Flood Hazard and Risk Assessment Using GIS and Remote Sensing in Lower Awash Sub-basin, Ethiopia

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Abstract
Awash River basin is a major river basin that has serious flood problems in Ethiopia. Given that flood hazard is spatial phenomenon, the application of GIS and Remote Sensing techniques are essential to the flood hazard/risk management process. Flood hazard and risk map are effective tools for reducing flood damage. The purpose of this study was to assess flood hazard and risk of Lower Awash sub-basin using GIS and Remote Sensing techniques. Flood causative factors such as slope, elevation, drainage density, soil type and land cover were developed in the GIS environment. The computed Eigen vector was used as a coefficient for the respective factor maps to be combined in weighted overlay in the Arc GIS environment. Flood risk assessment was done using the flood hazard layer and the two elements at risk, namely population and land use. The major finding of the flood hazard map of Lower Awash sub-basin indicated that 107,145.01ha (5%), 522,116.92ha(23%), 897388.95ha(39%) and 763045.31ha (33%) of the area considered in Lower Awash Sub-basin were subjected respectively to low, moderate, high and very high flood hazards. Thus, land use planners of Afar Region and Flood Management Units in the Awash Basin (Lower Awash Basin Area) could use those two maps to make environmentally sound land use decisions and manage the flood problems of the Lower Awash Sub-basin respectively.
Keywords: Flood hazard; flood risk; geographic information system; remote sensing; Lower Awash Sub-basin.

1. Introduction

Flood disasters have a very special place in natural hazards. Floods are the costliest natural hazard in the world and account for 31 percent of economic losses resulting from natural catastrophes (Sanders & Tabuchi, 2000).Floods are the main cause of climate-related hazards in the Greater Horn of Africa region (Artan, et al., 2001).

The rainy season in Ethiopia is concentrated in the three months between June and September when about 80% of the rains are received. Kefyalew (2003) stated that as the topography of the country is rather rugged with distinctly defined watercourses, large scale flooding is rare and limited to the lowland areas where major rivers cross to neighboring countries. However, intense rainfall in the highlands could cause flooding of settlements close to any stretch of river course.

United Nations Office for the Coordination of Humanitarian Affairs (2006) reported that in 2006 a total of 357,000 people were affected by flooding in Ethiopia from which 136,528 people were homeless due to the flood. In Amhara region in 2006 extreme flooding affects and displaced 43,127 and 8,728 peoples respectively. Flood occurred in Dire Dawa during August 1981 were killed about 80 people, However the unpredicted August 6, 2006 flooding was worst of all flooding event in Dire Dawa that killed 256 people from which 244 were missed and 15,000 people were displaced.

Kefyalew (2003) identified the areas commonly flooded annually in Ethiopia as:(a)Baro-Akobo Basin, (b)Awash River Basin (lower, middle and upper Awash sub-basins),(c) Wabi Shebelle,(d) Ribb and Gumara Area (Fogera Plain) and(e) Localized Flooding Risks such as Lake Awassa, Lake Besseka and Dire Dawa.

A major river basin that has serious flood problems is the Awash River basin located in the Rift Valley. It is estimated that in the Awash Valley almost all of the area delineated for irrigation development is subject to flood. An area in the order of 200,000-250,000 ha is subject to be flooded during high flows of the Awash River (Kefyalew, 2003).

This raises the need to address flood related problems through planning based on studies and detailed researches on flood prone areas and formulating possible mitigating measures. To address the problem, there is a need to compile the flood related data or information to identify the areas exposed for flood hazard and elements at risk that enable more effective management and decision making regarding the hazard/risk.

One of the most common approaches in the flood risk and flood hazard study in other countries is using multi-criteria analysis approach in geographic information system (Daniel, 2007). Khan G. & Khan S. (2013) emphasis that "the use of remote sensing and GIS technique is an important tool of information for flood hazard mapping and monitoring"(p.23).Since the blueprint paper by Freeze and Harlan (1969), flood modeling has greatly improved in recent years with the advent of geographic information systems (GIS), radar-based rainfall estimation, high resolution digital elevation models (DEMs), distributed hydrologic models, and delivery systems.

However, according to Herold & Sawada (2012), in developing countries there are numerous barriers to the effective use of geospatial information technology (GIT), especially at the local level, including limited financial and human resources and a lack of critical spatial data required to support geospatial information technology (GIT) use to improve disaster management related decision making processes.

In Ethiopia most flood hazard studies have been concentrated in Tana sub-basin (Assefa et al, 2008; Mossie, 2008; Hagos, 2011; Wubet & Dagnachew, 2011; Zelalem, 2011 Yalelet, 2013), in Dire Dawa (Daniel, 2007) and in Middle and Upper Awash sub-basin (Alemayehu, 2007; Sifan, 2012).The Lower Awash sub-basin flood hazard and risk using GIS and Remote Sensing technique has not been studied. Therefore, this study will help to fill the existing gap on available information and identify the areas exposed for flood hazard and elements at risk.

The overall objective of the study was to assess the flood hazard and flood risk of Lower Awash Sub-basin using GIS and remote sensing techniques. The specific objectives of the study were to (a) build geo-database for flood hazard and flood risk assessment of Lower Awash Sub-basin and (b) map areas in Lower Awash Sub-basin in terms of flood hazard and flood risk using multi-criteria evaluation in GIS environment.

2. Methods and Materials

2.1 Study Area Description

Lower Awash Sub-basin is located in Afar National Regional State (ANRS), within Awash Basin. It is located between 10^0 33’ to 12^0 15’ N latitude and 39^0 51’ to 41^0 49’ E longitude (*Figure-1*). It borders Amhara region to the west and Teru sub basin to the North, middle Awash Sub-basin to the south and Republic of Djibouti to the east. The sub basin comprises nine districts (here after refers woredas) from Zone-1**,** Mille, Dubti, Aysayta, Afambo, Chifra and Ada’ar Woredas, from Zone-4 Ewa woreda and from Zone-5 Telalak, and Dewe Woredas.

The study area is characterized by significant variations in topography. Altitude variations, ranged from 214 m at Afambo to 1538m around Chifra and Ewa woreda. The sub-basin is highly characterized by low rainfall zone. The major soil groupings of Lower Awash Sub-basin are Fluvisol, Leptosol, Regosols, Arenosols, Gleysols, Solonchaks, Solonetz, Vertisols, Cambisol, and Calcisols (Amhara Design Supervision Works Enterprise, 2010).

Awash River is one of the main and the largest perennial river in Ethiopia that passes across many woredas in the Lower Awash Sub-basin. Telalak, Dawe and Ewa rivers are others main rivers that originated from Amhara region and runs crosses the whole area of basin. Lake Abe, lake Afambo and Lake Gamare are also major lakes that are found in the sub-basin.

