FLOOD HAZARD, VULNERABILITY AND RISK ASSESSMENTS:ITANG AREA OF GAMBELLA

Thesis submitted for Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Remote Sensing and Geographical Information Systems (GIS) of Addis Ababa University, Addis Ababa, Ethiopia.

By

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JULY 2007

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List of Acronyms

AHP	Analytical Hierarchy Process
CSA	Canadian Standard Association
DPPA	Disaster Prevention and Preparedness Agency
DPP	Disaster Prevention and Preparedness
DEM	Digital Elevation Model
ETM	Ethiopian Map Authority
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
MCE	Melti-Criteria Evaluation
MCDM	Melti-Criteria Decision Making
MCDA	Melti-Criteria Decision Analysis
MWR	Ministry of Water Resources
NMA	National Meteorological Agency
OFDA	Office of Foreign Disaster Assistance (USA)
RADASAT	Radar satellite
SAR	Synthetic Aperture Radar
UNDRO	United Nations Disaster and Relief Organization
WMO	World Meteorological Organization

ABSTRACT

The town of Itang is located in the lower part of the Baro-Akobo basin. The geographical position and the topographical composition have made the area vulnerable to flooding. The heavy rainfall of the area and the high discharges of Baro River, with the source from high lands, are determining factors for the occurrences of flooding in the area. The uncontrolled populating to flood plain area and the river channel characteristics also contribute for the severity of the flooding. The geomorphologic units, land use/ land cover, the digital elevation models (DEM) and the frequency analysis of hydrologic data for the study area are utilized as inputs for this study in order to deal with the nature and characteristics of the Baro river flooding. The floodwater depths and the flooding extents of different return periods on the basis of hydrologic data and actual flood event of 1988 have been analyzed. GIS provides the broad rang of tools for determining areas affected by floods and for predicting areas that are likely to be flooded due to high water level. This method also helps to assess vulnerability of different elements in addition to flood hazard zonation maps. This involves a combination of flood scenarios of different return periods, elements at risk and DEM of the area through the application of vulnerability functions. The function relates the floodwater depth and the degree of loss or damage to each elements or group of elements on the basis of flooding extents. Based on vulnerabilities, probabilities and degree of damage, methods for risk assessments for the three return periods have been developed. And finally, recommendations were forwarded in order to reduce the damages and losses that would arise from flooding.

CHAPTER ONE
INTRODUCTION

1.8 Background

Floods are the most common of all environmental hazards. Every year, floods claim over 20,000 lives and adversely affect around 75 million of people worldwide. The relation lies in the wide spread geographical distributions of river flood plains and low-lying coasts, together with their long –standing attractions for human settlements (Smith, 2001). Floods are recurring phenomena, which form a necessary and enduring feature of all river basin and low land coastal system. Major floods are the largest causes of disaster related deaths, mainly in less developed countries. Despite recent advances in the understanding of the relevant climatologically, fluvial and marine mechanisms and a greater investment in flood reduction mechanisms, floods take a large number of lives and damage more properties each year, mainly because of unwise land management practices and growing human vulnerability (Smith and Ward, 1998)

Historically, flood plains have been a preferred place for human settlements and socio-economic development because of their proximity to rivers, guarantying rich soils, abundant water supplies and means of transport, and because floods replenish wetlands, recharge ground water and support fishers and agricultural systems.

At the same time, flood hazards produce the most sever impacts on the economy and people's safety. There is clear evidence that economic losses caused by flooding are increasing at the global level. This in part is a reflection of sharp population increases, expanding economic growth and development, greater investment in infrastructure, inadequate understanding of flood risks and a largely top –down approach to decision-making (WMO, 2006)

Floods are natural phenomena. However, flood disasters are the results of interaction between the natural phenomena with the environment, social and economic processes. For these conditions, an integrated approach to flood assessment that requires an understanding of social and physical vulnerability to flood hazards as well as knowledge of geomorphic and hydrologic characteristics of flood risks and how the society perceives them is better to be employed (WMO, 2006).

Flood is the most devastating natural phenomenon that affects and disrupts the well being of a society. Among natural phenomena flood causes maximum damage to lives and properties as it covers wider areas in comparison to others. Table-1.1 gives the losses and damages caused by floods around the world.

Table- 1.1 percentage of all recorded flood disaster and associated flood impacts 1964-96 by continental area (excluding USA)

Area	Event	Killed	Affected	Homeless	Damage
Africa	16.0	4.5	1.0	5.1	1.9
Asia	41.1	82.2	95.3	85.1	65.6
C.America	7.1	1.7	0.1	0.5	1.3
Caribbean	3.2	1.2	0.3	0.2	0.2
Europe	8.7	2.1	0.6	0.5	20.1
Near East	4.1	1.5	0.2	1.0	0.7
Pacific	1.2	0.1	0.0	0.0	0.2
S.America	18.6	6.7	2.5	7.6	10.0
Total	100.0	100.0	100.0	100.0	100.0

Source: OFEDA (1996): in Smith and Ward, 1998

In Ethiopia flooding is relatively common during rainy seasons between June and September especially in areas adjacent to main rivers of the country. For instance, in early May 2003, heavy rains led to flooding across southern Ethiopia that displaced tens of thousands of people. After a two-day deluge on April 23 and 24, 2005, Shebele River swelled in an angry froth of floodwater that swept away as many as 35 villages in the Somali region of southeastern Ethiopia. More than 40 died and many more remain missing (United Nations Office for the Coordination of Humanitarian Affairs).

In addition to this, the August 2006 flooding, unusually intense and extensive occurred in different parts of the country resulted in the following damages and loss as reported to DPPA.

- Dire Dawa: 10,400 people affected, 10,000 vulnerable and 256 dead;
- SNNPR: 44,000 people affected, 106,300 vulnerable and 368 dead
- Gambella region: 26,100 people affected 62,000 vulnerable and 2 dead out of this, 9200 people were affected in Itang area. The big rivers like Baro. Gillo, Akobo, Alwero and others that flow through the region are often the main causes of inundation especially during rainy seasons.

Therefore, this study is an attempt to contribute to the better understanding of the pattern of floods in the Gambella region particularly in Itang area in regard to terrain attributes, land use/land cover and topographic characteristics and relate them with the local knowledge and results of different hydrological approaches.

1.2 Statement of the problem

Knowing the fact that floods are part of Itang, the study area, for residents' life and that this natural phenomena cannot be fully controlled, it is important to focus and improve knowledge about the prevention. In order to achieve these issues it is crucial that more specific and scientific method should be developed to a better understanding of the flooding phenomena and their related geographical, hydrological, meteorological and geomorphologic causes. The recent, 2006 extreme flood event occurred unusually at different locations of the country including Gambella highlighted once more this necessity.

1.3 Significance of the study

This study is primarily aimed at flood disaster experts, its purpose being to enable them to understand the full range of flood issues related to its causes and consequences. At the same time it provides useful information for policy makers, researchers, civil society, and national, state and local government officials responsible for disaster management to help them understand the physical and socio-economic interrelationships while dealing with flood nature and characteristics so as to reduce the consequences.

1.4 OBJECTIVES

1.4.1 General objectives

The main objective of the study is to map flood hazard zones and assess vulnerabilities of different land use classes besides evaluating the risk to different elements that are likely to damage or loss

1.4.2 Specific objects include

- ✓ Identifying the factors contributing to flooding and prepare flood hazard zone map of the study area
- ✓ To outline inundation areas for different return period floods
- ✓ To assess vulnerabilities of different elements at risk
- ✓ To estimate the potential impacts of a flood if it occurs and evaluate damages to elements at risk so as to assess the risk

1.5 AVAILABLE DATA, MATERIALS AND METHODS

1.5.1 Data and Materials

Table-1.2 gives different data types and materials for the research

Data/materials	Data sources	Data type
Paper maps /data	EMA (Ethiopian Map Authority)	- Topographic maps And other thematic maps
Hydrologic data, geology , soil and geomorphology	MWR (Ministry of Water resources)	-Flow (discharge) -Water level -Soil -Litho logic units - geomorphologic map
Meteorological data	EMA (Ethiopian Meteorological Agency)	-Gauge data -Climate data
-history data or information - reports, documents and other publications	-DPPA and - Regional DPP	-Years of flooding, -Affected people, Properties and other resources - and others
-Satellite images -GPS	The Department	
- Software Arc GIS 9.1 ERDAS 8.7	The Department	
IDRISI 32		

1.5.2 METHODOLOGY

The methods intended to be followed includes

- Image analysis using Remote sensing techniques and employing different GIS analysis methods that aid manipulation at different stages and reach on presentations of the results
- Statistical and probability methods for flood frequency analysis
- Identifying the causes of the flooding by analyzing the available and field data.
- Maps of flood hazard zones will be prepared based on the field observations, image interpretations of some factors and flood frequency analysis outputs and other thematic maps
- Different year flood scenarios will be computed based on the hydrologic data
- Database for different factors will be prepared after field observations and this will make ready the identification of factors for damage assessments of elements that are supposed to be at risk
- Vulnerability functions for different categories of elements will be formulated and then preparation of maps that show different degrees of vulnerability for different return periods
- Damage or loss assessments for different classes of elements so as to help in obtaining of risk maps of different return period floods.

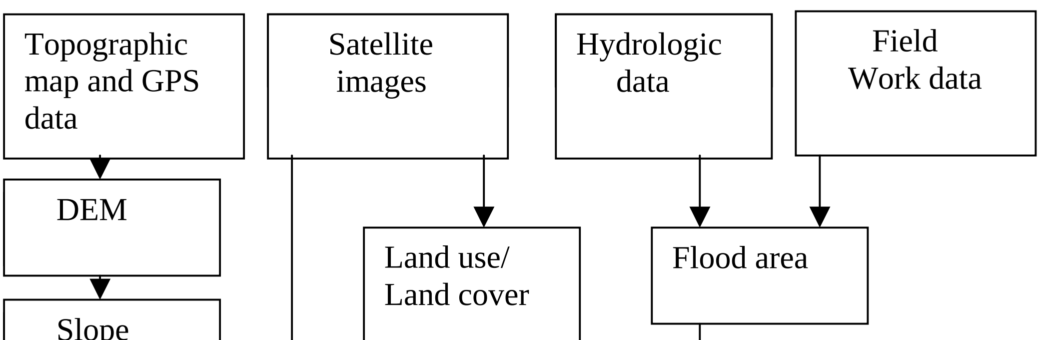


Figure-1.1 Flow chart for flood hazard zones mapping

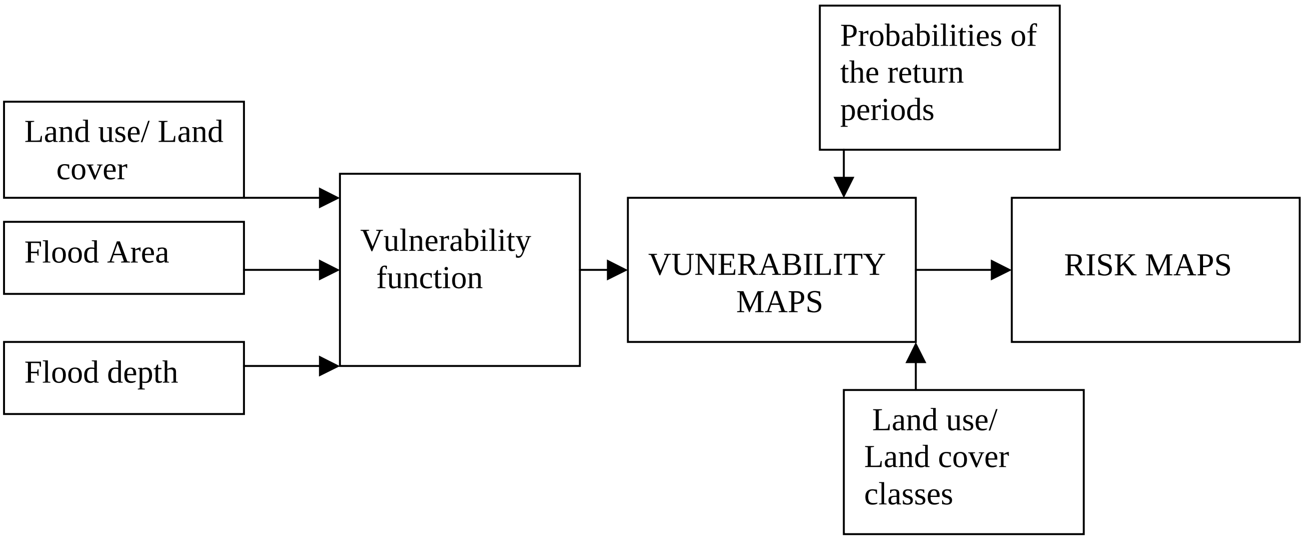


Figure-1.2 Flow chart for vulnerability and risk mapping

1.6 Limitations of the research

Data related to intensities of rainfall was not available so that the descriptions based on the precipitation have been limited relative to the discharges and water level. The absence of population data in the study area also made impossible to estimate the damage and danger to human life consequently, the analysis shifted to location of villages. Moreover, the high resolution and temporal images that play the role in delineating flood extents was not available, as a result the intention to base on remote sensing techniques for flood studies was shifted to base completely on hydrologic data. Due to lack of time, during the fieldwork information related to vulnerabilities of some land use classes was not collected. In addition to this, the effect remained to perform verification. The unusual financial restrictions have also impacts on the quality of the research.

1.7 Outlines of the remaining chapters

Chapter two presents general descriptions of the study area including its flooding problems. Chapter three contains literature review basically in relation to methods employed in the research and previous studies carried out in the Gambella region. Chapter four focuses on the analysis of input data and procedures and methods used for flood hazard, vulnerability and risk assessment. Chapter five presents the interpretations and discussions of the results of flood analysis.

Chapter six focuses on conclusions and recommendations of the research

CHAPTER TWO

Descriptions of the study area and its flooding problems

2.1 Locations and Accessibility

Itang is one of aged town in the Nuwer nations Zone. It is found adjacent to Baro River and almost on flat to gently sloping area. It is located in 8° 00 t0 8° 30 N and 34° 00 to 35° 15 East. The elevations of the area ranges from 410 to 560meters.The area are covered with unconsolidated sediments widely. The study area covers 535km^2.

There is a gauging station on Baro River at Itang town. The station is located at $8^0$12'N latitude and $34^0$16'E longitude. This is the most downstream gauging station on Baro River, since the station near Jikewa is abandoned. The Catchment area of Baro River at this gauging station is about 23,461 square kilometers. The station is equipped with six sectional staff gauges that are in good condition.

Accessibility is one of the major constraints to the development of the Region. There are limited weather gravel roads that connect the regional town to other wereda towns.

Itang is located about 45km from Gambella town accessed through gravel road that links Gambella to Lare, the other wereda town West of Itang, and is passable at any weather.

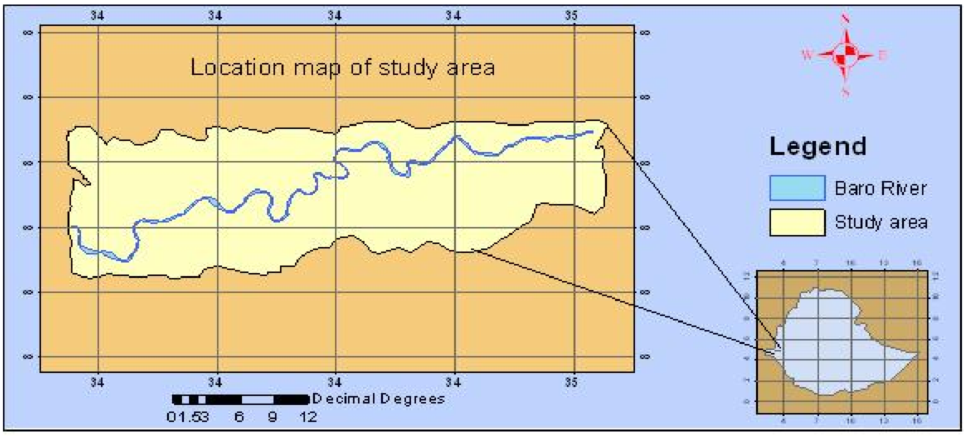


Figure-2.1 shows the location map of the study area and River Baro

2.2 Population and settlements

Based on the 1994 census, the population size of Itang wereda was 18768; out of which 1877 (10%) live in urban areas and the rest 16891(90%) are in rural areas. The wereda comprises of 35 kebeles. The settlement is commonly along the river owing to the hot temperature of the region and benefits from the river.

2.3. Geomorphology

The Gambella region lies between the two geomorphic regions, i.e. the Ethiopian Highland and the Southern Sudanese plain, differentiated by four distinct zones with their peculiar surface pattern, such as precipitation, vegetation, hydrology, geology and soils.

These are;

- The Mekonnen plateau generally underlain by pre-Cambrian basement rocks and some tertiary basalt and tuffs.
- The Masongo Mountain Ranges, which are dissected mountain chain and inter Montane plains, generally underline by pre-Cambrian basement rocks.
- The Higher Gambella plain, which is descending gently west wards generally is underline by Miocene basalts
- The Lower Gambella plain, which is a flat to slightly inclined plain at 440 to 400 m is underlain by Quaternary alluvial and lacustrine deposits and consisting of river flood plains and swamps.

Out of these four geomorphic zones, the research area is included with in the higher Gambella plain and lower Gambella plain. The latter dominates the geomorphic settings of this location. (More detail about the geomorphology of the area will be discussed in chapter-4)

2.4 Geology

According to A. Davidson's study of 1983, the geology of the Gambella Region can be divided into;

- The pre-Cambrian crystalline basement rocks of gneisses and schist.

- The sedimentary rocks (Gilo Formation) of the Pliocene-Oligocene age crystalline and pyro-crystaline rocks (trachytes), which have faulted structures of the higher Gambella Plain pulling Westwards and the predominant parent rocks are sand stones.
  - The Miocene effusive rocks (Gog Basalt) overlap with the Pliocene sedimentary (Alwero Formation) parts of that of crystalline basement with the Higher Gambella plain and Gilo formation on the Lower Gambella plain gently plunging westwards underneath the Quaternary deposits.

