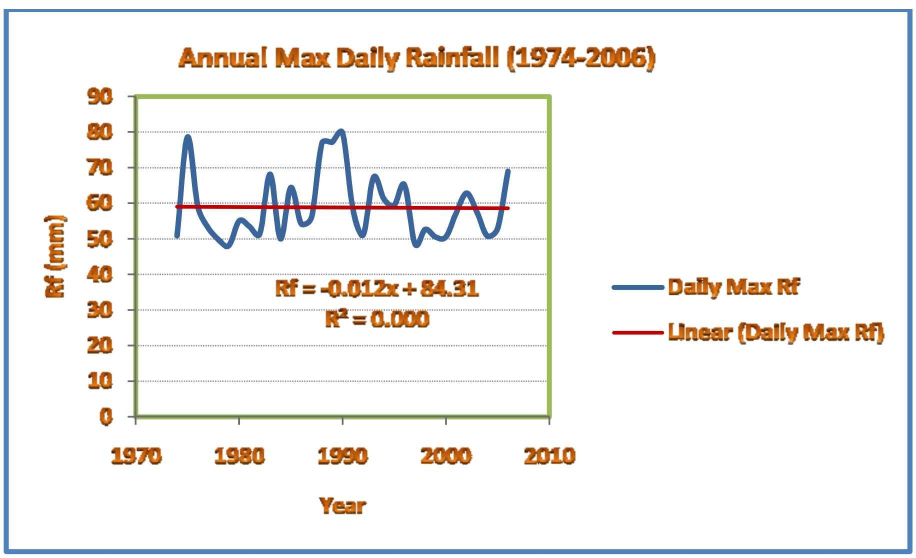


Figure 15: Trends in Average Daily Max Rainfall from Ten Meteorological Stations in & around Ribb-Gumara Catchment (1974-2006)

5.2.2 Gauge Level Trend Analysis

As discussed in the previous section, overflow of Ribb and Gumara rivers causes flooding in Ribb-Gumara catchment. Vast areas that lie below the point where there is a sharp decline in slope (2200m) are prone to flooding in the main rainy season. Almost all such areas are found in the so called Fogera Plain just adjacent to Lake Tana where the two rivers empty their water.

The hydrographs of the two rivers on Figure 16 shows that the wet season contributes the dominant share of gauge level of these rivers. During the rest eight months the gauge level is extremely small. This indicates a lower contribution of the base flow in to the rivers. On the other hand, this shows runoff during rainfall is dominantly overland flow, subsurface flow processes generally being minor. Such highly peak hydrograph in the wet season or very small base flow is closely linked to very low infiltration rate and quick overland flow. In other words, it shows the absence of water abstraction.

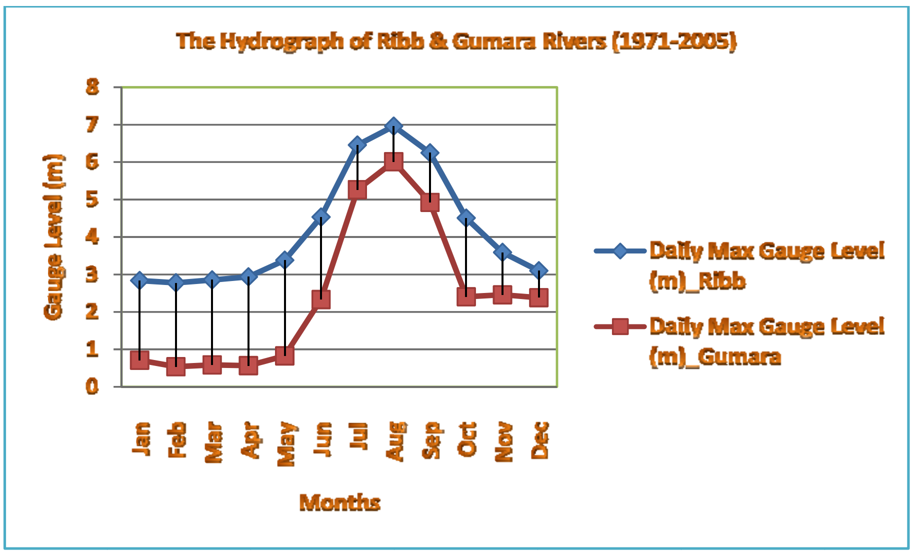


Figure 16: The Hydrograph of Ribb and Gumara Rivers (1971-2005)

According to Fogera Woreda disaster prevention and preparedness office (FWODPP) flooding in the Woreda has a short history. Flooding, which is the first in its kind in the area occurred some ten years ago, in 1996. As discussed earlier, the flooding of that year affected eight PAs of the Woreda, namely, Wagtera, Nabega, Kidiste Hana, Shaga, Shina, Woreta Zuria, Kuhar Michael, and Abatihua. From this year onwards, flooding has a regular incidence in some areas especially those PAs adjacent to Lake Tana. Such frequency of the flooding is related to high gauge levels of the two rivers (Fig. 17). Analysis of gauge level data of more than thirty years shows a general increase in daily maximum gauge level. As indicated on Fig. 17 below, daily maximum gauge level of Ribb and Gumara rivers are increasing at a rate of 0.042 and 0.045 per annum respectively. A relatively higher rate of increase in the daily maximum gauge level is observed in the 1990s and onwards. The 2006 flood was the most severe of all the flood events experienced in the area so far. During this time (1990s and onwards) flood incidence was very high as discussed previously. Therefore, the patterns of gauge level in the catchment reflect the contributions of changes in the physical characteristics particularly landuse/landcover changes which will be discussed in this chapter latter. This can be evident from the comparison of trends in the rainfall and gauge level in the catchment. While rainfall was relatively high in the middle of the 1970s and around 1990 (Fig. 15), gauge level was not that much high compared to that of the middle of the 1990s and onwards. This implies that small proportion of the rainfall turns in to runoff thereby increasing the gauge level which can possibly held by some abstractions such as vegetation and infiltration in to the ground water table.

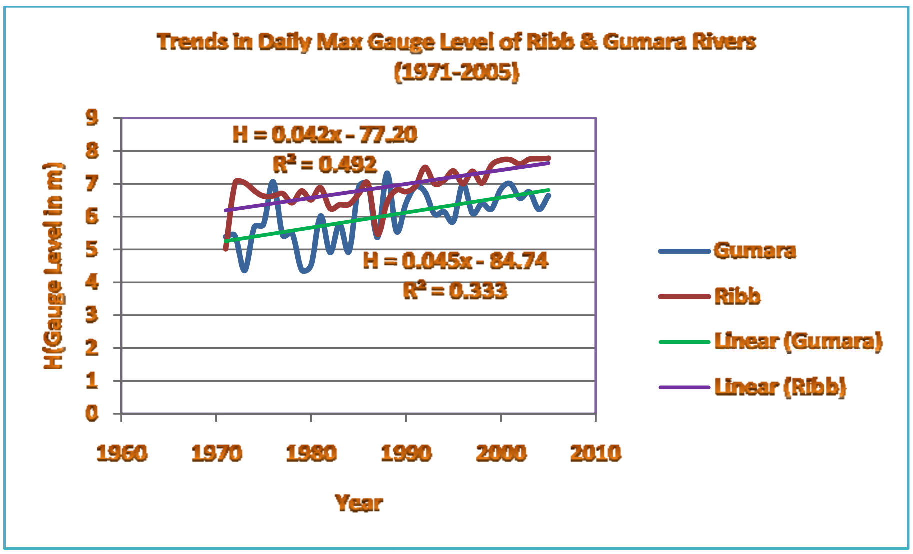


Figure 17: Trends in Daily Maximum Gauge Level (m) of Gumara and Rib Rivers (1971-2005)

5.2.3 Flood Frequency Analysis

Hydrologic systems are sometimes impacted by extreme events, such as severe storms, floods and droughts. The magnitude of an extreme event is inversely related to its frequency of occurrence, very extreme events occurring less frequently than more moderate events. According to Show (1988), the probability of occurrence of an event in any observation is the inverse of its return period; $P(X>=X_T) = {}^1/_T$.

The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions. The hydrologic data analyzed are assumed to be independent and identically distributed, and the hydrologic system producing them (e.g., a storm rainfall system) is considered to be stochastic, space-independent, and time-independent (Chow et.al, 1988). The hydrologic data employed should be carefully selected so that the assumptions of independence and identical distribution are satisfied. In practice, this is often achieved by selecting the annual maximum of the variable being analyzed (e.g., the annual maximum discharge, which is the largest instantaneous peak flow occurring at any time during the year) with the expectation that successive observations of this variable from year to year will be independent. The result of flood frequency analysis can be used for many engineering purposes: for the design of dams, brides, culverts, and flood control structures; to determine the economic values of flood control projects; and to determine flood plains and determine the effect of encroachments on the flood plain.

Flood frequency analysis in this study was done using annual maximum daily gauge level data at Ribb-Addiszemen gauge station and Gumara station (1971-2005). Ribb-Addiszemen station is located at $12^0$0' N latitude and $37^0$43' E longitude, and has elevation 1795m amsl, while that of Gumara is $11^0$50' N and $37^0$38', and 1800m amsl.

The following tables (Table 10 to 19) show all the calculation steps of flood frequency based on Gumbel's- and Log-Pearson Type III Distribution methods that were described previously in the methodology part of this study. Moreover, the CHI Square Test made to test the best fit distribution method of flood frequency analysis for Ribb and Gumara rivers was also done. The results were discussed in the result and discussion part of this study. In the result and discussion part, using the 100 year base flood level of the best fit distribution, areas that are likely to be inundated in case of embankment failure of the two rivers were mapped and compared with the results of flood hazard and flood risk maps done through overlay process of other topographic and meteorological flood causative factors. All the neighborhood pixels in the DEM which has an elevation lower or equal to the specified flood levels were marked likely to be inundated using the Spatial Analyst (Map Calculator) extension of ArcGIS 9.1 software.

Table 10: Frequency Analysis (Gumara Gauge Station)

			Gumbel's Method			Log-Pearson Type III Method		
Year	Rank	Rearg Flood Level	$X-X_{avg}$	$(X-X_{avg})^2$	Rec.Int	Z=LogX	$Z-Z_{avg}$	$(Z-Z_{avg})^3$
1988	1	7.32	1.29	1.656737	36	0.864511	0.088033958	0.000682261
1976	2	7.06	1.03	1.055022	18	0.848805	0.072327578	0.000378366
1996	3	7	0.97	0.935365	12	0.845098	0.068620917	0.000323124
2001	4	7	0.97	0.935365	9	0.845098	0.068620917	0.000323124
1986	5	6.98	0.95	0.89708	7.2	0.843855	0.067378299	0.000305886
1991	6	6.9	0.87	0.751937	6	0.838849	0.062371968	0.000242643
1985	7	6.89	0.857143	0.734694	5.142857	0.838219	0.061742099	0.000235366
2000	8	6.84	0.807143	0.65148	4.5	0.835056	0.058578979	0.000201014
1992	9	6.75	0.72	0.514294	4	0.829304	0.05282665	0.000147421
2003	10	6.75	0.717143	0.514294	3.6	0.829304	0.05282665	0.000147421
2005	11	6.64	0.607143	0.368622	3.272727	0.822168	0.045690956	9.53873E-05
2002	12	6.56	0.527143	0.27788	3	0.816904	0.040426716	6.60702E-05
1990	13	6.41	0.377143	0.142237	2.769231	0.806858	0.030380906	2.80416E-05
1998	14	6.4	0.367143	0.134794	2.571429	0.80618	0.029702851	2.62056E-05
1999	15	6.23	0.197143	0.038865	2.4	0.794488	0.018010924	5.84262E-06
2004	16	6.22	0.187143	0.035022	2.25	0.79379	0.017313262	5.18963E-06
1994	17	6.15	0.117143	0.013722	2.117647	0.788875	0.012397993	1.9057E-06
1997	18	6.1	0.067143	0.004508	2	0.78533	0.008852712	6.93792E-07
1993	19	6.08	0.047143	0.002222	1.894737	0.783904	0.007426456	4.09586E-07
1981	20	6.02	-0.01286	0.000165	1.8	0.779596	0.003119368	3.03529E-08
1995	21	5.86	-0.17286	0.02988	1.714286	0.767898	-0.008579507	-6.3152E-07
1983	22	5.78	-0.25286	0.063937	1.636364	0.761928	-0.014549285	-3.0798E-06
1975	23	5.77	-0.26286	0.069094	1.565217	0.761176	-0.01530131	-3.5825E-06
1974	24	5.67	-0.36286	0.131665	1.5	0.753583	-0.022894064	-1.2E-05
1989	25	5.55	-0.48286	0.233151	1.44	0.744293	-0.03218414	-3.3337E-05
1978	26	5.5	-0.53286	0.283937	1.384615	0.740363	-0.036114434	-4.7102E-05
1977	27	5.44	-0.59286	0.35148	1.333333	0.735599	-0.040878223	-6.8309E-05
1972	28	5.41	-0.62286	0.387951	1.285714	0.733197	-0.043279858	-8.1069E-05
1971	29	5.39	-0.64286	0.413265	1.241379	0.731589	-0.044888358	-9.0448E-05
1987	30	5.37	-0.66286	0.43938	1.2	0.729974	-0.046502837	-0.00010056
1984	31	4.94	-1.09286	1.194337	1.16129	0.693727	-0.082750174	-0.00056664
1982	32	4.91	-1.12286	1.260808	1.125	0.691081	-0.085395631	-0.00062274
1980	33	4.52	-1.51286	2.288737	1.090909	0.655138	-0.121338688	-0.00178648
1979	34	4.38	-1.65286	2.731937	1.058824	0.641474	-0.135003013	-0.00246054
1973	35	4.36	-1.67286	2.798451	1.028571	0.639486	-0.136990634	-0.00257083
	Sum	**211.15**	**Sum**	**22.3423**	**Avg**	**0.77648**	**Sum**	**-0.0052309**
	Avg	**6.032857143**			**SD**	**0.06113**	**Cs**	**-0.71424233**
	SD	**0.81**						

Table 11: Flood Calculations using Gumbel's Distribution (Gumara Gauge Station)

Rec.Int	**T/(T-1)**	**Yt=-LN*LN(T/T-1)**	**K**	**Gauge**
2	2	0.3665	-0.16413	5.899806
5	1.25	1.4999	0.71961	6.616197
10	1.111111111	2.2513	1.305497	7.091137
20	1.052631579	2.9633	1.860663	7.541173
25	1.041666667	3.1907	2.037973	7.684906
30	1.034482759	3.398	2.19961	7.815935
40	1.025641026	3.6625	2.405848	7.983118
50	1.020408163	3.9219	2.608109	8.147078
100	1.01010101	4.61	3.144639	8.582008

Table 12: Flood Calculations by using Log-Pearson Type III (Gumara Gauge Station)

RT	Cs	Kz	$Zt=Z_{avg} + Kz*SD$	Xt=AntilogZt
2	-0.71424	0.116	0.783569108	6.075319299
10		1.183	0.848776679	7.059544481
25		1.488	0.867416144	7.369128744
50		1.663	0.878110919	7.552851032
100		1.806	0.886850078	7.706373928

Table 13: CHI Square Test for Gumbel's Method (Gumara Gauge Station)

Rank	Rt	Flood (o)	t/(t-1)	Yt	K	Flood ©	Diff	DiffSqr	DiffSqr/f©
1	36	7.32	1.028571429	3.569467	2.333307	7.922836027	-0.60284	0.363411	0.045868837
2	18	7.06	1.058823529	2.861929	1.781621	7.475969991	-0.41597	0.173031	0.023144961
3	12	7	1.090909091	2.441716	1.45397	7.210572763	-0.21057	0.044341	0.006149427
4	9	7	1.125	2.138911	1.217864	7.019327266	-0.01933	0.000374	5.32164E-05
5	7.2	6.98	1.161290323	1.900247	1.031771	6.868591864	0.111408	0.012412	0.001807033
6	6	6.9	1.2	1.701983	0.87718	6.743372946	0.156627	0.024532	0.003637947
								CHI.Sq	**0.080661421**

Table 14: CHI Square Test for Log-Pearson Type III Method (Gumara Gauge Station)

Rank	Rt	Flood (o)	Cs	Kz	Zt	AntilogZt	Difference	Diff.Sqr	DiffSqr/fl©
1	36	7.32	-0.714242331	1.565	0.872148	7.449866	-0.12987	0.016865128	0.125643
2	18	7.06		1.345667	0.858741	7.223382	-0.16338	0.026693791	0.192819
3	12	7		1.223667	0.851283	7.100399	-0.1004	0.010079924	0.071571
4	9	7		1.1178	0.844811	6.995377	0.004623	2.13737E-05	0.00015
5	7.2	6.98		1.00044	0.837637	6.880768	0.099232	0.009847046	0.067755
6	6	6.9		0.9222	0.832854	6.805407	0.094593	0.008947887	0.060894
								CHI.Sq	**0.518833**

Table 15: Frequency Analysis (Ribb-Addiszemen Gauge Station)

			Gumbel's Method			Log-Pearson Type III Method		
Year	Rank	Rearg Flood Level	$X-X_{avg}$	$(X-X_{avg})^2$	Rec.Int	Z=LogX	$Z-Z_{avg}$	$(Z-Z_{avg})^3$
2005	1	7.78	0.872857	0.76188	36	0.89098	0.053489597	0.000153041
2004	2	7.76	0.852857	0.727365	18	0.889862	0.052371721	0.000143645
2003	3	7.75	0.842857	0.710408	12	0.889302	0.051811703	0.000139086
2001	4	7.73	0.822857	0.677094	9	0.888179	0.050689494	0.000130243
2000	5	7.72	0.812857	0.660737	7.2	0.887617	0.0501273	0.000125957
2002	6	7.6	0.692857	0.480051	6	0.880814	0.043323592	8.13155E-05
1999	7	7.56	0.652857	0.426222	5.142857	0.878522	0.041031796	6.90815E-05
1992	8	7.5	0.592857	0.35148	4.5	0.875061	0.037571263	5.30356E-05
1995	9	7.39	0.482857	0.233151	4	0.868644	0.031154438	3.02385E-05
1997	10	7.38	0.472857	0.223594	3.6	0.868056	0.030566362	2.85582E-05
1994	11	7.1	0.192857	0.037194	3.272727	0.851258	0.013768349	2.61003E-06
1972	12	7.03	0.122857	0.015094	3	0.846955	0.009465325	8.48021E-07
1973	13	7.03	0.122857	0.015094	2.769231	0.846955	0.009465325	8.48021E-07
1998	14	7.02	0.112857	0.012737	2.571429	0.846337	0.008847112	6.92476E-07
1986	15	7	0.092857	0.008622	2.4	0.845098	0.00760804	4.40371E-07
1993	16	7	0.092857	0.008622	2.25	0.845098	0.00760804	4.40371E-07
1996	17	7	0.092857	0.008622	2.117647	0.845098	0.00760804	4.40371E-07
1991	18	6.93	0.022857	0.000522	2	0.840733	0.003243235	3.41142E-08
1981	19	6.88	-0.02714	0.000737	1.894737	0.837588	9.84382E-05	9.53875E-13
1989	20	6.81	-0.09714	0.009437	1.8	0.833147	-0.004342888	-8.191E-08
1974	21	6.79	-0.11714	0.013722	1.714286	0.83187	-0.005620226	-1.7753E-07
1979	22	6.78	-0.12714	0.016165	1.636364	0.83123	-0.006260306	-2.4535E-07
1990	23	6.76	-0.14714	0.021651	1.565217	0.829947	-0.007543304	-4.2922E-07
1977	24	6.7	-0.20714	0.042908	1.5	0.826075	-0.011415197	-1.4875E-06
1985	25	6.68	-0.22714	0.051594	1.44	0.824776	-0.012713538	-2.0549E-06
1976	26	6.63	-0.27714	0.076808	1.384615	0.821514	-0.015976472	-4.078E-06
1975	27	6.62	-0.28714	0.082451	1.333333	0.820858	-0.016632011	-4.6008E-06
1980	28	6.51	-0.39714	0.157722	1.285714	0.813581	-0.023909011	-1.3667E-05
1988	29	6.43	-0.47714	0.227665	1.241379	0.808211	-0.029279027	-2.51E-05
1978	30	6.42	-0.48714	0.237308	1.2	0.807535	-0.029954972	-2.6879E-05
1984	31	6.37	-0.53714	0.288522	1.16129	0.804139	-0.033350568	-3.7095E-05
1983	32	6.36	-0.54714	0.299365	1.125	0.803457	-0.034032884	-3.9418E-05
1982	33	6.25	-0.65714	0.431837	1.090909	0.79588	-0.041609983	-7.2043E-05
1987	34	5.46	-1.4471	2.09422	1.058824	0.737193	-0.100297357	-0.00100895
1971	35	5.02	-1.8871	3.56131	1.028571	0.700704	-0.136786283	-0.00255934
	Sum	**241.75**		**12.9719**	**Avg**	**0.83749**	**Sum**	**-0.0028351**
	Avg	**6.907142857**			**SD**	**0.04093**	**Cs**	**-1.2901801**
	SD	**0.617678631**						

