ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF EARTH SCIENCES

DEVELOPING FLOOD HAZARD FORECASTING AND EARLY WARNING SYSTEM IN DIRE DAWA, ETHIOPIA

BY

MEZGEBEDINGIL ABEBE GEZAHEGN

Advisor

Dr. K. V. SURYABHAGAVAN

Co-Advisor

Dr. DESSIE NEDAW

A thesis submitted to

The school of Graduate Studies of Addis Ababa University In partial fulfillment of the requirements for the Degree of Masters of Science in Remote Sensing and Geo-informatics

Addis Ababa, Ethiopia

June, 2017

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This is to certify the thesis prepared by Mezgebedingil Abebe entitled as "***Developing flood hazard forecasting and early warning system in Dire Dawa, Ethiopia*** " is submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geo-informatics compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Dr. K.V.Suryabhagavan	____________________	________/_______/________
Advisor	Signature	Date
Dr. Dessie Nedaw	____________________	________/_______/________
Co-Advisor	Signature	Date
Prof. Tenalem Ayenew	_____________________	________/_______/________
Chairperson	Signature	Date
Prof. Tenalem Ayenew	____________________	________/_______/________
Examiner	Signature	Date
Dr. Binyam Tesfaw	____________________	________/_______/________
Examiner	Signature	Date

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Contents

List of Tables

List of Figures

List of Appendices

Acronyms

AMC	Antecedent Moisture Condition
C#	C Sharp
CN	Curve Number
DEM	Digital Elevation Model
D-FHEWS	Dire Dawa – Flood Hazard Early Warning System
DRMFSS	Disaster Risk Management and Flood Security Sector
FDRE	Federal Democratic Republic of Ethiopia
GDAL	Geospatial Data Abstraction Library
HFA	Hyogo Framework for Action
HSG	Hydrologic Soil Group
LU/LC	Land-use/ land-cover
MoWR	Ministry of Water Resource
SCS-CN	Soil Conservation Service – Curve Number
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WWDSE	Water Works Design and Supervision Enterprise

Developing flood hazard forecasting and early warning system in Dire Dawa, Ethiopia

Mezgebedingil Abebe Gezahegn, MSc. Thesis

Addis Ababa University,June 2017

Abstract

Floods are one of the leading causes of destruction from natural disasters. Flooding causes major stresses on the economic, social and environmental regimes. Structural and non-structural measures are applied to prevent flood hazard destruction. Meanwhile, the flooding of August 5 2006 in Dire Dawa town demonstrated that structural measures undertaken so far are not adequate to withstand flood threats. Non-structural techniques for preventing flood damage are based on acceptance of flooding as a natural process that cannot be completely controlled. This approaches focus on altering human behavior and awareness. In this study, flood hazard forecasting and early warning system in Dire Dawa was developed using SCS-CN method, i.e. one of the techniques under non-structural approaches. The developed system has seven incorporated applications namely, initial abstraction analysis, maximum retention analysis, flood analysis, antecedent moisture content calculator, curve number conversion, flood prone areas analysis and messaging, and developed using C# object oriented programming language. The study was carried out by using Landsat 7 ETM+ and Landsat 8 OLI satellite imageries of the years 2005 and 2015, respectively, 15 m × 15 m digital elevation model and harmonized world soil data for hydrologic soil group classification. Images were classified into classes using supervised image classification. The results showed that 74.53% area of Dire Dawa town has high value of CN, 10.21% is moderate and 16.07% of the town has low CN value, this implies most part of the area has low maximum retention and initial abstraction value. A reliability assessment of the system was conducted on the produced flood map of the first week of August 2006. The assessment result revealed that the system is fully functional for the intended application.

Keywords: SCS-CN method, flood forecasting, early warning system, Dire Dawa.

CHAPTER ONE

1. Introduction

1.1 Background

Flooding is a natural process and part of the hydrological cycle. It happen at whatever point the limit of the natural or manmade drainage system cannot cope to the volume of water created by rainfall (Daniel, 2007). Flood can be disastrous to the point that the infrastructure is washed away, the people and the creatures drown, and the people can be stranded for long periods. Beside, the society and the economy of the country will suffer from multiple points of view after the flood.

The extent of the damage caused by the hazard is related with the capability of people living in disaster-prone areas to prepare for and resist it. Therefore, efforts to reduce flood hazard disaster risk have focused on developing early warning systems. It helps to provide timely and effective information that enables people to respond when a disaster hits (Mioc *et al.*, 2008). These systems are composed of four elements: knowledge of the risk, a technical monitoring and warning service, dissemination of meaningful warnings to at-risk peoples and public awareness and preparedness to act (Rajendra, 2013). Warning services lay at the core of these systems, and how well they operate depends on having a sound scientific basis for predicting and forecasting (Hoedjes *et al.*, 2014).

Giving response on the basis of early warning and disaster assessment information enables resources allocated for response to be licitly used for the proposed purposes and, in case of a disaster, to save lives and livelihoods by giving timely and appropriate response by appropriately distinguishing areas and people needing emergency relief assistance (UNISDR, 2007; FDRE, 2013).

The Disaster Risk Management system of Ethiopia is divided along six pillars and three phases (Fig. 1). The three pillars– prevention, preparedness and mitigation – constitute the core of disaster risk reduction (DRMFSS, 2013).

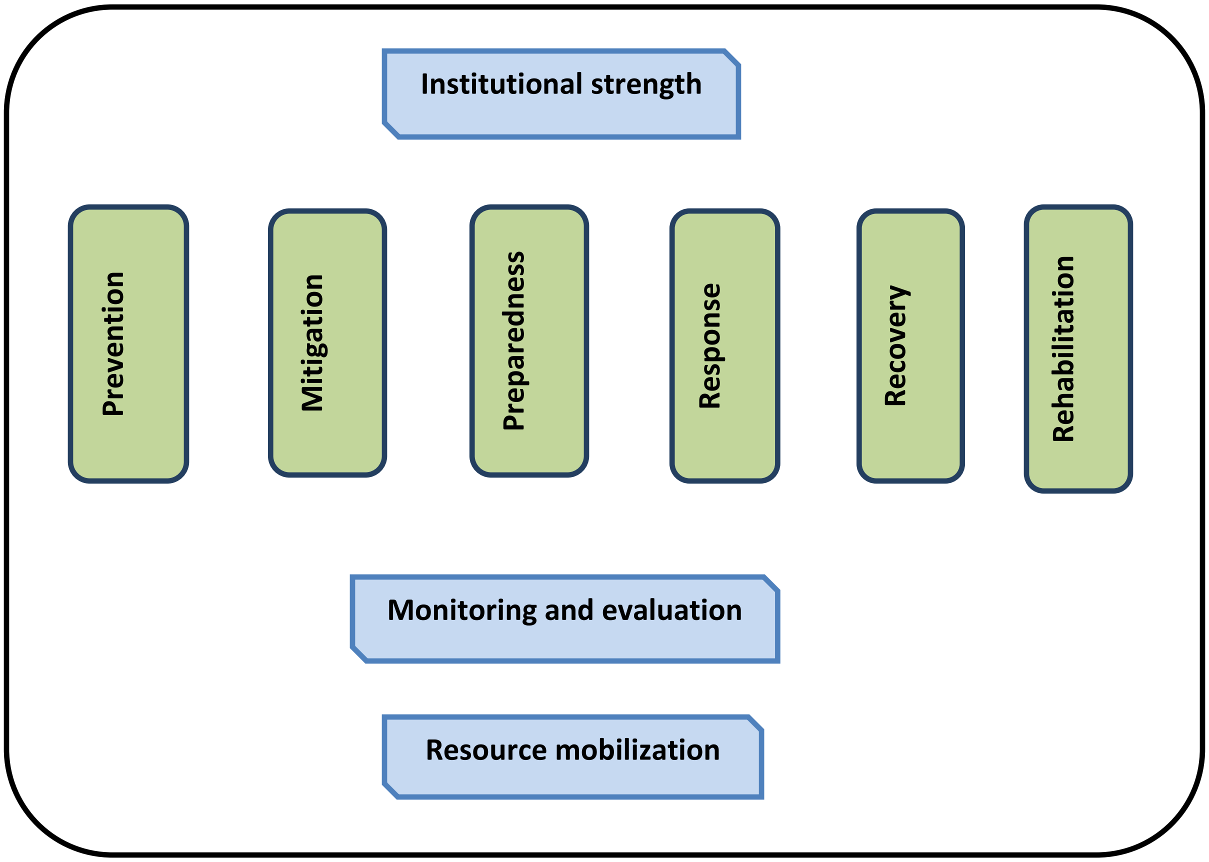


Figure 1: Ethiopia's Disaster Risk Management and Investment Framework (DRMFSS, 2013).

Many of previous researches in Ethiopia focus only on flood hazard risk assessment. The concern of this study is on developing flood hazard forecasting and early warning system in Dire Dawa based on SCS-CN method. The SCS-CN method is supported with empirical data to surface runoff depth estimation from single rainfall event (Ponce and HawKins, 1996).

The origin of the methodology traced back to thousands of infiltrometer tests carried out by United States soil conservation service during the 1930s and 1940s at experimental sites (Ponce and Hawkins, 1996; Williams *et al.*, 2011). Although it was originally developed mainly for agricultural watersheds, the CN method has since been adapted for urbanized and forested areas (Cronshey, 1986).

1.2 Statement of the problem

Ethiopia's topographic characteristic has made the country vulnerable to flood and resulting devastation (Enyew and Steeneveld, 2014). The increasing flood damages in many parts of Ethiopia over years in general and the serious damages occurred recently in Dire Dawa in particular remind us the urgent need in change of paradigm in order to reduce the human vulnerability and to guarantee sustainable development. Recurrence of flood hazard in Dire Dawa is increasing (Billi *et al.*, 2015). Flood cause loss of life, damage to property and advance the spread of disease. According to the practice up until now, however, response is not fully informed by early warning or disaster assessment information in the event of a disaster (FDRE, 2013). There is no event based lumped rainfall-runoff system for flood hazard management in Dire Dawa town (Semu, 2007). This research focused on developing forecasting system of flood hazard before the occurrence and its warning system in a single rainfall event.

1.3 Objective of the study

1.3.1 General objective

The general objective of this research was developing flood hazard forecasting and early warning system in Dire Dawa.

1.3.2 Specific objective

- To develop initial abstraction, maximum retention and flood analysis applications.
- To create initial abstraction and maximum retention map of the study area.
- To develop AMC calculator application.
- To develop CN conversion application.
- To develop flood prone area analysis and information dissemination applications in the study area.

1.4 Research questions

The following questions have been formulated to achieve the objectives:

- What type of method can be used to flood hazard forecasting?
- What type of technique can be used to early warning information dissemination?
- How to develop flood hazard forecasting and early warning system?
- How to evaluate the reliability of the system?

1.5 Significance of the study

Having flood hazard forecasting and early warning system is used to prepare the society and the concerned stakeholders. Preparedness is one of the major pillars of disaster risk management, having it in flood hazard has many advantages;

- It gives people time to flee from hazard.
- Provide information on the occurrence of a public health hazard.
- Enable a faster response to problems of food and water insecurity.
- Enable people to protect some property and infrastructure.
- Local authorities can position equipment for emergency response.

Moreover, it may be helpful for researchers to provide a scientific basis on flood hazard forecasting and early warning system. The system developed in this study will have wider application within and outside the country.

1.6 Scope

The main part of this research is to develop flood hazard forecasting and early warning system using SCS-CN method. Forecasting rainfall amount is out of the scope of this research. It's because of that, forecasting rainfall amount from remote sensing data needs detail study, so this is not possible to do it with specified time to finish this research and available resources.

1.7 Organization of the study

This thesis is organized into six chapters: The first chapter contains introduction, where the background, statement of the problem, objectives of the study, research questions and significance of the study discussed. The second chapter focuses on review of related literatures. The third chapter is on the details of the study area in terms of location, topography, climate, soil and Land-use/land-cover. This section also elaborates the source of the data and software used and methodologies applied to achieve the desired objectives with details of the data sources and conceptual models. In the fourth chapter results and evaluation is provided and fifth chapter is discussion. The sixth chapter provides conclusion and recommendations based on results and discussions presented.

1.8 Limitation of the study

The limitation of the study was lack of Aerial photograph data for 2015 Land-use/land cover classification. Due to this limitation Landsat 8 OLI imagery was used.

CHAPTER TWO

2. Literature review

2.1 Flood

In November 2011, the Australian Government introduced a standard definition of flood. According to the definition "flood is the covering of normally dry land by water that has escaped or been released from the normal confines of any lake, or any river, creek or other natural watercourse, whether or not altered or modified; or any reservoir, canal, or dam". There are a lot of causes for flooding, for example; intensive rainfall, snow melt, collapse of dikes or other protective structures etc. In Africa flood is one of the most devastating natural hazard, whereas flash flood is among the greatest hazards (Yonas, 2015). Flash floods are defined by the American Meteorological Society (AMS) as a flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area.

According to 2014, United Nations International Strategy for Disaster Reduction (UNISDR) report, next to drought flood is hazardous disaster in Ethiopia (Fig. 2).

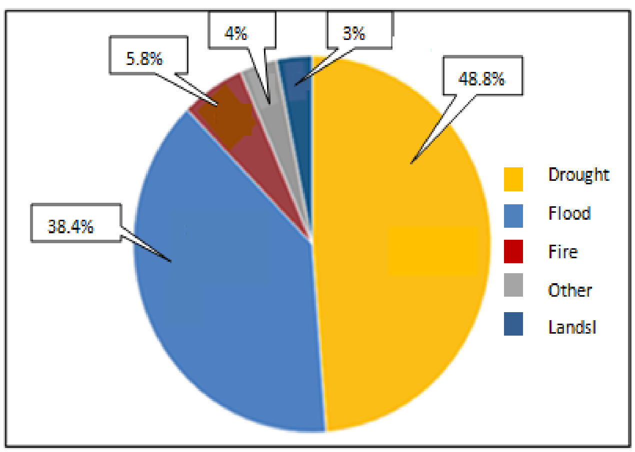


Figure 2: Nationally reported mortality losses in 1990–2014, Ethiopia (UNISDR, 2014).

Among the major flood disasters in Ethiopia, flooding in Wonji and Metehara in 1996, Wabishebele river flooding in Somali in 2003, flooding from Wabe Shabelle, Hargeysa, Bilate, Genale, Dawa, Fafen, Sile and Sego rivers in 2005 are listed. The 2006 flood scenario occurred in Ethiopia was the worst hazard, resulting loss of lives, damage of property and destruction of livelihoods of tens of thousands of people, a total of 635 people have been died - 364 in South Omo, 256 in Dire Dawa and 19 in other parts of the country (Lelisa and Kifle, 2006).

Specifically, frequency of flash flood in Dire Dawa is increasing, it occurs in 1945, 1977, 1981, 1997, 2001, 2004, 2005, 2006 and 2010 (CORDAID, 2011).

2.2 Soil Conservation Service-Curve Number (SCS-CN) method

The SCS-CN method was originally established by the united state department of agriculture-soil conservation service in 1954 (Paul, 2014). Its aim is to estimate direct surface runoff from rainfall depth, based on a parameter referred to as the curve number. Curve number of the area is derived from Land-use/land-cover, digital elevation model and hydrologic soil group characteristic combinations. It is used to determine initial abstraction and maximum retention of the area. The CN value is a primary input parameter for the SCS runoff equation. It is a dimensionless number limited in the range, $1 \leq CN \leq 100$ (Ponce and Hawkins, 1996). A high curve number means high runoff and low infiltration, whereas a low curve number means low runoff and high infiltration (Shadeed and Almasri, 2010).

The origins of the methodology can be traced back to thousands of infiltrometer tests carried out by SCS during the 1930s and 1940s at experimental sites (Ponce and Hawkins, 1996; Williams *et al.*, 2011). Originally, it was developed for agricultural watersheds but the SCS-CN method has since been adapted for all kinds of areas (Cronshey, 1986).

Among the perceived advantages of the method are its simplicity, practicality, predictability, stability, reliance on a single parameter and responsiveness to watershed properties such as soil type, Land-use/land-cover, surface condition and antecedent condition (Ponce and Hawkins, 1996; Ling and Yusop, 2014).

2.3 Hydrologic soil group

The Hydrologic Soil Group (HSG) refer to the standard SCS soil classifications ranging from A, which refers to sand and aggregated silts with high infiltration rates, to classification D, which corresponds to soils that swell significantly when wet and have low infiltration rates (Soulis and Valiantzas, 2012). The HSG reflects soil’s permeability and surface runoff potential (Table 1).

Table 1: Summary of HSG characteristics.

HSG	Surface runoff potential	infiltration rate (mm/h)
A	Low	25
B	Moderately low	13
C	Moderately high	6
D	High	3

Source: (Schulze, 1985)

2.4 Initial abstraction (Ia) and potential maximum retention (*S*)

The initial abstraction ratio (initial abstraction / potential maximum retention) plays an important role in the calculated runoff in SCS-CN method. It largely depends on climatic conditions and is the most ambiguous assumption and requires considerable refinement (Ponce and Hawkins, 1996). The initial abstraction (Ia) consider all losses before runoff begins, and includes water retained in surface depressions, water taken up by vegetation, evaporation, and infiltration. This value is related to characteristics of the soil and the Land-use/land-cover of the area. Potential maximum retention is also related to soil and its cover. It is potential maximum retention of water by the soil (Bansode and Patil, 2014).

2.5 Antecedent moisture condition (AMC)

According to Soulis and Valiantzas (2012), antecedent Moisture condition is the preceding relative moisture of the pervious surfaces prior to the rainfall event. Antecedent Moisture is considered to be low when there has been little preceding rainfall and high when there has been significant preceding rainfall prior to the modeled rainfall event (Paul, 2014).

2.6 Precipitation

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the earth. According to USGS-Water science school (2016), most precipitation falls as rain, it is one of the different types of precipitation.

2.7 Image classification

Remote sensing data are huge sources of data for studying spatial and temporal variability of the environmental parameters. Among the main application of remotely sensed data is to create a classification map of features or classes of land cover types in a scene (Perumal and Bhaskaran, 2010).

There are two methods of image classification: supervised and unsupervised. With supervised classification, the user develops the spectral signatures of known categories and then the software assigns each pixel in the image to the cover type to which its signature is most similar. With unsupervised classification, the software groups pixels into categories of like signatures, and then the user identifies what cover types those categories represent.

During supervised classification, there are operations that must be followed, which are defining of the training Sites, extraction of signatures and classification of the Image (Gao *et al.*, 2007). This kind of classification is important as the analyst can have clues in editing and creating the signatures or training areas. This is a merit used to segregate features with nearby reflectance values (Campbell and Wynne, 2011).

2.8 Object oriented programming language (OOPL)

Object-Oriented Programming (OOP) refers to a type of computer programming (software design) in which programmers define not only the data type of a data structure, but also the types of operations (functions) that can be applied to the data structure. In this way, the data structure becomes an object that includes both data and functions. In addition, programmers can create relationships between one object and another (Manish, 2013).

2.8.1 Data type

In computer science and computer programming, a data type or simply type is a classification of data which tells the compiler or interpreter how the programmer intends to use the data. Most programming languages support various types of data, for example: real, integer or boolean. A data type allows a set of values from which an expression (i.e. variable, function) may take its values. The type defines the operations that can be done on the data, the meaning of the data, and the way values of that type can be stored (Cleaveland, 1986).

2.8.2 Data structure

The term data structure refers to a system for organizing related pieces of information. The basic types of data structures include files, lists, arrays, records, trees and tables (Aspnes, 2015).

2.8.3 Operation (function)

Operation (function) is a named section of a program that performs a specific task. In this sense, a function is a type of procedure or routine. Some programming languages make a distinction between a function, which returns a value, and a procedure, which performs some operation but does not return a value. Most programming languages come with a prewritten set of functions that are kept in a library. It is possible to write new functions to perform specialized tasks (Frauke, 2014).

2.9 Flow chart

A flowchart is a type of diagram that represents an algorithm or process presented in the system. Each step in the process is represented by a different symbol and contains a short description of the process step. The flow chart symbols are linked together with arrows showing the process flow direction. A flowchart typically shows the flow of data in a process, detailing the operations/steps in a pictorial format, which is easier to understand than reading it in a textual format. Flowcharts are, generally drawn in the early stages of formulating computer solutions. Flowcharts often facilitate communication between programmers and other people (Frauke, 2014).

2.9.1 Flow chart symbols

Flowcharts are usually, drawn by using some standard symbols (Fig. 3), which are frequently required for flowcharting many computer programs (Frauke, 2014; Ezeife, 2015).

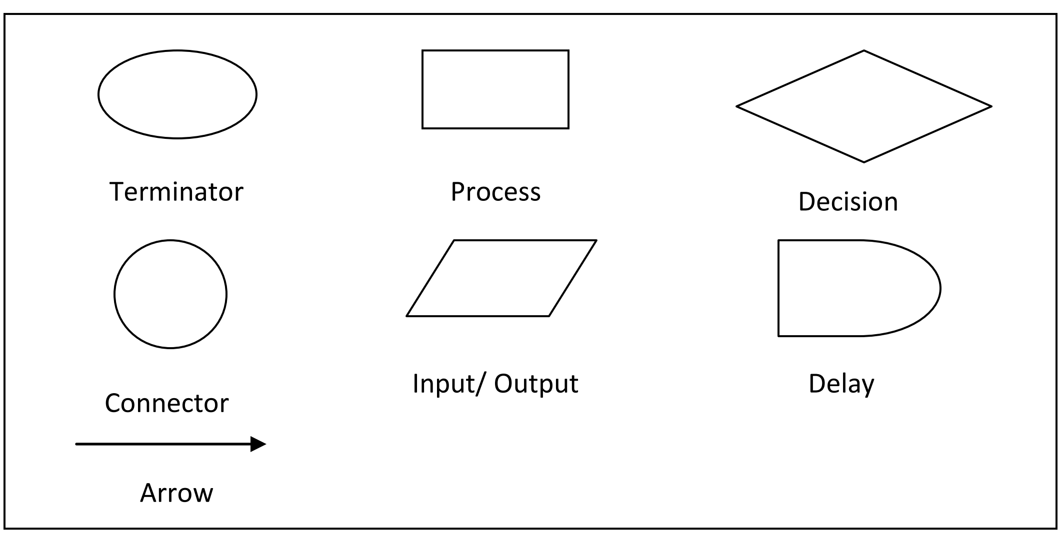


Figure 3: Flow chart symbols.

Terminator:

An oval flow chart shape indicates the start or end of the process, usually containing the word “Start” or “End”.

Process:

A rectangular flow chart shape indicates a normal/generic process flow step.

Decision:

Diamond flow chart shape indicates a branch in the process flow. This symbol is used when a decision needs to be made, commonly a Yes/No question or True/False test.

Connector:

A small, labeled, circular flow chart shape used to indicate a jump in the process flow.

Input/ output or Data:

A parallelogram is used to indicate data input or output (I/O) for a process.

Delay:

Used to indicate a delay or wait in the process for input from some other process.

Arrow:

It is used to show the flow of control in a process. An arrow coming from one symbol and ending at another symbol represents that control passes to the symbol the arrow indicates.

2.10 Early warning system

An early warning system comprises event detection and message broker subsystems (FDRE, 2013). They work together to forecast and signal disturbances that adversely affect the stability of the physical world, providing time for the response system to prepare for the adverse event and to minimize its impact.

In January 2005, the United Nations convened the second world conference on disaster reduction in Kobe, Hyogo, Japan. During this conference, an agreement called the “Hyogo Framework for Action 2005−2015: Building the Resilience of Nations and Communities to Disasters” (HFA) was negotiated and adopted by 168 countries; Ethiopia is one of the member countries. The paradigm for disaster risk management was broadened from simply post-disaster response to a more comprehensive approach that also includes prevention and preparedness measures. HFA also stresses the need for, identifying, assessing and monitoring disaster risks and enhancing early warning systems.

Providing response on the basis of early warning and disaster assessment information enables resources allocated for response to be properly utilized for the intended purposes and, in the event of a disaster, to save lives and livelihoods by providing timely and appropriate response by properly identifying areas and people in need of emergency relief assistance (FDRE, 2013).

According to Rajendra (2013), there are four elements in natural hazard early warning systems.

- *Risk Knowledge* – systematic assessment of hazards and vulnerabilities, and mapping of their patterns and trends.
- *Monitoring & Warning Service* – accurate and timely forecasting of hazards using reliable, scientific methods and technologies.
- *Dissemination & Communication* – clear and timely distribution of warnings to all those at risk.
- *Response Capability* – national and local capacities and knowledge to act correctly when warnings are communicated.

2.10.1 Flood hazard protection measures

Flood protection measures can be structural (“hard”) or non-structural (“soft”). Structural flood protection defenses as dikes, dams and flood control reservoirs, diversions, floodways, etc. Non-structural flood protection measures include source control, flood proofing, insurance, flood forecast and warning system, awareness raising and improving information, etc. There is no flood protection measure guaranteeing complete safety (Menzel and Kundzewicz, 2003).