Based on Davidson's (1983) division and Slkhozpromexport(1990) reclassification of the geology of the region, it is possible to adapt the geology of the study area. The Russian study included both the Cenozoic and Quaternary formations. Accordingly, the geology of the area is composed of six lithologies:

- Gog basalts : include basalts of different verities and other miocene subordinate rocks
- Rhyolites: in this class although rhyolite is dominant, there are some Oligocene-Miocene igneous origin rocks
- Recent alluvial deposits
- Alwero rock mass: covers the area widely and comprises of sedimentary rock of different varieties with dominant sandstones and some sediments of different origins (see figure-4)
- Ortho gneisses includes both ortho and para gneisses which are usually fine grained in some places
- Undifferentiated gneisses this is primarily of granitoid and mixed origin

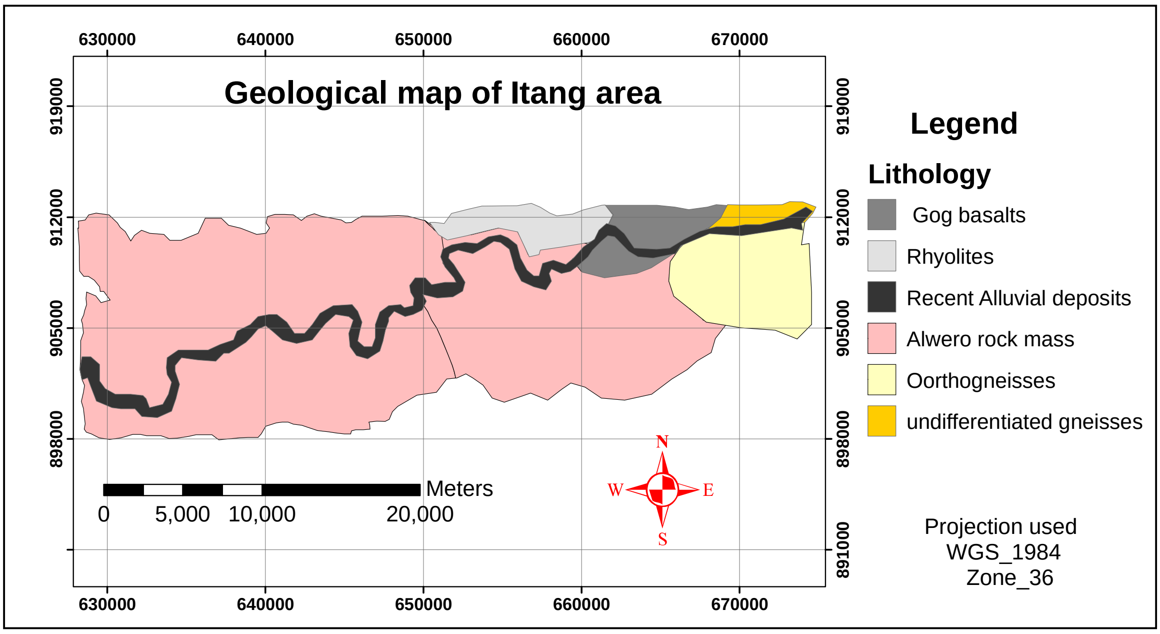


Figure-2.2 Geological map of study area

2.5 Hydrology

Among the major rivers of the region, Baro River flows through the study area and it is the main cause of flooding in the study area.

In general the flow of the river is from East to West crossing the Gambella plain and eventually to Sudan. The river discharge increases from May to September (the main rainy season) and decreases from October to April.

2.6 Climate

Climate governs the formation of organic substances, mineralization of organic matter, nitrification and leaching of nutrients, and etc.

The climate of the area is formed under the influence of the tropical monsoon from the Indian Ocean, which is characterized with high rainfall in the wet period from May to October and has little rainfall during the dry period from November to April.

Temperature and rainfall are important factors that have relation with the flooding nature and characteristics.

The mean annual temperature of the area varies from 17.3 ^{0}C to 28.3 ^{0}C and annual monthly temperature varies from 27 ^{0}C to 33 ^{0}C. The absolute maximum temperature occurs in mid March and is about 45 ^{0}C and the absolute minimum temperature occurs in December and is 10.3 ^{0}C. The annual rainfall of the area varies from 900-1,500mm.

2.7 Vegetation and soil

Generally the dominant land cover in the highlands is dense broad leaved and disturbed forest with patches of cultivation and the lowlands are covered widely with agriculture and with grassland and wetlands.

The area is divided in to seven soil types' classes. The FAO soil classification scheme was followed for the categories. They are

- Fluvisols that include both dystric and eutric fluvisols. This is the dominant soil type of the study area (figure-2.3)
- Plinthosols : includes both dystric and eutric plinthosols and coveres limited locations
- Eutric gleysols: these have characteristics of water logging
- Eutric vertisols: they are seasonally water logged and generally fertile and often flooded.
- Liptosols: these class include rock scree, lithic and eutric leptosols
- Haphic lixisols : often shallow fromover gravels and strongly weathered materials
- Planosols: these are associated with drainage lines and swamps and water logged for part of the year

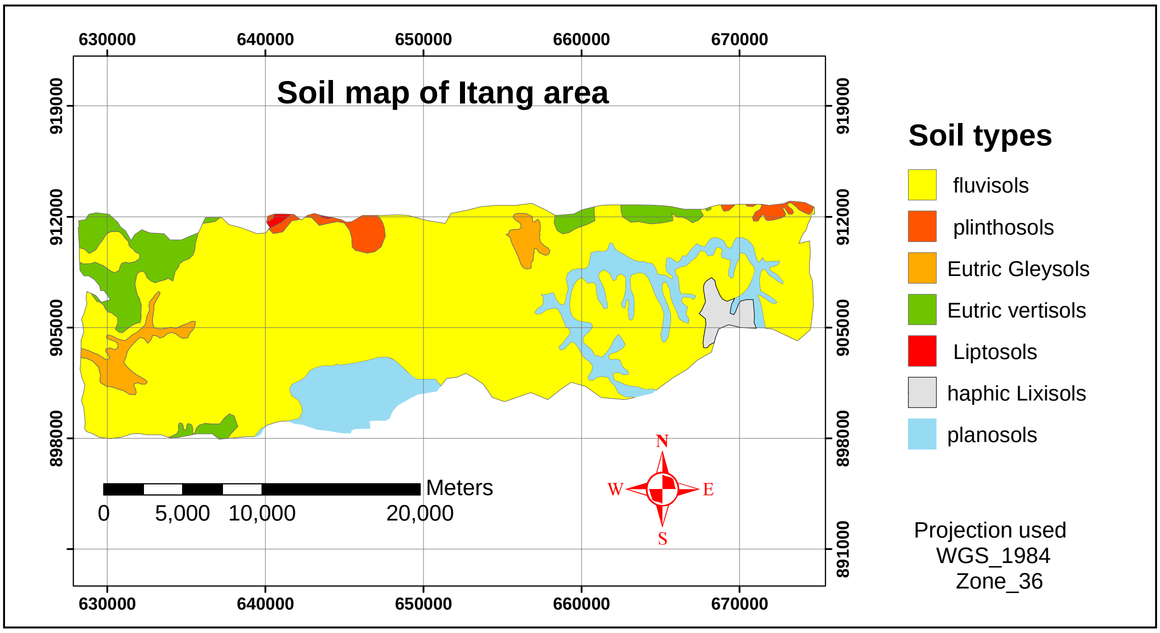


Figure-2.3 Soil map of study area

2.8 Flooding in Itang area

Flooding has been a common problem in Itang area and year to year the inhabitants have good experiences of the problem. However, during large floods they often face the consequences severely due to physical and social constraints related to susceptibility of the community. Table-2.1 summarizes the flooding and its impacts for some years

Table-2.1 Flood occurred and its impacts for the last few sampled years

Year	Impacts				
	Human affected	Livestock	crop	Property	Remark
1989	12000	NA	NA	-	Dueto overflow of Baro river
1990	6200	110 hen, 18 cattle and 28goats died	3 Ha maize and sorghum		
1991	11500	NA	NA	-	Due to Baro River overflow
1992	3350	112 cattle	116 Ha		
1993	44072	21cattle	38.5Ha	1 traditional boat and 42 houses affected	
1994	-	-	-	-	Drought year
2006	9200	160 cattle	388.3 ha. maize		

NA = Data not available. Source- Different reports from DPP Office

CHAPTER THREE

LITRATURE REVIEWS AND PREVIOUS STUDIES

3.1 Theoretical background

3.1.1 Geographic Information Systems (GIS)

Geographic information systems (GIS) have emerged as a useful computer-based tool for spatial description and manipulation. Although often described as a decision support system, there have been some disputes regarding whether the GIS decision support capabilities are sufficient Since current GIS do not provide decision-making modules that reason a decision and are primarily based on manual techniques and human judgments for problem solving, the individual should have the decision rules in place before GIS can be utilized. Other limitations in current GIS approaches include the incapability of processing multiple criteria and conflicting objectives (Carver 1991). They are also limited in integrating geographical information with subjective values/priorities imposed by the decision maker (Malczewski 1999).

3.1.2 Multi criteria Evaluation (MCE)

The techniques adopted in the various approaches of decision analysis are called multi-criteria decision methods (MCDM). These methods incorporate explicit statements of preferences of decision-makers. Such preferences are represented by various quantities, weighting scheme, constraints, goal, utilities, and other parameters. They analyze and support decision through formal analysis of alternative options, their attribute, evaluation criteria, goals or objectives, and constraints. MCDA method is very important since it has a significant effect on the final outcome. If there is a conflict between the various factors, they can negotiate the subjective parameter, like the weights associated with each criterion before adopting a common set of values. It is also possible to repeat the MCDA process and thus select, for each different group of stakeholders, a solution that is adapted to its specific needs. MCDA results can be mapped in order to display the spatial extent.

The negotiating parties can then discuss and compare the results by overlaying these

GIS and MCDM techniques far be used in flood hazard zoning in different areas there fore combining GIS and MCDM is a powerful approach to flood hazard assessment. Integration of these tools is needed so that each tool is used to address certain aspects of the problem. In this paper Arc GIS 9.1 has been used to manage the spatial data and to conduct the required spatial analysis operations in that GIS enables computations of the criteria while MCDM can be used to group them in to a priority index by taking in to account the decisions made by the decision makers. The final results may differ for different individuals as it considers the subjective judgments. Under this section it has been given more emphasis to the roles of the input datasets that how they are affecting the degrees of hazard.

3.1.3 The Analytical Hierarchy Process (AHP)

The most frequently raised problem in MCDM is how to establish weights for a set of activities according to importance. Location decisions such as the ranking of alternative communities are representative multi-criteria decisions that require prioritizing multiple criteria. Saaty (1980) has shown that this weighting of activities in MCDM can be dealt with using a theory of measurement in a hierarchical structure.

The analytic hierarchy process (AHP) is a comprehensive, logical and structural framework, which allows improving the understanding of complex decisions by decomposing the problem in a hierarchical structure. The incorporation of all relevant decision criteria, and their pair wise comparison allows the decision maker to determine the trade-offs among objectives. Such multi-criteria decision problems are typical for flood hazard zoning. The AHP allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the goal, objectives (criteria), sub-objectives, and alternatives. Uncertainties and other influencing factors can also be included. It does not only support decision makers by enabling them to structure complexity and exercise judgments, but also allows them to incorporate both objective and subjective considerations in the decision process (Saaty, 1980).

Saaty (1980) developed the Pair wise comparison method in the context of the Analytical Hierarchy Process (AHP). This method involves pair wise comparisons to create a ratio matrix. As input, it takes the pair wise comparisons of the parameters and produces their relative weights as output. The intensities of importance for the assigned values are based on the nine linguistic scales are given in table-3.1

Table 1: Pairwise Comparison Matrix

Intensity of importance	**Definition**
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

Source: Satty (1980)

Table-3.1 Pair-wise comparison matrix

Criteria weighting using Pair wise comparison Matrix

This requires determination of factor weights in the following three steps:

1) Filling the eigenvector value of the reciprocal matrix by comparing the priority importance of every two factors with respect to the problem. Either the upper or the lower triangle filling is sufficient
2) Adding every values of the column
3) Dividing values corresponding to every factor by the column total to determine the relative weight of the factors

On the basis of the above techniques the criteria weights for the four parameters were determined using the IDRISI 32 software after they get prioritized.

3.1.4 Flood Frequency Analysis

Chow (1988) described the objective of frequency analysis of hydrologic data to relate the magnitude of extreme events to their frequency of occurrences through the use of probability distributions. The magnitude of extreme events is inversely related to its frequency of occurrence.

The hydrologic data analyzed are assumed to be independent and identically distributed, and the hydrologic system producing them (e.g storm rainfall system) is considered to be stochastic, space-independent and time-independent.

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 variables being analyzed (eg. 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 results of flood flow frequency analysis can be used for many engineering purpose: for the design of dams, bridges and flood control structures to determine the economic value of flood control projects and to delineate flood plains and determine the effect of encroachments on the flood plain.

The 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. Estimation of the frequencies of flood is essential for the quantitative assessment of the flood problem.

Smith et al (1998) stated that flood frequency is an important concept in the design of many flood alleviation measures, which are constructed to withstand the effects of floods up to and including the design flood.

He also mentioned that the extent of inundation associated with a given water surface elevation defines another dimension of flooding that is the flood outline, which expands as water level increases. Floods of given return periods each have a unique outline which, when mapped, represent a valuable planning tool.

Suppose that an extreme event is defined to have occurred if a random variable X is grater or equal to some level x_t. The recurrence interval t is the time between occurrences of $X >= x_t$

The return period, T of the event $X>=x_t$ is the expected value of T, E(t), its average value measured over a very large member of occurrences. Thus the return period of an event of a given magnitude can be defined as the average recurrence internal between events equally or exceeding a specified magnitude.

3.2 Roles of remote sensing and GIS in flooding

Li Jiren (2001) described the applications of remote sensing and GIS in china for flood control and disaster mitigation. The area has been suffering from water logging and flooding of major rivers like: changjiang, nenjiang-Songhujiang, Yongjiang and other rivers in addition to Tailhu Lake. Satellite images that were taken before, during and after flood occurrences were vital for carrying out this case study. The study was carried out in four levels of platforms such as meteorological satellites, high-resolution satellites and space-born SAR, air-born SAR and helicopter and ground observations stations for measurements of discharge and water elevations. For the case of their study, the rainfall measurements by meteorological satellites and Doppler radar and conversion from inundated area to water levels with the support of GIS extended the applications of the method and ascertained the need of these tools for flood monitoring and assessment. GIS-based flood routing provided the inundation areas under different regulation alternatives and the combining with other databases was the base for flood forecasting tasks. After the final flood monitoring and assessment out puts were obtained, It was recommended that the extensions of the applications of remote sensing and GIS to decision-making before the flood occurrences will be significant challenge in the near future.

Another case study that employed remote sensing and GIS was the one that was conducted in Munshiganj district of Bangladeshi. Here, the techniques were used for flood vulnerability assessment and mitigation planning. Kulapramote, P. and Lal, S. (2005) utilized landsat TM, JERS-SAR and RADASAT and integrating with other thematic maps using GIS assisted them to accomplish the study. During their study the emphasis was given to combine optical images with SAR to obtain reasonable accuracy. Their output comprised of flood hazard and vulnerability maps, maps that contained criteria for shelter locations and route of evacuation and at the end proposed flood mitigation and evacuation plan. The final risk map produced was a combination of land use, flood area and population distribution that easily carried out with in GIS environment which demonstrated the potential of GIS system.

3.3 FLOODS

3.3.1 Nature and causes of flooding

The hydrologic cycle driven by solar energy provides freshwater resources to the earth through annual precipitation, which is constant in a given location over long periods of time but varies form year to year. Part of the precipitation infiltrates in to the ground and is stored as ground water. Depending on the spatial and temporal distribution and intensities of the precipitations, annual flood pulses are generated in rivers and streams. When the flows in streams and rivers surpass their carrying capacity, the water spills over to the adjacent lands, causing inundation, also called flooding. Therefore, flooding results from excessive rainfalls or snowmelts or a reduction in a river conveyance capacity owing to silt or inadequate design of waterways.

Anthropogenic changes in flood plains also affect the natural frequency, intensity, and characteristics of flooding.

Some of meteorological, hydrological and human factors that contribute to flooding are given below in table

Table-3.2 Factors contributing to flooding

Meteorological factors	Hydrological factors	Human factors
-Rainfall -Storms -Temperature - Snowfall and snow Melt -etc	-Soil moisture levels - Surface infiltration rate -Channel cross sectional shape -Presence or absence of over bank flow and etc	-Land use activities -Occupations of the flood plains -etc

Source: WMO, 2006

A flood is usually defined as the flow, which overtops the natural or artificial banks of a stream. However, it does not lend itself to any precise definition. Broadly speaking, it may be considered as when a river is about to overflow its banks or when the water level in the river reaches a stage that may be called the 'danger level' and if exceeded

might cause significant damage to life and property or endanger the safety of a structure.