Table 16: Flood Calculations using Gumbel's Distribution (Ribb-Addiszemen Gauge Station)

Rec.Int	**T/(T-1)**	**Yt=-LN*LN(T/T-1)**	**K**	**Gauge**
2	2	0.3665	-0.16413	6.805762
5	1.25	1.4999	0.71961	7.351631
10	1.111111111	2.2513	1.305497	7.713521
20	1.052631579	2.9633	1.860663	8.056434
25	1.041666667	3.1907	2.037973	8.165955
30	1.034482759	3.398	2.19961	8.265795
40	1.025641026	3.6625	2.405848	8.393184
50	1.020408163	3.9219	2.608109	8.518116
100	1.01010101	4.61	3.144639	8.849519

Table 17: Flood Calculations Using Log-Pearson's Distribution (Ribb-Addiszemen Gauge Station)

RT	Cs	Kz	Zt=Z_{avg} + Kz*SD	Xt=AntilogZt
2	-1.2901801	0.21	0.8460853	7.015930851
10		1.064	0.88103952	7.603954684
25		1.24	0.8882432	7.731133987
50		1.324	0.89168132	7.792580906
100		1.383	0.89409619	7.836031804

Table 18: CHI Square Test for Gumbel's Method (Ribb-Addiszemen Gauge Station)

Rank	Rt	Flood (o)	t/(t-1)	Yt	K	Flood ©	Diff	DiffSqr	DiffSqr/f©
1	36	7.78	1.028571429	3.569467	2.33330726	8.348376894	-0.5683769	0.323052	0.038696419
2	18	7.76	1.058823529	2.861929	1.7816208	8.007611954	-0.247612	0.061312	0.007656675
3	12	7.75	1.090909091	2.441716	1.4539699	7.805228995	-0.055229	0.00305	0.000390795
4	9	7.73	1.125	2.138911	1.21786435	7.659391641	0.07060836	0.004986	0.000650906
5	7.2	7.72	1.161290323	1.900247	1.03177126	7.544445917	0.17555408	0.030819	0.004085023
6	6	7.6	1.2	1.701983	0.87718	7.448958201	0.1510418	0.022814	0.00306266
								CHI.Sq	**0.054542477**

Table 19: CHI Square Test for Log-Pearson Type III Method (Ribb-Addiszemen Gauge Station)

Rank	Rt	Flood (o)	Cs	Kz	Zt	AntilogZt	Difference	Diff.Sqr	DiffSqr/fl©
1	36	7.78	-1.290180093	1.27696	0.889756	7.758111	0.02188929	0.000479141	0.00381351
2	18	7.76		1.157867	0.884881	7.671521	0.08847892	0.00782852	0.06230768
3	12	7.75		1.087467	0.882	7.62079	0.12920971	0.01669515	0.13287774
4	9	7.73		1.0188	0.879189	7.571632	0.15836824	0.025080501	0.19961727
5	7.2	7.72		0.93744	0.875859	7.513796	0.20620366	0.042519951	0.33841894
6	6	7.6		0.8832	0.873639	7.475485	0.12451497	0.015503978	0.12339713
								CHI.Sq	**0.86043227**

The return period T of major flood is the expected value of recurrence interval (τ), *E*(τ), its average value measured over a very large number of occurrences. For the Ribb-Gumara Rivers data, there are six recurrence intervals covering a total period of ten years between the first and last occurrences of major flooding, so the return period of major flooding of the Ribb-Gumara rivers is approximately τ_{av}=10/6=1.67 years (Table 20). Thus the return period of an event of a given magnitude may be defined as the average recurrence interval between events equaling or exceeding a specified magnitude (Chow et.al, 1988). As discussed in the previous chapter, in Fogera Woreda major flood peaks occurred in 1996, 1998, 1999, 2000, 2001, 2003 and 2006.

Table 20: Years of Major Floods with their Corresponding Recurrence Intervals

Major flood Year	1996	1998	1999	2000	2001	2003	2006	Average
Recurrence Interval (years)	2	1	1	1	2		3	1.67

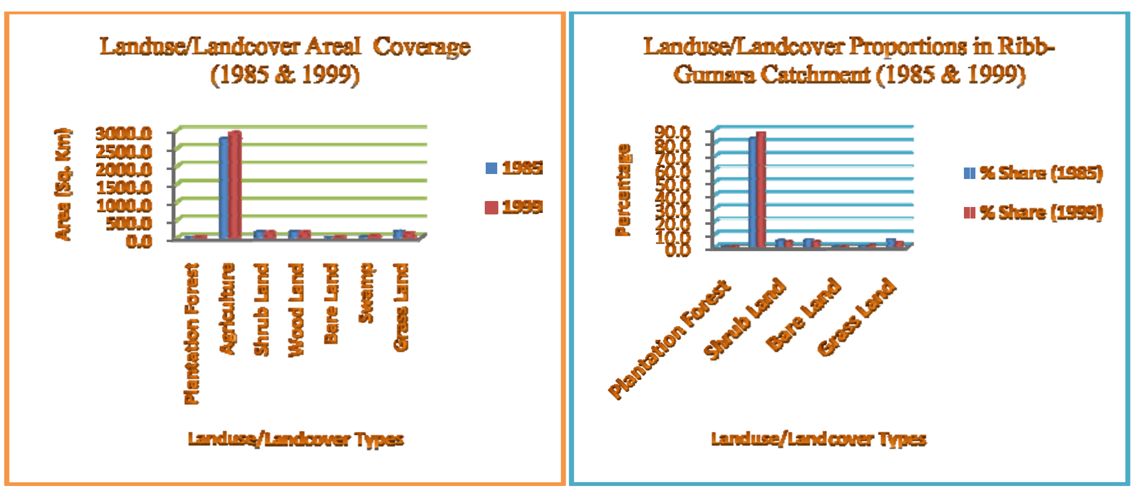
Therefore, from the flood frequency analysis, the calculated two year return period gauge level is expected in Ribb-Gumara catchment in general and Fogera Woreda in particular. That is, 6.79m and 5.913m gauge levels are expected approximately in every two year in Ribb and Gumara Catchment respectively. In other words, these gauge levels have a 60% probability of occurrence in every year in the respective rivers.

5.3 Landuse/landcover Analysis

5.3.1 Landuse/Landcover Classification

As explained in the first session of this chapter, data processing, the 1985 TM and 1999 ETM Landsat images were used "to define the different classes of land cover types (WBISPP, 2004)" and there by for the landuse/landcover change detection. The Landsat TM/ETM image with 7 spectral bands, a nominal ground resolution (pixel size) of 28.5 x 28.5 metres and a nominal scene size of 185 x 185 Km is an ideal source of data for a reconnaissance scale survey.

Supervised image classification which is a widely used technique (Sluiter, 2005); (Nangendo, 2005) was applied in this study. Accordingly, the two landuse/landcover maps of the year 1985 (Fig 19) and 1999 (Fig 20) were generated using the widely used maximum likelihood classifier algorithm Lillesand et al (2004). The change in the landuse/landcover and their signal on flooding was discussed in the next chapter, result and discussion.



(a) *(b)*

Figure 18: Areal coverage (a) & Percentage Share (b) of Landuse/Landcover Types in Ribb-Gumara Catchment

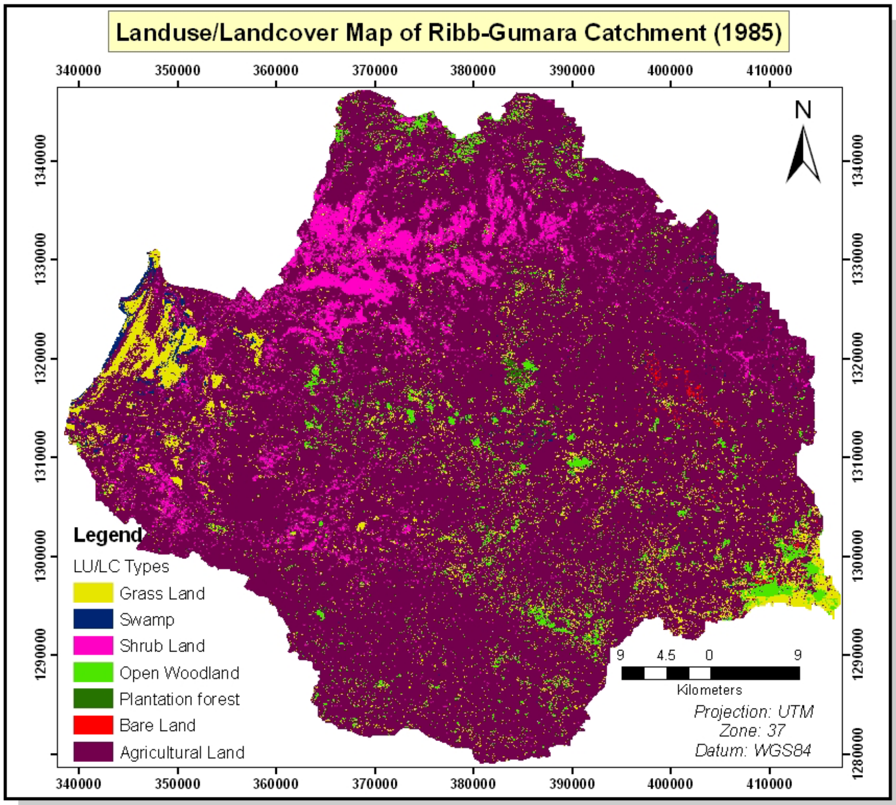


Figure 19: Landuse/Landcover Map of Ribb-Gumara Catchment (1985)

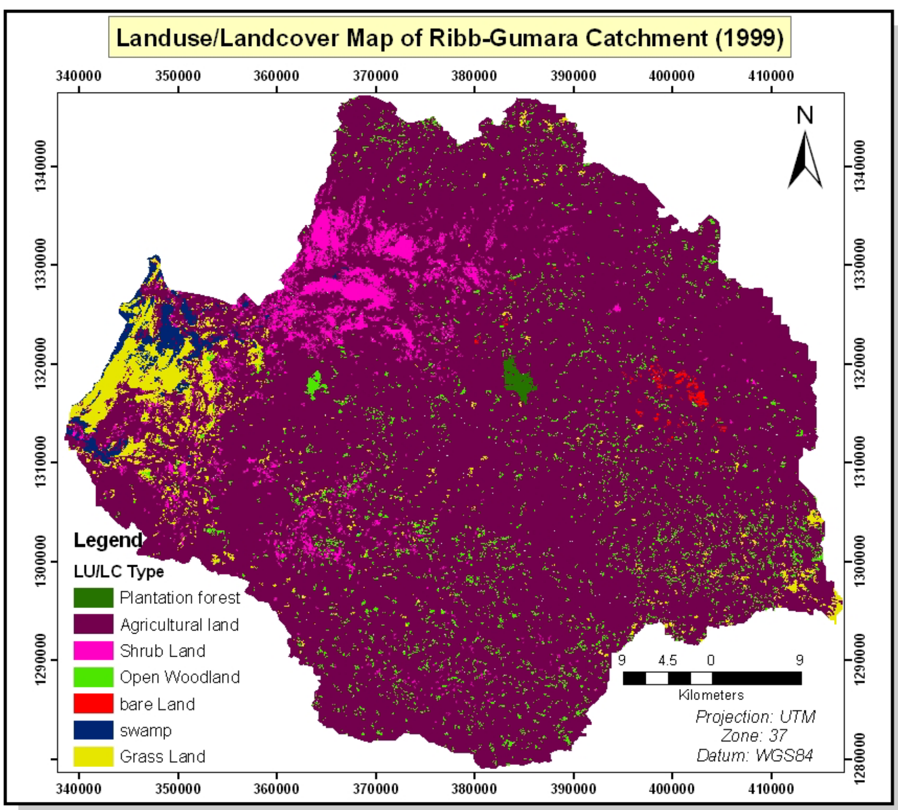


Figure 20: Landuse/Landcover Map of Ribb-Gumara Catchment (1999)

5.3.2 Accuracy Assessment

The Maximum Likelihood procedure is the most commonly used procedure for classification in remote sensing. The foundation for this approach is Bayes' Theorem, which expresses the relationship between evidence, prior knowledge, and the likelihood that a specific hypothesis is true (Lillesand, 2004).

The ground truth data were utilized in the maximum likelihood report as the independent data set from which the classification accuracy was compared. The accuracy is essentially a measure of how many ground truth pixels were classified correctly. An overall accuracy of *87.63% was* achieved with a Kappa coefficient of ***0.8402*** for Landsat 1999 ETM image (Table 21). The overall accuracy is a similar average with the accuracy of each class weighted by the proportion of test samples for that class in the total training or testing sets. Thus, the overall accuracy is a more accurate estimate of accuracy.

Table 21: Confusion matrix of 1999 land use classification of Ribb-Gumara Catchment (Overall Accuracy = (5117/5839) 87.6349%; Kappa Coefficient = 0.8402)

Class	grass land	plantation	Shrub land	agriculture	bare ground	Wood land	swamp	Total
Unclassified	0	0	0	0	0	0	0	0
grass land	1971	0	0	0	0	0	0	1971
plantation	0	28	0	488	9	0	0	516
Shrub land	0	0	304	153	10	0	0	467
agriculture	0	0	3	1823	0	0	11	1837
bare ground	0	0	0	34	413	0	0	447
Wood land	0	0	0	0	14	68	0	82
swamp	0	0	0	9		0	510	519
Total	1971	28	307	2507	446	68	521	5839

Class	Producer Accuracy's (%)	User Accuracy's (%)
grass land	100	100
plantation	100	5.43
Shrub land	99.02	65.1
agriculture	72.72	99.24
bare ground	93.86	92.4
Wood land	1oo	82.93
swamp	97.89	98.27

The Kappa coefficient represents the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Leica Geosystem, 2000). This implies that the Kappa value of 0.8402 represents a probable 84.02% better accuracy than if the classification resulted from a random, unsupervised, assignment instead of the employed maximum likelihood classification. The Kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into 3 groupings: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Leica Geosystem, 2000). Therefore, the classification in this study meets the specified requirement.

5.4 Factor Development

The major causes of floods include intensity, duration and spatial distribution of rainfall on catchments; sedimentation on river channels and overflow of water from the river banks; steep slopes, deforestation and poor soil infiltration capacity; failure of hydrologic structures and sudden release of waters from dams; and land slides. These factors influence the magnitude, run-off or velocity of the flood and increase the risk of flood damage.

In Ethiopia, most of the factors exist. Excessive and torrential rainfall, steep slops with low-lying plains along the major rivers, deforested catchment, etc are causing both flash-and river-floods. The flash-floods damages are not well recorded and documented compared to river floods damage. The most publicized flood type in Ethiopia is river flood (DPPC, 1997).

Flood causative factors particularly in Fogera Woreda were identified from field survey, and literature. Accordingly slope, soil type, elevation, land use type, drainage density, and rainfall are listed in order of importance. Standardized values of each factor in the reclassification process were listed in Table 22 and 23 below.

5.4.1 Slope Factor

Slope has a great influence on flood hazard. The flatter the slope, the higher is the probability of the area to be inundated. Slope of the Catchment was derived from 20 m interval contour that is digitized from 1:50000 Topographic Map. This contour was converted to 3d shape file using 3D Analyst in Convert feature to 3D module by interpolating contour using an attribute as a source. Further Tin was created using 3D Analyst in Create Tin from Feature (3D shape). Slope was derived using 3D Analyst in Tin Surface/ Tin Slope module. Slope feature class was further converted to raster using Conversion Tool in To Raster/ Feature to Raster module. The slope raster layer was further reclassified in five sub group using standard classification schemes namely Quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while ArcMap determines where the breaks should be. Finally the slope was reclassified in to continuous scale in order of flood hazard rating (Fig 21).

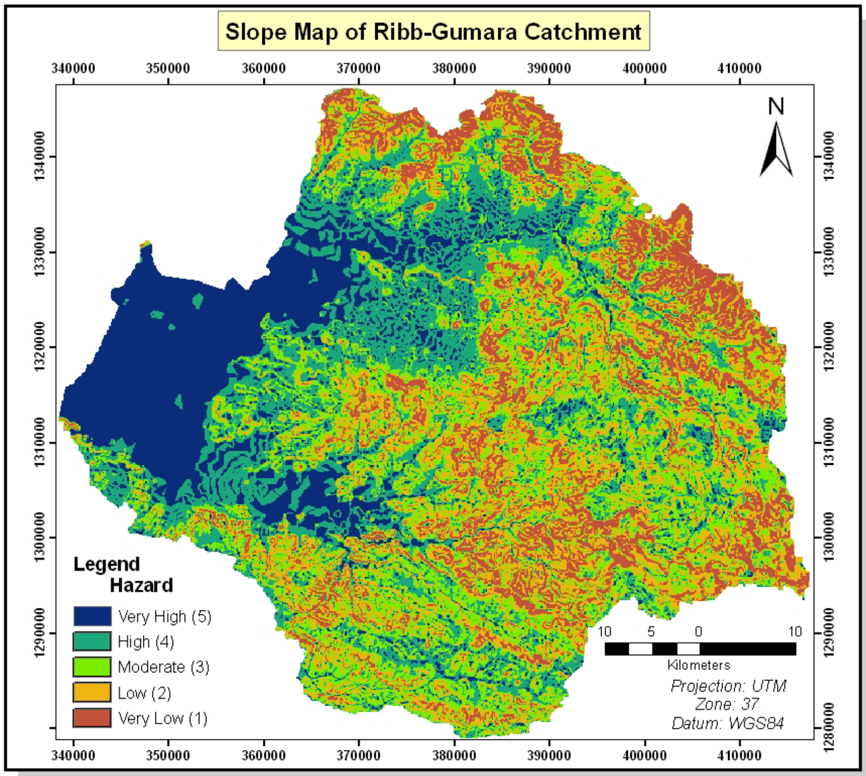


Figure 21: Reclassified Slope Map of Ribb-Gumara Catchment

5.4.2 Soil Factor

Soil drainage is defined as the rate and extent of water movement in the soil, including movement across the surface as well as downward through the soil. Slope is a very important factor in soil drainage. Other factors include texture, structure, and physical condition of surface and subsoil layers. Major soil types in Ribb-Gumara Catchment include Chromic Luvisols, Eutric Fluvisols, Eutric Leptosols, Eutric Vertisols, and Haplic Luvisols.

