



**ASSESSMENT OF FLOOD RISK IN DIRE DAWA TOWN,
EASTERN ETHIOPIA, USING GIS**



**A THESIS
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES**

**IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN GIS AND REMOTE SENSING**

BY

DANIEL ALEMAYEHU DEMESSIE

MARCH, 2007



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List of Acronyms

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CSA	Central Statistics Agency
DDAC	Dire Dawa Administrative Council
DDRA	Dire Dawa Road Authority
DEM	Digital Elevation Model
EM	Electro Magnetic
ESRI	Environmental System Research Institute
GPS	Global Positioning System
IDP	Integrated Development Plan
IDW	Inverse Distance Weight
IR	Infra Red
ISS	Information System Service
MCE	Multi Criteria Evaluation
MoWR	Ministry of Water Resource
MSS	Multi Spectral Scanning
NMA	National Meteorological Agency
SCS	Soil Conservation Service
SWIR	Short Wave Infra Red
TIN	Triangulated Irregular Network
TIR	Thermal Infra Red
TM	Thermal Mapper
UV	Ultra Violet
VNIR	Visible and Near Infra Red
WBISPP	Woody Biomass Inventory and Strategic Planning Project
WLC	Weighted Linear Combination
WMS	Watershed Modeling System
WSDP	Watershed Development Program
WWDSE	Water Works Design and Supervision Enterprise

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Abstract

Flooding in any circumstance causes major stresses on the economic, social and environmental regimes of the affected area. The flooding of 5/6 August 2006, however, demonstrated that structural measures undertaken so far are not adequate to withstand flood threats resulting in over 300 fatalities and significant damage to the flood defenses, public infrastructure, housing and livelihoods in Dire Dawa town.

This paper studied flood risk analysis of Dire Dawa town and flash flood hazard mapping of Dechatu catchment. To do this an original GIS-based approach was used to build geodatabase for the selected flood hazard layers and elements at risk (land use and population density). Then the important factors were developed to a uniform raster layers with 28.5 m pixel and were masked by the town area in the catchment. Each factor was standardized and then a pair wise comparison method was used to determine the factor weights. Then weighted overlay analysis in multi criteria evaluation (MCE) was used to carry out flood hazard and risk analysis.

DEM and mean annual daily maximum rainfall data were used to make flash flood hazard mapping using hydro extension version 1.1 in Arc View 3.2 for Dechatu catchment. Sink filled DEM was used to compute flow direction, flow accumulation, watershed, mean slope, shape factor, and mean precipitation from raster layer generated from mean annual daily maximum rainfall. All these parameters were entered into stream attribute table for characterization. Eight Pour points were computed from the delineated watershed of Dechatu catchment. Accordingly, Lege Dole, Lege Dechatu, Lege Gogeti and Lege Ala were the flash flood hazard wadis in the catchment.

The major findings of the paper showed that most of the land use types in the town are within low to moderate flood hazard and flood risk level. With these Dire Dawa town flood risk map and flash flood hazard map, Development of future land use in development policy should be done to decrease the hazard of flooding in Dire Dawa town.

Key words: - Flood, Risk, Hazard, GIS, MCE, Dire Dawa, Dechatu

Chapter One

Introduction

1.1 Background

River flooding is a natural process and part of the hydrological cycle of rainfall, surface and groundwater flow and storage. Floods occur whenever the capacity of the natural or man made drainage system is unable to cope with the volume of water generated by rainfall. Floods vary considerably in size and duration. Field-scale flooding is usually due to intense local storms where water and soil can flow straight off the land surface and may be over in a matter of hours. With prolonged rain falling over wide areas rivers are fed by a network of ditches, streams and tributaries and flows build up to the point where the normal channel is overwhelmed and water floods onto surrounding areas. On large rivers flooding occur a considerable period after the Rainfall and last for many days or weeks as the large volumes of water drain out of the catchment.

Taking heed of South-East Asia which is part of the most flood hit continent in the world, topped the list of disaster impacts over the first 6 months of 2006, with 85% of worldwide deaths from natural disaster over this period occurring in South-East Asia. An interesting point to note about the first semester of 2006 is the significant number of recorded flood disasters, with a total of 113 floods representing all-time high of 65% of all natural disasters. The first semester average for the preceding 10 years was of 58 floods, representing an average of only 36.5% of all natural disasters. In fact, floods constitute an increasingly large proportion of all disasters recorded in the EM-DAT database over the last 50 years Debarati (2006).

In Ethiopia context, the rainy season is concentrated in the three months between June and September when about 80% of the rains are received. Torrential down pours are common in most parts of the country. As the topography of the country is rather rugged with distinctly defined watercourses, large scale flooding is rare and limited to the lowland areas where major rivers cross to neighboring countries. However, intense rainfall in the highlands could cause flooding of settlements close to any stretch of river course. A major river basin that has serious flood problems is the Awash River basin located in the Rift Valley. Irrigation development in the river basin is quite advanced and is located in the flood plains on either side of the Awash River. High economic damage

occurs during flooding along this river basin. Therefore, flood protection practices and river training are limited to this river basin. It is estimated that in the Awash Valley almost all of the area delineated for irrigation development is subject to flood. An area in the order of 200,000-250,000 ha is subject to be flooded during high flows of the Awash River Kefyalew (2003).

1.2 Problem Statement

Soil erosion, land degradation, vegetation loss, over utilization of fuel wood, ground water pollution and sanitation problem, exotic weeds and trees and rainy season flooding are some of the environmental problems in the Dire Dawa town and its surrounding are facing.

Accordingly, rainy season flooding is one of the major environmental problems of the people living in Dire Dawa town. High flood, which is normally due to the intensive rainfall in the up lands of the watershed, sparse vegetation cover, steep slopes and low infiltration capacity of the ground surface, is a major threat to the people living down town WWDSE (2003).

This flood at times of unusually high rainy days over top the normal flood ways and create a lot of calamity to the residents of Dire Dawa town. In the past, several flood events occurred and caused a lot of distraction on properties and people.

Some people with low income are forced to sprawl over river bed and around the river bank. The nature of streams of Dire Dawa town which is dry through out the year except very limited number of days, makes the people dwelling on and around the river bed to develop false security. This has aggravated the flood hazard disaster in the rainy seasons. Besides, the town land use also has problem on the delineation of flood risk areas for the current and future settlement development program. This is witnessed on the last flood hazard disaster for instance public service areas like bus station was also damaged.

Recently on the night of 5/6 August 2006, a major flood swept through Dire Dawa town, resulting in over 300 fatalities and significant damage to the flood defenses, public infrastructure, housing and livelihoods. Although this was the most severe flood for many years, flash floods occur in the wadis that pass through the town every year, often causing loss of life and damage to property and infrastructure.

Presently in the existing situation like this, it is important to consider major factors that contributed most in the past flood hazard calamities. It has of paramount importance to

take notice of these factors to arrive at wise and comprehensive solution towards mitigating the challenge (that is flooding) which is erratic and unpredictable.

Hence, GIS is the best assemblage of computer equipment and a set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis, and display (soft copy) and printing (maps) of the factors (spatial data) affecting flood hazard. One of the most common approaches in the flood risk and flood hazard study in other countries is using multi-criteria analysis approach in Geographic Information System (GIS).

1.3 Objectives

1.3.1 General Objectives

- To assess flood risk in Dire Dawa town using Multi-Criteria Evaluation in GIS environment

1.3.2 Specific Objectives

- To build geodatabase for flood hazard and flood risk assessment of Dire Dawa town
- To map areas in Dire Dawa town in terms of Flood risk and Flood hazard using multi-criteria evaluation in GIS environment
- To see land use change of Dechatu basin
- To identify flood prone wadis in the event of a flash flood
- To identify pour points for future intervention in alleviating flood hazard

1.4 Material and Method

1.4.1 Materials

The data and their sources used to generate land-use maps and flash flood hazard map of Dechatu catchment and to assess flood risk in Dire Dawa town are reported below. (Table 1.1)

1.4.1.1 Software

Software used in this study is selected based on the capability to work on the existing problems in achieving the predetermined objectives. Hence software package like ERDAS was used for image processing activities on satellite images. Moreover, ENVI

4.2 was used to compute change detection analysis on land use/ land cover map of classified images. The factor map development was carried out using ArcGIS9.1 software package. The factors that are input to for multi-criteria analysis should be preprocessed in accordance to the criteria set to develop flood hazard analysis. So using Spatial Analyst and 3D Analyst extension, some relevant GIS analyses were undertaken to convert the collected shape files. Eigen vector for the selected factor was computed using Weight module in IDRISI 32 software. Arc View 3.2 software was also employed to identify dangerous wadis in the catchment using Hydrologic Modeling version 1.1 extension for computing flow accumulation, mean slope, mean elevation, shape factor and mean annual rainfall for each wadi and pour point of the catchment.

1.4.2 Methods

1.4.2.1 Flood Risk Analysis in Dire Dawa town

Flood risk of the town was analyzed from the following general risk equation Shook, (1997).

$$\text{Risk} = (\text{Elements at risk}) * (\text{Hazard} * \text{Vulnerability}) \dots \dots \dots \text{Equation 1.1}$$

The flood hazard analysis was computed using multi criteria evaluation (MCE). To run MCE, the selected flood disaster causative factors such as elevation, slope, drainage density, road density and land-use were developed and weighted. Then weighted overlay technique was computed in ArcGIS9.1 Model Builder to generate flood hazard map. Considering the degree of loss to be total for the study area, the vulnerability is assumed to be one. Finally to generate flood risk map of the town, elements at risk layer (land use and population density) and the flood hazard map were overlaid using weighted overlay analysis technique in ArcGIS9.1 environment. (Fig 1.1)

1.4.2.2 Land use change in Dechatu catchment

Land use change of Dechatu catchment was analyzed using multi-temporal satellite images: 1985 Landsat TM image and 2006 ASTER image. Ground truth and accuracy assessment points were collected using Global Positioning System (GPS). Satellite images were geometrically corrected using the collected ground-truth points and enhanced using linear stretch technique. Supervised classification method was carried out based on the existing land use map of Dechatu catchment developed by Water Works

Design and Supervision Enterprise (WWDSE). Accuracy assessment was computed using Ground Truth ROI technique in Post Classification method. Land use change analysis was done by Change Detection Statistics technique in Change Detection method in ENVI.4.2 software.

Table 1.1: Data and their sources

Areas	Data	Data Type	Scale	Data Sources
Dechatu Basin	1. Boundary, Contour	Topographic map	1: 50,000	EMA
	2. Land use	Land sat and Aster image	Land sat (28.5m) Aster (14.5m)	AAU
	3. Daily Rainfall	Rainfall records	-	NMA
	4. Daily Temperature	Temperature records	-	NMA
Dire Dawa town	1. Boundary	Town shape file	-	ISS
	2. Drainage density	Town drainage shape file	-	ISS
	3. Population density	Population records of 1994 Census	-	CSA
	4. Road	Town road shape file	-	ISS
	5. Ground Truth and Accuracy Assessment Points	Point data	-	Field survey
	6. Slope & Elevation	Contour shape file		ISS
	7. Land use	Existing land use shape file	-	ISS

1.4.2.3 Flash Flood hazard Analysis in Dechatu Catchment

Major streams of Dechatu catchment were characterized using Hydrological modeling approach in Hydro Extension Version 1.1. Accordingly, this approach was used along with an elevation raster layer, in order to identify the following parameters in an automated way: flow accumulation, mean land slope, mean annual daily maximum rainfall, and shape factor. Pour points of the catchment were derived from the delineated watershed, which was generated from DEM.

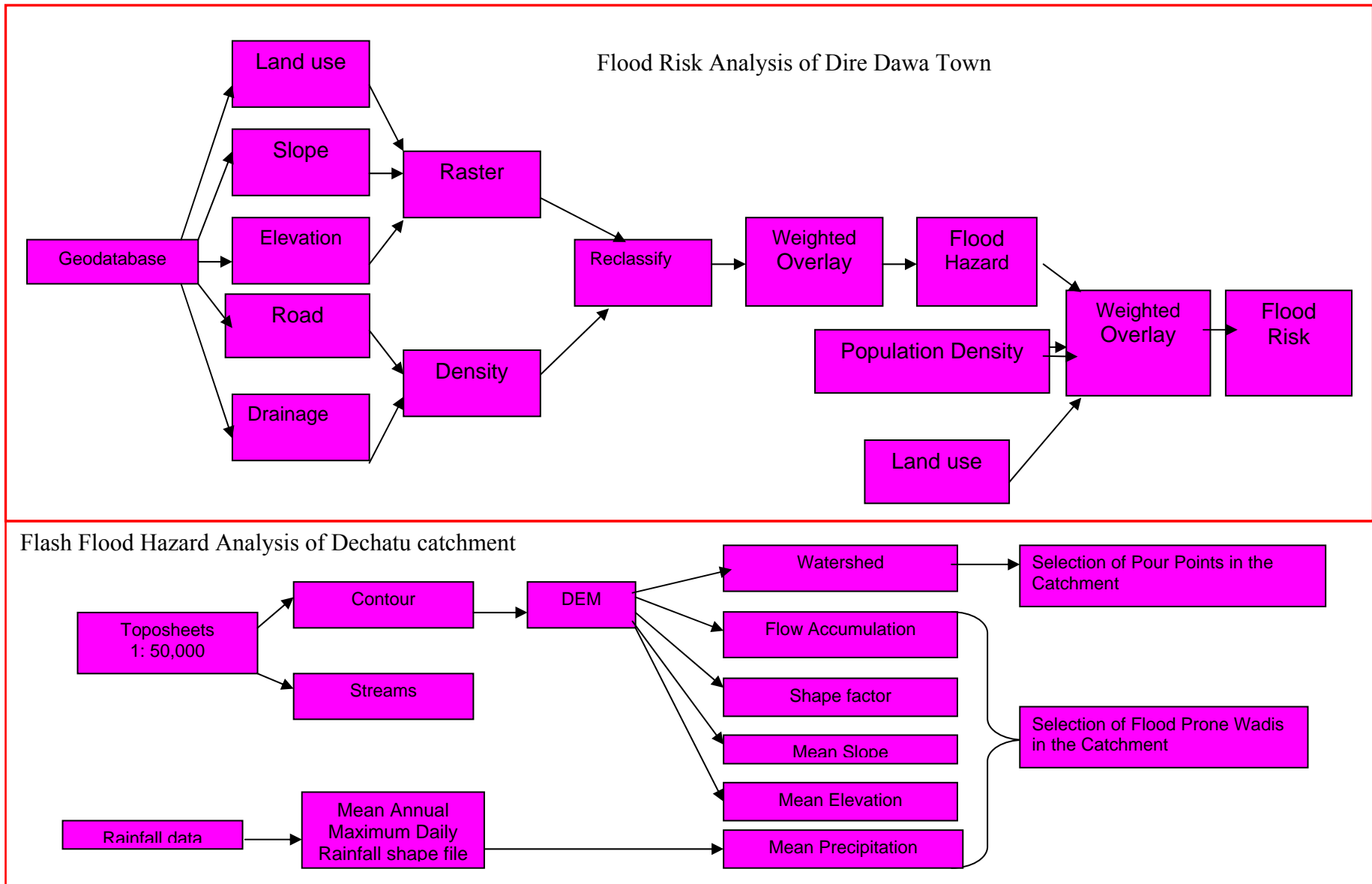


Fig 1.1: Work Flow of Flood Risk and Flash Flood Hazard Analysis

CHAPTER TWO

Literature Review

2.1 *Theoretical Background*

2.1.1 What is Geographic Information System (GIS)?

The heart of GIS is the analytical capabilities of the system. What distinguishes the GIS from other information systems are its spatial analysis functions. Although the data input is, in general, the most time-consuming part, it is for data analysis that GIS is used. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Such models illuminate the underlying trends in geographic data and thus make new information available. Results of geographic analysis can be communicated with the help of maps, or both.

The organization of database into map layers is not simply for reasons of organizational clarity; rather it is to provide rapid access to data elements required for geographic analysis. The objective of geographic analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers at all levels in terms of detail. An important use of the analysis is the possibility of predicting events in another location or at another point in time.

A working Geographic Information System seamlessly integrates five key components: hardware, software, data, people, and methods.



Fig2.1: Components of Geographic Information System

2.1.2 Data Models in GIS

There are two types of data models in GIS. There are two conceptual representations used in GIS: grid (sometimes called 'raster') and vector. These are very different ways of thinking about geography, which lead to very different methods of analysis.

The grid or 'raster' representation of a map assumes that the map area is divided into cells (sometimes erroneously called pixels), normally square or at least rectangular, on a regular grid. Each cell is supposedly homogeneous, in that the map is incapable of providing information at any resolution finer than the individual cell. The map shows exactly one value (land use, elevation, political division, etc.) for each cell. This is a very simple representation in the computer: conceptually, a 2-D matrix of values which correspond to a grid placed over the paper map. (Fig 2.2)

The vector representation of a map is points on a map are stored in the computer with their 'exact' (to the precision of the original map and the storage capacity of the computer) coordinates. Points can be connected to form lines (straight or described by some other parametric function) or chains; can be connected back to the starting point to enclose polygons or areas. (Fig 2.2)

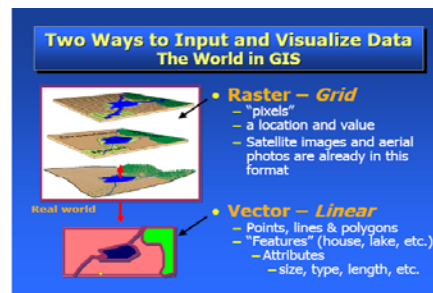


Fig2.2: Data Models in GIS

2.1.3 Raster Data Analysis

2.1.3.1 Raster Overlay

In raster overlay, the pixel or grid cell values in each map are combined using arithmetic and Boolean operators to produce a new value in the composite map. The maps can be treated as arithmetical variables and perform complex algebraic functions. The method is often described as map algebra. The raster GIS provides the ability to perform map layers mathematically. This is particularly important for the modeling in which various maps

are combined using various mathematical functions. Conditional operators are the basic mathematical functions that are supported in GIS.

2.1.4 Multi-Criteria Evaluation (MCE)

In Decision theory, Multi-Criteria Evaluation is the process of applying a decision rule to a set of alternatives. A decision rule is a procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon. A decision is a choice between alternatives (such as alternative actions, land allocations, etc.). The basis for a decision is known as a criterion. Criteria may be of two types: factors and constraints. Factors are generally continuous in nature (such as the slope gradient or road proximity factors); they indicate the relative suitability of certain areas. Constraints, on the other hand, are always Boolean in character (such as the reserved lands constraint in the example above). They serve to exclude certain areas from consideration. Factors and constraints can be combined in the MCE module using one of three methods (Boolean intersection, Weighted Linear Combination and Ordered Weighted Average); each method is characterized by different levels of control over tradeoff between factors and the level of risk assumed in the combination procedure.

Trade off is the degree to which one factor can compensate for another; how they compensate is governed by a set of factor weights sometimes called tradeoff weights. Factor weights are given for each factor such that all factor weights, for a set of factors, sum to one; they indicate the relative importance of each factor to the objective under consideration. A factor with a high factor/tradeoff weight may compensate for low suitability in other factors that have lower factor/tradeoff weights.

In a Multi-Criteria Evaluation, an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective. For example, a decision may need to be made about what areas are the most suitable for industrial development. Criteria might include proximity to roads, slope gradient, exclusion of reserved lands, and so on. Through a Multi-Criteria Evaluation, these criteria images representing suitability may be combined to form a single suitability map from which the final choice will be made Eastman (2001).

The second method in MCE is a Weighted Linear Combination (WLC) where criteria may include both weighted factors and constraints. WLC starts by multiplying each factor by its factor/tradeoff weight and then adding the results; constraints are then applied by successive multiplication to "zero out" excluded areas. This procedure is characterized by full tradeoff between factors and average risk. Factor weights, not used at all in the case of Boolean intersection (no tradeoff), are very important in WLC because they determine how individual factors will tradeoff relative to each other. In this case, the higher the factor weight the more influence that factor has on the final suitability map. (Contrast this with method 3 below where the importance of factor weights is variable). Along with full tradeoff, this combination procedure is characterized by an average level of risk, as it is exactly midway between the minimization (AND operation) and maximization (OR operation) of areas to be considered suitable in the final result Eastman (2001).

2.1.5. Satellite Systems

A satellite system that operates within the optical spectrum, which extends from approximately 0.3 to 14 μm is my concern in this study. This range includes (Ultra Violet), visible, near-, mid-, and thermal IR (Infra Red) wavelengths. (It is termed the optical spectrum because lenses and mirrors can be used to refract and reflect such energy.) Substantial remote sensing from space is also performed using systems that operate in the microwave portion of the spectrum (approximately 1mm to 1m wavelength).

The description of satellite system focuses on the two major sensors known as Landsat 4 & 5 and ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer). The design of the Landsat-4 and -5 satellites, which includes both the MSS (Multi-Spectral Scanning) and the TM (Thematic Mapper) weighs approximately 2000 kg and includes four 1.5X 2.3-m solar panels that are mounted to one side. The high antenna shown protruding above the spacecraft can be used to relay data through geosynchronous communication satellites included in the Tracking and Data Relay Satellite System (TDRSS). Direct transmission of MSS and TM to ground receiving stations is made

possible via the X-band and S-band antennas onboard the satellite. The data transmission rates involved are substantial; the MSS transmits 15 megabits per second (Mbps) and the TM transmits 85 Mbps. (The MSS has been flown on these missions primarily to ensure continuity of data for receiving stations unable to receive and process TM data.) Table 2.1 indicates basic characteristics of sensors.

ASTER consists of three separate instrument subsystems, each operating in a different spectral region, using a separate optical system, and built by a different Japanese company. These subsystems are the Visible and Near Infrared (VNIR), the Short Wave Infrared (SWIR), and the Thermal Infrared (TIR), respectively. Table 2.2 indicates the basic characteristics of each of these subsystems Lillesand et al. (2000).