3.3.2 Types of floods and their impacts

1 River floods

River floods occur when the river runoff volume exceeds local flow capacity. They are triggered by heavy rainfalls in upstream areas, snow melt or tidal influences, failure of flood control works upstream can some times lead to river floods. Ground conditions such as soil, seasonal variations in vegetation, snow cover depth and imperviousness that are affected by urbanization, have a direct bearing on the amount of runoff. Direct impacts caused by river floods include: damage to property and crucial infrastructures, disruption to livelihood and economic activities, threats to the lives of people and animals by possible drowning in deep water, contamination of drinking water supplies and shortage of food owing to destroyed crop fields and

loss of livestock's. Flooding that is caused by Awash River can be exemplified for this type of floods

2 Flash floods

Flash floods occur as a result of the rapid accumulation and release of runoff water from upstream mountainous areas, which can be caused by heavy rainfall, cloudbursts, landslides, and the sudden break up of an ice jam or failure of flood control works. They are characterized by a sharp rise followed by relatively rapid recession causing high flow velocities. Discharges quickly reach a maximum and diminish almost as rapidly. They are common in mountainous areas and desert regions but are potential threat in any area where the terrain is steep, surface runoff rates are high, streams flow in narrow canyon and sever thunderstorms prevail. They are most destructive than other types of flooding because of their unpredictable nature and unusually strong currents

carrying large concentrations of sediments and debris, giving little or no time for communities living in its path to prepare for it and causing major destructions to infrastructures, humans and animals, crop fields and whatever stands in their way.

3.3.3 Flooding of Gambella Plain

The Gambella plain west of $34^{0}15'$ is flooded every year but the degree of flooding depends on the water availability of the year. SELKHOZPROMEXPORT (1990), the Russian study identified the reasons for the flooding problems of the lower Gambella Plain area. These are due to flooding resulting from overflows of riverbanks; and flooding resulting from rainfall over the plain and poor drainage. The flooding resulting from the river overflow is stated as the consequences of two possible phenomena; a riverbank full capacity being too small and the backwater effects from the Pibor and Sobat Rivers, rivers in to which Baro and other rivers of the region drain. Flooding in the Gambella plain varies from year to year.

For each flooding situation the Russian study estimated the probability of the land flooding. The total area of the lower basin subjected to frequent flooding is about 9,720 square kilometers.

The flood frequency analysis has been made to estimate the flood at the river gauging stations. Based on the values of flood Peak Factors as suggested by SELKHOZPROMEXPORT, the annual momentary flood Peaks are estimated at each of the gauging stations, which have more than ten years, recorded data.

The annual flood peaks of the gauging stations were fitted to the distribution that most commonly used for flood frequency analysis-Extreme-Value Type II.

The annual runoff of the Baro-Akobo River basin is predominantly influenced by rainfall. The basin is characterized by seasonal fluctuation of the runoff much like other basins in the country. Two seasons can be observed by the quantities of the flows in the rivers.

The stream flows in the basin generally increases from May through September and decreases from October to April. Minimum flows occur in March or April and, in general, the highest flow period lasts from June to October (Figure-3.1). During this period the rivers of the area carry 75% to 85% of their total annual flows. The greater part of annual runoff occurs in September while the lowest flow season is from January to April.

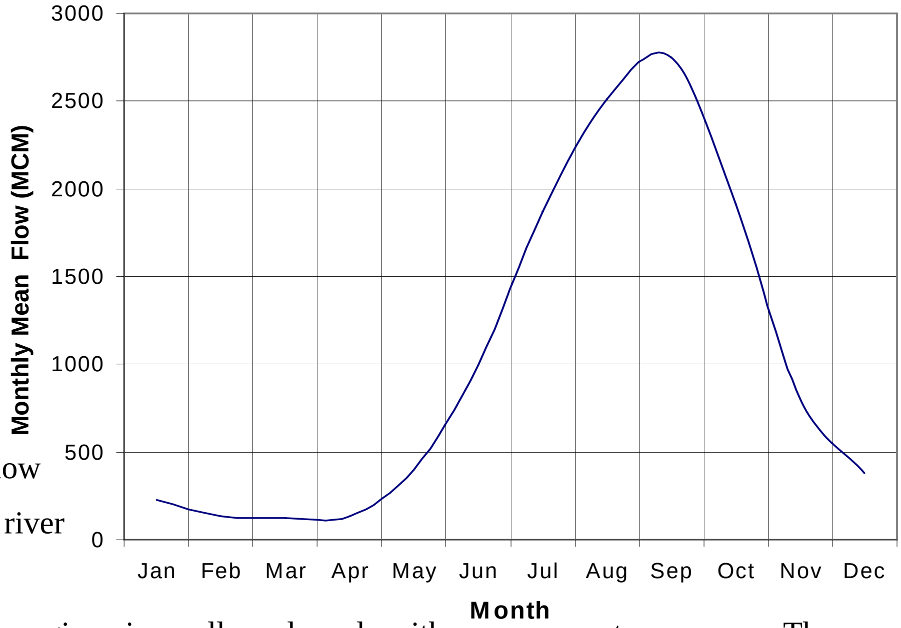


Figure: 3-1 the monthly mean flow for Baro-Akobo river basin

Gambella region is well endowed with water resource .The mean annual flow in the basin, at the border, is estimated to be 20 billion cubic meters. Ground water is available almost everywhere with the depth of 0-150m (DPPA)

The sources of rivers are from the highlands of Mocha and Illubabour, the names of town and zonal Administrative respectively, so that the rainfall distribution, duration and intensity in the highlands highly affect the volume of the rivers. Moreover the region itself receives more than 1200mm per annum. Having this during the rainy season, the rivers are full, most of the time they even over flow their banks and the flood plains of the region gradually gets covered with water. Similarly the removal of forests by fire, cutting trees for firewood, house construction etc, clearing land for agriculture and other purposes reduces the overall absorption at the ground resulting in higher volumes of run-off. This will increase the magnitude of flooding. This magnitude of flooding in turn leads to high disturbance of environment. The side effect of this condition can be enumerated by citing the experiences of different woredas in the region. (Gizachew, 1999)

The fertility and easy life in the riverbank lands in the region encourages the concentration of human activities along riversides. This concentration of peoples and human activities in unprotected settlement contribute to heavy losses of property and life. Hence, around 108 'kebeles' in seven of the nine woredas of the region are vulnerable to flooding. Table-3.3 gives detail information on people and 'Kebeles' vulnerable to flooding in seven woredas of the region.

Table-3.3 Woredas and number of 'kebeles's vulnerable to flooding disasters

No	Name of the woreda	Number of kebeles vulnerable to flooding
1	Gambella	11
2	ITANG	25
3	Jikawo	33
4	Akobo	20
5	Aboho	6
6	Gog	6
7	Jor	7

Source: Different reports from Bureau of Disaster Prevention preparedness, Gambella

Vulnerability of an area to flooding has an influence in the magnitude of the damage from a flood. In some areas, farming steep slopes with no proper conservation techniques, deforestation etc that are the practices of human beings in the region increase runoff and potential of flooding.

Flooding is a natural hazard in which its occurrence and its severity is highly determined by climatic, Topographic and human action. The climatic (meteorological) conditions are highly related with phenomenon of excessive rainfall. Often the intensity, duration and distribution of rain fall on the catchments area influence the magnitude of the floods. As climatic factors have an influence on the occurrence of flood non- meteorological factors also affect the flood intensity.

The Baro-Akobo basin study as earlier outlined the causes of flooding in the region and these factors may be aggravated by man’s misuse of land and topography. All of the factors contribute to increase the vulnerability of peoples and environment to flood disasters (Table-3.4). Individually each factor may reduce the capacity to respond successfully to disaster situation. But more importantly, these factors are mutually reinforcing.

Duration of flooding in the region may vary from season to season depending on the intensity of rains in the high lands and in the region. In the past the floods in the region were not as intensive as the latest incidents. In some places because of the afore mentioned factors the areas under flood are gradually increasing and new areas, which previously were not flooded, are now becoming inundated with flood. Besides, the time needed for the flood to recede is extending overtime. The extended duration of flooding time prohibits the cattle from getting palatable grasses and prolongs the planting periods of flood recession agriculture and sometimes results in loss of life to domestic animals due to shortage of pasture. To conclude the flood time varies depending on the intensity of rains from July to September. But nowadays it does not recede till the end of October.

Table-3.4 Flood prone woredas and damages occurreing due to flooding

Region	Zone	Woreda	Year EC	Type of flood	Affected population	Remarks)
GAMBELLA	ONE	Gambella	1985	River		
			1987	River	6157	
			1989	River	10684	
			1990	River	12700	
		Itang	1985	River		
			1987	River	28413	
			1989	River	12500	
			1990	River	11546	
		Jikawo	1985	River	27236	
			1987	River	19910	
			1989	River	10000	
		Akobo	1985	River	12921	
			1987	River	17641	
			1989	River	20000	
	TWO	Abobo	1985	River	500	
			1989	River	3810	
		Dimma	1989	River	8000	
		Gog & Jor	1985	River	900	
			1987	River	19910	
			1989	River	1700	

Source: DPPA research unit and reports from Regional DPP Bureau.

3.3.4 Flood event of 1988

According to Baro Akobo Basin study aero-visual surveys in Gambella plain under taken in 1988 showed that the area of 9720 sq. km in the west of the plain was covered with water for one month. This flood, which lasted long enough, destroyed the grain crops on an area of 4.5 thousand ha in the area of inundations, expecting an average yield of 14 quintal per ha and a price of 355 birr per ton, the losses came to 2.2 million birrs. The 1988 flood occurrence claimed the lives of many cattle, sheep and goats.

The hydroelectric power station was flooded and the power supply was disrupted for a month, several administrative and economic buildings, houses, hotels etc were also flooded. In spite of its side effect, in times of flooding a river may spread a thin veneer of alluvium soils over its whole flood plain, a fact of major economic importance to the farmers of Gambella.

Actual cultivation is done after the floodwater recedes and a layer of new sediment has been deposited. This way the crop benefits from the residual moisture and the newly deposited nutrients in the soil. Similarly, according to Baro-Akobo basin study the yearly occurrence of flood in the western part favors the growth of grass. If the flood recession time does not elongated, this plain serves as pastures for cattle. These two may be taken as economic importance of flooding to the region. But the benefit cannot commensurate the damage.

To summarize its effect, flooding in the region cause a widespread damage and loss to property and life, disrupt economic activities and services. It imposes hardship and suffering on those affected, the magnitude of flood disaster is tremendously increased by the after effect namely epidemics and starvation. Generally because of what it destroys flood is a factor in increasing vulnerability to food shortage. All the above effects caused by flooding directly or indirectly influence the condition of the environment.

Gambella is perhaps the most seriously affected region by flood. Floods usually cause a substantial damage to maize and sorghum, important food crops in the region. The inundation of water in the plain area of the region has caused a remarkable damage both to human and animal lives. Huge numbers of people had migrated to the neighboring kebeles and woredas in search of shelter for existence.

Different feeder roads sometimes including the main roads become non-functional disrupting the normal economic and social activities in the region.

One of the tributaries of Baro River during the rainy season is Jejebie, around this area there is improper and unsafe waste disposal, which encourages the reproduction of disease vectors in that particular area. Thus it reduces the quality of water for down stream users by polluting the water. This contributes to the occurrence of epidemics.

Generally the condition of flooding is worse and need high follow up to prevent and mitigate the problem. Having said this, the emergency relief response to save the life of the victims may be taken as a strong point. Where as policy issues are highly biased to slow on set and drought induced disaster response .The response to flood disaster is highly neglected.

Flooding being such a wide spread problem in the region was not also treated equally with other disaster agents. Flood is one of the most formidable problems faced by our country and region;

despite this the case the national policy on disaster prevention and management does not fully address all hazards which are disaster threats in the country (Gizachew, 1999).

CHAPTER FOUR
ANALYSIS

4.1 Input data analysis

The present research requires the following input data that comprises both digital and hard copy information as described below.

1. Land use /Land cover
2. Geomorphologic map
3. DEM (slope)
4. Hydrological and meteorological Data: discharge, water levels, Rainfall

4.1.1 Hydrologic data analysis

It was earlier out lined that the causes of flooding in the study area have been related to discharge and stage of the river and heavy rainfalls of the surrounding, consequently analysis of this data are required.

Flood frequency analysis is a statistical measure of probable occurrence of flood of a given magnitude. Large floods occur relatively infrequently and have a long average return period or recurrence interval, which is the average recurrence intervals between two floods of equal or exceeded a specified magnitude. Where as small floods occur frequently and therefore have a very small return period or recurrence interval.

According to punmis et.al (1995) the estimation of peak flow or flood can be made by physical indication of past floods, flood discharge formulae, flood frequency studies and by unit hydrograph method.

Suresh (2005) gave emphasis to the method of statistical and probability knowledge to handle hydrologic data as hydrologic events are highly erratic, random and complex in nature and are not dependent on physical and chemical laws, but completely on nature as a result they can not be computed exactly by using any relationship, but can be predicated at different probability levels.

According to Suresh hydrologic data are generally presented in chronological order by their magnitude and are expressed in an arbitrary unit. More commonly, a hydrologic data series contains the following sub-series

1. Complete duration series
2. Partial duration series

3. Extreme value series

For present study hydrologic data, flows and water levels were collected from the MWR. These data were incomplete for a few years thus the gaps were filled from the Baro-Akobo water resources and master plan study documents. They employed models to fill the gaps and checked for their consistently and acceptability.

Whereas the meteorological data were collected from NMA for three stations that are found in the surrounding of the study area although the data were incomplete.

The extreme value series that includes largest or smallest values selected from an equal time interval of the record has been followed for computation of flood frequencies of different return periods. For this research, the annual maximum series was considered and annual maximum data of discharge, water levels and annual peak precipitation of 22 years (1985-2006) has been used for analysis.

Among different types of probability distributions, the log-Pearson type-III distribution and Gumbel's method are commonly employed for determining the frequency of continuous random variables. After a detailed study of the distribution of the random variables and its parameters (such as mean, STDV, skew-ness and etc) and applying probability theory one can reasonably predict the probability of occurrence of any major flood events in terms of discharge or water levels for a specified return period.

Selecting annual maximum discharges and water levels that have been recorded at Gambella gauging site located with in the study area performed flood frequencies analysis.

Gumbel's Method

This extreme value distribution was introduced by Gumbel (1941) and is commonly known as Gumbel's distribution. It is one of the most widely used probability analysis. For example values in hydrologic and meteorological studies for predication of flood, rainfall and etc.

Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. In this attempt to compute water levels/ discharges at different return period, this method has been used as alternative method. The Gumbel's equation for this purpose is given as

$$\mathbf{X_t = X + K * STDV}$$

Where

Xt = value of variate with a return period ‘T’

X = mean of the variate

STDV = standard deviation of the sample

K = frequency factor expressed as

K= Yt-Yn/Sn or according to Suresh (2005), K=Yt-0.577/1.2825

Where, Yt is the reduced variate of given retutn period T; is given by

Yt=-(in.in(T/T-1)) or

= -(0.834+2.303log.log(T/T-1))

T= return period

Yn = reduced mean from table

Sn= reduced standard deviation from table

Accordingly, flood calculations for three different return periods were computed and the results are given in table 4.1.The procedures and the input data analysis are given in annexes-1,2 and 3

Table-4.1 Flood level calculation result using Gumbel’s method

T	Yt	Yn	Sn	K	Xt
10	2.251	0.577	1.283	1.305	6.1
50	3.903			2.593	7.2
100	4.601			3.138	7.5

Log – Pearson type III method

Suresh (2005) stated that log-Pearson type-III distribution is a commonly used probability distribution technique for flood frequency analysis.

Chow (1988) described that the use of the log person type-III distribution is justified by the fact that it has been found to give good results in many applications, particularly for flood peak data. The fit can be checked using X^2 or chi-test

In this method, the variate is first transformed in to logarithmic form and the transformed data is then analyzed. If ‘X’ is the variate of a random hydrologic series, then the series of ‘Z’ variates where Z= logX are first obtained. For this ‘Z’ series, for any recurrence interval ‘T’ the equation is

$$\mathbf{Z_t = Za + Kz * STDV}$$

Where, Kz = frequency factor taken from table with values of coefficient of skew ‘Cs’ and recurrence interval ‘T’

STDV = standard deviation of the 'Z' vairate sample

Cs = co-efficient of skewness of variate 'Z_t' given as

Cs = $(N\sum (Z-Za)^3)/ (N-1) (N-2) (STDV^3)$

RT	Cs	Kz	Zt=Zavg+(Ks*SDV)	Xt=AntiloZt
10	0	1.282	3.16234	1453.249
50	0	2.054	3.2019	1591.842
100	0	2.326	3.21584	1643.799

Where, Za= mean of the 'Z_t' variate

N = sample size = number of years of record

After finding Za with the equation above, the corresponding value of Xt is obtained by Xt = Antilog Z_t.

Similarly, flood calculations for three different return periods were computed and the results are given in table 4.2 and 4.3.The procedures and the input data analysis is given in annex.

RT	Cs	Kz	Zt=Zav+Kz*SDV	Xt=AntilogZt
10	-1.2	1.086	0.78153	6
50		1.379	0.79182	6.2
100		1.449	0.79183	6.3

Table-4.2 Flood level calculation using Log Pearson type-III

Table-4.3 Flood discharge calculation using Log Pearson type-III

For the present research, after obtaining gauge levels and discharges by above two methods for the three return periods (10, 50 and 100), then the chi-square test (X^2) checking were carried out for "goodness of fit".

$X^2 = \sum(\text{observed values} - \text{computed values})^2/\text{computed values}$

Therefore, the chi-square results obtained for Gumbel method is 0.12275 and for Log Pearson type-III 0.02951.From these values, the lowest value corresponds to Log Pearson type-III and this method has been used for levels and discharge analysis.

4.1.2 Statistical analysis of precipitation data

For this study precipitation data from Gambella station was obtained and simple statistical approach was used to calculate the probabilities of occurrences for different records. The Gumbel's method, different from the one previously used, was followed as follows

- Sorting the precipitation records from the lowest to the highest
- A rank value (J) is assigned starting with a value 1 for the lowest and n to the highest
- The probability, P can be calculated using the formula, P =J/n+1 and the corresponding return period, R= 1/1-P
- In order to graph the values, a plotting position, Y = -ln(-ln(P)) is calculated and the precipitations are plotted against it. After this a line of best fit is constructed
- From this graph the value Y for different precipitations can be read and the return period can be simply calculated

Based on the above formula the probable flood producing precipitation was calculated for the return periods. This has been done only to show simple correlation between precipitation and the flood that may occur regardless of the factors that have to be considered.