Fluvisols accommodate genetically young, azonal soils in alluvial deposits. They are predominantly recent, fluvial and marine deposits found along alluvial plains and river fans of the major Ribb and Gumara rivers. Fluvisols under natural conditions are flooded periodically (FAO, 2006). Leptosols are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony. Various kinds of continuous rock or of unconsolidated materials with less than 20 percent (by volume) fine earth. They are well drained, shallow to moderately deep, stony and very rocky soils of varying colors and texture so that given the lowest scale. Luvisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. They are formed from a wide variety of unconsolidated materials including alluvial and colluvial deposits. Haplic Luvisols are most common in flat or gently sloping land of the southern and south eastern part of the catchment while Chromic Luvisols are common in moderately sloping or steep areas of the southern western and central part. Vertisols are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. Vertisols, which dominate the down stream of the catchment, are imperfectly drained to poorly drained, deep, very dark grey to greyish brown, mottled firm clay soils so that are given the highest scale in the flood hazard rating (Fig. 22).

These soil types are converted to raster format and finally reclassified based on their water infiltration capacity.

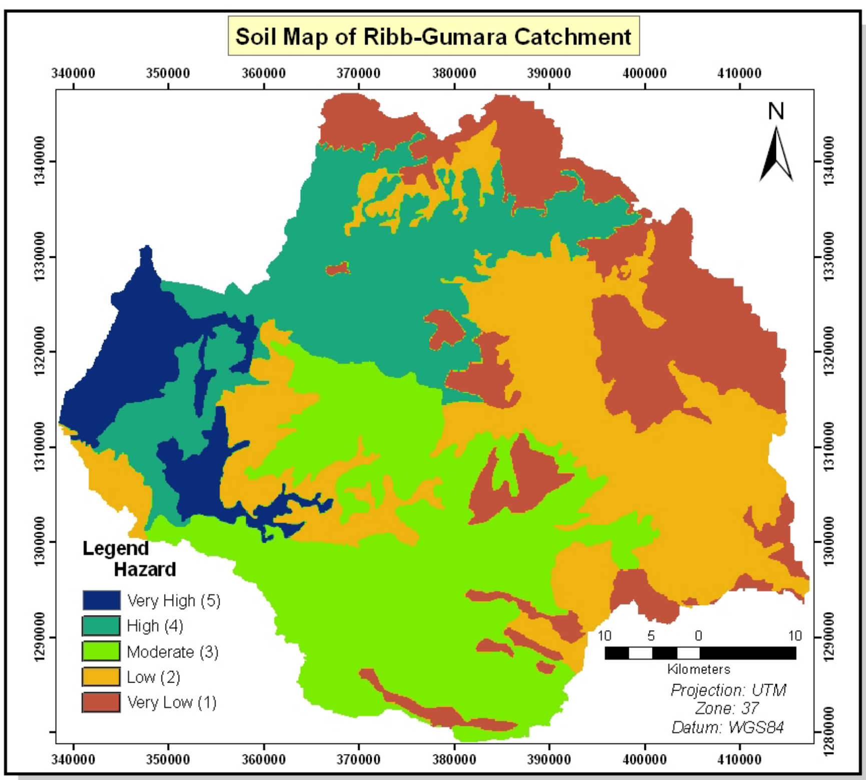


Figure 22: Reclassified Soil Map of Ribb-Gumara Catchment

(Source: Endaweke, 2007)

5.4.3 Elevation Factor

All the processes for the development of the elevation factor are as explained above in the slope factor development. The raster layer is then reclassified in to a common scale according to their influence to flood hazard (Fig. 23). The lower the elevation, the higher will be its vulnerability to flooding.

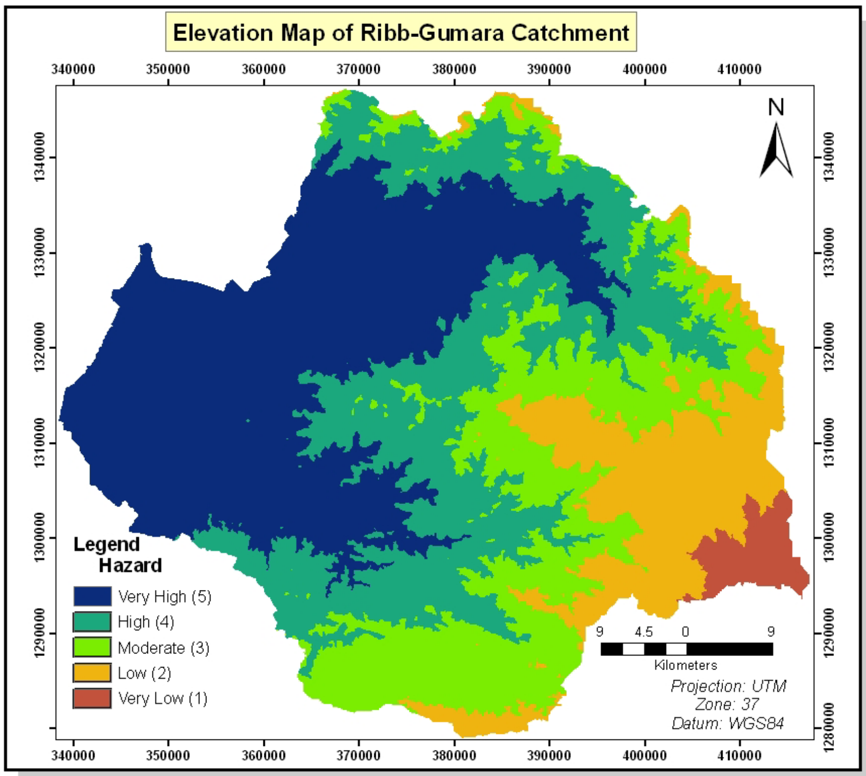


Figure 23: Reclassified Elevation Map of Ribb-Gumara Catchment

5.4.4 Landuse/Landcover Factor

The landuse/landcover map was developed from the October 1999 satellite image. This is because; first 1999 was one of the major flooding years in Fogera Woreda that severely affected five PAs. Secondly, this month is shortly after the major rainy season in that part of the country. These are important to consider back flow of Lake Tana and areas that are covered by flood water. Generally, this raster data layer shows the different types of land use/land cover across the Ribb-Gumara Catchment for the flood hazard analysis and Fogera Woreda for the flood risk analysis. The data layer is already in raster format; this raster format was further reclassified into a common scale in order of their rainwater abstraction capacities. And new values re-assigned in order of flood hazard rating for hazard analysis (Fig 24) and flood risk rating for flood risk analysis (Fig 25).

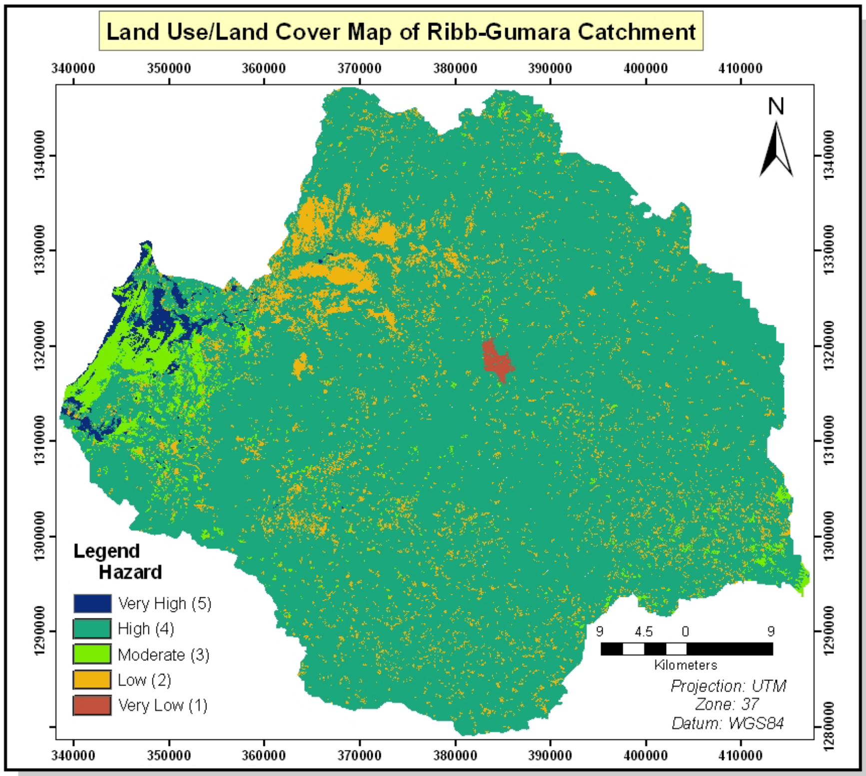


Figure 24: Reclassified Land Use/Land Cover Map of Ribb-Gumara Catchment

5.4.5 Drainage Density Factor

Drainage networks of Ribb and Gumara Rivers were digitized from 1:50000 Topographic Maps. And using the spatial analyst, line density module, drainage density of Ribb-Gumara Catchment was calculated. Line density module calculates a magnitude per unit area from polyline features that fall within a radius around each cell. Density is measured in length of lines per unit area. The density layer is further reclassified in five sub group using standard classification schemes namely equal interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while ArcMap determines where the breaks should be. And new values (common scale) re-assigned in order of flood hazard rating in the assumption that the lesser the drainage network in a given area the higher the flood hazard (Fig 26). Highest scale is given for the denser class and the scale decreases as density decreases.

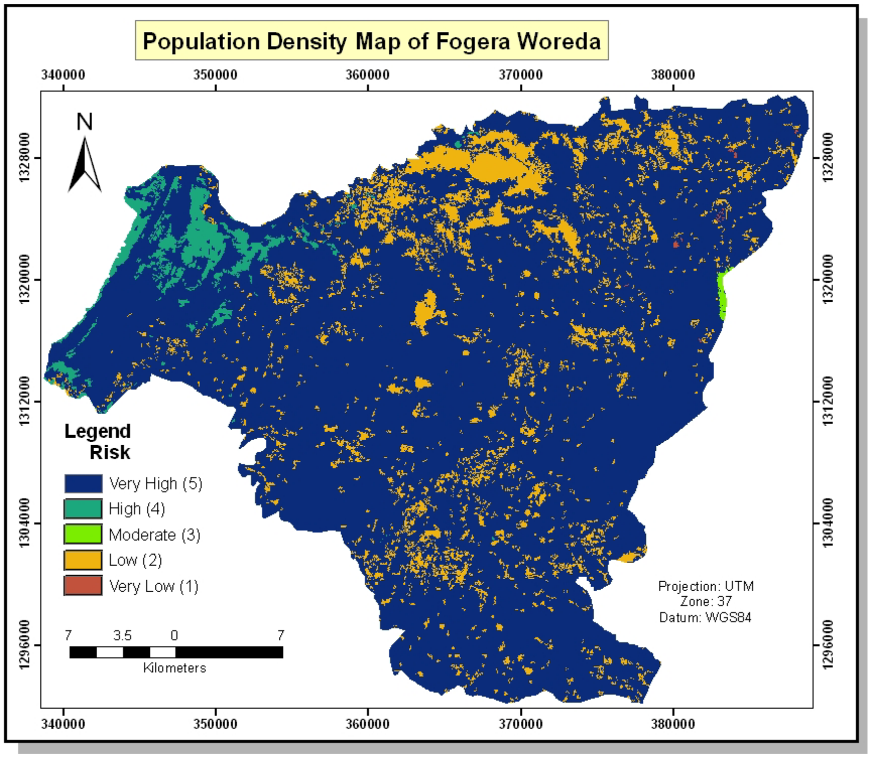


Figure 25: Reclassified Land Use/Land Cover Map of Fogera Woreda

5.4.6 Rainfall Factor

Flood hazard and risk assessment requires an areal rainfall intensity data. However, NMA only provides point rainfall from eleven Meteorological Stations within and around the catchment. In addition, even though rainfall intensity is the best data for flood hazard analysis, this type of data is not available for most of the Meteorological stations in Ethiopia and therefore daily maximum rainfall was used. And also, ordinary kriging technique in the geostatistical analyst extension in ArcGIS 9.1 was used to convert the point rainfall to areal rainfall. Kriging is a geostatistical method of interpolation that weighs the surrounding measured values to derive a prediction for an unmeasured location. This rainfall surface was then reclassified in to common scale in the assumption that the higher the rainfall amount the higher the flood hazard will be (Fig. 27).

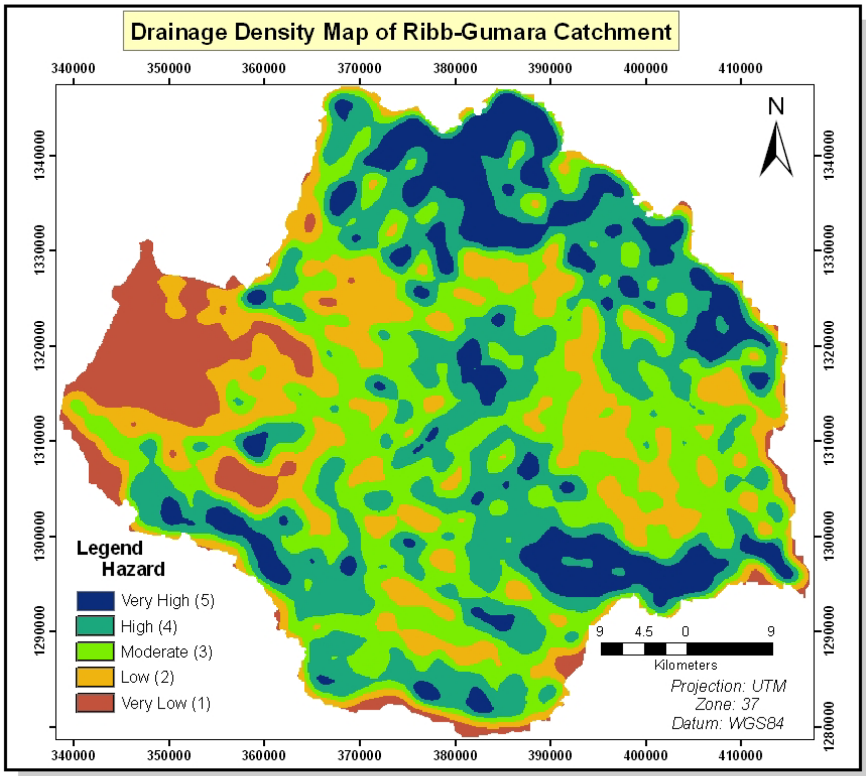


Figure 26: Reclassified Drainage Density Map of Ribb-Gumara Catchment

5.4.7 Population Density Factor

Analogue map of Fogera Woreda from ELRI was scanned, georeferenced, onscreen digitized, and populated with the 1999 population attribute against the respective PAs. Gross population density calculation method was used to calculate the number of person per square kilometres per PA. Right after updating, population shape file was converted to raster layer using Conversion Tools/Feature to Raster. Then further the data layer was reclassified into fiver sub-factors which are classified using manual method. As explained in the study area description above, Woreta town is the head quarter of Fogera Woreda while this Woreda constitutes other twenty five PAs. Thus, the town population density is many folds that of other PAs. Therefore, manual method of classification was used to avoid the very great influence of town population density in the flood risk map development. Finally, new values re-assigned in order of increasing number of population that is more susceptible to flood hazard (Fig 28).

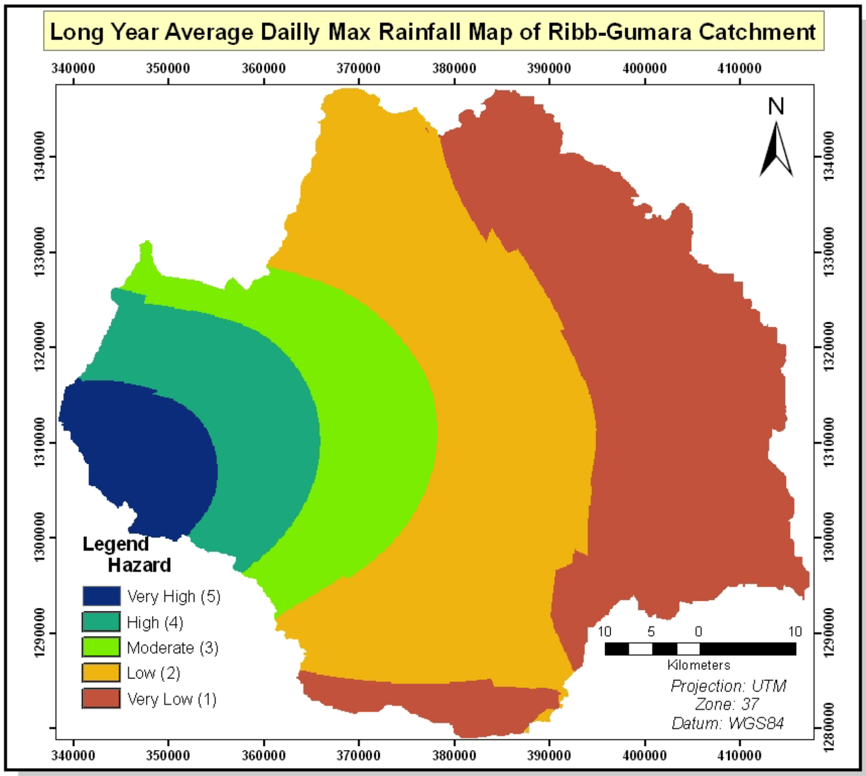


Figure 27: Reclassified Long Year Average (1951-2006) Daily (24 Hours) Maximum Rainfall of Ribb-Gumara Catchment

5.5 Flood Hazard Analysis

Multi-Criteria Evaluation technique was used to assess flood hazard of the Catchment using GIS. As explained above in the literature part, MCE is a procedure which needs several criteria to be evaluated to meet a specific objective. It is most commonly achieved by one of two procedures. The first involves Boolean overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). The second procedure which was used in the study is known as weighted linear combination (WLC) where continuous criteria (factors) were standardized to a common data model that was raster layer with a resolution of 30 m cell size, and then combined by means of a weighted overlay. The result is a continuous mapping of flood hazard and finally thresholded to yield a final decision.