The importance of having effective flood hazard forecasting and early warning system, i.e. one of the non-structural flood protection measures, is widely accepted as one component to manage flood disaster risk. Mostly, it has high applicability in developed countries. Flood early warning gives people time to flee from a flood, enable local authorities to evacuate or shelter large numbers of people, provide information on the occurrence of a public health hazard and enable a faster response to problems of food and water insecurity (Rogers and Tsirkunov, 2011).

CHAPTER THREE

3. Materials and methods

3.1 Description of the study area

3.1.1 Location

Dire Dawa is one of the two chartered cities in Ethiopia (the other being the capital, Addis Ababa). The administrative council consists of the city of Dire Dawa and the surrounding rural areas. The council has no administrative zones but one woreda - Gurgura woreda. There are 4 Keftegnas, 24 urban kebeles and 28 rural peasants associations. It is found at a road distance of 515 km from Addis Ababa. Dire Dawa is the capital city of the administrative council, lays in the eastern part of the country, geographically, it is bounded by latitudes 9^{o} 27' 3"–9^{o} 49' 54" N and longitudes 41^{o} 38' 6"–42^{o} 19' 17"E covering a total area of 1,288 km^{2} (Fig. 4).

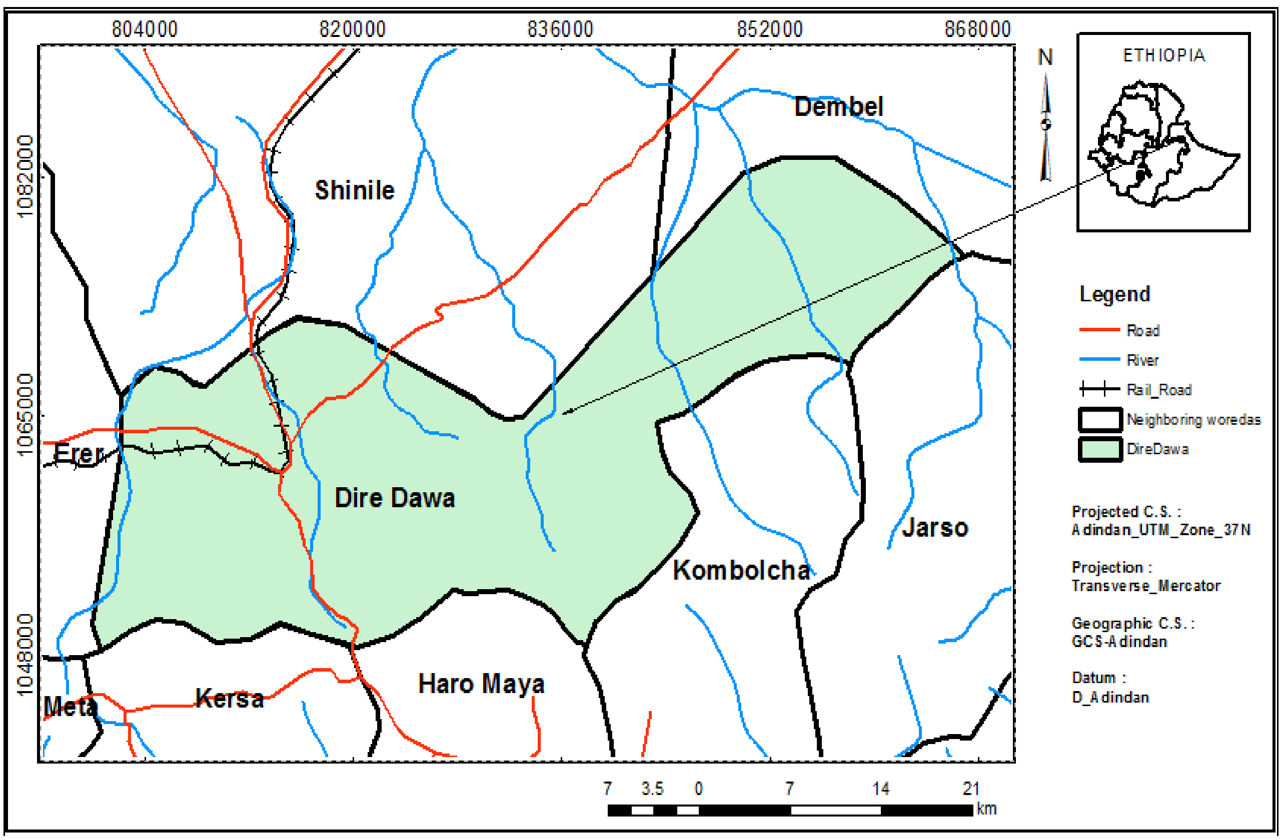


Figure 4: Location map of the study area.

3.1.2 Population

Based on the 2007 census conducted by the Central Statistical Agency of Ethiopia (CSA), Dire Dawa has a population of 341,834, of whom 171,461 are men and 170,461 women; 233,224 or 68.23% of the population are urban inhabitants. For all of Dire Dawa 76,815 households were counted living in 72,937 housing units, which results in an average of 4.5 persons to a household, with urban households having on average 4.2 and rural households 4.9 people. Ethnic groups in the region include the Oromo (45%), Somali (25%), Amhara (23%), Gurage (3%), and Harari (1%). The religion with the most believers in Dire Dawa is Muslim with 70.8%, 25.71% are Ethiopia Orthodox, 2.81% Protestant, and 0.43% Catholic.

3.1.3 Climate and topography

Dire Dawa administrative council is situated in kola agro-climatic region; because of its tropical location Dire Dawa is experiencing high temperature throughout the year with minor seasonal variations. Temperature progressively increases northward from somewhat temperate type along the mountain side of the city in its southern most point (Amente and Tesega, 2014). The mean annual temperature of Dire Dawa is about 25.4^{o}C. The average maximum temperature is 31.4^{o}C, while its average minimum temperature is about 18.2^{o}C (Fazzini *et al.,* 2015). The region has two rain seasons; that is, a small rain season from March to April, and a big rain season that extends from August to September. According to Fazzini et al. (2015), the aggregate average annual rainfall that the region gets from these two seasons is about 611 mm (Annex E). The variability of annual rainfall in Dire Dawa during the last 30-year period is a bit larger than neighboring stations (Rediat, 2012).

3.1.4 Land-use and land-cover

The total area of the city is about 1,288 km^2. The land use types in the study area are classified into seven classes (Fig. 5). These are cultivated land, bare land, grassland, settlements, shrub land, wetland and woodland (Table 2).

Table 2: Land-use/land-cover classification and area coverage of Dire Dawa.

Land-use/land-cover	Area (%)
Cultivated land	3.96
Bare land	18.25
Grassland	30.07
Settlement	2.02
Shrub land	38.08
Wet land	0.16
Wood land	7.46

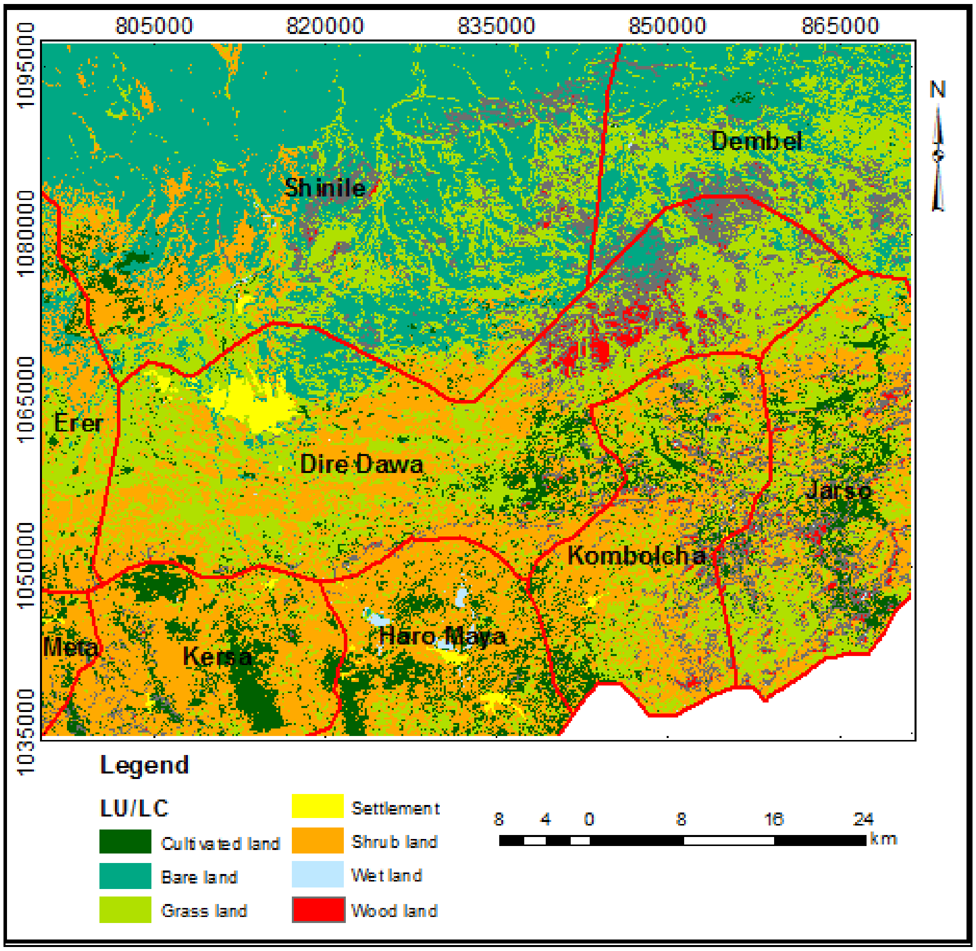


Figure 5: Land-use/land-cover map of Dire Dawa and surrounding, 2015.

3.1.5 Geology

The geology of Dire Dawa comprises various metamorphic, volcanic and sedimentary rocks. 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 near Dire Dawa. Very limited out crops of volcanic rocks are exposed in the immediate area 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 within 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 within the town and its vicinity (WWDSE, 2004; Abbate *et al.*, 2015).

3.1.6 Drainage density

There are few intermittent and perennial streams pre dominate the natural water flow system of Dire Dawa. According to the study made by the agricultural development office of Dire Dawa administrative council (DDAC) in the year 2000, 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. 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 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 sometimes causes flash flooding that result 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). Dire Dawa is vulnerable to flood hazard, which originate from uphill areas, especially Meta, Kersa and Alemaya (Eleni, 2011).

3.1.7 Soil

The major soil types of Dire Dawa exhibit a general relationship with altitude, climate and vegetation. Shallow and infertile soil is being the characteristics of the mountains. This is due to the fact that the mountains experienced serious forest degradation and resulting soil erosion. While fertile soils are the major properties of river terraces and flat plains of the study area (Fig. 6). Generally, the soils of the valley are developed on recent alluvial sediments derived from the adjacent mountain ranges. Texturally dominating soils are clay loam and loam soils (MoWR Ethiopia, 2006).

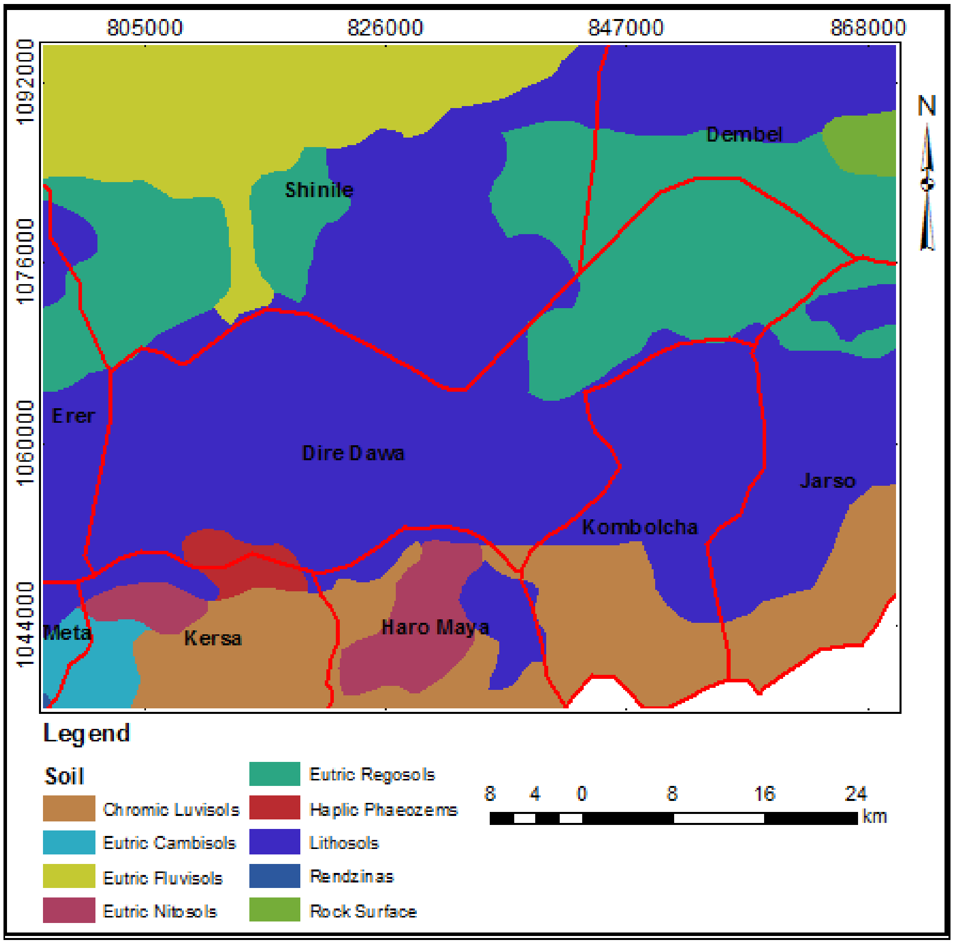


Figure 6: Soil map of Dire Dawa and surrounding.

3.1.8 Ground water

The main source of water supply for Dire Dawa is ground water, but its problems are ground water resource depletion, high pollution from domestic and industrial origins due to rapid infiltration conditions of the unsaturated zone of the sandy formation of the area and shallow ground water conditions and pathways created from poor design and construction (MoWR, 2006).

3.2 Data description, Software's and Hardware's

3.2.1 Data Description

To achieve the objective, data were collected and organized from primary and secondary sources. Global Positioning System (GPS) data was one of the primary data sources to verify Land-use/land-cover map. The Land-use/land-cover map was produced from Landsat 7 Enhanced Thematic Mapper (ETM+) image for the year 2005 and Landsat 8 Operational Land Imager (OLI) image for the year 2015; it was also the primary data, downloaded from United States Geological Survey Global Visualization Viewer Website (glovis.usgs.gov). Digital elevation model (DEM) data with spatial resolution of 15 m × 15 m from FDRE Information network security agency was used for terrain analysis.

Published and unpublished documents were among the secondary data sources. National Meteorological Agency, it was the main source to test the system using five days rainfall data (August 1-2006 – August 6-2006) of Dire Dawa and neighboring woredas during the flood hazard time and to drive antecedent moisture content of the area. Place names of Dire Dawa town and surrounding are derived from USGS Geographic Names Information System (GNIS), Digital chart of the world (DEW) and FDRE Information Network Security Agency (INSA) gazetteer. Soil data from Harmonized World Soil Database (HWSD) was used to create hydrologic soil groups (HSG) of the study area. It is the result of collaboration between Food and Agriculture Organization (FAO) with the International Institute for Applied Systems Analysis (IIASA), International Soil Reference and Information Centre (ISRIC), Institute of Soil Science, Chinese Academy of Sciences (ISSCAS), and the Joint Research Centre of the European Commission (JRC). Topographic map from Ethiopia mapping agency (EMA), lambada (ƛ) coefficient for initial abstraction calculation from Ethiopia road authority and different data related with flood hazard forecasting and early warning system were collected from Dire Dawa city administrative council.

3.2.2 Software Packages and hardware's used

Software Packages

The software packages used for this study were ERDAS (Earth Resources Data Analysis System) Imagine 2013 for remote sensing application in order to process satellite images and

Land-use/land-cover classification, ArcGIS 10.3 for terrain analysis, curve number calculation, map presentation and data storage, and visual studio 2012 for system development.

Hardware's

Garmin GPS 60 was used to collect point data for Land-use/land-cover verification and GSM cell phone for information dissemination application development.

3.3 Methods

The method for this research includes two phases, broadly and different stages under the phases: The first phase contains four stages these are; i) identification and evaluation of flood hazard analysis method ii) data collection iii) preprocessing and iv) input dataset. The second phase is about flood hazard forecasting and early warning system development (Fig.7).

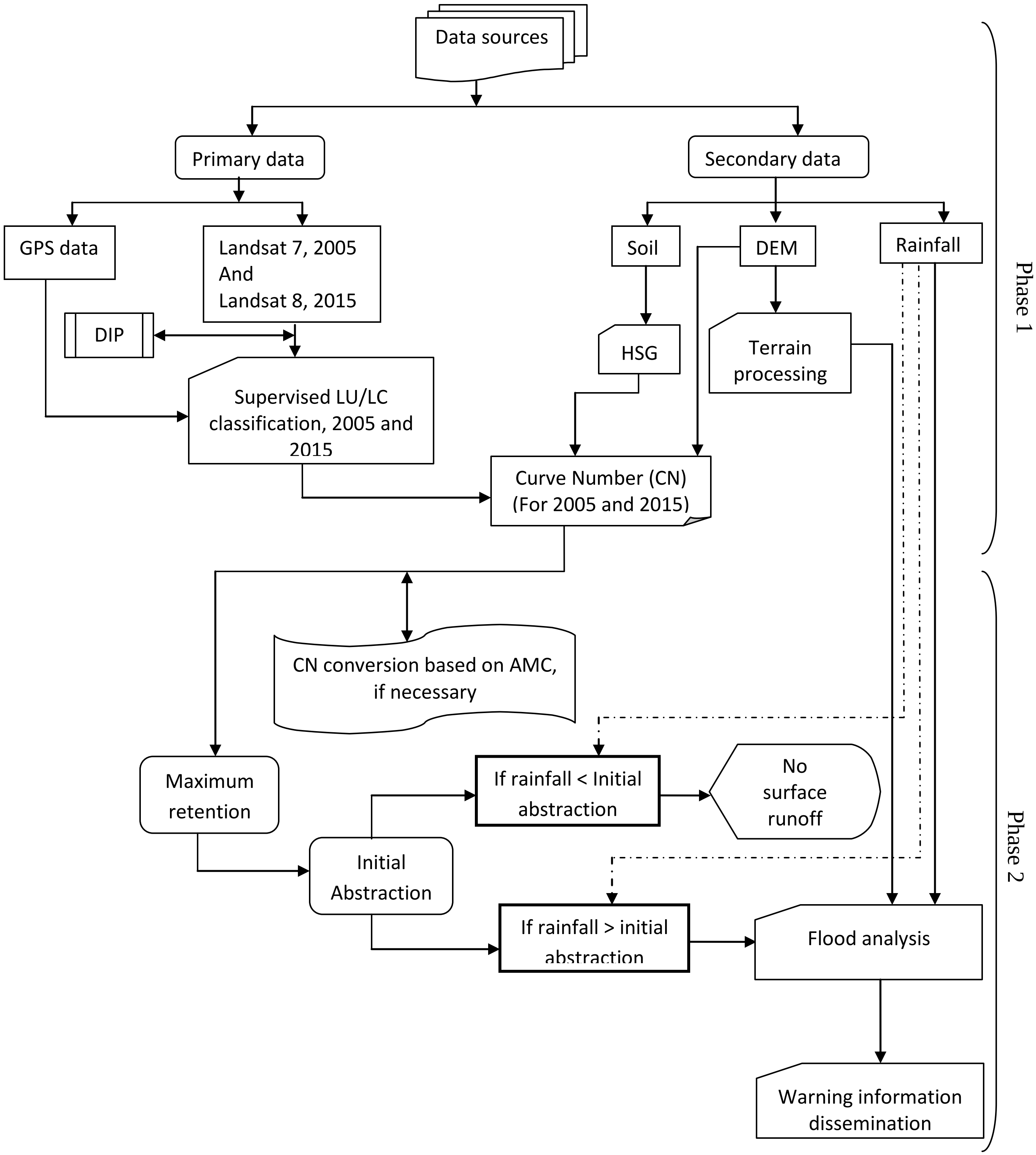


Figure 7: Flow chart of the methodology.

3.3.1 Phase 1: Method identification and data organization

I) Identification and evaluation of method

Different options are available for flood management and mitigation measures. These measures are classified broadly into structural and non-structural measures (Minea and Zaharia, 2011). The factors such as the type and characteristics of the flood and cost implications are considered in selecting feasible solution. The structural measures are designed and constructed to modify the characteristics of floods before arriving to the flood damage area through various physical constructions such as reservoirs, diversions, dykes and river retaining works. Structural measures may be suitable to prevent the damage of flash floods but the enormity of the financial, economical and ethical requirement undermines the importance of the flood prevention measures (Menzel and Kundzewicz, 2003).

Non structural measures are designed to modify the damage potential of the flood without interfering to the characteristics of the flood. Such methods focus on software and hardware technological aspects, and awareness creation, such as flood proofing, flood warning system and LU/LC control. Early warning system can be implemented to vacate the population and property at risk before the flood wave reaches to the flood prone area (Steven, 2002).

There are generalized physically based and spatially distributed hydrologic computer models that are able to compute sequences of runoff generation for a given rainfall event. The main advantage of these models is the accuracy of their predictions. Their major disadvantage is that they require considerable expertise, time, and effort to be used effectively. In between the extremes SCS-CN (Soil Conservation Service curve number) method is relatively easy to use and yield satisfactory results (Schulze *et al.*, 1985). The SCS-CN method is one of the most popular methods for computing surface runoff for a given rainfall event. The major factors to select SCS-CN method among the others are listed hereunder;

a) Simplicity and reliability

Soil Conservation Service − Curve Number (SCS-CN) method is the most common and widely used empirical method. Many catchment models, such as AGNPS−Agricultural Non-Point Source Pollution (Young *et al.*, 1987), EPIC−Environmental Policy Integrated Climate (Williams, 1995) and SWAT−Soil and Water Assessment Tool (Arnold *et al.*, 2012), use the SCS-CN method to determine runoff. Due to its simplicity and reliability, it can also be applied to hydrological forecasts of the un-gauged areas (Wang *et al.*, 2015). In this approach a simple empirical formula and readily available tables and curves are used.

b) Required data

Curve Number (CN) is a crucial factor considered for runoff estimation (Bonta, 1997). It is a function of LU/LC, Hydrologic Soil Group (HSG) and DEM. Maximum retention data is a function of curve number, and initial abstraction is derived from maximum retention data. All these data were prepared for the system; the only data required from the user is rainfall amount in millimeter to forecast the flood hazard.

c) Applicability

The CN method has been applied throughout the world (Krysanova *et al.*, 2005; Abbaspour *et al.*, 2007; Krysanova and Arnold, 2008; Rostamian *et al.*, 2008; Stehr *et al.*, 2008; Yu, 2011). However, other authors (Liu *et al.*, 2008; Collick *et al.*, 2009; Steenhuis *et al.*, 2009; White *et al.*, 2011) have questioned the representativeness of the approach in different climates and geological settings as it was originally developed for applications in temperate regions, especially in the United States. The SCS-CN method performs well during both low and high antecedent rainfall conditions and it can simulate surface runoff in tropical regions with acceptable level of accuracy (Dile *et al.*, 2016).

d) Warning information dissemination

Knowing the information dissemination mechanisms of different media and having an efficient information dissemination plan for disaster pre-warning plays a very important role in reducing losses and ensuring the safety of human beings. Social media including short messages, micro-blogs, and news portals, because of their high impact and coverage ratio made possible by developments in information technology, are becoming increasingly popular and therefore critical tools of information dissemination (Allen *et al.*, 2013). Among these information dissemination techniques, SMSs have the highest speed while cell phones can disseminate more detail information (Zhang *et al.*, 2014).

e) Availability

The method is free to any user and the system, resulted from this study is available for users with all functionalities except warning message application. Because, to make it more reliable and secured, the warning message should be disseminate from authorized government organization.

II) Data collection

Vector and raster primary and secondary data were collected from different governmental organizations as shown in Table 3.

Table 3: Description of GIS data layers used in the study.

No	Data	Description	Data source
1	Vector (Polygon)	Administrative boundary	Central statistics authority
2	Vector (Point)	GPS point data of different Land-use/land-cover types for verification	GPS
3	Raster	Land-use/land-cover classification	Landsat 7 ETM+ and Landsat 8 OLI (glovis.usgs.gov)
4	Raster	DEM	FDRE Information network security agency
5	Vector (Polygon)	Soil	Harmonized world soil database
6	Raster	Topographic map	Ethiopia mapping agency

III) Preprocessing

This stage includes:

i. Layer stacking, mosaicking and sub-setting of satellite image based on the boundary of the study area.
ii. Radiometric and geometric correction in order to reduce distortion of the image in ERDAS Imagine 2013 software.
iii. Geo-referencing the image using topographic sheet provided by EMA.
iv. Reprojecting the data to make it accessible for further analysis.