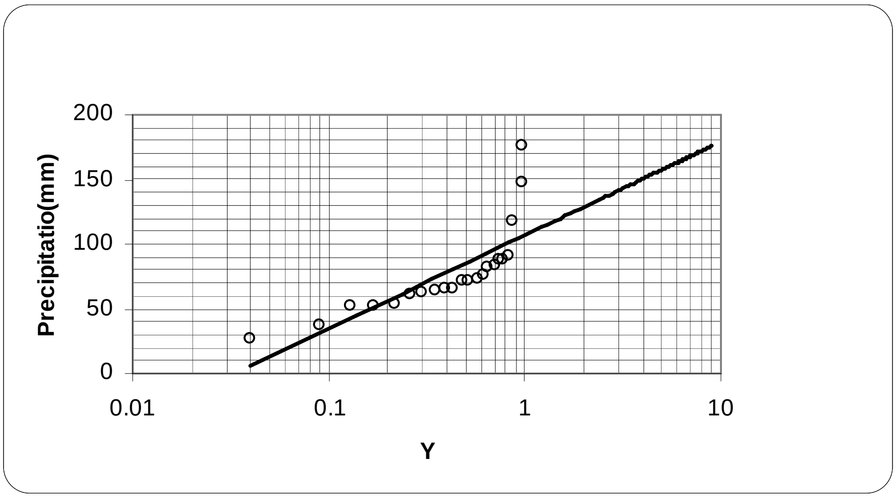


Figure-4.1 Probable flood-producing precipitation determination from plotting positions corresponding to the three returns periods and recorded precipitations

Table-4.4 Probable Precipitations for the return periods

Return period(year)	Plotting position	Precipitation(mm)
10	2.3	130
50	3.9	150
100	4.6	155

The rainfall intensity affects the size of flood especially if it occurs over small areas as it drains quickly to the outlets that drained to streams. Similarly, if the duration is long, it has the potential to increase the volume of the runoff consequently the flood size depending on the river capacity.

4.1.2 Geomorphology

In order to map geomorphic units, terrain classification is required. Image interpretation is considered as an essential means of obtaining data related to landforms. It shows the natural terrain, and thus some classification method is required to group natural aggregates of terrain features. Meijerink (1988) proposed a terrain mapping unit (TMU) approach as a method of data acquisition and storage that makes use of the interrelationships between geology, geomorphology and soils.

For the purpose of this research, definitions of TMU proposed by Majerink ware followed so as to produce geomorphic units based on geology, soil, DEM, image interpretation and reading materials on detailed geomorphologic descriptions of the Baro-Akobo basin carried out by SELKHOZPROMEXPORT (1990).

- A TMU describe a natural division of the terrain that can be distinguished on aerial photographs and can be verified on the ground.
- A TMU is a unit which groups interrelationships of land form, litho- logy and soil.
- A TMU differs for another – adjoining – unit because either the land forms are evidently different or the phenomena associated with the land form differ
- In terms of GIS, a TMU may be described as the geographic location of entities, which relate to a unique set of attributes.

Remote sensing and GIS had brought in recent years and different types of approaches to assess floods, particularly in mapping terrain units and later integrating them with other thematic data. Meijerink(1988) in enhanced the important roles of satellite images in regional scale analysis in deriving zones with homogeneous conditions (Terrain mapping units) due to the fact that these images represent clearly the result of the integration of the reflectance of different terrain attributes like soil, vegetation and others, showing a higher degree of correlations between them , rather than between the image and any single terrain attribute

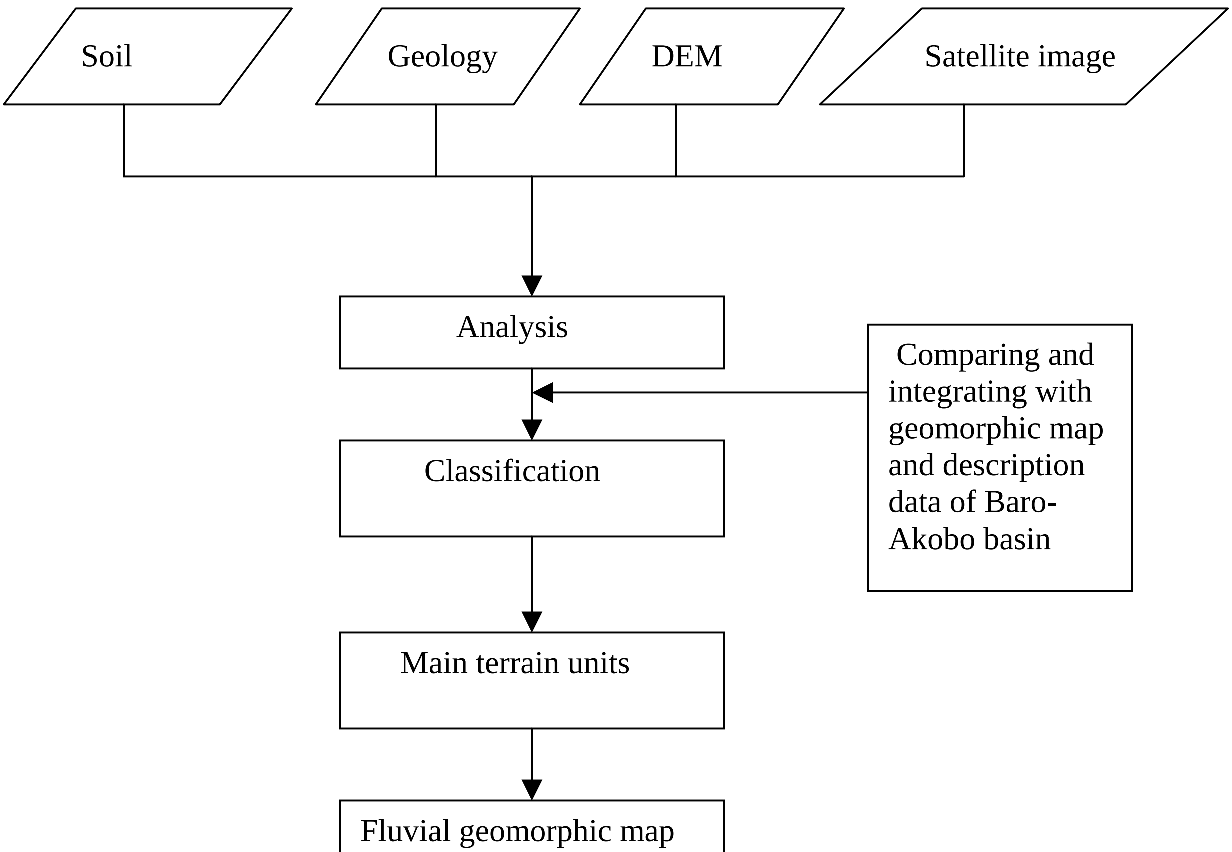


Figure-4.2 Flow chart for terrain mapping units

This study is an attempt to this better understanding of the pattern of the floods in the stag are in regard to the terrain attributed and relate them with local knowledge, other thematic maps and some results of different hydrological approaches.

The study area is composed by flood plain, mainly composed of un- consolidated materials derived form sediments of Alwero formation that consists of quartz sand stone, argillites, ferruginous montimorinolite clays and other subordinate rocks which cover wide are and some transported materials by the river itself. The main genetic origin of the terrain units in the study area is of fluvial. Geomorphologic mapping of the train units was based on the interpretation of satellite images, soil and geology of the area, in combination with published materials and local experience of other area besides observations made during field work and then classifying them in to six units.

The characteristics of types of the units that were attempted to map:

- Low depression areas: depressions characterized by dark tone showing high moisture content and lithologicaly sedimentary origin sediments and clayey soils are dominants.
- High terrace deposits (higher remnant): topographically higher portions, visible due to higher reflectance of sandy materials and may not be affected by flood. Most of the settlement are situated here, Itang town and other big villages. They are also with some agricultural practice around them and the dominant lithology is of sedimentary basin.
- Non-differentiated flood lain units: These are along the lower potion of the riverbank and extend to gently slopping areas. The different vegetation cover type gives different reflectance. Intensively used for agriculture and some settlements. Meandering of the river system also characterize them. These units consist of the alluvial plain along the river and sand bank along the river channel.
- Non-differentiated uplands: not differentiated but presenting gently to moderate step slops and slightly dissected. Gog basalts formations dominate this unit.
- Water logging lands: this unit includes the swamps and marshy areas. The process of mapping landforms created by surface process is always an issue with several critical

constraints and choices. It is so clear that the experience of the researcher is a key and important issue influencing the nature of the map produced.

There were some difficulties in mapping small units and it was believed that the mapped units are sufficient in order to incorporate with other data and then to see the flooding conditions from other angles.

Understanding the geomorphologic features of an area is crucial in the process of hazard exogenous studies as they are mainly the results of geomorphic process that happen on earth's surface. In case of flood hazards, smith and ward (1998) considered that they are result of combination of physical exposure and human vulnerability to geophysical processes.

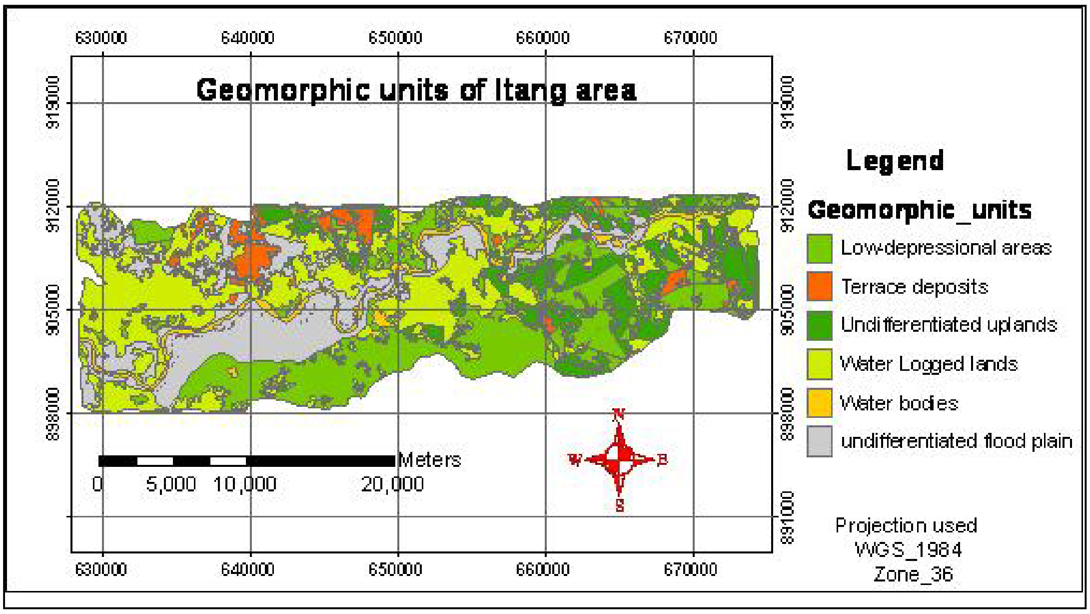


Figure4.3 Fluvial-geomorphic units of the study area

4.1.3 DEM

The preparation of DEM of the landscape started with digitizing the existing contour line from topographic map of the area (1:50.000) with 10 meters interval. The attempt was also made to obtain DEM from collected elevation points by taking in to account the topographic characteristics of the study area besides digitizing. And finally the second alternative became successful to produce the DEM. It is important also to mention the use of DEM of the landscape of the area during flood area computation in addition to for slope calculation.

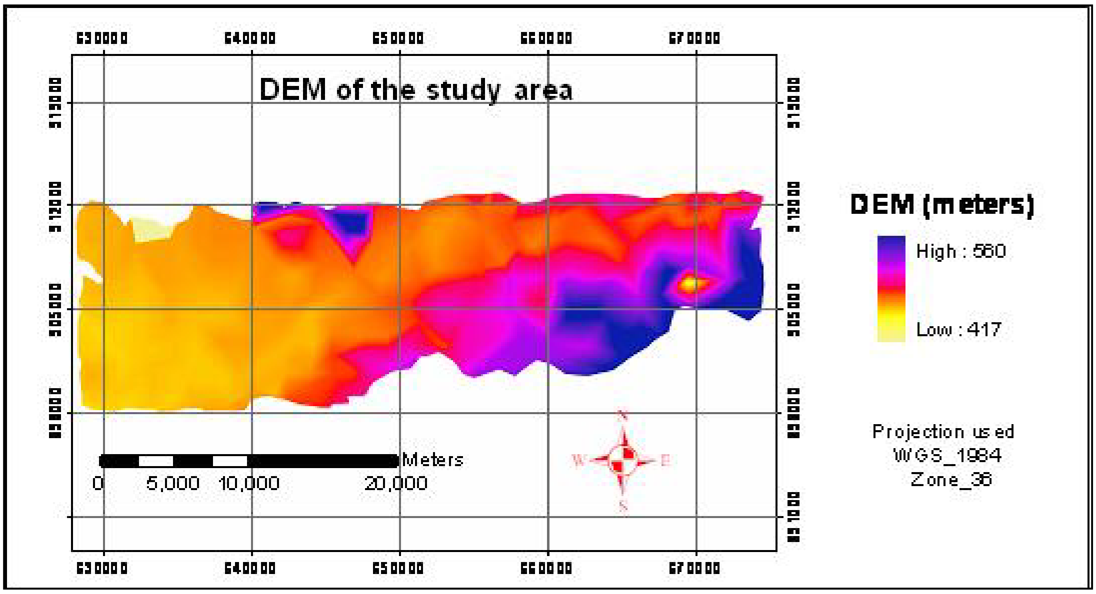


Figure-4.4 Digital elevation model of the study area

4.1.4 Flooded area map

To create the flooded area map in event of flooding, elevations collected along the banks of the river connected to different water levels calculated by flood frequency method and average elevations were taken for every return period.

Then all the lands, which have elevation lower, or equal to the specified average flood levels, were marked after comparing with the DEM of the landscape.

If the floods of a given return period occur, inundation will take place in the areas that have elevations lower than those average water levels. The process is applied for 10, 50 and 100-year return period floods and their areas of inundations were demarcated.

Table-4.5 summarizes the inundation areas and flood depths for the return periods computed by Log Pearson type-III

Return period(year)	Flood extent(km^2)	Dischargesm^3/sec)	Depth(m)
10	216.26	1453.25	6

50	277.23	1591.84	6.2
100	284.49	1643.77	6.3

Averaging the elevations along the river banks were assumed to be better to represent in the computations of those lands with lower elevations rather than taking the elevation of the gauging station, which is located at far east of the study area. Figure-4.5 indicates the locations of the gauging stations at Gambella and Itang and the elevations along the

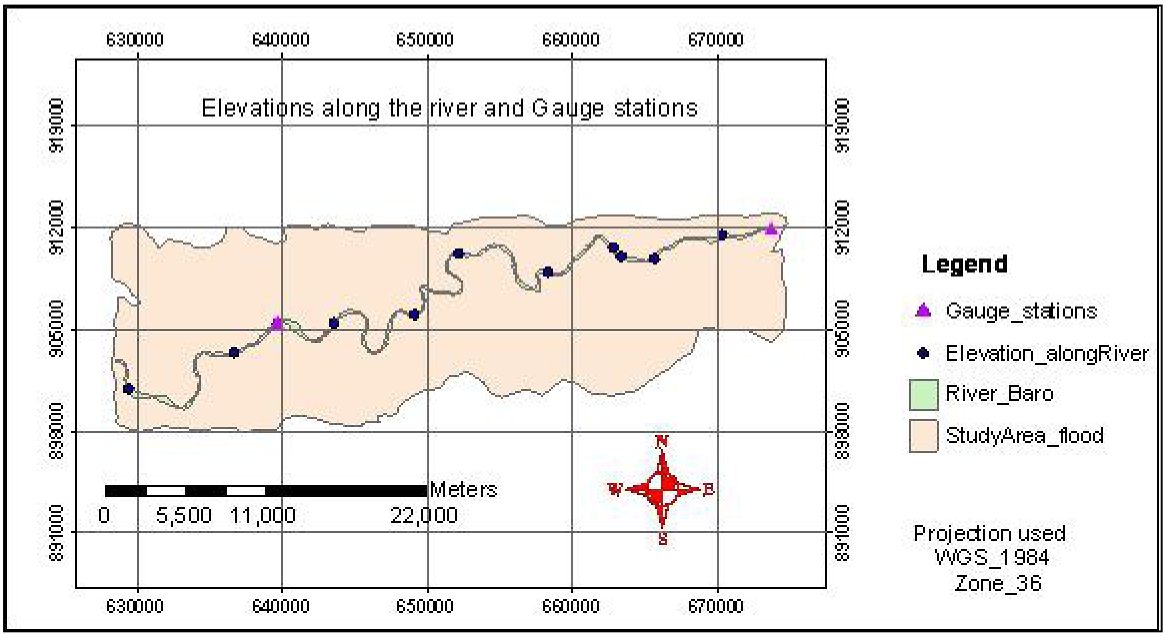


Figure-4.5 Elevations along the river and Gauge stations

riverbanks. Because of the absence of records from Itang station, the data used for analysis were from Gambella station.