The standardized raster layers were weighted using Eigen vector that is important to show the importance of each factor as compared to other in the contribution of flood hazard. Accordingly, the Eigen vector of the weight of the factors was computed in IDRISI 32 software in Analysis menu Decision Support/Weight module. The Weight module was fed with the pair wise comparison matrix file of the factors in a Pair wise comparison 9 Point continuous scale (Fig 29).

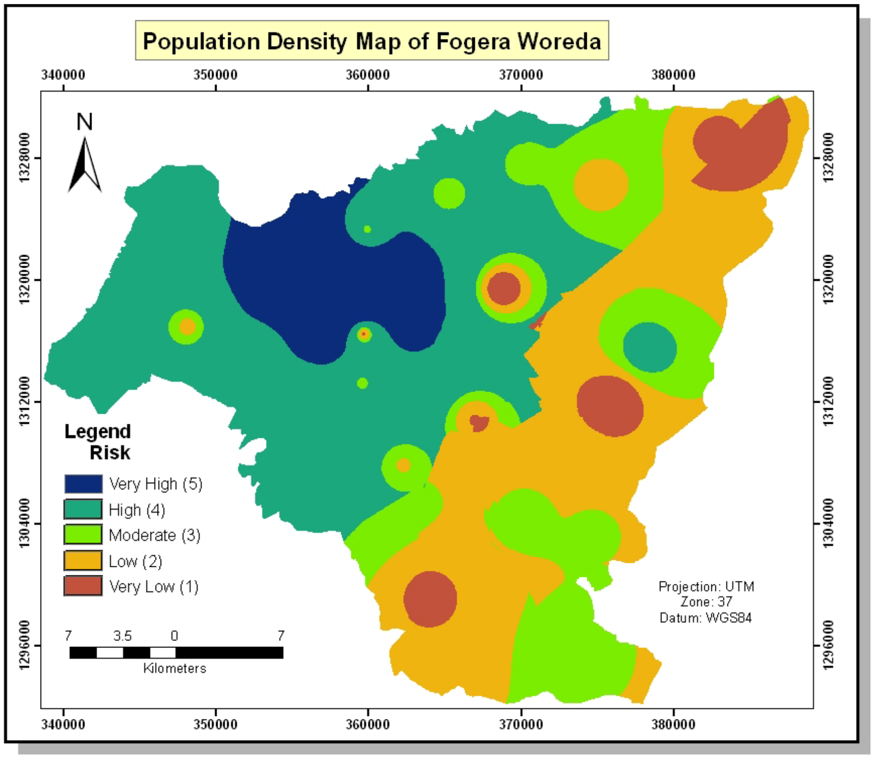
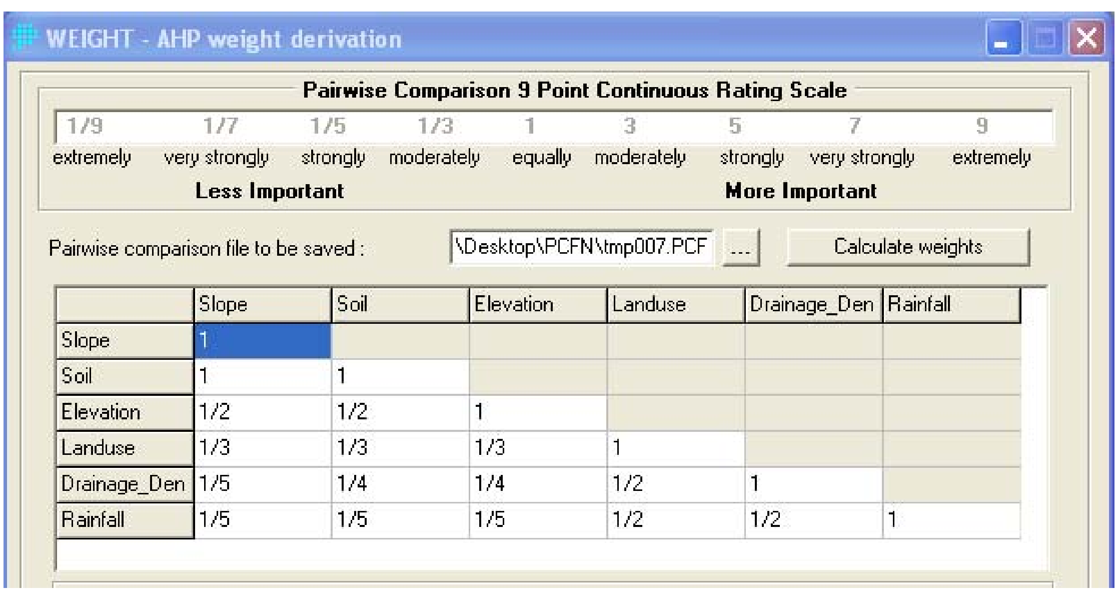


Figure 28: Reclassified Population Density Map of Fogera Woreda



	Slope	Soil	Elevation	Landuse	Drainage_Den	Rainfall
Slope	1					
Soil	1	1				
Elevation	1/2	1/2	1			
Landuse	1/3	1/3	1/3	1		
Drainage_Den	1/5	1/4	1/4	1/2	1	
Rainfall	1/5	1/5	1/5	1/2	1/2	1

Figure 29: The Pair Comparison Matrix of the Flood hazard inducing factors

The principal eigenvector of the pair wise comparison matrix using the factors affecting flood hazard was calculated as follows:

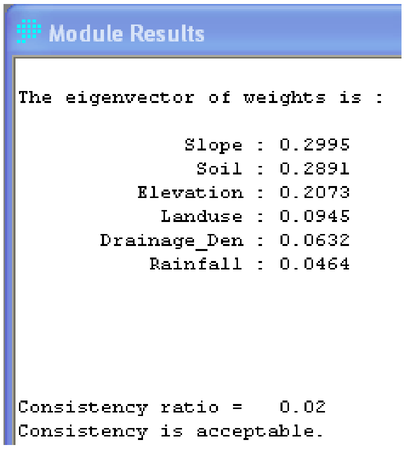


Figure 30: Weights derived by calculating the principal eigenvector of the pair wise comparison matrix

The computed Eigen vector (Fig. 30) was used as a coefficient for the respective factor maps to be combined in Weighted Overlay in ArcGIS environment.

Table 22: Scaled and waited flood hazard inducing factors

Factor	Weight	Sub-Factor	Scale (Hazard)
1. Slope (Percent)	0.2690	0 –0.9 0.9 – 6.4 6.4 – 12.8 12.8 – 22.8 22.8 – 88.9	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
2. Soil (based on drainage capacity)	0.1793	Eutric Vertisols Eutric Fluvisols Haplic Luvisols Chromic Luvisols Eutric Leptosols	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
3. Elevation (meter)	0.0860	1780 – 2240 2240 – 2700 2700 – 3160 3160 – 3620 3620 - 4080	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
4. Land use (Level of flood abstraction)	0.0562	Swamp Agriculture/Bare land Grass Land Wood & Shrub land Plantation Forest	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
5. Drainage density (Km/Sq. Km)	0.3712	0 – 0.7 0.7 – 1.4 1.4 – 2.1 2.1 – 2.8 2.8 – 3.5	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
6. Daily Max Rainfall (mm)	0.0383	76.9 - 70.5 70. 5-64.0 64. 0 -57.5 57.5 -51.1 51. 1 -44.6	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)

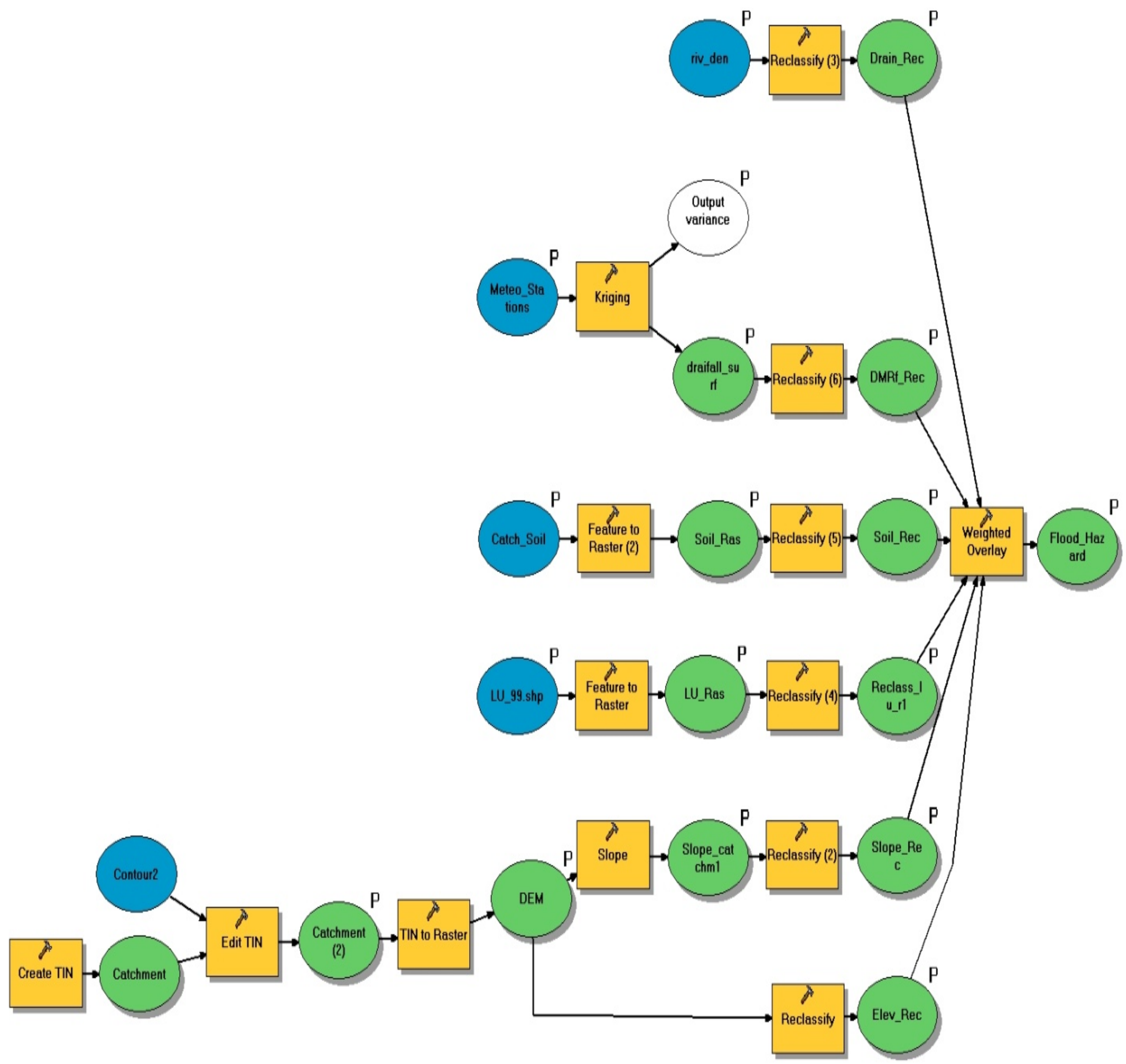


Figure 31: Flood Hazard Analysis Model Builder dialogue box

5.6 Flood Risk Analysis

As the flood hazard result of the catchment revealed in the next chapter, all of the very high and high hazard areas of the Catchment fall in Fogera Woreda. Therefore, it is found important to do the flood risk assessment for this Woreda. Flood risk assessment was done for Fogera Woreda using the flood hazard layer and the two elements at risk, namely population density and land use. Vulnerability was assumed to be one. These three factors remained to be equally important in the Weighted Overlay process (Table 23).

Table 23: Scaled and weighted flood risk analysis factors

Factors	Weight	Sub-factors	Scale (Risk)
1. Flood hazard	0.3333	very high high moderate low very low	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
2. Population density (person/Sq. Km)	0.3333	2396-400 400-225 225-200 200-175 175-149	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)
3. Land use types (based on their sensitivity to flooding)	0.3333	Agriculture/Grass Land Swamp Plantation Forest Wood & Shrub land Bare land	5 (Very High) 4 (High) 3 (Moderate) 2 (Low) 1 (Very Low)

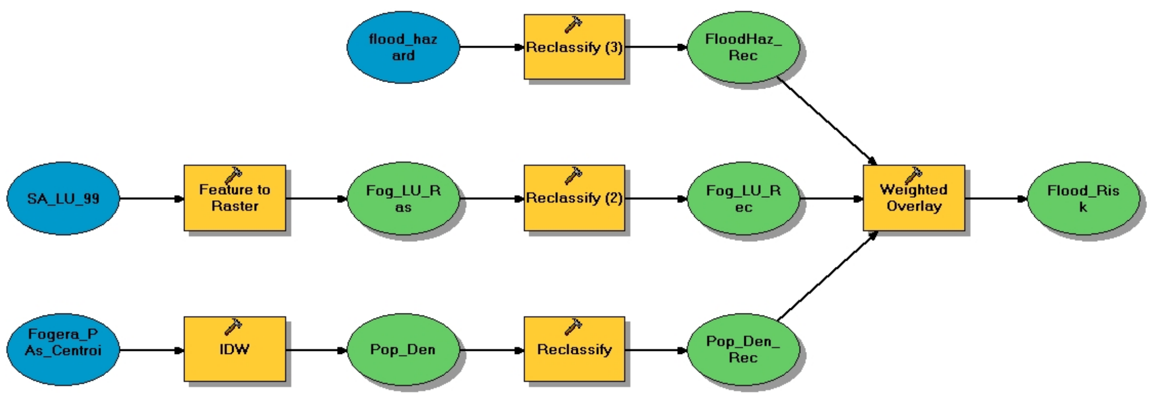


Figure 32: Flood Risk Analysis Model Builder dialogue box

6. Result and Discussion

6.1 Flood Hazard

The flood hazard maps (Fig 33 & 34) below shows that 192.8, 502.7, 547.2, 1099.7, 974.3 square kilometer of Ribb-Gumara Catchment, and 141.6, 178.8, 324.3, 355.7, 108.8 square kilometer area of Fogera Woreda were subjected respectively to very high, high, moderate, low and very low flood hazards (Table 24).

As it is explained in the previous parts, a more detailed study was done for Fogera Woreda. Almost all of the flood hazard areas fall under this Woreda (Table 24). PAs with more than three-fourth of their areas fall under high and very high flood hazard include Wagtera (100%), Nabega (99.6%), Kidiste Hana (98.9%), Shina (93.1%), and Shaga (92.2%) (Fig. 34). All of these areas lie in the downstream part of Ribb and Gumara Rivers where they join to Lake Tana. Further analysis revealed that 99.7% swamps, 93.8% grass lands, 27.9% shrub lands, and 24.1 Agricultural lands fall under high to very high flood hazard (Table 35).

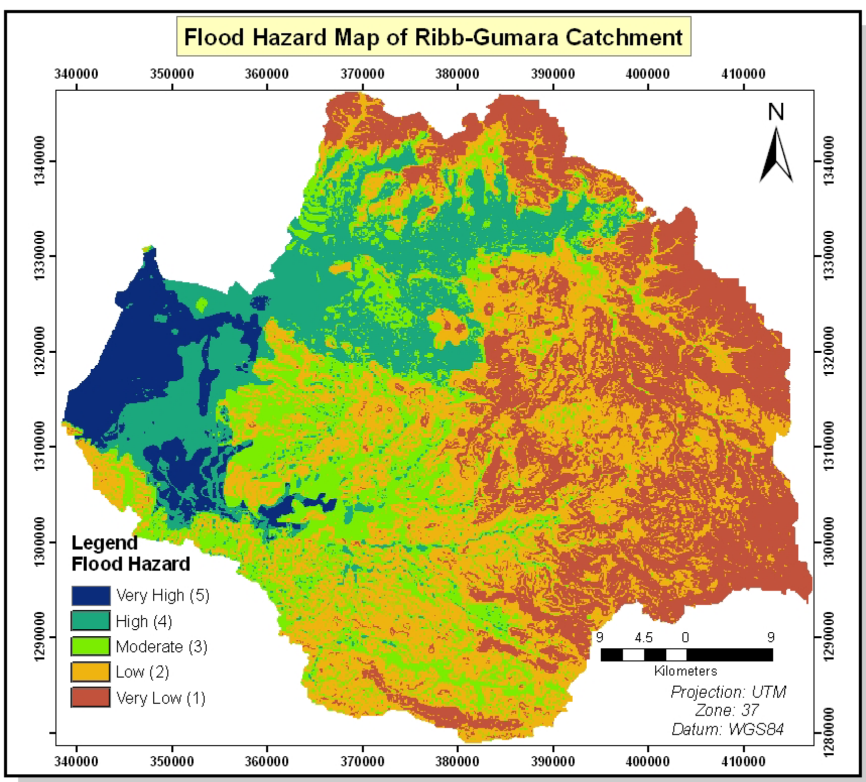


Figure 33: Flood Hazard Map of Ribb-Gumara Catchment

Table 24: Area Comparison of the Catchment and Fogera Woreda by Flood Hazard Level

Flood Hazard	Ribb-Gumara Catchment Area (Sq. Km)	Fogera Woreda Area (Sq. Km)	% (Fogera Relative to Catchment)
Very High	192.8	141.6	**73.4**
High	502.7	178.8	35.6
Moderate	547.2	324.3	59.3
Low	1099.7	355.7	32.3
Very Low	974.3	108.8	11.2
Total	**3316.6**	**1109.2**	**33.4**

From the area of the catchment under very high flood hazard about three-forth is in Fogera Woreda while this Woreda is only one-third of the catchment.