Table 2.1: Sensors used on Landsat-1 to -7 Missions

^a79 m for Landsat-1 to -3 and 82 m for Landsat-4 and -5; ^b Failed shortly after launch (band 8 of Landsat-3); ^cLandsat-6 launch failure

Sensor	Mission	Sensitivity (μm)	Resolution (m)
RBV	1,2	0.475-0.575	80
		0.580-0.680	80
		0.690-0.830	80
	3	0.505-0.750	30
MSS	1-5	0.5-0.6	79/82a
		0.6-0.7	79/82a
		0.7-0.8	79/82a
		0.8-1.1	79/82a
	3	10.4-12.6 ^b	240
TM	4,5	0.45-0.52	30
		0.52-0.60	30
		0.63-0.69	30
		0.76-0.90	30
		1.55-1.75	30
		10.4-12.5	120
		2.08-2.35	30
ETMC	6	Above TM bands plus 0.50-0.90	30 (120 m thermal band) 15
		ETM+	7

Table2.2: ASTER instrument Characteristics
^a Stereoscopic imaging subsystem

Characteristics	VNIR	SWIR	TIR
Spectral range	Band 1: 0.52-0.60 μm , nadir looking	Band 4: 1.600-1.700 μm	Band 10: 8.125-8.475 μm
	Band 2: 0.63-0.69 μm , nadir looking	Band 5: 2.145-2.185 μm	Band 11: 8.475-8.825 μm
	Band 3: 0.76-0.86 ^a μm , nadir looking	Band 6: 2.185-2.225 μm	Band 12: 8.925-9.275 μm
	Band 3: 0.76-0.86 ^a μm , backward looking	Band 7: 2.235-2.285 μm	Band 13: 10.25-10.95 μm
		Band 8: 2.295-2.365 μm	Band 14: 10.95-11.65 μm
		Band 9: 2.360-2.430 μm	
Ground resolution (m)	15	30	90
Cross-track pointing (deg)	± 24	± 8.55	± 8.55
Cross-track pointing (km)	± 318	± 116	± 116
Swath width (km)	60	60	60
Quantization (bits)	8	8	12

2.1.6 Remotely Sensed Data

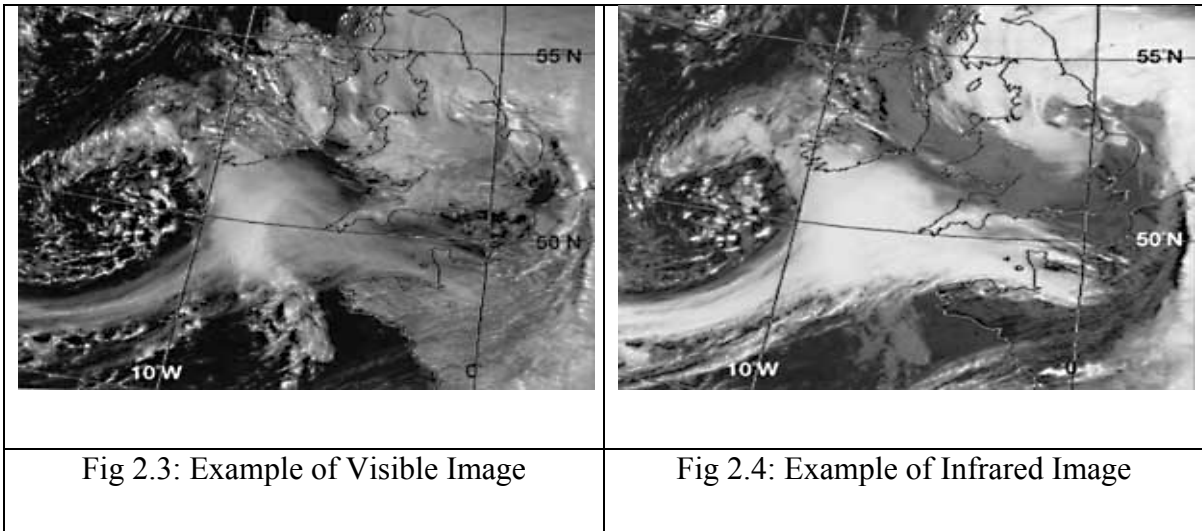
2.1.6.1 Types of Satellite Images

Satellite images are available from a number of different channels which are used individually or in combination to reveal information about the atmosphere and surface. Two of these channels are commonly referred to as visible and Infra-red.

One type of radiometer measures visible light and provides visible images (just like a camera taking black and white photographs). What is being viewed is sunlight that has been reflected from the Earth or clouds. In general, the brighter the cloud appears, the thicker it is. The only disadvantage of visible images, as their name suggests, is that they are only available during daylight (Fig 2.3).

Infrared images are effectively measuring the temperature of the top of the cloud or, if no cloud is present, of the Earth's surface. The images are usually prepared in such a way that cold surfaces appear white and warm ones darker.

Because of the adiabatic lapse rate, temperatures in the lower part of the atmosphere normally decrease with height, so high cloud (with low temperatures) appears white, with low cloud or the Earth's surface appearing darker. Unlike visible images, infrared images are available even when there is no daylight. (Fig 2.4)



A combination of visible and infrared images is very useful and can help distinguish between high and low cloud. For example, if a bright area appears on both the infrared and visible images in the same place, it is likely to be thick, high cloud. However, if the area appears bright on the visible image but dark on the infrared one, it is probably low cloud or perhaps fog. On the other hand, high-level cirrus cloud is readily detected on an infrared image but, unless quite thick, is barely detectable on a visible image.

2.1.6.2 Description of Electromagnetic Radiation

The fundamental unit involved in electromagnetic phenomena is the photon (one form of quanta, as considered in quantum physics). This is the subatomic particle which comprises radiation given off by matter when it is excited thermally, or by nuclear processes (fusion, fission), or by other radiation. Photons, which are without mass, in transfer move at the speed of light: 300,000 km/sec (186,000 miles/sec). As such, these particles also move as waves - hence, they have a "dual" nature. These waves follow a pattern described in terms of a sine (trigonometric) function, as shown in two dimensions in the figure 2.5.

The distribution of the continuum of radiant energies can be plotted either as a function of wavelength or of frequency in a chart known as the electromagnetic spectrum (EM).

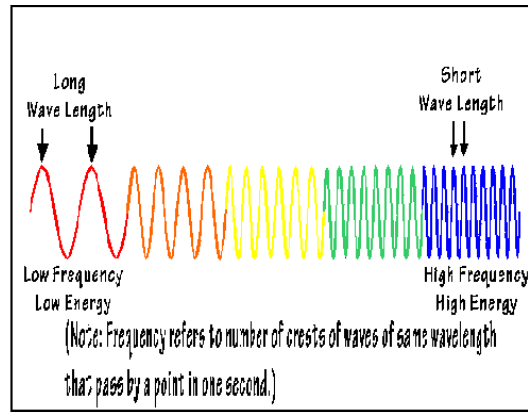


Diagram of sine waves at different frequencies.

Fig 2.5: Diagram of Sine waves at different frequencies

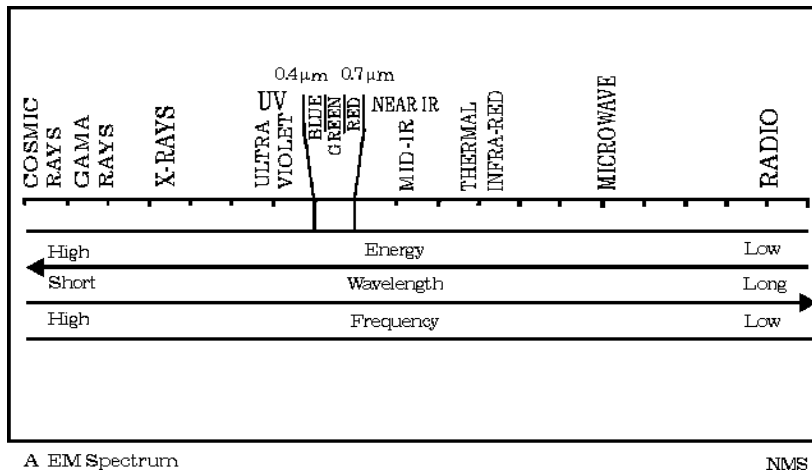


Fig 2.6: Electro Magnetic Spectrum

The EM spectrum has been arbitrarily divided into regions or intervals to which descriptive names have been applied. At the very energetic (high frequency; short wavelength) end are gamma rays and x-rays (whose wavelengths are normally measured in angstroms [\AA], which in the metric scale are in units of 10^{-8} cm). Radiation in the ultraviolet extends from about 300 \AA to about 4000 \AA . It is convenient to measure the mid-regions of the spectrum in one of two units: micrometers (μm), which are multiples of 10^{-6} m or nanometers (nm), based on 10^{-9} m. The visible region occupies the range between 0.4 and $0.7 \mu\text{m}$, or its equivalents of 4000 to 7000 \AA or 400 to 700 nm . The

infrared region, spanning between 0.7 and 100 μm , has four subintervals of special interest: (1) reflected IR (0.7 - 3.0 μm), and (2) its film responsive subset, the photographic IR (0.7 - 0.9 μm); (3) and (4) thermal bands at (3 - 5 μm) and (8 - 14 μm). Longer wavelength intervals are measured in units ranging from mm. through cm. through meters. The microwave region spreads across 0.1 to 100cm; this includes the entire interval used by man-made radar systems which generate their own active radiation that is directed towards (and reflected from) targets of interest. The lowest frequency-longest wavelength region beyond 100 cm is associated with radio bands. An enlarged figure 2.6, from which the one above was derived, indicates many of the atomic or molecular mechanisms by which these different forms of radiation are generated.

2.1.7 Digital Image Processing

Digital image processing involves the manipulation and interpretation of digital images with the aid of computer. The central idea behind digital image processing is quite simple. The digital image is fed into computer one pixel at a time. The computer is programmed to insert an image into an equation, or series of equations, and then store the results of the computation for each pixel. These results form a new digital image that may be displayed or recorded in pictorial format or may be further manipulated by additional programs. Basically all the digital image manipulation can be categorized in to seven broad types of computer assisted operations Lillesand et al. (2000).

In this study only three types of digital image processing operations were used: image rectification and restoration (preprocessing), image enhancement and image classification.

Preprocessing is aimed to correct distorted or degraded data to create a more faithful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortions, to calibrate the data radiometrically, and to eliminate noise present in the data. Image enhancement is a procedure applied to image data in order to more effectively display or record the data for subsequent visual interpretation. Normally, image enhancement involves techniques for increasing the visual distinction between features in a scene. For instance, Linear Stretch, which is one of the Contrast Stretching techniques, is the uniform expansion of limited image levels

range to fill the range of display values (0-255). Subtle variations in input image data values would now be displayed in output tones that would be more readily distinguished by the interpreter. Light tone areas would appear lighter and dark areas would appear darker.

The algorithm for linear stretch that would be applied to each pixel in the image:

$$DN' = \left[\frac{DN-MIN}{MAX-MIN} \right] * 255 \dots\dots\dots \text{Equation 2.1}$$

Where:

DN' = digital number assigned to pixel in output image

DN = digital number of pixel in input image

MIN = minimum value of input image, to be assigned a value of 0 in the output image

MAX = maximum value of input image, to be assigned a value of 255 in the output image

Image classification is an operation to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This normally involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image. When these decision rules are based solely on the spectral radiances observed in the data, we refer to the classification process as spectral pattern recognition. In contrast, the decision rules may be based on the geometric shapes, sizes, and patterns present in the image data. These procedures fall into the domain of spatial pattern recognition. In either case, the intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or themes. These categorized data may then be used to produce thematic maps of the land cover present in an image and/or produce summary statistics on the areas covered by each land cover type.

A classification is not complete until its accuracy is assessed. A thorough overview of the principles and practices currently in use for assessing classification accuracy has been prepared by Congalton et al. (1999).

2.1.8 Land use change

Knowing the changes in land use/cover could be taken as a good indicator of ecosystem health that includes biodiversity. Therefore, mapping the land use/cover can be considered as benchmark for land use/cover change detection in the future and it could be a pillar for different land use planning. Hence, it becomes important to undertake studies of land use/cover changes to see the severity of the changes with time Belay (2002).

Land use/cover studies have been commonly carried out using aerial photographs and the recent aerial photographs that cover the study site are those taken in 1994. With the current, economy and technology, getting aerial photographs that covers large area with a better resolution is becoming difficult. Thus, currently, more attention has been given to the use of satellite imagery. Although it depends on the type of image data and purpose of study, the applicability of space borne remote sensing is becoming important Sluiter (2005).

2.1.9 Basin Morphometric Characteristics

The main morphometric characteristics of a given hydrographic basin is its catchment area represented by A expressed in km^2 , which is given by its horizontal projection drawn out from topographic maps at different scales, depending on the accuracy that we want to attain. Another important character is its perimeter (P), expressed in km , which represents the total length of the watershed line surrounding a given basin. Geographical location and orientation have to be considered. Regarding geographical location, for small basins it has to refer to their center of gravity. Compactness index (Gravelius coefficient) which is defined by its watershed line or water divide, which have certain shape and aerial extent. The shape of the basin influences significantly the response to precipitation and the spatial and temporal variations of runoff processes. For example, all other conditions being equal, a very elongated basin will not react, with respect to those hydrological factors, in the same way as a compact one, which will be characterized by a more uniform aerial distribution of rainfall and then by far more heavy periods of floods than the former one. Gravelius coefficient or compactness index (K) is used to characterize a basin from this perspective. The dimensionless coefficient K is obtained by comparing

the perimeter P of a given basin with the perimeter P' of a circle having the same aerial extent A . If the perimeter is expressed in km and the area in km^2 , by the above definition we obtain equation 2.1:

$$K = P/P' = P/2\sqrt{\pi A} = 0.28 * P/\sqrt{A} \dots \dots \dots \text{Equation 2.2}$$

The more K value tends to unity, the more the hydrographic basin approaches a circular shape.

The behavior of slope gradients of any hydrographic basin is extremely important both for the assessment of surface and groundwater flow systems. The mean slope gradient or slope index, S , of a certain basin is given by the weighted mean of the slope gradients belonging to all the elementary areas for which the line of maximum gradient can be considered as a constant. One of the methods of calculating slope index is given by graphic method which is called the grid method. According to this method, the whole area of a given basin has to be enclosed within a grid of squares whose size is conditioned by the topographical scale of the map. According to well known statistical considerations, at least 100 intersections, or knots, have to present within the basin's watershed line. In any case all these knots must be taken into consideration as representative, within the basin, of the different behavior of the local slope gradients. For each knot the minimum distance, d_i , between two level contour lines has to be first calculated and then, knowing the equidistance, D , the corresponding local slope gradient is given by as equation 2.2:

$$S_i = D/d_i \dots \dots \dots \text{Equation 2.3}$$

So that, the slope index, S , of the basin will be evaluated as the arithmetic mean of the whole local values Tenalem et al. (2001).

2.1.10 Flood Hazard and Risk Assessment using GIS

A case study conducted on flooding hazard of Jhelum and Neelum rivers in the district Muzaffarabad (capital of Azad Kashmir) is an important consideration in flood hazard studies using GIS. River Neelum is the main contributor of flooding in this area. Other important river of the study area is river Jhelum. Both these rivers meet at Domel in

Muzaffarabad. Flood of 1992 has been found to be more severe flood in the in the history of Muzaffarabad, which cause severe damage to economy and number of lives were lost. For a number of reasons the most frequent choice should be the protection from the flood by means of physical control of the river but there is also need for a broader and comprehensive program for managing flood hazard in the study area. Flood protection has been helpful and must be continued side by side other preventive tools like effective planning for the growth of the city, creation of a computerized GIS database for the flood prone area and a detailed flood risk mapping and zonation are required to minimize the harmful affects of flood hazard. Keeping in view the importance of the problem, an intensive study of the problem has been carried out. For this purpose Geographical Information System (GIS) were applied as a tool as a result, detailed mapping were drawn for the flood hazard assessment Nawaz (2006).

A case study of Kosi River Basin, India, Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation/ response efforts. This article presents an efficient methodology to accurately delineate the flood-hazard areas in the Kosi River Basin, North Bihar, India in a GIS environment. They have used one of the multi-criteria decision-making techniques, Analytical Hierarchical Process (AHP) which provides a systematic approach for assessing and integrating the impact of various factors, involving several levels of dependent and independent, qualitative and quantitative information. They present a novel methodology for computing a composite index of flood hazard derived from topographical, land cover, geomorphic and population related data. All data are finally integrated in a GIS environment to prepare a final flood hazard map. This flood hazard index computed from AHP method not only considers susceptibility of each area to be inundated but also takes into account the factors that are inherently related to flood emergency management Bapalu et al. (2006).

2.2 Flood and related facts

2.2.1 Identified Dechatu Flood risk areas

Dechatu is the major devastating river as it passes through the middle of the city. Dechatu River is named after the three rivers joins together at the gauging station. The three major rivers which come together are Laga Chrichi, Laga Anani, and Laga Gogoyti and they originates from the highlands of Kersa, Lange, Dengego and Alemaya catchments respectively. The two flood damage sites by lege Chiri river outside Dire Dawa town are shown in Fig 2.7 scouring of the left embankment of the main road near by Harla Belina village and in Fig 2.8 flood damage on Genet Menafesha bridge. Location of all identified risk areas in Dechatu catchment is shown Fig 2.13.



Fig 2.7 Complete Damage of the Main Highway at Hego Village On the main Dengego - Dire Dawa Road by Chirichi River



Fig 2.8 Overtopped Menafesha Bridge

The major problem areas on Dechatu River in Dire Dawa town are described as follows according their order from up to the tail end of the city towards the river flow direction Ephrem (2006).

The major problem areas on Dechatu River are:

1. Addis Ketema (or Gende Gurage) over toping: Gende Gurage is located just at the upstream end of the city where the river enters in to the city. The right side river bank is rocky hill mountain which is not exposed to flood except otherwise peoples are getting inside the river width. The left side river bank at this reach is relatively low with alluvial deposit. As a result the flood overtopped and flooded the whole Coca Kebele.

Currently the emergency response unit is doing river channeling, sandbag protection work and sand bund to protect the left side dwellers from further flood damage. However, all these activities will not last long. Specially the sand bund and deepening of the river channel can easily be eroded and may not extend more than one simple flood. Therefore, permanent gravity retaining wall should be constructed starting from the point where the maximum flood level touches the left abutment.

This recommended retaining wall should be extended downstream and joins Coca retaining wall. In such a case the Kefira Irish bridge crossing may no longer serve as a vehicle crossing unless an overpass is provided.

2. Washed out retaining wall on the left bank downstream of Kefira Irish bridge crossing. The problem to this specific reach of the retaining wall may be attributed to the flood that hit it from the back side of the wall. Once the flood enters into Gende Gurage localities it can get an access to this wall from the back side.

Coca kebele has always been exposed to all previous flood events. This is because the flood gets an access through an overtopping on Gende Gurage localities or through low level of the Kefira Irish bridge crossing.

3. Washed out retaining wall on the right bank at Coca bridge crossing: This is small length just d/s of the Coca Irish bridge crossing and may be attributed through river bed scouring. Anchoring the foundation of the retaining wall enough to the scouring depth may qualify the local problem (Fig 2.9).



Fig 2.9 Washed out Coca Retaining wall and its vicinity

4. Scouring of Dechatu main bridge river bed level (lowering of river bed level in the main bridge reach). Currently the river bed level at and around Dechatu main bridge is scoured and lowered by more than 1.5 meter from the previous river bed level. As a result the whole bridge structure is at danger and it needs immediate rehabilitation. Currently there is construction of gabion around the pier and abutments (Fig 2.10).

However, this work should be supported through restoration of the river bed to its previous or original position. This can be achieved through providing anchor walls across the river both upstream and downstream. The anchor walls can be constructed either by masonry or gabion depending on the availability of material and cost effectiveness. The anchor walls should start at 25 m from the centre of the bridge and then at 50 m interval on both direction till the maximum of 150 m. The anchor wall should be enough deep in to the ground (say 1 – 1.5 m) to resist scouring depth and maximum of 50 cm above the ground level to retain sediment and rehabilitate to its original position.



Fig 2.10 Damage Dechatu Main Bridge river bed

5. Scouring of downstream of Taiwan Crossing and the river banks (Fig 2.11); and scouring of downstream of Halfkat River Crossing and the river banks (Fig 2.12). Both Taiwan and Halfkat Irish river crossing are the same and have the same downstream scouring problems. The problem may be attributed to the poor hydraulic performance of the downstream glaciously wall and stilling basins. The downstream glaciously wall will be damaged in such extreme flood event and scouring will start at some weak point which will tend to create progressive retrogression effect to damage the whole structure as we have seen in both cases.

Therefore, proper study of the hydraulic jump is required based on the design flood estimate and provide proper stilling basin to accommodate such extreme flood event.

In addition the above providing two anchor walls (at spacing of 50 m) downstream of the stilling basin will stabilize the downstream reach more effectively Ephrem (2006).