During geo-referencing and reprojection process, Adindan _ UTM _ Zone_37N spatial reference system was followed for raster data as well as vector data in the research to maintain uniformity.

IV) Input dataset

a) Dire Dawa town and surrounding gazetteer

Gazetteer is a work of geographic reference that supplies place name and location information. It uses to identify and notify flood prone areas using their place name (Fig. 8).

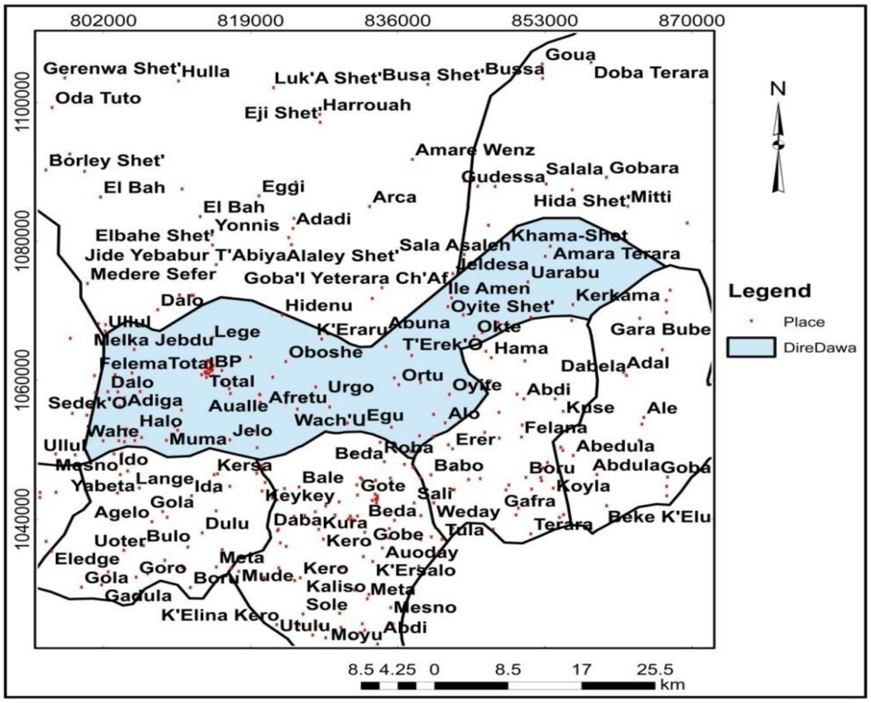


Figure 8: Dire Dawa town and surrounding gazetteer.

b) Drainage

Drainage was generated from 15 m × 15 m Digital Elevation Model (DEM) using the output from the flow accumulation (Fig. 9). Mostly, areas along the drainage side are susceptible to flood hazard.

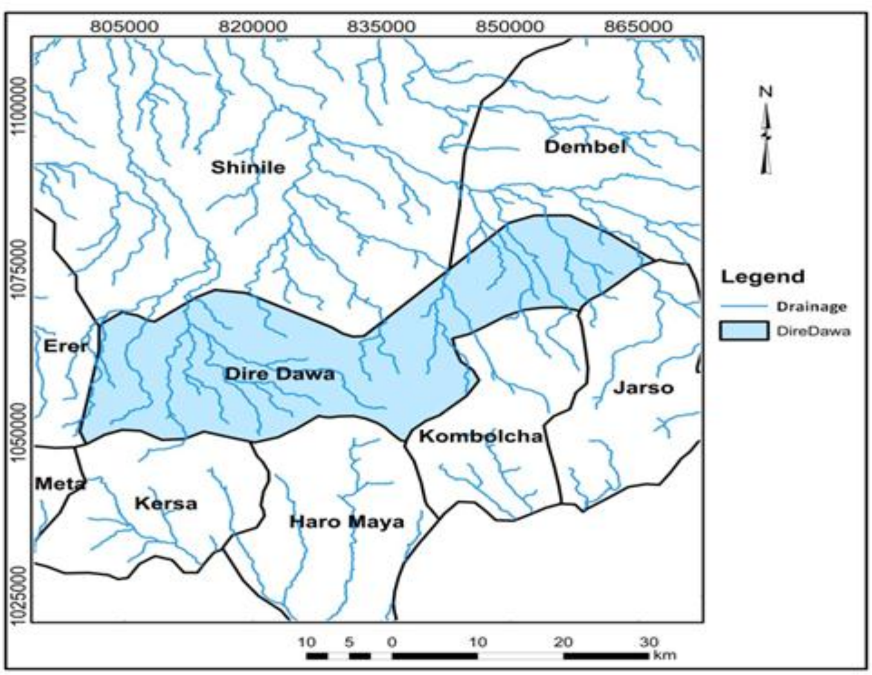


Figure 9: Drainage map of Dire Dawa and surrounding.

c) Contour line

The contour line was generated from 15 m × 15 m DEM in 50 m interval. Dire Dawa is highly affected by flood from the flow of upland areas, especially from Meta, Kersa and Alemaya, so it was necessary to consider and analyze elevation variation on the upland areas.

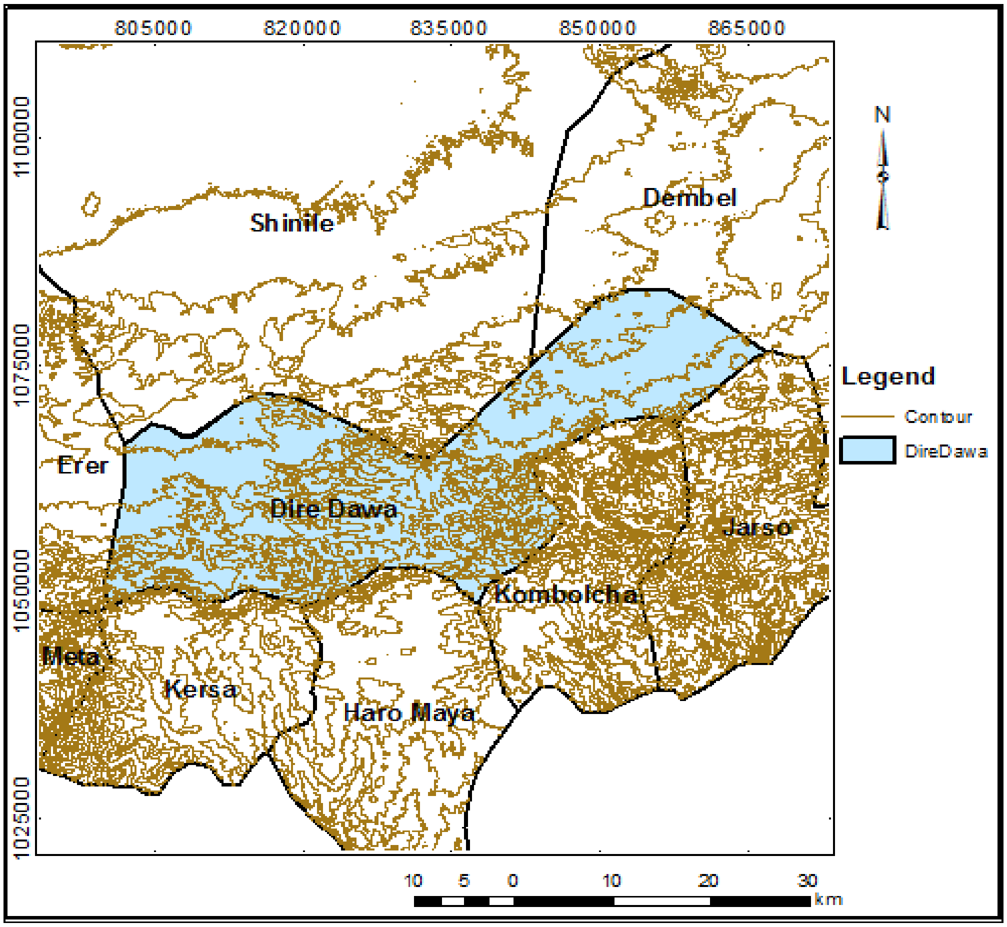


Figure 10: Contour map of Dire Dawa and surrounding.

d) Land-use/land-cover

Land-use/land-cover of the area was classified in to seven classes for the years 2005 (Fig. 11) and 2015 (Fig. 5), based on USDA technical releas-55 standard. It was used to generate CN, the 2005 CN was used to system reliability test and the 2015 CN was generated for future activities conducted by using the system (Table 4). In this study, one of the types of supervised classification, which is maximum likelihood classification, was used in order to classify and produce a LU/LC map. The 2015 LU/LC map was produced and validated based on field data with over all accuracy of 94.24% and the 2005 was validated based on reference data from Google earth with accuracy of 91.97% (Annex D).

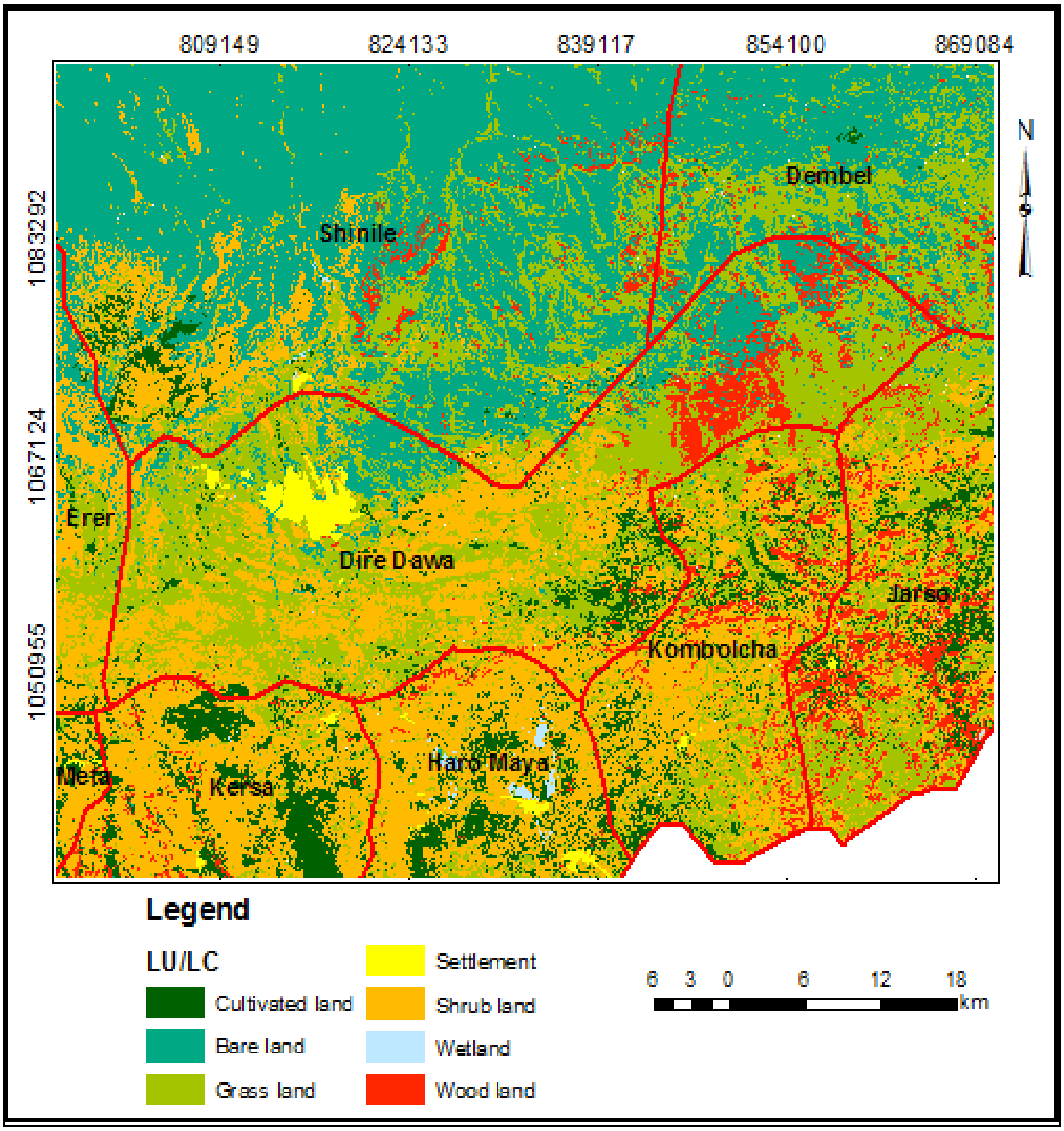


Figure 11: Land-use/land-cover map of Dire Dawa and surrounding, 2005.

Table 4: Classification and CN value of LU/LC of Dire Dawa and surrounding in different HSG.

Data set	Classification	CN in Hydrologic Soil Group (HSG)			
		A	**B**	**C**	**D**
Land-use/land-cover	Wood land	30	58	71	78
	Grassland	68	79	86	89
	Shrub land	50	69	79	85
	Cultivated land	66	77	84	87
	Wet land	98	98	98	98
	Settlement	57	72	81	86
	Bare land	80	82	90	95

Source: (USDA-TR-55, 2014)

e) Hydrologic soil group (HSG)

Soil data was classified into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential (Table 5). Where "A" refers to low runoff potential and "D" corresponds to high runoff potential (Viji *et al.*, 2015). It was used to determine CN value (Fig. 12).

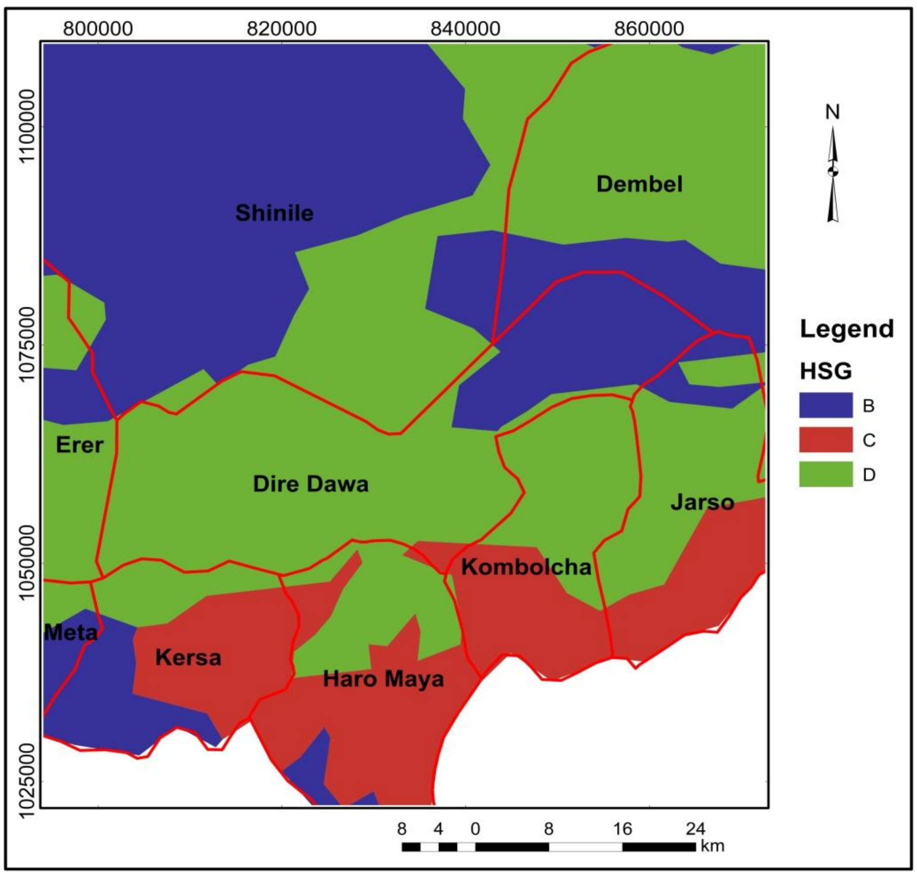


Figure 12: Hydrologic Soil Group (HSG) map of Dire Dawa and surrounding.

Table 5: Hydrologic Soil Group based on USDA soil classification.

Soil texture	Hydrologic soil group
Sand, sandy loam or loamy sand	A
Silt or loam	B
Sandy clay loam	C
Clay loam, silt clay loam, sandy clay, silt clay or clay	D

f) Rainfall data

The amount of rainfall within the study area and its surrounding woredas, Kersa, Alemaya and Meta, at the first week of August 2006 is described in Table 6. It was used to show how accurate the system is, according to the flood hazard on August 5, 2006. The data was also used to determine AMC of the area to test the system.

Table 6: Rainfall data.

Date	Rainfall in (mm)			
(August, 2006)	Dire Dawa	Kersa	Alemaya	Meta
1	0	0	0	0
2	0	0	0	0
3	4.3	7.9	18.9	26.7
4	10.2	0	24.5	4.7
5	36.9	166	118	100
6	1	0	7.3	0

Source: (National Metrological Agency)

g) Digital Elevation Model (DEM)

The whole area DEM has a spatial resolution of 15 m x 15 m. According to the DEM, the elevation of Dire Dawa and surrounding woredas ranges from 380 m − 3011 m (Fig. 13) this shows that the area has a huge topographical variation; it is used to calculate CN value of the area. Dire Dawa is highly vulnerable to flood hazard, which originate from uphill areas, especially from Meta, Kersa and Alemaya (Eleni, 2011).

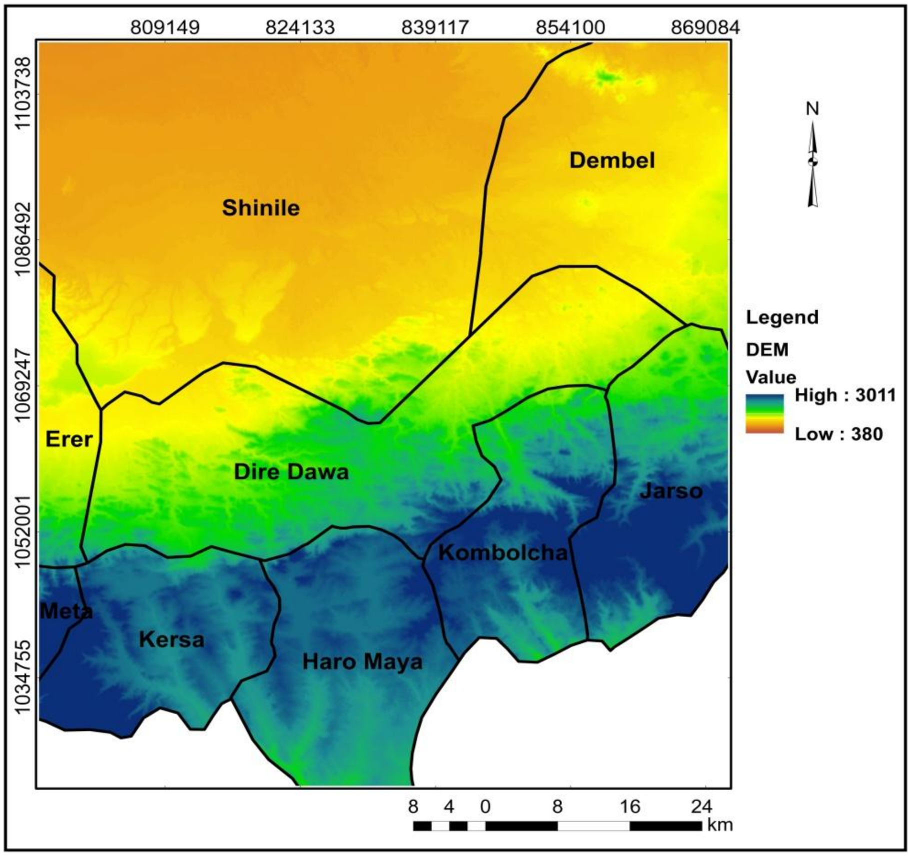


Figure 13: Digital Elevation Model (DEM) of Dire Dawa and surrounding.

3.3.2 Phase 2: Flood hazard forecasting and early warning system development

I) SCS-CN method

The basis of the soil conservation service − curve number method is the empirical relationship between the retention (rainfall not converted into runoff), runoff properties of the area and the rainfall. The basic assumption is that, for a single rainfall, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall (Eq. 3.1). Victor Mockus found Equation 1 appropriate to describe the curves of the field measured runoff and rainfall values (USDA-NRCS, 2004).

$$\frac{F}{S} = \frac{Q}{P} \qquad \text{Eq. 3.1}$$

Equation 1 describes the conditions in which no initial abstraction occurs.

Where; F = Actual retention after runoff begins

Q = Actual runoff

S = Potential maximum retention after runoff begins

P = Potential maximum runoff

$$F = P - Q \qquad \text{Eq. 3.2}$$

In this study, it was assumed that a certain amount of rainfall is abstracted. The three important abstractions for any single rainfall event are rainfall interception, depression storage, and infiltration into the soil (USDA-NRCS, 2004). The curve number method lumps all three abstractions into one term, the initial abstraction (Ia), and subtracts this calculated value from the rainfall total. The total rainfall must exceed this initial abstraction before any runoff generated. This gives the potential maximum runoff (rainfall available for runoff) as P – Ia substituting this value in equation 3.1 yields the following equation:

$$\frac{P - Ia - Q}{S} = \frac{Q}{P - Ia} \qquad \text{Eq. 3.3}$$

It is important to note the potential maximum retention term, S, excludes Ia. Hence, for a given rainfall, maximum loss of rainfall is "$S + Ia$". Rearranging terms in equation 3.3 for Q gives

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad \text{Eq. 3.4}$$

The SCS-CN method provides the following empirical equation based on the assumption that "Ia" is a function of the potential maximum retention, S.

$$Ia = \lambda S \qquad \text{Eq. 3.5}$$

According to Ethiopia road authority $\lambda = 0.2$

Therefore;

$$Ia = 0.2S \qquad \text{Eq. 3.6}$$

The potential maximum retention, S is related to the dimensionless parameter CN in the range of $0 \leq CN \leq 100$.

$$S = \frac{25400}{CN} - 254 \qquad \text{Eq. 3.7}$$

Substituting Equation 3.6 into Equation 3.4 yields,

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{Eq. 3.8}$$

Equation 3.8 has only one parameter that needs to be evaluated (i.e., S) which determined by using equation 3.7.

II) Curve Number (CN)

Curve Number (CN) is essential coefficient to reduce the total rainfall to runoff potential. Therefore the higher the CN value the higher the runoff potential will be. The CN value is a dimensionless number and limited in the range 1−100 (Ponce and Hawkins, 1996), it has direct relationship with runoff potential (Table 7). The classification of CN is customized based on the HSG and elevation characteristics of the study area.

Table 7: CN classification.

CN Range	Runoff potential
60 −67	Low
67−76	Moderate
76−100	High

Source: (Nagarajan *et al.*, 2015)

Curve Numbers for different Land-use/land-covers is determined by USDA-NRCS technical release in 2014 using experimental method. It was for average condition, i.e. AMC II. For dry condition, AMC I is applied and for wet conditions AMC III (Table 8). It is possible to drive CN for AMC I and AMC III using CN of AMC II. To derive CN for AMC I from CN of AMC II Equation 3.9 is applied and for CN at AMC III from CN of AMC II Equation 3.10 is used.

$$CN(I) = \frac{4.2CN(II)}{10-0.058CN(II)} \quad \text{Eq. 3.9}$$

Where; CN (I) = Curve Number for Antecedent Moisture Content I (AMC I)

CN (II) = Curve Number for Antecedent Moisture Content II (AMC II)

$$CN(III) = \frac{23CN(II)}{10+0.13CN(II)} \quad \text{Eq. 3.10}$$

Where; CN (III) = Curve Number for Antecedent Moisture Content III (AMC III)

CN (II) = Curve Number for Antecedent Moisture Content II (AMC II)

Table 8: Classification of Antecedent Moisture Condition.

AMC group	Soil characteristics	Total 5-day antecedent rainfall (mm)	
		Dry condition	**Wet condition**
AMC I	Dry soil	< 13	< 36
AMC II	Average condition	13 – 28	36 – 53
AMC III	Heavy rainfall have occurred, saturated soil	>28	>53

Source: (Lalitha and Helen, 2015)

Among the input datasets, Land-use/land-cover of 2005, soil data, DEM and rainfall data from August 1 – 6, 2006 of Dire Dawa and surrounding woredas were used for CN value calculation of the year 2005, this value was again calculated using 2015 Land-use/land-cover, DEM and soil input datasets, assuming average antecedent moisture condition i.e. AMC II. The first CN value was used to test the system accuracy and reliability and the second one is used for future analysis carried on by using the system.

Based on Table 6 rainfall data, during the flood hazard time the antecedent moisture content of Dire Dawa was 51 mm that is in AMC II, Kersa, Alemaya and Meta had 174 mm, 162 mm and 132 mm of antecedent moisture content, respectively and classified under AMC III. To convert CN values from AMC II to AMC III, an application that integrated within the system was used (Annex A.2).

