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Developing Flood Hazard Forecasting and Early Warning System in Dire Dawa, Ethiopia

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Keywords

Floods,
natural disasters,
hazard destruction,
SCS-CN method.

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. 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.

1. Introduction

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 people 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].

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]. 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, to Dire Dawa town (Fig. 1).

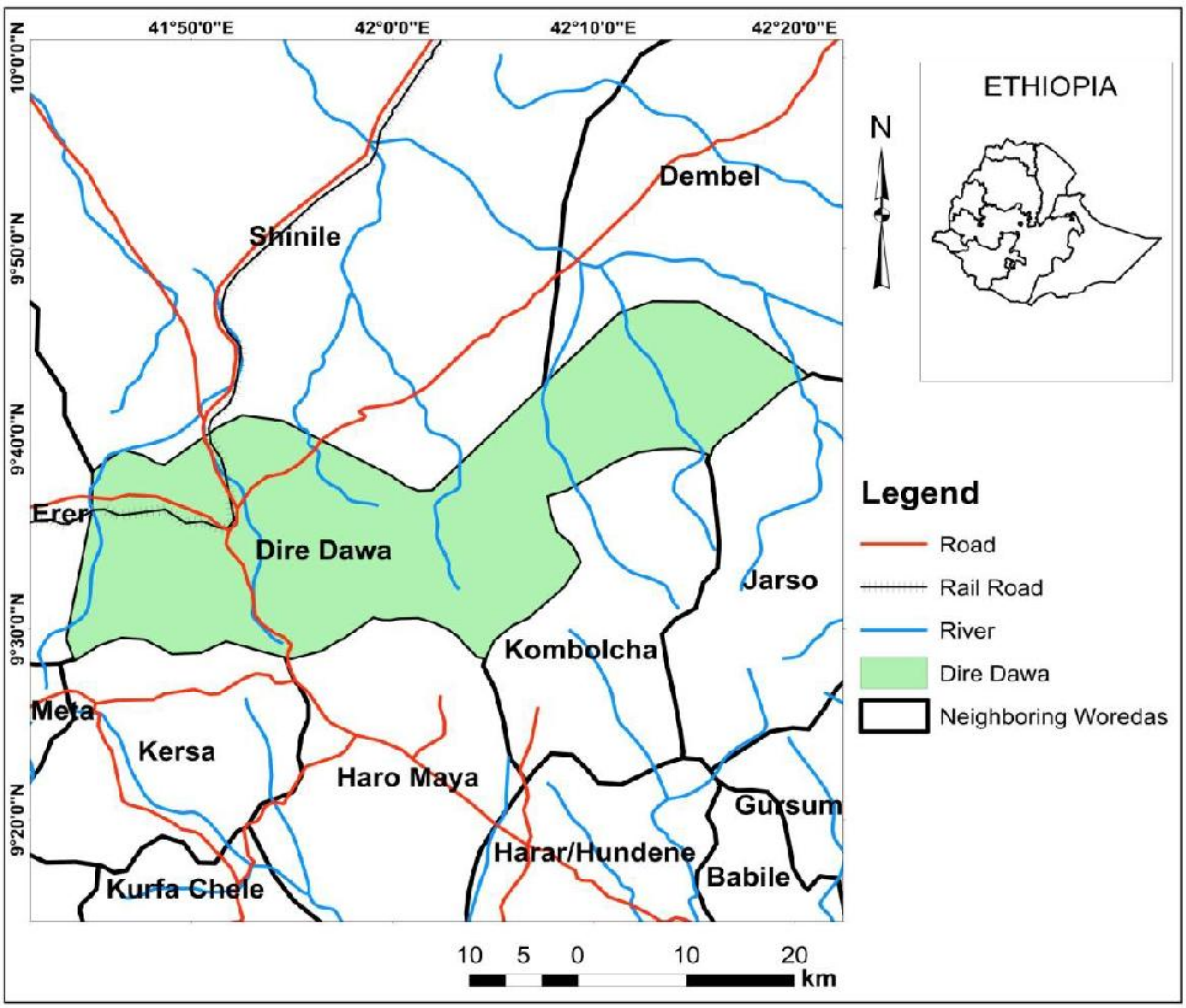

Figure 1: Location map of the study area

Dire Dawa is one of the two chartered cities in Ethiopia (the other being the capital, Addis Ababa). It is found at a road distance of 515 km from Addis Ababa, covering a total area of 1,288 km2.

Many of previous researches in Ethiopia focus only on flood hazard risk assessment. The main objective of this study is on developing flood hazard forecasting and early warning system in Dire Dawa based on Soil Conservation Service Curve Number (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 Curve Number (CN) method has since been adapted for urbanized and forested areas [Cronshey, 1986].

2. 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.

3. Data used

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 (LU/LC). The LU/LC 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 (INSA) 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 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), lambda (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 town administrative council.

4. Method

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.2).