Fig 2.11 Damaged Taiwan Crossing



Fig 2.12 Damaged Halfcat crossing

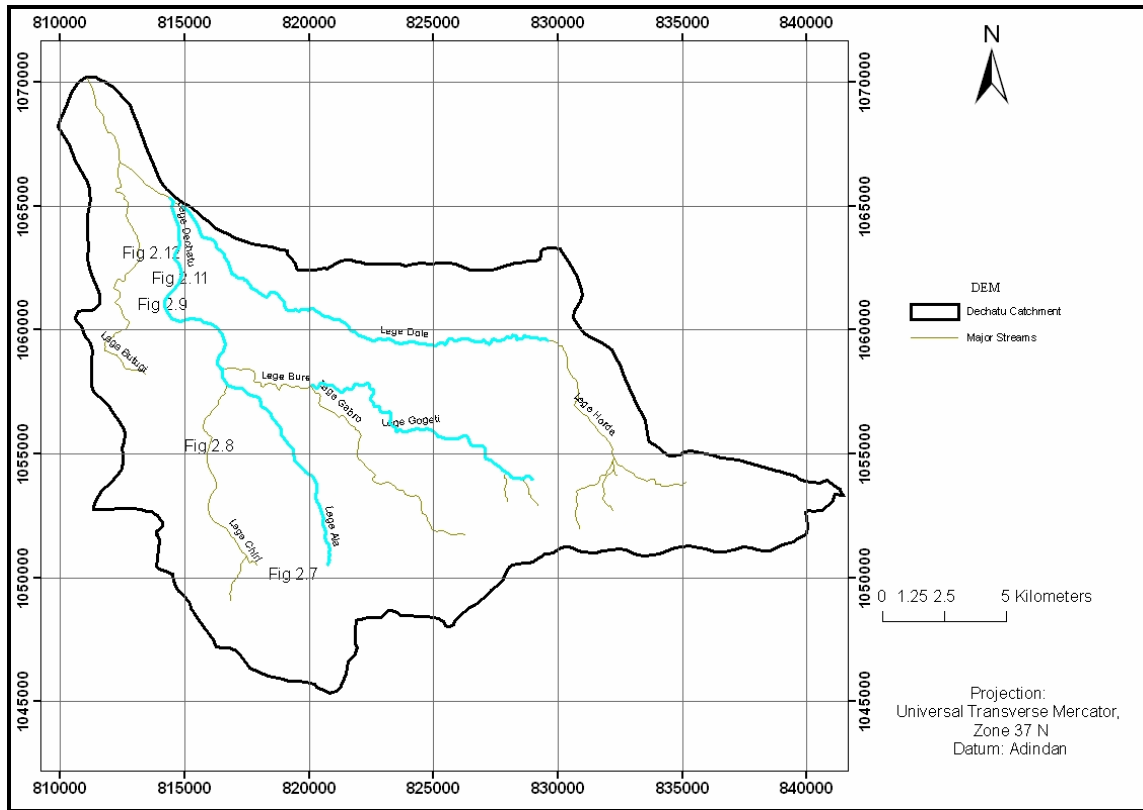


Fig 2.13 Flood risk areas in Dechatu catchment

2.2.2 Flood damage

2.2.2.1 Roads

The two major Irish crossings have suffered a serious damage and as a result a route that used to link the locally called Taiwan and Number One areas, ceased road service provision. The damage is estimated to be 900,000.00 ETB. The route that links the locally called Halfcat and Vera Pasta areas has been devastated partly and due to that, it is providing partial service. The damage is calculated to be 500,000.00 ETB DDRA (2006).

2.2.2.2 Flood protection structures

The flood protection structures constructed in different flood prone parts of the city has also been victims of the flood to some extent.

The guide wall found in Kefira area out of its total length 120m has been hit and destroyed by the flood. The damage is estimated to be 950,000.00 ETB.

The GTZ settlement area retaining wall has been destroyed some 100m of its total length (850m). The damage is estimated to be 930,000.00 ETB.

Dechatu retaining wall in two parts has been hit by the flood. The total length of the affected part is 60m. The damage is estimated to be 400,000.00 ETB DDRA (2006).

2.2.2.3 Silt deposit

All roads found within a radius of approximately up to 40m from the river bed on average, has been completely covered with silt brought by the flood, and hence, the traffic movement has been affected till the total removal of sand deposit. The damage caused due to this is calculated to be 517,100.00 ETB DDRA (2006).

2.2.2.4 Dechatu Bridge

It is a bridge playing a sole important role in joining the two locally named Kezira and Dechatu areas. The only means to reach to Dechatu area from all corners of the city is by using this bridge. The same had been rehabilitated at a cost of 2.4 million birr some year back, but the flood totally devastated the rehabilitation solution given and has put it in danger. This damage is estimated to be 3 million birr DDRA (2006).

2.2.2.5 Electric Service damage

Due to the fatal destruction caused by the flood on utility lines especially on electric lines and poles found along the Dechatu river bed, there was a power interruption till the active response of the Ethiopian Electric and Power Corporation eastern region branch. The damage recorded is estimated to be 500,000.00 ETB. The affected areas were: Kebele 05, 06, 07 and 09 (DDRA, 2006).

2.2.2.6 Telephone Service damage

The damage on telephone service due to the flood is estimated to be 6,098.36ETB. The areas affected were Kebele 05, 07 and 09 DDRA (2006).

2.2.2.7 Affected Population

Table 2.3 shows that number of casualties in Dire Dawa town is 35.6% of the national records next to SNNPR (Southern Nations and Nationalities People Republic) which is 51.2%. Accordingly, flash flood in August, 2006 in Dire Dawa, SNNPR and Amahara

regions and in November, 2006 in Somali regions are the launching appeals for flood intervention at national level. Due to lack of organized database management system on flood disasters records in Dire Dawa town, there is no available records on past flood catastrophes.

2.2.2.8 Urban Flood Prevention by the Administrative Council

The Dire Dawa Administrative Council in alliance with different government and non government institutions is undertaking some urban flood defense works. This includes construction of gravity retaining walls along some of the eroded banks of Dechatu and Goro Rivers to stabilize the slopes and protect property on top of the banks from being washed out into the river. Construction of Irish road crossings on Dechatu River is also part of the city road networks.

2.2.2.9 Emergency response activities in Dire Dawa town

The emergency response unit did river channeling; sandbag protection work and sand bund to protect the left side dwellers from further flood damage. However, all these activities will not last long. Specially the sand bund and deepening of the river channel can easily be eroded and may not extend more than one simple flood. Therefore, permanent gravity retaining wall should be constructed starting from the point where the maximum flood level touches the left abutment Ephrem (2006).

2.2.2.10 Dire Dawa town Flood history and attempts so far

Dire Dawa lying at the foot of a mountain range is subjected to annual flooding by runoff from the mountain during torrential rains.

From the records the last three major flood event occurred during in April 1981, 1994 and last year in May, 2005. The last year flood which occurred in May 2005 has caused loss of 35 human lives as well as an estimated amount of 10 million birr damages to property.

According to Ephrem (2006) the flood history is changed and the most devastating flood in the history of Dire Dawa occurred on the fifth day of August, 2006. This flood is the worst of its kind which resulted for the loss of more than 240 human lives. Property damages is also more than ever before.

This catastrophe draws government attention for proper planning and immediate response for Dire Dawa Urban Flood Alleviation. The administration of the city in collaboration with neighboring regions has plans for watershed management programs to be implemented during the national water sector development program. This intervention is expected to reduce flood risks in the city.

The planned watershed management programs comprise construction of check-dams and weirs for water conservation and retaining floods, construction of terraces along mountain slopes to reduce runoff and encourage ground water recharge, and re-forestation along the slopes draining towards Dire Dawa. As most of these slopes are part of neighboring regional states, the planned projects will be jointly implemented by these states and Dire Dawa administration. These plans are to be implemented during the period of the WSDP, which started in 2002 and will continue for 15 years.

2.2.2.11 Year 2006 Floods of Omo River

The flooding in the Omo River Valley is part of a nation wide crisis following the unusually intense and continuous rainfall that has resulted in flash flooding and overflowing of rivers in the year 2006. The heavy rainfall that washed the central plateau and highlands of South West Ethiopia forced the backing of water from Lake Turkana (Lake Rudolf), a lake without an out let that receives most of its water from the Omo River. This forced the river to leave its banks and wash away the people and their livelihoods. By any account, this area is one of the worst affected by the prevailing floods in Ethiopia DPPC (2006).

2.2.2.12 Description of the hydrologic Model in Arc View

2.2.2.12.1 Introduction

The hydrologic extension was developed with specific goals in mind. Get the user up and running quickly. The primary focus was on usability and providing the user easy access to key hydrologic functionality in Arc View Spatial Analyst. Develop attribute encoding scheme on a direct-use, open data structure. This provided a common language and format for exchange of spatial hydrologic information. Provide a framework and tools that could be expanded. Depending on the model used, there are dozens of parameters that may need to be calculated.

Consequently, the extension has a modular structure that can be readily modified. With these goals in mind, developers from ESRI, Brigham Young University's Engineering Computer Graphics Lab, and University of Texas at Austin's Center for Research in Water Resources designed a software framework, an attribute encoding scheme, and an Arc View GIS extension to work with rainfall-runoff models. By using an open data format, both the GIS and the model can directly read and write in the file without conversion.

The result was the new hydrology extension for Arc View Spatial Analyst Version 1.1. This new tool extends the Arc View Spatial Analyst user interface for creating input data for hydrologic models. With this extension, users can create watersheds and stream networks from a digital elevation model (DEM), a grid data source representing elevation. Users can calculate physical and geometric properties of watersheds, and aggregate these properties into a single attribute table that can be attached to a grid or shape file.

Depending on your needs there are two ways of approaching this functionality. If you simply want to create watersheds or stream networks, or a particular property of them, work directly with each of the functional choices under the Hydrology pull down menu (Table 2.4). If you want to create watersheds and calculate attributes for them, use the Hydrologic Modeling choice under the Hydrologic pull down menu ESRI (2006).

2.2.2.12.2 Working with Models

Using Arc View Spatial Analyst Version 1.1 and a DEM, a scientist can easily delineate drainage basins and calculate basin parameters necessary for runoff modeling. Arc View Spatial Analyst converts this information into shape files of watersheds, stream networks, and watershed pour points that can be read directly by the Watershed Modeling System (WMS) to perform runoff calculations using a variety of models such as HEC-1 and TR-20. Surface water profiles created using HEC-2, RAS, or other modeling software, can be read back into Arc View Spatial Analyst to create flood maps for further map overlay analysis.

Though this project was developed to share information between Arc View Spatial Analyst and WMS, the file format and description for this extension are easy to

understand and can be used as a starting point for development of similar GIS-model interfaces.

Work is also under way to combine this extension with the University of Texas PREPRO program which would allow an Arc View GIS user to directly create input files for HEC HMS, Danish Hydraulic Institute's MIKE Basin, and perhaps the SWAT models.

Additional work is being done to further connect HMS and RAS in a single Arc View GIS environment that would allow you to move easily from a DEM to a floodplain map within a single application.

Table 2.3: Number of affected Population in Ethiopia in 2006 Kiremet/ main rainy season flood

Source: Briefing note for DAG-DPPA meeting (General Director Simon Mechale)

Region	Affected	Displaced	Casualties
Dire Dawa	9,927	9,927	256
SNNPR	106,666	28,775	368
Amhara	97,824	37,863	3
Somali	361,619	125,000	80
Oromia	20,156	3,392	10
Afar	42,100	4,050	-
Gambella	30,915	30,915	2
Tigray	582	582	-
Harari	3475	-	-
Total	674,479	241,699	719

Table 2.4: The menu choices and functions available with the hydrology extension.

Hydrologic Extension Menu -- Choices And Functions	
Menu Choice	Function
Hydrologic Modeling	Creates watersheds then calculates additional attributes.
Flow Direction	Computes the direction of flow for each cell in a DEM.
Identify	Sinks Creates a grid showing the location of sinks in a DEM.
Fill	Sinks Fills the sinks in a DEM.
Flow Accumulation	Calculates the accumulated flow, or number of upslope cells.
Watershed	Creates watersheds based on a user-specified flow accumulation threshold.
Area	Calculates the area of each watershed.
Perimeter	Calculates the perimeter of each watershed.
Length	Calculates the straight line distance length of each watershed.
Flow Length	Calculates the length of flow path for each cell to the pour point.
Flow Length by Watershed	Calculates the maximum distance along the flow path within each watershed.
Shape Factor by Watershed	Calculates a shape factor for each watershed.
Stream Network as Line Shape	Creates a vector stream network.
Centroid as Point Shape	Creates a point shape file of watershed centroids.
Pour Points as Point Shape	Creates a point shape file of watershed pour points.
Mean Elevation	Calculates the mean elevation within each watershed.
Mean Slope	Calculates the mean slope within each watershed.
Mean Precipitation	Calculates the mean precipitation in each watershed.
Mean Curve Number	Calculates the mean curve number for each watershed.

CHAPTER THREE

GENERAL DESCRIPTION OF THE STUDY AREA

3.1 Location

Dire Dawa Administrative Council is located between 9⁰27`N and 9⁰49`N latitude and 41⁰38`E and 42⁰19`E longitude, and in the eastern marginal catchment of Awash basin (Fig 3.1). East Hararge Administrative zone of Oromiya Regional State borders it in the south and southeast and Shinele zone of Somalia Regional State in the north, east and west. Dire Dawa city is accessible by airplane, train and cars, and is about 515kms road distance to the east of Addis Ababa and 311kms to the west of Djibouti port.

The total area of the region is about 128,802ha; out of this urban accounts for 2684ha (2%) and the balance 98% is for rural IDP (2006). The total Dire Dawa area can be divided into three major areas; the south and south-eastern part of the city is characterized by a chain of mountains and upland at the foot of the mountain chain covering 45%; and low lying flat land accounting for 40% of the land area Ephrem (2006).

3.2 Population

The total population of Dire Dawa is estimated to be 384,000 out of which 74% (284,000) live in urban while the rest 26%(100,000) live in rural areas.

According to the 1994 census result, Dire Dawa Administration had a total population of 252 thousands during the census period and in the year 2005; the population of the region has reached 384 thousands which exceeded the census period population by 132 thousands. The incremental within a decade time accounts more than half of the size of the 1994 population, which is tremendous in magnitude.

On the other hand, the average annual growth rate of the population was 4% for the region during the years 1995-2000. The growth rate declined to 3.8% for the years between 2000 and 2005 and expected to further go down to 3.5% for the years between 2005 and 2010 IDP (2006).

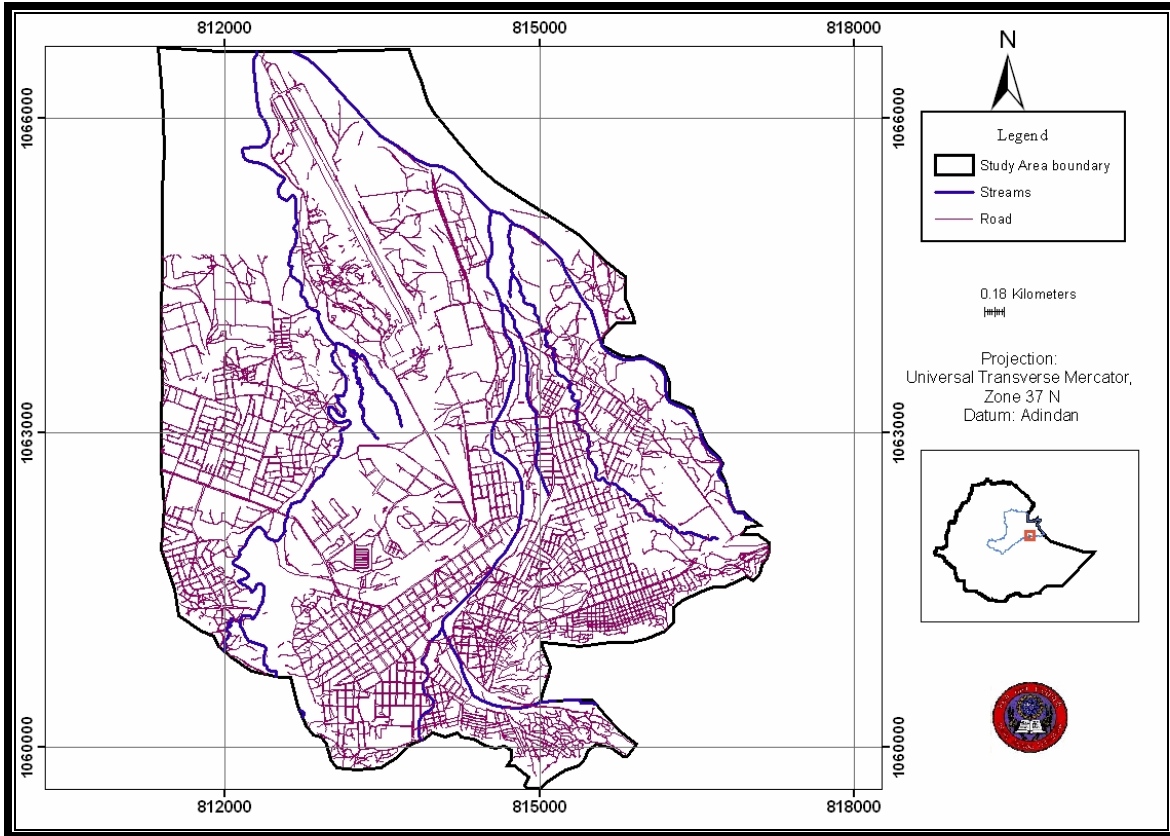


Fig 3.1: Location map of Dire Dawa Town for flood risk analysis

3.3 Climate

Dire Dawa Administrative Council is situated in Kola agro-climatic region, temperature is hot through out the year with minor seasonal variations. Temperature progressively increases northward from somewhat Woina-Dega type along the mountain tops of the mountain ranges along the southern border and the low alluvial plains in the northwestern margin experience the lowest and the highest temperature recordings respectively in the region.

The seasonal rainfall has a bimodal distribution with peak in April and August. The two seasons are 'Meher' and 'Belg' and they receive about 80% of the annual rainfall separated by a short dry spell in June. The mean annual rainfall is 657mm and mean monthly values varies between 5.7mm (December) and 119mm (April), which indicate poor temporal distribution of rainfall. The mean annual average air temperature is 25.3⁰ and June is the warmest month of the year while December and January are the coldest. Dire

Dawa enjoy a sunny climate with mean annual daily value of bright sunshine equal to 8 hours IDP (2006).

3.4 Land Degradation

Land degradation is a serious concern in the Dire Dawa Administration. The problem has its root causes to man made and natural factors:

- * The soil loss rate of 0.4 – 21.8tons/ha/yr is by far higher than the annual soil formation rate of 0.4 – 0.5 ton/ha/yr resulting in continuous soil erosion and thus about 75% of the region is severely degraded by soil erosion.

- * Deforestation due to unbalanced fuel wood demand and supply, which is equal to 150000 and 34550 tons respectively.

- * Overgrazing (carrying capacity of the grazing land is limited to 75% of the livestock population)

- * Lack of appropriate land use policies and regulations

- * Poor afforestation i.e. less than 1%

- * Low stocking, which is equal to 0.19 – 4.49 tons/ha/yr and low incremental yield, which is equal to 0.0135 – 0.27 tons/ha/yr

- * Lack of administration for vast open access that is equal to 36635 hectares

- * Decrease in stream and spring discharges, which are manifested by driving up of streams in peri urban areas IDP (2006).

3.5 Drainage Density

The Dire Dawa Administrative Council (DDAC) is not blessed by large rivers, which flow through out the year as that of the regions of the country. Only few intermittent and perennial streams pre dominate the natural water flow system of the region. According to the study made by the agricultural development office of the DDAC in the year 1992 EC, the region has over 130 springs with different water discharging capacity and over 44 perennial and intermittent streams. The most important intermittent and perennial streams that drain the Dire Dawa region are Dechatu, Butiji, Lega Hare, Dube, Goro and Elbah WWDSE (2004).

All the rivers originate from the southern highland catchments of Kulibi, Dengego and Alemaya. The city is bounded by Lege Hare in the eastern and by Goro Rivers in the west. Dechatu and Butugi Rivers pass through the middle of the city Ephrem (2006).

The first three passes through the town of Dire Dawa and the others are flowing to the west sides of the town. The intermittent streams except Lega Hare start from the escarpment zone and flow northwards into the alluvial plain. Secondary streams join them both east and west. There are also a number of Wadis and oasis in the region.

Among the main intermittent streams in the Dire Dawa region, Dechatu is the major one where most of the precipitation as run-off from the south (escarpment zone) drains into it. Although this stream is dry for the most part of the year, it carries very large flow in the rainy season which some times causes flash flooding that result in some damage in the town, mainly because it passes through the middle of the town. Most of the runoff from Dechatu and the other streams spread in the low lying and flat topographic areas north of the town contributing a lot to the ground water WWDSE (2004).

3.6 Soil

The major soil types of Dire Dawa Administrative Council exhibit a general relationship with altitude and slopes (Annex 6). Shallow and infertile soils being the characteristics of the mountains and hills where as the deep and fertile soils are the major properties of valley bottoms, river terraces and flat plains. Generally, the soils of the valley are developed on recent alluvial colluvial sediments derived from the adjacent mountain ranges. Fluvisols and Vertisols are generally dominating the region and particularly lowland flat plains, valley bottoms and river terraces. Texturally these soils are sandy loam and sandy clay respectively. Shallow Leptisols are the dominant type of soils found in the mountain and hills of the region WWDSE (2004).

3.7 Geology

The geology of Dire Dawa Administrative Council comprises various metamorphic, volcanic and sedimentary rocks (Annex 6). The metamorphic rock, which mainly includes gneisses and migmatites, represent the oldest rock types in the area. They are largely of pre-Cambrian origin or crystalline basement complexes. They mainly exposed

in the escarpment zone and limited out crop occur in the vicinity of Dire Dawa. Very limited out crops of volcanic rocks are exposed in the immediate vicinity of the town. However, significant out crops of extrusive lava flow (mainly basalt) and few small out crops of intrusive can be observed in the bordering areas with in Dire Dawa watershed. Sedimentary rocks of the area include various sandstone, limestone, alluvial sediments and travertine. The alluvial sediments are composed of sands, silt and clay with minor wadi gravel. They occupy nearly the entire low-lying flat alluvial plain. The travertine is exposed in limited areas with in the town and its vicinity WWDSE (2004).

3.8 Ground water

The water resources in Dire Dawa are mainly derived from the ground water. The contribution of surface water is limited to the rainy seasons. The surface water in most of the wadis disappears into the ground up on reaching the plains. During the dry season the only surface water is the base flow from springs WWDSE (2004).

The geological formation and hydro geological conditions of the area is a function of geomorphology, on the escarpment outcrops pre-Cambrian rocks, Adigrat sandstone, Hamanalei limestone, upper sandstones and basalts, the down thrown plain (foot of the escarpment) is dominantly covered by alluvial deposits. Both the plains (down thrown block) and the escarpment are highly dissected by east-west trending faults. The groundwater occurrence, distribution and flow regime is highly governed by topography, tectonics, and geological formation, aerial and topological relationship of the geological formation. Based on these major factors, the Dire Dawa Administrative Council can be categorized into two groundwater systems i.e. the escarpment and the foot of the escarpment that is groundwater basin of Dire Dawa Town WWDSE (2003).

3.9 Urban Infrastructure

3.9.1 Town Plan

As per the surveillance made, majority of the existing kebeles are already saturated except those at the periphery of the town like kebeles 01, 03, 07, and 24. The only prospective future development direction is to the west side of the town, which is the left

and right side of the road to Melka Jebdu. The other sides of the town are already expanded to the foot of Amhara Mountain WWDSE (2004).

Currently Dire Dawa town is under regularization process for better land use development work. Accordingly, the previously twenty five kebeles were restructured in nine kebeles which facilitates town plan management. Table 3.1 shows how the previous kebeles were merged into the newly formed kebeles.