The system was developed using C# object oriented programming language in visual studio integrated development environment (Annex F). It has integrated seven applications; Initial abstraction (Ia) analysis, maximum retention (S) analysis, flood analysis, Antecedent Moisture Content (AMC) calculator, Curve Number (CN) converter, flood prone areas analysis and messaging.

III) Applications development

a) AMC calculator

Antecedent soil moisture content calculator is an independent application in the system. It uses to compute AMC of the area and to categorize the value (Fig 14). Soil has different moisture content in different seasons, generally dry and wet seasonal conditions. CN is determined based on AMC value of the area. The appropriate moisture group AMC I, AMC II and AMC III is determined based on previous five-day rainfall amount.

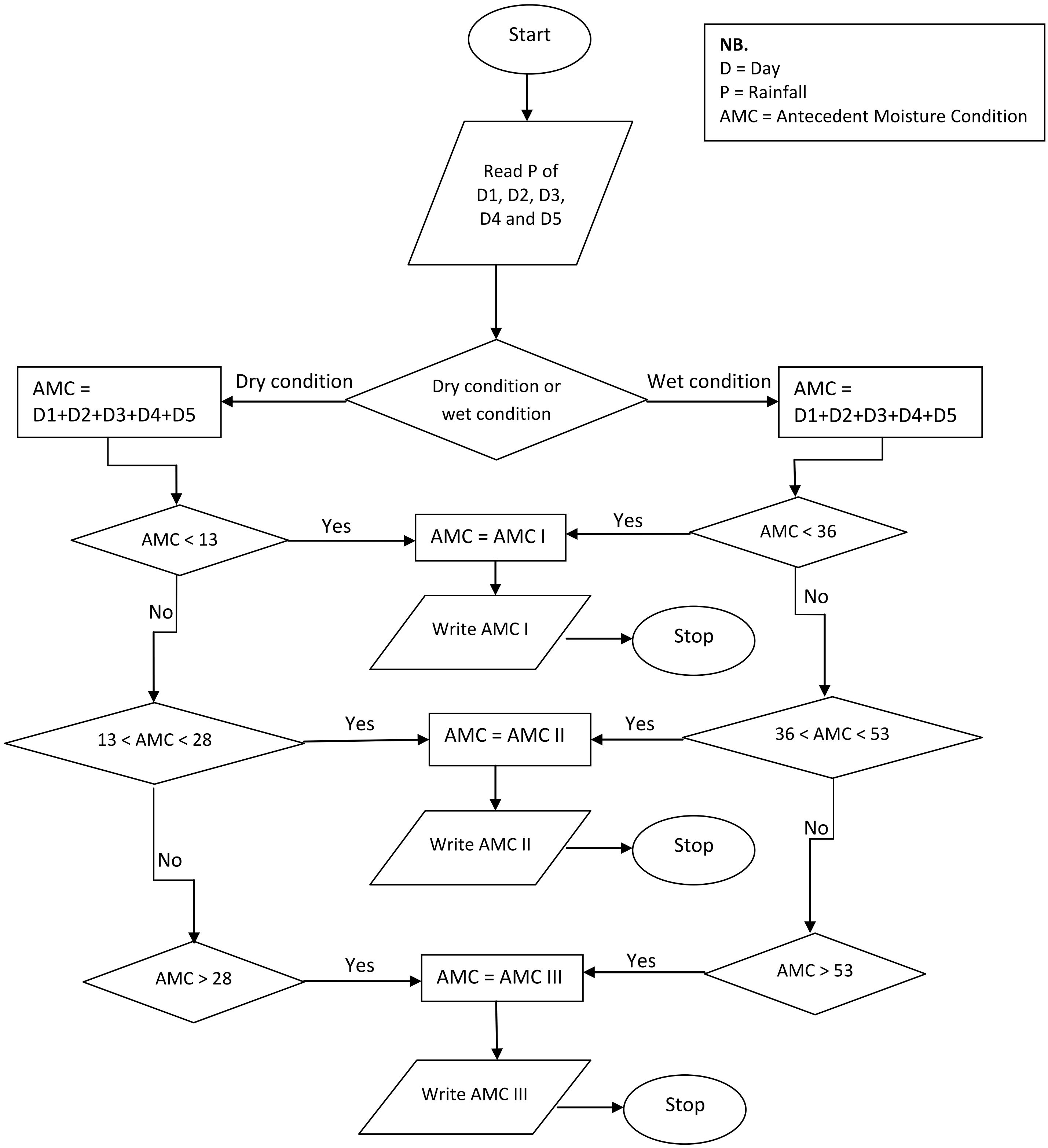


Figure 14: Conceptual model of Antecedent Moisture Content (AMC) calculator.

The application window has rainfall data entry boxes, the user have to fill all five days rainfall data and select seasonal condition (Annex A.1).

b) CN conversion

Curve number value of the study area was prepared by assuming average antecedent soil moisture content condition, i.e. AMC II, but AMC will vary in different seasonal conditions, that affect CN value. The equations were derived based on SCS-CN formulas for CN I and CN III which described in Equation 3.9 and 3.10, respectively. The application window can convert CN I, CN II and CN III from one to another (Fig. 15) and the system has an application window to perform this conversion.

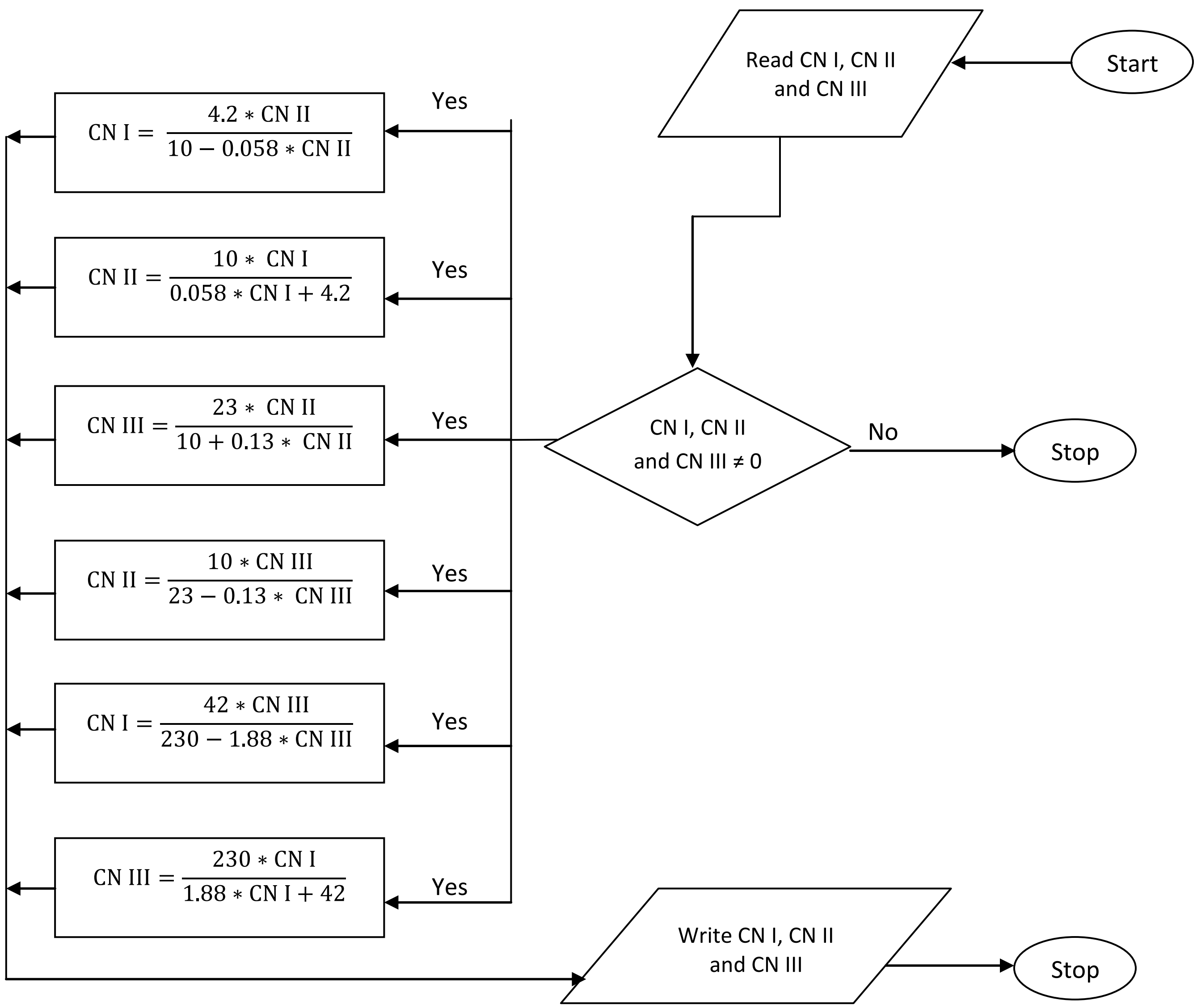


Figure 15: Conceptual model of Curve Number conversion application.

c) Maximum retention analysis

Maximum retention is related with soil, DEM and LU/LC condition of the area. It is potential maximum retention of water by the soil. CN was used to generate maximum retention map of the study area (Annex A.3). When CN becomes 100 (i.e. the maximum value) maximum retention becomes zero, that means there is no retention (Fig. 16).

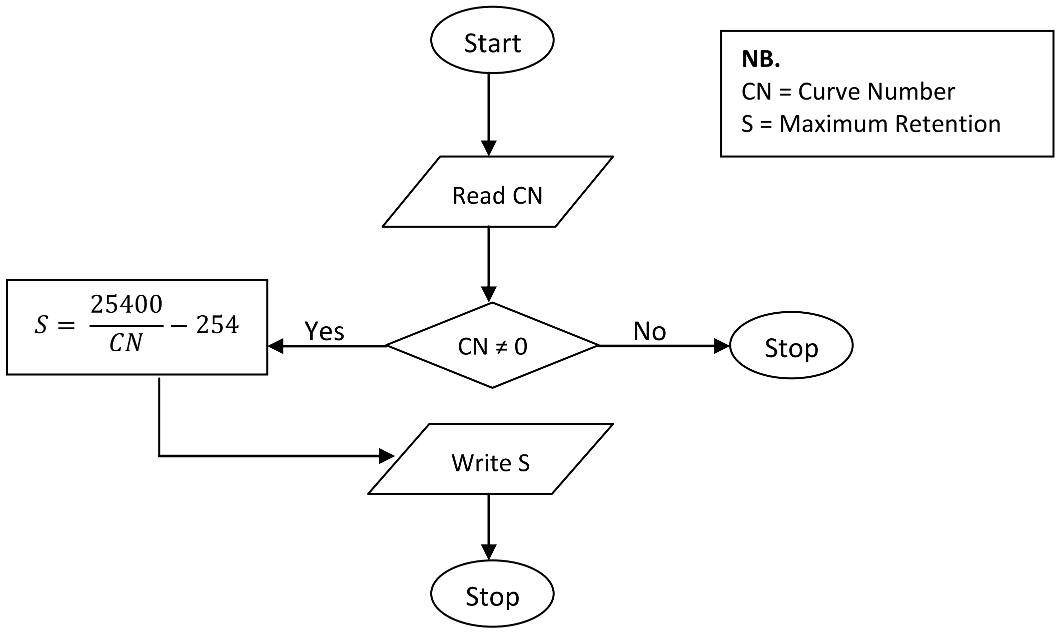


Figure 16: Conceptual model of maximum retention (S) analysis application.

d) Initial abstraction analysis

This application was used to generate initial abstraction map of the area (Fig. 17). It shows all losses before runoff begins, and includes water retained in surface depressions, water taken up by vegetation, evaporation and infiltration. This value is related to characteristics of the soil, elevation and the soil cover. The input data for initial abstraction computation is maximum retention (Annex A.4).

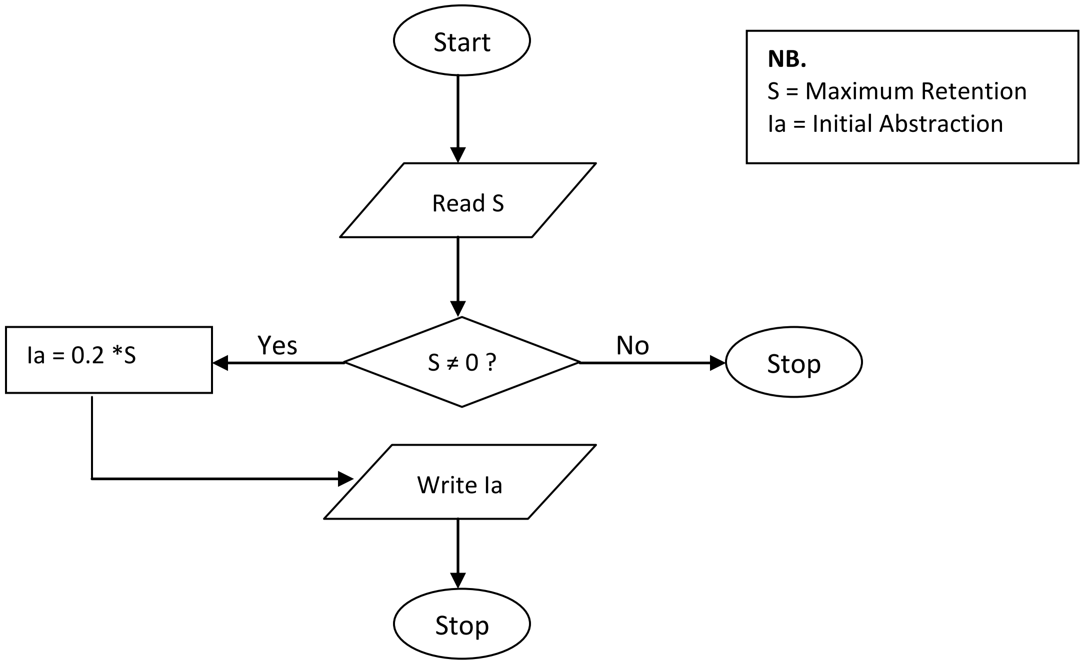


Figure 17: Conceptual model of initial abstraction (Ia) analysis application.

e) Flood prone areas analysis

The amount of rainfall required for the occurrence of surface runoff is must be greater than the initial abstraction.

$$\text{If } P > Ia, Q = \frac{(P-0.2S)^2}{P-0.8S} \quad \text{Eq. 3.11}$$

$$\text{If } P \leq Ia, Q = 0 \quad \text{Eq. 3.12}$$

Where; P = Precipitation

Ia = Initial abstraction

S = Maximum retention

The flood prone areas analysis application determines areas with the probability of flood. To this end, the user provides rainfall amount (Annex A.5). Areas with the probability of flood will have the value of "one" and areas without this dread will not have any value i.e. zero (Fig. 18).

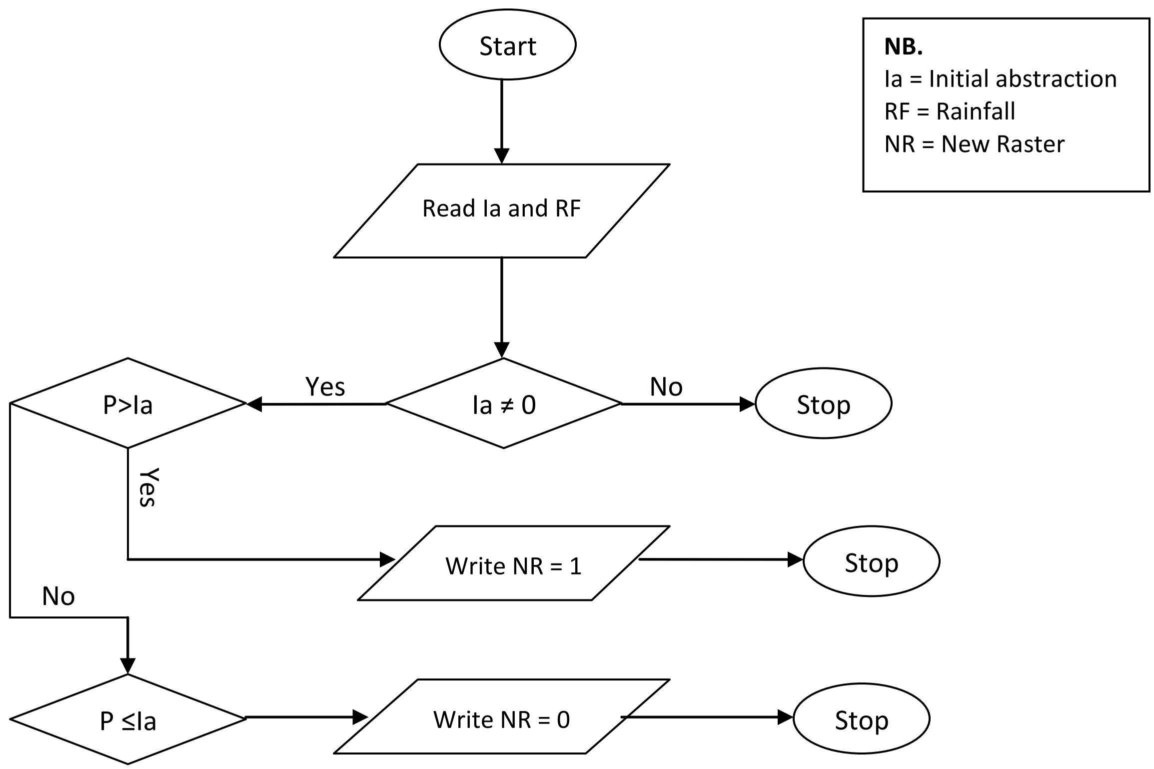


Figure 18: Conceptual model of flood prone are identification application.

f) Flood analysis

Soil conservation service-curve number method was used to calculate surface runoff using the formula described in Equation 3.8 (Fig. 19). Rainfall is the main parameter to forecast flood hazard, it is provided by the user. Surface runoff analysis application has data entry box for rainfall (Annex A.6), then the system computes the value of surface runoff depth of the area.

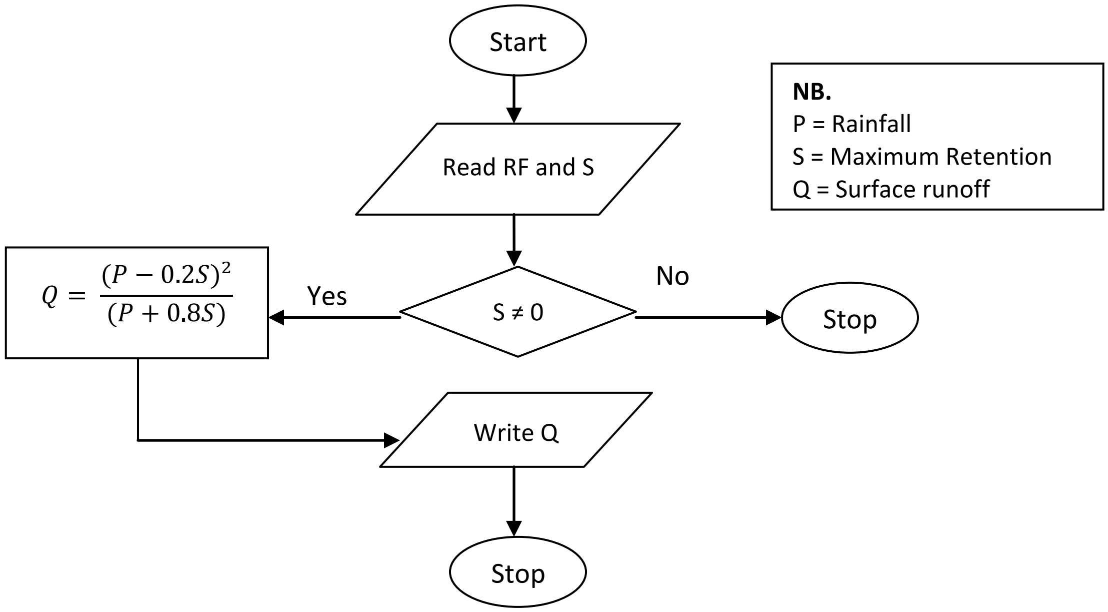


Figure 19: Conceptual model of flood analysis application.

g) Information dissemination

One of the major applications of the system is messaging. The analyst can send warning text message for concerned stakeholders and peoples. It has four main tools; port number entry and connector, phone number browser, message entry and sender (Fig. 20). The application window is easily manageable and accessible. To make it secured information distributor this application is not included for public use (Annex A.7).

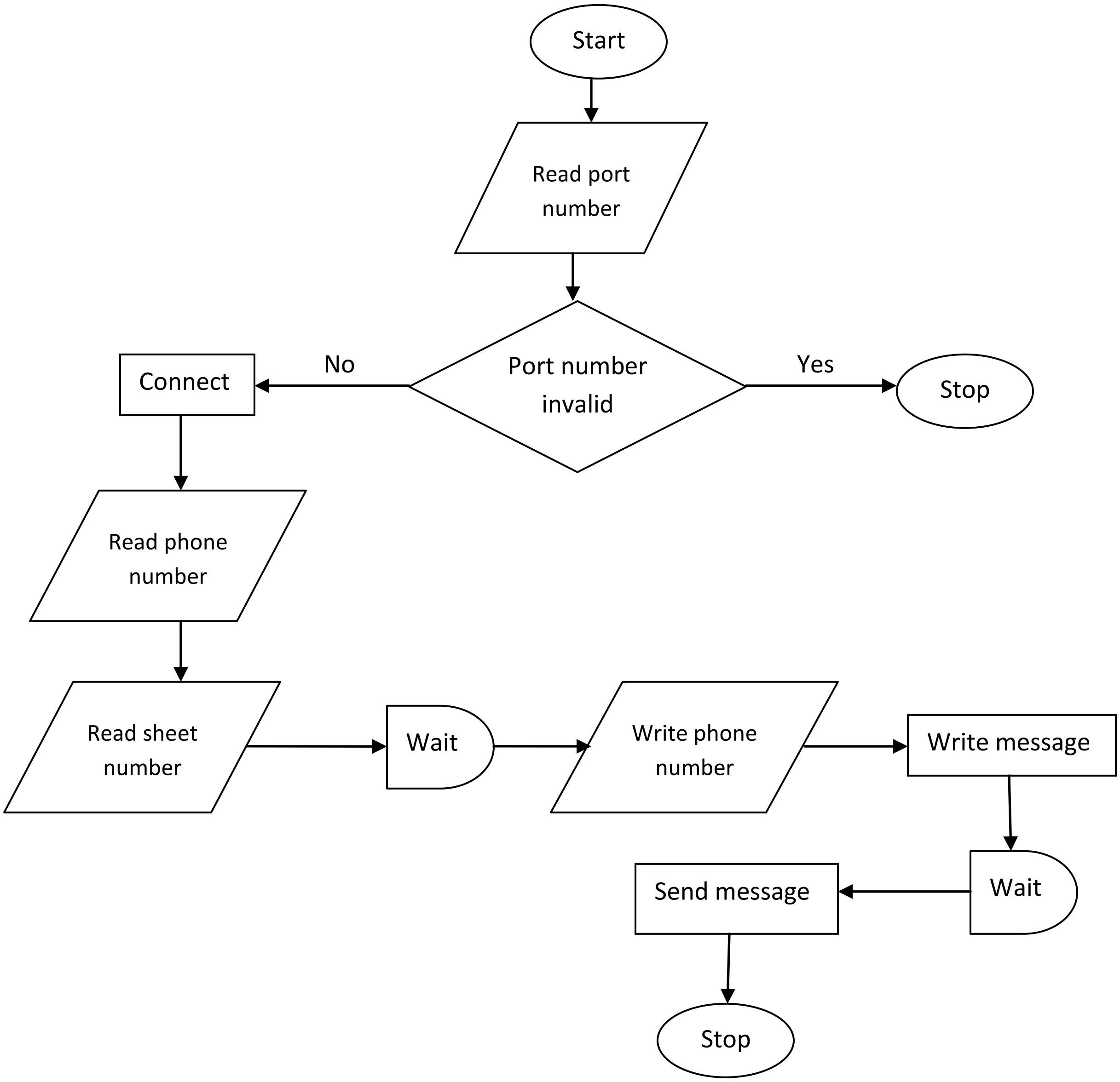


Figure 20: Conceptual model of messaging application development.

h) Home window

The home window of the system contains basic map functionalities, analysis tool for initial abstraction, maximum retention and flood, flood prone areas identification tool, AMC calculator, CN converter, information dissemination and help tool. It has built-in data for analysis; these are contour, place name, stream and woredas name. This helps the analyst to identify areas with high level of flood hazard severity (Annex A.8).

CHAPTER FOUR

4. Results

The study was conducted to develop flood hazard forecasting and early warning system for the study area. Results revealed that, the method SCS-CN can simulate flood hazard condition of the area effectively and the developed system performs correctly. Results are explained as follows:

4.1 Curve Number

Curve Number (CN) is prepared by using LU/LC classification data of 2005 and 2015 with HSG and DEM. The 2005 CN map was used to test the system (Annex C.1) and the 2015 CN (Fig. 21) for future flood hazard forecasting and early warning activities conducted by using the system.