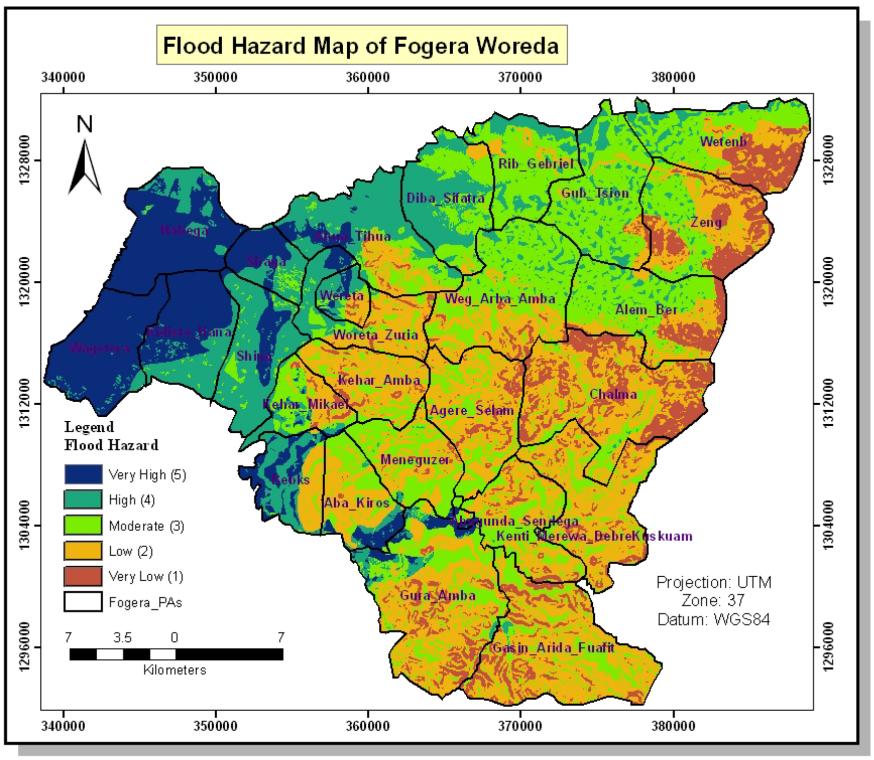


Figure 34: Flood Hazard Map of the Study Area

Table 25: Cross-Tabulated areas of Land use and Flood Hazard in Fogera Woreda

S.N	Landuse/Land Cover Type	Flood Hazard (Area in Sq. Km)					Total
		Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	
1	Woodland	12.3	18.5	9.9	2.2	0.2	43.1
2	Agriculture	93.9	327.3	264.5	136.6	51.2	873.5
3	Bare Land	0.4	0.0	0.0	0.0	0.0	0.5
4	Swamp	0.0	0.0	0.1	2.9	26.9	29.9
5	Grassland	0.3	2.1	3.1	16.8	62.5	84.9
6	Plantation Forest	1.3	0.0	0.0	0.0	0.0	1.3
7	Shrub land	0.7	7.7	46.7	20.2	0.8	76.1
Total		108.8	355.7	324.3	178.8	141.6	**1109.2**

Table 26: Cross-Tabulated Areas of PAs and Flood Hazard in Fogera Woreda

S.N	PA Name	Flood Hazard (Area in Sq. Km)					Total
		Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	
1	Gasin_Arida_Fuafit	12.3	43.3	16.1	0.5	0.0	72.1
2	Gura_Amba	9.6	39.0	23.2	4.9	4.8	81.4
3	Abagunda_Sendega	3.1	18.3	13.9	0.1	0.4	35.9
4	Aba_Kiros	0.1	13.3	8.7	2.1	3.8	28.1
5	Bebks	0.0	7.0	1.4	10.9	8.0	27.3
6	Kenti Merewa DebreKuskuam	6.2	34.1	10.3	0.0	0.0	50.5
7	Meneguzer	0.9	13.7	16.3	0.4	0.3	31.6
8	Kehar_Mikael	1.5	5.8	8.4	5.0	0.9	21.6
9	Agere_Selam	4.7	27.9	12.0	0.0	0.0	44.7
10	Kehar_Amba	2.3	21.0	6.5	0.1	0.0	29.9
11	Chalma	26.9	39.4	9.7	0.3	0.0	76.3
12	Wagetera	0.0	0.0	0.0	2.0	37.7	39.7
13	Kidiste_Hana	0.0	0.0	0.4	13.1	24.0	37.6
14	Shina	0.0	0.0	2.5	26.8	6.5	35.9
15	Woreta	0.5	2.3	1.5	4.4	1.5	10.2
16	Alem_Ber	7.3	11.7	28.6	3.4	0.0	51.0
17	Woreta_Zuria	1.5	13.9	6.0	7.8	2.1	31.3
18	Shaga	0.0	0.0	1.4	7.0	9.2	17.6
19	Weg_Arba_Amba	2.9	19.6	36.9	4.3	0.0	63.7
20	Nabega	0.0	0.0	0.2	8.6	37.6	46.4
21	Zeng	14.9	18.9	15.2	2.1	0.0	51.1
22	Rib_Gebriel	0.0	2.9	22.8	8.8	0.0	34.5
23	Gub_Tsion	0.9	3.3	34.9	9.7	0.0	48.8
24	Wetenb	12.3	10.0	21.4	6.3	0.0	49.9
25	Abua_Tihua	0.8	8.4	9.5	27.8	4.8	51.3
26	Diba_Sifatra	0.0	2.0	16.5	22.4	0.0	40.9
	Total	108.8	355.7	324.3	178.8	141.6	1109.2

6.2 Flood Risk

Flood risk mapping and assessment was done for Fogera Woreda by taking population and landuse/landcover elements that are at risk combined with the degree of flood hazards of the Woreda.

According to the flood risk map (Fig 35), it was estimated that 40.1, 165.5, 331.3, 385.8 and 186.4 square kilometre areas of Fogera Woreda were subjected respectively to very high, high, moderate, low, and very low flood risk (Table 35).

Elements at risk considered in this study show different levels of risk. PAs that are about half of their area under flood risk include Wagtera (96.1), Shaga (90.3), Nabega (87.5), Woreta (65.2), Bebks (55.8), Kidiste Hana (53.3), Shina (49.4), and Abua Thua (47.1). With regard to the other element at risk, landuse/landcover, 81.8% swamps, 81.6% grass lands, 12.8% agricultural lands were under high to very high flood risk.

The 2006 flood worst hit PAs of Fogera Woreda were among the above flood risk PAs. Therefore, the result was congruent with the reality that is going on in the study area. Specifically, results were compared with ground truth data of the 2006 flood disaster damaged areas which were collected with GPS during field survey. All these damaged schools, water pumps, crops, and so on fall in the high to very high flood risk areas of the flood risk map. In addition, the above PAs are traditionally known as flood prone areas.

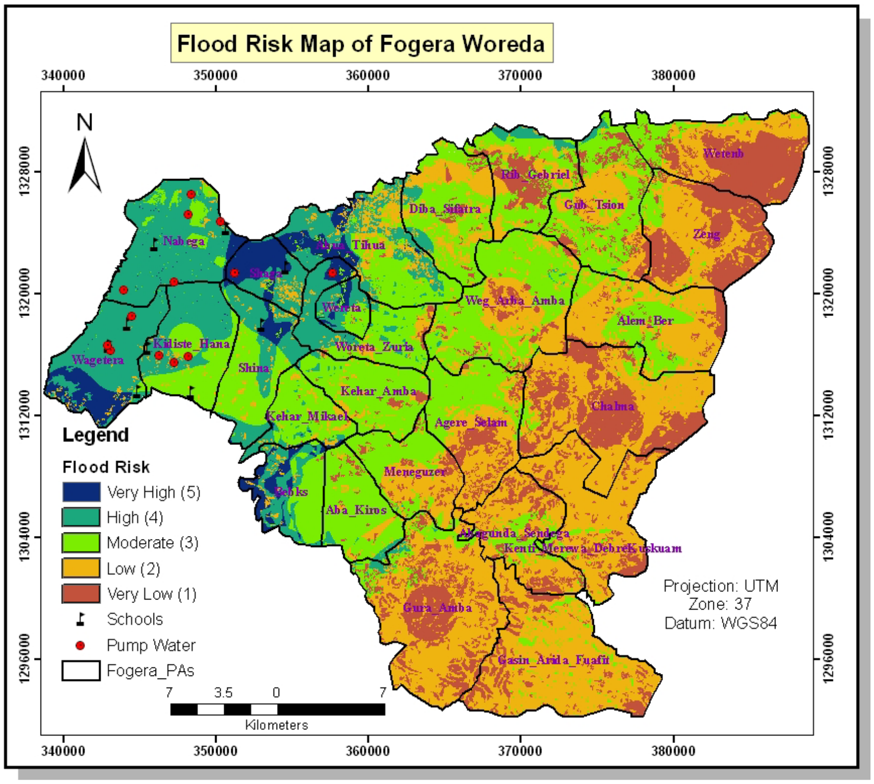


Figure 35: Flood Risk Map of the Study Area

Table 27: Cross-Tabulated Area of Land Use and Flood Risk in Fogera Woreda

S.N	Land use/Land Cover Type	Flood Risk (Area in Sq. Km)					Total
		Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	
1	Woodland	38.4	4.2	0.6	0.0	0.0	43.1
2	Agriculture	112.0	337.3	312.3	87.7	24.3	873.5
3	Bare Land	0.4	0.1	0.0	0.0	0.0	0.5
4	Swamp	0.0	0.0	5.4	20.3	4.1	29.9
5	Grassland	0.3	3.0	12.3	57.4	11.8	84.9
6	Plantation Forest	1.3	0.0	0.0	0.0	0.0	1.3
7	Shrub land	34.1	41.2	0.7	0.0	0.0	76.1
Total		186.4	385.8	331.3	165.5	40.1	1109.2

Table 28: Cross-Tabulated Areas of PAs and Flood Risk in Fogera Woreda

S. N	PA Name	Flood Risk (Area in Sq. Km)					Total
		Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	
1	Gasin_Arida_Fuafit	12.0	56.1	4.0	0.0	0.0	72.1
2	Gura_Amba	25.9	47.0	6.9	1.6	0.0	81.4
3	Abagunda_Sendega	8.7	20.8	6.4	0.0	0.0	35.9
4	Aba_Kiros	1.2	2.3	23.4	1.2	0.1	28.1
5	Bebks	0.1	1.3	10.7	9.0	6.2	27.3
6	Kenti	8.9	39.1	2.6	0.0	0.0	50.5
7	Meneguzer	3.9	12.5	15.1	0.1	0.0	31.6
8	Kehar_Mikael	0.1	2.3	15.8	2.8	0.4	21.6
9	Agere_Selam	8.2	18.0	18.4	0.0	0.0	44.7
10	Kehar_Amba	1.4	2.6	25.0	0.9	0.0	29.9
11	Chalma	32.3	40.4	3.6	0.0	0.0	76.3
12	Wagetera	0.0	1.0	0.5	28.9	9.2	39.7
13	Kidiste_Hana	0.0	1.4	16.2	20.0	0.1	37.6
14	Shina	0.0	2.0	16.1	14.8	2.9	35.9
15	Wereta	0.1	0.5	2.9	5.2	1.5	10.2
16	Alem_Ber	5.1	29.8	16.0	0.1	0.0	51.0
17	Woreta_Zuria	0.9	3.0	14.3	10.9	2.1	31.3
18	Shaga	0.0	1.5	0.2	6.7	9.2	17.6
19	Weg_Arba_Amba	5.8	19.3	38.3	0.4	0.0	63.7
20	Nabega	0.0	0.6	5.2	39.0	1.5	46.4
21	Zeng	25.6	21.8	3.8	0.0	0.0	51.1
22	Rib_Gebriel	8.3	7.7	15.6	2.9	0.0	34.5
23	Gub_Tsion	8.6	14.8	24.5	0.9	0.0	48.8
24	Wetenb	26.5	15.9	7.4	0.1	0.0	49.9
25	Abua_Tihua	0.3	10.2	16.6	17.3	6.9	51.3
26	Diba_Sifatra	2.4	13.8	22.0	2.7	0.0	40.9
	Total	186.4	385.7	331.3	165.6	40.1	1109.2

6.3 Flood Frequency

By using Gumbel's Method, the calculated Gauge levels of Gumara River for 2, 10, 25, 50 and 100 year return period flood are 5.9m, 7.091m, 7.685m, 8.147m, and 8.582m respectively while that of Ribb-Addiszemen are 6.806m, 7.714m, 8.166m, 8.518m, and 8.85m respectively. The same gauge data are then analyzed by Log-Pearson Type III Method and gauge levels obtained for 2, 10, 25, 50 and 100 year return period flood for Gumara are 6.075m, 7.06m, 7.369m, 7.553m, and 7.706m respectively, while that of Ribb are 7.016m, 7.604m, 7.731m, 7.793m, and 7.836m respectively.

The Chi square test comparing computed values with observed values is carried out to find the best fit method and Gumbel's method is found to be the best fit for both rivers. That is, this method is with the lower CHI Square value than the Log-Pearson Type III (0.081 Vs 0.519 for Gumara River, and 0.055 Vs 0.860 for Ribb). Therefore, inundation area mapping was done using the Gumbel's method base flood result.

An 8.582 m gauge level in Gumara River is expected to occur in every 100 year while that of the Ribb is 8.85 m. In other words, the probability of occurrence of an 8.582 m gauge level in Gumara River in a given year is 1/100 or (1%), while with this probability, a 8.85 m gauge level is expected in Ribb River. In Gumara, a 5.9m gauge level has a 50% probability to occur in any year while in Ribb 6.806m gauge level has the same probability of occurrence.

From the Gumbel's distribution result, given the same return periods, gauge levels for Ribb River are found to be a bit greater than that of Gumara (Table 29). This is because, river density in the Ribb catchment is relatively greater than that of Gumara and again Ribb has more perennial tributaries than that of Gumara.

Table 29: Gauge Levels for Selected Return Periods

Return Period	Gauge Level (m)	
	Gumara	Ribb-Addiszemen
2	5.900	6.806
5	6.616	7.352
10	7.091	7.714
25	7.685	8.166
50	8.147	8.518
100	8.582	8.850

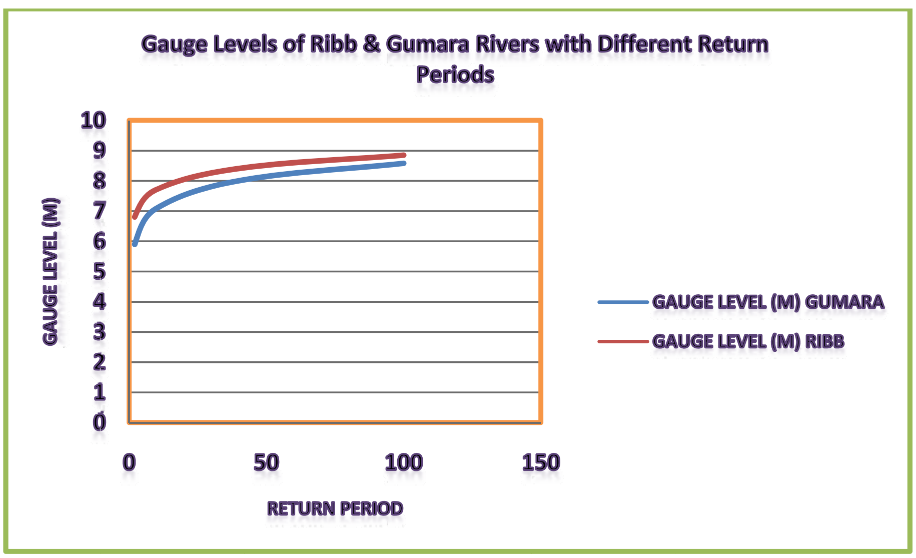


Figure 36: Graph of Calculated Gauge Levels against Selected Return Periods of Ribb & Gumara Rivers (Flood Frequency Analysis Using Gumbel's Method)

As discussed previously, in times of embankment failure, inundation will occur in the areas that have an elevation lower than the gauge level and that are connected with the location of the embankment failure. In this study, the 100 year gauge level, which is considered as base flood or project flood, for the Ribb and Gumara rivers were taken to map the likely inundation areas in the two respective catchments (Fig. 36). These flood maps are merged in the GIS environment so as to see their aggregate effects in the Ribb-Gumara Catchment in general and Fogera Woreda in particular. This map was crossed with the maps of elements at risk in Fogera Woreda (Table 31 & 32). The quality of the DEM highly limited the inundated area mapping for other return periods. The difference in gauge level between the two year and hundred year return period was calculated as 2.682m (Gumara) and 2.044m (Ribb), while the DEM was developed from a 20 m interval counter, therefore failed to show different inundated area maps for different return periods.

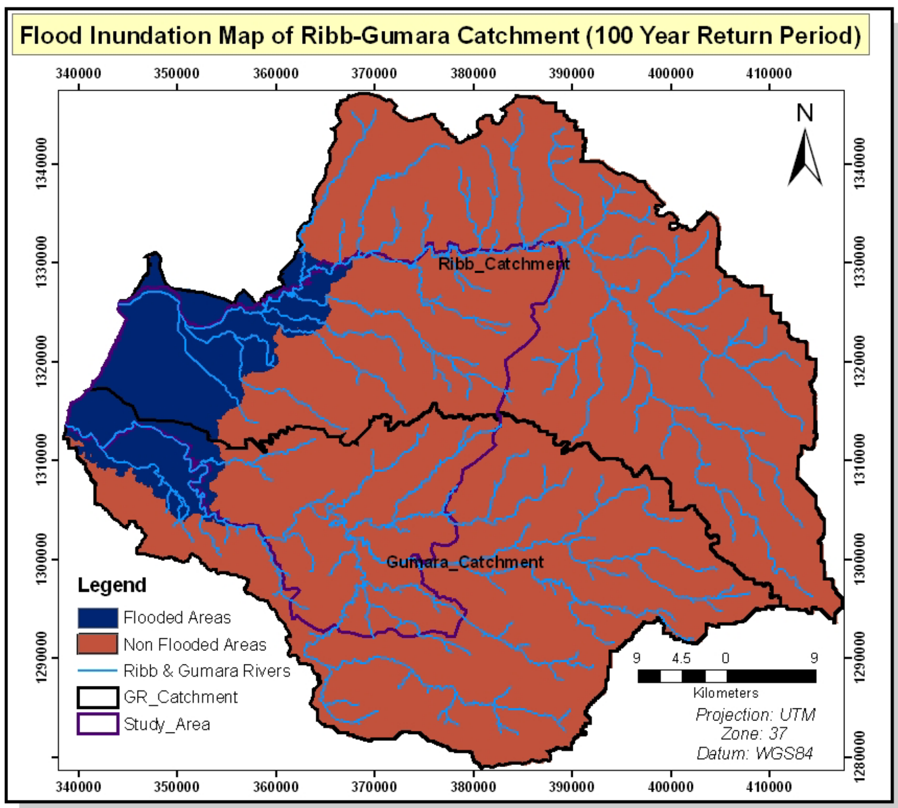


Figure 37: Flood Inundation Map of Ribb-Gumara Catchment (100 Year Return Period)

For a 100 year return period flood which gage level was calculated as 8.582m (Gumara) and 8.85 m (Ribb), the total area inundated by the flood will be 352 square kilometers. This area is about 12% of the total catchment area, and that of Fogera Woreda is 256 square kilometers (23%). As the above map shows, almost all the area likely to be inundated by a 100 year return period flood fall in Fogera Woreda. Important to mention here is that the identified areas likely to be flooded by the flood frequency analysis fall in the high and very high hazard areas identified by the overlay analysis of the flood hazard assessment.