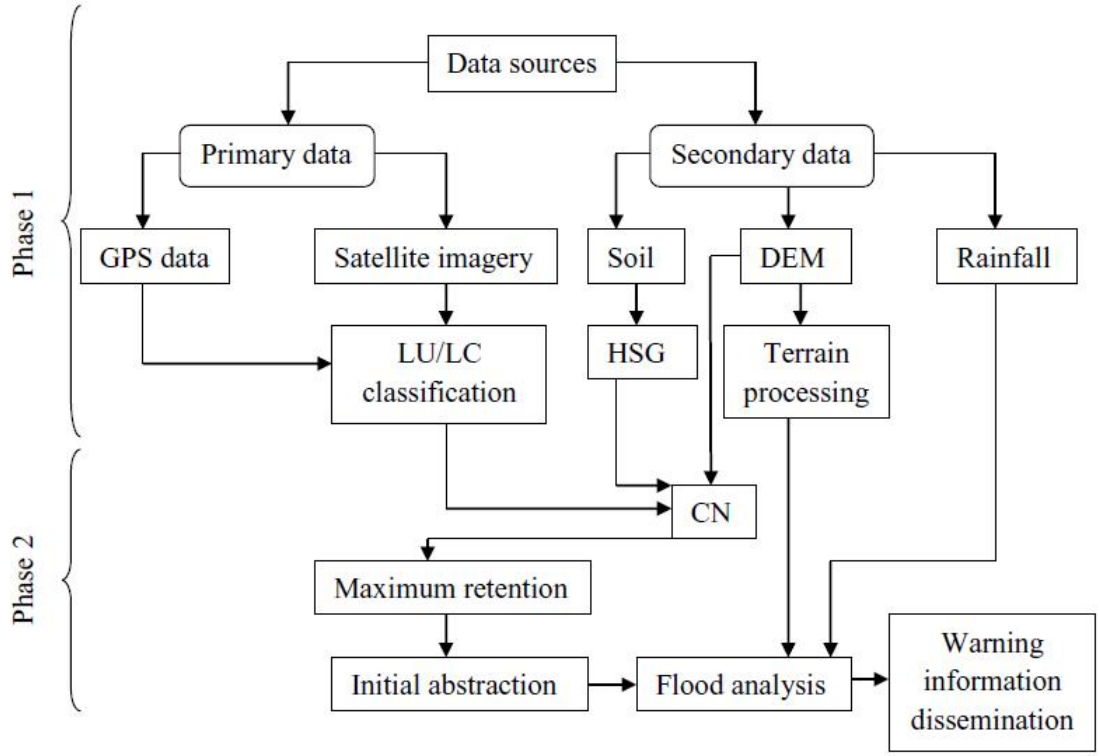

Figure 2: Flow chart of the methodology.

4.1 Phase 1: Method identification and data organization

4.1.1 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 type and characteristics of the flood and cost implications are considered in

4.1.2 Data collection

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 method is relatively easy to use and yield satisfactory results [Schulze et al., 1985]. SCS-CN method is one of the most popular methods for computing surface runoff for a given rainfall event. The major factors to select the method are its simplicity and reliability, required data, applicability, warning information dissemination and availability.

Vector and raster data were collected from different primary and secondary sources as shown in Table 1.

Table 1: Description of GIS data layers used in the study.

No.	Data type	Description	Data source
1	Vector (Polygon)	Administrative boundary	Central statistics authority
2	Vector (Point)	GPS point data of different LU/LC types for verification	GPS
3	Raster	LU/LC 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

4.1.3 Input datasets

One of the input datasets is Dire Dawa town and surrounding gazetteer. Gazetteer is a work of geographic reference that supplies place name and location information. In this system, it uses to identify and notify flood prone areas using their place name. The other is drainage; it was generated from 15 m × 15 m DEM using the output from the flow accumulation. Mostly, areas along the drainage side are susceptible to flood hazard. Contour line was also generated from 15m × 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. LU/LC of the area, i.e. the other input dataset, was classified in to seven classes for the years 2005 and 2015, based on United States Department of Agriculture (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 2). The 2015 LU/LC map was produced and validated based on field data with over all accuracy of 94.24% (Fig. 3) and the 2005 was validated based on reference data from Google earth with accuracy of 91.97%.

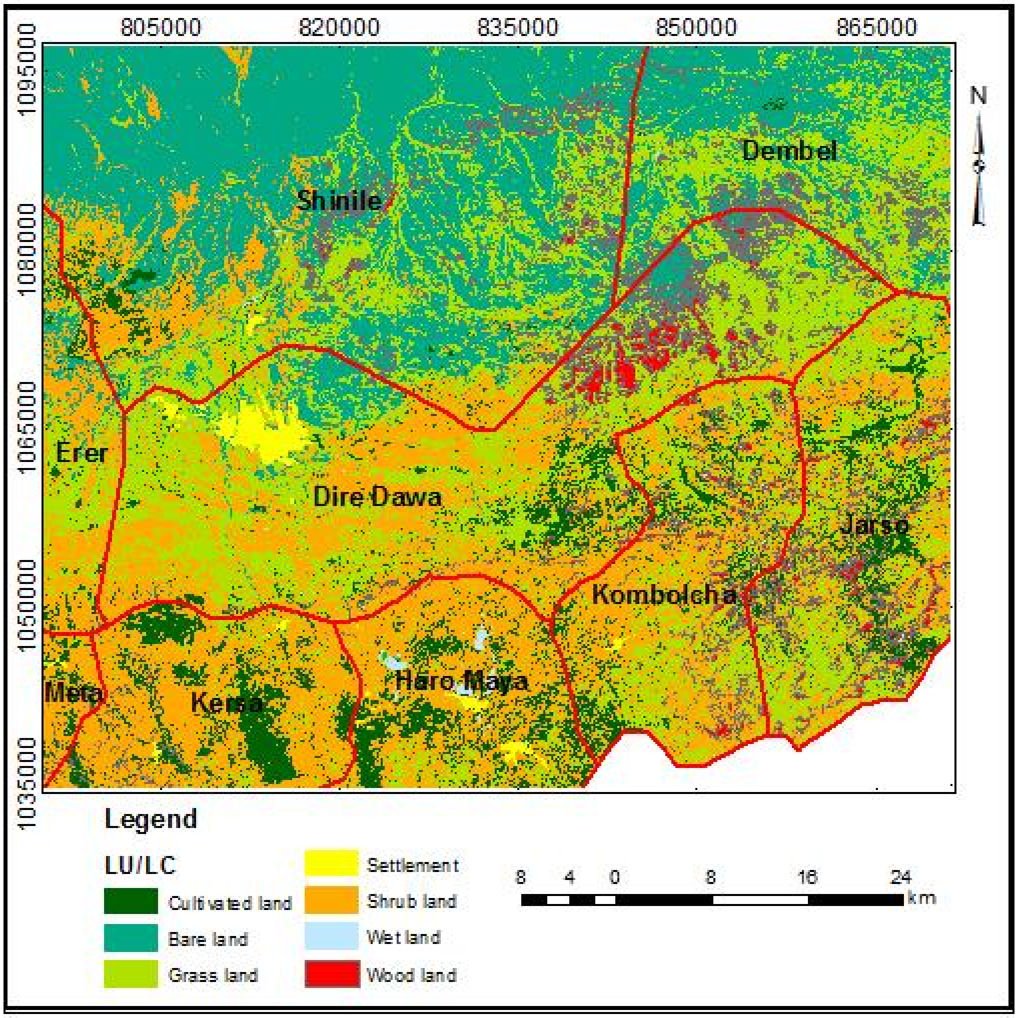

Figure 3: Land-use/land-cover map of Dire Dawa and surrounding, 2015.