According to the CN result, 74.53% of Dire Dawa town shows high (> 76) value of CN, 10.21% is moderate (67−76) and 16.07% of the town has low (<67) CN value, that means most part of the area has high value of CN (Fig. 22), this implies that the value of initial abstraction and maximum retention is low. Because of this, intense rainfall makes Dire Dawa town victim of flood hazard, especially from the flow of upland areas.

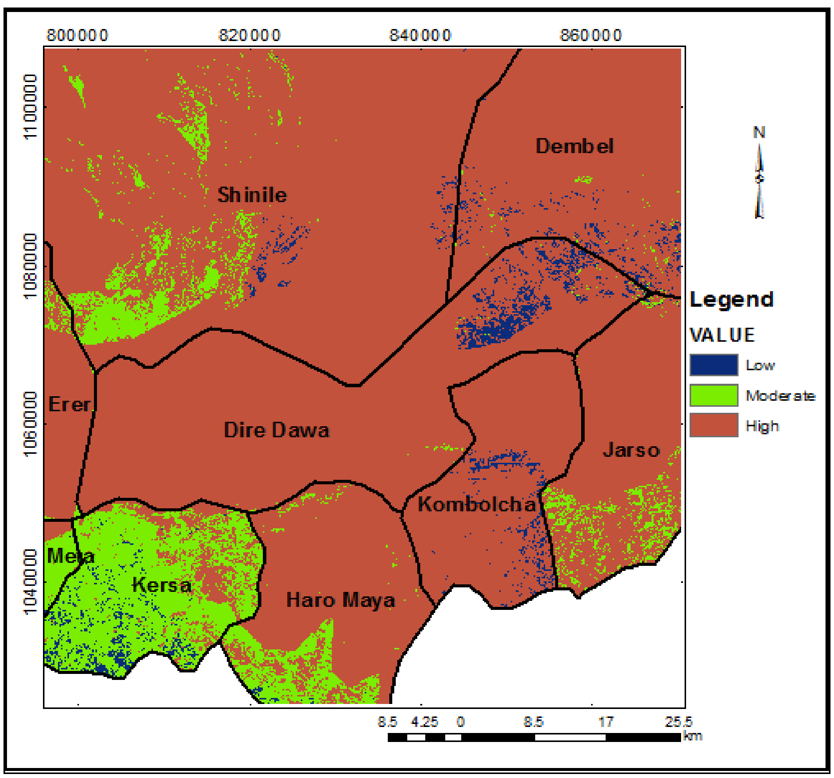


Figure 21: CN value map of Dire Dawa town and surrounding, 2015.

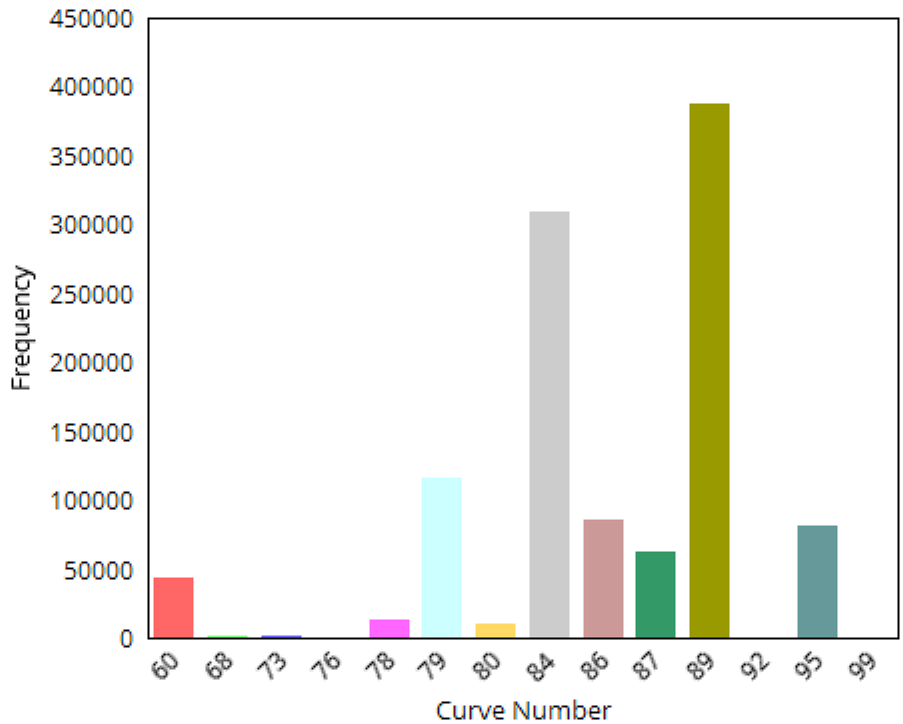


Figure 22: CN value distribution of Dire Dawa town, 2015.

4.2 Maximum retention

Maximum retention map is prepared to both 2005 (Annex C.2) and 2015 years (Fig. 23) for system testing and future forecasting activities, respectively; it is derived from CN value. Dire Dawa has low maximum retention value (Fig. 24); this entails, the vulnerability of the city to flood hazard is high because of low retention of water by the soil. Classification of maximum retention value is depends on curve number range (Table 9).

Table 9: Maximum retention value classification.

Maximum retention		Runoff potential
Range	**class**	
0−80.21	Low	High
80.21−125.1	Moderate	Moderate
125.1−169.33	High	Low

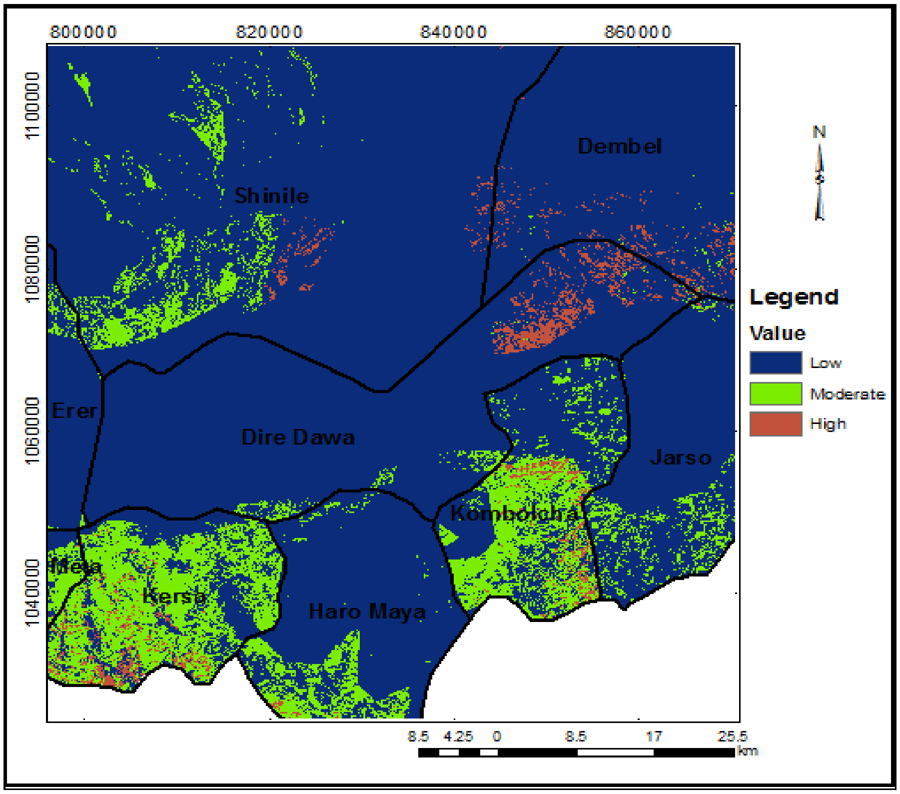


Figure 23: Maximum retention map of Dire Dawa town and surrounding, 2015.

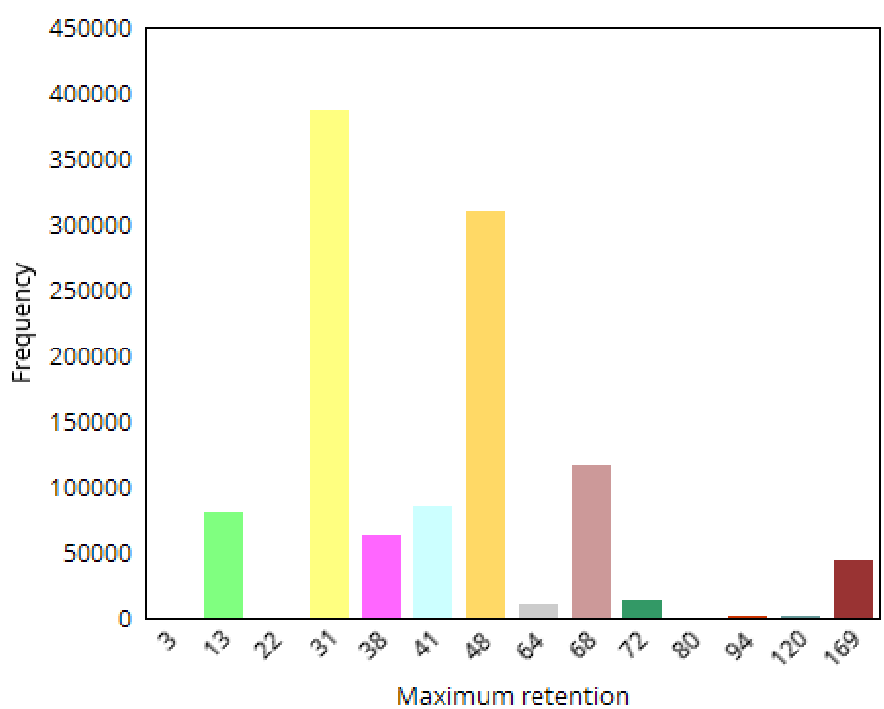


Figure 24: Maximum retention value distribution of Dire Dawa town, 2015.

4.3 Initial abstraction

Value of initial abstraction is inversely related with CN value. It is prepared to both 2005 and 2015. The first one was used for system applicability test (Annex C.3), and the second one is for future flood hazard forecasting activities. Most part of the neighboring upland woredas of Dire Dawa town has minimum value of initial abstraction (Fig. 25); this makes easy the flow of water from upland areas to Dire Dawa town. The town also has low value of initial abstraction (Fig. 26). The value of initial abstraction is classified according to maximum retention and CN value classification (Table 10).

Table 10: Initial abstraction value classification.

Initial abstraction		Runoff potential
Range	Class	
0−16.04	Low	High
16.04−25.02	Moderate	Moderate
25.02−33.86	High	Low

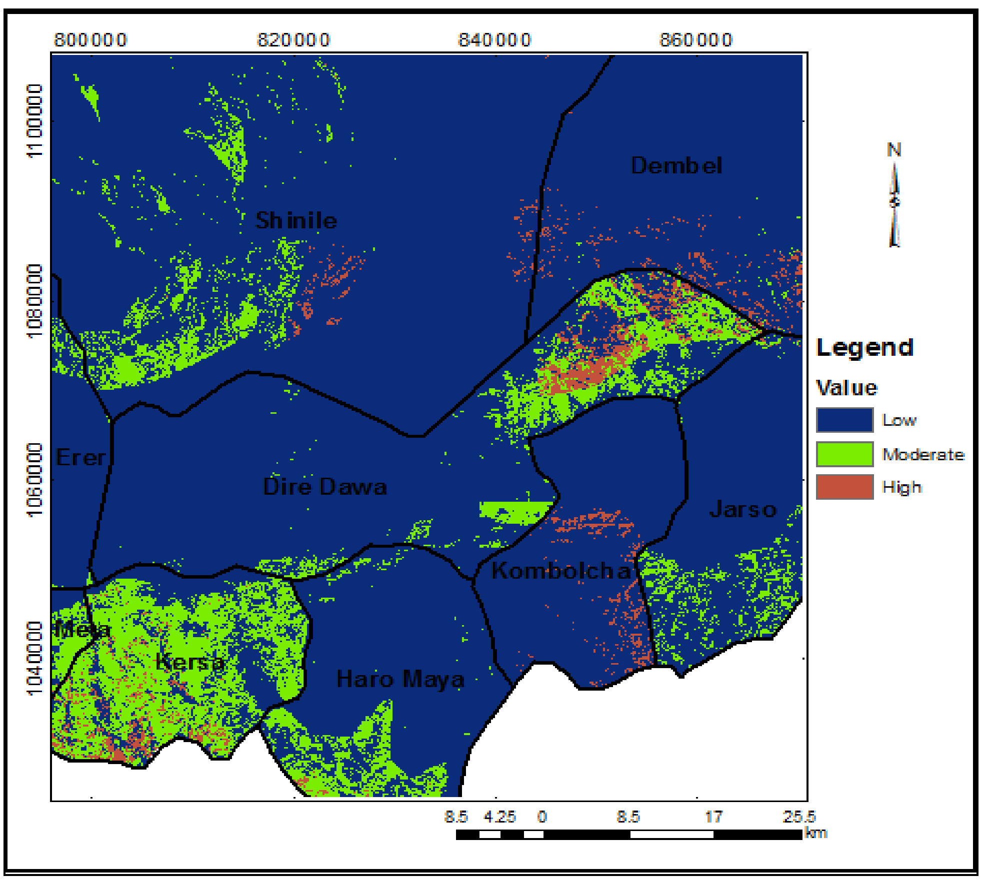


Figure 25: Initial abstraction map of Dire Dawa tow and surrounding, 2005.

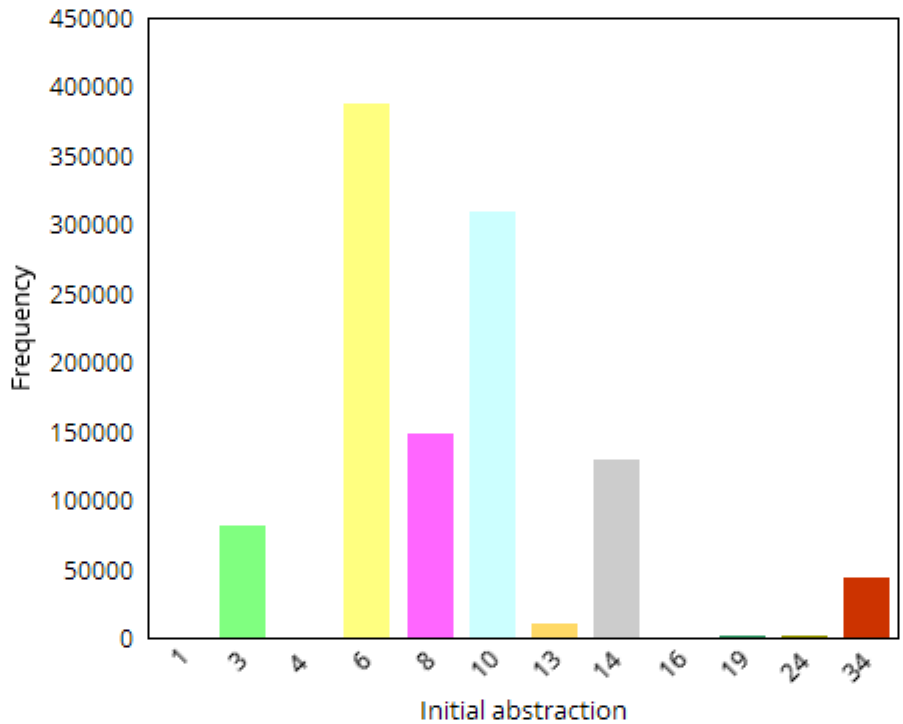


Figure 26: Initial abstraction value distribution of Dire Dawa town, 2015.

4.4 D-FHEWS 1.0

The system is named to D-FHEWS 1.0 (Dire Dawa-Flood Hazard Early Warning System, Version 1). It has seven incorporated applications; Initial abstraction (Ia) analysis, maximum retention (S) analysis, Antecedent Moisture Content (AMC) calculator, Curve Number (CN) converter, flood analysis, flood prone areas analysis and messaging (Fig. 27). All applications have their own user interface and are functional. The functionality of the system is tested based on August 5, 2006 flood hazard occurred in Dire Dawa town.

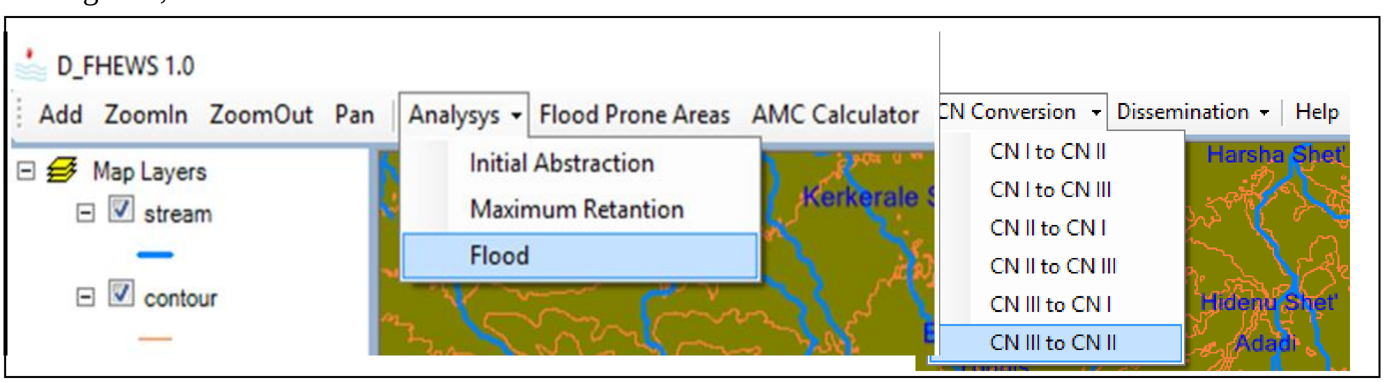


Figure 27: The user interface of Dire Dawa Flood Hazard Early Warning System, Version 1.

4.5 Evaluation of the system

The system is evaluated according to international Organization for Standardization, (ISO) 9126, standard. It is an international standard for the evaluation of systems. It has six main quality characteristics, namely:

- Functionality
- Reliability
- Usability
- Efficiency
- Maintainability
- Portability

These characteristics are broken down into sub-characteristics; it is at the sub-characteristic level the measurement for standard occurs.

4.5.1 Functionality

Functionality describes the capability of the system (i.e. D-FHEWS 1.0) to meet the objective. Its functionality is evaluated according to the following sub-characteristics:

a) Accuracy

The accuracy of D-FHEWS 1.0 was validated based on August 5, 2006 flood hazard occurred in Dire Dawa town by using the rainfall measured at that time, (Table 6), there was high potential of surface runoff in the surrounding highland areas (Fig. 28). The strength of surface runoff is determined based on CN value classification (Table 7), elevation and HSG characteristics of the area (Table 1). The analyst can interpret and analyze the flood direction and susceptible areas easily, because D-FHEWS 1.0 has built-in terrain interpretation data, which are, contour and stream network. Woredas and place names are also included in the built-in data (Fig. 29).

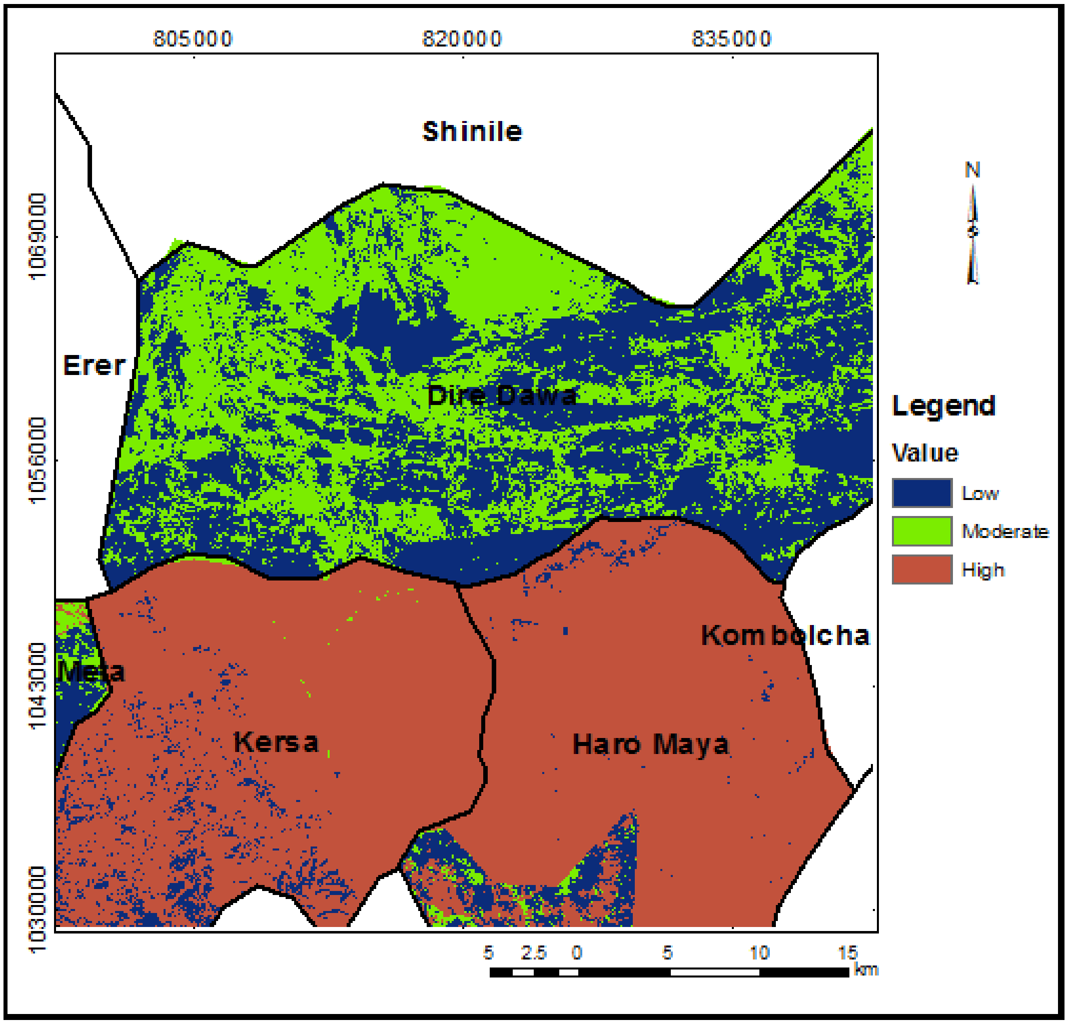


Figure 28: Surface runoff potential on August 05, 2006.

Dire Dawa is highly affected by flood from the highland areas, as figure 28 shows, the upland areas especially, Kersa and Alemaya had huge surface runoff amount on August 5, 2006. It was measured between 28 – 162 mm in unit area. Here unit area is the cell size that is 30 m × 30 m.

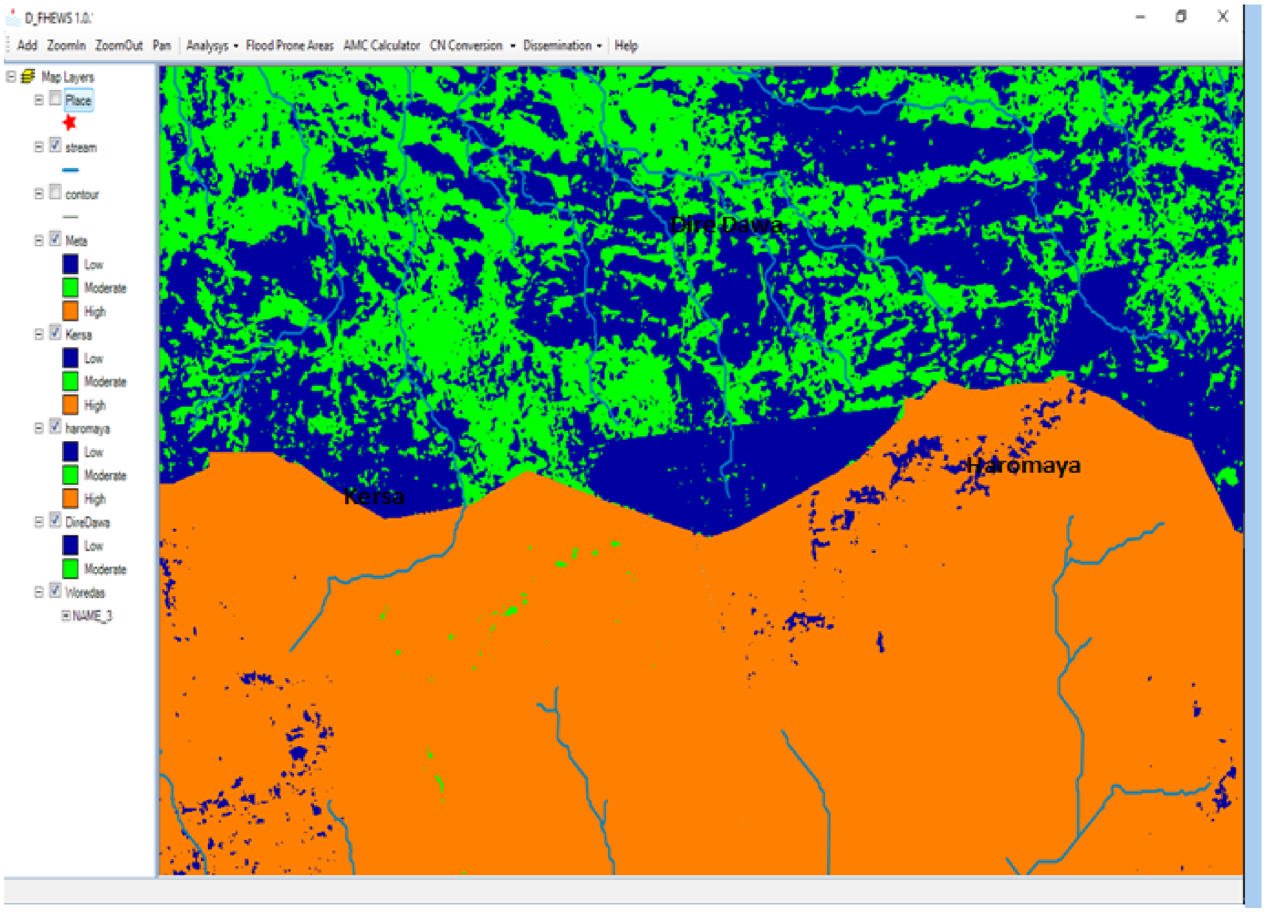


Figure 29: Flood analysis on Dire Dawa Flood Hazard Early Warning System, Version 1.