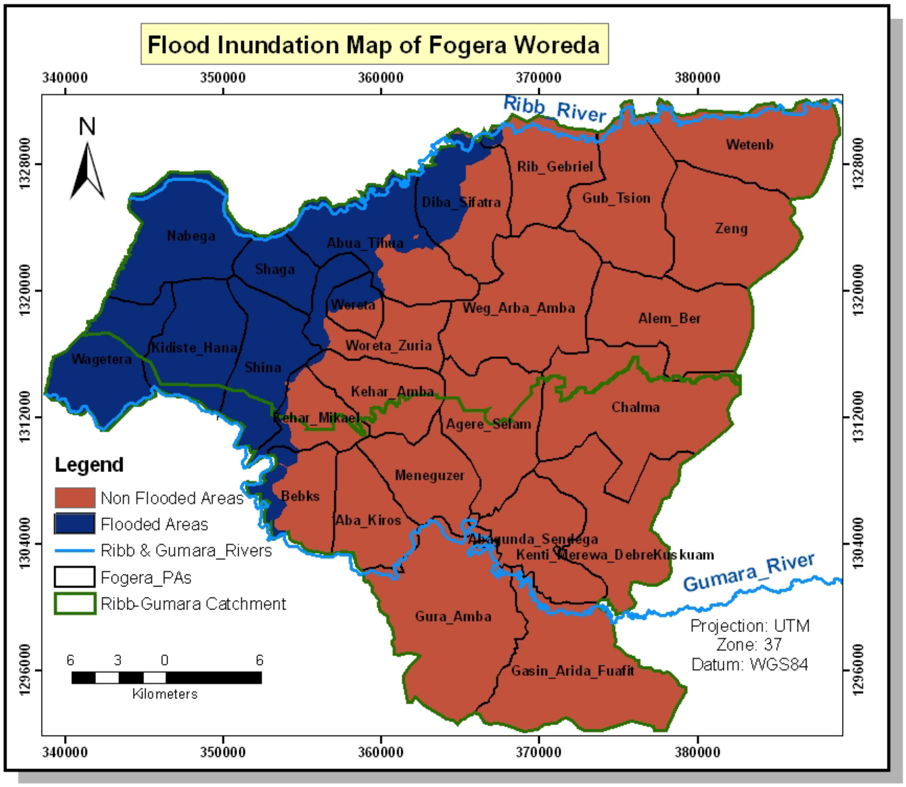


Figure 38: Flood Inundation Map of Fogera Woreda (100 Year Return Period)

Table 30: Comparison of Ribb-Gumara Catchment by Flood Inundation Areal Extent

	Ribb-Gumara Catchment	Fogera Woreda	% Share
Flooded Area (Sq. Km)	352	256	72.7
Non Flooded Area (Sq. Km)	2966	853	28.8
Total	3318	1109	33.4

The areal comparison above shows that about three-fourth of the inundated area fall in Fogera Woreda while this Woreda is only one-third of the catchment.

With regard to landuse classes, with the above mentioned return period flood, 99.8% swamps, 94.0 grass lands, 30.6% shrub land, and 13.9% agricultural lands were found likely to be inundated. It inundates 100% of Wagtera, Kidiste Hana, Nabega, Shaga, and Shina. 64.7% of Abua Tihua is also likely to be flooded (Table 32). Most areas of these PAs was actually inundated by the last year (2006) flood and the people was displaces from its residence. Moreover, agricultural crops including grazing lands of the pastoralist people of these areas were severely damaged by the 2006 flood. As explained before, these areas have been affected by flood almost every year and therefore traditionally identified as flood prone areas.

Table 31: Inundated Landuses by the 100 Year Return Period Flood

S.N	Landuse/Landcover	Flooded Area (Sq. Km)	Non Flooded Area (Sq. Km)	Total	% Flooded
1	Woodland	1.6	41.5	43.1	3.7
2	Agriculture	121.5	751.7	873.3	13.9
3	Bare Land	0.0	0.5	0.5	0.0
4	Swamp	29.7	0.1	29.7	99.8
5	Grassland	79.7	5.1	84.9	94.0
6	Plantation Forest	0.0	1.3	1.3	0.0
7	Shrub land	23.3	52.8	76.1	30.6
	Total	**255.8**	**853.0**	**1108.8**	23.1

The 100 year return period flood is expected to totally inundate some PAs found adjacent to Lake Tana.

Table 32: Inundated PAs by the 100 Year Return Period Flood

S.N	PA Name	Flooded Area (Sq. Km)	Non Flooded Area (Sq. Km)	Total	% Flooded
1	Gasin_Arida_Fuafit	0.0	72.1	72.1	0.0
2	Gura_Amba	0.0	81.4	81.4	0.0
3	Abagunda_Sendega	0.0	35.9	35.9	0.0
4	Aba_Kiros	0.0	28.1	28.1	0.0
5	Bebks	6.8	20.5	27.3	25.0
6	Kenti	0.0	50.5	50.5	0.0
7	Meneguzer	0.0	31.6	31.6	0.0
8	Kehar_Mikael	4.1	17.5	21.5	18.9
9	Agere_Selam	0.0	44.7	44.7	0.0
10	Kehar_Amba	0.7	29.2	29.8	2.2
11	Chalma	0.0	76.2	76.2	0.0
12	Wagetera	39.6	0.0	39.6	100.0
13	Kidiste_Hana	37.6	0.0	37.6	100.0
14	Shina	35.8	0.0	35.9	99.9
15	Wereta	5.3	4.9	10.2	51.9
16	Alem_Ber	0.0	51.0	51.0	0.0
17	Woreta_Zuria	9.2	22.1	31.3	29.4
18	Shaga	17.6	0.0	17.6	100.0
19	Weg_Arba_Amba	0.0	63.7	63.7	0.0
20	Nabega	46.3	0.0	46.3	100.0
21	Zeng	0.0	51.1	51.1	0.0
22	Rib_Gebriel	1.3	33.3	34.5	3.7
23	Gub_Tsion	0.0	48.8	48.8	0.0
24	Wetenb	0.0	49.9	49.9	0.0
25	Abua_Tihua	33.2	18.1	51.3	64.7
26	Diba_Sifatra	18.3	22.6	40.9	44.8
Total		255.8	853.0	1108.8	23.1

6.4 Dynamics in Landuse/Landcover Types

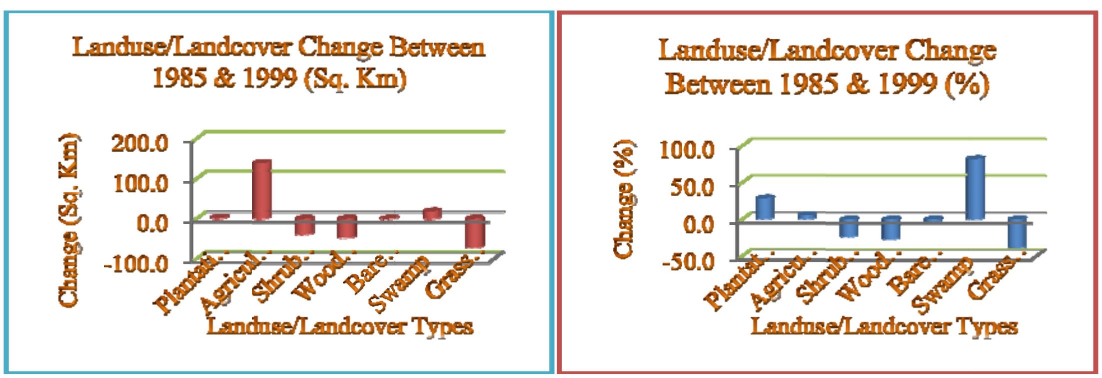
Changes in land cover driven by land use can be categorized into two types: modification and conversion. Modification is a change of condition within a cover type; for example, unmanaged forest modified to a forest managed by selective cutting. Conversion is a change from one cover type to another, such as deforestation to create cropland or pasture.

The most important change from 1985 to 1999 was observed in the expansion of swamps at the expense of grass lands and to some extent agricultural lands. And agricultural lands show an areal expansion to the previous shrub, wood and grass lands. This has impacts on the past flooding hazards by decreasing surface roughness which retards the peak flow down stream. The table below shows areal extent of the different landuse/landcover classes in two different periods, (1985 and 1999). It also incorporates the change of the Landuses/Landcovers between the given years and their percent change.

Table 33: Landuse/Landcover changes in Ribb-Gumara Catchment Between 1985 and 1999.

Landuse/Landcover Type	1985 (Sq. Km)	1999 (Sq. Km)	Change between 1985 & 1999 (Sq. Km)	% Change
Plantation Forest	6.0	7.7	1.7	28.4
Agriculture	2757.4	2896.2	138.8	5.0
Shrub Land	164.6	125.6	-39.1	-23.7
Wood Land	175.7	128.3	-47.4	-27.0
Bare Land	6.4	6.2	-0.2	-3.4
Swamp	22.3	40.5	18.2	81.9
Grass Land	184.7	112.6	-72.0	-39.0
Total	3317.0	3317.0	0.0	0.0

The following Figure show the areal extent change (Fig. 39) and percentage change of the landuse/landcover of Ribb-Gumara Catchment.



(a) *(b)*

Figure 39: Landuse/Landcover Dynamics (area in Sq. Km) (a), (% Change) (b) between 1985 & 1999

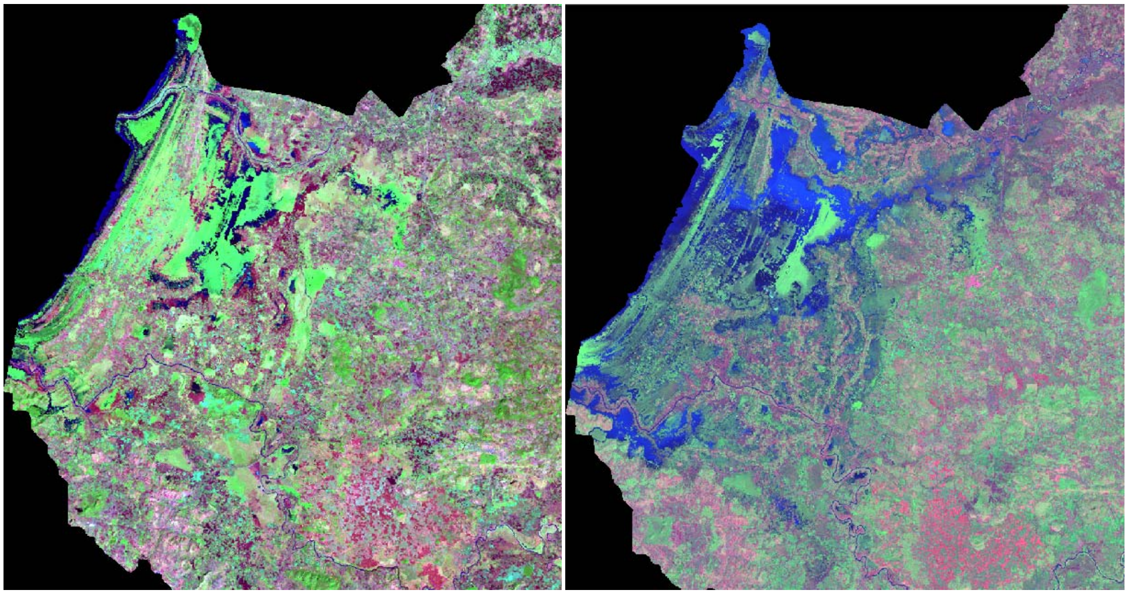


Figure 40: Expansion of swamps at the expense of other landuses/Landcovers
(October 23, 1985 Landsat TM Image (left) and November 9, 1999 Landsat ETM Image (right)

6.5 Landuse/Landcover Change and Flood Hazard/Flood Risk

The land covers (shrub land, wood land, grass land) of the upland sites and the flood plain area is decreased. Therefore, there is high soil erosion in the upstream and sediments and dissolved substances cumulatively called river load deposited in the river channels and on adjacent flood plains in down stream of the major rivers.

According to Shiferaw and Wondafrash, sediments deposited in Ribb and Gumara rivers have changed the rivers gradient, cross sectional area, average velocity of water flow and discharge of rivers. Therefore overflow of rivers occurred and flooded the local communities. The cross sectional area of Gumara and Rib rivers is decreasing from time to time as a result of sediment deposition. In some areas the depth of Rib River diminished from 35 meter to 11 meter. Deep rooted and tall grasses that had been grown along river banks have been buried by soil sediments, which are transported by rivers. Some agricultural land crops have been buried by the deposited sediments. Over all the river channels depth and width decreased and the water discharging capacity of the major rivers (Gumara and Rib) and their tributaries minimized in which it leads to overflow of water and flooding consecutively. All this indicates that the rate of erosion and soil loss in the upstream is high due to lack of abstraction flood water abstraction.

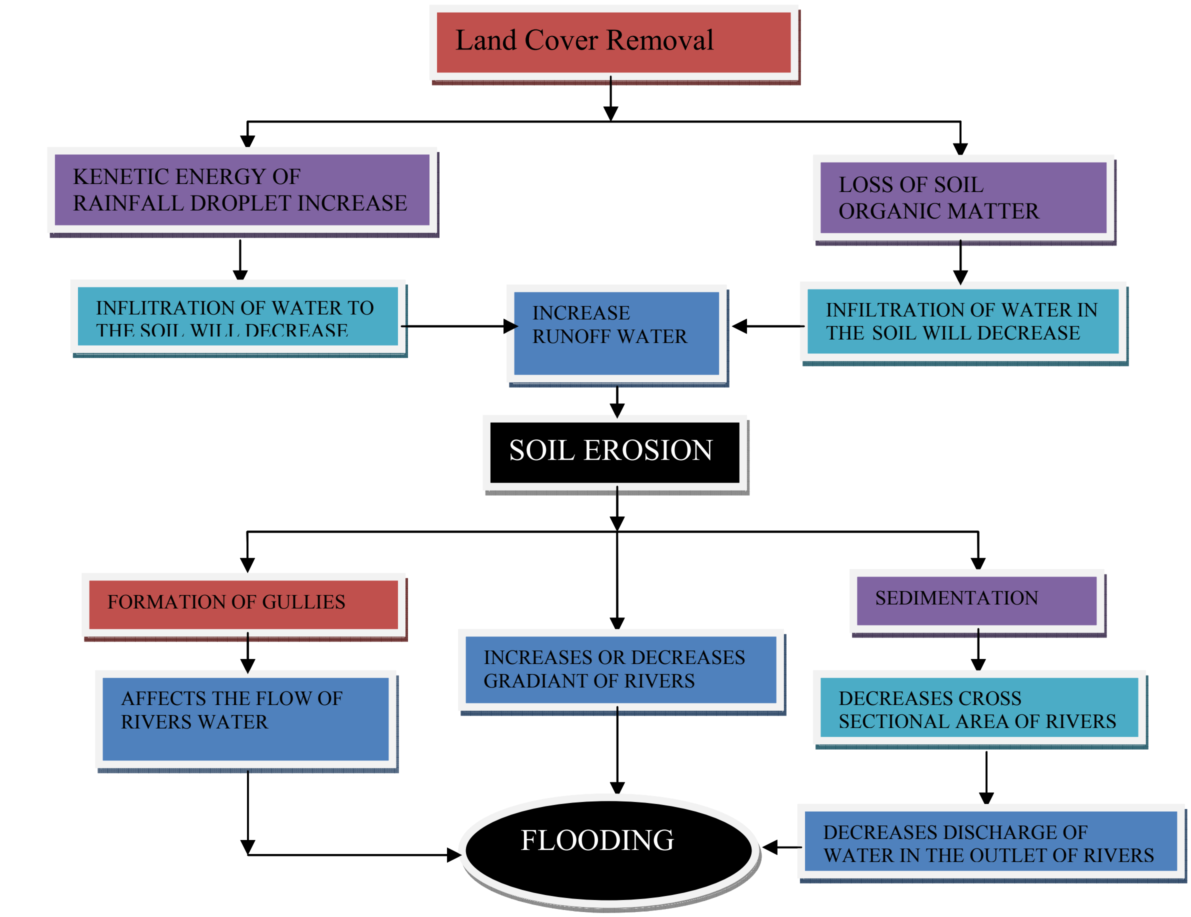


Figure 41: The Relation between Landuse/Landcover Removal and flooding

7. Conclusion and Recommendations

7.1 Conclusion

The basic idea of flood hazard and risk assessment and mapping as undertaken in this study is to regulate land use by flood plain zoning in order to restrict the damages. In the light of above discussion, it can be said that flood risk mapping, being an important non-structural flood management technique, will go long way in reducing flood damages in areas frequented by flood.

Pair wise comparison method of flood hazard map generation is a good approach to deduce a sound decision for a forthcoming flood disaster, provided the required data are standardized to a common scale in personal geodatabase. This study confirmed that the method used was capable to integrate all the flood hazard causative factors and the components of flood risk as well in a GIS environment. In this fashion, composite maps were generated to assess flood risk of Fogera Woreda.

One of the Multi Criteria Evaluation techniques known as Weighted Overlay in GIS environment was shown to be useful for delineating areas at different rating in terms of flood hazard and flood risk. Moreover, factor weight computation in Weight module, that is developed by providing a series of pair wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated, has generated valuable information. This could be useful for disaster studies in the future.

Therefore, it has been shown that MCE–GIS based model combination has potentiality to provide rational and non-biased approach in making decisions in disaster studies.

Satellite images were shown to be very important for Landuse/Landcover change studies with certain limitations like cloud cover and striping. The change statistics of landuse/landcover of Ribb-Gumara Catchment showed that clearance of landcover for agricultural expansion has been aggravating flood hazard in the downstream areas of Ribb and Gumara Rivers, Fogera Woreda.

Flood frequency analysis of peak hydrological data yielded the return periods of each major peak discharges and the magnitude and probability of occurrence of flood peaks of specified return periods so as to help preparedness to cope with such peaks. Flood frequency analysis combined with GIS was found very important to map the likely inundated areas of a given catchment. In this study, the likely inundated areas mapped using the 100 year return period base flood and DEM, and the flood hazard map obtained from the overlay analysis of flood causative factors in the study area soundly agree to each other. And therefore, the combination of the two results would be a step forward for flood management and mitigation strategies.

Although flooding is a natural phenomenon, we can not completely stop it; we can minimize its adverse effects by better planning.

The study has shown that automatic flood map delineation can be produced for big river system in short time with the support of GIS and Remote Sensing.

7.2 Recommendations

This investigation provides information on flood hazard at a catchment and Woreda level and flood risk at a Woreda level that could be used by the pertinent decision makers to act upon the current land use policy for reducing vulnerability to flood disaster in Fogera Woreda in particular and that of the Ribb-Gumara Catchment at large. Thus the responsible bodies of the Woreda as well as the Region should incorporate the flood hazard and flood risk assessment studies in their development strategies.

Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in the study area. Land use planning can play very important role to reduce the adverse effects of flooding. It is recommended to adopt an appropriate landuse planning in flood prone area. The ideal form of planning would be to evacuate the flood prone completely but practically it is not possible as to involve high costs and some social problems are associated. It is possible to change the functional characteristics of the flood plain areas. Now days, most flood prone areas in Fogera Woreda have been changed in to rice cultivation fields. Strengthening this practice and revilagizing the population in these areas to the safe ground would be better to reduce the frequently recurring flood risks. According to Cadwallader (1986) regulation not only reduce the incidence of and severity of flooding but also decrease long-term average flows downstream.

Disaster related research activities should be undertaken. Application of advance techniques in soil physics, geotechnical engineering, GIS and remote sensing for flood risk assessment and risk reduction are also needed. The priority research question should be what major factors contribute to flood hazard and also reducing the vulnerability of elements at risk in the known frequent flood prone areas.