3.9.2 Housing

Though shelter is the basic necessity and right of human being, it is one the major challenges Dire Dawa city faces in its endeavor to bring about a sustainable development. Currently it is estimated that more than 24,000 housing backlog exist in the city. On top of this, due to population growth, on average the backlog is expected to grow annually by 2900 for the coming five years. The housing problem in Dire Dawa is not only of quantity but the quality of many housing units is also a prime concern. It is observed that out of the total housing stock, about 30.5 percent are built-up of wood and mud. Stone and cement houses constitute about 26.4 percent and about 17 percent of the houses are made up of stone and mud. The percentage share of houses built by hollow blocks and bricks is insignificant and constitute about only 12.6 percent.

The present problem of residential houses in the city is putting pressure on unplanned growth of the city and poor quality of life. Moreover, high population growth, municipal ineffectiveness, high cost of construction materials, low level of income and saving, shortage of infrastructure and shortage of financial sources, contributed a lot for the current gap between demand and supply of residential houses IDP (2006).

Table 3.1: The current kebeles of Dire Dawa town setting
 Source: (Policy Study & Plan Commission, quoted in IDP (2006))

Previous Kebeles	New Kebeles	Area (Km ²)	Population per Kebele (1994)
25	01	29.56	130870
01, 02, 24	02	40.81	36185
03, 04, 05	03	9.27	26363
06, 07, 08	04	2.26	30336
09, 10, 11, 12	05	0.61	30662
13, 14, 15, 16	06	0.66	29492
17, 18, 21	07	0.73	35668
19, 20	08	1.06	39477
22, 23	09	8.02	30798

CHAPTER FOUR

DATA ANALYSIS AND RESULTS

4.1 Introduction

The factors that are necessary for the incidence of the flood catastrophe were reviewed and the local dwellers were interviewed. Accordingly drainage density, slope, elevation, land use type and road density are listed in order of importance.

To assess flood risk of the town using GIS, Multi-Criteria Evaluation was used. MCE is a procedure which needs several criteria to be evaluated to meet a specific objective. It is most commonly achieved by one of two procedures. The first involves Boolean overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). The second procedure which was used in the study is known as weighted linear combination (WLC) where continuous criteria (factors) were standardized to a common data model that was raster layer with a resolution of 28.5 m cell size, and then combined by means of a weighted overlay. The result is a continuous mapping of flood risk and finally thresholded to yield a final decision.

The standardized raster layers were weighted using Eigen vector that is important to show the importance of each factor as compared to other in the contribution of flood hazard. Accordingly, the Eigen vector of the weight of the factors was computed in IDRISI 3.2 software in Analysis menu Decision Support/ Weight module. The Weight module was fed with the pair wise comparison matrix file of the factors in a Pair wise comparison 9 Point continuous scale (Fig 4.1).

The pair wise comparison matrix used for the weight computation is:

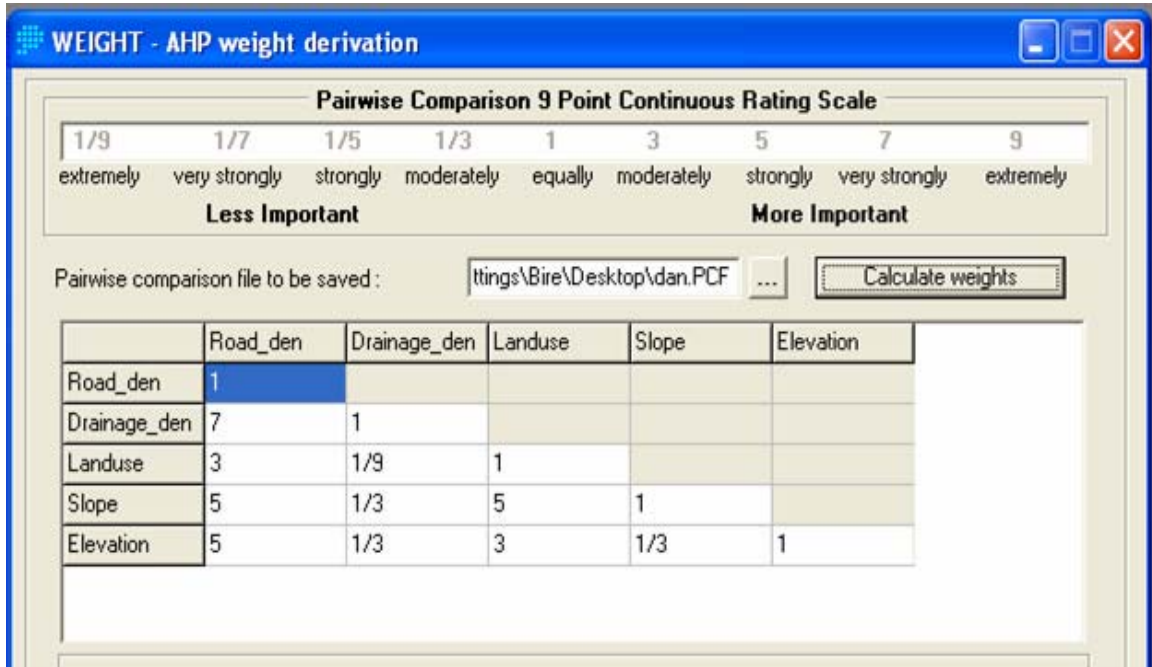


Fig 4.1: The Pair Comparison Matrix of the factors affecting Flood hazard

The computed Eigen vector, which is an out put of the pair wise comparison matrix to produce a best fit set of weight, of Weight Module was:

- Drainage density: __ 0.4849
- Slope: __0.2620
- Elevation: __0.1489
- Land use type: __ 0.0641
- Road density: __0.0401

The critical ratio of the calculated Eigen vector is 0.07 which is acceptable.

The computed Eigen vector is used as a coefficient for the respective factor maps to be combined in Weighted Overlay in Arc GIS environment, whereas in Flood risk assessment all the factors remained to be equally important in Weighted Overlay (table 4.2).

All the above mentioned factors were generated from the processed vector layers such as 2 meter interval contour feature layer, town road feature layer, land use type layer and town drainage line feature layer (table 4.1) and the geodatabase of the factors was built to make easier to conduct GIS analysis on the selected hazard inducing factors (Fig 4.2).

Table 4.1: Weighted flood hazard ranking for Dire Dawa town (Hazard Analysis)

Factors	Weight	Sub-factors	Ranking
1. Drainage density (Km / Sq.Km)	0.4849	0 – 8.6	5
		8.6 – 17.2	4
		17.2 – 25.8	3
		25.8 – 34.4	2
		34.4 – 43.0	1
2. Slope (degree)	0.2620	0 – 1	5
		1 - 2	4
		2 – 3	3
		3 – 5	2
		5 - 84	1
3. Elevation (meter)	0.1489	1090 – 1141	5
		1141 – 1178	4
		1178 – 1207	3
		1207 – 1273	2
		1273 - 1474	1
4. Land use (related to water absorption and drainage capacity)	0.0641	Sand Deposit	1
		Agriculture	2
		Open Shrub land	3
		Open land	4
		Urban & Built-up Areas	5
5. Road density (number/ Sq.Km)	0.0401	0 – 43.5	1
		43.5 – 87.1	2
		87.1 – 130.6	3
		130.6 – 174.1	4
		174.1- 220	5

Table 4.2: Weighted flood risk rankings for Dire Dawa town (Risk Analysis)

Factors	Weight	Sub-factors	Ranking
1. Flood hazard	1	very low	1
		low	2
		moderate	3
		high	4
		very high	5
2. Population density	1	1596.82 – 6911.56	1
		6911.56 – 12226.29	2
		12226.29 – 17541.03	3
		17541.03 – 22855.76	4
		22855.76 – 28170.5	5
3. Land use types	1	Shrub land, Open land, Sand deposit	1
		Agriculture	2
		Public Utilities and Critical facilities	3
		Institutional areas	4
		Residential, Commercial and Industrial area	5

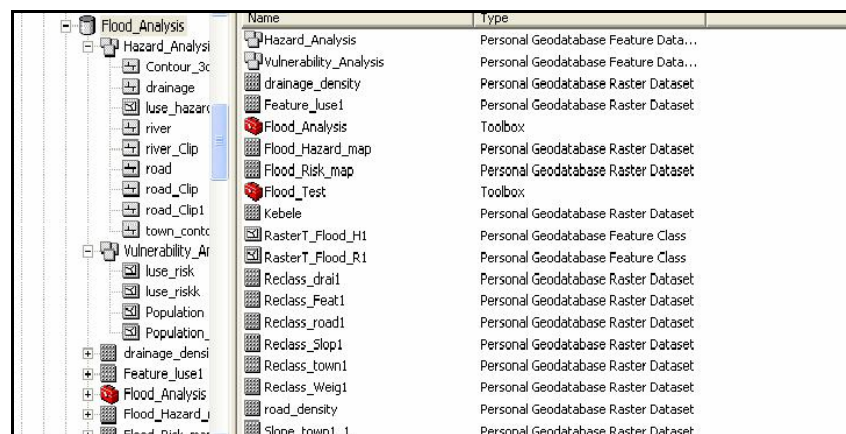


Fig 4.2: Built Geodatabase for flood hazard and flood risk analysis

4.2 Factor Development

4.2.1 Drainage Density Factor

The town drainage was not compiled in a way that is usable for the user. Hence in the field survey, spatial point locations on local open and closed drainage line were collected using Global Positioning System (GPS) receiver. These spatial points were digitized into a line feature to create a drainage line feature for drainage density factor. And using the spatial analyst, line density module was used to compute drainage density of the town.

Line density module calculates a magnitude per unit area from polyline features that fall within a radius around each cell. Density is measured in length of lines per unit area. The density layer is further reclassified in five sub group using standard classification schemes namely equal interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while ArcMap determines where the breaks should be. And new values re-assigned in order of flood hazard rating (Fig 4.3).

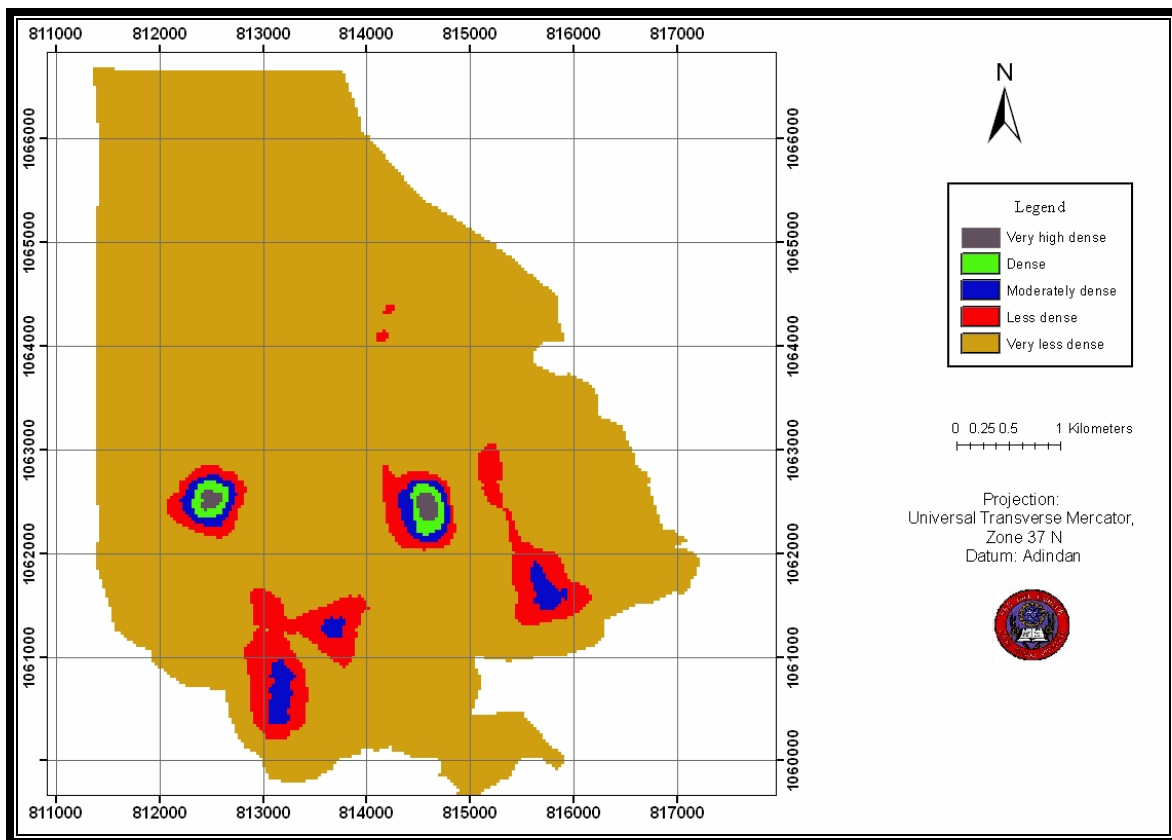


Fig 4.3: Reclassified Drainage density layer

4.2.2 Slope Factor

The town slope is derived from 2-meter contour interval feature class which is digitized from aerial photograph and further rectified in GIS environment (source: ISS). This feature was converted to 3d shape file using 3D Analyst in Convert feature to 3D module by interpolating contour using an attribute as a source. Further Tin was created using 3D Analyst in Create Tin from Feature (3D shape). Slope was derived using 3D Analyst in

Tin Surface/ Tin Slope module. Slope feature class was further converted to raster using Conversion Tool in To Raster/ Feature to Raster module. The slope raster layer was further reclassified in five sub group using standard classification schemes namely Quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while ArcMap determines where the breaks should be. And new values re-assigned in order of flood hazard rating (Fig 4.4).

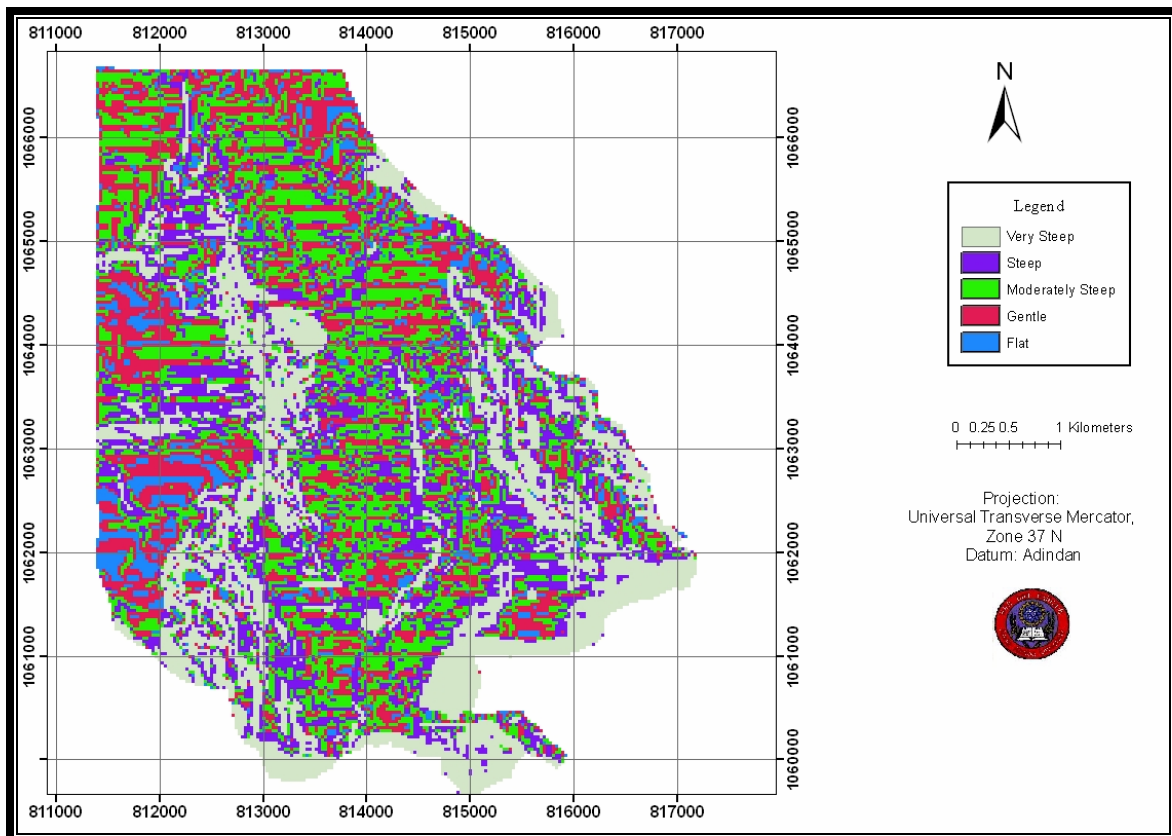


Fig 4.4: Reclassified Slope layer

4.2.3 Elevation Factor

The town slope is derived from 2-meter contour interval feature class which is digitized from aerial photograph and further rectified in GIS environment. This feature was converted to 3d shape file using 3D Analyst in Convert feature to 3D module by interpolating contour using an attribute as a source. Further Tin was created using 3D Analyst in Create Tin from Feature (3D shape). Elevation raster layer was derived from the created Tin. The elevation raster layer was further reclassified in five sub groups

using standard classification schemes namely equal interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determines where the breaks should be. And new values re-assigned in order of flood hazard rating (Fig 4.5).

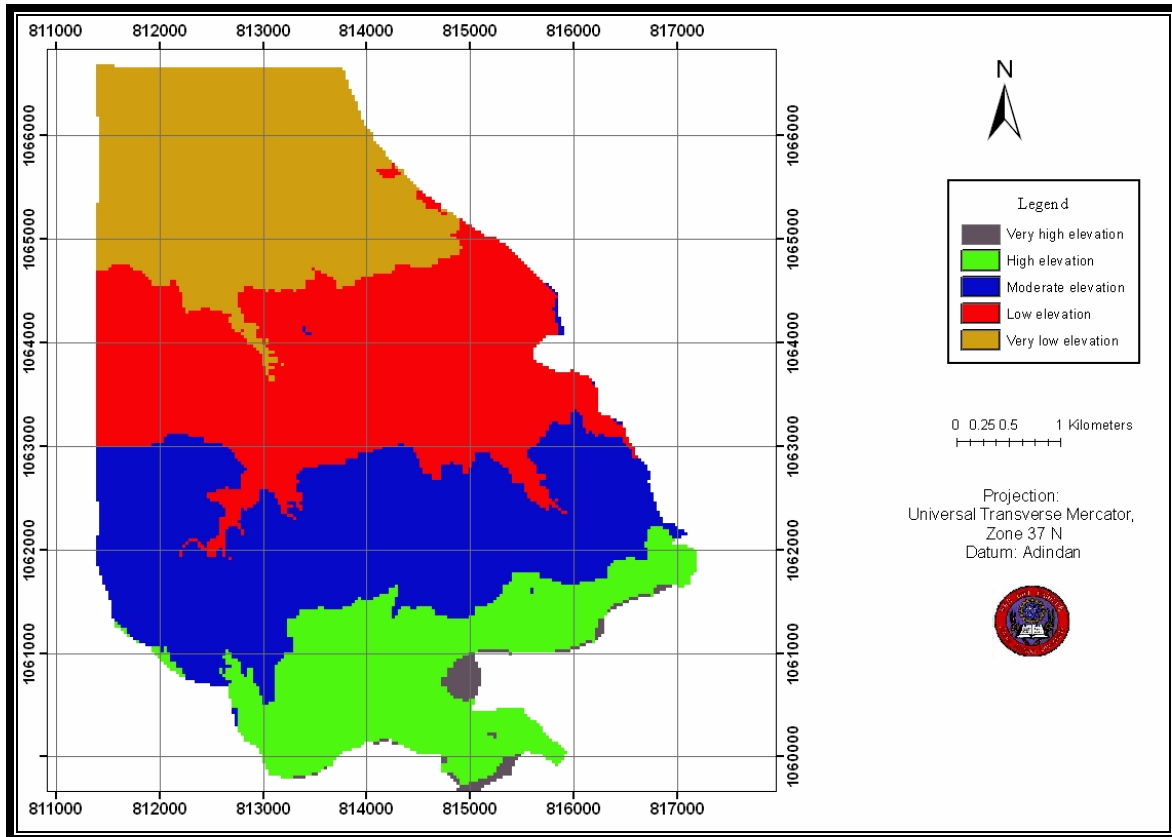


Fig 4.5: Reclassified Elevation layer

4.2.4 Land Use Factor

Land use type of the town was reassigned by categorizing land use types using Query builder into five general classes (Table 4.3) and converted to raster layer. Further the existing land use types of the town reclassified into five groups in order of their water absorption and drainage capacities. And new values re-assigned in order of flood hazard rating for hazard analysis (Fig 4.6) and flood risk rating for flood risk analysis (Fig 4.7).