The messaging application of D-FHEWS 1.0 is also fully functional using GSM network (Fig. 30). It is possible to use this application by integrating any mobile phone or GSM modems.

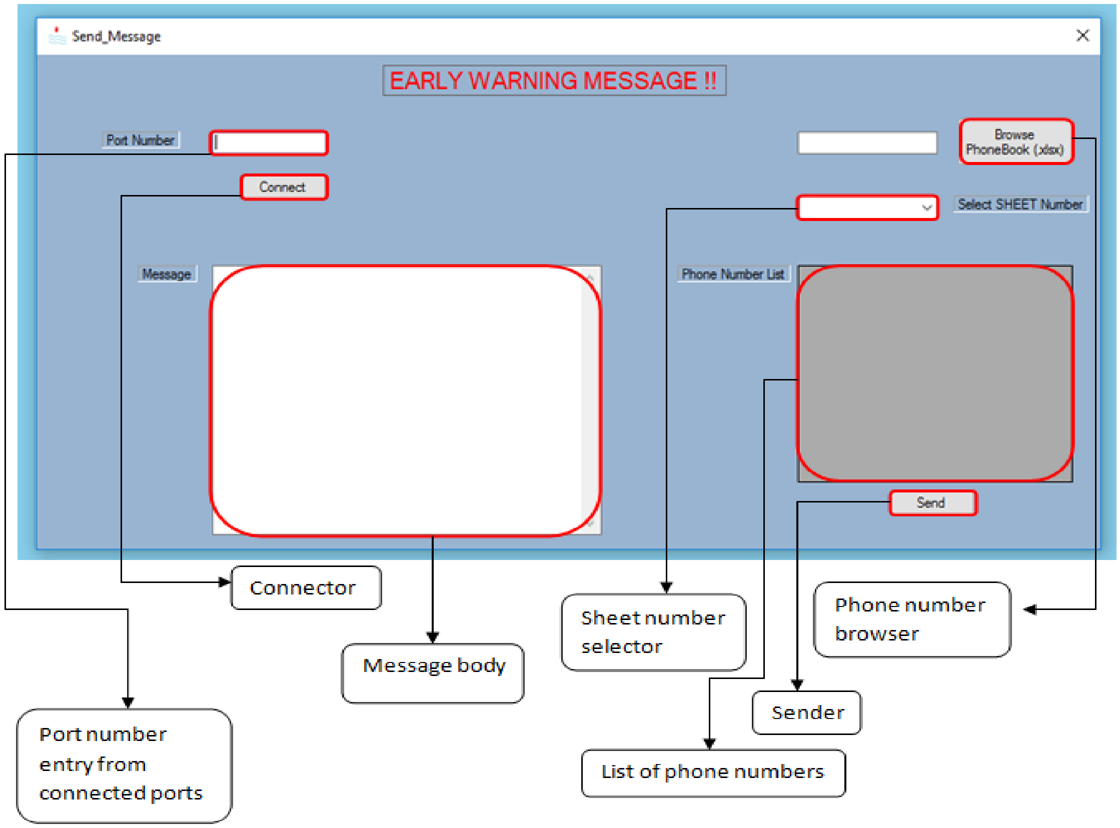


Figure 30: Early warning information dissemination application.

b) Suitability

The system is suitable to any user with computer skill and basic GIS and remote sensing knowledge. It has full help document and manual. The tools in the system are also easily identifiable and manageable.

c) Interoperability

The system does not typically function in isolation. This sub-characteristic concerns the ability of the system to interact with other spatial software's and applications. D-FHEWS 1.0 supports GDAL (Geospatial Data Abstraction Library), so it supports to read raster and vector formats from other software's and applications and it is possible to access results from D-FHEWS 1.0 on others software's and applications (Annex B.1).

d) Security

D-FHEWS 1.0 is open sources to any user with all functionalities except the warning message application. To make it secured, information dissemination application is provided only for concerned stakeholders.

4.5.2 Reliability

a) *Maturity*

This sub-characteristic concerns frequency of failure of the system. There is no need to have special software or hardware to run D-FHEWS 1.0. It is applicable through all condition. To use the messaging application; the only external device needed is GSM modem or mobile phone. The system is not dependent on internet. There is no failure by the system itself.

4.5.3 Usability

Usability refers to the ease of use for flood hazard forecasting and early warning application. It has two sub-characteristics:

a) Understandability and operability

It determines the ease of which the systems applications can be understood. All applications in the system have user-friendly interface. The user can easily understand and interact with the system. D-FHEWS 1.0 is operable in all windows environment and the user with basic computer skill and GIS and remote sensing knowledge is needed for its operability.

b) Learnability

The learning effort to use the system for different users, i.e. beginner or expert is very easy. The first thing that makes the learnability process easy is the manual and help document integrated with the system and the other factor is all tools are descriptive and easily accessible.

4.5.4 Efficiency

This characteristic is concerned with the system resources used when providing the required functionality.

a) Time behavior

Time behavior characterizes response time of D-FHEWS 1.0 for a given thru put. Actually, it is dependent on the size of processed data, but it does not consume unnecessary time relative to the size of the data. It was tasted using Dire Dawa and all surrounding woredas spatial data.

b) Resource

The system needs not less than 500 MB memory space, including built in data. It is operable in all CPU, i.e. 32-bit and 64-bit. D-FHEWS 1.0 needs GSM network for information dissemination. The user have to have feed rainfall data to the system to forecast flood hazard from a single rainfall event.

4.5.5 Maintainability

Maintainability describes the ability to identify and fix a fault within a system component. Anything that helps with identifying the cause of a fault and then fixing the fault is the concern of maintainability.

a) Analyzability

D-FHEWS 1.0 has seven incorporated applications. Each application has its own functionality; this makes the system easily analyzable. Based on the analysis done, D-FHEWS 1.0 can show the hazard accurately.

b) Changeability

D-FHEWS 1.0 is the first version; it does not need much effort to add additional functionalities and to change to the next version. The whole system is done on the same platform this makes the changeability of the system easy.

c) Stability

Because all results from D-FHEWS 1.0 are stored in GDAL formats, the user can analyze it using any spatial software. Any change on D-FHEWS 1.0 cannot affect either the previous or the future works on D-FHEWS 1.0.

d) Testability

Of course, the system is developed for Dire Dawa, it is possible to apply to any area. There was different flood hazard occurrence in Ethiopia, so it is possible to taste the system using CN value and rainfall data of interested area.

4.5.6 Portability

Installability

Because D-FHEWS 1.0 is open source it does not need any installation effort without running the set up. It is adaptable with all kinds of windows operating systems.

CHAPTER FIVE

5 Discussion

In this study flood hazard forecasting and early warning system is developed. The system uses SCS-CN method, which is a method of estimating rainfall excess from rainfall. Dire Dawa, the second largest city of Ethiopia, has been suffering from disastrous floods in its history. The 2006 flooding was unheard-of disaster that caused severe impacts on human lives and property (Yonas, 2015).

The developed system has seven integrated applications; Initial abstraction (Ia) analysis, maximum retention (S) analysis, flood analysis, antecedent Moisture Content (AMC) calculator, Curve Number (CN) converter, flood prone areas analysis and messaging. Initial abstraction (Ia) includes all losses before runoff begins, and includes water retained in surface depressions, water taken up by vegetation, evaporation, and infiltration. This value is related to characteristics of the soil and the soil cover (Mishara and Singh, 2004). It is used to determine flood prone areas using rainfall event, if the amount of rainfall is greater than initial abstraction there will be surface runoff on the area. Potential maximum retention is also related to soil and land use condition of the area. It is potential maximum retention of water by the soil (Bansode and Patil, 2014), initial abstraction is generated from potential maximum retention. AMC calculator requires five days rainfall data to determine the moisture content of the area, it is the preceding relative moisture of the pervious surfaces prior to the rainfall event (Soulis and Valiantzas, 2012). CN value is a primary input parameter for the SCS runoff equation (ponce and Hawkins, 1996). According to Shadeed and Almasri (2010), a high curve number means high runoff and low infiltration, whereas a low curve number means low runoff and high infiltration. CN converter, in the system, is used to convert the value of CN in different antecedent moisture content conditions. Flood analysis application requires rainfall data from the user. Initial abstraction is used to analyze flood prone areas, as described here above if initial abstraction exceeds rainfall there will be flood and vice versa. The system also has the capability of disseminating information to community or governmental and non-governmental organizations. To make it secured, messaging application is available to only concerned organizations.

The SCS-CN method, adapted for the analysis, has been widely applied in the lake Tana watersheds in particular and the Ethiopian highlands in general (Setegn *et al.*, 2009; 2010a;

2010b; Betrie *et al.,* 2011; Dile *et al.,* 2013; 2016; Gebremicael *et al.,* 2013; Dile and Srinivasan,2014) and provided satisfactory results. Generally, SCS-CN method can simulate surface runoff in tropical regions with acceptable level of accuracy (Dile *et al.,* 2016). This study demonstrates that in relative to the surrounding upland areas Dire Dawa has high CN value, this implies, there is low value of initial abstraction and maximum retention. This makes the area highly vulnerable to flood hazard, especially from the flow of upland areas.

The system is developed using C# Object Oriented Programming Language (OOPL) platform. OOPL is modular, as it provides separation of duties in object-based program development. It is also extensible, as objects can be extended to include new attributes and behaviors. Objects can also be reused within an across applications. Because of these factors – modularity, extensibility, and reusability–object-oriented programming provides improved system development productivity (Manish, 2013). It is tested using ISO 9126 standard, an international standard for the evaluation of systems and the reliability of the result is assured by referring August 5, 2006 flood hazard in Dire Dawa. ISO 9126 has six characteristics with different sub-characteristics; the main characteristics applied for evaluation are Functionality, reliability, Usability, efficiency, maintainability and portability. Based on the evaluation and reliability result the system is functional for flood hazard forecasting and early warning system.

In flood hazard disaster reduction, there are two techniques, structural and non-structural. Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and early warning systems (Minea, 2011). The expanding pattern of flooding effect on one hand especially what has occurred in the year 2006 and the lesser consideration given particularly for non-structural measures demonstrates that floods and its monstrous calamities will keep on occurring later on and will bring about significantly higher harms. In recent years, the nearby organizations have built gabion and high flood retaining walls that have contained the last flood happened in 2010 keeping the town from further inundation. However, the rocks drawn by the spillover from the upland region have collided with the wall and damaged its part in 2010 flooding (Yonas, 2015).

CHAPTER SIX

6 Conclusion and recommendations

6.1. Conclusion

This study attempts to develop flood hazard forecasting and early warning system in Dire Dawa, Ethiopia. Forecasting the hazard and disseminating information were the major tasks and SCS-CN method was applied. SCS-CN method for flood analysis is a good approach to deduce a sound decision for forecasting and analyzing flood disaster using a single rainfall event. This research confirmed the method used was capable to integrate all surface runoff properties of the area. It accounts for many of the factors affecting runoff generation including soil type, Land-use/land-cover, elevation and antecedent moisture condition, comprising them in a single CN parameter.

To achieve the objective seven interrelated applications were incorporated in the system, these are, initial abstraction (Ia) analysis, flood analysis, maximum retention (S) analysis, Antecedent Moisture Content (AMC) calculator, Curve Number (CN) converter, flood prone areas analysis and messaging. The reliability of the system was tested based on August 5, 2006 flood hazard and it has agreement with the phenomena occurred at that time. The result obtained from the study was evaluated in accordance with its functionality, reliability, usability, efficiency, maintainability and portability and it meets all characteristics.

It was observed that Dire Dawa has high CN value, this means the area has low value of initial abstraction and maximum retention value. This makes the city susceptible to flood hazard. Hence, it is important to have easy and accurate flood hazard forecasting and early warning system. It is hoped that the findings of this research will contribute to minimize flood hazard disaster.

6.2. Recommendations

Based on the result of the present study, the following recommendations are suggested for decision makers and future researchers:

- The government has to give high attention for flood hazard forecasting and early warning systems and encourage professionals who need to innovate on non-structural flood protection measures.

- Land-use/land-cover data should be updated at least in a year to have accurate CN value.
- Concerned decision makers on flood disaster management should adopt the system, i.e. D-FHEWS 1.0 of this study as a flood hazard forecasting and early warning system for other areas of the country by using updated CN value of the area.
- In addition to SCS-CN method, in future research other methods for flood analysis should be investigated.

References

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., & Srinivasan, R. (2007). Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of hydrology*, **333(2):** 413−430.

Abbate, E., Bruni, P., & Sagri, M. (2015). Geology of Ethiopia: a review and geomorphological perspectives. In *Landscapes and Landforms of Ethiopia* (pp. 33-64). Springer Netherlands.

Adepoju, M. O., Millington, A. C., & Tansey, K. T. (2006, May). Land use/land cover change detection in metropolitan Lagos (Nigeria): 1984-2002. In *ASPRS 2006 Annual Conference Reno, Nevada May* (pp. 1-5).

Allen, H. G., Stanton, T. R., Di Pietro, F., & Moseley, G. L. (2013). Social media release increases dissemination of original articles in the clinical pain sciences. *PLoS One*, **8(7)**.

Amente, G., & Tesega, H. M. (2014). *Analysis of Regional Climate Variability and Trends in Dire Dawa Administration* (M.Sc dissertation, Haramaya University).

American metorological society (2017). Flash floods: The role of science, forecasting and communications in reducing loss of life and economic disruptions https://www.ametsoc.org/ams accessed on March 11, 2017.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., & Kannan, N. (2012). SWAT: Model use, calibration, and validation. *Transactions of the ASABE*, ***55*****(4):** 1491−1508.

Aspnes, J. Notes on Data Structures and Programming Techniques (CPSC 223, Spring 2015).

Billi, P., Alemu, Y. T., & Ciampalini, R. (2015). Increased frequency of flash floods in Dire Dawa, Ethiopia: Change in rainfall intensity or human impact?. *Natural Hazards*, ***76*****(2):** 1373−1394.

Australia government, geosciences Australia (2011). What is flood? http://www.ga.gov.au/scientific-topics/hazards/flood/basics/what accessed on January 3, 2017.

Bansode, A., & Patil, K. A. (2014). Estimation of Runoff by using SCS Curve Number Method and Arc GIS. *International Journal of Scientific & Engineering Research*, ***5*****(7):** 1283−1287.

Betrie, G. D., Mohamed, Y. A., van Griensven, A., & Srinivasan, R. (2011). Sediment management modelling in the Blue Nile Basin using SWAT model. *Hydrology and Earth System Sciences*, **15(3):** 807−818.

Bonta, J. V. (1997). Determination of watershed curve number using derived distributions. *Journal of Irrigation and Drainage Engineering*, **123(1):** 28−36.

Burnett, C., & Blaschke, T. (2003). A multi-scale segmentation/object relationship modelling methodology for landscape analysis. *Ecological modelling*, **168(3):** 233−249.

Campbell, B. J. and Wynne, H. R. (2011). *Introduction to Remote Sensing*, 5th ed., CRC Press, London.

Cleaveland, J. C. (1986). An Introduction to Data Types, *Addison-Wesley,* **7(2).**

Collick, A. S., Easton, Z. M., Ashagrie, T., Biruk, B., Tilahun, S., Adgo, E., Awulachew, S.B., Zeleke, G., & Steenhuis, T. S. (2009). A simple semi- distributed water balance model for the Ethiopian highlands. *Hydrological processes*, **23(26):** 3718−3727.

CORDAID (Catholic Organization for Relief and Development AID). (2011). Flash floods and approaches to prevent disaster in Dire Dawa, Ethiopia, CORDAID.

Cronshey, R. (1986). *Urban hydrology for small watersheds*. US Dept. of Agriculture, Soil Conservation Service, Engineering Division.

CSA. (2007). Federal Democratic Republic of Ethiopia Statistical Abstract, Addis Ababa.

Daniel, A. (2007). *Assessment of Flood Risk in Dire Dawa Town, Eastern Ethiopia, using GIS* (M.Sc dissertation, Addis Ababa University).

Dile, Y. T., & Srinivasan, R. (2014). Evaluation of CFSR climate data for hydrologic prediction in data- scarce watersheds: an application in the Blue Nile River Basin. *JAWRA Journal of the American Water Resources Association*, **50(5):** 1226−1241.

Dile, Y. T., Karlberg, L., Srinivasan, R., & Rockström, J. (2016). Investigation of the Curve Number Method For Surface Runoff Estimation In Tropical Regions. *JAWRA Journal of the American Water Resources Association*, **52(5):** 1155−1169.

Dile, Y. T., Berndtsson, R., & Setegn, S. G. (2013). Hydrological response to climate change for gilgel abay river, in the lake tana basin-upper blue Nile basin of Ethiopia. *PloS one*, **8(10)**.

Dile, Y.T., Karlberg, L., Daggupati, P., Srinivasan, R., Wiberg, D., & Rockstr€m, J., (2016). Assessing the Implications of Watero Harvesting Intensification on Upstream-Downstream

Ecosystem Services: A Case Study in the Lake Tana Basin. *Science of the Total Environment* **542**:22−35.

DRMFSS. (2013). Disaster risk management strategic programe and investment framework, Ministry of agriculture, Addis Ababa.

Eleni, G. (2011), coping strategies of displaced flood victims: the case of Dire Dawa, M.Sc dissertation, Addis Ababa University, Addis Ababa.

Enyew, B. D., & Steeneveld, G. J. (2014). Analysing the impact of topography on precipitation and flooding on the Ethiopian highlands. *J Geol Geosci*, **3(173):** 2.

Ephrem, D. (2006). Preliminary assessment of Dire Dawa flood damage. M.Sc dissertation, Addis Ababa University, Addis Ababa.

Ezeife, C.I. (2015). Introduction to Algorithms and Programming I, *school of computer science, university of windsor*, 60−140.

Fazzini, M., Bisci, C., & Billi, P. (2015). The climate of Ethiopia. In *Landscapes and Landforms of Ethiopia* (pp. 65-87). Springer Netherlands.

FDRE. (2013). National policy and strategy on disaster risk management, Addis Ababa, Ethiopia.

Frauke, L. (2014), Basic Introduction into Algorithms and Data Structures, Computer Science Department University of Cologne Germany.

Gao, Y., Mas, J. F., Niemeyer, I., Marpu, P. R., & Palacio, J. L. (2007, June). Object-based image analysis for mapping land-cover in a forest area. In *Proc. of 5th International Symposium on Spatial Data Quality*.

Gebremicael, T. G., Mohamed, Y. A., Betrie, G. D., van der Zaag, P., & Teferi, E. (2013). Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin: A combined analysis of statistical tests, physically-based models and landuse maps. *Journal of Hydrology*, **482:** 57−68.

Hoedjes, J. C., Kooiman, A., Maathuis, B. H., Said, M. Y., Becht, R., Limo, A., Mumo M., Nduhiu-Mathenge J., Shaka A., & Su, B. (2014). A conceptual flash flood early warning system for Africa, based on terrestrial microwave links and flash flood guidance. *ISPRS International Journal of Geo-Information*, **3(2):** 584−598.

Howard Perlman (2016), Precipitation: The Water Cycle https://water.usgs.gov/edu/mwater.html accessed on February 1, 2017.

Jawak, S. D., Devliyal, P., & Luis, A. J. (2015). A comprehensive review on pixel oriented and object oriented methods for information extraction from remotely sensed satellite images with a special emphasis on cryospheric applications. *Advances in Remote Sensing*, **4(3):** 177−19.

Kavi K. K. (2013). Real-time flood monitoring using wireless sensor networks, *The Journal of the Institution of Engineers Mauritius-IEM Journal*, **1:** 59−69.

Krysanova, V., Hattermann, F., & Wechsung, F. (2005). Development of the ecohydrological model SWIM for regional impact studies and vulnerability assessment. *Hydrological Processes*, **19(3):** 763−783.

Krysanova, V., & Arnold, J. G. (2008). Advances in ecohydrological modeling with SWAT—a review. *Hydrological Sciences Journal*, **53(5):** 939−947.

Lelisa, S. and Kifle, W. (2006). Disaster prevention and preparedness, Jimma University, Jimma.

Lalitha, A.C., and Helen, M.S. (2015). Estimation of Surface Runoff Potential using SCS-CN Method Integrated with GIS, *Indian journal of science and technology*, **8(28).**

Ling, L., & Yusop, Z. (2014). A micro focus with macro impact: Exploration of initial abstraction coefficient ratio (λ) in Soil Conservation Curve Number (CN) methodology. In *IOP Conference Series: Earth and Environmental Science IOP Publishing* **18(1).**

Liu, B. M., Collick, A. S., Zeleke, G., Adgo, E., Easton, Z. M., & Steenhuis, T. S. (2008). Rainfall- discharge relationships for a monsoonal climate in the Ethiopian highlands. *Hydrological Processes*, **22(7):** 1059−1067.

Manish A. (2013), Introduction to Object Oriented Programming Concepts in C#, C# corner.

Menzel, L., & Kundzewicz, Z. W. (2003, September). Non-Structural Flood Protection-A Challenge. In *International Conference 'Towards National Flood Reduction Strategies', Warsaw* (pp. 6-13).

Minea, G., & Zaharia, L. (2011, June). Structural and Non-Structural Measures for Flood Risk Mitigation in the Bâsca River Catchment (Romania). In *Forum geographic* (Vol. 10, No. 1, p. 157). University of Craiova, Department of Geography.

Ministry of Water Resources Ethiopia (2006), Oda-Gunufeta- Cherecha-Dechatu Watershed in Dire Dawa administration and East *Harerge*zone-*Oromiya*, Integrated Watershed management, Term of Reference Draft.

Mioc, D., Nickerson, B., MacGillivray E., Morton, A., Anton, F., Fraser, D., Tang P., and Liang, G., (2008). Early warning and mapping for flood disasters, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **9(4):** 1507–1512.

Mishra, S. K., & Singh, V. P. (2004). Validity and extension of the SCS- CN method for computing infiltration and rainfall- excess rates. *Hydrological Processes*, **18(17):** 3323−3345.

Ognjen B. (2009). Accuracy of suspended sediment measurements in natural stream flows, *Journal of Hydraulic Research*, **19(3)**.

Ponce, V. M., & Hawkins, R. H. (1996). Runoff curve number: Has it reached maturity?. *Journal of hydrologic engineering*, **1(1):** 11−19.

Paul P.E. (2014). Basic Hydrology –Runoff Curve Numbers, Mercer County Soil Conservation District.

Rajendra S. (2013). Effectiveness of Early Warning System in Recent Flood Disasters in Nepal, Department of Hydrology and Meteorology.

Rediat, T. (2012). *Statistical Analysis of Rainfall pattern in Dire Dawa, Eastern Ethiopia*, M.Sc dissertation, Addis Ababa University, Addis Ababa.

Rogers, D., & Tsirkunov, V. (2011). Costs and benefits of early warning systems. *Global assessment report on disaster risk reduction. ISDR and World Bank*.

Rostamian, R., Jaleh, A., Afyuni, M., Mousavi, S. F., Heidarpour, M., Jalalian, A., & Abbaspour, K. C. (2008). Application of a SWAT model for estimating runoff and sediment in two mountainous basins in central Iran. *Hydrological Sciences Journal*, **53(5):** 977−988.

Schulze, R. E., Hutson, J. L., & Cass, A. (1985). Hydrological characteristics and properties of soils in Southern Africa 2: Soil water retention models. *Water SA*, **11(3):** 129−136.