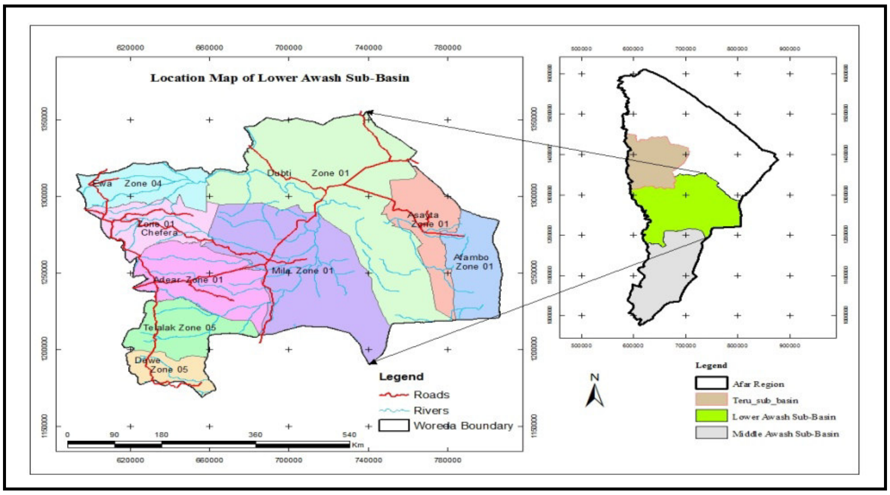

Figure 2: Location Map of Lower Awash Sub-basin

2.2 Methods

The methodology for flood hazard and risk assessment of Lower Awash Sub-basin using GIS and remote sensing techniques, divided into three phases namely: pre-field work, field work and post field work. These three phases have been briefly described below:

2.2.1 Pre-field Work

In the pre-field work phase, base map preparation, downloading images, secondary data collection, geo-referencing and projection were undertaken Land sat imagery, Thematic Mapper (TM) of November 2010 which has a30m resolution was downloaded from internet (www.glovis.usgs.gov). Lower Awash sub-basin is covered by four Land sat scenes of path and rows 167/052, 053, 168/052, 053.Since the downloaded image was zipped, it was unzipped and each single band was obtained. All bands were layer stacked using ERDAS IMAGINE software. Finally, though 5 scenes were downloaded for Lower Awash, four of them (path and rows of 167/052,053, 168/052,053) were mosaic for Lower Awash Sub-basin. Then, using subset tool of ERDAS EMAGINE, the sub basin image was obtained with a 1km buffer of the exact sub basin shape file. Here the exact shape file of the study area was buffered with 1km and saved as an Area of Interest (AOI). Buffering with some distance helps to avoid area loss around border line of the shape file. At this pre-field work stage, the unsupervised classification method was used to classify the images into the various land cover categories.

Topographic data that include DEM were used in this study. In recent times, DEM become very important data sources for geoscientists and has been intensively using in a wide range of topographic analysis, flood modeling and other natural hazard studies (Dewan et al., 2004; Mohammad, 2011).DEM data derived from the elevation data of Shuttle Radar Topography Mission (SRTM) 90 meter resolution was used in this study. Soil physical properties of the Lower Awash Sub-basin were also used for flood hazard/risk assessment.

Regarding the generation of surface run off, infiltration rate is the most sensitive variable (Morgan, 1995). It is controlled by gravitational forces, capillary action and soil porosity (Rattan, 1990; Ward & Robinson, 1990; William et al., 1990). Thus soil physical properties particularly soil texture was considered as one of the parameters among others for Lower Awash Sub-basin flood hazard and risk mapping. Soil physical properties (soil textural class) were taken from Lower Awash Sub-basin integrated land use planning project-soil survey study report produced by Amhara Design Supervision Works Enterprise (2010).

Collected satellite image was geo-referenced according to the geographical co-ordinate system of GCS-WGS-1984. Projected co-ordinate system used for this study area was Universal Transverse Mercator (UTM) projection system zone 37N (WGS, 37N).All other datasets such as DEM and soil maps were also projected in this projection system.

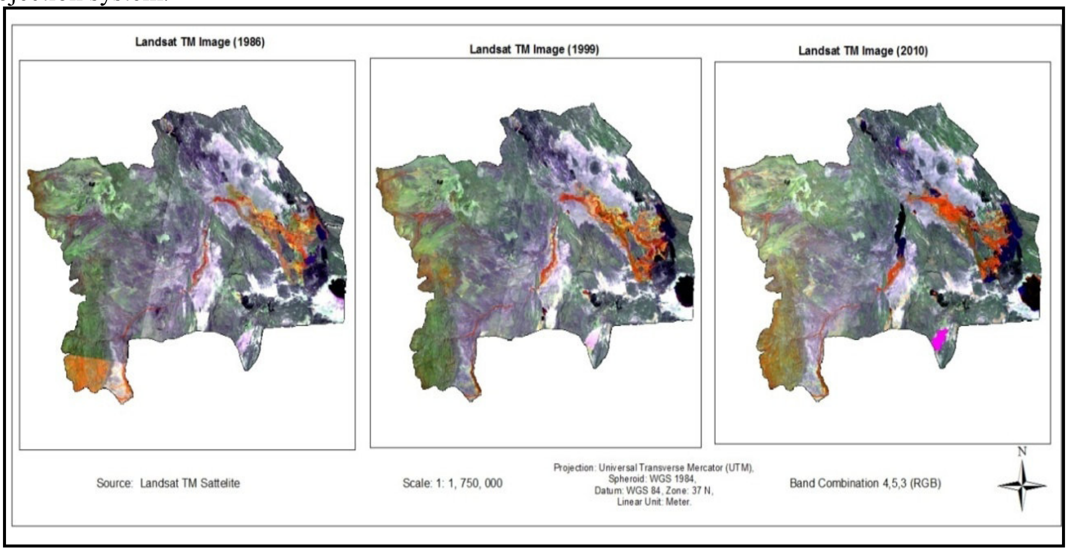

Figure 3: Land sat Thematic Mapper (TM) Images (adapted from Land sat Thematic Mapper image 1986, 1999 &2010)

2.2.2 Field Work

The field survey covered representative land cover types falling in different land cover type's and agro-ecological zones that include sub moist warm, sub moist hot, semi arid warm, arid warm, semi arid hot and arid hot of falling in the sub basin. Tracking of the roads were also done during the field survey. The routes followed and ground control points (GCPs) taken and other relevant field data collected (ground truth) for land use/ land cover, topography, flood prone areas, soil types and other resource assessment.

2.2.3 Post Field Work

2.2.3.1 Flood hazard and Risk Mapping

Slope, elevation, soil, drainage density, and land use/cover were used to model the flood hazard of Lower Awash Sub-basin using satellite Remote Sensing data and GIS technology. Arc Hydro 9.3 software, which works as an extension on ARC GIS 9.3 version software was used to delineate the sub-basin for which flood hazard analysis was done and to generate drainage network map of the sub-basin.

The factor map development was carried out using ARC GIS 9.3. Detail steps for each factor map development is presented in the results and observations (factor development) part. The factors that are input for multi-criteria analysis was pre-processed in accordance to the criteria set to develop flood hazard mapping. Using spatial Analyst, 3D Analyst and Geo-statistical Analyst extensions, relevant GIS analysis were undertaken to convert the collected shape files.

Eigen vector for the selected factor was computed using Weight Module in IDRISI 32 software. The weighted module was fed with the pair wise comparison 9 point continuous scale. Then the principal Eigen Vector of the pair wise comparison matrix using the factors affecting flood hazard was calculated. The computed Eigen Vector was used as a coefficient for the respective factor maps to be combined in weighted Overlay in the Arc GIS environment.

Flood risk assessment was done for Lower Awash Sub-basin using the flood hazard layer and the two elements at risk, namely population and land use. These three factors considered to be equally important in the weighted overlay process. Flood risk assessment and mapping was done for Lower Awash Sub-basin by taking population and land use elements that are at risk combined with the degree of flood hazards of the Lower Awash sub-basin.