Table 2: Classification and CN value of LU/LC of Dire Dawa and surrounding in different HSG.

Data set	Classification	CN in Hydrologic Soil Group (HSG)			
Land use/Land cover		A	B	C	D
	Wood land	30	58	71	78
	Grass land	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

Soil data was classified into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential (Table 3). 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. 4).

Table 3: Hydrologic Soil Group based on USDA soil classification

Soil texture	Hydrologic Soil Group (HSG)
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

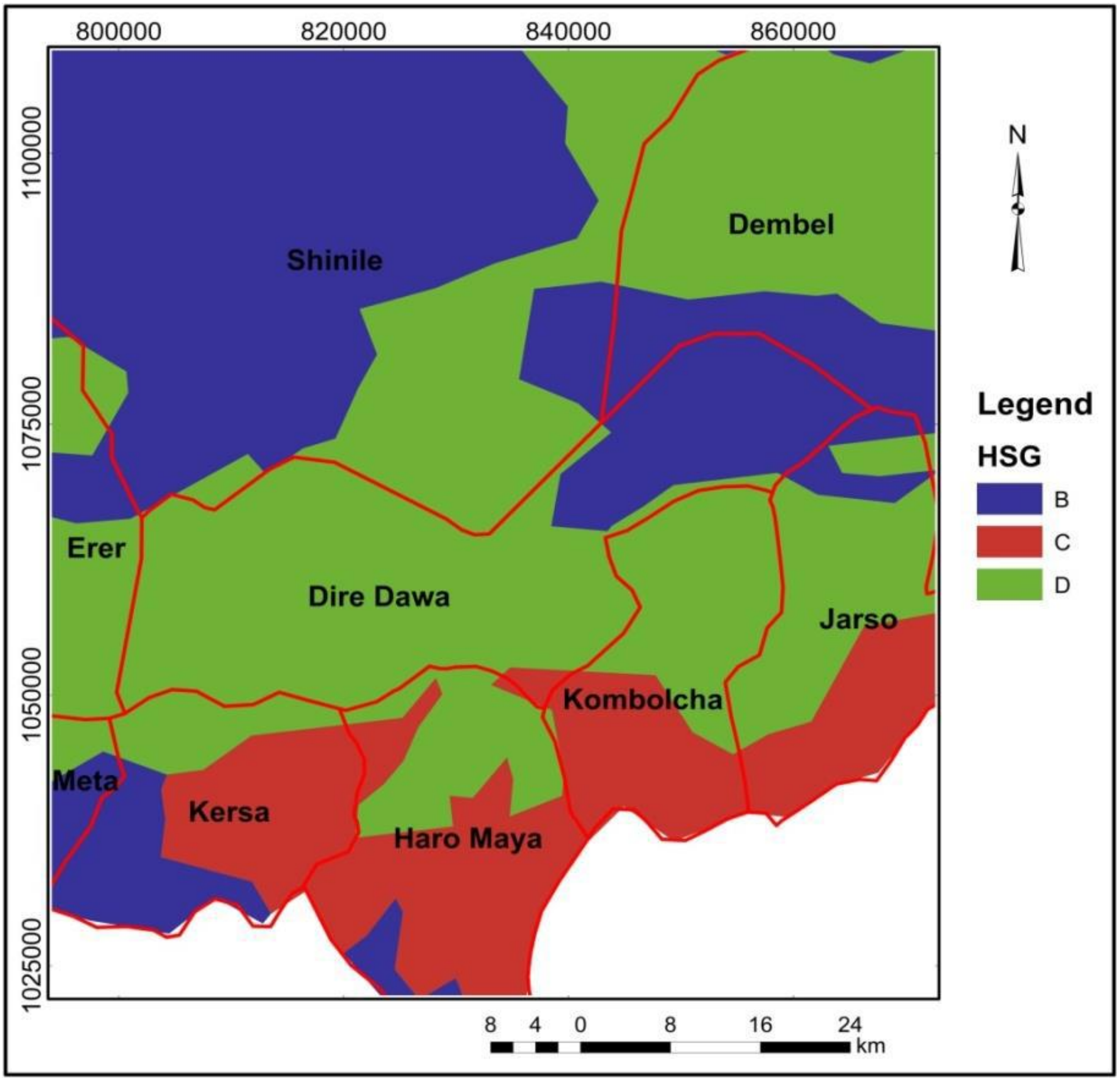

Figure 4: Hydrologic Soil Group (HSG) map of Dire Dawa and surrounding.

The amount of rainfall within the study area and its surrounding woredas; Kersa, Alemaya, and Meta, during the first week of August 2006 is described in Table 4. 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 Antecedent Moisture Content (AMC) of the area to test the system.

Table 4: Rainfall data.

Data (August, 2006)	Rainfall (mm)			
	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

Finally DEM (Digital Elevation Model) is the other input dataset. 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. 5) 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 [Eleni, 2011].