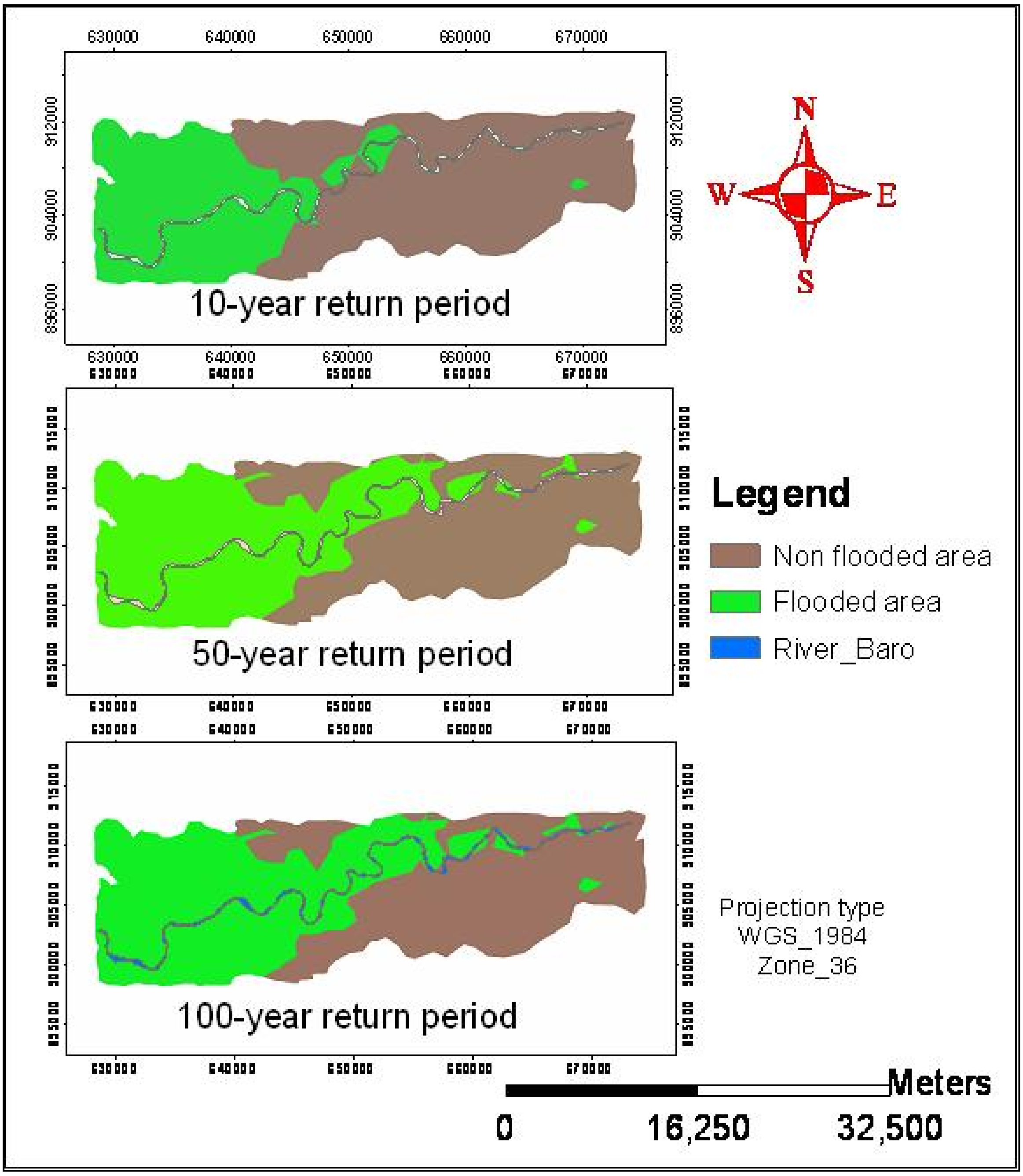


Figure-4.6 Inundation areas of the three return periods

These flood area maps were then crossed with land use/ land cover map and with map that shows location of villages. Finally the area of each land use/land cover class that would be affected by inundation extents of the three return periods was calculated. These inundation areas will be the base for vulnerability and risk assessments.

As it was indicated earlier, from the hydrologic data, the elevations along the bank of the river and the DEM of the landscape of the area, floodwater depths for the three return periods (10,50,100- years flood) were calculated; the comparison of the results of the calculation with precipitation data was made.

The 10-year flood scenario shows flooded area widely extended in the western part of study area but with limited extension to the central part of the research area. The average floodwater depth of this return period is also smaller. The 50-year flood scenario shows flooded area almost identical in extension to the 100-year flood but a few differences in the distributions of the floodwater depths. Their areas appear to have extended more to the eastern part than does the 10 years flood area.

The comparison of the flood water levels and discharges for the actual damages of the 1988 flood was made with the flood depths and discharges of the return periods. This would also help to evaluate the degree of damages that might be occurred in relation to flooding of different return periods.

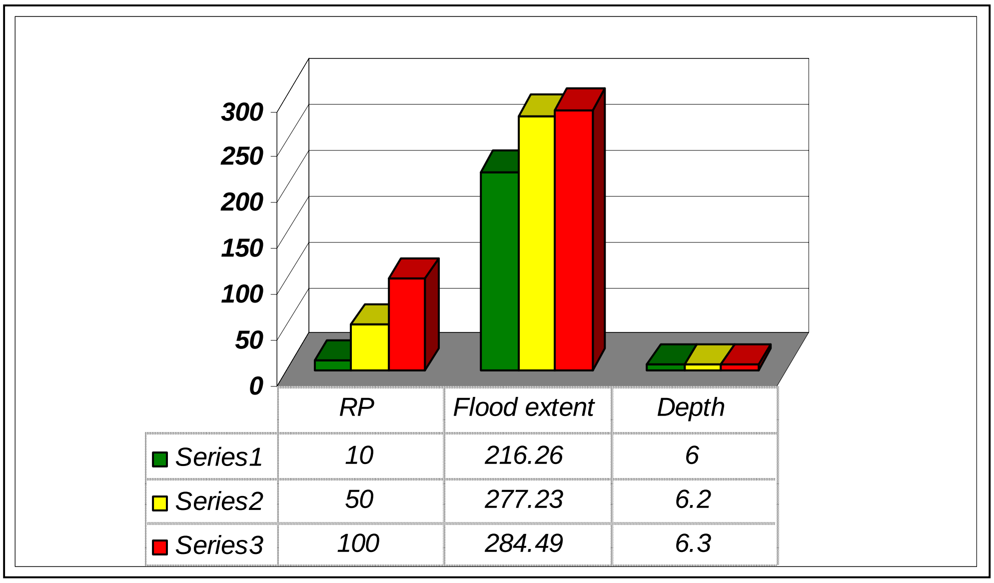
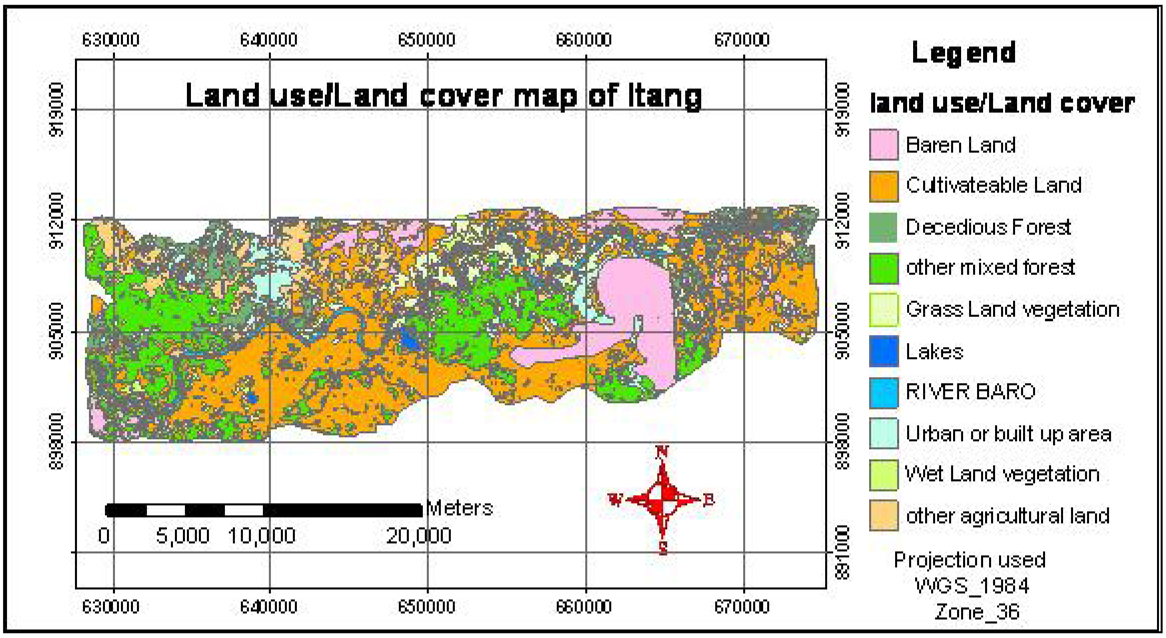


Figure-4.7 Relationships between flood extents, depth and return period

4.1.5 Land use /land cover

The land use / land cover of the study are has been generated from land sat ETM^+ taken in 2000. It was found to be very heterogeneous. Therefore, visual interpretation, the most primitive method in land feature interpretation has been applied during pre-field analysis. Data collected on the field and ancillary data were used for further interpretation of the land features of the study area. Land use/land cover pattern of this area has been classified using supervised classification technique in to ten classes. The nature of land surface affects greatly by affecting the run off producing characteristics of the watershed. A land with vegetation has reduced runoff rate and affects the flood, accordingly. Similarly, the lands having less moisture content, absorb more rain water and accordingly the flood occurrence gets affected. This impact of the land use has influenced in turn the discharge of the river. On another hand, encroachments to flood plain have effect in increasing the severity of the flood consequently the damages or losses that may be occurred to different classes of land use.

Figure-4.8 land use / Land cover map of the study area



4.1.6 Slope

Slope also affects the run off rate and its volume as a result the discharges to rivers or streams. As slope increases, the run off also increases which results to flood occurrence. Provided that the out flow rate of river is less than the inflow rate of run off from the area. The inhabitants of low-lying flat area, with small slope, have been affected by flooding especially where the lands are with relatively smaller slopes than the banks of the river. In the study area some parts of the banks of the Baro-River merges in to the adjacent lands and even in these areas the flood plain is relatively restricted. In other parts, the banks have higher slope than the adjacent lands consequently resulted in inundation of the lands will take place. However, if consideration is made from the view of slope length, a long slope produces more runoff than shorter one because the water gathers momentum as it flows.

Therefore, as the study area has long slope, the contributions of the precipitations to river discharges then flooding is higher. This can be evidenced by the higher correlations between flood producing precipitations and flood discharges for different return periods computed in sections.

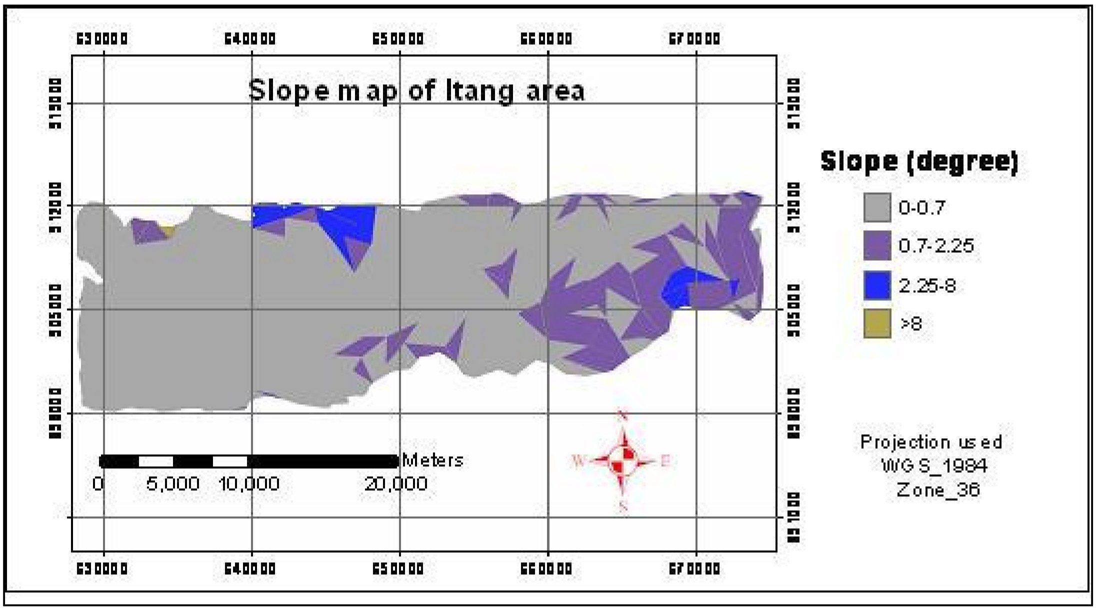


Figure-4.9 Slope map of the study area

4.2 FLOOD ASSESSMENTS

4.2.1 Flood Hazard Assessment

According to UNDRO (1982), a natural hazard is the probability of occurrence, with in a specified period of time and with in a given area, of a potentially damaging phenomenon. It is a physical event that can have an impact on human beings and their environment and, unless this conjunction occurs, there will be no damage or disaster. The hazard involves the human population placing it self at risk from physical events.

Flood hazards result from a combination of physical exposure and human vulnerability to geophysical processes. Physical exposure reflects the type of flood events that can occur, and their statistical pattern at a particular site, whilst human vulnerability reflects key socio-economic factors such as the numbers of people at risk on the flood plain, the extent of any flood defense works and the ability of the population to anticipate and cope with hazard smith (1998)

This specific combination of factors happens in Itang area where inhabitants of the area are populating the food plain area on one hand because of their living style being along the rivers in most of the areas and on another hand for searching of pasturelands for their cattle.

This situation is again increasing from time to time probably because of lack of awareness of their influencing conditions to trigger flooding.

As mentioned in chapter1, this research intends to assess flood hazard that affects the area and to construct flood scenarios based on past events and hydrologic data, in order to develop basis for further vulnerability and risk analysis.

4.2.1.1 Methods for Hazard Assessment

Flood hazard can be assessed by approaches: The statistical or hydrological and Geomorphologic and meteorological data analysis.

Alexander (1993) stated that hydrological approach comprises methods of calculating or analyzing mainly variables like discharge recurrence intervals, water levels and etc. On the other hand the geomorphic approach consists of geomorphic analysis of the landforms and the fluvial system to be supported wherever possible by information on the past floods and detailed topographic information.

After a detailed review of different papers and publications related to the topic and a limited research that have been carried out in the study area besides physical exposure to the environment helped to propose alternative approaches to study flooding in the lower Gambella plain. Both TAMS (1997) and SELKHOZPROMExport (1990) carried out studies based on hydrologic data analysis and past flood event records for flooding nature and characteristic of Baro-Akobo basin that includes the research area.

For this reason, the present assessment made base on the above approaches in addition to inclusions of issues related to past flood events. The flood hazard zoning map for this study, was done based on data acquired during field through interviews and documents and reports on historical flood events, analyzed data of discharges and water levels from gauging stages and calculated return period floods of different magnitudes and frequencies, topographical characteristic of the area (slope analysis) and finally including geomorphologic units (fluvial geomorphologic units) and land use/land cover the study area.

The prioritizations of these factors were carried out using pair-wise comparisons of AHP.

During pair-wise comparison, the first priority was given to flood inundation areas and then to geomorphology. The slope of the area and land use classes was assigned the third and fourth ranks respectively.

After the weights corresponding to the factors an acceptability of the consistency ratio were analyzed and evaluated, the integration of the factors was carried out.

Comparison matrix of flood hazard factors

	Flood area	Geomorphology	Slope	Land use	Weight
Flood Area	1				0.407
Geomorphology	1/2	1			0.305
Slope	1/2	1/2	1		0.199
Land use	1/3	1/4	1/3	1	0.089

Consistency ratio = 0.05

Consistency is acceptable

4.2.2 VULNERABILITY ANALYSIS

4.2.2.1 Vulnerability and elements at risk

For land use planning and management purpose, a hazard map alone was not being sufficient for use. The locations where the largest economical losses due to natural disaster could occur should be identified and evaluated to reduce the consequent of the damage.

Therefore need of complementing natural hazard studies with vulnerability and risk assessments.

WMO (2006) explained vulnerability to floods is a community's proneness to be impacted adversely by flooding and is represented by the inability or incapacity of a community group to anticipate, cope with, resist and /or recover from its impacts. It is a condition that determines the transformation of a hazard in to a disaster. Vulnerability to floods is a combination of complex, dynamic and interrelated mutually reinforcing conditions like physical or constitutional or organizational and motivational or altitudinal. These conditions of vulnerability can be broadly grouped into these types of factors: physical, social and psychological.

CSA (1997) described vulnerability as a measure of the robustness (or alternatively, the fragility) of the even (hazard). Vulnerability of an element depends up on its type and character. It is conditional on the element being at the site at the time of the event.

Quantitatively, vulnerability can be the estimated probability of total loss or damage to specific element, or in the case where the probability of some loss or damage is assumed to be certain, it is the estimated proportion of loss or damage to specific element. Both can be expressed as a number between 0 and 1.

Qualitatively, it can be expressed by vulnerability ratings in two ways; first when total loss or damage is assumed, ratings such as very high, moderate, low and very low likelihood of total loss or damage and on the other hand when probability of some loss or damage is assumed to be certain, vulnerably can be exposed by the qualitative proportion of loss or damage (ratings), such as no loss or damage low loss or damage, moderate lose or damage high loss or damage and total loss or damage.

Vulnerability is often defined with regard to a given element or set of elements at risk. These are elements of social, environmental and economic value and include humans; property, the environment, and other things of value some combination of these that are put at risk (adapted from CSA, 1997).

These may include human life and bodily harm, public and private properly (buildings, structure, land, resources, recreational site and cultures heritage feature), domestic water supply, wildlife habitant, visual resource and timber and etc. when elements are known to be at risk; they are referred to as elements at risk.