Semu, A. (2007). Flood Forecasting and Early Warning System (FFEWS) an Alternative Technology for Flood Management System and Damage Reduction in Ethiopia: A Concept Note, Arba Minch University, School of Graduate Studies.

Setegn, S. G., Srinivasan, R., Dargahi, B., & Melesse, A. M. (2009). Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. *Hydrological Processes*, **23(26):** 3738−3750.

Setegn, S. G., Dargahi, B., Srinivasan, R., & Melesse, A. M. (2010a). Modeling of Sediment Yield From Anjeni- Gauged Watershed, Ethiopia Using SWAT Model. *JAWRA Journal of the American Water Resources Association*, **46(3):** 514−526.

Setegn, S. G., Srinivasan, R., Melesse, A. M., & Dargahi, B. (2010b). SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia. *Hydrological Processes*, **24(3):** 357−367.

Shadeed, S., & Almasri, M. (2010). Application of GIS-based SCS-CN method in West Bank catchments, Palestine. *Water Science and Engineering*, **3(1):** 1−13.

Soulis, K. X., & Valiantzas, J. D. (2012). SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds-the two-CN system approach. *Hydrology and Earth System Sciences*, **16(3):** 1001.

Stevan, B., (2002). A landmark workshop on non-structural measures for water managament problems, International Workshop on Non-structural Measures for Water Management Problems.

Stehr, A., Debels, P., Romero, F., & Alcayaga, H. (2008). Hydrological modelling with SWAT under conditions of limited data availability: evaluation of results from a Chilean case study. *Hydrological sciences journal*, **53(3):** 588−601.

Steenhuis, T. S., Collick, A. S., Easton, Z. M., Leggesse, E. S., Bayabil, H. K., White, E. D., Awulachew, S.B., Adgo, E., & Ahmed, A. A. (2009). Predicting discharge and sediment for the Abay (Blue Nile) with a simple model. *Hydrological processes*, **23(26):** 3728−3737.

Tilahun, S. A., Guzman, C. D., Zegeye, A. D., Dagnew, D. C., Collick, A. S., Yitaferu, B., & Steenhuis, T. S. (2015). Distributed discharge and sediment concentration predictions in the sub- humid Ethiopian highlands: the Debre Mawi watershed. *Hydrological Processes*, **29(7):** 1817−1828.

UNISDR. (2007). Terminology. Geneva: The United Nations Office for Disaster risk Reduction. http:// www.unisdr.org/we/inform/terminology, accessed on April 23, 2017.

UNISDR. (2014). Basic country statistics and indicators, nationally reported losses 1990 – 2014. http://www.preventionweb.net/countries/eth/data/, accessed on May 03, 2017.

UNISDR the United Nations office for disaster risk reduction (2005), Hyogo Framework for Action (HFA). https://www.unisdr.org/we/coordinate/hfa, accessed on March 1, 2017.

USDA-TR55 (2014). Curve Number (CN) tables, United States department of agriculture, Natural resource conservation service, conservation engineering division.

USDANRCS. (2004). United States Department of Agriculture-Natural Resource Conservation Service, Estimation of direct runoff from storm rainfall, national engineering handbook.

USDANRCS (2004). United States Department of Agriculture-Natural Resource Conservation Service, Hydrologic soil groups, national engineering handbook.

Viji, R., Rajesh, P. and Ilangovan, R., (2015). Gis Based SCS - CN Method For Estimating Runoff In Kundahpalam Watershed, Nilgries District, Tamilnadu, *Earth Sciences Research Journal*, **19(1).**

Williams, J. R., Kannan, N., Wang, X., Santhi, C., & Arnold, J. G. (2011). Evolution of the SCS runoff curve number method and its application to continuous runoff simulation. *Journal of Hydrologic Engineering*, **17(11):** 1221−1229.

Weih, R. C., & Riggan, N. D. (2010). Object-based classification vs. pixel-based classification: comparative importance of multi-resolution imagery. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **38(4).**

WWDSE. (2004). Water Works Design and Supervision Enterprise (2004). Dire Dawa Town Water supply project, Final design report, Addis Ababa.

Williams, J.R., (1995). The EPIC Model, Computer models of watershed hydrology, *water resources publication, Littleton, Colorado*, 909−1000.

Wang, D., Qin, L., Chang, B., Wang, M., & Zhang, W. (2015). Application of SCS-CN Model in Runoff Estimation.

White, E. D., Easton, Z. M., Fuka, D. R., Collick, A. S., Adgo, E., McCartney, M., Awulachew, Y.G., Selassie & Steenhuis, T. S. (2011). Development and application of a physically based landscape water balance in the SWAT model. *Hydrological Processes*, **25(6):** 915−925.

Wirth, N. (2004), Algorithms and Data Structures, *New York; Academic Press*, **12(10):** 1−82.

Yonas T. A. (2015). Flash Flood Hazard in Dire Dawa, Ethiopia, *Journal of Social Sciences and Humanities*, **1(4):** 400–414.

Young, R. A., Onstad, C. A., Bosch, D. D., & Anderson, W. P. (1987). *AGNPS, Agricultural Non-Point-Source Pollution Model: a watershed analysis tool. Research report* (No. pb-88-135876/xab; conservation/rr-35). Agricultural Research Service, Albany, CA (USA). Western Utilization Research and Development Division.

Yu, B. (2011). Validation of SCS method for runoff estimation. *Journal of Hydrologic Engineering*, **17(11):** 1158−1163.

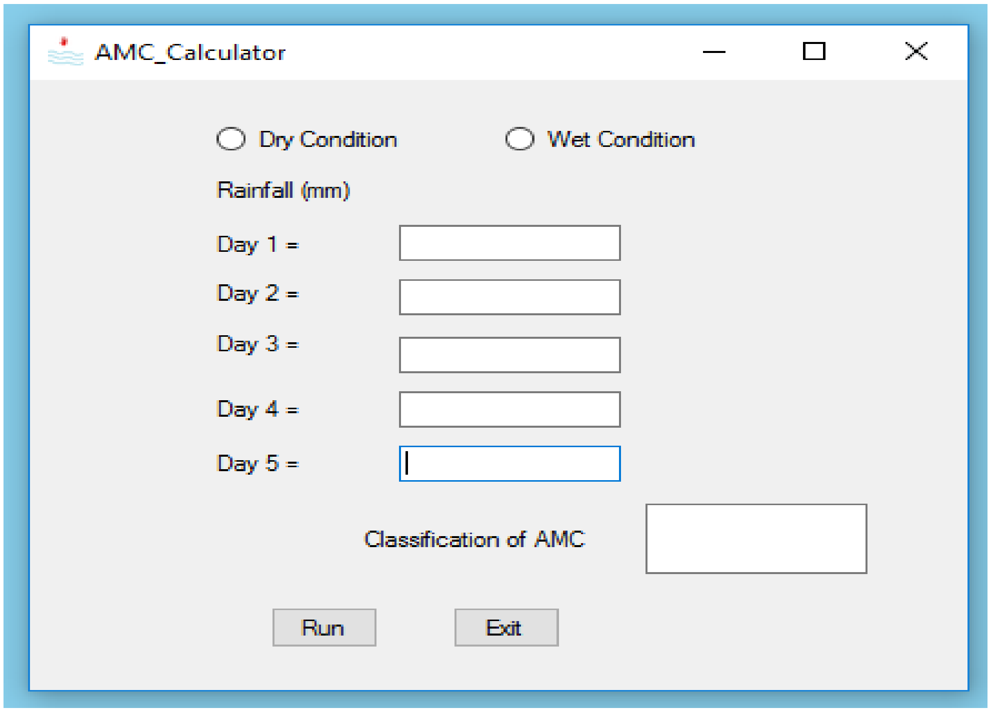
Zhan, X., & Huang, M. L. (2004). ArcCN-Runoff: an ArcGIS tool for generating curve number and runoff maps. *Environmental Modelling & Software*, **19(10):** 875−879.

Zhang, N., Huang, H., Su, B., Zhao, J., & Zhang, B. (2014). Information dissemination analysis of different media towards the application for disaster pre-warning. *PloS one*, **9(5).**