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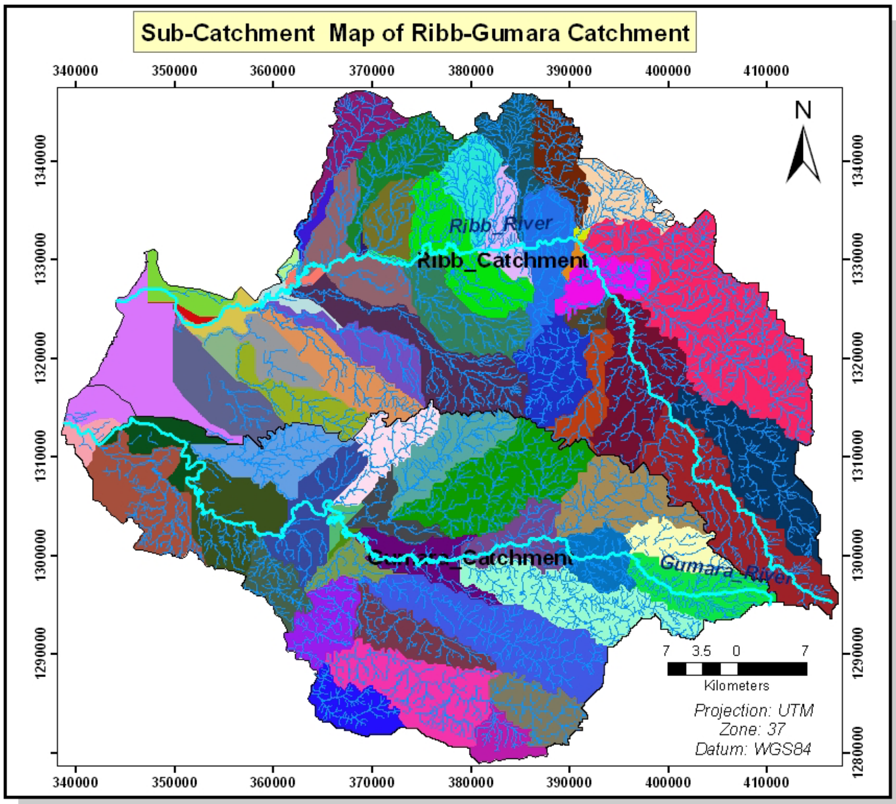
Annexes

Annex 1: Sub-Catchments in Ribb-Gumara Catchment



Annex 2: Annual Maximum Daily Gauge Level of Ribb and Gumara Rivers

	Ribb	Gumara
Year	**Peak (m)**	**Peak (m)**
1971	5.02	5.39
1972	7.03	5.41
1973	7.03	4.36
1974	6.79	5.67
1975	6.62	5.77
1976	6.63	7.06
1977	6.7	5.44
1978	6.42	5.5
1979	6.78	4.38
1980	6.51	4.52
1981	6.88	6.02
1982	6.25	4.91
1983	6.36	5.78
1984	6.37	4.94
1985	6.68	6.89
1986	7	6.98
1987	5.46	5.37
1988	6.43	7.32
1989	6.81	5.55
1990	6.76	6.41
1991	6.93	6.9
1992	7.5	6.75
1993	7	6.08
1994	7.1	6.15
1995	7.39	5.86
1996	7	7
1997	7.38	6.1
1998	7.02	6.4
1999	7.56	6.23
2000	7.72	6.84
2001	7.73	7
2002	7.6	6.56
2003	7.75	6.75
2004	7.76	6.22
2005	7.78	6.64

Source: MoWR

Annex 3: Annual Maximum Daily Rainfall (mm)

Year	**Stations**										
	Woreta	Amed Ber	Wanzaye	Dera Hamusit	Arb Gebeya	Mekane Eyesus	Gassay	Ibnat	Debre Tabor	Addis Zemen	Yifag
1951									53.4		
1952									53.6		
1953									51.4		
1954									44		
1955									70		
1956									44.5		
1957									75		
1958									58		
1959									47		
1960									52		
1961	37								67		
1962											
1963											
1964	40.3										
1965											
1966											
1967											
1968									58		
1969									62		
1970								36.2			
1971								56.4			
1972	37.5							41.8			
1973								38.4			
1974	81						36.4	44	54.5	38.4	
1975	71.4							67.5	70.9	104.5	
1976	34							49.7	63.8	89.2	

1977		66.1					38.9	31.2	56.7	72.8	
1978		62.6					43.8	51.2	42.5	48.8	
1979		41.2					38.8	68.4	54	38	
1980	72.4	45.8					50.8	46.9	45	69.2	
1981	49.8	65					45.6	41.3	48.8	70.3	
1982	76.1	61.7					23.9	48.9	55	42.7	
1983	112.5	53.7						44.5	55	75	
1984	43	32.2						42.7	62.1	70	
1985	61.5	65.6	83.6						66	45.3	
1986	46.4	43	80.7						58	43	
1987	50	76.2	53	69.2					42.3	45.3	
1988	108.2	78.3	94.9						19.8	53	
1989	114.8	67.3	51.4							70.5	
1990	70.2	12.4	94.8							59	
1991	64.6		38.4	106.9						24.3	
1992	65.8		48.7	81.8					35.5		
1993	62.4		83	162.4					45.1	46.5	
1994	68		91	106.7		44.8			69.9	83.5	
1995	48		79	54.4		57.9			57.4	39.5	
1996	72.3		57.5	99.5		84.8			44.6	48.2	
1997	35.9		54.7	10		45.2		43.1	49.9	42.5	
1998	55		57.7			47.6		37	67.7	32.4	
1999	64.5		54.8	74.9		49.4		56.6	55.5	42	
2000	51	61.5	66.6			46.8		34	47.3	46.5	
2001	73.5	99.8	47.9	83.4	65.2	39.5		50.9	62.7	27	
2002	100.6	43.5	60	68.7	73.7	51.8		49.5	81.3	53.2	
2003	108	59.1	60	71.1	50.4	37		31.3	33.8	73.3	
2004	100.2	53	59.7	30.8	43.6	45.2	40.6	34.2	24.8	48.4	50.9
2005	79	55.7			56.7	47.3	58.2	53.2	20	57	51.4
2006	73.7	53.8	134.2		6.8	79.6	60	43.7	56	50.8	41.3

Annex 4: Average Monthly Total Rainfall (mm)

- Woreta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980								225.5	155.9	52.3	19.8	0
1981	0	0	0	0	67.8	163.5	397.9	455.1	108.2	28.4	23.3	0
1982	0	0	5.5	33.7	18.3	147.6	395	428.2	117.3	80.6	0	0
1983	2.5	0	0	0	42.5	36.4	314.4	388.6	149.1	58.2	0.1	0
1984	0		4.1	1	126.7	159.5	276	238.3	145.6	0	0	14.7
1985	0	0	0.2	24.9	125.7			360.5	192.7	33.4	5.2	0
1986	0	0	7	9.6	8.9	219.7	347.6	357.7	158.6	26.6	0	0
1987	0	0	14	6.5	176.4		368.8	548.4	96.6	194.1	35.2	0
1988	0	11.7	0	0	41.4	164.1	728.2	339.9	315.9	125.3	5	0.5
1989	0	0	11.5	16	163.1	169.1	465.9	361.9	294.5	88.2	2.1	1.2
1990	1	0		5	25.4	106.2	333.7	354	233.8	3.4		
1991	0	0	0	99.5	149.7	492			295.2	41.7		
1992				67	29.2	241.8	641.2	820.7	234.6	90.1	26.4	
1993				4.9	67.8	43.2	257.2	479.9	99.8	9.9	0	0
1994	0	0	0	0	19.3	236.6	641.5	471.6	185.5	0	0	3.2
1995	0	0	0	0	89.3	178.9	357.1	282.9	119.9	0	16.1	18.1
1996	0	0	36.2	55	87.5	353.2	439.9	286.9				
1997	0	0	1.5	8.9	71.1		217.1	205.8	143.5	109.8	15.5	0
1998	0	0	0			119.5	589.8	417.3	237	57.2	0	0
1999	0	0	0	6.2		109.8	451.4	480.5	177.8	269.4	0	2.9
2000	0	0	2	81.1	109.8	122.2	453.5	373.5	121	156.4	24.1	0
2001	0	0.5	4	14.2	39.7	176.5	335.8	270.7	158.6	97.9	26.5	6.5
2002	0	0	0	18.7	22.8	309.1	327.3	335.4	115.2	13.5	0	0
2003	0	0	0	2.6	0	251.2	298.4	397.4	292.9	9.5	6.3	5.2
2004	1.3	5.9	6.7	37.5	3.2	163.1	382.1	410.2	132.5	55.6	29.5	0
2005					37.9		261.8	461.6	271.3	44.6	28.4	0
2006	0	4.8	0	3.7	195.7	118.9	388.7	503				
Average	**0.2**	**1.0**	**4.2**	**20.7**	**71.6**	**185.6**	**402.9**	**394.4**	**182.1**	**65.8**	**11.5**	**2.4**

- Amed Ber

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	0	0	23	0	77.1	583.6	1134.2	1191.3	971.7	458.2	0.6	54.8
1978	0	0	17.4	37.3	64.8	215	372.4	314.2	145.8	54.6	49.4	11.6
1979	0	0	0	13.3	97.2	178.4	356.2	369.1	146.7	73.3	0	0
1980	0	39	18.5	120.8	24	116.3	442.7	382.8	187.3	350.5	18.1	1
1981	15.5	0	0	25.8	58.9	140.8	469.1	487.5	165.5	71.4	25.6	0
1982	0	0	89.4	12	55.4	49.2	300	380.7		126.5	34	0
1983	0	0	0	2.2	81		302	428.9	109.1	79.7	26.4	0
1984	0	0	9.4		91.2	196.3	364.3		187.7		2	6.6
1985	1.3	0	2.7	22.1	174	215.2	413.9	351.2	133.2	34.8	36.7	0
1986	0	1.1	6.9	22.9	44	252.6	394.5	373.4	181.4	55.7	0	1.9
1987	0	0	17.6	64	260.7	134.3	293	279.2	69.7		0	0
1988	0		0	4.6	49.4	202.2	806.4	392.7	208.8	155.3	9	0
1989		3.5	34.9		145.9	71.6	269.1	412.2	157.4	136.2	16.7	32.6
2000					116.1	143.2	381.9	342.6	211.8	111.1	14.4	0
2001	0	0	8.8	15.2	30.5	378.1	443.5	329.1	80.1	92.8	33.2	4.2
2002	0	0	8.4	12.1	8.4	219.5	274.2	292.3	134.5		6.9	5.9
2003	0	8.9	5.7	26	3.9	245.7	405.2	490.2	234.2	10.6	7.3	2.3
2004	1	11.6	9	63.5	14.2	226.6	340.2	274.5	138.3	104.2	16.7	1.7
2005	0	0	18.6	6.2	41.1	211.4	352.1	400.2	249.1	44.2	12.4	0
2006	0	0	0	11.7	177.2	132.3	456.6	366.3				
Average	**1.0**	**3.6**	**14.2**	**27.0**	**80.8**	**205.9**	**428.6**	**413.6**	**206.2**	**122.4**	**16.3**	**6.5**

- Yifag

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978		0	12.1	3.2	12	155.1	224.1	300.4	21.3	31.3	5.3	0
1979	1.5	0	0	27.4	121.4	116.5	320.8	251.6	169.9	68.4	0	0
1980	0	11.5	5	44	44.7	117.2	363.9	425.1	188.7	14.9	1.6	2
1981	0	0	2.4	31.9	10.7	74.1	399.1	297.9	85.1	14.5	14.2	0
1982	3.3	0	46.9	21.6	21.9	81.6	183.3	203.4	89.3	75.6	0	
1983							254.4	330.9	119.4	104.1	6.2	0
1984	0	0	7.9	0	65	162.1	301.8	251.1	102.8	0	0	2.2
1985	0	0.8	4.7	10.7	93.2	85.4	327.1	295.1	112.9	29	9.1	4.8
1986	0	0.8	0	1.8	6.7	171.9	276.3	256	126.9	10.8	0	0
1987	6.2	0	3.7	6	175.9	86.1	205.3	257.8	138.9	55.6	0	0
1988	0	39.5	0	0	10.7	193.8	591.6	324.2	151.5		0	0
1989	0	5.6	5.2	17.7	41.9	163.9	259.1	360.7	132.9	78.5	16	0.8
1991		0	0				303.5	405.7	98.2	20.8	0	
1992	0	0	3	50.2	9.2	65	351.5	311	62.5	128.8	16.5	0
1993	0	1.4	30.3	9	72.9	114.3	266.7	259.5	209.7	68.9	0	0
1994	0	18.9	0	4.3	59.4	223.4	415.6	486.4	50.5	0.6	0.9	14
1995	0	0	11.8	16.2	34		193	335.8	49.2	14.6	0	9.1
1996	0	0	20.9	37.3	175.3	312.1	383.2	245.1	89.7	5.8	39.3	0
1997	0	0	5.6	15.5	106.5	110.6	154.4	171.4	103.3	55.8	13.4	9.8
1998	0	0	13.5	9.4	42.6	98.1	419.5	322.2	150.4	30.3	0	0
1999	17	0	0	2	8.4	113.3	396.9	340.5	86.5	185.3	0	0
2000	0	0	0	73.9	55.5	102	367.4	252.9	145.4	140.5	48	0
2001	0	0	0	7.1	81.6					21.6	4.4	0
2002	0.0	0.0	7.7	4.4	7.7	118.2	271.0	221.2	101.7	26.0	2.8	0.0
2003	0.0	9.6	13.8	3.3	6.2							
2004	0.0	5.0	0.0	54.5	7.3	115.4	341.9	247.9	118.6	20.3	28.1	0.0
2005	0.5	0	20.1	3.9	35.9	193.4	252.8	390.8	169.4		3.2	0
Average	**1.2**	**3.6**	**8.3**	**18.2**	**52.3**	**135.2**	**313.0**	**301.8**	**115.0**	**50.1**	**8.0**	**1.8**

- Arb Gebeya(Dera)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	11.5	18.1	47.3	53.4	60.3	16.1	359.6	259.5				
2000	0	0	1.3	35.3	3.4	17.7	349.6	205.2	72	83.8	0	5.7
2001	0.2	0.2	13.4	42.2	85.7	233.2	384.6	457.9	179.1	64.3	25.1	16.1
2002	0.9	0.9	47.3	61	18.9	247.5	246.9	348.7	162.7	88.5	3.3	1.2
2003	0	19	15.5	25.2	8.9	130.4	343.1	471.2	250.4	37.8	11.8	12.6
2004	0	27.7	6.6	56.1	12.6	184.3	466.1	287.3	188.8	111.5	22.3	0.4
2005	0	0	11.3	13.1	20.5	143.5	334.5	186.3	97.5	25.3	4.1	0.5
Average	**1.8**	**9.4**	**20.4**	**40.9**	**30.0**	**139.0**	**354.9**	**316.6**	**158.4**	**68.5**	**11.1**	**6.1**

- Gassay

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1974	31.9	79.4	119.8	37.2	46.1	67.9	212	336.8	157.2	129.1	2.3	32.4
1977	0	1.8	29.1	0	94.1	158.8	338.5	372.8	159.2	229.1	0	31.5
1978	11.6	0	47.9	37.3	40.5	165.5	474.4	319.7	93.6	27	73.7	30
1979	20.4	13.5	11.7	45.8	207.8	221.5	423.3	287.7	161.4	71.8	0	0
1980	0	41.2	63.6	147.2	88.7	162	395.9	337.5	77.5	47.3	36.6	5.5
1981	10.8	11.4	13	70.6	61	73.3	420	250.6	156.4	30.8	13.3	19.6
2004						131.2	308.9	232.4	105.3	43.1		6.5
2005	3.8	0		11	46	173.8	431.3		137.1	26.3		2.1
2006	0	2.6	16.1	43.1	129.2	116.1	370	494.3				
Avarage	**9.8**	**18.7**	**43.0**	**49.0**	**89.2**	**141.1**	**374.9**	**329.0**	**135.8**	**135.2**	**129.0**	**120.5**

- Ibnat

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	0	0	21.1	0	76.9	111.2	167.4	133.6	22.4	64	0	14.4
1978	3.4	0	33.2	25.7	14.3	107.6	288.9	260.3	79.8	24.3	30.6	0
1979	14.6	0	0	9.5	102.9	90.6	331.7	340.3	126.9	56.8	0	0
1980	0	10.3	13.3	30.1	16.7	59.8	357.9	260	131.9	22.1	18.1	21
1981	4.7	0	1.5	48.5	59.1	59.1	304.1	309.1	82	60.2	18.6	0
1982	2.3	0	41	7.7	72.1	53.1	150.2	275.8	78.3	117.4	70.3	0
1983	0	0	0	11.9	44.4	56.8	254.7	324.7	38	22.1	16.1	0
1984	0	0	12.5	0	96	207	173.7	63.3	0	0		
1997				33.3	168.4	146	276.9	223.7	47.7	149.6	34.1	1.1
1998	1.7	0	12.2	1.1	137.6	134.6	360		126.7			
1999	39	0	0	10.1		47.7	409.2	393.5	168.6	162.3	0	
2000	0	0	0.9	0	39.3	87.4	290.2	261	26.5	101.1	60	0
2001	0	0	14.1	16	47.9	246	505.9	384.7	64.8	18.7	0	
2002	0		29.9	11.3	10.1	134	204.4	183.5	110	0	0	9.1
2003	0	22	20.9	17	3.8	112.6	261.5	272.5	79.6	0	11.1	0
2004	0	39.8	26.7	31	0		247.8	187.5	55.3	22.5	3.4	0
2005	6.4	0	43.3		13.5	191.2	229.4	186.6	99.4	1	0	0
2006		0	0					330.6				
Average	**4.5**	**4.5**	**15.9**	**15.8**	**56.4**	**115.3**	**283.2**	**258.3**	**78.7**	**51.4**	**17.5**	**3.5**

- Mekane Yesus

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0	32.9	0	0	11.8	133.7			232.4			
1989						182.1	356.6	295.2	218.4	18.2	30	2.3
1990	20.3	12.5	83.9		124.2	183.9	511.5	345.2	257.5	19.6	32	5.4
1991	0.3		63.6	32.6	99.9		363.3	326.7	129.2	102.5	100.5	5.6
1992	2.9	0	35.1	16.9	75.3	265	301.1	262.5	249.2	100	1.2	0
1994							356.6	295.3	219	18.2	30	2.3
1995	0	0	26.1	68.8	102.4		296.5	222.9	133	0.2	7.2	24.2
1996	20.3	12.5	83.9	79.8	124.5	183.9	511.5	345.2	257.5	19.6	32	5.4
1997	0.3	0	79.6	32.6	99.9		363.3	351.6	129.2	102.5	100.2	5.6
1998	2.9	0	35.1	16.9	75.3	265	301.1	262.5	249.2	100	1.2	0
1999	24.3	0	0	72.2	24.4	125.8	365	349.5	184.6	193.5	7.9	30.8
2000	0	0	26.9	67.4	40.2	183.3	426.7	279.2	143.1	145.2	73	27.7
2001	0	4.7	52.2	79.3	58.8	260.5	377	401.9	64.9	73.6	0	12.1
2002	3.8	1.2	52.1	34.5	5.8	191.1	344.3	362.8	207.1	14.6	3.2	3.6
2003	0	16.5	76.8	6.3	10.7	168.6	379.2	316.4	237.2	16.5	3.7	20.7
2004	5.2	8.3	11.2	57.7	23.2	132.2	415.1	194.2	103.1	44.7	22.3	2.4
2005	3.9		56.6	12.9	35.8	115.8	330.2	257.1		39.8		0
2006	0	2.9	16.5	42.2	125.1	257.4	310.8	277.2				
Average	**5.3**	**6.5**	**43.7**	**41.3**	**64.8**	**189.2**	**371.2**	**302.7**	**188.4**	**63.0**	**29.6**	**9.3**

