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Flood Hazard Assessment and Mapping of Flood Inundation Area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS Model

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Abstract

Flood is a natural disaster and causes loss of life and property destruction. The objective of this study was to analyze flood hazard and inundation area mapping of Awash River Basin. Flood generating factors, i.e. slope, elevation, rainfall, drainage density, land use, and soil type were rated and combined to delineate flood hazard zones using a multi-criteria evaluation technique in a GIS environment. The weight of each flood generating factor was computed by pair wise comparison for a final weighted overlay analysis of all factors to generate the flood hazard map. The flood hazard map indicates that 2103.34, 35406.63, 59271.09, 162827.96, and 1491.66 km^2 corresponds with very high, high, moderate, low, and very low flood hazard, respectively. The flooded areas along the Awash River have been mapped based on the 5% exceedance highest flows for different return periods using the HEC-RAS model, GIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and GIS. The areas along the Awash River simulated to be inundated for 5, 10, 25, 50 and 100 years return periods. The flooded areas were high particularly from Dubti down to Lake Abe for all return periods. The flooded areas along the Awash River are 117, 107, 84, 68, and 38 km^2 for 100, 50, 25, 10, and 5 year return periods, respectively when using 5% highest data from the Adaitu gauging station. The major findings in the study revealed that inundated areas in the upper and middle part of Awash River Basin are low as compared to the downstream part. Proper land use management and afforestation, is significant to reduce the adverse effects of flooding particularly in the low-lying flood prone areas.The result of the report will help the concerned bodies to formulate develop strategies according to the available flood hazard to the area.

Keywords: Awash River basin; DEM; Flood hazard mapping; GIS; HEC-RAS mode; HEC-GeoRAS; Inundation along the river; Multi-criteria analysis; Return period; Weighted overlay

Introduction

Floods can be explained as excess flows exceeding the transporting capacity of river channel, lakes, ponds, reservoirs, drainage system, dam and any other water bodies, whereby water inundates outside water bodies areas [1]. Flood is a continuous natural and recurring event in floodplains of monsoon rainfall areas like Ethiopia, where over 80% of annual precipitation falls in the four wet months [2]. The flooding can be caused by, for instance, heavy rain, snow melt, land subsidence, rising of groundwater, dam failures. Moreover, since the industrial revolution, climate change has been clearly influencing many environmental and social sectors; in particular, it has been showing significant impact on water resources. The natural disaster related to the weather system variability, climate change, and environmental degradation have been frequently influencing human beings and their impacts seem to have greatly increased in recent decades [3] Flood is one of the major natural disasters that have been affecting many countries or regions in the world year after year [4].

An inundation map displays the spatial extent of probable flooding for different scenarios and can be present either in quantitative or qualitative ways. The hazard assessment is to identify the probability of occurrence of a specific hazard, in a specific future time, as well as its intensity and area of impact. Hazard is a potentially damaging physical event, phenomenon that may cause the loss of life or injury, property damage, environmental degradation, social and economic disruption. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro meteorological and biological) or induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential or combined in their origin and effects [5]. Each hazard is characterized by its location, intensity, and probability. The flood hazard assessment need to be presented using a simple classification as simple as possible, such as indicating very high, high, medium, low, or very low hazard. The later means no danger [5-7]. The inundation or hazard assessment mapping delineates flood hazard areas in the river basin by integrating local knowledge, hydrological, meteorological, and geomorphologic data using different approaches. The final flood hazard feature requires large local or field knowledge inclusion in the model. For example, assigning a rank to a flood hazard indicator requires local knowledge and it may vary based on different circumstances [8].The inundation or hazard mapping is an essential component of emergency action plans; it supports policy and decision makers to decide about how to allocate resources, flood forecasting, ecological studies, and significant land use planning in flood prone areas [9].

The excess flows in water bodies can happen due to several factors, but seasonal heavy rainfall is the main cause of flooding in the Awash River Basin [10]. The problem of river flooding due to excess rainfall in short time and the following high river discharge is a great concern in the Awash River Basin, Ethiopia. In the main rainy season (June, July, August, and September); the floodplain of the Awash River extends to particular areas that are not normally covered with water. The river or flash flooding usually occurs in the low-lying flat topographic areas

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of the Awash River Basin. The intense rainfall in the highlands of the Awash River Basin causes flooding at its downstream and damages settlements close to any section of the river [10].