Table 4.3: land use types for flood hazard and flood risk analysis

Factor	Sub-factor for flood hazard analysis	Sub-factor for flood risk analysis	Ranking
Land use Types	Sand Deposit	Shrub land, Open land and Sand deposit	1
	Agriculture	Agriculture	2
	Open Shrub land	Public utilities and Critical facilities	3
	Open land	Institutional areas	4
	Urban & Built-up Areas	Residential, Commercial and Industrial areas	5

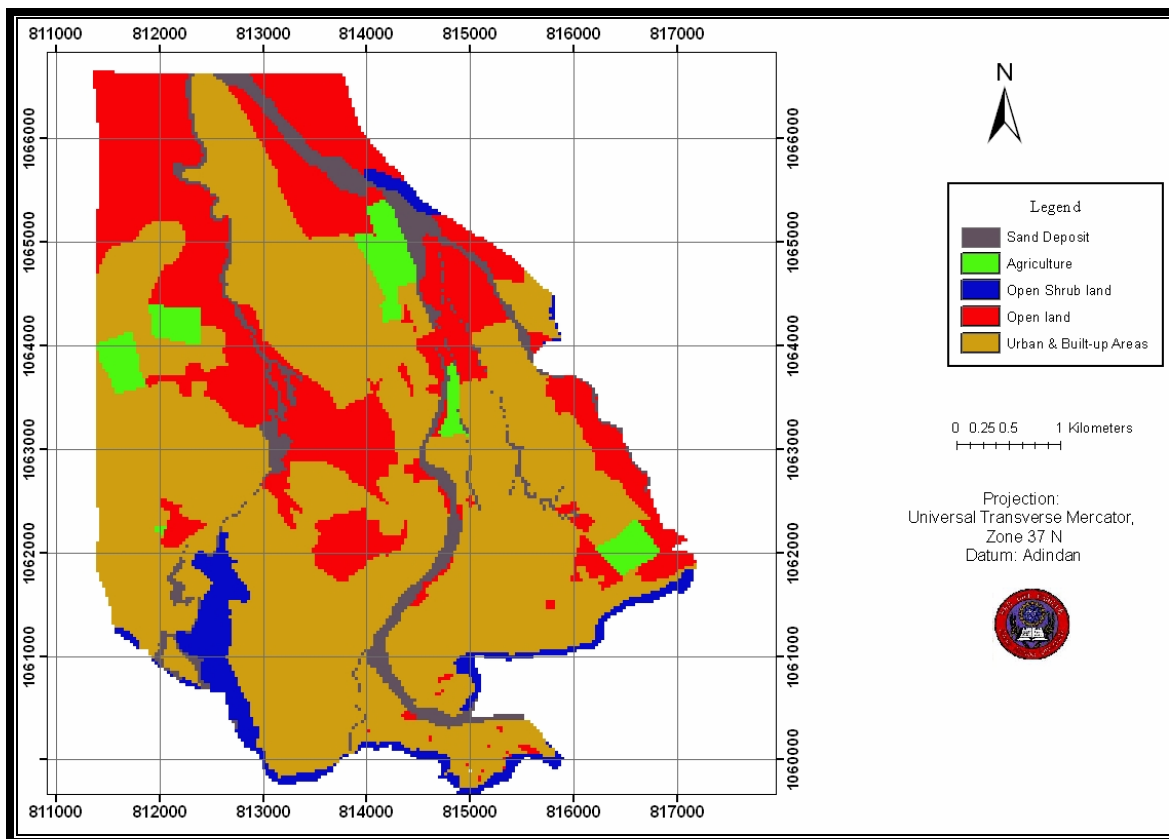


Fig 4.6: Reclassified Land use layer (for flood hazard analysis)

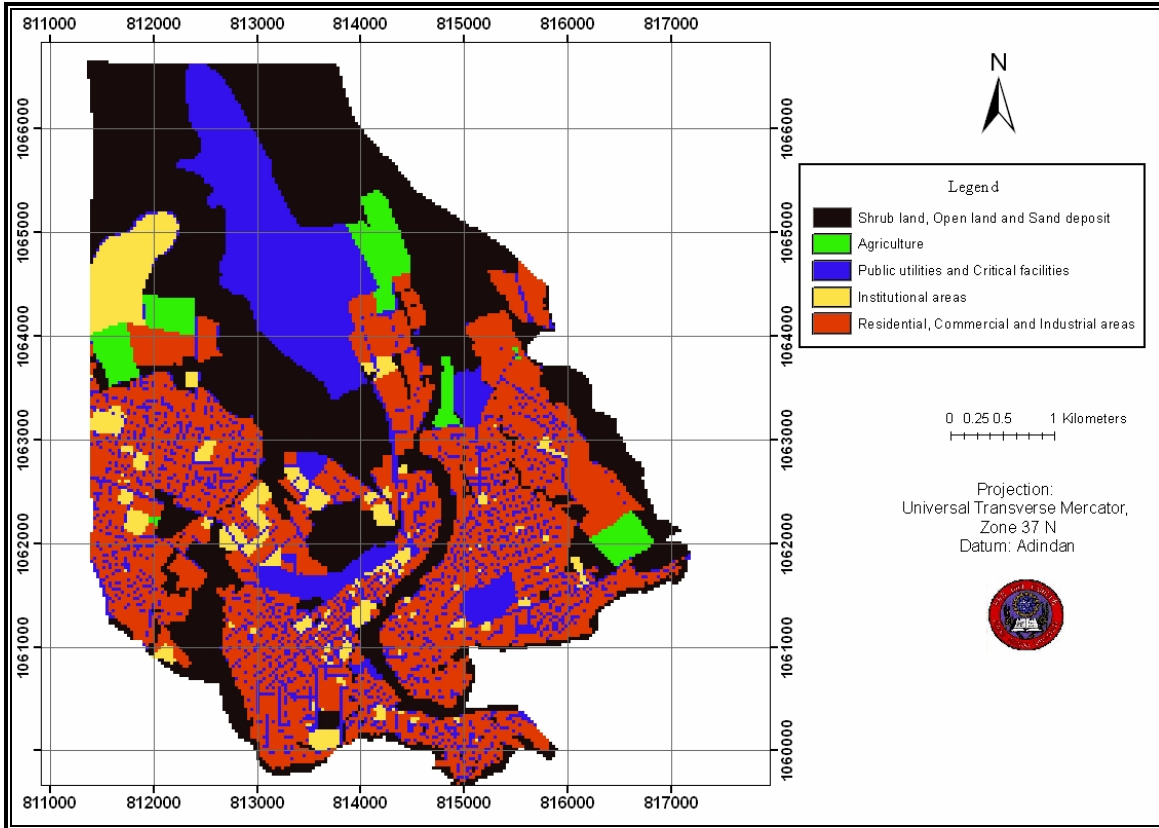


Fig 4.7: Reclassified Land use layer (for flood risk analysis)

4.2.5 Road Density Factor

Road density was computed from road network layer of the town using line density module in Spatial Analyst toolbox. The road density layer was further reclassified in five sub groups using standard classification schemes namely equal interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determines where the breaks should be. And new values re-assigned in order of flood hazard rating (Fig 4.8)

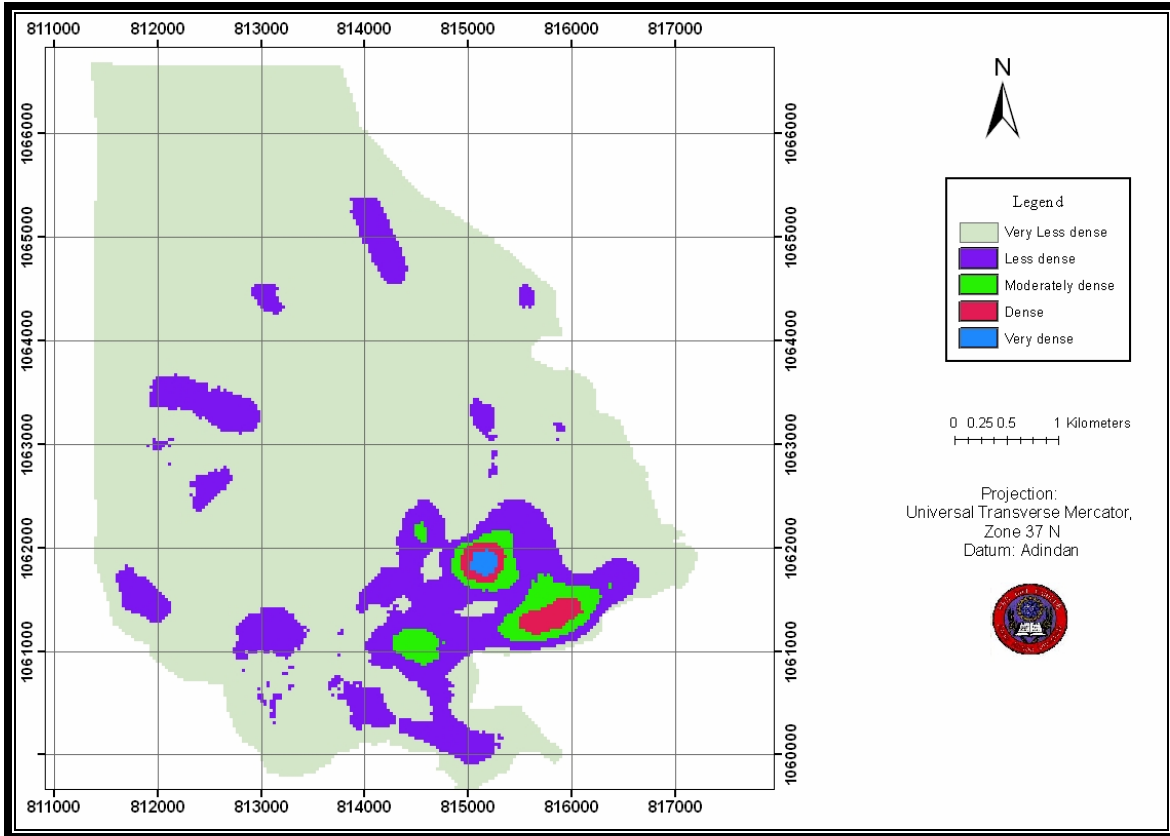


Fig 4.8: Reclassified Road density layer

4.2.6 Population Density Factor

Kebele shape is updated with population data from census CSA (1994). Gross population density calculation method is used to calculate the number of person per square kilometers per kebele. Right after updating, population shape file was converted to raster layer using Conversion Tools/ Feature to Raster. Then further the data layer was reclassified into five sub-factors which are classified using equal interval method. And new values re-assigned in order of increasing number of population that is more susceptible to flood hazard (Fig 4.9).

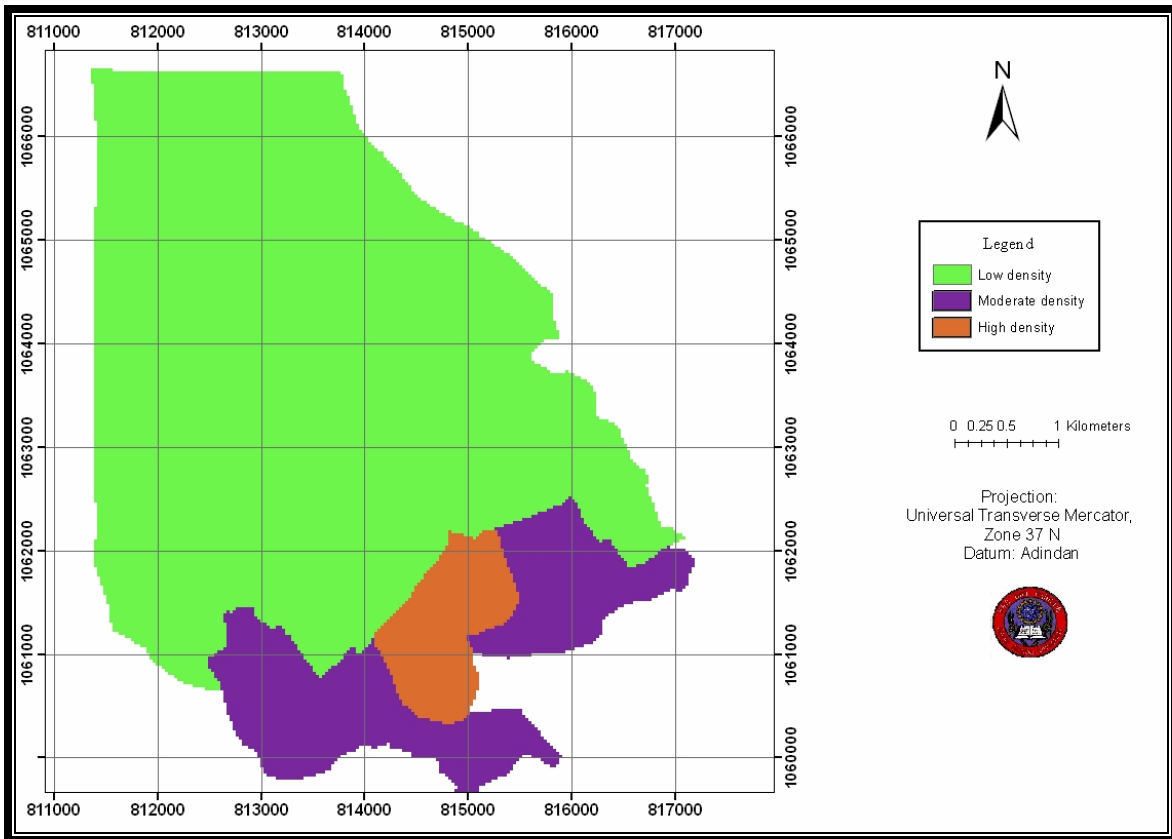


Fig 4.9: Reclassified Population density layer

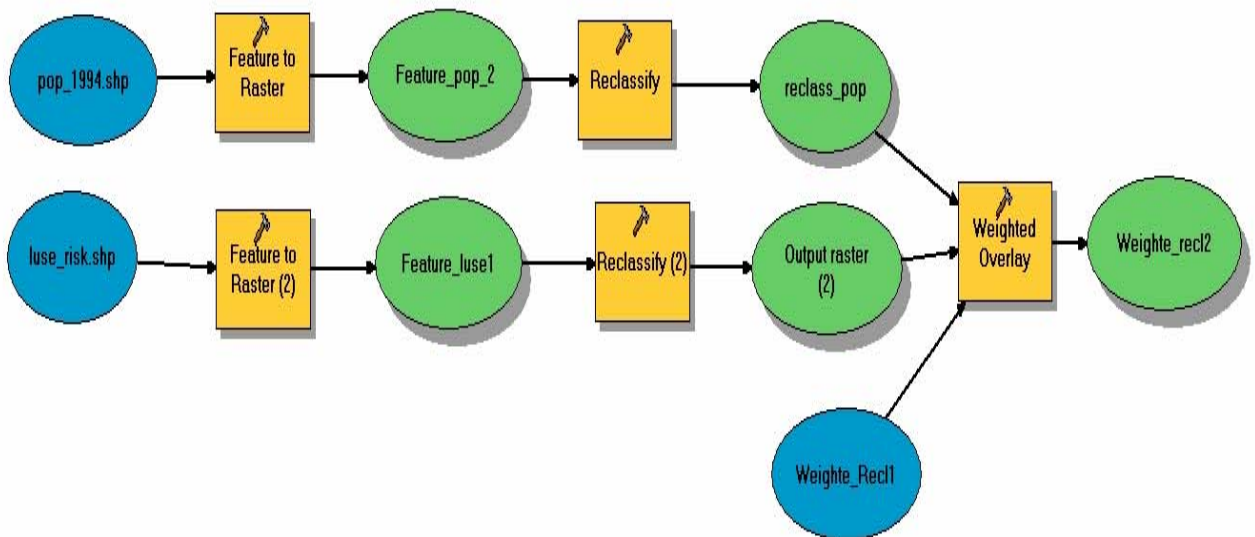


Fig 4.11: Flood Risk Analysis Model Builder dialogue box

4.3 Data Analysis

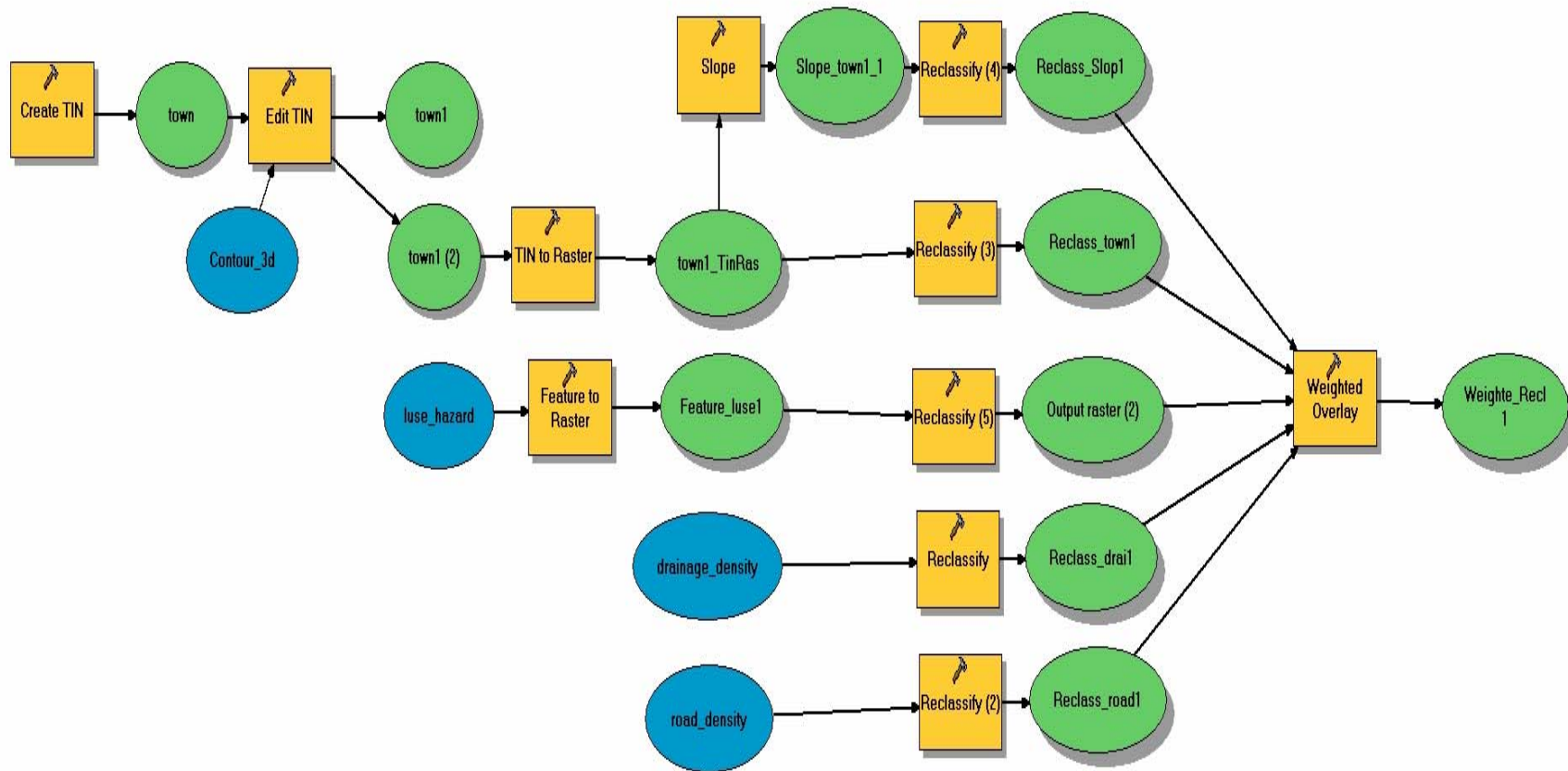


Fig 4.10: Flood Hazard Analysis Model Builder dialogue box

4.3.1 Flood Hazard Analysis

The study was conducted on 32.3% (one third) of the total Dire Dawa town area coverage (Annex 3). That means, according to new land regularization policy, Kebele 01 and Extension are out of the study area and kebele 02, 03 and 09 were partly considered.

Flood hazard analysis was computed by Weighted Overlay of drainage density, slope, elevation, land use and road density developed factors (Fig 4.10)

From the flood hazard map (Fig 4.12), it was estimated that 88.4, 989.2, 1381.2, 216.8 and 61.2ha of the area considered in Dire Dawa town were subjected respectively to very low, low, moderate, high and very high flood hazards (Annex 2). Further analysis revealed that (100%) cultivated, (95.7%) open land, (84.5%) sand deposit, (83.4%) built-up area and (74.7%) open shrub land faces low to moderate flood hazard. Besides (16%) of the built-up areas is categorized into high to very high hazard (table 4.4).

Kebeles were also classified in terms of flood hazard level as it is an important domain to administer the population in the town. Accordingly, kebele 07, 06, 04 and 05 are respectively 81.8%, 68.9%, 30.2% and 26.7% of the total area under consideration are subjected to high to very high flood hazard (table 4.5). Hence these kebeles needs immediate attention for alleviating future potential flood hazard. Moreover, this result was compared with ground truth data which shows that flood victim sites fall in moderate to high flood hazard zonation (Annex 6).



Fig 4.12: Flood hazard analysis map of Dire Dawa town

Table 4.4: Area tabulation of Flood hazard map and land use of Dire Dawa town

Land use type	Flood hazard					Total
	Very low	Low	Moderate	High	Very high	
	1	2	3	4	5	
Area (ha)						
Sand deposit	24.7	110.6	38.1	2.5	0.08	176.0
Cultivated land	0	85.5	8.4	0	0	93.9
Open shrub land	26.4	69.4	18.0	3.2	0	117
Built-up area	8.9	76.2	1290.9	200.1	62.9	1639
Open land	27.7	646.0	34.0	2.8	0.2	710.7
Total	88.7	987.8	1389.4	208.6	63.2	

Table 4.5: Area tabulation of Flood hazard map and existing Kebeles of Dire Dawa town

Kebele name	Flood hazard					Total
	Very low 1	Low 2	Moderate 3	High 4	Very high 5	
	Area (ha)					
Kebele 02	11.7	313.9	331.6	24.8	0	682
Kebele 03	49.2	439.0	550.9	6.8	0	1045.9
Kebele 04	0.5	19.2	86.3	45.9	0	151.8
Kebele 05	0	17.2	64.9	30.0	0	112.1
Kebele 06	0.2	0.2	21.7	28.4	20.5	71.2
Kebele 07	0	0.2	14.5	24.1	42.1	80.9
Kebele 08	0	31.0	91.9	42.0	0.3	165.2
Kebele 09	25.9	163.7	226.9	6.7	0.2	423.4
Total	87.6	984.4	1388.7	208.7	63.2	

4.3.2 Flood Risk Analysis

Flood risk analysis is computed by Weighted Overlay setting equal importance to all factors (Fig 4.11). The developed factors for overlay are Flood hazard analysis layer and the two elements at risk of the town are Population density and land use for flood risk analysis (table 4.2).

According to the flood risk map (Fig 4.13), it was estimated that 0.2, 1053.0, 1266.7, 355.8 and 61.2 ha of the area considered in Dire Dawa town were subjected respectively to very low, low, moderate, high and very high flood risk (Annex 2). Further analysis revealed that (32.4%) residential, commercial and industrial area, (16.7%) Public utilities and critical facilities, (9.8%) institutional areas, (0.1%) agricultural areas of the study area faces high to very high flood risk level (table 4.6).