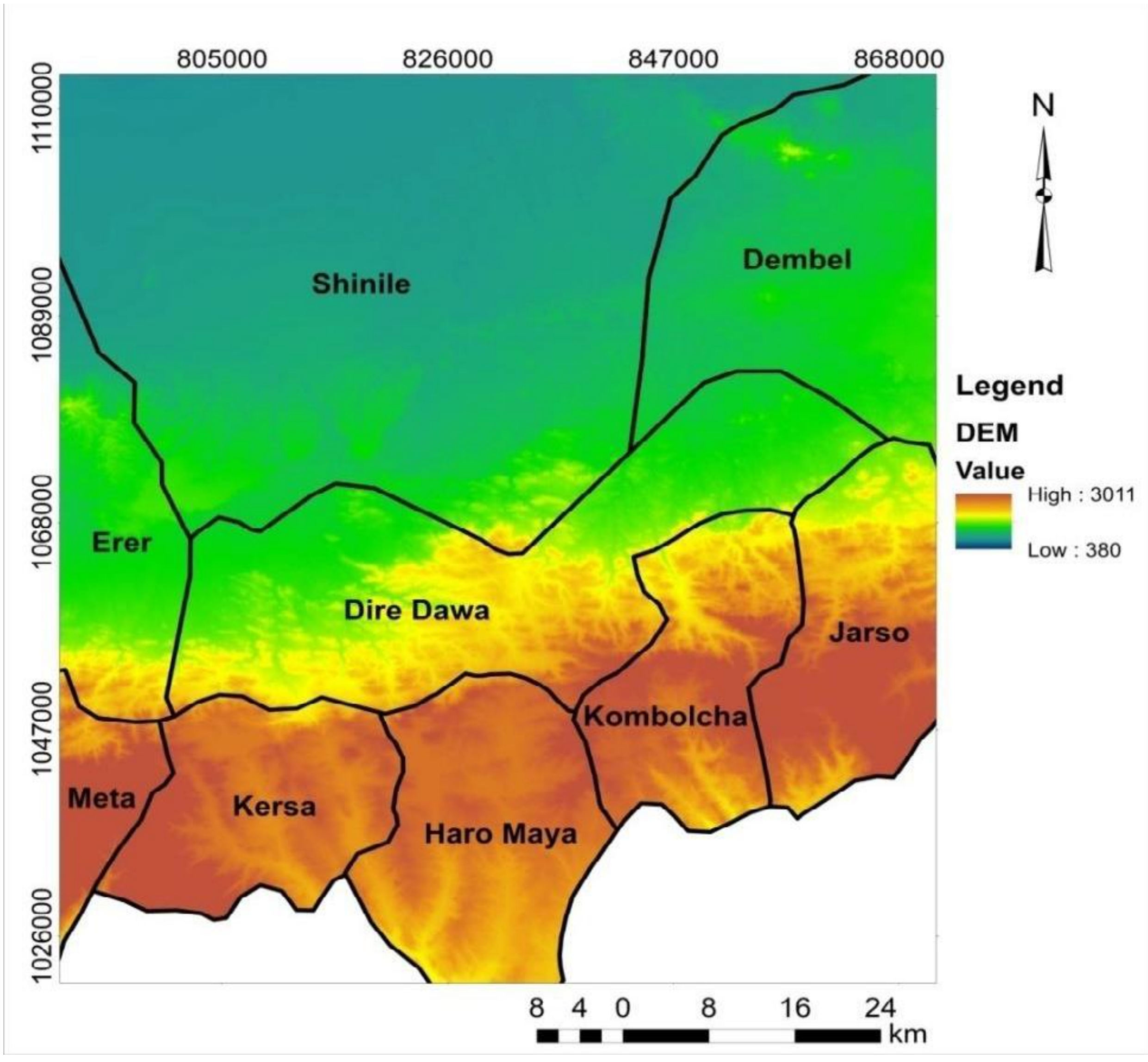

Figure 5: Digital Elevation Model (DEM) of Dire Dawa and surrounding.

4.2 Phase 2: Flood hazard forecasting and early warning system development 4.2.1 SCS-CN method

4.2.2 Curve Number (CN)

The basis of the SCS-CN 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. 1). Victor Mockus found Equation 1 appropriate to describe the curves of the field measured runoff and rainfall values [USDA-NRCS, 2004].

$FS=QP$ …………………………… Eq. 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

Curve Number (CN) is essential coefficient to reduce the total rainfall to runoff potential. 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). In this study, the classification of CN is customized based on the HSG and elevation characteristics of the study area.

Table 5: CN classification

CN Range	Runoff Potential
60 – 67	Low
67 – 76	Moderate
76 – 100	High

Curve Numbers for different LU/LC 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 6).

Table 6: Classification of AMC

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

4.2.3 Application development

Among the input datasets, LU/LC of 2005, soil data, DEM and rainfall data from August 1, 2006 – August 6, 2006 of Dire Dawa and surrounding woredas were used for CN value calculation of the year 2005, this value was again calculated using the 2015 LU/LC, 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 4 rainfall data, during the flood hazard time the antecedent moisture content of Dire Dawa was 51 mm that lays in AMC II. Kersa, Alemaya and Meta had 174 mm, 162 mm and 132 mm of AMC, respectively and classified under AMC III. To convert CN values from AMC II to AMC III, an application that integrated within the system were used i.e. CN conversion.

The system was developed using C# object oriented programming language in visual studio integrated development environment. It has 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.

i. 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. 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 groups AMC I, AMC II and AMC III are determined based on previous five-day rainfall amount of the area.