The upstream area of the Awash River Basin has been flooded for short durations after intense or prolonged rainfall events, but the downstream area has been flooded for weeks or months every year during the wet season [11]. The timing and size of the flood will influence the production of the crops cultivated in the floodplain. Plenty of rainfall at the start of the rainy season in the Upper Awash River Basin will cause the area to flood, and to deposit fertile sediment in the floodplain. If the intense rainfall in the Upper Awash River Basin will occur at the end of rainy season, the floods can damage the crops. The floods are becoming highly unpredictable in many ways [11]. Flooding is becoming a big concern in the Awash River Basin due to crop damage and human welfare losses, so that GIS based flood hazard assessment and extent mapping is crucial. There is a need for flood regulation, timely forecasting and hazard extent mapping in the Awash River Basin.

Some literatures suggest that the frequency and magnitude of river flood might increase due to climate change [12-14]. In the last decade, the frequency of flash floods markedly increased all over Ethiopia, which caused a number of fatalities and large property damage [15]. They concluded that the whole country is potentially prone to the flash floods hazard and these may be associated with climate change, intense monsoon rainfall in short time during the main rainy season. Flooding in the Awash River Basin, especially in the downstream part is a combined effect of rainfall in the highlands that goes through tributaries of the main river, and high release of discharge from the Koka reservoirs during the wet season, particularly in August [16].

The main objective of this study is to analyze the inundation area along the Awash River network, and to assess the flood hazard in the whole Awash River Basin by integrating geomorphic, topographic, and hydrological data using GIS and the HEC-GeoRAS/HEC-RAS model. Specifically, the study aims to identify the inundated area along the river basin with a particular return period of 5,10,25,50 and 100 years period and to identify the most flood prone areas of the basin.

Description of Study Area

Location

The geographic location of the Awash River Basin is between 7°53'N and 12°N latitudes and 37°57'E and 43°25'E of longitudes [17]. The largest part of the Awash River Basin is located in the arid lowlands of the Afar Region in the northeastern part of Ethiopia (Figure 1).

The total length of the main course is about 1200 km and it is the principal stream of an endorheic drainage basin covering parts of the Oromia, Somali, Amhara, and Afar region [18]. The Awash River Basin is the most important basin in Ethiopia, and covers a total land area of 110,000 km^2 and serves as home to 10.5 million inhabitants [19]. The River rises on the high plateau near Ginchi town, in the west side of the capital city of Addis Ababa, Ethiopia and flows along the Rift Valley into the Afar Triangle, and terminates in the salty Lake Abbe on the border with Djibouti [19].

Climate

The River basin extends from semi-desert lowlands to cold high mountainous zones with extreme ranges of temperature and rainfall. The movement of the Inter-Tropical Convergence Zone (ITCZ) and

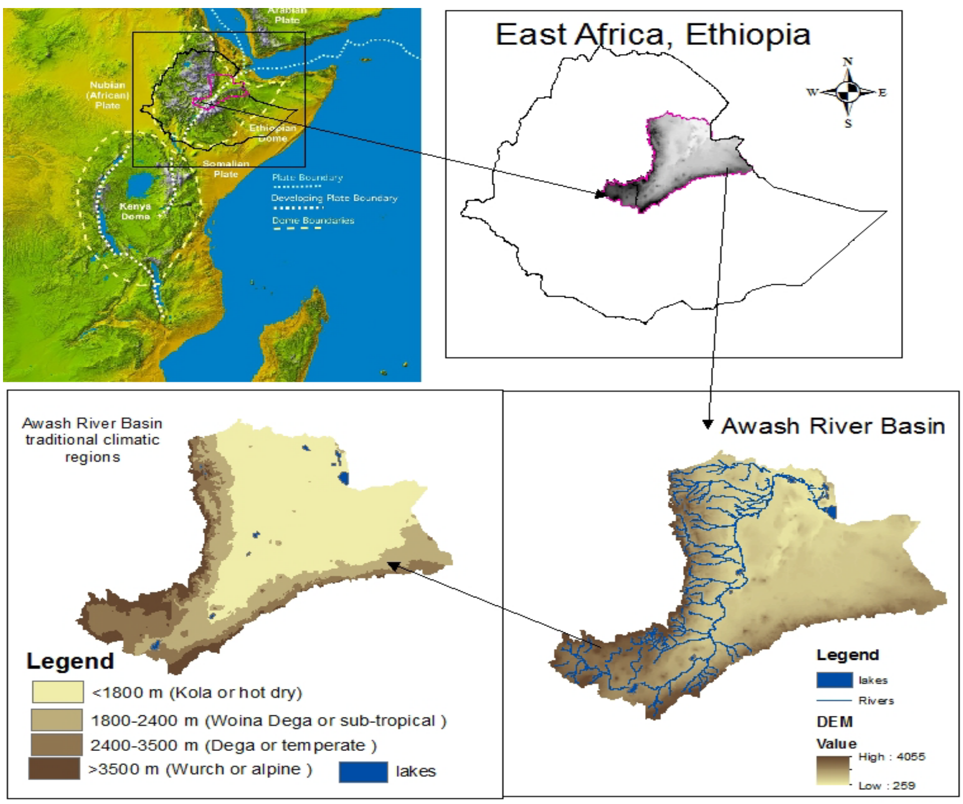

Figure 1: Study area with traditional climatic regions based on DEM.