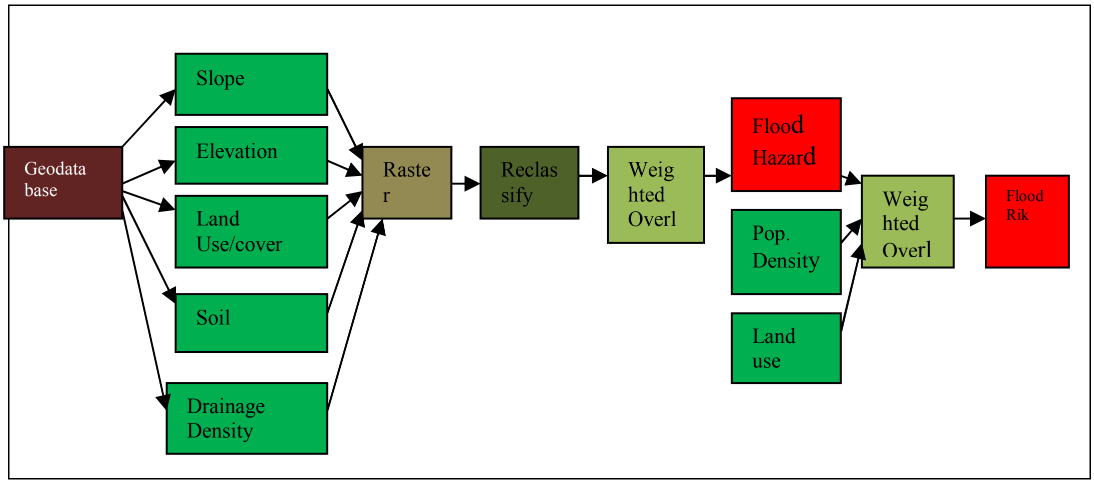

Figure 4: Work Flow of Flood Hazard and Risk Analysis of Lower Awash Sub-basin

2.2.3.2 Verification and Observation

Finally, flood hazard and risk maps were composed, in Arc GIS environment and the maps were validated in the field to assess its accuracy. This was conducted through field visit to define how closely the flood hazard and risk map agrees with the actual field situation. The selection of samples of identified locations on the map, which were then checked in the field. In carrying field validation, 114 GPS reading ground truth data of flood affected areas (see 错误!未找到引用源。) together with their respective land use types were registered and converted to shape file. The land use elements that are found within flood affected area verified at the ground could be used as a flood risk indicators which are at risk of being affected regarding all kinds of hazards in a specific areas for instance built-up areas, cultivated land, grazing land and ecological species and landscapes located in a hazardous area on connected to it. These point shape files superimposed with the flood hazard and risk maps and then the flood hazard and risk maps were verified with the actual field situations.

2.3 Materials

For pre-field phase and the main field survey of this research, the following equipment, devices, hard-wares, soft-wares, and softcopy and hard copy materials were used: (1) Different satellite imageries such as Land Sat, SPOT, SRTM, (2) Topographic maps at 1:50,000 scale, (3) Laptop computer installed with appropriate software like Arc GIS 9.3, Arc Hydro 9.3 software, ERDAS IMAGIN 9.1, IDRISI-32, Global Mapper 8,3, DEM visualization, (4) Relevant shape files (Regional, woreda, rivers, roads), (5) Global Positioning System (GPS), (6) Digital Camera, (7) Guidelines used to describe land use/land cover major units and sub units, (8) Base maps (Land use land cover in hard copy and soft copy, and (9) Field observation data collection format.

3. Results and Observations

3.1Flood Hazard Mapping

3.1.1 Factor Development

Flood causative factors particularly in the study area were identified from field survey, and literature. Accordingly, slope, elevation, drainage density, soil type, and land use were listed in order of their importance to flood hazard. Therefore, the following factor developed for flood hazard mapping.

3.1.1.1 Slope Factor

Slope plays a major role in flood hazard mapping (Alemayehu, 2007). It has a great influence on flood hazard assessment because it governs the amount of surface runoff produced the precipitation rate and displacement velocity of water over the equi-potential surface. Practically high rating is assigned to low slopes for the gentle gradient of the floodplain where as low rating is assigned for high slopes. The slope map was produced by the processing the DEM (90m resolution), using Arc GIS software, Spatial Analysis Tool, Surface Analysis, Slope.

The slope raster layer, which was reclassified in five sub-group using standard classification schemes namely quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determining where the breaks should be. Finally, the slope was reclassified into continuous scale in order of flood hazard rating. The slope in the sub-basin ranges from 0 to 63.38 degree.

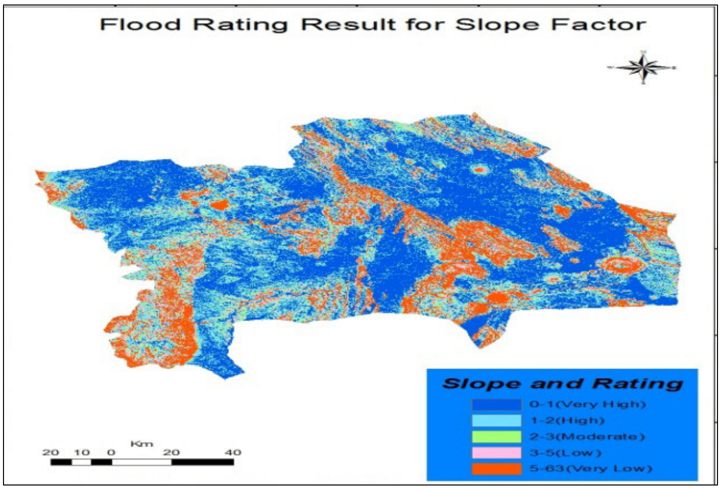

Figure 5: Flood Rating Result for Slope Factor (adapted from DEM data derived from the elevation data of Shuttle Radar Topography Mission (SRTM) 90 meter resolution, 2000)

3.1.1.2. Elevation Factor

All the processes for the development of the elevation factor are as explained above in the slope factor development. The raster layer is then reclassified in according to their influence to flood hazard.

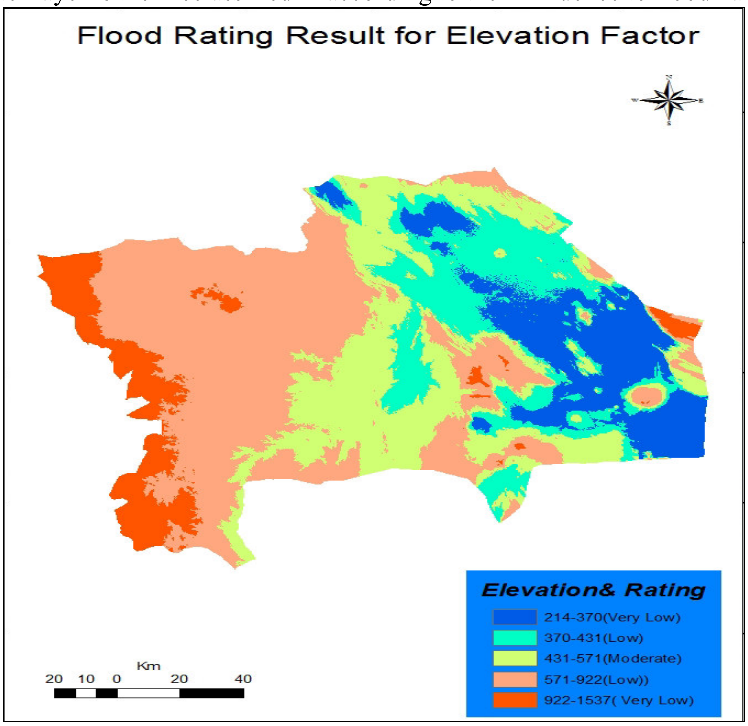

Figure6: Flood Rating Result for Elevation Factor (adapted from DEM data derived from the elevation data of Shuttle Radar Topography Mission (SRTM) 90 meter resolution, 20

3.1.1.3 Drainage Density Factor

Drainage is an important ecosystem controlling the hazardous as its densities denote the nature of the soil and its geotechnical properties (Pareta, 2004).

Drainage system, which develops in an area, is strictly dependent on the slope, the nature and attitude of bedrock and on the regional and local fracture pattern (Alemayehu, 2007).Drainage density (DD) a fundamental concept in hydrologic analysis is defined as the ratio of the length of drainage per basin area. Drainage density is controlled by permeability, erodability of surface materials, vegetation, slope and time.