- Addis Zemen

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	0	0	14	0	94.6	352.4	913.5	568.8	187.4	274.3	92	45.4
1978	5.7	1.3	0	41.6	43.6		253.2	383.6	393.2	42.9	12.4	0
1979	13.9	0	0	4.2	64.8	130.3	320.3	201.3	132.1	75.1	0	0
1980	0	6.3	0	65.7	79.6	208.5	581	440.6	237.2	31.8	12.5	6.7
1981	4.6	0	23.3	71.4	46.9	156.9	441.9	396.1		17	15.3	0
1982	0	0	1.5	12	26.7	55.3	240.6	328.5	164.8	62.1		
1983		0	0	0	79.3	146.9	406.8	373.7	86.2	62.3	3	0
1984	0	0	0	9.2	125.5	206.9	337.1	330.7	170.4	0	0	16.5
1985	0	9	0	25.6	96	137.1	535.8	415.9	83.6	17.2	2.2	0
1986	0	0	5.2	3.2	0	207.5	256.5	410	194.2	0	0	0
1987	0	0	0	4.3	97.6	162.8	355.4	328.4	75.4	21.3	0	0
1988	0	37.3	0	0	7	193.6	675.2	324.4	158.9		6	0.5
1989	0	0	2.2	17.4	52.3	189.5	445.9	260.4	134	96.1	5	9
1990	0	0	0	17.5	0	60	539	439.2	342.4	108.3	0	0
1991	0	0	2.4	24.2	16.3	81.5						
1993				25.2	66.4	160.2	335.2	376	243	48.5	6.9	0
1994	0	0	0	16.3	46.3	292.1	383.5	357.3	134.7	0	4.6	4.1
1995	0	3.4	17.2	0	91.3	91.4	292.7	312.4	58.6	2.3		2.3
1996	0	0	14.8	21.7	82.4	421.1	219.5	262.3	106.4	12.6	23	0
1997	0	0	4.7	26.2	97	118.3	337.1	49.4	33.7	56.9	5	0
1998	0	0	0	11.1	32.4	106.8	325.5	187	19.9	1.2	0	0
1999								349.1	162.1	107	0	0
2000	0	0	0	71.8	19.8	166.1	598.7	512.2	150.2	51.7	24	0
2001	0	0	0	15.6	71.2	200.3	147.4	212.2	36.2	14	0	0
2002					13	270.3	424.4	459.3	150.9	2	0	
2003						182.2	461.3	338.5	183.9	7.9	0	0
2004	0	7.5	0	50.5	20	121.5	421.9	315.8	135.6	47.2	44.6	0
2005	0	0	50	50	36.9		391.6	319.3	243.7	5	2	0
2006	0	0	2.4	2.5	113.7	221.3	513.2	321				
Average	**1.0**	**2.6**	**5.5**	**22.6**	**56.3**	**116.3**	**413.1**	**341.9**	**154.6**	**44.8**	**10.3**	**3.4**

- Debre Tabor

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988				31.9	69.8	155.5	592.1	462.5	182.3	84.9	7.5	5.5
1989	6.2		84.4	45.8	94.8	84.7	304.5	425.5	139.3	103.6	12.4	
1992	0.5	0	12.8	98.8	38.6	115.9	330.5	365.5	124.6		60.5	5.9
1993	0.8	2	86.3	79.8	199	136.5	429.8	289.9	208.8	118.6	23.3	1.1
1994	1.8	9.1	0	17	89.7	237.7	496.2	628.5	248	10	24.8	31.7
1995	0	0	22.7	34.6	100.4	73	399.7	403.6	184.9	5	23.4	
1996	4.3	1.2	49.4	92.1	146.1	197	349.4	374	155.4	30.6	76.2	4.4
1997	3.4	0	73.7	43.1	197.6	215.1	449.7	419	197	305	12.3	82.5
1998	13.6	0		6.9	203.6	126.2	400.6	410.8	244.8	75.9	0.5	0
1999	34.5		0	12.1	41.2	181.4	476.5	345.7	244.8	250.6	11.2	19.5
2000		0.3	6.3	118.3	61.1	168.1	423.6	462.4	232.3	137.9	34.8	0.5
2001	0	1.3	17.2	24	95.4	191.2	489.7	410	184.8	45.6	4.5	7.2
2002	0.4	1	60.2	45.1	47.2	203.3	256.6	313.4		2.9	16.9	18.8
2003	0	13.9		28.1	10.4	86.2	435.7	396.8		16.7	33.3	14.8
2004	0.5	37.6	33.7	75.5	19.1	141	333.7	295.2	120.8	85.8	42.5	12.7
2005				10.3	56.3	224.4	473.6	436	216.2	5		
Average	**5.1**	**5.5**	**37.2**	**47.7**	**91.9**	**158.6**	**415.1**	**402.4**	**191.7**	**85.2**	**25.6**	**15.7**

- Dera Hamusit

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	0	0	0	0	140.3	460.3	630	550.8				40
1987										9.1	2.8	0
1988	0	8.7	0	0	75.8	14.6	792.6	463.2	249.7	228.2	15	0
1989	0	0	9.1	0		128	494	449.7	195.3	114.3	4.1	0
1992		0	0	27.6	51.6	182.4	426.3	570.8	140.6	194.8	42.8	2.5
1993	0	0	26.6	27.4	56	244.9	390.7	356.5	384.9	70.5	0	4.5
1994	0	5.2	0	16.2	119.8	316.1	591.8	620.9	251.8	36.9	14.5	21.3
1995	0	0	42.2	23.9	90.1	160.3	636.9	266	119.9	14.8	27.3	13.7
1996	0	2.3	47	65.3	158.9	386.7	409.9	363.8	210.1	25.7	18.8	0
1997	0	0	14.6	22.8	144.7		344.5	263.2	217.2	248.4	16.6	0
2001	0	0	0	34.3	52.7	149.5	478.4	510.9	160.3	84.4	0	4.1
2002	0	0	6.4	23.1	6.5			440.3	170.1	35.5	0	0
2003	0	0	3.2	0	12.7	229.1	490.7	388.4	314.1	21.9	15.1	6.1
2004	0.1	3.6	5.3	11.3	8.9	150.3	454.7	279.6	216.7	127.3	22.8	0
2005				42.7	8.7	138.8			282.6			
Average	**0.0**	**1.5**	**11.9**	**21.0**	**71.3**	**213.4**	**511.7**	**424.9**	**224.1**	**93.2**	**13.8**	**6.6**

Wanzaye

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985									360.7	51.3	0	0
1986	0	0	1.1	0	4.1	216.4	586.1	294.8	193.8	111.4	0	0
1987	0	0	20.4	21.1	215.8	165.6	400.6	368.9	192.1	121.2		0
1988	0	12.9	0	0	88.5	208.8	691.7	266.7	235	129.2	13.7	4.2
1989	0	0	16	9.2	110.7	170.9	395.5	418	257.4	113.3	4.5	
1990		0	0	0	27.2	65.8	340.6	523.2	295	7.8	0	
1991	0								256.5	36.7	0	
1992			0	58	15.6	164.2	194.1	477.6	210.1	161.7	11.9	0
1993	0	0	1	14.6			425.1	404.9	437.7	62.3	18.4	0
1994	0	0	7.7	6.6	70	332.8	329.3	423.5	222.3	21.8	0	0
1995	0	0	37.9	51.9	68.7	141.1	458.8	381.3	164.9	0	18.5	12.2
1996	0	0	42.6	97.4	96.4	315.7	375	404.3	207.3	7.9	42.8	0
1997	0	0	1.8	15.2	197	222.2	259	201.1	180.2	101.7	33.1	0
1998	9.2	0	1.4	2.3	99	226.6	408.6	496.6	283.2	103	0	0
1999	5.9	0	0	0	23	217.9	437.9	495.9	238.4		0	0
2000	0	0	0	76.5	45.6	218.9	551.2	393.3	202	171.7	5.6	
2001	0	0	0	7	75.8	142.6	719.2	260.9	150.4	33	0	
2002	0	0	0	29.2	0	194.1		460.6	210.3	6	48.8	0
2003	0	0	0	0	2.2	214.8	402.9	347.8	346.5	0	1.2	0
2004	0	0	0	24.5	0	117.9	378.8	262.4	211.1	87.2	9.8	0
2006	2.9	0.3	2.1	99			413.1	599.4				
Average	**1.0**	**0.7**	**6.9**	**27.0**	**67.0**	**196.3**	**431.5**	**393.7**	**242.7**	**69.9**	**11.0**	**1.1**

Annex 5: Average Monthly Maximum Temperature (^{0}C)

- WoretaT^{o} (Max)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	28						23.2	23.3	24.8	26.3		
1983	27.6		29.3	29.6	28.3	23.8	24	22.8	24	26.6		
1984	27.9	29.2	29.4	29.8	29.4	27.2	25	23.2	24.7	25.7	26.9	27.2
1985	28.8	27.7	30.2	31.4	30.7	27.1	24.1	23.4	24.6	26	27.4	27.3
1986	28.9	29.4	31.1	32.3	29.4	28.2	23.5	23.2	25.2	28.7	27.7	28.5
1987	29.1	28.6	31.1	30.3	28.7	25.8	23.4	23.2	24.8	26.2	27.6	27.8
1988	28.7	29.3	30.8	29.6	30.9	26.7	25.5	24.9	23.8	26.5	29	28.6
1989	29.3	30.5	30.6	31.4	27.4	26.3	23	22.4	26.8	30	28	28.4
1990	30.4	30	32.4	32.1	30.4	27.1	24.9	23.1	24.4	26.8	28.1	28.3
1991	29.8	29.5	30.2	30.2	29.6	27.1	25.7	20.2	25	29.7	30.4	31.2
1992	30.9	30.6	31	30.7	31	26.9	25	25.3	19.8	20.3	28.6	29.9
1993	31.9	32.6	31.5	31.2	26.3	25.4	26.7	25.8	26.9	27	31.4	30
1994	27.9	27.5	28	27.5	26.3	25.8	25.4	25.7	26.4	27.2	27.2	27.6
1995	27.8	28.1	28.2	28	27.8	27.1	25.3	25.4	26.2	27.1	27.9	27.6
1996	27.5	28	27.7	28.2	28	26.6	25.7	26.6	26.2	27.5	26.8	27
1997	27.9	28.2	29	27.9	28.5	27.4	26	25.9	27.5	26.5	26.6	26
1998	27	28.6	29	28.5	27.4	25.8	25	25.5	26.6	26.3	27.1	27.8
1999	28.9	29.4	30.9	28.6	27.9	29	24.4	24.6	26.5	27.8	29	29.3
2000	29.3	32.5	32.8	33.1	29.8	28.7	25.5	24.6	25.6	26.2	28.2	28.5
2001	29.7	30.9	32.1	29.1	31.1	27.1	25	24.5	25.5	26.2	27.3	28.4
2002	29	30.1	30.8	33.3	32.5	27	25.9	24.9	27.1	28.1	29.1	29.3
2003	29.4	31.2	31.6	33.8	32.9	28.3	24.6	24.2	25.5	28.1	28.9	28.3
2004	28.7	30.5	31.8	31.6	32	27.8	24.3	24.1	24.9	27.4	29	28.7
2005	28.5	29.8	30.7	30.3	29.6	27.8	23.5	24.5	25.1	27.1	28.1	28.3
2006	28.9	30.3	30.5	30.8	28.8	25.7	24.8	24.1	25.2	26.6	28.2	28.4
Average	**28.9**	**29.7**	**30.4**	**30.4**	**29.4**	**26.9**	**24.8**	**24.2**	**25.3**	**26.9**	**28.2**	**28.4**

- Amed Ber

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979		26.8	26.9		25.7	25.3	21.8	23.1	24.5	23.7	25.1	25.5
1980	26	26.9	28.1	25.5	27.8	25.6	23.1	22.4	23.2	25.3	26.7	26.7
1981	24.6	26.9	32.6	28.9	26.6	24.6	22.5	22.7	24	25.5	25.4	25.7
1982	26.9	25.5	25.6	36.5	25.6	27.2	22.8	22.5	24.2	25.3	26.2	27
1983	25.7	28.5	28	25.9	28.3	26.9	23.8	23	23.7	26.1	26.7	27.2
1984	27.1	27.9	29.3	29.2	28.5	27.6	24.7	22.1	24.7	25.7	25.6	25.4
1985	27.7	28.2	29.6	29.1	29.3	23.9	22.7	22.8	24.2	25.5	26.4	26.8
1986	26.5	29.4	29.8	30.1	28.2	25.9	24.1	23.3	23.9	27.6	28.2	27.3
1987	27.4	27.4	30.1	29	27.6	25.4	22.8	22.4	23.8	26.4	27.1	26.8
1988	28.2	28.5	30.3	29	30.4	25.4	24.8	23.5	23.6	26	27.6	27.4
1989	27.5	29.1	29.4	29.9	26.5	26.3	21.7	21.9	26	27.1	27.8	27.9
1990	27.5	27.7	31.2	30.9	29.7	25	22.8	22.7	23.7	24.9	26.1	26.9
2000	28.6	27.9	28.9	30.2	29.2	28.1	25.2	24.8	23.3	24.3	26.5	25.7
2001	27.1	29.6	29.5	30.7	29.2	25.5	23.4	23.8	25.6	25.4	26	27.3
2002	27.8	30.1	30.9	31.9	31	26.9	25	24.1	25.6	27	26.9	27.4
2003	28.5	30.2	30.9	31.3	31.8	27.2	23.5	24	25.9	27.5	28.3	27.7
2004	28.6	29.3	30.6	29.1	30.6	26.7	23.9	23.9	25.3	27.2	28.2	28.3
2005	27.8	31.3	31.1	30.8	30.5	28.6	23.9	24.7	25.2	26.2	27.2	28.2
Average	**27.4**	**28.5**	**29.7**	**29.9**	**28.7**	**26.2**	**23.5**	**23.2**	**24.5**	**26.0**	**26.8**	**27.0**

Annex 6: Average Monthly Minimum Temperature (^{0}C)

- Woreta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982							12.5	12.5	11.2	9.6		
1983			11.8	12	12.9		12.8	12	11.9	10.4		10.8
1984	9.2	10.4	12.2	11	12.5		12.5	12.8	11	10.3	11	6.2
1985	8.4	9.1	11.3	12.1	12.6	13.2	12.4	11.7	12.7	11.7	9.2	5.7
1986	28.8	9.5	12	13.7	13.3	13.1	12.2	12.5	11.6	7.5	8.6	6.7
1987	6.1	9.2	13.2	12	13.1	13.3	13.7	13.5	12.1	13.3	7.6	5
1988	7.9	9.3	13.6	14	15.8	13.4	8.7	8.2	13	11.8	7.9	9.9
1989	7.5	11	13	11	10.5	15.4	8.3	8.6	7.3	7.4	8.2	9.2
1990	8.5	11.8	12.1	11.7	9.1	9.3	5.5	5.1	7.9	6.8	9.6	8.3
1991	6.7	10	7.6	6.7	6.8	6.6	7.1	5.7	4.9	4.6	9.3	7.5
1992	4.8	5.8	7.7	9.7	10.1	9	12.5	12.4	6.4	6.2	6.9	8.2
1993	6.2	6.4	13.2	13.9	14.6	13.9	12	11.9	14.3	14.5	5	5
1994	12.1	14	12.6	15.2	15.1	14.3	13.1	12.6	12.9	12.9	12.5	13
1995	11.6	12.2	12.6	13	13.6	12.2	10.9	11.5	12.3	12.3	12.2	11.5
1996	12.4	12.6	12.3	12.6	12.3	11.1	12.7	12.7	12.1	12.4	11.8	11.5
1997	12	12.4	12.8	12.4	12.8	11.9	11.3	11.4	12.4	12.1	12.1	11.9
1998	12.4	12.5	12.2	12.6	12.2	12.6	10.3	10.1	11.3	11	11	11.6
1999	12.6	12.8	11.3	12.3	12.1	12.3	10.6	10.6	10.2	9.7	6.3	5.1
2000	6.5	7.1	8.2	11.2	14.1	10.9	13.7	13.5	10	10	6.4	6.9
2001	6.5	8.3	6.1	11.5	10.6	14.1	5.8	10.8	13	12.7	11	8
2002	6.7	9.7	11.3	10.5	14.6	7.9	14.5	14.2	11.8	11.5	8.8	8.4
2003	9.6	11.3	13.5	14.6	17.1	15.3	14.6	14.5	13.1	11.9	11.4	10.3
2004	9.8	12.2	15.6	15.6	14.6	15.4	13.8	14.3	13.2	12	10.7	9
2005	9.9	10.6	12.7	14.8	14.9	15.1	14.3	14.4	13.8	11.1	10.7	9.9
2006	9.5	11.9	13.8	14.9	15.2	14.8	14.2	14.4	13.7	12.8	10.1	7.4
Average	**9.8**	**10.4**	**11.8**	**12.5**	**12.9**	**12.5**	**11.6**	**11.7**	**11.4**	**10.7**	**9.5**	**8.6**

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Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979					11.7	14.6	13	12.9	12.5	12.3	13	12.4
1980	12.3	13.3	13.2	12.7	15.3	13.9	12.8	12.9	12.1	13.2	12.6	11.9
1981	13.1	12.7	14	16.1	14.8	11.6	12.9	12.8	12.8	13	12.5	12.4
1982	12.4	13.2	14.6	14.9	12.1	14.3	12.9	12.9	12.8	13.1	10.6	10.1
1983	12.3	11.7	13.4	12.9	14.8	17.4	16.7	12.3	12.3	11	10.6	9.6
1984	11.4	11.5	14.1	14	17.9	14.2	13.8	16.3	16.1	13.7	14.1	12.9
1985	11.2	13.2	15.3	16.3	15.9	13.3	12.3	13.2	12.8	11.7	10.6	9.4
1986	11.8	11.8	14.8	15.6	14.4	13.8	12.2	11.8	11.8	10.3	10.9	10.9
1987	10.1	14.2	17.6	14.5	14.1	13.7	12.6	12.2	11.6	10.9	11.4	10.6
1988	11.3	11.8	13.8	13.3	14.8	11.8	11.5	11.1	11.8	11.6	10.7	10
1989	9.5	11.2	12.6	13.4	13.3	13.1	11.9	11.8	11.1	12	10	10.1
1990	10.1	9.6	13.3	14.1	13.8	13.6	12.4	12.5	11.6	10.6	8.5	7.7
2000	10.4	10	10.1	9.5	9	8.2	6.9	6.4	12.5	11.8	11.4	12.3
2001	6.8	9.1	9.9	9.8	9.6	7.7	7.3	7.3	6.7	6.7	5.6	5.8
2002	7.3	9	10.5	10.8	11.5	10	9.6	8.8	6.5	7.7	7.1	7.3
2003	7.6	14.3	15.7	16.2	17.2	13.8	14	13.7	8.3	8.4	8.4	7.5
2004	12.2	12.6	14.4	15.3	15.1	14.5	13.2	13.7	13.1	12.3	12.1	11.5
2005	11.5	14.6	10.9	12.1	11	10.4	9.9	9.9	13.4	12.2	12.4	12.2
2006	8	9.4	9.9	10.7	10.4	10	9.5	9.6	9.4	8.6	7.4	6.2
Average	**10.5**	**11.8**	**13.2**	**13.5**	**13.5**	**12.6**	**11.9**	**11.7**	**11.5**	**11.1**	**10.5**	**10.0**