4.2.2.1 Methods for flood vulnerability assessment

The basic method to evaluate losses is dependent up on the development activities in the area and use of stage damage curves alternatively called loss functions or vulnerability functions. A stage –damage curve mainly related to a specific class of buildings or crops and present information on the relationship of flood damage to depth of flooding or stage (Smith, 1994).
Among different types of flood damages, tangible and intangible damages whether or not monetary values can be assigned to the consequences of flooding are the commonest ones. Intangible losses may include inconveniences and health related problems. Tangible damages can be divided in to the direct and the indirect damages. Direct damages result from the physical contact of floodwater with damageable property. These are the functions of many variables. Some of these are controlled by the physical make up of the flood prone areas that is land use and its susceptibility to flood damage. Others are related to the characteristics of the flood event, including the area covered, the depth, duration of flooding and etc.

Indirect damages are losses caused by disruption of physical and economic linkages of the economy. In general loss functions are mostly related to the description of direct damages to the elements at risk.

Smith and Ward (1998) distinguished two approaches to the calculation of loss from floods. The first is based on collection of actual flood damage information. And the second method involves estimating the potential losses expected to result from the flood events of specified severity based on generalized relationships between certain flood characteristics and physical damage. This is based on synthetic stage damage curves rather than actual direct loss values as the method is regarded as more systematic. Most synthetic methods of estimating flood losses rely on simpler relationships between flood depths or stage and damage.

The synthetic stage damage curves can be constructed based on existing databases and field survey. Both methods require subdivision of elements at risk in to different classes.

Among several factors related to damages due to flooding this study will focus only in damages due to floodwater depth and flood extents. The method developed in this research for vulnerability assessment can be considered as a GIS-based hybrid between the actual flood damages and the existing database approaches. That is because the assessment is based on the databases of some of the classes of the land use (elements at risk) with in the study area in addition to information related to the 1988 flood events in Itang area. This method can be defined as a way of assessing the flood vulnerability of specific area though the combination of map of land use and flood scenarios for different return periods. This combination is carried out using a GIS and applying loss functions.

Elements at risk of the study area can be generated from the land use/ land cover map of the area. The different categories of the land use/land cover to be considered as elements at risk are: Agricultural lands, urban or built up areas, forested lands and grass and wet land vegetations and locations of villages. It has been assumed that the locations of the villages represent the center of the areas occupied by the house inhabitants.

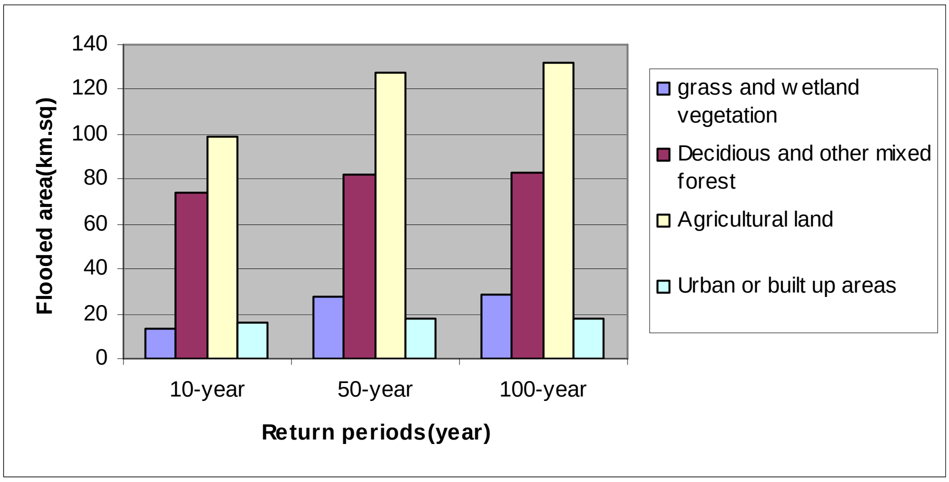


Figure-4.9 Inundation areas of land use classes for the three return periods

Agricultural fields including cultivatable lands and other agricultural lands have been assumed to be covered with crops and the details of the crop type was disregarded. And the forested lands were considered to included the both deciduous and the other mixed forest classes. Grass and wetland vegetations have been treated together.

Table-4.7 Percentages of inundated areas of land use classes

Classes of elements at risk	Proportions of the classes for different return periods (%)		
	10-years	50-years	100-years
Grass and wet land vegetation	34	69	72
Forest	57	63	64
Agricultural land	37	48	50
Urban or built up areas	30	34	35

4.2.2.3 Vulnerability function

Known also as stage damage or depth curves, the vulnerability or loss functions relate floodwater depths and degree of losses or damages on specific type of element at risk.

It is important to mention that aim of this research is to employ GIS tools for flood vulnerability assessment by integrating the available data. This means the suggested loss functions may not necessarily be the exact ones, because they are based on assumptions and limited data.

Some assumptions, needs to be established before defining the loss function.

- The flooding is assumed to be passive that is floodwater flows gently over the adjacent lands to the banks of the river and the water with almost no sediment load.

- No damages to the elements associated with stagnated water as the water logging depressions are common in the study area.
- The flood water depth is considered as mean and believing that its distribution is uniformly over the terrain
- The calculated flood depths for the three returns periods 10,50 and 100- year's floods are 6,6.2,6.3 meters respectively. Therefore if any of the classes of the elements is totally located with in the flooded area, it is assumed as complete loss, for the other classes the proportions of their total area is assumed to correspond with their degree of vulnerabilities.
- The assignment of vulnerability values depended directly on the total area covers of each element (except for the villages) and the assumptions made for each class.

Several steps were followed in order to obtain the final flood variability maps for the study area.

- Flood water levels computed form flood frequency analysis for each return period was added to the elevations collected along the riverbanks and considered to represent the bank full stages (floods stages).
- Average elevations along the river bank were taken by assuming that these values represent better than the gauge station location and the average elevations after adding, are 427, 431,and 431.5 meters for 10year, 50 and 100-years floods respectively
- Using the DEM of the land escape and the average elevations, it can be possible to determine the extent of floods corresponding to the return periods assuming that the land surfaces lower than those elevations would be inundated with floods of those magnitudes.

The computed flood areas and flood depths have been related to each category of the elements and made available as in put for loss function determination.

Knowing the water depths and the proportion of the inundated area for each class of the elements out of its total area, then corresponding vulnerability values assignment is done using an. **If Function** similar to this one:

Vulnerability for 10-year floods

a) *Agricultural Land*

$$\text{Vulnerability} \begin{cases} 0 \text{ if depth } =0 \\ 0.37 \text{ if depth } <=6 \\ 1 \text{ if depth } >6 \end{cases}$$

b) For forested lands

$$\text{Vulnerability} \begin{cases} 0 \text{ if depth} = 0 \\ 0.57 \text{ if depth} <= 6 \\ 1 \text{ if depth} > 6 \end{cases}$$

c) Grass and wet land vegetation

$$\text{Vulnerability} \begin{cases} 0 \text{ if depth} = 0 \\ 0.5 \text{ if depth} <= 6 \\ 1 \text{ if depth} > 6 \end{cases}$$

d*) Urban or built up areas*

$$\text{Vulnerability} \begin{cases} 0 \text{ if depth} = 0 \\ 0.3 \text{ if depth} <=6 \\ 1 \text{ if depth} > 6 \end{cases}$$

In the same way, the values can be assigned for other two periods and the final vulnerability map for a specific return period is obtained after reclassifying the values in to different vulnerability categories (high, moderate, low or no vulnerability). Table-4.8 gives the vulnerability values of elements at risk for the three return periods.

Table-4.8 Vulnerability values of the elements at risk

Elements at risk classes	Vulnerability values with the corresponding flood depths of the return periods		
	10year	50year	100year
	0-6m	0-6.2m	0-6.3m
Grass and wet land vegetation	0.34	0.69	0.72
Forests	0.57	0.63	0.64
Agricultural lands	0.37	0.49	0.50
Urban or built up	0.30	0.34	0.35

areas			

The final categories of vulnerability for the three return periods will have the form

No vulnerability vuln = 0

Low vulnerability vuln <=0.35

Moderate vulnerability vuln <=0.5

High Vulnerability vuln <=1

Where, vuln refers to vulnerability

Vulnerability assessment for villages was based on the locations of the villages and whether a specific return period flood inundates them or not. Therefore, two categories of vulnerabilities would be obtained and table- 4.9 gives the number and percentages of villages that would be inundated or not inundated for every return period. Accordiingly,

No vulnerability vuln = 0 (not inundated)

High vulnerability vuln =1(complete inundation)

Table-4.9 vulnerability values of villages

Return period	No of villages Inundated	Percentage	No of villages Not inundated	Percentage
10	9	30	21	70
50	20	67	10	33
100	20	67	10	33

4.2.3 Risk analysis

According to CSA (1970) risk is the chance of injury or loss as defined as a measure of the probability and the consequences of an adverse effect to health, property, the environments, or other things of value. WMO (2006) defined flood risk as the expected losses from given flood events over a specified time period. It is imperative to understand the construct of flood risks which consists of

- The magnitude of the flood expressed in terms of frequency and severity (depths of inundation and related velocities)
- The exposure of human activities to flooding
- The vulnerability of the elements at risk

Risk is a combination of vulnerability of elements at risk and the probability of occurrence of the event and can be expressed as

*Risk= vulnerability * elements at risk * probability*

The quantification or qualification of economical and non- economical losses caused by natural disasters and the creation of further risk maps can be seen as the final step in the process which involves hazards and vulnerability assessments. Risk assessments play a very important role in the planning and design to disaster mitigation measures. Li Jiern (2001) stated that for risk and loss investigation, main contents are the inundated area of each county and its mapping, including its land use classification, especially the inundated area of cultivated land and that of residence area.

4.2.3.1 Method for risk analysis

As it was stated earlier, the main aim of this study is to use GIS tools for assessment of flood risk zones at different flood levels calculated by frequency analysis methods, different categories of land use land cover of the area and vulnerability of the elements. The basic idea of flood risk mapping in this study is to regulate land use by flood plain zoning in order to restrict damages that may occur by different return period's floods. The approach of this method can be considered as an important non-structural flood management technique through flood risk mapping.

- First the area of each land use classes (elements at risk) will be computed
- The proportions of the inundated classes of the land use for the return periods computed and the degree of damage or loss would be assigned
- Combining the vulnerability values previously determined will carry out the damage estimation and the proportion of the impacted part of the land use classes or the assumed complete damage or loss corresponding to the villages.
- Integrating the probabilities corresponding to return periods and the damage already calculated will produce the final risk map.
- Finally, different degrees of risk will be assigned based on the results of the calculation. This map shows the probable total loss that may occur. The flood damage assessment for each classes of the land use should be done by calculating values per pixels and not for the whole plot of the class. This would avoid that high damage and risk in some categories are related to their large area not to their vulnerability, as it should be.

Risk calculations of 10-year flood for each considered elements at risk

a. Grass and wet land vegetations,

*Risk = vulnerability*elements at risk*probability*

$= 0.34*13.64*0.1 = 0.464km^2$

b. Forest

$Risk = 0.57*74.01*0.1 = 4.219km^2$

c. Agricultural land

$Risk = 0.37*98.78*0.1 = 3.655km^2$

d. Urban or built up area

$Risk = 0.3*15.75*0.1 = 0.473km^2$

In the same way, risks that may arise from floods of the 50 and 100-years return periods for each land use classes would be determined and the table below gives the results of risk calculations for the three return periods and classes of land use/ land cover.

Table-4.10 Amount of damages to different elements at risk

Classes of elements at	Risk calculation results for different return periods (km^2)

risk	10-years	50-years	100-years
Grass and wet land vegetation	0.464	0.382	0.207
forest	4.219	1.030	0.532
Agricultural land	3.66	1.228	0.658
Urban or built up areas	0.47	0.120	0.063

CHAPTER FIVE

INTERPRETATION AND DISCUSSION OF THE RESULTS

5.1 Flood hazard zones map

Considering those factors different degrees of hazard zones were assigned to the whole area. Accordingly, four categories to flood hazard zones were established

1. **Zones with high flood hazard**

They are located mostly to the west part of the study area around the town itang and extend to the east till village pukumu. From the north they are restricted to the town Itang surroundings. These areas also included the southwestern terrains being margined with the flood plain. On the basis of historical flood information, these are the commonly inundated areas, which comprise most of the waterlogged units, and topographically almost flat lands. Selkhozpromexport (1990) described the area from geomorphologic point as part of the low Illubabur plain, which occupies the western Gamabell Plain. According to this study, the table-like flat surface of the plain and the dominant processes of accumulations and water logging characterize these areas.

These geomorphic settings of the area may contribute to have inundated by facilitating the runoff and then increase the discharges of the river. The lower flood plain that extends a few distances to both sides of the riverbank is also included with in this hazard category. Therefore, settlements with in this flood prone area would face the consequences of the hazard. Most agricultural lands and some grass lands that are commonly used as pasture lands for cattle are part of their areas. This hazard class would affect the rural part of Itang and villages that are relatively with higher number of houses like pot, pino, penyman, penkimalr, ibago and imero. And some portions of Ugala, Kerul and Guranyiyuko villages would possibly be inundated. The extensive use of the area for agriculture and as a pasture can be considered as triggering factor to contribute to a more danger of the floodwaters. These areas are affected by discharges of $1452 m^3/sec$, which is less than 1988 flood.

The 10-year floods are dominant to contribute to this degree of hazard zones as compared to the other two flood scenarios. Although, its inundation area is smaller, its percentages of contributions are higher than the 50 and 100-years floods. This shows the priorities of frequencies (probabilities) of occurrences for flooding of these areas rather than the magnitudes to have categorized in to high hazard zones. On the other hand, even equally rating of the available factors clearly shows the more significance of the inundation areas. Therefore as long as the sounding of the factors is concerned, these zones are highly governed by the 10-year floods. The narrowly extension to ward east along the riverbanks indicates the influences of the anthropogenic factors. For this condition, the effects of settlements and the intensive uses of lands for agricultural activities can clearly take the responsibilities. Most of forested lands are also inundated by this degree of hazards.

2. **Zones with moderate flood hazard**

These are areas in which the medium frequency floods and return periods of 50 and 100-years predominate. They correspond to most of the southern and the central parts in addition to some parts of the northern and eastern terrains of the research area. The low-depression areas, in spite of being flatter and located relatively further a way from the river banks, and that comprise most of the swamps and other water logging lands are usually inundated. For this reason, this unit shows a lower degree of flood hazards because the floodwater gets time to gather with in this area. However, this condition may have influences to duration of flooding. Some of the forests and grass and wetland vegetations of the area are found with in this category of hazard and as a result the cattle may face food shortage.

Terul, pukumu, penyiwo, pomal, upanyiya, penkwo villages and the recertly reformed wereda town, Abol would be affected with the medium degree flood hazard partly or completely. Being along the banks of the river, would make them susceptible to flooding. In these areas, it is also necessary to note the contributions of vegetation cover and soil types especially during intense rainfall when water get stagnated in the low-depression areas and water logged units of the area. The category includes all those units that would be affected by flood with discharges of the 50 or 100-years return periods that has potential of affecting areas that may suffer during these flood events.

For these zones, the 50 and 100-years floods have played the influencing role better than the 10-year flood next to the low-depress ional geomorphic units. Being low-lying lands, floodwater can easily flow toward these locations and inundate the agricultural and bare lands. The high magnitude floods of these zones can be related to the 50 and 100-year floods for their potential of covering larger areas relative to the most probable floods. The contributions of the probable flood-producing precipitations corresponding to return periods have been excluded. Though, their role is relatively high as their analysis was based on amounts rather than intensities. The topographic nature in combination with human activities can be seen as intensifying factors for the degree of these zones. Again, if it can be considered from hydrologic factor point of view, these zones would be taken as the 50 or 100-year return period flood. In the moderate hazard zone, the integrated influences of the available factors have been implied well than they do in the outlining of the hazard zones for high hazard areas.

3. Zones with low Flood hazard

Low frequency floods with return period of 100-years have limited involvement to these locations. Non-differentiated uplands located in the eastern and southeastern and some surrounding northern parts of the town Itang, are the ones included with in this category. Topographically, these units are with relatively higher slopes and mostly found away from flood sources. Even it is rare to find reports of historical flooding in this sector. For this degree of hazard high magnitude of discharges are expected to reach those locations when the floodwater overflows its banks and spread over these areas. Therefore, because floods of this magnitude are rare and less probable, these locations become categorized as low hazard zones

4. Zones with no flood hazard

Some portions of high old terrace deposits, which are higher remnants on which the northern part of the Itang town is located, are considered as non-hazardous zones. On the contrary, their relatively steep slopes make them to be optimum zones for the concentration of runoff water during heavy rainfall that may cause flooding in the lower areas. The flood hazard map generated was based on the above-mentioned factors and is order to give an idea of the characteristics the flood may have and how often is likely to occur. The concepts of flood frequency, magnitude and geographic position of the area are essential for the assessment of the flood hazards as well as for the process of flood vulnerability and analysis. These types of maps can be used as tools particularly to planners and decision makes for formulating better strategies in terms of reducing the vulnerability.