Drainage density is an inverse function of infiltration (Ajin et al., 2013). Greater drainage density indicates high runoff for basin area along with erodible geologic materials, and less prone to flood. Thus the rating for drainage density decreases with increasing drainage density.

DEM was used to extract the drainage network, to calculate the drainage density of the streams. Arc Hydro9.3 software, which works as an extension on ARC GIS 9.3 version software was used to generate drainage network map of the sub-basin. Using the spatial analyst, line density module was used to compute drainage density of the sub-basin. Line density module calculates a magnitude per unit area from poly line features that fall within a radius around each cell. The density layer is further reclassified in five sub-groups using standard classification schemes namely quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determining where the breaks should be. Finally, the drainage density was reclassified into continuous scale in order of flood hazard rating. The drainage density in the sub-basin ranges from 0.014 to 0.949 km/km^2.

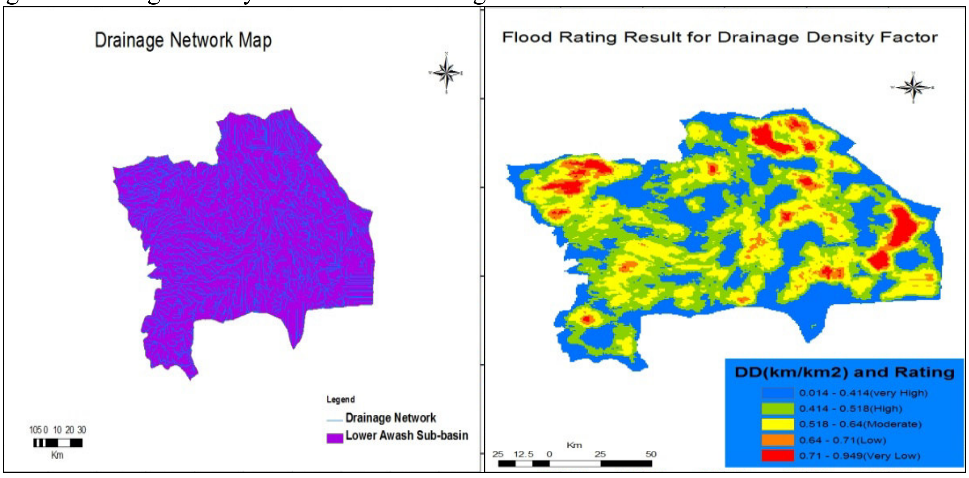

Figure 7: Drainage Network Map (Left) and Flood Rating Result for Drainage Density Factor (Right) (adapted from DEM data derived from the elevation data of Shuttle Radar Topography Mission (SRTM) 90 meter resolution, 2000: DEM was used to extract the drainage network, to calculate the drainage density of the streams using Arc Hydro 9.3 software, & drainage density of the sub-basin was computed using ARC GIS 9.3, the spatial analyst, line density module)

3.1.1.4 Soil Type Factor

Different soil types have different capacities to infiltrate water. Morgan (1995) stresses that "infiltration is a key component that significantly influences the rainfall -runoff process and plays an important role in controlling the amount of water that will be available for surface runoff after a rain storm event"(p.198).

The soil factors influencing the rate of infiltration are: the total amount of pores (soil porosity), the particle size distribution and the structure of pores (grain size distribution), soil structures (size distribution and structure of aggregates) and organic matter content of the soil(Wischmeier et al 1971; Yamamoto & Anderson, 1973; Juo and Franzluebbers,2003;).In general, sandy soils have higher saturated hydraulic conductivities than finer textured soils because of the larger pore space between the soil particles. As such, the infiltration rate of clayey soils is much lower than that of sandy soils (Ward & Robinson,1990; Maidment, 1993;).Porous soils with stable soil aggregates have higher saturated hydraulic conductivity values than soils that are compact and dense (Hill,1980).

By taking into account the above facts, soil physical properties particularly soil texture was considered to develop soil type factor. Soil texture types of the sub-basin (figure-7[left]) was converted to raster format and reclassified based on their water infiltration capacity into flood rating result for soil factor map (figure-7[Right]).

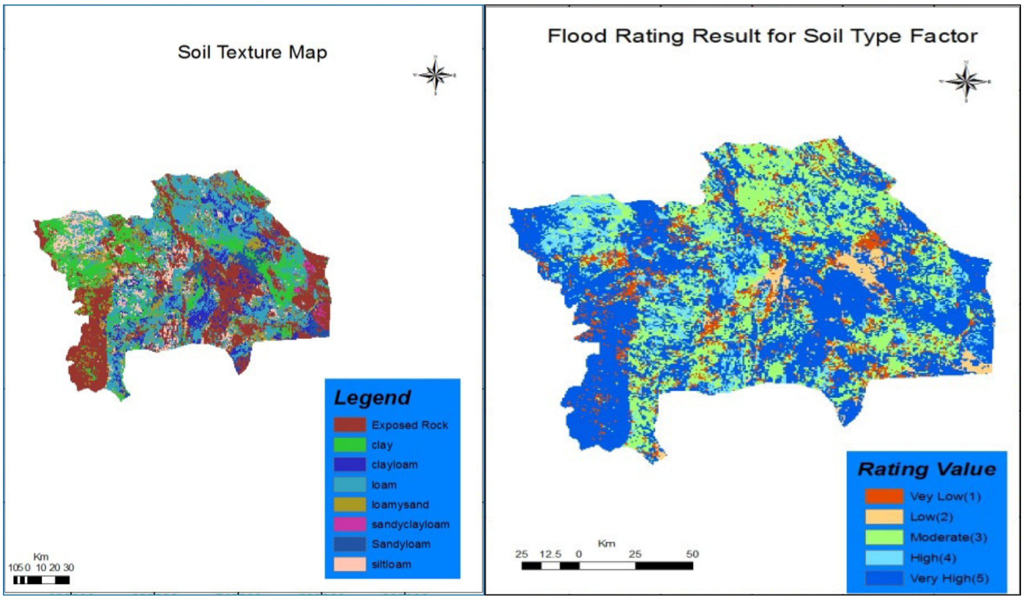

Figure 8: Soil Texture Map of Lower Awash Sub-basin (Left) and Flood Rating Result for Soil Type Factor (adapted from Amhara Design Supervision Works Enterprise, 2010)

3.1.1.5 Land Cover Factor

Vegetation can aid infiltration by slowing the flow of water over the surface and providing passage ways along root systems for water to enter the soil. The infiltration capacity of a given soil is affected by the type and density of the vegetation cover, as demonstrated by the numerous studies reviewed by (Dunn 1978; Faulkner 1990; Thornes 1990, Ziegler, 2004) proposes that infiltration capacity increases exponentially with increasing vegetation and increasing percentage of organic matter and decreases in the bulk density of the soil.

In desert regions or areas that have recently been deforested either by fires or humans, infiltration will be reduced, thus increasing the rate of runoff and decreasing the lag time. Land use/cover types of the Sub-basin that is presented(figure-8[left] was reclassified into a common scale in order of their rain water abstraction capacities for the flood hazard analysis into flood rating result for land cover factor map (figure-8[Right]).