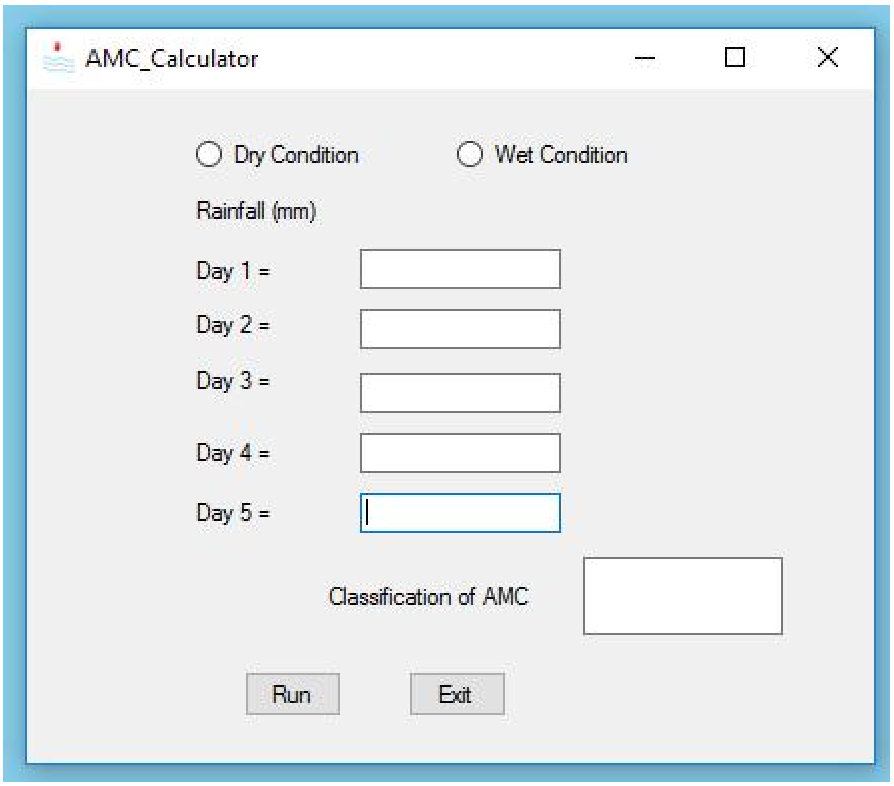

Figure 6: AMC calculator user interface.

ii. 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. This application window can convert CN I, CN II and CN III from one to another.

iii. Maximum retention analysis

Maximum retention is determined by 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. When CN becomes 100 (i.e. the maximum value) maximum retention becomes zero, that means there is no retention.

iv. Initial abstraction analysis

This application was used to generate initial abstraction map of the area. 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.

v. Flood prone areas analysis

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

$$\left.\begin{array}{ll} \text{If} & P > Ia, Q = \frac{(P-0.2S)^2}{P-0.8S} \\ \text{If} & P \leq Ia, Q - 0 \end{array}\right\} \text{.................................... Eq. 2}$$

Where: P − Precipitation

Ia = Initial abstraction
S = Maximum retention

The flood prone areas analysis application determines areas with the probability of flood. Areas with the probability of flood will have the value of "one" and areas without this dread get "zero" value.

vi. Flood analysis

The system uses a single rainfall event as the main parameter to forecast flood hazard.

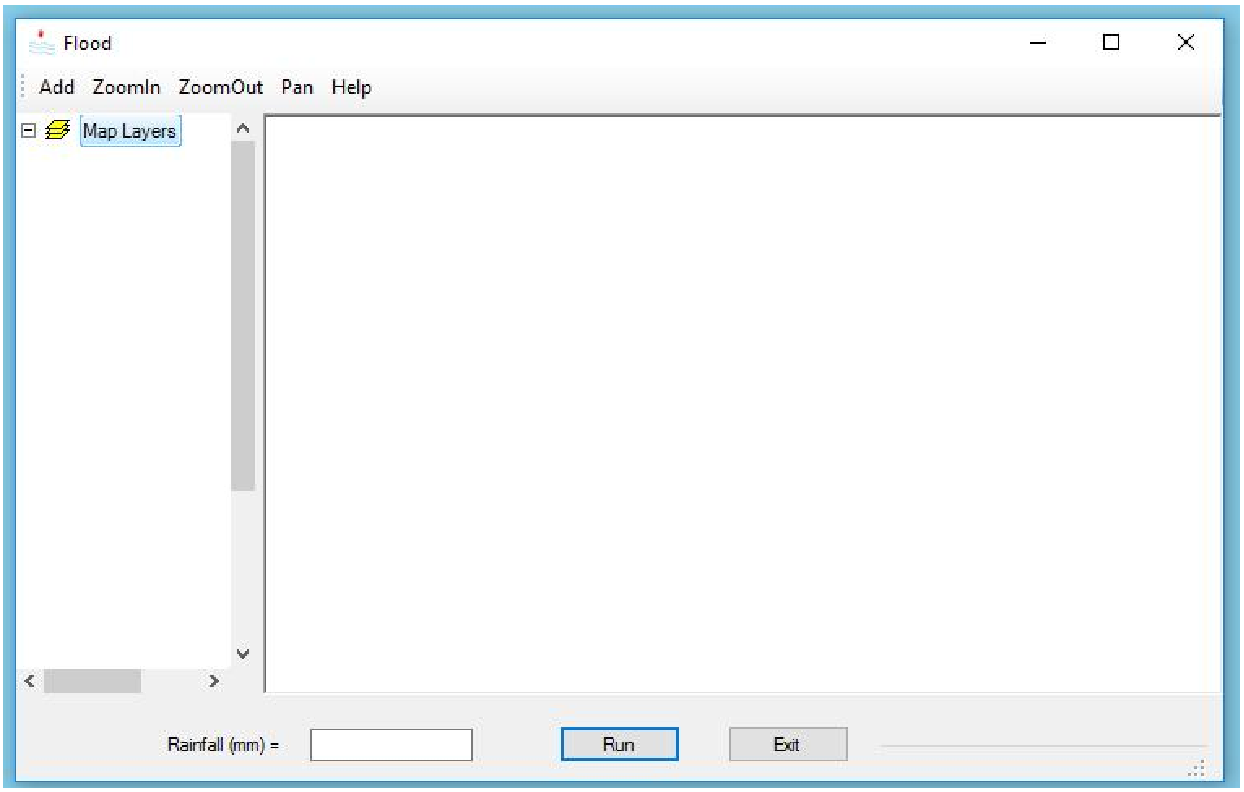

Figure 7: Flood analysis user interface.

vii. Information dissemination

One of the major applications of the system is messaging. The analyst can send warning text message for concerned stakeholders and people.