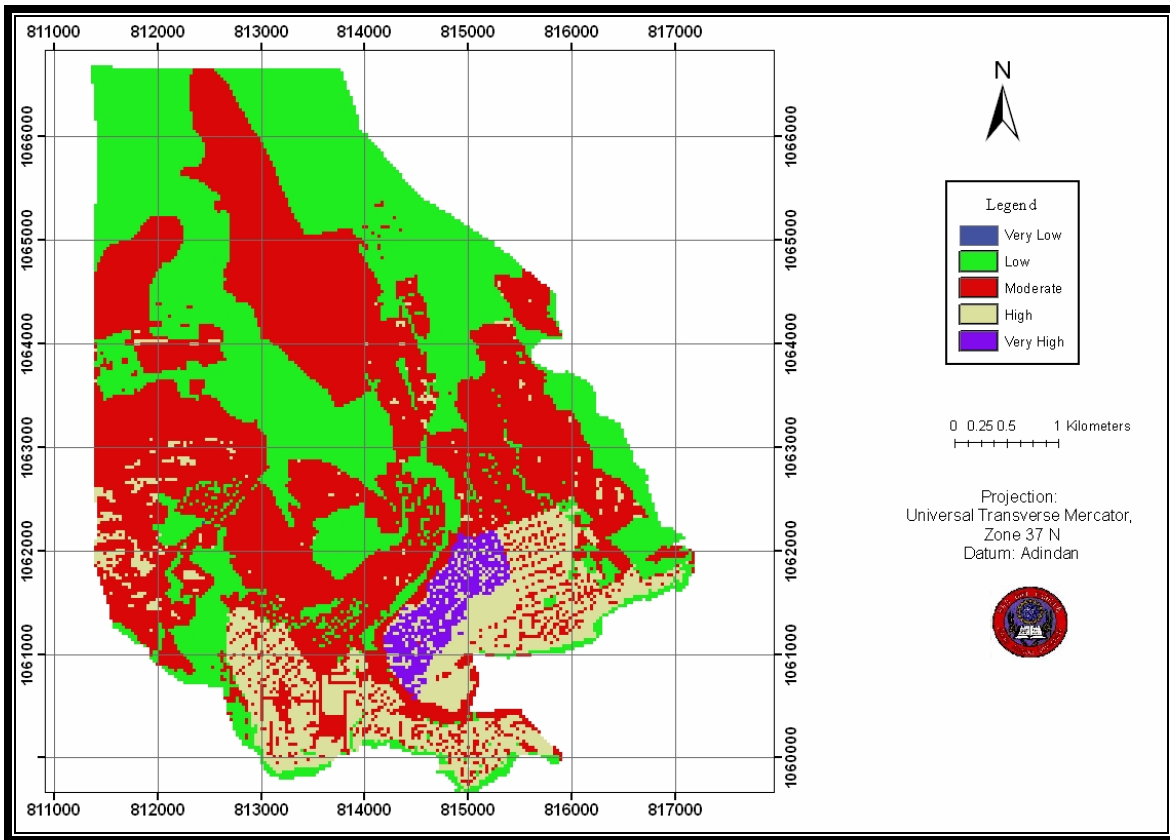


Fig 4.13: Flood risk analysis map of Dire Dawa town

Kebeles were also classified in terms of flood risk level as it is an important domain to administer the population in the town. Accordingly, kebele 07, 06, 04, 08 and 05 are respectively 83.4%, 73.3%, 62.0%, 59.5% and 55.7% of the total area under consideration are subject to high to very high flood risk. Hence these kebeles needs immediate attention for alleviating potential future flood risk (table 4.7).

Table 4.6: Area tabulation of Flood risk map and land use of Dire Dawa town

Land use type	Flood risk					Total
	Very low 1	Low 2	Moderate 3	High 4	Very high 5	
	Area (ha)					
Residential, commercial & industrial areas	0	36	589.6	250.7	48.7	924.9
Institutional areas	0	2.5	132.6	14.5	0.2	149.9
Shrub land, open land and sand deposit	0.1	913.7	83.4	9.8	0.2	1007.3
Agriculture	0	82.0	13.0	0.1	0	95.1
Public utilities and critical facilities	0.1	21.8	447.5	79.9	14.1	563.4
Total	0.2	1056.0	1266.2	355.0	63.2	

Table 4.7: Area tabulation of Flood risk map and existing Kebeles of Dire Dawa town

Kebele name	Flood risk					Total
	Very low 1	Low 2	Moderate 3	High 4	Very high 5	
	Area (ha)					
Kebele 02	0.1	319.5	338.1	24.8	0	682.4
Kebele 03	0.1	475.3	563.5	7.1	0	1046.0
Kebele 04	0	19.2	38.5	94.2	0	151.9
Kebele 05	0	18.3	31.4	62.5	0	112.1
Kebele 06	0	0.6	18.4	31.6	20.5	71.2
Kebele 07	0	0.3	8.1	0.4	42.1	50.9
Kebele 08	0	27.0	39.8	98.0	0.3	165.2
Kebele 09	0	188.6	227.1	6.7	0.2	422.7
Total	0.2	1048.8	1264.9	325.3	63.2	

4.4 Land use Change

4.4.1 Land use/ Land cover classification

The Land sat-TM/ETM image with 7 spectral bands, a nominal ground resolution (pixel size) of 30 x 30 metres and a nominal scene size of 185 x 185 Km is an ideal source of data for a reconnaissance scale survey. Land sat-TM/ETM will be used to define the different classes of land cover types WBISPP (2004).

Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument which is managed by NASA and Japan's Ministry of International Trade and Industry.

ASTER is a multispectral (14 band) high-resolution sensor with three different instruments that works in the Visible and Near Infrared (VNIR), Short wave Infrared (SWIR), and the Thermal Infrared (TIR) regions of the electromagnetic energy Mather (2004).

The data used is the VNIR bands (Band 1: 0.52-0.60 μm ; Band 2: 0.63-0.69 μm and Band 3N: 0.76- 0.86 μm) of ASTER imagery with 15m spatial resolution. A colour composite of the three bands was used as background during image classification and enhanced by Contrast Stretching technique specifically Linear Stretch.

Supervised image classification which is a widely used technique Sluiter (2005); Nangendo (2005) was applied in this study. From six major land use/ land cover types (Open Wood land, Shrub land, cultivated land, Barren land, Sand deposit and Settlement), 124 ground truth points were collected from the field. Each point was marked with GPS which was later integrated with the image. Half of this data was used as input for supervised image classification and the remaining for accuracy assessment. Accordingly, the two land use/ land cover maps of the year 1985 (Fig 4.14) and 2006 (Fig 4.15) were generated using the widely used maximum likelihood classifier algorithm Lillesand et al (2000).

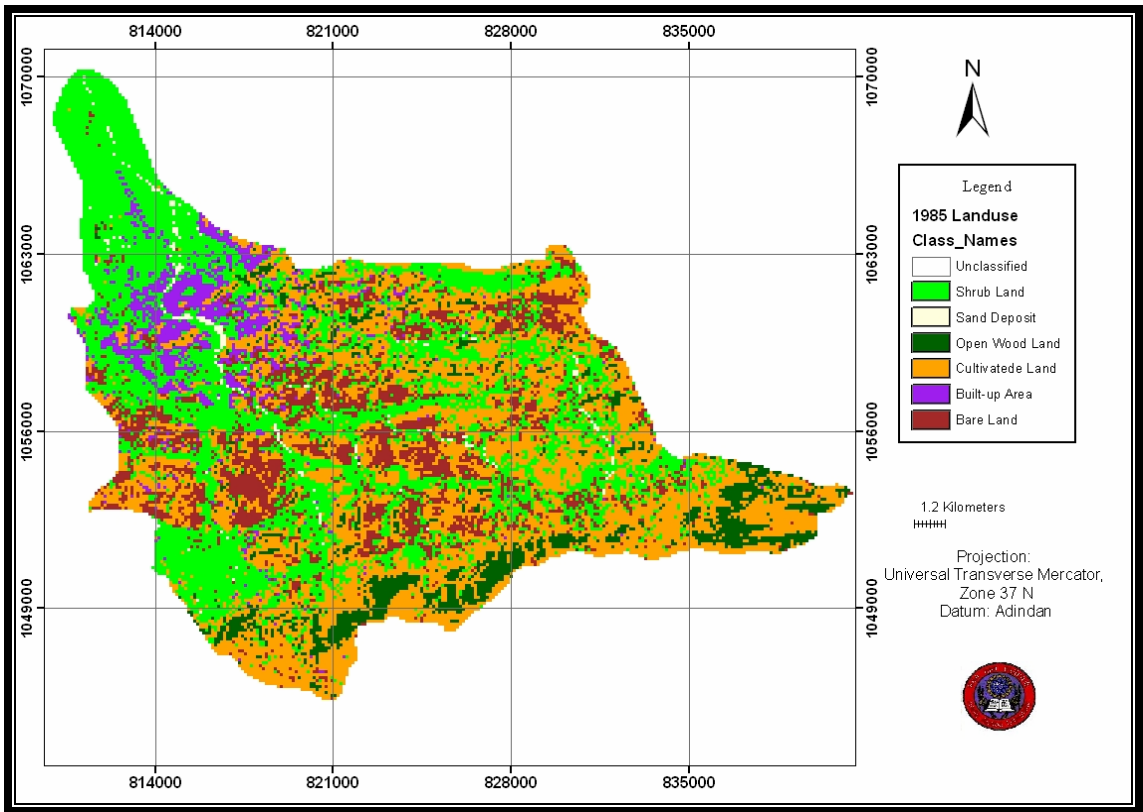


Fig 4.14: 1985 land use map of Dechatu catchment

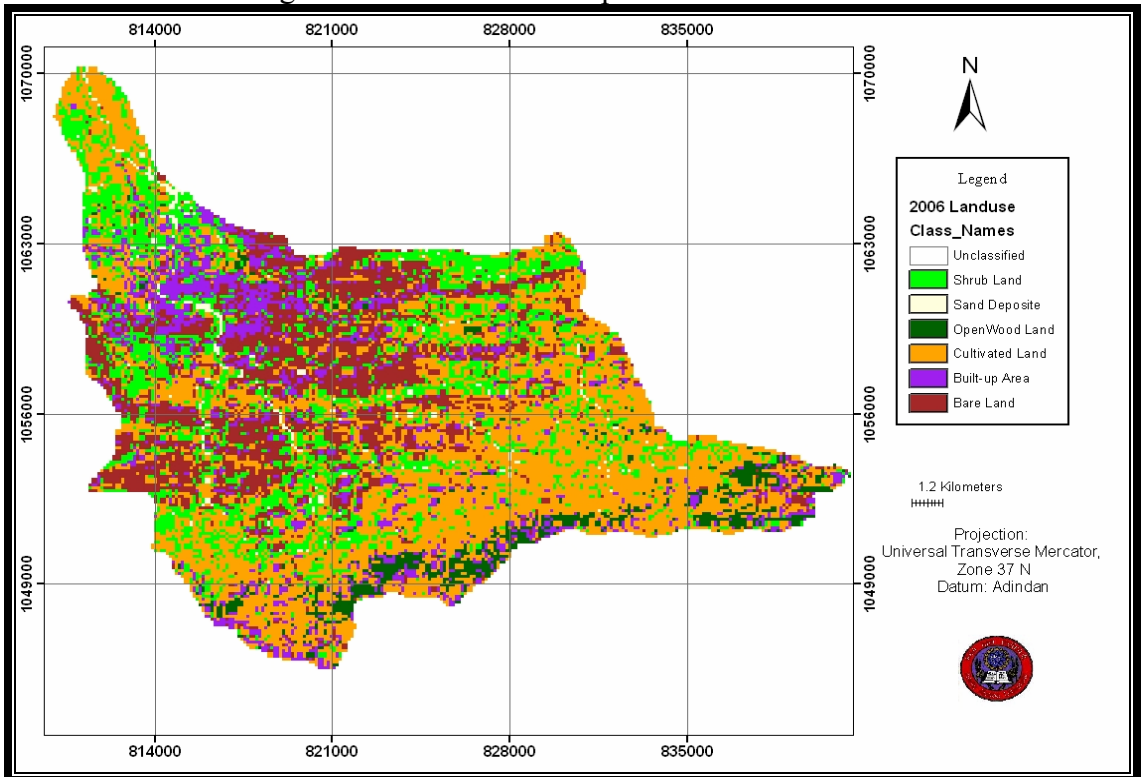


Fig 4.15: 2006 Land use map of Dechatu catchment

4.4.2 Accuracy Assessment

To assess the classification accuracy, confusion matrix was used. Confusion matrix is strong in that it indicates the nature of the classification error ITC (2001) and used in many other research works Sluiter (2005); Nangendo (2005). Confusion matrix (table 4.8) was generated by crossing the two maps generated using the training sets and the independent data (Fig 4.16).

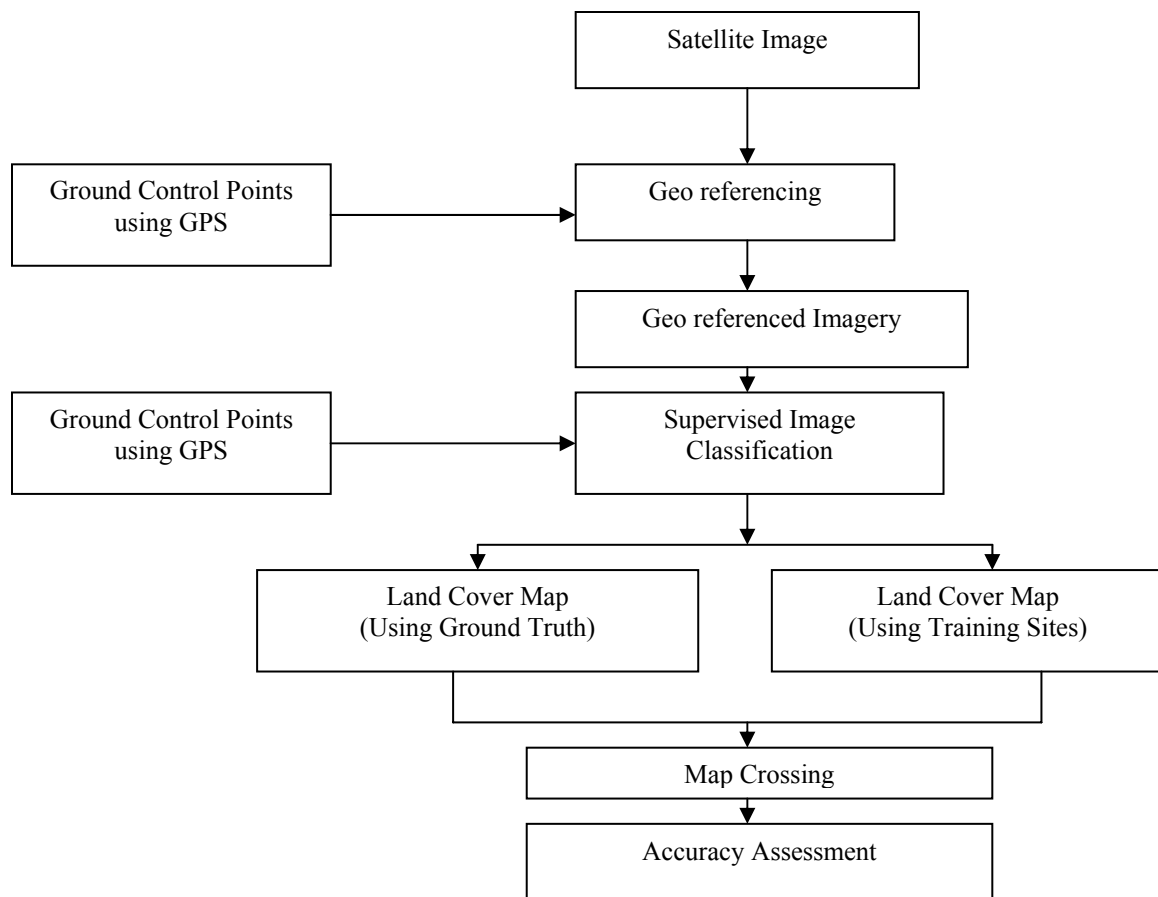


Fig 4.16: Schematic diagram showing the major image processes of Accuracy Assessment

Table 4.8: Confusion matrix of 2006 land use classification of Dechatu catchment
(Overall Accuracy = (239/2820) 84.82%; Kappa Coefficient = 0.8133)

Class	Open wood land	Cultivated	Shrub land deposit	Sand deposit	Bare land	Built-up area	Total
Unclassified	0	0	0	0	0	0	0
Open wood land	600	54	0	0	0	0	654
Cultivated	28	403	15	6	9	1	462
Shrub land deposit	0	21	185	35	10	26	277
Sand deposit	0	0	0	230	0	0	230
Bare land	0	0	36	0	413	120	569
Built-up area	36	17	0	0	14	561	628
Total	664	495	236	271	446	708	2820
Class	Producer Accuracy's (%)		User Accuracy's (%)				
Open Wood land	90.4		91.7				
Cultivated land	81.4		87.2				
Shrub land	78.4		66.8				
Sand deposit	84.9		100.0				
Bare land	92.6		72.6				
Built-up area	79.2		89.3				

4.4.3 Land use change of Dechatu catchment

Land use change trends like persistent urbanization, intensification or expansion of agriculture, consolidation of farmland, deforestation/afforestation strongly affect the constitution of the landscape and thus land-cover conditions. Increases of surface sealing, soil degradation, such as densification or soil siltation are only examples of negative consequences caused by human society. Up to what extent and in which spatial scale these environmental changes are likely to affect storm runoff generation and

subsequently the extreme discharges of rivers, is still uncertain. It is conditional upon different reasons: (1) data scarcity about land-use changes in a catchment scale, (2) the imperfect representation of land-use and its poor parameterization within hydrological models and finally (3) the disregard of spatial complexity for land-use scenarios Fritsch et al., (2001). According Moussa et al., (2003) the main hydrological processes are affected by the spatial variability of soils, topography, land use and cover, climate, and human-induced changes and management.

The change detection statistics of the area coverage of different land use/land cover in Dechatu catchment was cross-tabulated using ENVI 4.2 software package. This analysis shows that the cross classification of 1985 Land sat TM satellite image (RGB: band 7, band 4 and band 2 combinations) and 2006 ASTER image (RGB: band 3N, band 2 and band 1 combinations). Change Detection Statistics display the analysis result in three ways (Number of Pixel, percentage and in area terms)

Land use change of Dechatu catchment was studied based on 9th March, 1985 Land Sat TM and 15th June, 2006 ASTER images. The spectral bands combination in RGB order respectively is 7, 4, 2 and VNIR bands (Band 1: 0.52-0.60 μm ; Band 2: 0.63-0.69 μm and Band 3N: 0.76-0.86 μm) for Land Sat TM and ASTER sensors. Accordingly, six land use/land cover classes are identified in the catchment: built-up area, bare land, cultivated land, sand deposit, shrub land and open wood land.

Referring 1985 Land Sat TM as initial state image and 2006 ASTER as final state image, the change of each land use/land cover class is listed as follows: (93.8%) built-up area, 40.5% bare land, 16.4 % cultivated land, 59.9% sand deposit, -41.9% shrub land and -39.6% open wood land (table 4.9).

The built-up area has shown the highest change in terms of area coverage expansion which is highly correlated with the population growth. In the contrary, shrub land shows the highest clearing rate which is directly correlated with surface runoff generation potential. That means this circumstance has a direct impact on the increment of flood volume and discharge.

Table 4.9: The land use/ land cover of Dechatu catchment change detection statistical summary in percentage

	Percentage (%)	1985 Land Use						Row total	Class total
	Percentage (%)	Built-up area	Bare land	Cultivated land	Sand deposit	Shrub land	Open wood land		
2006 Land Use	Unclassified	0.256	0.09	0.23	0	0.25	0.17	0.16	
	Built-up area	39.55	4.96	14.07	3.28	5.39	17.92	99.8	100
	Bare land	31.45	39.33	22.68	4.16	12.5	8.88	99.95	100
	Cultivated land	11.04	38.62	45.24	25.42	44.9	36.1	99.83	100
	Sand deposit	0.37	0.34	0.46	31.39	2.5	0.21	99.95	100
	Shrub land	16.96	16.11	12.17	35.22	34.3	5.54	99.93	100
	Open wood land	0.37	0.51	5.15	0.53	0.89	31.2	99.72	100
	Class total	100	100	100	100	100	100		
	Class change	60.46	60.67	54.76	68.6	65.74	38.78		
	Image difference	93.81	40.49	16.39	59.89	-41.93	-39.58		

4.5 Flash Flood hazard mapping of Dechatu catchment

Flash floods are generated when precipitation saturates the drainage capacity of the basin slope and causes impoundment of the drainage network, resulting in exceptionally high discharge amounts at the basin's outlet. Flash-flood-prone wadis (dry river channels cut into the terrain) can be assessed and delineated through the use of GIS.

Data used in this study consisted of two raster layers: elevation map derived from contour digitized on 1: 50,000 scale topographic sheet (Annex 6), and a mean annual maximum 24 hours rainfall layer (Annex 1).

These layers were used as input data for Arc View GIS software in order to delineate the watersheds and calculate the flow accumulation for each wadis of Dechatu catchment.

Several morphometric parameters were identified for each sub-catchment in order to estimate its flash flood potential. The morphometric analysis consisted of classifying and measuring the geometry of drainage sub-catchments and their components in a quantitative manner. There are many morphometric parameters describing the geometry of drainage basins that have an effect on the creation of flash floods.

The GIS hydrologic modeling approach (using Arc View 3.2 GIS extension Hydrologic Modeling Version 1.1) was used along with an elevation raster layer, and 1:50,000

Topographical map, in order to identify the following parameters in an automated way: flow accumulation, mean land slope, mean annual 24 hours rainfall, and shape factor.

4.5.1 Deriving Flash Flood Hazard Parameters

4.5.1.1 Flow Accumulation

Major streams and contours of the catchment were digitized from 1:50,000 topographical maps. These streams were filled with the following parameters by updating the attribute of each stream.

Creation of DEM is the first to compute flow accumulation. Hence, the digitized contours were converted to 3D shape taking height source feature attribute. Then TIN was generated from the created 3D shape. Using elevation as a height source, Grid layer (DEM) was generated from the 3D shape contour. Sinks were filled using Fill menu and flow direction was computed for every cell in the grid layer.