Table 1: Land Use/cover of the Lower Awash Sub-basin

No	LULC Type	Area (ha)	Area (%)
1	Built-up Area	8822.74	0.38
2	Bush Land	48246.44	2.10
3	Cultivated Land	64110.42	2.78
4	Exposed Sand/Soil	305627.4	13.27
5	Forestland	9789.89	0.43
6	Grassland	242619.5	10.54
7	Riverine Forest	32255.02	1.40
8	Rock Out-Crop	823222	35.75
9	Shrub Land	660167.2	28.67
10	Water Body	80302.6	3.49
11	Wet Land	8677.58	0.38
12	Wood Land	18828.97	0.82

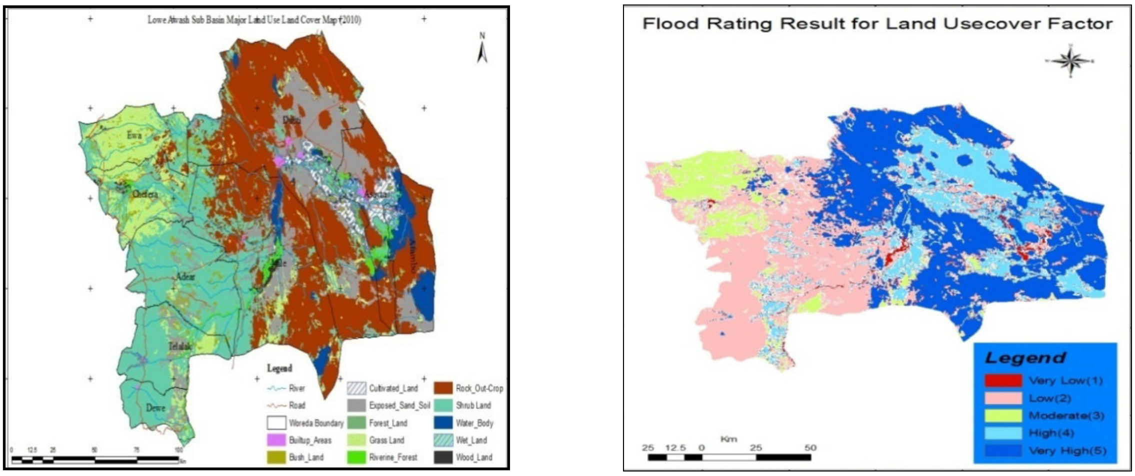

Figure 9: Lower Awash Sub-basin Major Land use/cover (Left) and Flood Rating Result for Land Cover Factor (Right)(adapted from Land sat Thematic Mapper image,2010)

3.1.2 Flood Hazard Analysis

Flood hazard analysis was computed by Weighted Sum Overlay of slope, elevation, drainage density, land use/cover and soil types developed factors. The weights for each factor were given through discussion with concerned bodies and based on literature.

The technique used in this study and implemented in IDRISI GIS software is that of pair wise comparisons developed by Saaty's (1977) in the context of a decision-making process known as the Analytical Hierarchy Process (AHP) (Eastman, 2001). It is one of the multi-criteria decision-making techniques. In the procedure for Multi-Criteria Evaluation using a weighted linear combination, it is necessary that the weights sum to one. In Saaty's technique, weights of this nature can be derived by taking the principal Eigen Vector of a square reciprocal matrix of pair wise comparisons between the criteria. Eigen vectors are a special set of vectors associated with a linear system of equations (i.e., a matrix equation) that are sometimes also known as characteristic vectors, proper vectors, or latent vectors (Marcus and Minc, 1988).The standardized raster layers were weighted using Eigen Vector that is important to show the importance of each factor as compared to other in the contribution of flood hazard.

Accordingly; the Eigen Vector of the weight of the factor was computed in IDRISI 32 Software in Analysis menu of the decision support/weight module based on the given pair-wise comparison (table3).The weighted module was fed with the pair wise comparison 9 point continous scale. Then the principal Eigen Vector of the pair wise comparison matrix using the factors affecting flood hazard was calculated. A consistency ratio values less than 0.1 is acceptable. The consistency ratio of the calculated Eigen Vector was 0.02 that shows that the given pair-wise weights are accepted.

The computed Eigen vector was used as a coefficient for the respective factor maps to be combined in weighted Overlay in the Arc GIS environment using the following equation:

Flood hazard*=0.5014 × [Slope] + 0.2580× [Elevation] + 0.1329× [Drainage density] + 0.0663× [Soil type] + 0.0414× [Land use]*

Table 2:**Saaty's Scale (Weight) for pair-wise comparison of flood factors**

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

Table3: Pair-wise Comparison matrix for assessing the comparative importance of five factors to flood hazard mapping of Lower Awash Sub-basin (adapted from Wubet et al, 2011)

Flood Causative Factors	**Slope**	**Elevation**	**Drainage Density**	**Soil Type**	**Land use**
Slope	1				
Elevation	1/3	1			
Drainage Density	1/5	1/3	1		
Soil Texture Type	1/7	1/5	1/3	1	
Land use	1/9	1/7	1/5	1/3	1

Table4: The Eigen Vector Weights of each flood factors obtained after the pair-wise comparison

Flood Factors	Weight
Slope	0.5014
Elevation	0.2580
Drainage Density	0.1329
Soil type	0.0663
Land use	0.0414

Table 5: Weighted Flood Hazard Ranking for Lower Awash Sub-basin

Factors	Weight	Sub-factors	Ranking	Naming
Slope(degree)	0.5014	0-1	5	Very High
		1-2	4	High
		2-3	3	Moderate
		3-5	2	Low
		5-63	1	Very Low
Elevation (meter)	0.2580	214-370	5	Very High
		370-431	4	High
		431-571	3	Moderate
		571-922	2	Low
		922-1537	1	Very Low
Drainage Density(km/km^2	0.1329	0.014-0.414	5	Very High
		0.414-0.518	4	High
		0.518-0.64	3	Moderate
		0.640-0.71	2	Low
		0.71-0.949	1	Very Low
Soil Texture type(Based on Drainage Capacity)	0.0663	Clay, clay loam &Rock Exposed	5	Very High
		Sandy clay loam &silt loam	4	High
		Loam	3	Moderate
		Sandy loam	2	Low
		Loamy sand	1	Very Low
Land cover(Level of flood abstraction)	0.0414	Wetland, Built-up area & Rock out crop	5	Very High
		Cultivated land &Exposed Sand	4	High
		Grassland	3	Moderate
		Wood, Shrub and Bush land	2	Low
		Forest Land and Riverine Forest	1	Very Low

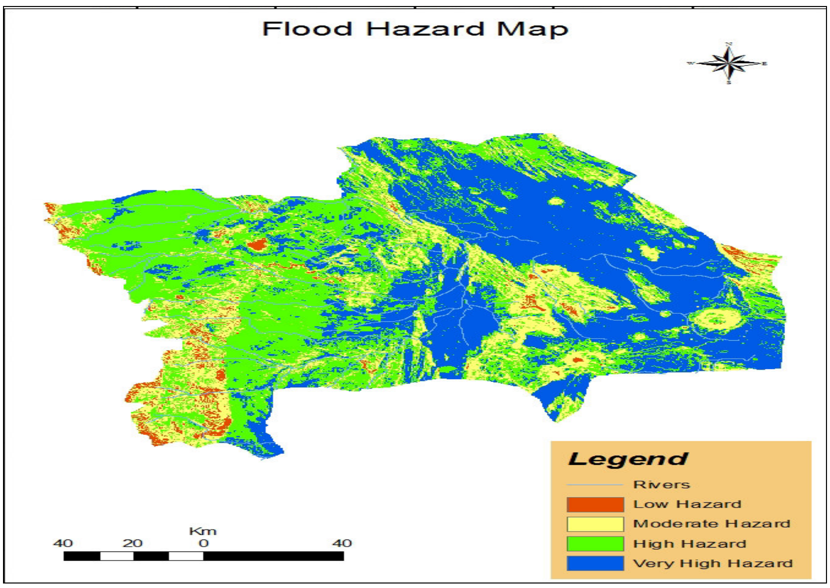

Figure 10: Flood Hazard Map of Lower Awash Sub-basin

From the above flood hazard map, it was estimated that 107,145.01ha (5%), 522,116.92ha (23%), 897388.95ha (39%) and 763045.31ha (33%) of the area considered in Lower Awash Sub-basin were subjected respectively to low, moderate, high and very high flood hazards. The above flood hazard map showed that about 763045.31ha (33%) of the area of the sub-basin under very high flood hazard falls in lower plains of Awash River parts of Mille, Dubti, Aysayta and Afambo woredas. This result is in confirmation of an earlier study of Kefyalew (2003) on integrated flood management of Ethiopian case study. In the Lower Plains of Awash, Kefyalew(2003) identified and explained that "the Dubti area plantation and most of Dubti town have been inundated with flood, mainly coming from Logiya and Mille rivers, such floods have also caused damages to the Afar pastoralists in the area between Dubti and Aysayta isolating them and their livestock "(p.5).