the influence of the Indian Monsoon throughout the year, mainly determine the climate pattern of the Awash River Basin [20]. There are three seasons in the Awash River Basin based on the movement of Inter-Tropical Convergence Zone (ITCZ), the amount of rainfall and the rainfall timing. The three seasons are Kiremt, which is the main rainy season (June-September), Bega, which is the dry season (October-January), and Belg, the small rainy season (February-May) [21]. The mean annual rainfall varies from 1600 mm in the elevated areas to 160 mm in the lower Awash River Basin [21]. In the same way, the mean annual temperature of Awash River Basin ranges from 20.8°C in the upper part to 29°C in the lower part.

Geology and physiography

The Awash River Basin flows through the Great Rift Valley gorges. The Ethiopian Plateau encompasses Tertiary and Quaternary volcanic units, as basalts, tuffs, ignimbrites, and rhyolites [21]. Through time the river deeply incised and the volcanic masses in the Plateau area rose to over 3,000 m. Fault scarps and the effects of Pleistocene and Holocene volcanic activity frequently break the flat floor of the Rift Valley [22].

Land use and soils

The common land use types in the Awash River Basin are cultivated agricultural land, lake, grassland, cropland with shrub land and forest land. The Awash River Basin consists of different soil types. The most common soil types in the study area are Cambisols and Vertisols. The Vertisols are dominated by the montomorillonite clay mineral. This clay mineral expands when there is a wet condition and shrinks when there is a dry condition, causing cracks at the surface in the dry season [23].

Hydrology

The main source of recharge for the vast groundwater system is the rainfall on the highlands during the rainy season. The major recharge occurs in the north-western, south-eastern highlands and upper basin, where annual rainfall is high. These aquifers are recharged by the streams that originate from the eastern highlands. Seasonal floods occur in summer and the highland's fractured volcanic cover is favorable for groundwater recharge [24]. The River flows in north-easterly direction through Amhara, Addis Ababa, Oromia, Afar, Dire Dawa, Somali territory and finally it drains to the low land Lake Abbe close to Djibouti, which has an altitude of about 250 m above sea level.

Data and Methodology

The HEC-GeoRAS floodplain mapping hydraulics model has been used based on the observed peak flow data from some selected gauging stations. The DEM and other important components of flood hazard and inundation extent mapping have been analyzed using ArcGIS and HEC-GeoRAS.

The most commonly used and selected flood generating factors, such as drainage density, digital elevation model, land use, soil type, rainfall, and slope were combined for flood hazard assessment using ArcGIS 10.1 (Figure 2). The HEC-GeoRAS/HEC-RAS hydraulics model has been used based on the observed peak flow data for six selected gauging stations to map inundation areas (Figure 3).

Methods

Flood hazard assessment: The selected flood generating factors, such as average annual rainfall, soil map, elevation, slope, drainage density, and land use were rasterized and classified in raster format and then weighted overlay using ArcGIS 10.1 to generate the final flood hazard map (Figure 2).

Inundation area mapping: The DEM (digital elevation model) was processed to create the TIN (triangular irregular network). After that, the river cross-sections, stream centerline, stream bank lines, flow lines, and other river geometry information were extracted from the TIN for the HEC-GeoRAS model. At the same time, the land use was processed to get the Manning's n value for the individual cross-sections. After the RAS geometry data preparation, the HEC-GeoRAS model was used to generate the RAS GIS import file (final river geometry file) that can be used as input for HEC-RAS (Figure 3).

Checking the cross-section; editing the river geometry, and making final correction of the river geometry file in the HEC-RAS model. After the compilation of the final river geometry file, the 5% highest flows imported from six gauging stations in different return periods and the HEC-RAS generated water level for different return periods. The water surface level for each return period has been exported in HEC-GeoRAS for final inundation area mapping along the river.