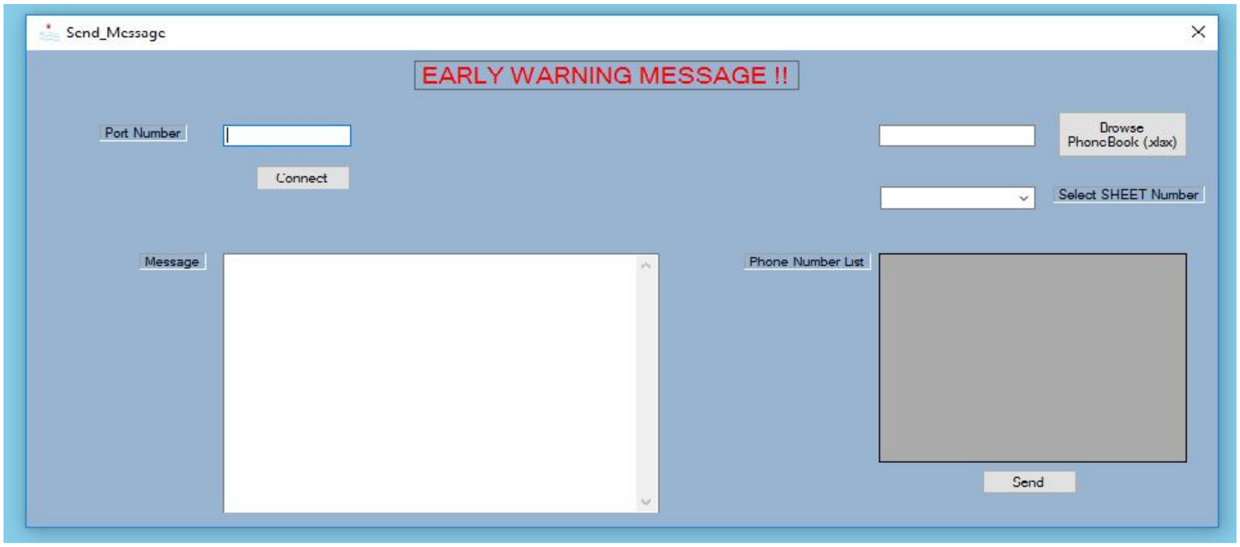

Figure 8: Information dissemination user interface

5. Results

5.1 Curve Number (CN)

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:

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 and the 2015 CN 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. 9), 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.

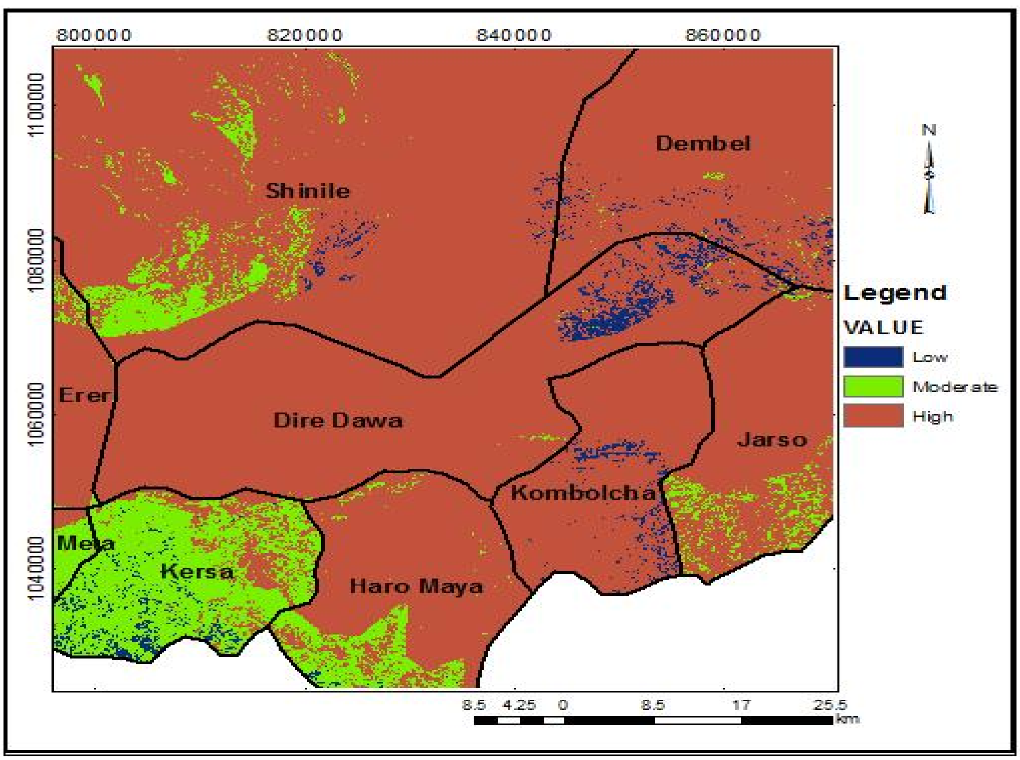

Figure 9: CN value map of Dire Dawa town and surrounding, 2015.

5.2 Maximum retention (S)

Maximum retention map is prepared to both 2005 and 2015 years (Fig. 10) for system testing and future forecasting activities, respectively; it is derived from CN value. Dire Dawa has low maximum retention value this entails the vulnerability of the town to flood hazard is high because of low retention of water by the soil.