The reason is associated with the Awash river in the Lower plains has a very unstable course. The river at this lower course has a very flat slope as well as low elevation tending to change its course with rising of its bed with silt deposition. As a result the river branches out into defluences reducing flows in the original river and denying to existing farms downstream. As long as the slope factor has been given the highest weight (influence) followed by elevation factor in the flood hazard analysis model, the flood hazard map model result seems to coincide with the ground truth.

Further analysis revealed that (61.65%) of built-up area, (95.10%) of cultivated land, (97%) of forestland, (22.70%) of grassland, and (76.87%) of riverine forest is categorized under very high flood hazard (for details See the table-4).

Table 6: Area Tabulation of Flood Hazard Map and Land Cover of Lower Awash Sub-basin Area

Land cover Type	**Flood Hazard**					
	Low	**Medium**	**High**	**Very High**	**No Flood Hazard Data**	**Remark**
	Area(ha)					
Built-up area	54.1	913	2424.33	5431.21		
Bush land	612.25	4866.31	36163.49	6425.1	4.36	
Cultivated land	223.74	1175.84	3120.72	60974.92	4.36	
Exposed Sand	784.54	8878.3	74889.46	223360.53	689.17	
Forestland	------	27.73	286.96	9496.71		
Grassland	3609.49	20044.26	162770.01	55078.68	1228.88	
Riverine Forest	40.29	1501.96	5568.48	24795.75	392.88	
Rock out-crop	22539.8	300692.7	293176.71	204908.81	411.29	
Shrub land	79301.81	182059.44	304035.58	90527.34	6114.29	
Water body	8.84	2084.61	13462.84	64407.46	338.86	
Wetland	------	45.76	193.76	8527.79		
Woodland	54.09	786.82	3649.28	14451.37	73.42	
No cover data	6.16	34.42	83.25	96.69		

According to the comparison of ground truth data of flood hazard affected sites and flood hazard map of Lower Awash Sub-basin as shown in the map below, the result was in agreement with the reality. The above flood hazard map of Lower Awash Sub-basin verified with 114 GPS reading ground truth data of flood affected areas collected by the researcher at the field using Garmin GPS-60 during August, 2010 flood. The Afar regional state government has prepared integrated rural land use plan at semi-detail level by awarding consultancy service for Amhara Design &Supervision Enterprise (ADSWE). Therefore, land use planners can use this information to make environmentally sound land use decisions. Furthermore, Flood Management Units in the Awash Basin (Lower Awash Basin Area) can also use this information to manage the flood problems of the Lower Awash Sub-basin.

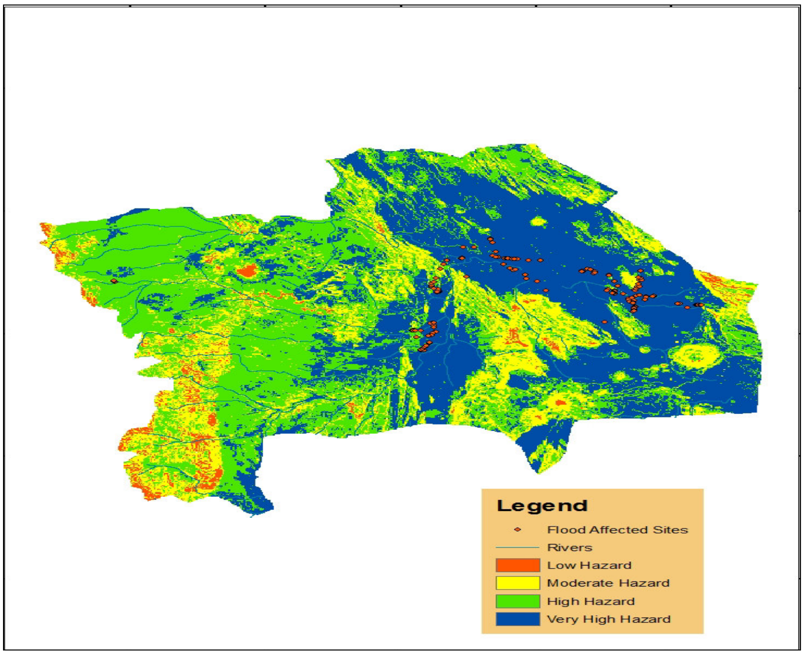

Figure11**:** Distribution of Ground Truth Points of Flood Affected Areas to Flood Hazard

3.2 Flood Risk Analysis

Elements at risk indicators specify the amount of social, economic or ecological units which are at risk of being affected regarding all kinds of hazards in a specific area e.g. persons, economic production, buildings, public infrastructure, cultural assets, ecological species and landscapes located in a hazardous area on connected to it. Flood risk assessment was done for Lower Awash Sub-basin using the flood hazard layer and the two elements at risk, namely population and land use. These three factors reminded to be equally important in the weighted overlay process. Flood risk assessment and mapping was done for Lower Awash Sub-basin by taking population and land use elements that are at risk combined with the degree of flood hazards of the Lower Awash sub-basin.

3.2.1 Population Density Factor

Gross population density calculation method is used to calculate the number of person per square kilometers. Then population shape file was converted to raster layer using Conversion Tools/Feature to Raster. Then further the data layer was reclassified into five sub-factors which are classified using equal interval method. And new values re-assigned in order of increasing number of population that is more susceptible to flood hazard. The population density was reclassified in the assumption that the denser the population, the more vulnerable it will be to flood hazard.

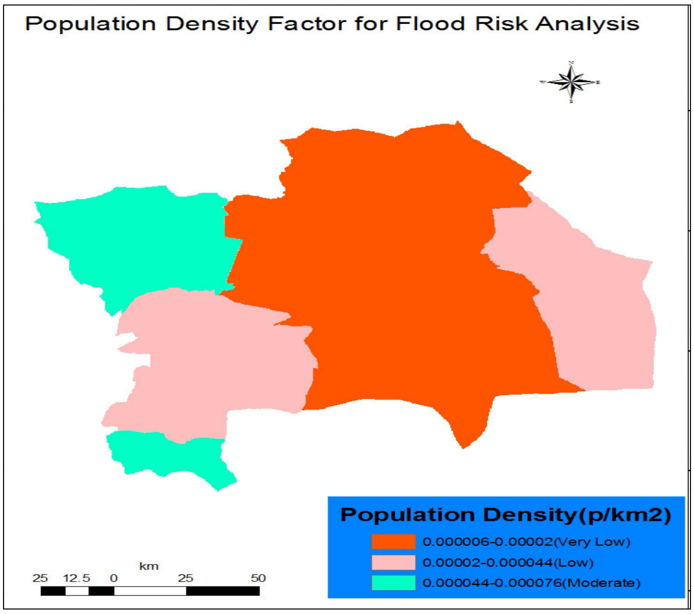

Figure 12: Population Density Factor for Flood Risk Analysis

3.2.2 Land Use Type Factor

The major land uses in Lower Awash Sub-basin was classified as cultivated, settlement, grazing, browsing and grazing, and undefined(exposed sand, rock out-crop, riverine forest, forestland, water body& wetland. The land use types of the sub-basin were reclassified into a common scale in order of sensitivity for the flood risk analysis.