Flow accumulation was calculated based upon the flow direction. This function calculates the accumulated flow as the weight of all cells flowing through each down slope cell in the output grid. Accordingly, flow accumulation was derived from the generated flow direction layer using Flow Accumulation menu. The computed flow accumulation of each selected streams in catchment is demonstrated in (table 4.10).

The output of flow accumulation represents the amount of rain that would flow through each cell, assuming that all rain would become runoff and there is no interception, evapotranspiration, or loss to groundwater. This can also be viewed as the amount of rain that falls on the surface, upslope from each cell (Annex 4).

4.5.1.2 Shape factor

Shape factor is a measure of the shape of a basin computed as the ratio of length of the basin to its computed area. The formula for such computation is as follows:

$$\text{Shape factor} = (\text{LB})^2 / \text{A} \dots \dots \dots \text{Equation 4.1}$$

Where: - LB- length of the basin A-computed area

Shape factor for each sub-watershed in the catchment was computed by Shape factor by Watershed menu in hydrologic model (Annex 4). This characterizes the circularity of

each watershed. The computed shape factor of each selected streams in catchment is demonstrated in (table 4.10).

4.5.1.3 Mean Annual Maximum Daily Rainfall

The collected rainfall data (Annex 5) which is mean annual maximum daily rainfall is interpolated using Spatial Analyst. The method used for interpolation was IDW (Inverse Distance Weight). The meteorological stations are Dire Dawa, Dengego and Kersa (Annex 1). Mean annual maximum daily rainfall raster layer was computed for each sub-watershed in the catchment using Mean precipitation menu (Annex 4). The computed mean annual maximum daily rainfall of each selected streams in catchment is demonstrated in (table 4.10). The limitation is rainfall intensity data not included in the analysis.

4.5.1.4 Mean Slope

Mean-land-slope values were derived for each watershed. The slope plays a large role in the estimation of hazardous floods. High slopes can lead to flash flood generation. Using the DEM, the slope of each basin was derived. Mean slope within each sub-watershed in the catchment was computed from the rasterized slope layer developed in ArcGIS environment (Annex 4). The computed mean slope of each selected streams in catchment is demonstrated in (table 4.10).

Table 4.10: Selected wadis of Dechatu catchment and their morphometric characteristics and Mean Annual daily rainfall

River name	Flow Accumulation	Mean Slope (%)	Mean Annual Maximum daily rainfall (mm)	Shape factor	Mean elevation (m)
Lege Dole	245386.22	10.60	59.87	0.04	1483.32
Lege Dechatu	184039.67	4.24	60.05	0.04	1355.55
Lege Gogeti	184039.67	4.24	59.87	0.04	1611.09
Lege Ala	122693.11	8.48	59.50	0.13	1738.87

4.5.1.5 Pour Points

Pour points are the points at which water flows out of an area. This is the lowest point along the boundary of the watershed. To generate pour points of the catchment, watershed should be delineated. Accordingly, watershed layer was generated from the already created sink filled DEM and flow direction layers by specifying the minimum number of the cells that comprise it Annex_4.

Other terms for watersheds include basin, catchment, or contributing area. This area is normally defined as the total area flowing into a given outlet, or pour point. Pour points are the points at which water flows out of an area. This is the lowest point along the boundary of the watershed.

As a continuation to watershed delineation, pour points were computed by using Pour Points as Point Shape menu. Finally eight pour points were computed (Table 4.11).

Table 4.11: Selected pour points and their catchment area

Pour point ID	Catchment Area (ha)	Remarks
1	3323.586	After passing the town
2	3323.586	After passing the town
3	895.382	Before passing the town
4	895.382	Before passing the town
5	101.209	Before passing the town
6	473.321	Before passing the town
7	442.848	Before passing the town
8	5.455	Before passing the town

4.5.2 Mapping

4.5.2.1 Identification of Flood Prone Wadis

Wadis that are expected to carry flash floods are ranked according to risk factors to establish the most dangerous places in the event of a flash flood. All the above mentioned

parameters are used to determine the hazardous wadis in Dechatu catchment. These parameters were computed and entered in the attribute table of the catchment, and by comparing the variations within the data. The most dangerous areas were identified based upon the computed parameters using vector/ query analysis.

All the wadis in Dechatu catchment shows nearly similar behavior in terms of shape factor which is more elongated that ranges from 0.04 – 0.17. A little variation is observed in mean slope gradient and flow accumulation. Accordingly, those wadis with the highest flow accumulation and mean slope were selected as flood prone wadis of the catchment. These are Lege Dole, Lege Dechatu, Lege Gogeti and Lege Ala. (Fig 4.17)

4.5.2.2 Selection of Pour Points

Eight pour points were computed for Dechatu catchment. These points are randomly distributed in the catchment. Out of which two points are after the stream passes Dire Dawa town and the rest six points are before the stream passes the town. (Fig 4.17)

Out eight pour points that are located in the catchment before the stream reaches the flood plain were selected as potential flood check dam sites. This indicates that the selected points are point of intervention to decrease volume of flow and peak discharge. On the other hand these points increase the time of concentration or lag time of the catchment

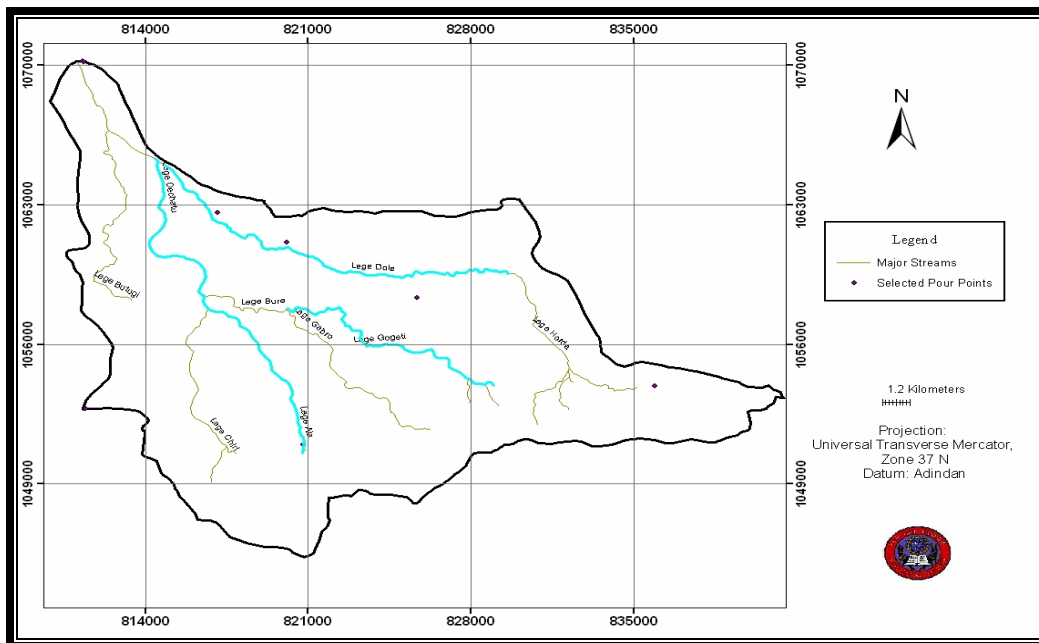


Fig 4.17: Selected flood prone wadis and pour points in Dechatu catchment

CHAPTER FIVE

DISCUSSION

5.1 Flood Risk and Hazard of Dire Dawa Town

Some of parts (16%) of the town (the land use which is built-up areas) are categorized in high to very high flood hazard zonation. This can be more elaborated in flood risk analysis. All the land use types in built-up areas like residential, commercial & industrial areas (32.4%), public utilities & critical facilities (16.7%) and institutional areas (9.8%) are subjected to high to very high flood risk level.

Risk of flooding can be reduced by decreasing hazards, reducing or eliminating the vulnerability of the elements at risk, or a combination of both actions De Graff (1989). Adoption of non-structural risk reduction measures for instance, development of land use planning can effectively reduce the effect of flooding on lives and property. Application of land use planning can reduce flood hazards by allocating less vulnerable land uses to the most hazardous areas or by avoiding development in those locations. Relocation of the residents of high risk areas would reduce their vulnerability.

In situations like in Dire Dawa town, there is an opportunity for relocation of residents to reduce vulnerability. Accordingly, the potential land use type which is the least in terms of flood hazard (3.1%) and flood risk (1%) at high to very high levels is open land & shrub land. There should be change in land use system in kebeles especially kebele 07, 06, 04, 08 and 05 because most part of these localities are in high to very high flood risk zonation and higher population density with poor drainage facilities.

5.2 Land Use Change of Dechatu Catchment

In the last twenty one years, the most positive change (93.8%) is observed in the expansion of built-up areas in the catchment which is in line with the development of cultivated land (16.4%). This is because most of the people dwelling the catchment is agrarian society whose livelihood is dependent on cultivation of cash crops like chat, coffee, and cereals like Sorghum and Maize as well as cattle rearing. In the contrary, the most negative change is observed in shrub land cover (-41.9%) and open wood land

coverage (-39.6%). This has impacts on the past flooding hazards by decreasing surface roughness which retards the peak flow down stream and resulting in (40.5%) bare land aerial increment.

The stream channel width increased in the last twenty one years due to increased erosion in the upstream of the catchment. As a result sand deposit increased by (59.9%) which facilitates for the peak flow to overtop easily the stream banks (table 4.9).

5.3 Land Use Change and Flood Risk

Dire Dawa town faces flooding every rainy season but the most devastating hazard is repeated in a cyclic manner. According to informal interview with local dwellers, the flood like 2006 flooding was observed in before 30 years ago and in the same way before, too. But at that time, there was not much death and destruction as of the year 2006. The big question is behind the current land use of the town. Fortunately in the past, most of the people were less vulnerable to flood hazard due to their land use system was out of flood risk areas. Gradually population density increment paves the way for the people to use all the marginal land as well for settlement and commercial land use system. This situation made the people dwelling in the town to develop false security and increased vulnerability to flood hazard. As consequence, the peak flood like August, 2006 ruined most of the people and the properties as well in the flood risk areas. Therefore, land use is one of the important elements at risk components in flood risk analysis. So in situation like Dire Dawa town there was no work observed integrating the two in mitigation the possible forthcoming hazard.

5.4 Flash Flood hazard in the catchment

Lege Dole, Lege Dechatu, Lege Gogeti and Lege Ala were identified as flash flood hazard wadis. These are major streams of Dechatu catchment that have highest influence in down stream flooding in Dire Dawa town. So this give insight on the supporting streams that make Dechatu stream more energetic in rainy season in the upstream catchment. Regulating these streams at some optimal location that are the lowest points (pour points) of the catchment highly reduces the flood peak discharge and flood hazard as well.

5.5 Pour Points in the catchment

According to Gore et al., (1989) Dams, reservoirs and diversion systems allow the modification of natural patterns of stream flow. Flood mitigation dams, for instance, reduce the peak discharges which would normally overflow the riverbanks and spill onto the floodplain. Reservoirs operated for irrigation water supply or hydropower production modify the natural flow regime through storage of water during high runoff periods for later release when demands are highest. Therefore, there is a potential for better watershed management practices in the uplands of the catchment.

Several environmental management measures could also be implemented to reduce flood disaster risk United Nations (2002). For instance, maintenance of environmental and ecological stability of the upland watershed through the enrichment of forest covers to restore its flood protection values and prevention of encroachment by cultivars to maintain a resilient environment to avert future disaster are some important issues worth mentioned. In this instance, adoption of check dams in the selected pour points of the catchment is important to reduce flood volume and to utilize the retained water for other agricultural activities. In fact, the existing soil and water conservation structures such as stone bund on the highlands of the catchment and within the cultivars farm is one of the points worth mentioned in environmental management issues.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

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

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

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

Satellite images were shown to be very important for Land use/ Land cover change studies with certain limitations like cloud cover and striping. The change statistics of land use / land cover of Dechatu catchment showed that expansion bare land is aggravating flood hazard in Dire Dawa Town.

Query analysis of flash flood hazard parameters like flow accumulation and mean slope which were generated from DEM was shown to be important for identification of wadis that are dangerous at time of flash flood. This approach could be done for other unguaged catchments in delineating flash flood hazard wadis in dry land areas.

Delineated watershed was shown to be important for computation of pour points in the catchment. This point generation could be the point where the flow is concentrated in the catchment.

6.2 Recommendation

This investigation provides information on flood risk at a town level that could be used by the pertinent decision makers to act upon the current land use policy for in reducing vulnerability to flood disaster in Dire Dawa Town. Thus the responsible bodies of Dire Dawa Administrative Council should incorporate the flood hazard and flood risk maps in the currently ongoing activities related to flood disaster, as one of the short term intervention recommendations of the town is identification of critical flood areas.

There should be an authority responsible for a disaster in the town. Thus set up Dire Dawa Disaster Management Authority (DDDMA) is important. The authority should review the progress of measures based on up-to-date information, check operational readiness for potential flood disasters, and prepare proper measures and action plans. The authority would also be responsible for managing and coordinating responses and relief measures during flooding.

Regulation of selected flood prone wadis by constructing flood mitigation dams on the selected six pour points is important for multi-purposes. According to Cadwallader (1986) regulation not only reduce the incidence of and severity of flooding but also decrease long-term average flows downstream.

Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in Dire Dawa town.

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

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ANNEX

Annex 1: Annual Maximum 24 hours Rainfall (mm)

Annex 2: Areas coverage of Flood risk analysis of Dire Dawa town

Annex 3: Areas coverage of the study area relative to the whole Dire Dawa town area

Annex 4: Flow Accumulation, Shape factor, mean elevation, mean slope, mean annual maximum daily rainfall and watershed map of Dechatu catchment computed by Hydrological extension version 1.1

Annex 5: Monthly rainfall and Temperature charts of Dire Dawa, Dengego and Kersa areas.

Annex 6: DEM, Soil and Geological maps of Dechatu catchment and Comparison map of Dire Dawa Town

Annex 1. Annual Maximum 24 hours Rainfall (mm)

Source: National Meteorological Service Agency

Year	Stations		
	Dire Dawa	Dengego	Kersa
1952	54		
1953	52.1		
1954	67		
1955	30.2		
1956	70		
1957	60		
1958	69.2		
1959	47		
1960	65		
1961	49		
1962	42		
1963	50		
1964	55.2		
1965	57		
1966	28		
1967	48		
1968	39.6		
1969	62.5		
1970	38.1		
1971	44.6		
1972	40.8		32.8
1973	23		
1974	35.1		
1975	54.9		
1976	30.4		
1977	80.9		
1978	76.5		
1979	87		
1980	79.2		
1981	37.5	71.4	
1982	44.1	70.2	
1983	72.7	73.7	
1984	30.5	90.2	
1985	50	92.8	
1986	51.1	34.1	
1987	84.5	68.8	
1988	86.4	52	
1989	44	67	
1990	57.4	36.2	
1991	40	54.9	
1992	40.8		
1993	68.9		

1994	61.3		
1995	43.7	69.6	
1996	68.3	67.2	87.2
1997	51.6	82.5	45.2
1998	59.2	73.3	63.8
1999	41	37.7	58.2
2000	37.3	55.8	82.9
2001	55	74.3	166
2002	58	22.8	28.5
2003	113.1	59	69.3
2004	47.5	48	35.5
2005	41.8	45.3	51.6
2006	36.9		
No. Of Sample	55	22	11
Mean	53.80	61.22	65.55
Standard Deviation	17.6281	19.10	40.82

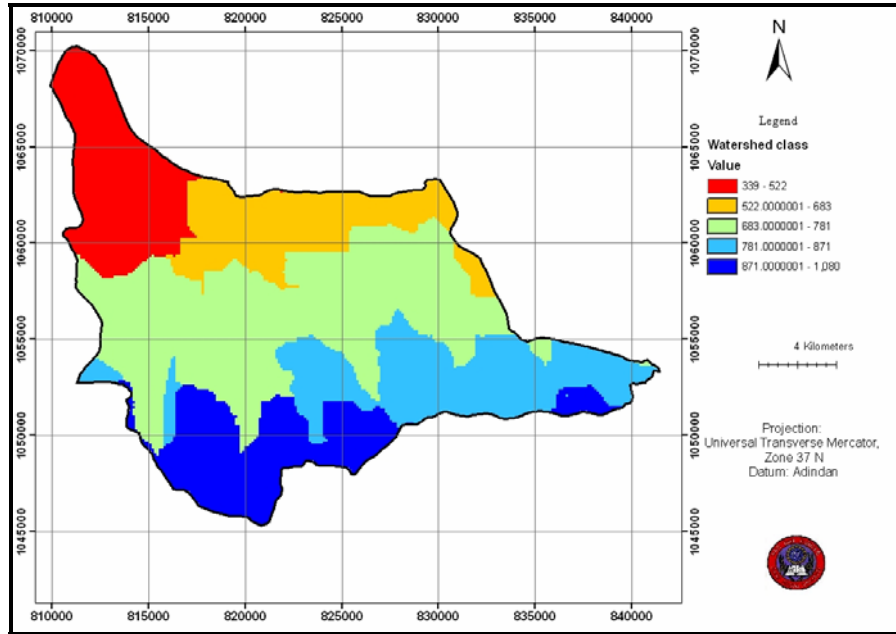
Annex 2. Areas coverage of Flood risk analysis of Dire Dawa town

	Area (ha)					Area _t
	1	2	3	4	5	
Flood Hazard Layers	Very Low	Low	Moderate	High	Very High	
Road density	2278.9	375.2	55.7	23.4	5.2	2738.4
Slope	662.1	611.7	696.9	595.9	171.6	2738.2
Elevation	26.8	451.3	813.3	822.7	624.1	2738.2
Drainage density	7.8	14.9	46.5	162.9	2506.3	2738.4
Land use	172.8	93.8	125.6	706.0	1639.4	2737.7
Flood Hazard Areas	0.0	19.9	447.2	1966.2	304.1	2737.4
Flood Risk Areas	0.2	1053.0	1266.7	355.8	61.2	2736.9

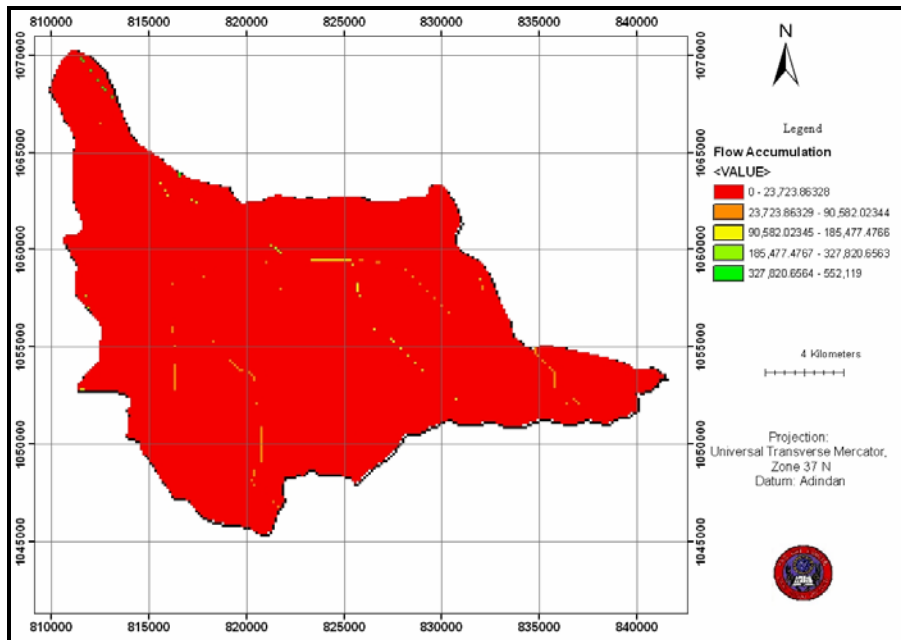
Annex 3. Areas coverage of the study area relative to the whole Dire Dawa town area

Old Kebele Name	New Kebele Name	Area (m ²)	Area (ha)	Kebele in Decahtu	Area (m ²)	Area (ha)	% of Total
25	1	25068370.7	2506.8				
1,2,24	2	21158646.8	2115.9	2	6915805.4	691.6	32.7
3,4,5	3	11780928.3	1178.1	3	10507752.1	1050.8	89.2
6,7,8	4	1511308.0	151.1	4	1511308.0	151.1	100.0
9,10,11,12	5	1104413.9	110.4	5	1104413.9	110.4	100.0
13,14,15,16	6	693454.3	69.3	6	693454.3	69.3	100.0
17,18,21	7	804787.7	80.5	7	804787.7	80.5	100.0
19,20	8	1649513.2	165.0	8	1649513.2	165.0	100.0
22,23	9	4854824.0	485.5	9	4300081.9	430.0	88.6
	Extension	16395819.4	1639.6				
Total		85022066.2	8502.2		27487116.4	2748.7	32.3

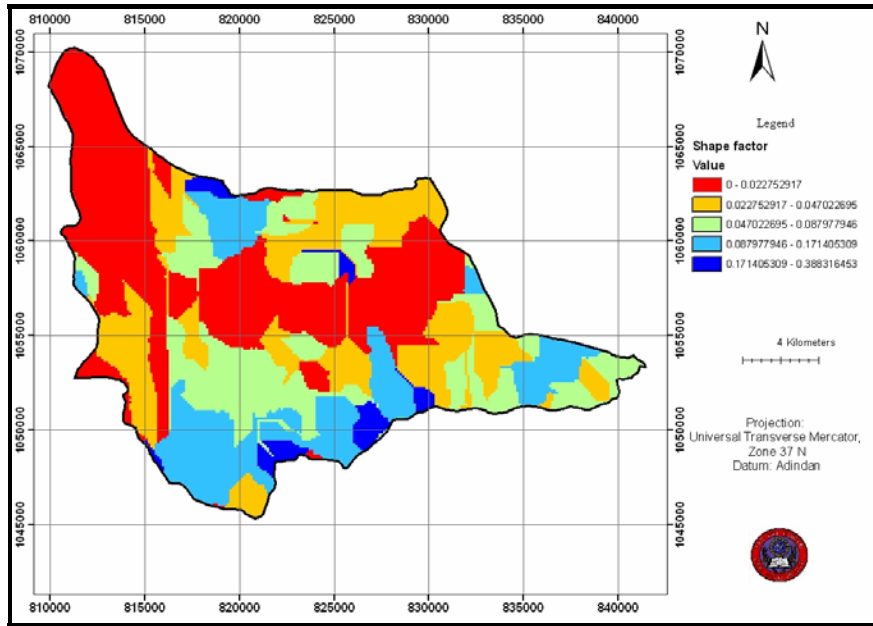
Annex 4. Flow Accumulation, Shape factor, mean elevation, mean slope, mean annual maximum daily rainfall and watershed map layouts of Dechatu catchment computed by Hydrological extension version 1.1