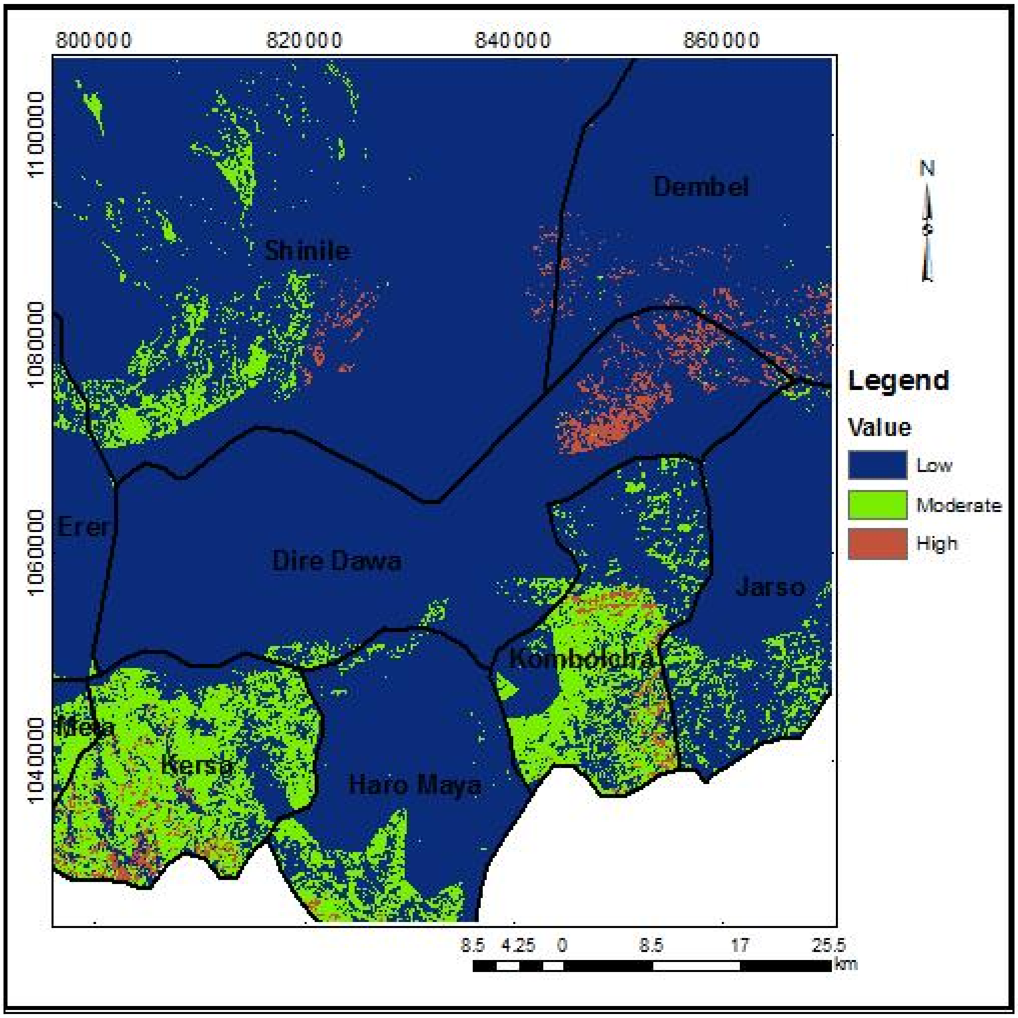

Figure 10: Maximum retention map of Dire Dawa town and surrounding, 2015.

Classification of maximum retention value is depends on curve number range (Table 9).

Table 7: Maximum retention value classification

Maximum retention (S)		Runoff potential
Range	class	
0-80.21	Low	High
80.21-125.1	Moderate	Moderate
125.1-169.33	High	Low

5.3 Initial abstraction (Ia)

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, 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. 11); this makes easy the flow of water from upland areas to Dire Dawa town. The town also has low value of initial abstraction. The value of initial abstraction is classified according to maximum retention and CN value classification (Table 8).

Table 8: Initial abstraction value classification

Initial abstraction (Ia)		Runoff potential
Range	class	
0-16.04	Low	High
16.04-25.02	Moderate	Moderate
25.02-33.86	High	Low

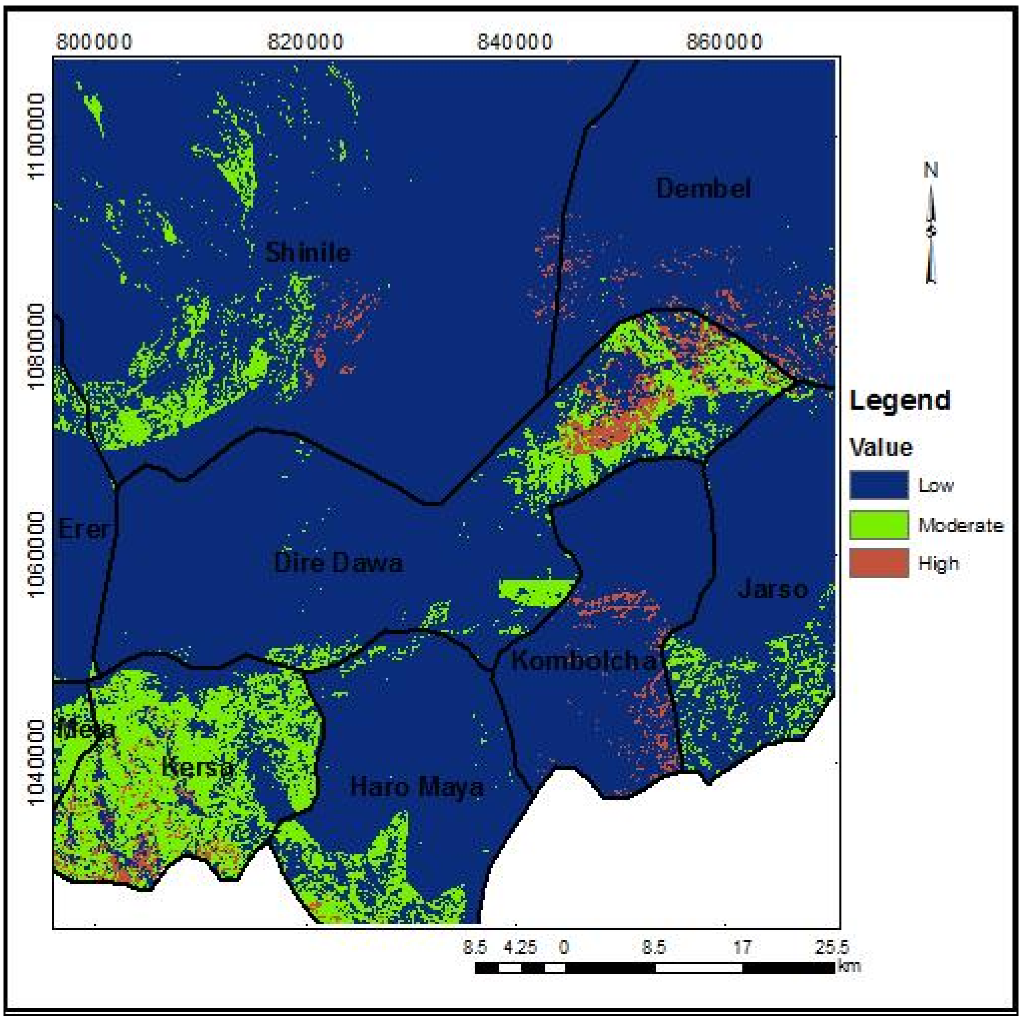

Figure 11: Initial abstraction map of Dire Dawa tow and surrounding, 2015.