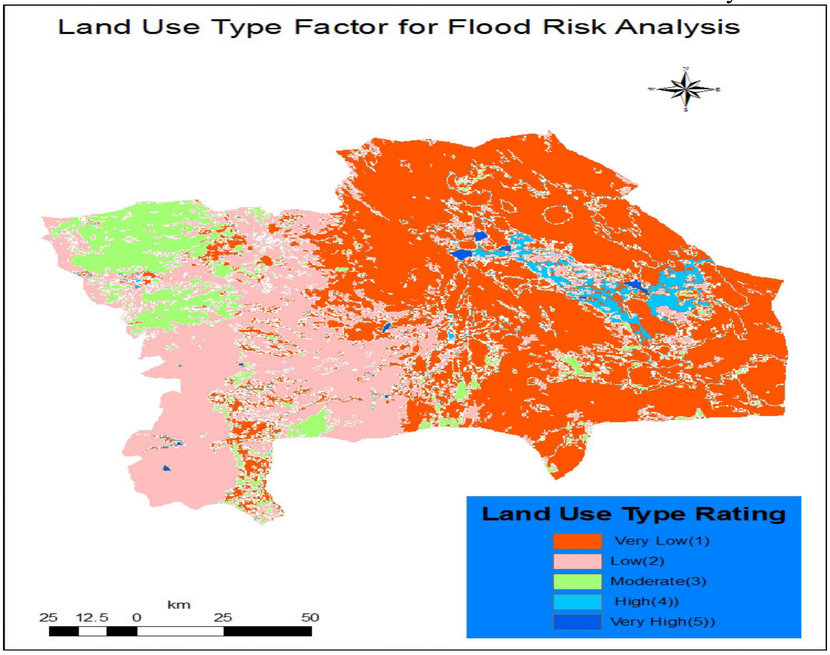

Figure 13: Land Use Factor for Flood Risk Analysis

Table7: Weighted Flood Risk Ranking for Lower Awash Sub-basin

Factors	**Weight**	**Sub-factor**	**Scale (Risk)**
1.Flood hazard	0.3333	Very High	5
		High	4
		Moderate	3
		Low	2
		Very Low	1
2.Population density(person per square kilometers)	0.3333	0.000006-0.00002	5
		0.00002-0.000044	4
		0.000044-0.000076	3
		0.000076-1.0	2
		>1.0	1
3.Land use Types(based On their Sensitivity to flooding)	0.3333	Settlement(Built-up area)	5
		Cultivated land	4
		Grazing(Grassland)	3
		Browsing &Grazing(bush, shrub& woodland)	2
		Undefined(Exposed Sand, Rock out-crop, Riverine Forest, Forestland, Water body& Wetland)	1

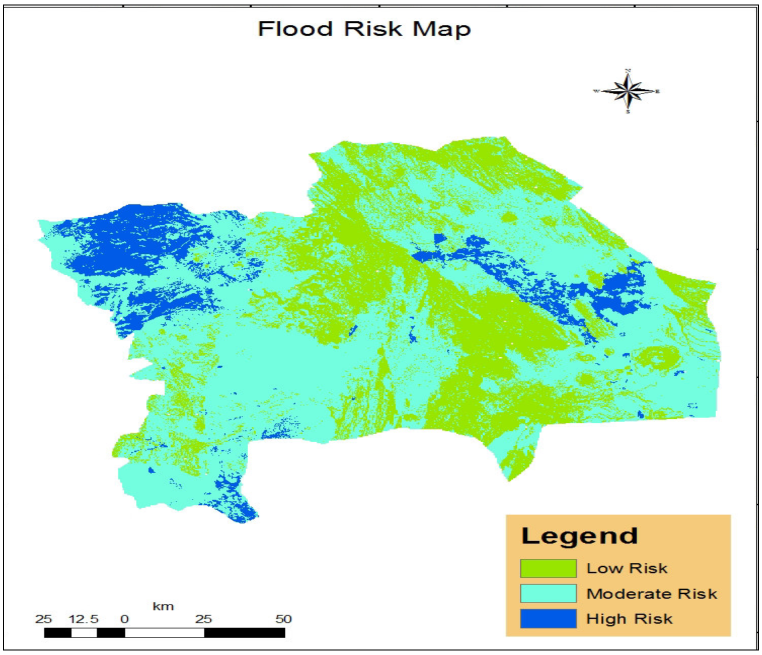

Figure14: Flood Risk Map of Lower Awash Sub-basin

According to the flood risk map, it was estimated that 699,305ha (30.54%), 1,358,520 ha (59.33%) and 231,881ha (10.12%) of the area considered in Lower Awash Sub-basin were subjected respectively to low, moderate and high flood risk. This showed that even though large areas of the Sub-basin are subjected to high and very high flood hazard area, relatively less areas of the Sub-basin are subjected to high flood risk and no at very high flood risk. This indicated that elements at risk particularly persons and sensitive land use types to flood risk located in flood hazardous areas or connected to it is relatively low as compare to the flood hazard.

Further analysis revealed that (94.87%) settlement area, (93.73%) cultivated land and (62.66%) grazing land of the study area faces high flood risk level (see details table-6). Dubti town, Logia town, Korele camp, Date-bahiri town, Sene'asna-Kusrtu Kebele (Hadera camp and kebele center), Deyelena-geraro kebele center, Handeg Kebele Center and Galefage kebele center are subjected to high flood risk. Hence those settlement areas need immediate attention for alleviating potential future flood risk.

Table8: Area Tabulation of Flood Risk Map and Selected Land Use types of Lower Awash sub-basin

Land use Type	**Flood Risk**			
	Low	**Moderate**	**High**	**Remark**
	Area(ha)			
Settlement(Built-up area)	31.25	406.29	8370	
Cultivated land	159.39	3,484.33	60,091.40	
Grazing	656.50	86926.20	152037.95	

According to the comparison of Ground truth data of land use types at Flood Risk and Flood Risk map of Lower Awash Sub-basin, the model result seems coincide with the reality.

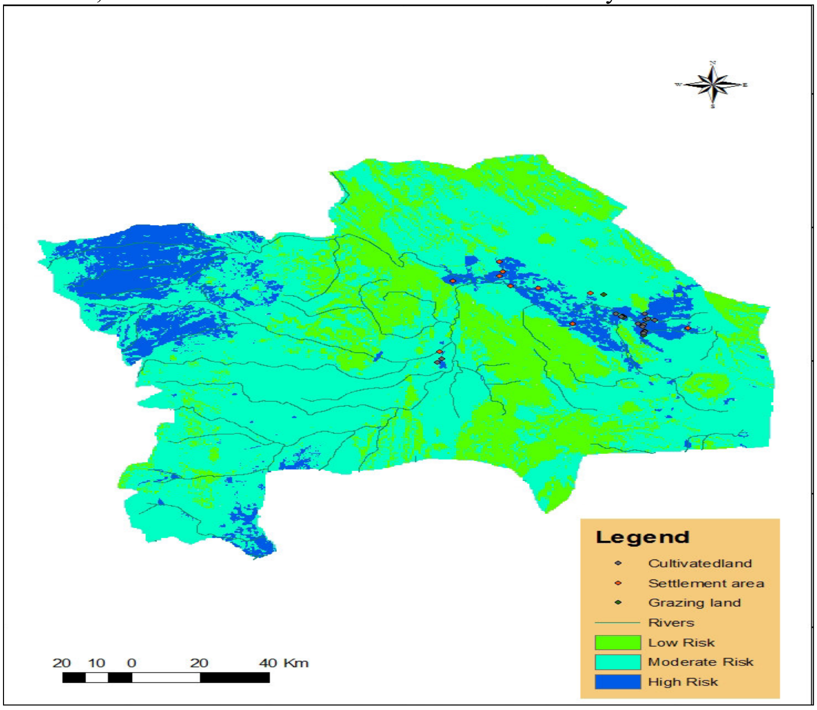

Figure15: Distribution of Ground Truth Points of Land Use Types in- relation to Flood Risk

4. Conclusion

The study has mapped flood hazard and risk of Lower Awash Sub-basin, which is a major river basin that has serious flood problems in Ethiopia using GIS and Remote Sensing techniques. The geo-database developed from the study provides information on the flood hazard and flood risk of Lower Awash Sub-basin and can serve as good decision support system for flood hazard managers. Thus, land use planners of Afar Region and Flood Management Units in the Awash Basin (Lower Awash Basin Area) could use those two maps to make environmentally sound land use decisions and manage the flood problems of the Lower Awash Sub-basin respectively.