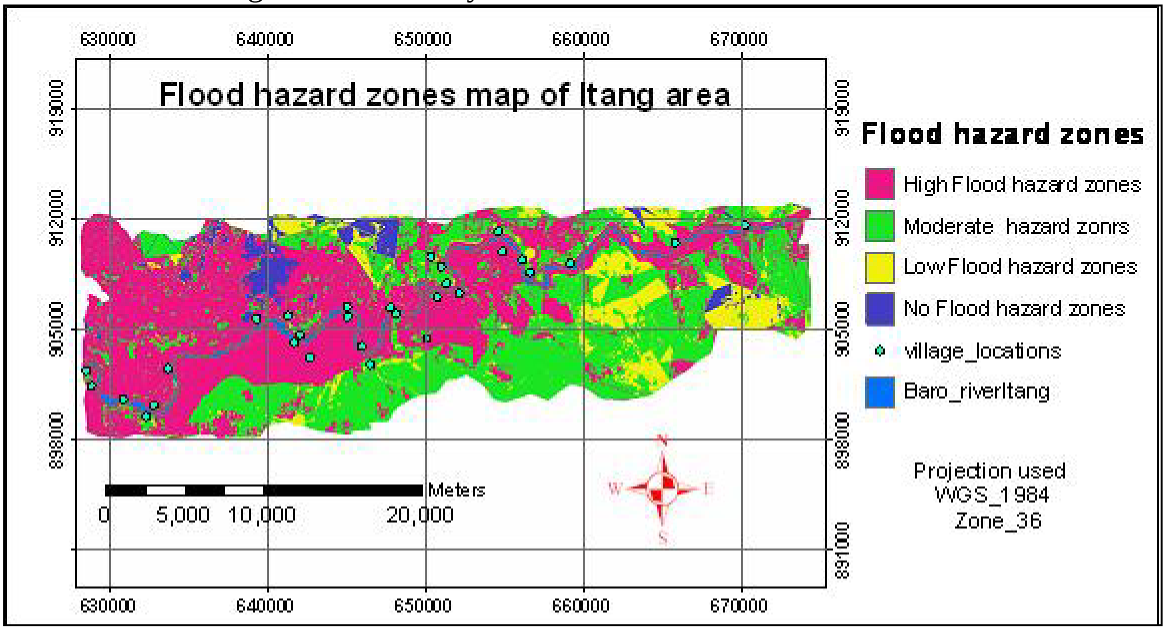


Figure-5.1 Flood hazard zonation map of study area

5.2 Flood vulnerability maps

A flood vulnerability map was obtained for each return periods analyzed, after all the steps described above were completed. Of course, these maps may not have to be considered as definitive results.

As it was explained earlier, the loss functions defined for this research are not necessarily the exact ones as they are based on limited data besides there are some classes for which the values were not determined by considering their limited value abilities and being less importance for others. More over information related to the effects of flood water on some items requires detailed studies by looking them from different angles so as to incorporate their vulnerabilities.

Also, not all the areas are vulnerable to flooding rather those, which are located with in hazard zones. Because of that, the analysis was reduced to potentially vulnerable areas using the degrees of hazardous zones in relation to inundation area as a mask.

Taking in to account the time of flooding at which most of the lands are covered with crops the values assigned for agricultural lands. For instance, according to Regional DPP office, 388.3 hectare of land with maize crops was destroyed by 2006 flooding in the study area. Some grassland is commonly used as pasture lands for cattle as most of the peasants are making their livings by raising cattle in addition to agriculture. Thus, it has been a common event for this area to be flooded and the animals become liable for food shortage during flooding. The table 4.8 and 4.9 show the vulnerability values for elements of consideration

After assessing vulnerability values and functions for the return periods the values were reclassified to categorize the degrees of vulnerabilities corresponding to the periods and to obtain vulnerability maps. It can be expected that the values increase with return periods.

1. No vulnerability

These are areas with zero vulnerability values and include locations in the central and eastern part of the study area. They are areas out of the inundation extents of the return periods as the bases for vulnerability assessments were flood depths and areas.

2. Low vulnerability

This class includes areas that have values less or equal to 0.35. For 10-year flood, the grass and wet land vegetations an Urban or built up areas are expected to face low vulnerability. Whereas, during 50 and 100-years flooding only urban or built up areas would face this degree of vulnerability. These scenarios are with large magnitude of flood so that they cover large inundation extents. The differences for the scenarios could be related to their direction of extensions relative to the locations of the land use classes and the size of inundation areas. The frequent flood that extends less than the infrequent ones, therefore only small parts of the vegetation class are included. The 50 and 100-years flood covered wide area of the grass and wetland vegetation as a result increases their vulnerability values and excluded from this category of vulnerability.

3. Moderate vulnerability

For all the three return period floods, agricultural lands would face moderate vulnerability with the values of from 0.35 to 0.50. However, the degree of vulnerability varies with in the return periods, which is less for the most probable one and higher to the rare ones for the same reasons that mentioned earlier.

4. High vulnerability

Forested and grass and wet land vegetations would be highly vulnerable for the 50 and 100-years flood whereas only forested lands are likely to have high vulnerability for 10-year flood. The less extension of the 10-year flood reduced the vulnerability value of forested lands. The values are larger for both classes in case of 50 and 100-year floods as consequences of their large magnitude

The magnitudes of their discharges are 1591.84 and 1643.77m^3/sec respectively and shows that they are among floods of extreme events and almost comparable with historical floods of the

1988 with peak discharge of 1607m^3/sec that caused sever damages and losses around Gambella and Itang towns. This event was so large to cover areas of 9720 km^2 and flooded large agricultural and pasturelands

As vulnerabilities of the villages are concerned, about 30% of the villages would be exposed to the 10-year floods for complete inundations that refer to high vulnerability and this flood may not affect the rest 70% of the villages that are not vulnerable. About 67% (20 villages) of the villages would be vulnerable to the 50 and 100-years flooding by complete inundation and 33% (10 villages) may not suffer from these rare events. The analysis of vulnerability was established based on the magnitudes of the return periods contrary to the hazard zonation, which gave emphasis to the frequencies of the return periods,

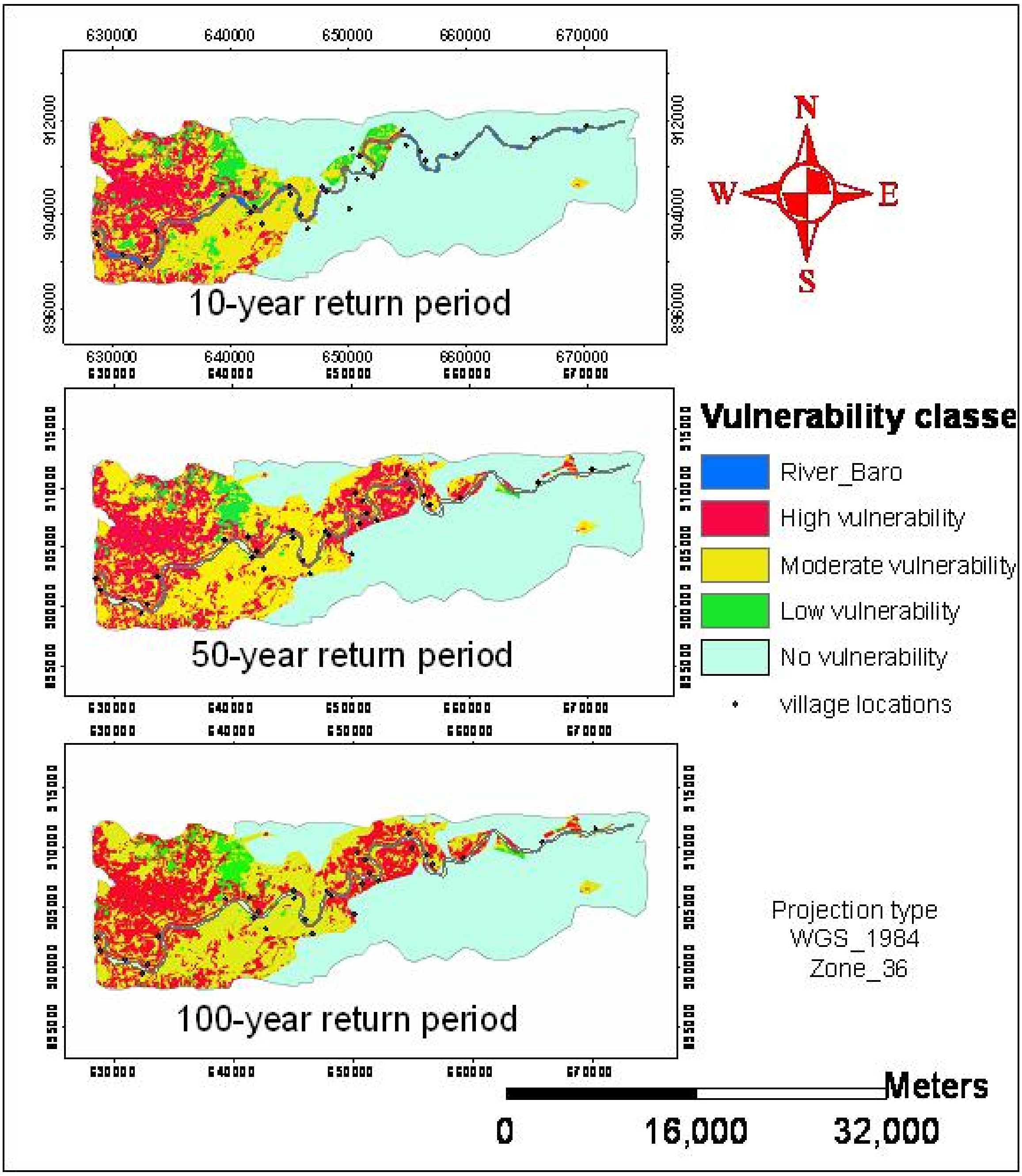


Figure-5.2 Flood vulnerability maps of the three return periods

5.3 Flood Risk maps

The analysis for various return periods, probabilities and vulnerabilities leads to the following risk assessments on the basis of return periods and elements at risk.

10-year return periods

For this return period with discharges of 1453.25m^3/sec and probabilities of 10%, the total areas inundated by the flood will be 216.62km^2.

Under this scenario, the average flood depth from the land would be 6m and approximately 0.464km^2, 4.21km^2, 3.66km^2 and 0.437km^2 of grass and wet land vegetation, forest, Agricultural land and urban or built up areas respectively would be affected. Of the 30 villages, 9(30%) of them are likely to suffer damages. The rest 21(70%) villages are estimated to be free from inundation

50-year return periods

This return period has magnitude of flood discharges of 1591.8m3/sec and 2% probability; the total area affected will be 277.23km. Under this scenario, the computed flood depth would be gm from the ground surface and approximately 1.030km of forested land would be covered with floodwater. The estimated damages to grass land and wet land vegetations and agricultural lands will cover 0.382 and 1.228km respectively and urban or built up areas may be affected least with 0.12km areas out of the total number of villages, 20(67%) of them would be expected to be flooded and the rest 10(33%) villages are assumed not to be affected by flooding from this return period.

100-year return periods

It is the return period of with discharge 1643.77km^2 and 1% probability. The total area flooded will be 284.50km^2 (figure-5.2) indicates the extent of inundation in itang area during this flood with computed average depth of flood 6.3 meters from the land surface.

Although this scenario is with the largest flood magnitude, damages that would be resulted to different land use/land cover classes are least as compared with the other scenarios relative to its large extent of inundation. Approximately 0.658 km^2 of agricultural land and 0.532 km^2 of forested lands would be affected highly relative to the less impacted grass and wetland vegetations of 0.20km^2 flooded area and the least damages to urban or built up lands with flooded areas of 0.063km^2.

Estimated damages to villages of this return period flood would be similar to the 50- years floods in which 67% (20 villages) of the villages are expected to be inundated and the rest 33%

(10 villages) would be free from damages of the 100-year return period floods. Risk analysis to other classes of land use/ land cover was excluded by assuming their less importance and invisible values (the sand deposits and bare lands). It is clear that this does not mean that they would not be damaged as long as they can be seen as elements at risk. The unforeseen damages to water bodies were also left inconsiderably for similar reasons in addition to there being permanent water bodies.

Risks to villages were analyzed based on the locations of villages collected during the fieldwork. In these cases, the locations of the villages were assumed to refer to the central position of the populated areas. The absence of updated population data corresponding to the study area forced to shift for use of the above alternative. The attempt was to categorize the villages' locations whether a specific return periods flood would inundate them or not.

Table-5.1 Conditions of damages to villages

Return period	No damage		High Damage	
	Number of villages	Percentage	Number of villages	Percentage
10	9	30	21	70
50	20	67	10	33
100	20	67	10	33

Based on vulnerability values of elements at risk and probabilities of return periods, the risks that would be occurred to different classes of land uses in terms of damage or losses have been estimated. The degrees of damages or losses are proportional to the areas of the classes that would be affected and the probabilities of the return periods.

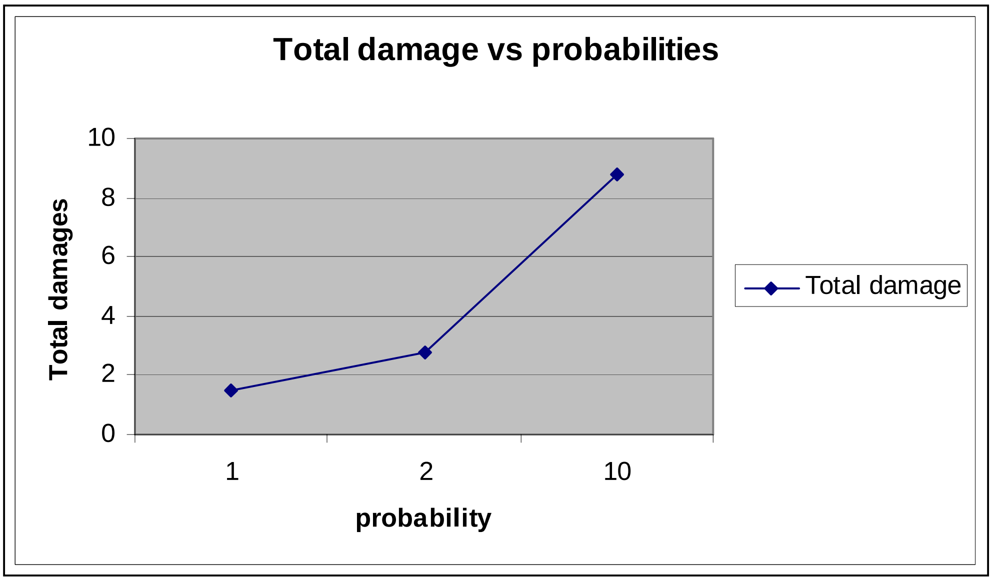


Figure-5.3 shows the relationships between probability and total damage

According to the definitions of risk given earlier, the risk assessment implies two stages: the damage estimation by multiplying the vulnerability with inundated portions of the elements and the final risk calculation was obtained by multiplying the results with probabilities. Normally, probabilities of the return period are inversely proportional to their return periods as a result more damages are expected from 10-year floods than 50 and 100-years floods. Then all the obtained values are added up to get a total risk values for each return period

Table-5.2 the total damage for the three return periods

Return Period	Total damage/risk (km^2)
10	8.811
50	2.76
100	1.46

In case of village damages, the risk can be seen as either high with the assumption of complete inundation or no damage where the villages are not inundated that is being in the no damage zone and regardless of their spatial extent.

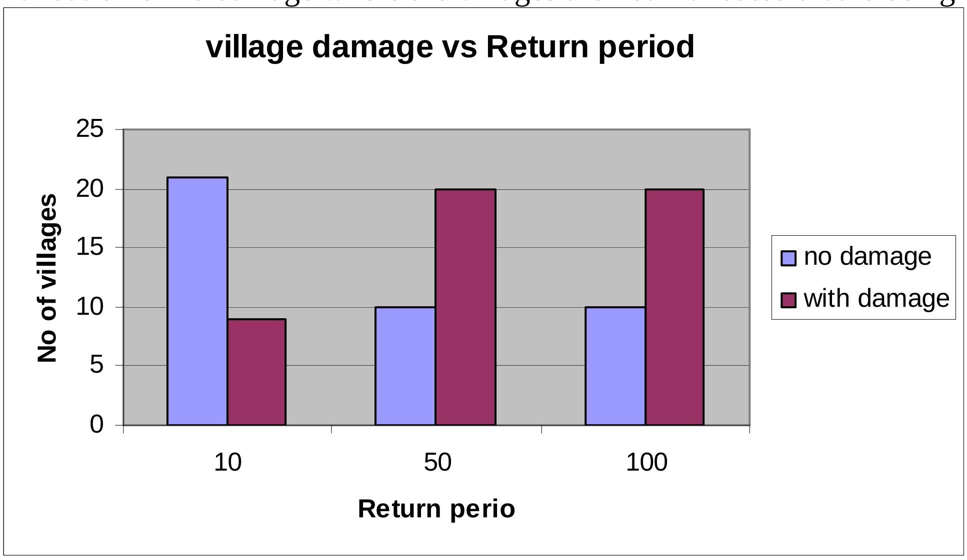


Figure- 5.4 Amount of damages to village

If the base for classification was made using the total risk value, the 10-year flood would cause high risk and the 50 and 100- year food could generate moderate and low risks respectively. This technique leads to the generalization of that a single element at risk will face different degrees of risk corresponding to the return periods. Taking this option in to account, the final risk maps corresponding to the three return periods were generated. This classification was preferred rather than combing the risk maps of the return periods in to a single map. Accordingly, the following reclassification gives four categories of risk for each return period on the basis of amount of damage for the every element at risk classes.

Table-5.3 Risk classes based on the return periods

Risk class	Amount of damages for the return periods		
	10-year	50-year	100-year
No risk	0	0	0
Low risk	0-0.5	0-0.4	0-0.2
Moderate risk	0.5-4	0.4-1.1	0.2-0.6
High risk	>4	>1.1	>0.6

This classification has been obtained by considering both the probabilities and magnitudes of the flood for the three return periods.