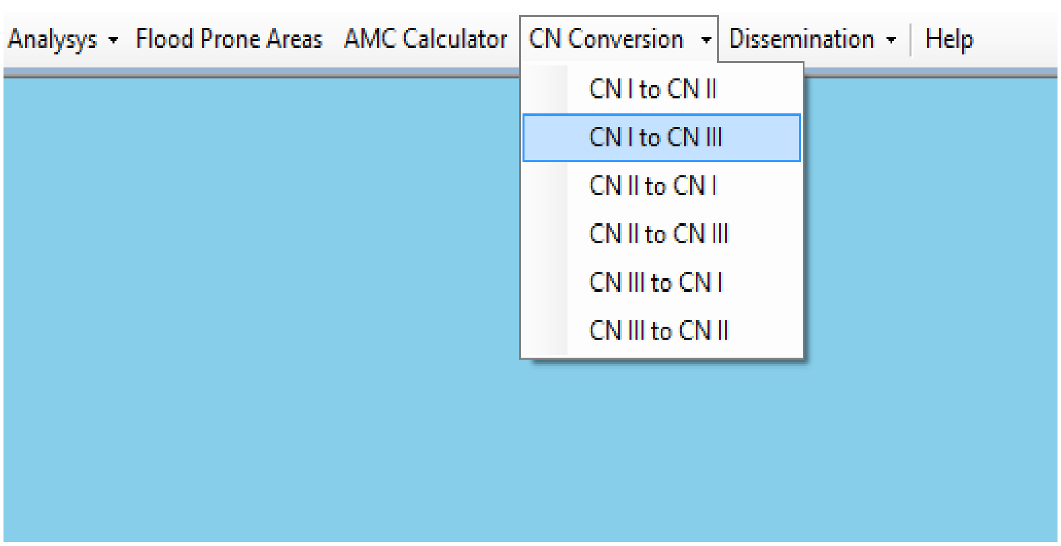
Appendices

Annex A: Application windows

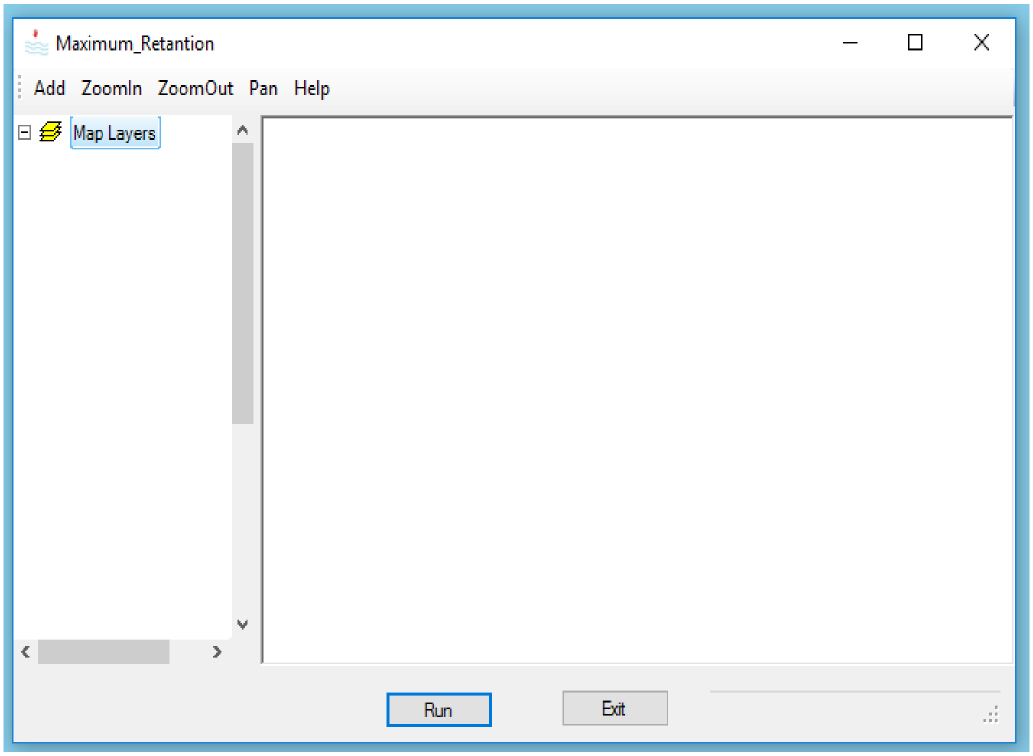
A.1: AMC calculator window



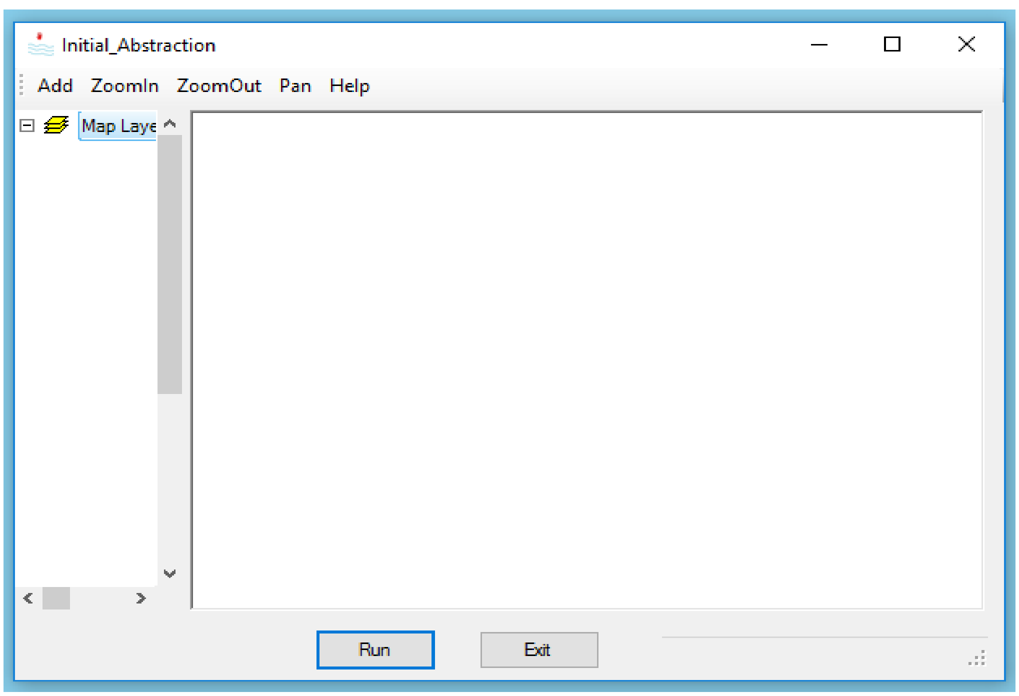
A.2: CN conversion window



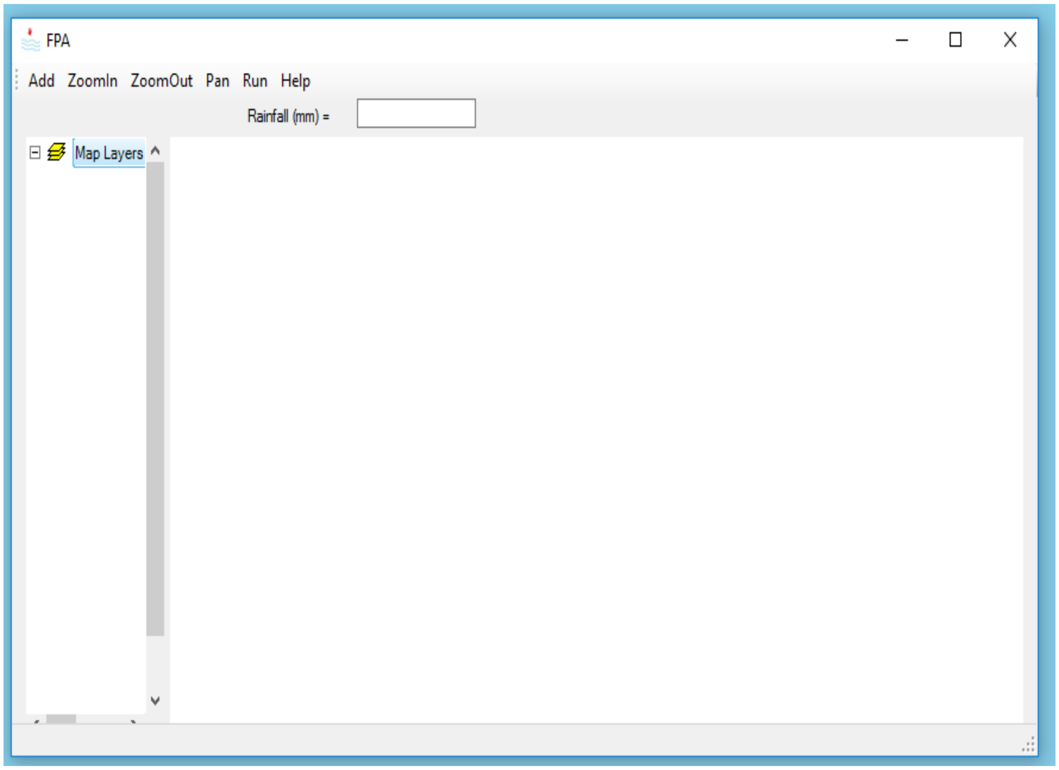
A.3: Maximum retention window



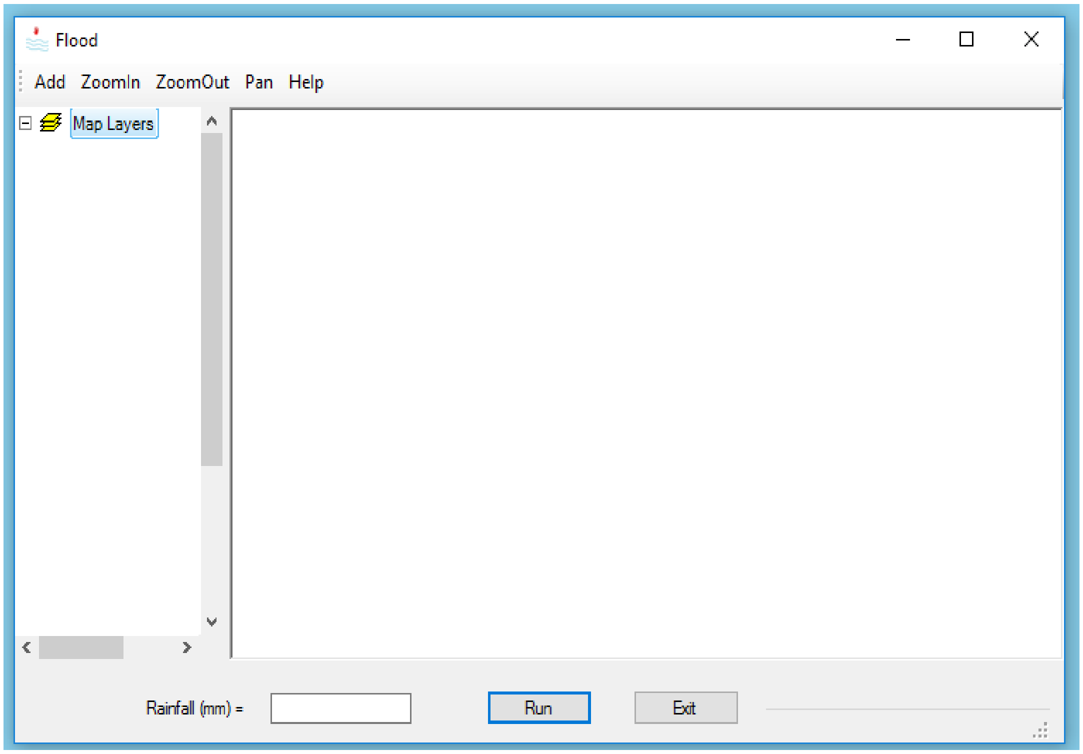
A.4: Initial abstraction window



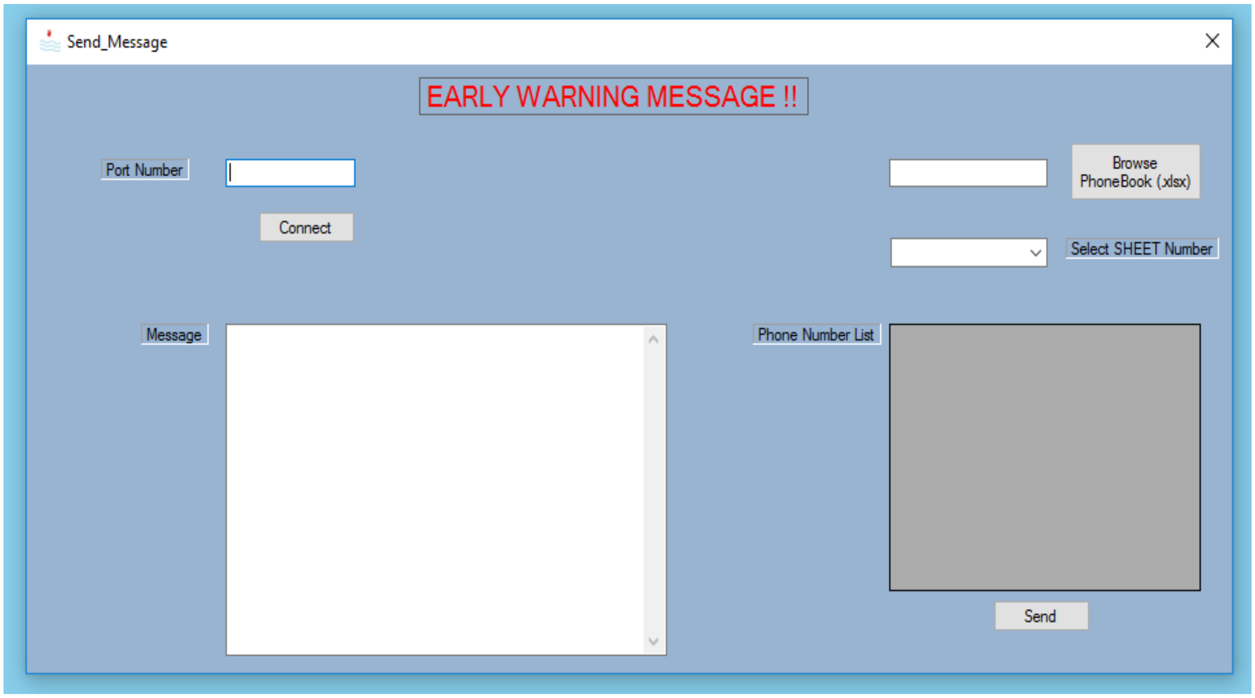
A.5: Flood prone areas analysis window



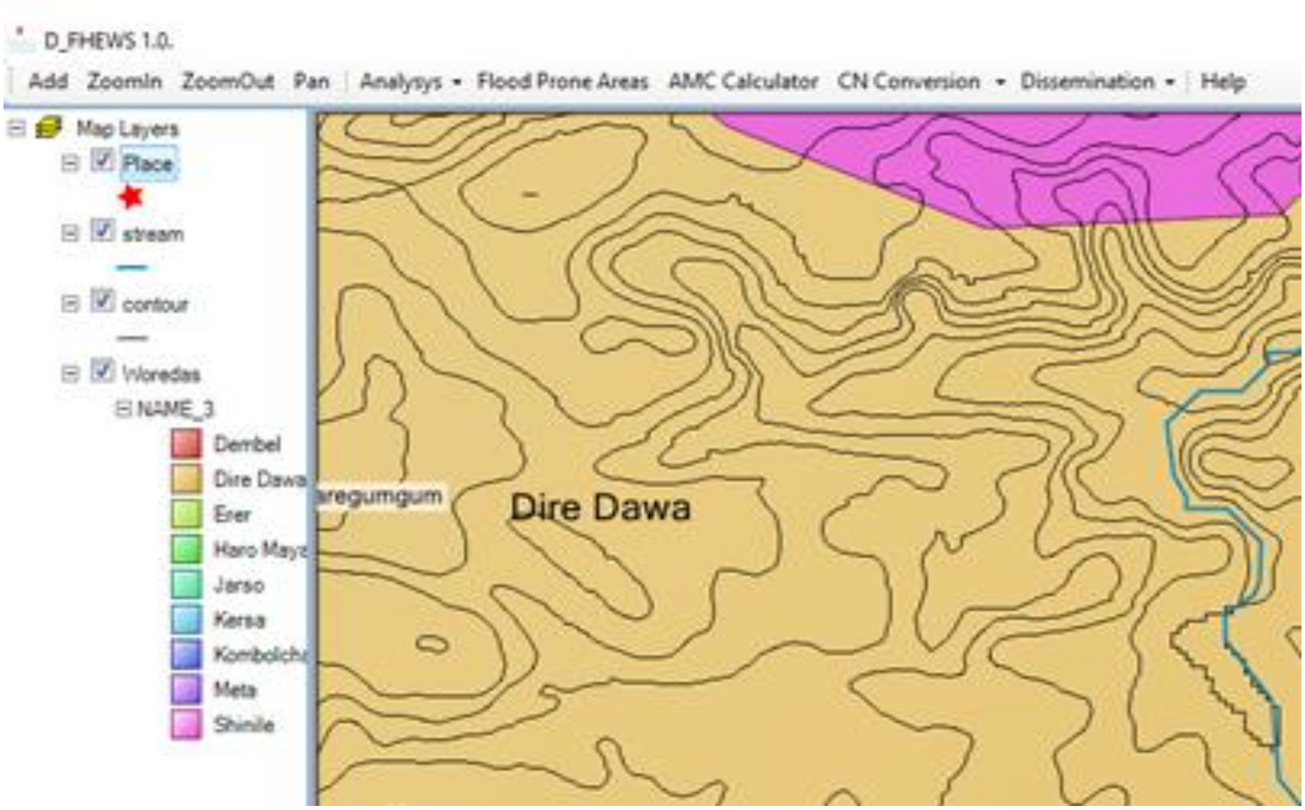
A.6: Flood analysis window



A.7: Information dissemination window

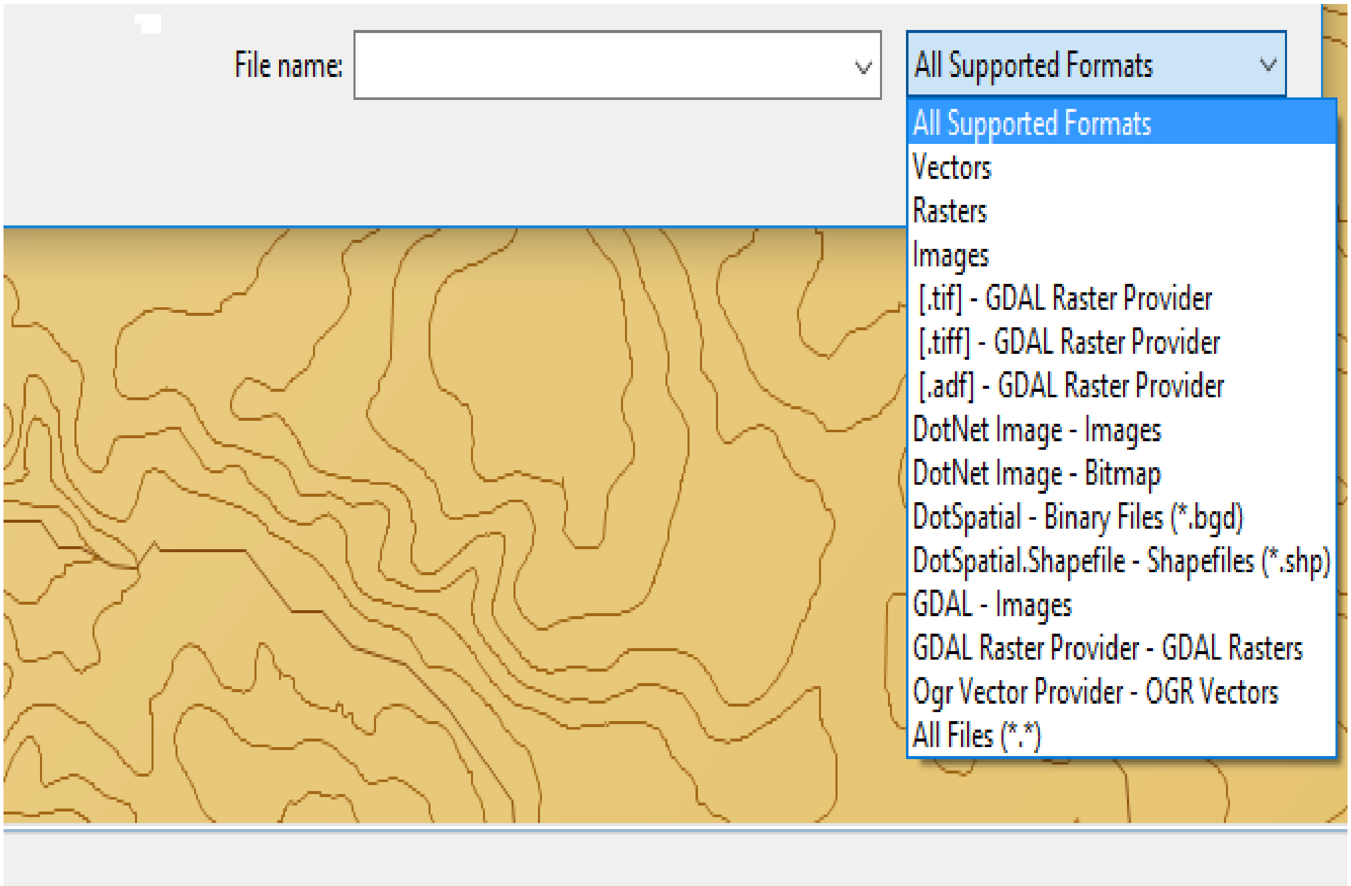


A.8: Home window



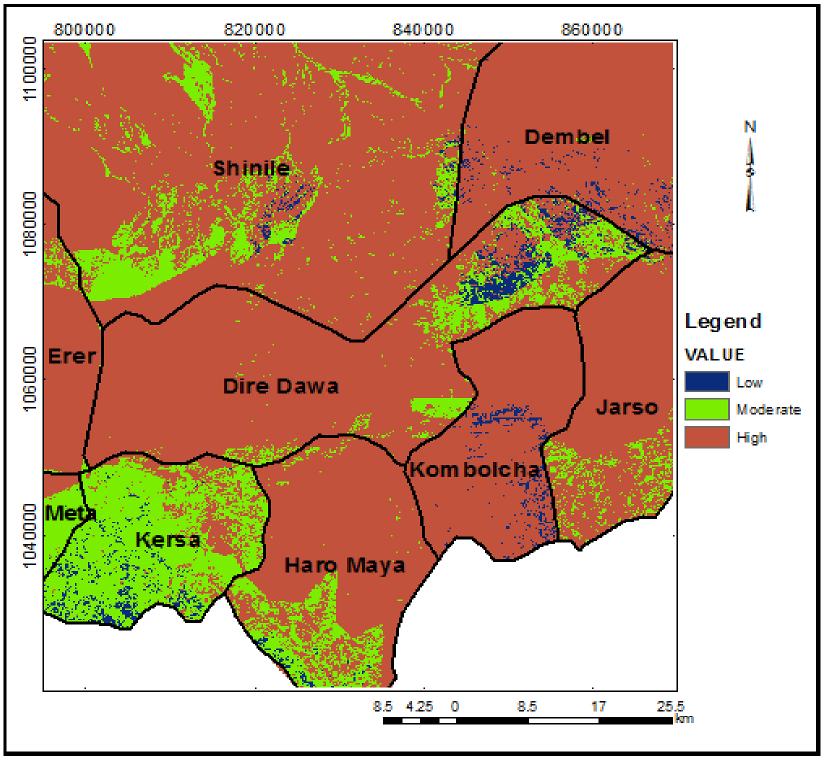
Annnex B

B.1 GDAL data formats supported by the system

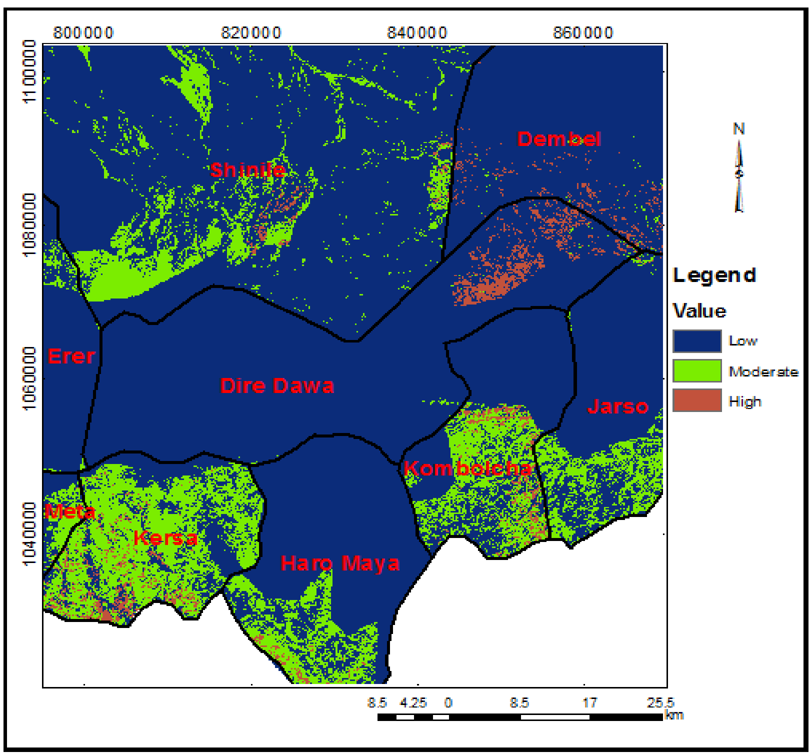


Annex C

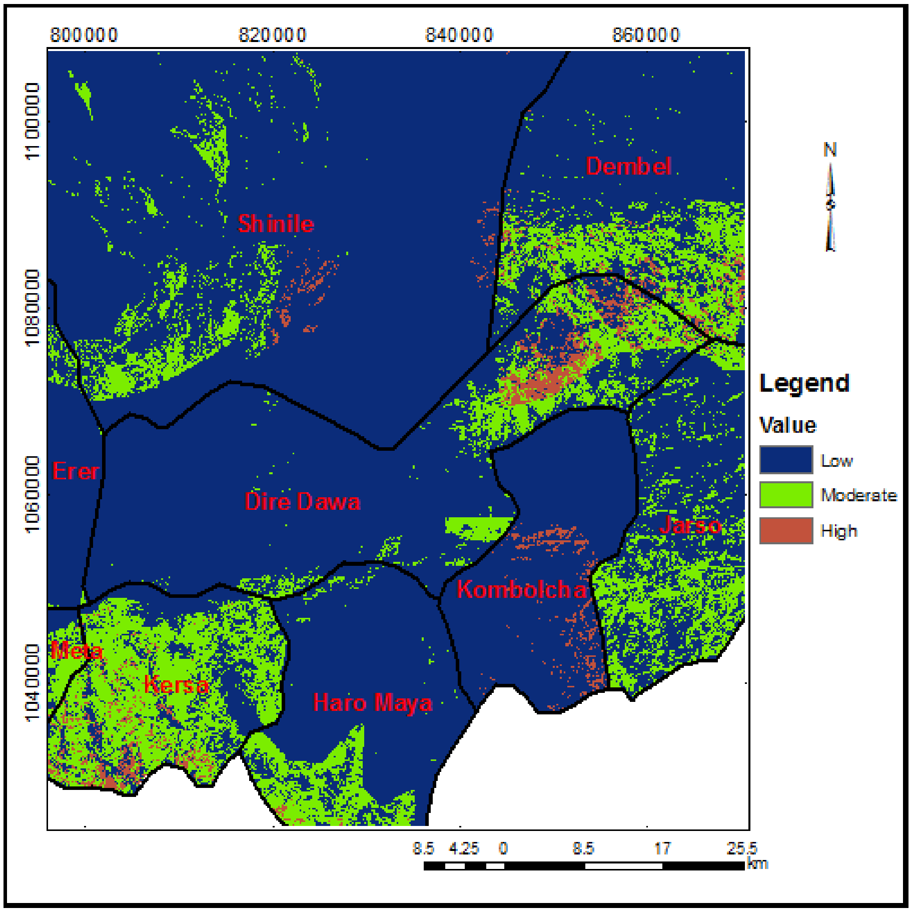
C.1 Curve Number map of Dire Dawa town and surrounding, 2005



C.2 Maximum retention map of Dire Dawa town and surrounding, 2005



C.3 Initial abstraction map of Dire Dawa town and surrounding, 2005



Annex D

D.1: Confusion matrix for the classification of 2005

		Reference data								
		CL	SL	GL	WL	S	BL	WoL	Total	User accuracy (%)
%Classification data	CL	19	1	1	2	0	1	0	24	82.6
	SL	0	17	0	0	0	0	0	17	100
	GL	0	0	18	1	1	0	0	20	90
	WL	1	0	0	16	0	1	0	18	90.9
	S	0	0	0	0	19	1	0	20	95
	BL	0	0	0	0	0	18	0	18	100
	WOL	0	1	0	0	0	0	19	20	95
	Total	20	19	19	19	20	21	19	137	
Producer accuracy (%)		95	89.4	94.73	84.2	95	85.71	100		

D.2: Confusion matrix for the classification of 2015

		Reference data								
		CL	SL	GL	WL	S	BL	WoL	Total	User accuracy (%)
Classification data	CL	18	0	0	0	0	0	0	18	100
	SL	0	21	2	0	0	0	0	23	91.3
	GL	1	0	16	0	0	1	0	18	88.88
	WL	0	1	0	20	0	0	0	21	95.23
	S	0	0	1	0	19	1	0	21	90.47
	BL	0	0	0	0	0	20	0	20	100
	WOL	0	1	0	0	0	0	17	18	94.44
	Total	19	23	19	20	19	22	17	139	
Producer accuracy (%)		94.73	91.3	84.2	100	100	90.9	100		

NB.

CL = Cultivated land

SL = Shrub land

GL = Grassland

WL = Wetland

S = Settlement

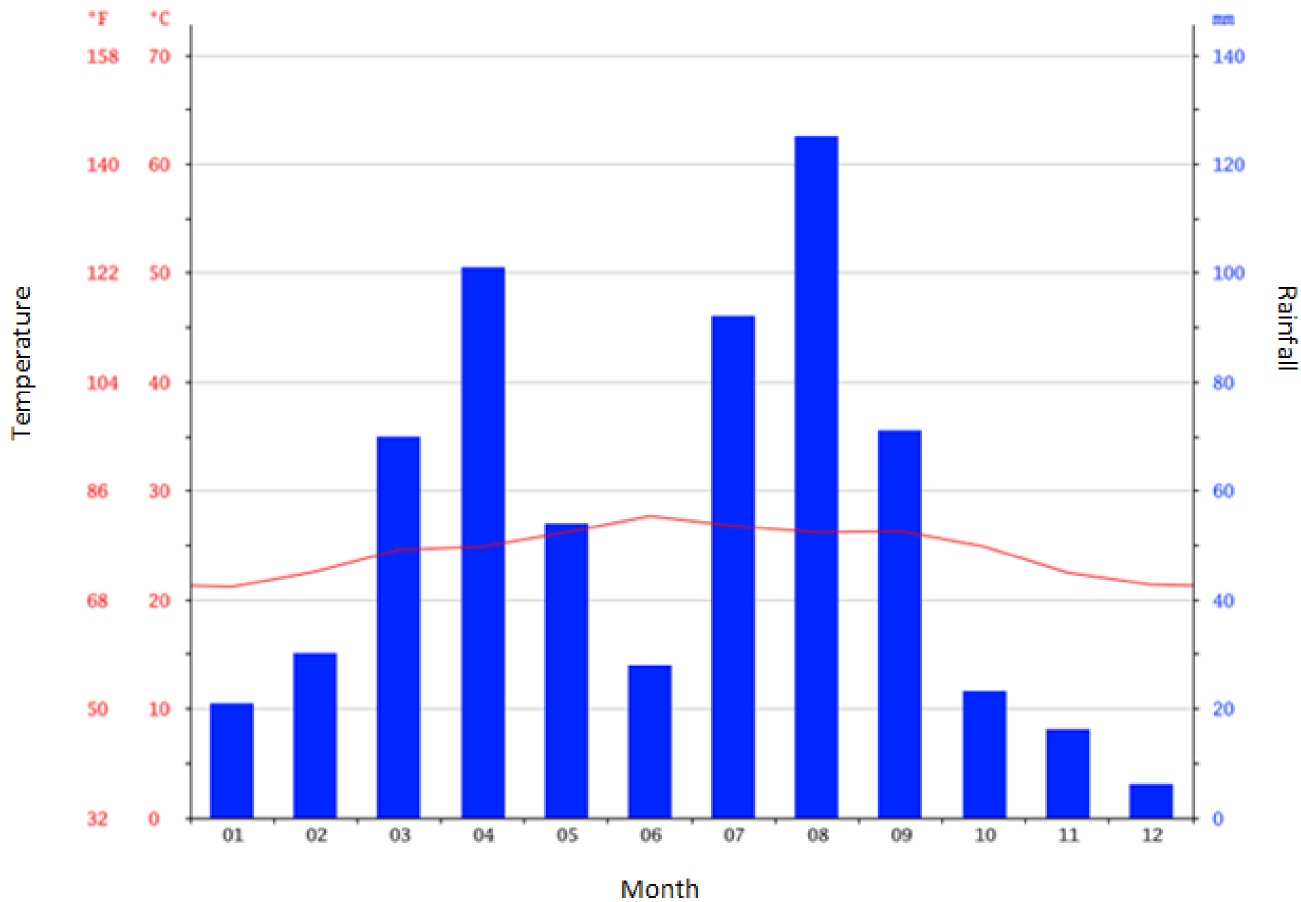
BL = Bare land

D.3: Summary of overall classification accuracy and kappa coefficient

Year	Overall classification accuracy (%)	Overall kappa coefficient
2005	91.97	0.9
2015	94.24	0.94

Annex E

E.1: Climate graph of Dire Dawa



Source: (en.climate-data.org/location/3658/)

Annex F

F.1: C# Rule

```
//AMC Calculator
if (DryCondtion.Checked)
{
int g = a + b + c + d + f;
if (g < 13)
{
textBox6.Text = "It is AMC I, the result is" + g;
}
if (g >= 13 && g <= 28)
{
textBox6.Text = "It is AMC II, the result is" + g;
}
if (g > 28)
{
textBox6.Text = "It is AMC III, the result is" + g;
}
}
if (WetCondition.Checked)
{
int h = a + b + c + d + f;
if (h < 36)
{
textBox6.Text = "It is AMC I, the result is" + h;
}
if (h >= 36 && h <= 53)
{
textBox6.Text = "It is AMC II, the result is" + h;
}
if (h > 53)
{
textBox6.Text = "It is AMC III, the result is" + h;
}
}
}
//CN Conversion
MessageBox.Show("Are you sure the data on the map window is CNI");
if (map1.Layers.Count > 0)
{
IMapRasterLayer layer = map1.Layers[0] as IMapRasterLayer;
if (layer == null)
{
```

```
MessageBox.Show("Please select a raster layer");
}
string[] rasterOptions = new string[1];
IRaster newRaster = Raster.CreateRaster("CNII.bgd", null, CNI.NumColumns, CNI.NumRows,
1, CNI.DataType, rasterOptions);
newRaster.Bounds = CNI.Bounds.Copy();
newRaster.NoDataValue = CNI.NoDataValue;
newRaster.Projection = CNI.Projection;
for (int i = 0; i <= CNI.NumRows - 1; i++)
{
for (int j = 0; j <= CNI.NumColumns - 1; j++)
{
if (CNI.Value[i, j] != CNI.NoDataValue)
{
newRaster.Value[i, j] = (10 * CNI.Value[i, j]) / ((0.058 * CNI.Value[i, j])+4.2);
}
}
}
//Maximum retention
if (map1.Layers.Count > 0)
{
IMapRasterLayer layer = map1.Layers[0] as IMapRasterLayer;
if (layer == null)
{
MessageBox.Show("Please select a raster layer");
}
string[] rasterOptions = new string[1];
IRaster newRaster = Raster.CreateRaster("Maximum Retantion.bgd", null, cn.NumColumns,
cn.NumRows, 1, cn.DataType, rasterOptions);
newRaster.Bounds = cn.Bounds.Copy();
newRaster.NoDataValue = cn.NoDataValue;
newRaster.Projection = cn.Projection;
for (int i = 0; i <= cn.NumRows - 1; i++)
{
for (int j = 0; j <= cn.NumColumns - 1; j++)
{
if (cn.Value[i, j] != cn.NoDataValue)
{
newRaster.Value[i, j] = (25400 / cn.Value[i, j]) - 254;
}
```

```
}
}
//Initial abstraction
if (map1.Layers.Count > 0)
{
IMapRasterLayer layer = map1.Layers[0] as IMapRasterLayer;
if (layer == null)
{
MessageBox.Show("Please select a raster layer");
}
string[] rasterOptions = new string[1];
IRaster newRaster = Raster.CreateRaster("Intial Abstraction.bgd", null, maxrt.NumColumns,
newRaster.Bounds = maxrt.Bounds.Copy();
newRaster.NoDataValue = maxrt.NoDataValue;
newRaster.Projection = maxrt.Projection;
for (int i = 0; i <= maxrt.NumRows - 1; i++)
if (maxrt.Value[i, j] != maxrt.NoDataValue)
{
newRaster.Value[i, j] = (0.2 * maxrt.Value[i, j]);
}
}
}
//Flood prone area analysis
if (map1.Layers.Count > 0)
{
IMapRasterLayer layer = map1.Layers[0] as IMapRasterLayer;
int a = Convert.ToInt32(textBox1.Text);
if (layer == null)
{
MessageBox.Show("Please select a raster layer");
}
string[] rasterOptions = new string[1];
IRaster newRaster = Raster.CreateRaster("Surface Runoff.bgd", null, maxrt.NumColumns,
maxrt.NumRows, 1, maxrt.DataType, rasterOptions);
newRaster.Bounds = maxrt.Bounds.Copy();
newRaster.NoDataValue = maxrt.NoDataValue;
newRaster.Projection = maxrt.Projection;
for (int i = 0; i <= maxrt.NumRows - 1; i++)
{
for (int j = 0; j <= maxrt.NumColumns - 1; j++)
```

```
{
if (a > maxrt.Value[i, j])
{
newRaster.Value[i, j] = maxrt.Value[i, j];
}
if (a <= maxrt.Value[i, j])
{
newRaster.Value[i, j] = 0;
}
}
}
//Flood analysis
if (map1.Layers.Count > 0)
{
IMapRasterLayer layer = map1.Layers[0] as IMapRasterLayer;
int a = Convert.ToInt32(textBox1.Text);
if (layer == null)
{
MessageBox.Show("Please select a raster layer");
}
IRaster newRaster = Raster.CreateRaster("Surface Runoff.bgd", null, maxrt.NumColumns,
newRaster.Bounds = maxrt.Bounds.Copy();
newRaster.NoDataValue = maxrt.NoDataValue;
newRaster.Projection = maxrt.Projection;
if (a != 0)
for (int i = 0; i <= maxrt.NumRows - 1; i++)
{
for (int j = 0; j <= maxrt.NumColumns - 1; j++)
{
if (maxrt.Value[i, j] != maxrt.NoDataValue)
{
newRaster.Value[i, j] = (Math.Pow(a - maxrt.Value[i, j] * 0.2, 2)) / (a + (0.8 * maxrt.Value[i,
j]));
}
}
}
//Messaging
if (ComPort.Text == "")
{
MessageBox.Show("invalid port number");
return;
}
```

```
int b = Convert.ToInt32(ComPort.Text);
comm = new GsmCommMain(b, 9600, 150);
Cursor.Current = Cursors.Default;
bool retry;
do
{
retry = false;
try
{
Cursor.Current = Cursors.WaitCursor;
Cursor.Current = Cursors.Default;
MessageBox.Show("connected successfully");
}
catch (Exception)
{
Cursor.Current = Cursors.Default;
if (MessageBox.Show(this, " GSM not available", "Check", MessageBoxButtons.RetryCancel,
MessageBoxIcon.Warning) == DialogResult.Retry)
retry = true;
else
{
return;
}
}
}
while (retry);
}
OpenFileDialog openDialog = new OpenFileDialog();
openDialog.Filter = "Excel|*.xlsx";
if (openDialog.ShowDialog() == DialogResult.OK)
{
excelFileTextBox.Text = openDialog.FileName;
string sourceConnectionString = String.Format(@"Provider=Microsoft.ACE.OLEDB.12.0;Data
Source={0};Extended Properties='Excel 12.0 Xml;HDR=YES'", excelFileTextBox.Text);
DataTable tables = connection.GetSchema("Tables", new String[] { null, null, null, "TABLE" });
if (tables != null && tables.Rows.Count > 0)
{
worksheetsComboBox.Items.Clear();
foreach (DataRow row in tables.Rows)
{
```

```
worksheetsComboBox.Items.Add(row["TABLE_NAME"].ToString());
}
}
}
}
string numberr;
for (int j = 0; j < excelDataGridView.RowCount - 1; j++)
{
try
{
SmsSubmitPdu pdu3;
numberr = excelDataGridView.Rows[j].Cells[0].Value.ToString();
byte dcs = (byte)DataCodingScheme.GeneralCoding.Alpha7BitDefault;
int time = 1;
for (int i = 0; i < time; i++)
{
comm.SendMessage(pdu3);
}
}
catch
{
MessageBox.Show("modem is not available");
}
}
}
```

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 materials used for the thesis have been duly acknowledged.

Mezgebedingil Abebe Gezahegn

Signature _________________________ Date________________________

School of Earth Science

June, 2017

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

Dr. K. V. Suryabhagavan

Signature _______________________ Date_________________________