The flood hazard map of Lower Awash Sub-basin indicated that downstream plains of Awash River part: Mille, Dubti, Aysayta and Afambo woredas were within very high flood hazard. Even though large areas of the Sub-basin are subjected to high and very high flood hazard area, relatively less areas of the Sub-basin are subjected to high flood risk and no areas at very high flood risk. Therefore, it is possible to conclude that elements at risk particularly persons and sensitive land use types to flood risk located in flood hazardous areas or connected to it is relatively low as compare to the flood hazard. There are towns, kebele centers and settlement in Lower Awash Sub-basin areas that are subjected to high flood risk. Hence those settlement areas need immediate attention for alleviating potential future flood risk.

A limitation that can be pointed to this method of flood hazard and risk mapping is that the GIS result is not combined with an applicable hydrologic/hydraulic method for estimating stages. As a result of this, the study is conducted without any hydrodynamic simulation and estimation of flood depth inundation. Therefore, in the future research on developing flood hazard map that can indicate the depth of inundation through hydrodynamic simulation should be done for the Lower Awash Sub-basin.

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Annex

Annex1: GPS Reading Ground truth Data of Flood Affected Areas

Point ID	UTME	UTMN	Elevation	Point Code
01	787104	1273922	345	Awash River
02	787229	1273965	342	Prosopis
03	787713	1273993	340	Wetland
04	787836	1273992	342	Wetland
05	788378	1273980	343	Awash River
06	788416	1273972	347	Awash River
07	788781	1274080	342	Lake Abe
08	782344	1274551	346	
09	784782	1272742	347	Awash River
11	781796	1274619	346	Afambo town
12	61599	1285816	874	Riverbank)(over top) across the road
13	615333	128611	880	Riverbank)(over top) near the tree
14	615983	128565	881	End of the flood(chiffera side
15	753490	1290586	369	Settlement, Animal Health Center
16	753569	1290427	369	Prosopis Juliflora
17	755161	1291622	367	Sand Cover
18	756180	1291230	366	Prosopis Juliflora
19	757380	1290543	366	
20	757311	1289729	363	Grazing Land
21	762999	1285656	359	Forest
22	761443	1288669	360	Near Hill
23	761457	1288619	370	
24	761542	1288593	364	
25	763940	1283295	364	Aysayta Town from Dubti Side
26	765782	1279492	372	Aysayta Town Basha Amare Hotel
27	767298	1277328	363	
28	768642	1275034	356	
29	767409	1276704	356	Cultivated land(maize production)
3-0	768800	1276403	353	Cultivated land(maize production)
31	768820	1276400	352	Prosopis Juliflora
32	767781	1275578	356	Prosopis Juliflora
33	768690	1275357	353	Cultivated land(maize production)
34	768697	1275299	354	Prosopis Juliflora
35	769340	1273363	354	Cultivated land(cotton)
36	769237	1273002	350	Cultivated land(cotton)
37	768974	1272659	350	Grazing land
38	768949	1272495	347	Grazing land
39	768927	1272410	350	Cultivated land(Maize))
40	768819	1271602	346	Grazing land(after AR3)
41	768624	1270938	347	Riverine Vegetation

42	768834	1271245	348	Swampy Area
43	761070	1281766	357	
44	760773	1281002	352	Cultivated land
45	760877	1281089	362	Dense forest
46	763254	1280845	361	(Awash River at Bridge)
47	763160	1280969	362	
48	763074	1280726	364	Awash River at Bridge)
49	763168	1280930	364	Prosopis Juliflora
50	762874	1280044	357	Grazing land
51	763038	1279866	356	Open grassland
52	763024	1279573	351	Shrub grassland
53	762666	1279656	361	Wooded scrubland
53	762562	1279887	356	Cultivated land(maize)
54	768408	1277702	357	
55	774464	1278370	355	
56	774695	1278397	352	
57	769447	1278505	355	Cultivated land(cotton)
58	770379	1278735	357	Cultivated land(cotton)
59	772309	1278359	359	Cultivated land(cotton)
60	772296	1277818	355	
61	772277	1276724	351	
62	769447	1278505	355	Cultivated land(cotton)
63	770379	1278735	357	Cultivated land(cotton)
64	772309	1278359	359	Cultivated land(cotton)
65	368926	1281340	357	Hills covered with Rock
66	768939	1281312	350	Marshy area
67	769356	1281253	350	Cultivated land(maize)
68	769568	1281971	363	
69	769657	1281996	361	Woodland(Keselto)
70	770702	1290756	360	Rock cover(weathered rock)
71	730470	1293802	375	Near Dubti town
72	727143	1298269	377	Dubti town
73	727972	1300194	376	Settlement of State farm camp(right side of road)
74	727219	1304581	370	Settlement of State farm camp(left)
75	726421	1306210	369	at the end of the Canal
76	726488	1306225	370	" "
77	726588	1306386	366	at the Getter
77	726542	1306290	370	Flood prevention embracement
76	723259	129998	394	End of flood from Du-Semera road beg of vol-rock
77	721723	1302179	410	Volcanic Rock
78	712808	1294038	403	Road to Tendaho Dam
79	713725	1295856	400	Logiya town(Mille side)
80	71632	1297400	400	Logiya town(Semera side)
81	718520	1302296	393	End of flood (bo. Gu &Ay,Semera v Rock-As-Road
82	719520	1287970		Alalobade Hotspring Area
83	728149	1297438	380	Near sugarcane production
84	732421	1292099	376	Prosopis Juliflora invasion
85	733301	1291047	376	Near ponds created by excavated materials
86	733900	1291440	371	Prosopis Juliflora invasion
87	731503	1296895	378	Prosopis Juliflora invasion
88	733020	1296636	377	End of Debelena Halibari kebele
89	733494	1296562	380	Road served as leverage
90	733671	1296534	378	" " "
91	741399	1295734	374	Prosopis Juliflora invasion
92	704032	1261377	437	Foot of Hills
93	708814	1259105	418	Near Demonstration

94	710217	1260720	415	woodland near to cultivation
95	710275	1260732	412	cultivated land
96	709367	1260255	420	settlement area of kebele center
97	709156	1259354	423	cultivated land near demonstration
98	708063	1258785	427	potentially flooded
99	705831	1252328	424	Near Hills
100	708530	1255267	421	Geraro Seasonal River
101	709632	1264114	416	Hadera settlement &kebele Center
102	708926	1265138	422	Cultivated land
103	709833	1265430	422	Riverine Vegetation
104	709729	1262993	423	Sandy cover
105	711034	1280412	437	Flood out flow (End of natural Emb.)
106	710985	1280475		Opposite side TRB
107	710956	1280617	413	" " "
108	710979	1280674	412	" " "
109	711142	1281636	413	" " "
110	70887	1282610	418	Near to Asphalt Road
111	709463	1282278	415	" " "
112	709152	1282552	418	Near Hills
113	709165	1282947	424	Volcanic Rock(Asphalt Road)
114	710798	1280380	412	Segento seedling