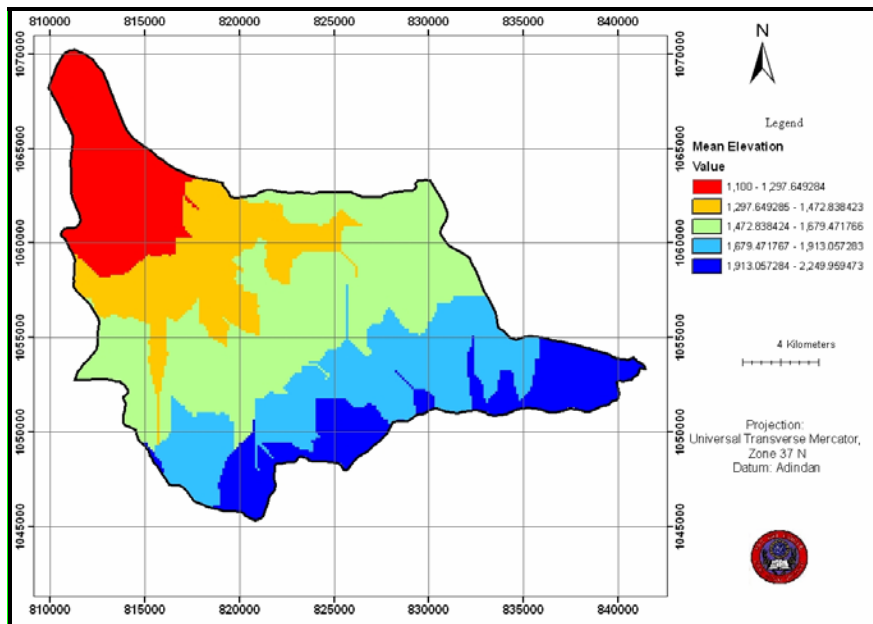
Watershed of Dechatu Catchment



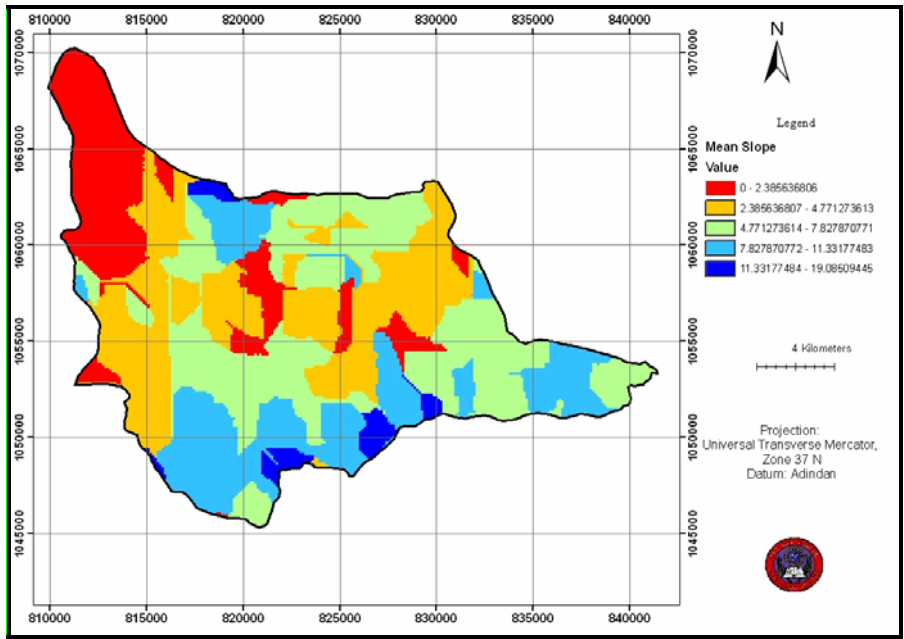
Flow Accumulation of Dechatu Catchment



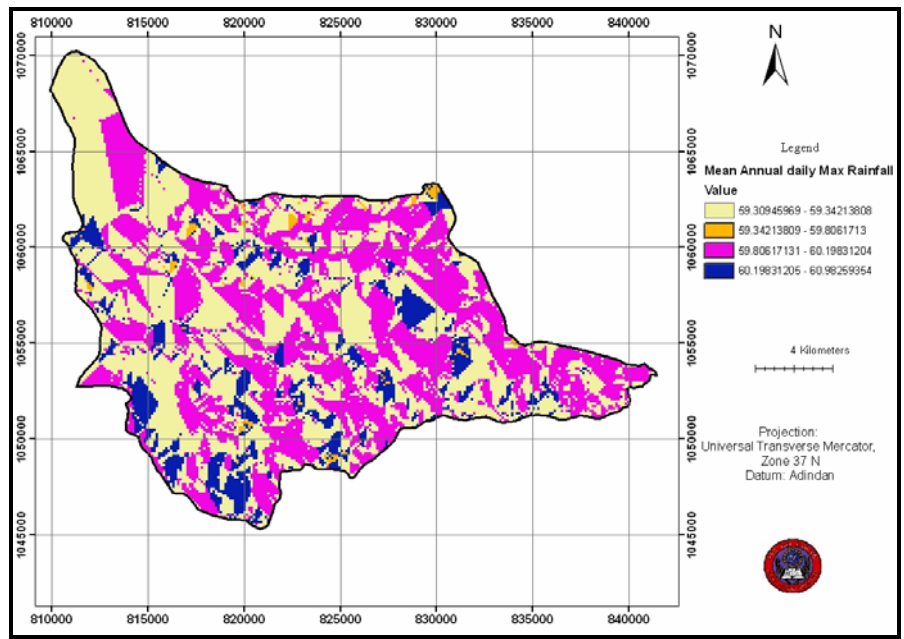
Shape factor of Dechatu Catchment



Mean Elevation of Dechatu Catchment

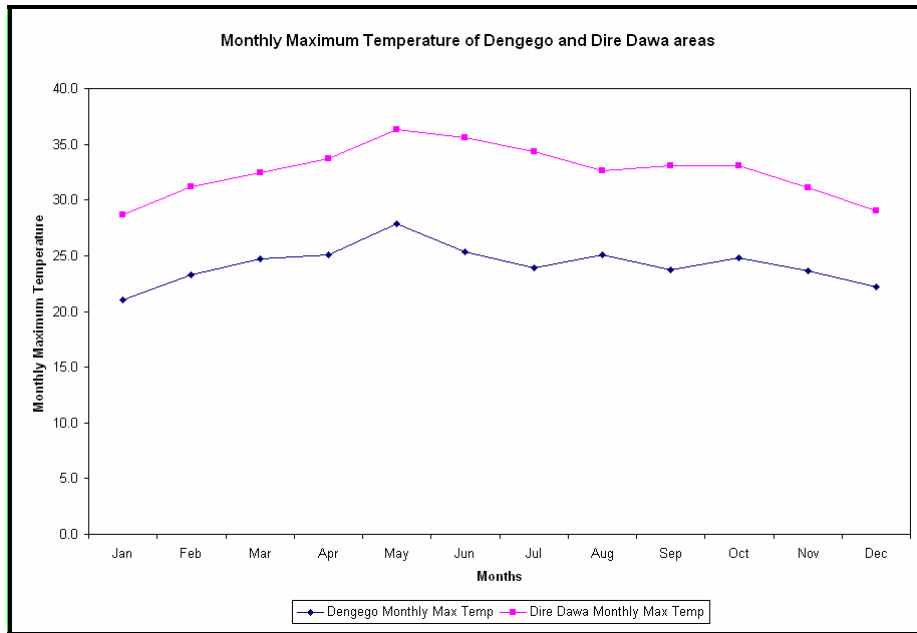


Mean Slope of Dechatu Catchment

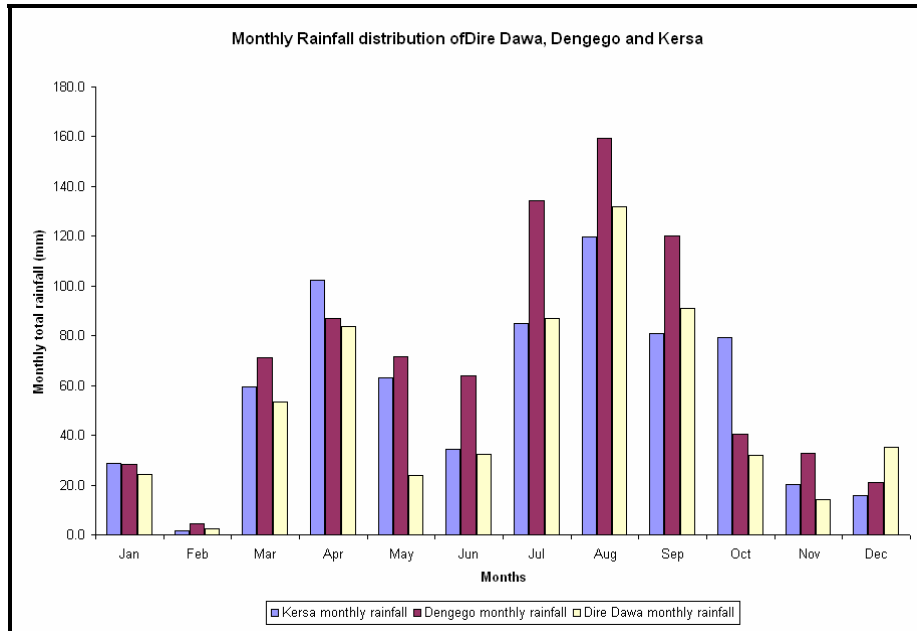


Mean annual maximum daily rainfall of Dechatu Catchment

Annex 5. Monthly rainfall and Temperature charts and tables of Dire Dawa, Dengego and Kersa areas



Average Monthly Maximum Temperature of Dire Dawa and Dengego towns



Average Monthly Total Rainfall of Dire Dawa , Kersa and Dengego towns

Kersa

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	98.6	2.5	32	188.5	169.9	28.3	90.2	221	34.4	0	35.4	0
1997	20.4	0	90.1	89.8	73.3	0	83.7	104.6	63.5	186.9	47.5	0
1998	32.1	3.9	31.4	23.7	90.3	10.4	231	160.8	137.8	57.4	20.7	0
1999	0	0.7	149.1	3.4	13.9	105.4	0	0	0	235.4	5.5	0
2000	0	0	20.1	135.2	125.6	29.6	53.4	161.1	148.5	91.4	41.1	
2001	6	0	69	171.3	88.4	15.8	84.3	148.4	0	0	0	0
2002	57	0	61.5	42.4	2.6	10.6	60.7	105	86.4	78.1	21.3	52.4
2003	0	6.3	47.3	128.4	2.6	92.1	143.1	105.3	123	1.4	0.2	63.4
2004	45.6	0	34.9	137.2	0	16.9	19	70	132.9	62.5	10.8	10.8
Av.	28.9	1.5	59.5	102.2	63.0	34.3	85.0	119.6	80.7	79.2	20.3	15.8

Dengego

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	32	2.3	230.5	86	157.8	157.3	111.9	243.7	107.4	1.2	24.8	0
1997	16	0	45.2	96.5	125	60	164	111.5	77.9	77.9	158.8	133.2
1998	107.4	27.3	19.8	15.9	144.9	25.8	253.5	127.7	173	24.5	8.2	0
1999	0	3.2	136.1	45.4	33.8	103	123.7	285.2	123.6	149.3	1.7	0
2000	0	0	9.3	102.8	58.7	7.8	52.9	0	120.1	56.8	83.2	8
2001	2.4	1	58.7	85.1	91.2	59.7	161.6	300.9	105.3	8.5	4.1	1.3
2002	41.8	0.5	85.6	61.2	12.8	20.8	75.2	95.6	73.2	10.9	0	0
2003	1.5	5.8	30.3	161	17.8	107.8	214.8	130.7	142.5	0	0.3	34.7
2004	53.1	0	26.5	129.5	1.2	31.8	49.9	140.4	159.3	35.2	15.2	11.7
Av.	28.2	4.5	71.3	87.0	71.5	63.8	134.2	159.5	120.3	40.5	32.9	21.0

Dire Dawa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	13.8	25.5	7.8	20	71.9	92	93	24.7	19.1	43.1
2001	0	0	99	28	49.5	22.3	112.3	241.5	74.9	15.8	4.7	6
2002	34.8	0	80.9	83.1	33.3	9.7	49.4	126.8	65.8	18.7	0	30.2
2003	14.4	11.3	37	98.5	2.2	65.2	136.3	53.1	63.6	2.1	0.8	129.8
2004	40.2	0	44.2	133.9	0.5	12.6	54.3	111	59.1	85.6	25.3	5.7
Av.	24.4	2.3	53.2	83.6	23.7	32.2	86.9	132.0	90.9	31.8	14.0	35.4

Average Monthly Maximum Temperature of Dire Dawa and Dengego

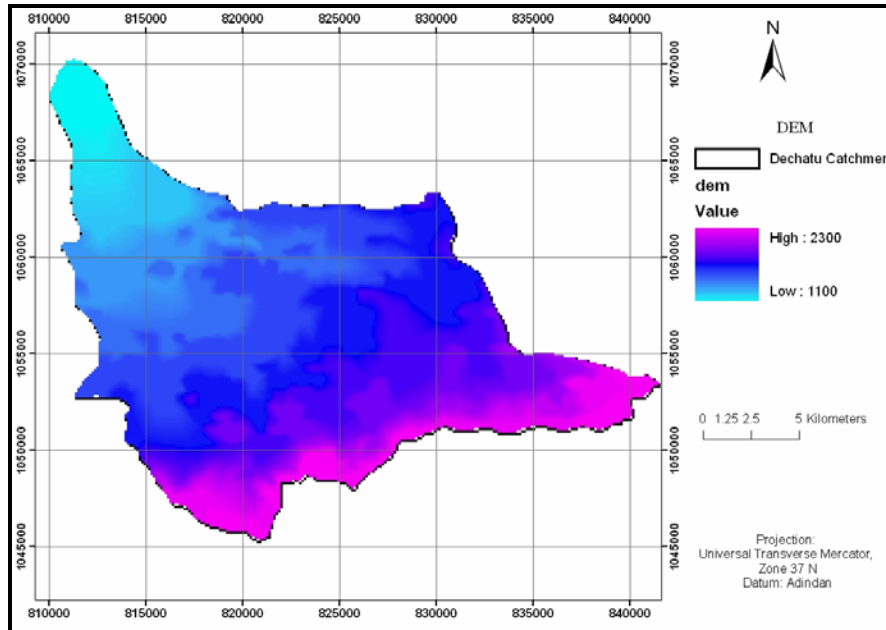
Dengego

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	21.3	23.5	24.9	25.4	24.9	25.0	24.4		22.9	23.1	21.4	20.7
2001	19.7	22.1	23.7	25.4	25.0	25.0	23.7	21.9	23.6	24.2	22.4	21.7
2002	20.0	23.2	23.9	24.9	26.3	26.2	23.3	24.0	23.6	25.6	23.6	
2003	21.2	23.8	25.4	25.4	34.4	24.7	23.7	29.4	23.2	26.2	24.9	21.8
2004	22.7	23.7	25.7	24.2	28.7	25.6	24.5	25.1	25.4	25.0	25.8	24.6
Av.	21.0	23.2	24.7	25.1	27.8	25.3	23.9	25.1	23.7	24.8	23.6	22.2

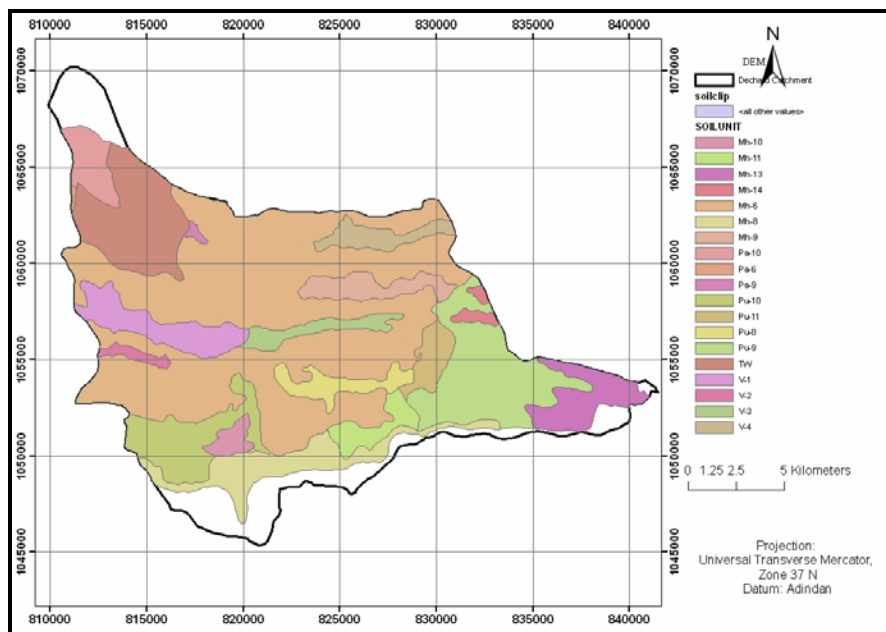
Dire Dawa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	29.6	31.4	33.1	34.5	35.9	35.1	34.6	32.3	32.7	32.2	29.9	28.7
2001	27.9	30.7	31.6	34.6	35.5	36.0	34.1	31.4	32.6	33.7	31.2	29.8
2002	27.4	31.6	32.1	33.4	36.7	36.4	35.4	33.6	33.3	34.1	32.0	28.8
2003	29.2	32.0	32.8	33.7	36.7	35.1	33.3	32.3	33.2	33.9	31.4	28.5
2004	29.2	30.4	32.5	32.4	36.6	35.5	34.4	33.6	33.4	31.5	31.0	29.2
Av.	28.6	31.2	32.4	33.7	36.3	35.6	34.4	32.6	33.0	33.1	31.1	29.0

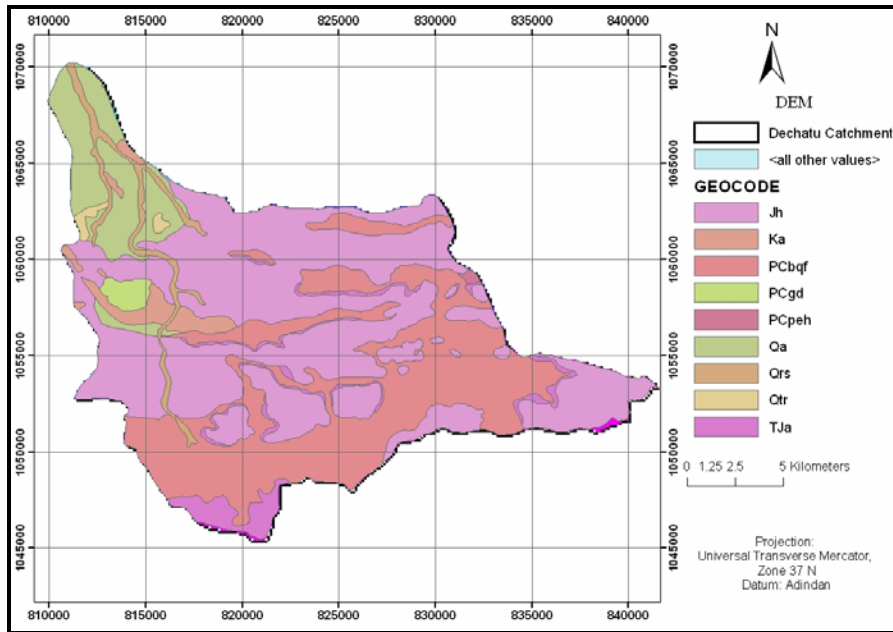
Annex 6: DEM, Soil and Geological maps of Dechatu catchment and Comparison map of Dire Dawa Town



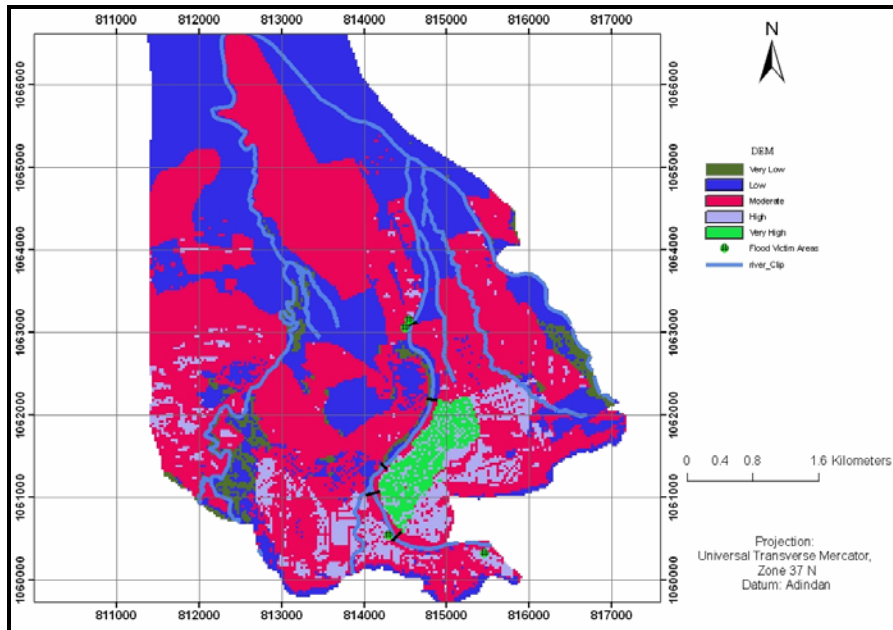
Digital Elevation Model of Dechatu Catchment



Soil map of Dechatu catchment



Geological map of Dechatu catchment



Comparison of Ground truth data of Flood Victim sites and Flood hazard map of Dire Dawa town

Declaration

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

Daniel Alemayehu Demessie

School of Graduate Studies

March, 2007

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

Dagnachew Legesse (Ph.D.) _____