For all the three periods grass and wet land vegetations and urban or built up areas would face low degree of risks. Agricultural lands are at moderate risk for 10-year flood whereas forested lands could suffer from this degree of risk for 50 and 100-year floods. High risks are expected to damage agricultural lands in cases of 50 and 100-year floods, however, it would be forested lands that are likely to face this class or risk in case of 10-year floods. Other classes of land use / land cover that have not been considered would not suffer from any degree of risk. Figure shows three risk maps of the return periods

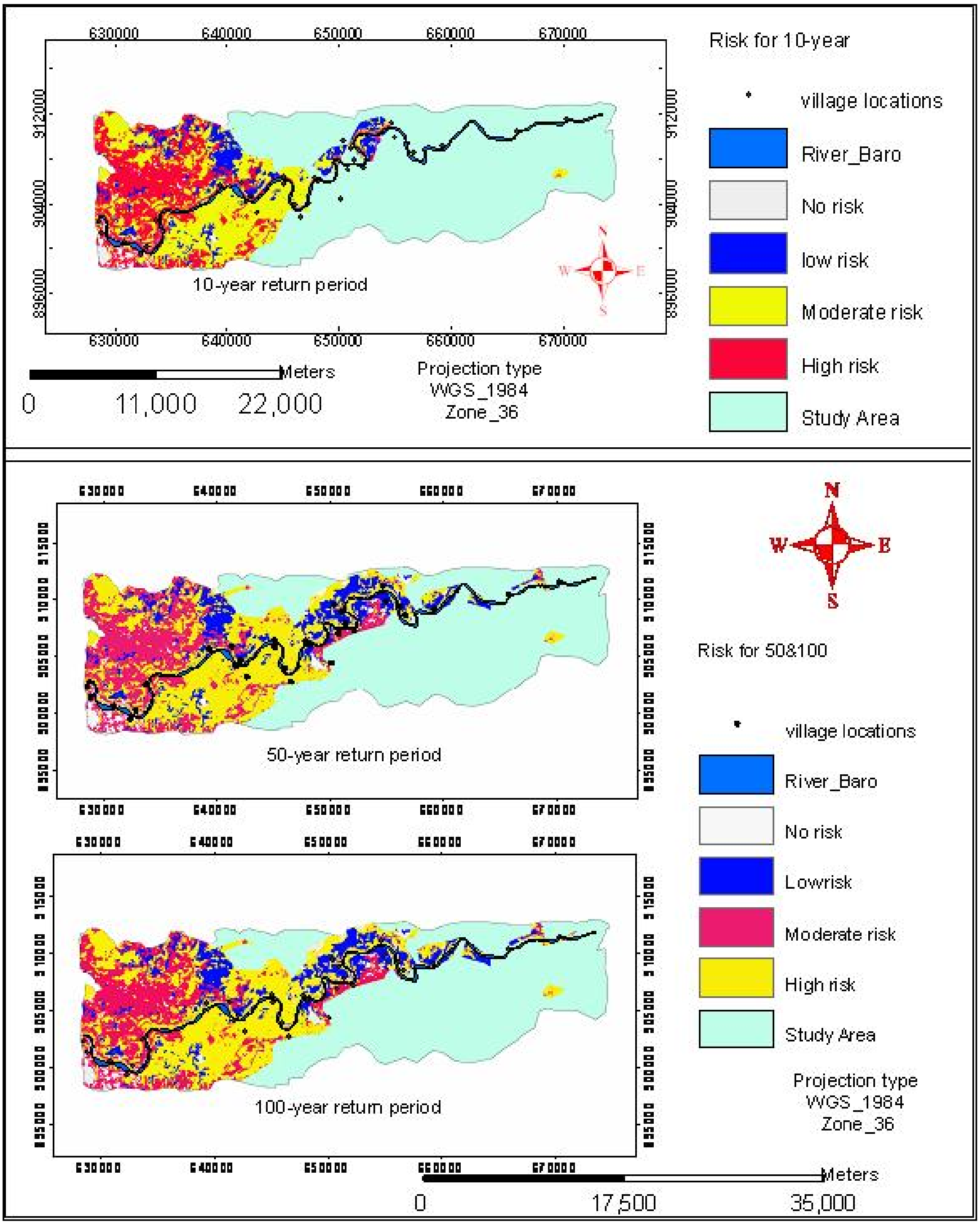


Figure-5.5 Risk maps of the three return periods

CHAPTER SIX
Conclusions and recommendations

6.1 Conclusions

The final stage of this research consists of a retrospective analysis of what has been done and which conclusions and recommendations it is possible to draw from it. After development of this study, it is possible to conclude the following:

- Flooding in the Itang area is primarily related to the high discharges of Baro river which makes its sources from t he high lands. The occurrences of high rainfalls especially in Gambella areas and the surroundings of the Itang summits also contribute to the flooding of the study area. But flooding is also due to the factors related to the location of population settlements and their rapid growth in addition to uncontrolled encroachments to flood prone areas, flood plain. This situation combined with absence of land use planning, has intensified the flood problems in the study area.
- As long as meteorological and hydrological reasons are considered, it is not uncommon to expect floods during rainy seasons usually June to September, but sometimes the time of flooding even extends to October, as it can be evidenced from the peak discharges and water levels besides some annual maximum precipitations data collected.
- The results of the analysis show some relatively low flood discharges with what would be expected. The rainfall on the area is relatively high, and although it is not an absolute indication of the flood discharges, it is unlikely that the flood would have such low value of peak discharges.
- The distribution of peak discharges and water levels with in the study area is mainly determined by the topographic characteristics of the surrounding lands during specific discharges of a given return period folding. It is to say that floods caused by the river tends to have often the same distribution, showing only small variations in water depths and slight changes in flood extensions. This could show the need for rainfall intensity and flood duration data for better representation of nature and characteristics of flooding in the area. An area of inundations covered by the 50 and 100 years floods clearly indicate this situations and even the extents of damages that may occur is almost similar. The land use / land cover classes that could suffer from high vulnerability and risk is also similar for the two return periods.

- Areas considered with a high flood hazard correspond mostly to the western part of the study area a little bit extensions to the central and eastern parts. This can be related to water logging depressions, land use changes and the flat slope of these locations. The nature and types of vegetations and soils that covered this area has also contributions usually in relation to the amount of runoff that produces flooding.
- On the other hand flooding in the areas with a medium or low hazard occurs more naturally due to the presence of very flat and depression lands although there exists less influences form inhabitants.
- The flood scenarios of the different return periods can be considered as having some degree of reliability, because it was observed to coincide with the inundation extent out lined previously based on the 1988 flood event during studies conducted by selkhozpromexport (1990).
- The method employed for flood vulnerability assessment was based on the combinations of different classes of land use /land cover and the flood scenarios of different return periods that played role in producing the extent of flooding. This combination was carried out applying loss functions, which reflect real conditions of the area as far as the reliability of hydrologic data are acceptable. The risk assessment plays a very impotent role in the planning and design of disaster mitigation measures. Its success depends on correct valuation of the elements at risk. But in this study the damage analysis was based on the proportion of inundated areas of elements at risk. This method could be assumed as an alternative approach to cost valuation that gives definitive results.

6.2 Recommendations

- For future research mitigation. the method of vulnerability assessment would be better if it was based on direct measurements of flood depths to each category of the elements at risk.
- Structural and non-structural measures should be put in to practice in the study area, in order to reduce losses or damages due to flooding.

- Development activities in highlands and close to flood prone areas, where river easily flows due to natural conditions should be carried out by taking in consideration their interrelationships with flooding to down streams.
- It is recommended for hydrological services to undertake an active campaign of flood measurements with an objective to establish reliable rating curves.
- Policies related to flood plain areas, and management which helps to control populating to flood plain areas, control the in crease of run off and changes related to erosion and soil fertility and the conditions that changes the capacities of discharge of the rivers should be applicable
- An effective flood warning system is crucial to the provision of an adequate warning period for flood preparations and evacuation in flood areas, especially when a flood is likely to exceed flood waters of the 50 a 100 years.
- Carry out flood studies by integrating flood management system approaches that requires involvement of communities at risk
- The practical contributions of precipitations for flooding in the area are dependent on the type of recording gauges and consistency of the collected data. Therefore, as the stations are recording only the amount of rainfall and other parameters, installations of intensity recording gauges are recommended.
- Based on the above discussion, it is possible to recommend employing of flood risk mapping method that is an important non-structural and cost effective flood management technique and will help further in reducing flood damages in areas frequently affected by flooding.

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Annexes

Annex-1 Flood water level frequency analysis using Gumbel method

Year	peak	Rank	X-Xavg	(X-Xavg)2	RI
1985	6.05	1	0.508636	0.25871095	23
1986	5.34	16	-0.20136	0.040547314	1.4375
1987	4.39	22	-1.15136	1.325638223	1.045454545

1988	5.45	14	-0.09136	0.008347314	1.642857143
1989	5.28	17	-0.26136	0.06831095	1.352941176
1990	4.68	21	-0.86136	0.741947314	1.095238095
1991	5.54	13	-0.00136	1.8595E-06	1.769230769
1992	5.86	5	0.318636	0.101529132	4.6
1993	5.12	19	-0.42136	0.177547314	1.210526316
1994	5.85	6	0.308636	0.095256405	3.833333333
1995	5.58	12	0.038636	0.001492769	1.916666667
1996	5.12	4	-0.42136	0.177547314	5.75
1997	5.85	9	0.308636	0.095256405	2.555555556
1998	5.58	2	0.038636	0.001492769	11.5
1999	5.88	3	0.338636	0.114674587	7.666666667
2000	5.66	8	0.118636	0.014074587	2.875
2001	6	10	0.458636	0.210347314	2.3
2002	5.94	20	0.398636	0.15891095	1.15
2003	5.69	15	0.148636	0.022092769	1.533333333
2004	5.61	18	0.068636	0.00471095	1.277777778
2005	5.84	7	0.298636	0.089183678	3.285714286
2006	5.6	11	0.058636	0.003438223	2.090909091
avg	5.54136364				
stdv	0.42037733				

Annex-2 Flood precipitation frequency analysis using Gumbel method

year	Annual max.ppt	J(rank)	P(probability)
1985	73.4	13	0.57
1986	176	22	0.96
1987	148	21	0.96
1988	71.4	11	0.48
1989	83.4	16	0.7
1990	88.1	17	0.74
1991	90.8	19	0.83
1992	75.8	14	0.61

1993	52.1	3	0.13
1994	54	5	0.22
1995	60.8	6	0.26
1996	37.7	2	0.09
1997	118.4	20	0.87
1998	65.8	10	0.43
1999	71.7	12	0.52
2000	88.7	18	0.78
2001	65.5	9	0.39
2002	26.4	1	0.04
2003	52.1	4	0.17
2004	62.6	7	0.3
2005	63.6	8	0.35
2006	82.6	15	0.65

Annex-3 Flood water level frequency analysis using Log Pearson type-III

Year	Peak	Rank	Z=logx	Z-Zavg	$(Z\text{-}Zavg)^3$	Cs
1985	6.05	1	0.782	0.038387	5.65656E-05	0.00008
1986	5.34	16	0.728	-0.01583	-3.96457E-06	
1987	4.39	22	0.642	-0.1009	-0.001027366	
1988	5.45	14	0.736	-6.97E-03	-3.389E-07	
1989	5.28	17	0.723	0.002074	8.91481E-09	
1990	4.68	21	0.67	-0.73123	-0.390986716	
1991	5.54	13	0.744	1.41E-04	2.80322E-12	
1992	5.86	5	0.768	0.024529	1.47584E-05	
1993	5.12	19	0.709	0.034099	3.96483E-05	
1994	5.85	6	0.767	0.023787	1.34592E-05	
1995	5.58	12	0.747	3.27E-03	3.48376E-08	
1996	5.12	4	0.769	0.026009	1.75943E-05	
1997	5.85	9	0.753	9.45E-03	8.43373E-07	
1998	5.58	2	0.778	0.034783	4.20825E-05	
1999	5.88	3	0.774	0.030418	2.81444E-05	
2000	5.66	8	0.755	0.011744	1.61975E-06	
2001	6	10	0.749	5.59E-03	1.75052E-07	
2002	5.94	20	0.799	0.055602	0.000171898	
2003	5.69	15	0.729	-0.0142	-2.86571E-06	
2004	5.61	18	0.718	-0.0257	-1.69706E-05	
2005	5.84	7	0.766	0.023044	1.2237E-05	
2006	5.6	11	0.748	4.82E-03	1.1198E-07	
		Avg	0.743			
		STDV	0.035			

Annex-4 Flood discharge frequency analysis using Log Pearson type-III

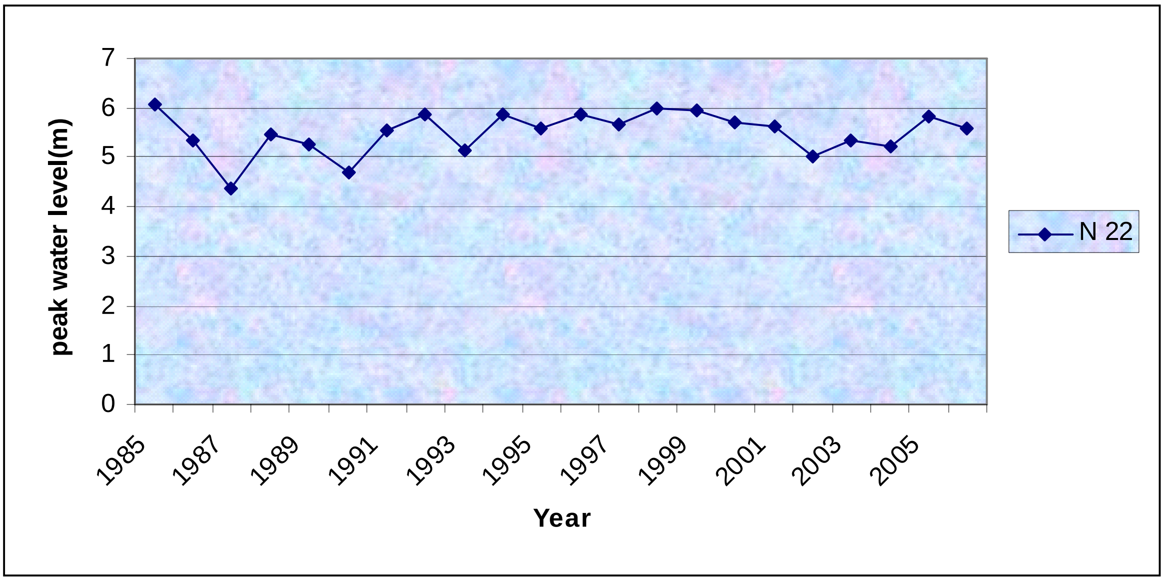
year	Q	Z=logQ	Z-Zavg	(Z-Zavg)3	Cs
1985	1228	3.089198	-0.007431526	-4.10425E-07	1.22E-08
1986	1162	3.065206	-0.031423765	-3.10295E-05	
1987	1092	3.038223	-0.058407255	-0.000199251	
1988	1607	3.206016	0.109385984	0.001308835	
1989	1260	3.100371	0.003740652	5.2341E-08	
1990	1610	3.206826	0.110195983	0.001338127	
1991	1330	3.123852	0.027221748	2.0172E-05	
1992	1428	3.154728	0.058098315	0.000196106	
1993	1456	3.163161	0.066531482	0.000294497	
1994	1252	3.097604	0.000974436	9.25252E-10	
1995	1162	3.065206	-0.031423765	-3.10295E-05	
1996	1270	3.103804	0.007173828	3.69193E-07	
1997	1195	3.077368	-0.019261988	-7.14666E-06	
1998	1305	3.115611	0.018980619	6.83803E-06	
1999	1286	3.109241	0.012611076	2.00566E-06	
2000	1196	3.077731	-0.018898713	-6.74989E-06	
2001	1187	3.074451	-0.022179174	-1.09103E-05	
2002	1015	3.006466	-0.090163851	-0.000732989	
2003	1122	3.049993	-0.046637036	-0.000101436	
2004	1071	3.029789	-0.066840422	-0.000298619	
2005	1249	3.096562	-6.74545E-05	-3.06926E-13	
2006	1187	3.074451	-0.022179174	-1.09103E-05	
	AVG	3.09663			
	STDV	0.051252			

Annex-5 Inundation areas of the land use land cover classes

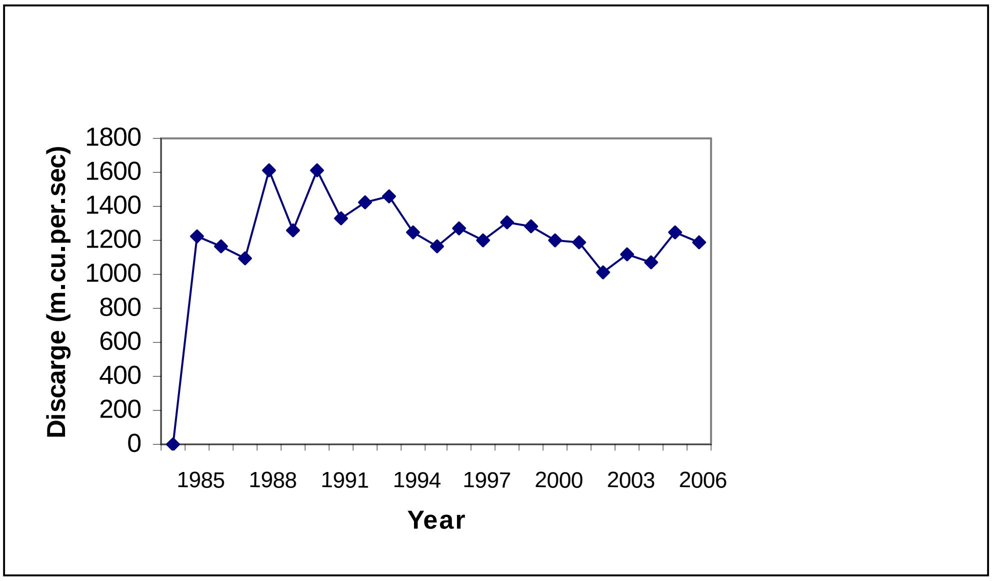
Elements at risk (land use/Land cover classes)	Total Areas (km^2)	Flooded areas of different return periods					
		10-year		50-year		100-year	
		(km)	%				

Grass and wet land vegetations	40.22	13.64	34	27.69	69	28.78	72
Forest	130.78	74.01	57	81.77	63	83.11	64
Agricultural Land	265.47	98.78	37	127.88	48	131.53	50
Urban nor built up areas	51.86	15.75	30	17.69	34	18.03	35

Annex-6 Flood water level verses year



Annex-7 Flood discharge verses year



Annex-8 Peak precipitation verses year