5.4 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. 12). 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 (Fig. 13), the figure shows that there was high amount of surface runoff potential on upland areas. The system is evaluated according to its functionality, reliability, usability, efficiency, maintainability and portability.

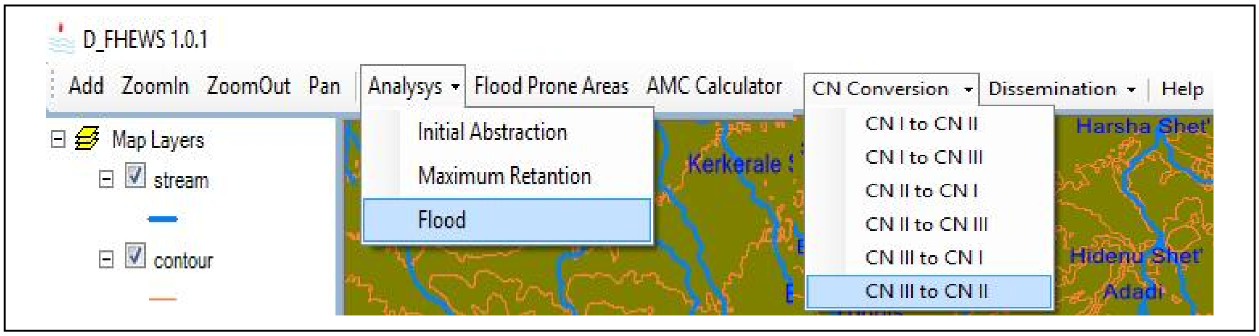

Figure 12: The user interface of D-FHEWS 1.0.

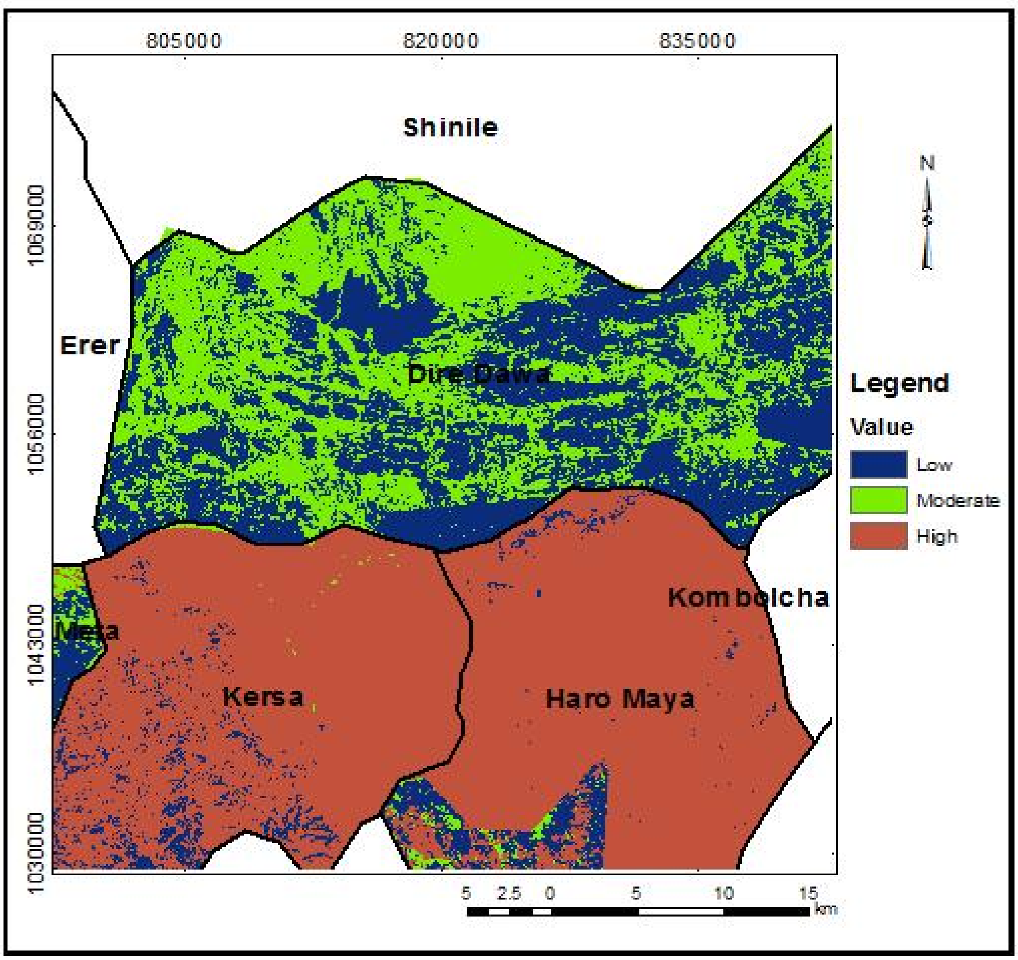

Figure 13: Surface runoff potential on August 05, 2006.

6. 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. The SCS-CN method is a good approach to deduce a sound decision for forecasting and analyzing flood disaster using a single rainfall event. 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, LU/LC, elevation and antecedent moisture condition, comprising them in a single CN parameter. 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 town susceptible to flood hazard. Hence, it is important to have easy and accurate flood hazard forecasting for timely warning to provide accurate and useful information.

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