In this case, it is not Aster image (Figure 3 right part) that was used to identify land use classes, but instead land use classes of the

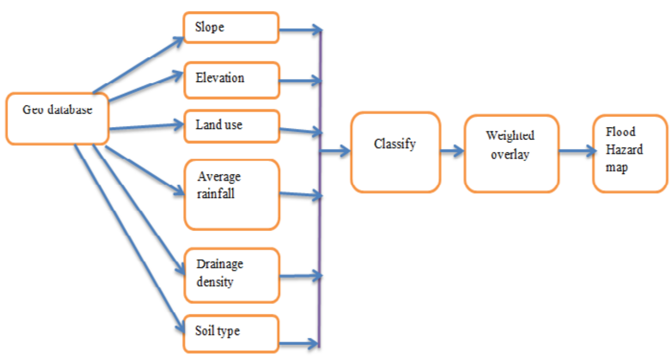

Figure 2: Methodology for computing the flood hazard map.

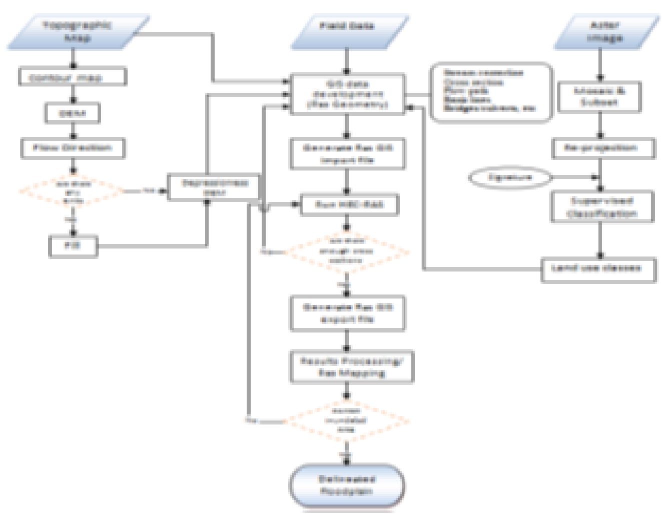

Figure 3: Steps in the River Flood Model Design (Adopted from HEC-RAS User's Manual).

Awash River Basin from Corn Land Cover Facility (CLCF) 2009, were reclassified and applied.

General HEC-GeoRAS or HEC-RAS Model Description

The Hydrologic Engineering Center's Geographical River Analysis System (HEC-GeoRAS) or HEC-RAS has developed by US Army Corps of Engineers Hydrologic Engineering Center and it is a free downloadable with other supportive documents about how to use the model for flooded area mapping. The HEC-GeoRAS is a GIS extension with a set of procedures, tools, and utilities for the preparation of river geometry GIS data to import into HEC-RAS and it is used to generate the final inundation map. The input data required for the River geometry preparation using the HEC-GeoRAS model are Triangular Irregular Network (TIN), DEM, and land use. The river geometry file and stream flow data are the input files for HEC-RAS to generate the water surface level along the River. The HEC-GeoRAS or HEC-RAS has been used worldwide for inundation mapping, such as in Europe [25,26] in the USA [27-29] in Africa [30-32] and in Asia [33-35].

HEC-GeoRAS is a data management interface between ArcGIS and HEC-RAS. This tool provides or creates the river geometric file to be analyzed in HEC-RAS model. The river stream centerline, bank lines, flow path centerlines, and XS cut lines should be digitized from a previous river file, aerial photographs, or topographical datasets using HEC-GeoRAS interface. The river reach (river segment between junctions), cross-section and other related data are stored in the geo database file of HEC-GeoRAS [30]. The river and cross-section data layers are created with predefined attribute tables that are manually populated in the case of the river and reach names, while all other attributes are automatically calculated by the HEC-GeoRAS [30].The interface extracts the geometric data in an .xml format that is imported into HEC-RAS. The results of the HEC-RAS model simulation will be entered into a GIS environment and further analyses will be performed using HEC-GeoRAS tool. The GIS data exchanged between HEC-RAS and ArcGIS are in sdf file format [36].

It is possible to edit the exported GIS geometric data in the HEC-RAS model using the HEC-RAS editor tools. The HEC-RAS consists of a number of editors tools to deal with different functions in the modeling process. For this study only the geometric, steady flow data, cross-section, and steady flow simulation editors are used. The .xml file exported from the HEC-GeoRAS is imported into the Geometric Editor, which is a Graphical User Interface (GUI) that is used to manage the geographic data [27,30]. In this editor, the Manning friction values are entered for the cross-sections of each reach. The stream flow data is entered into the steady flow data editor. This editor extracts the river and data for the reaches from the geometric editor [27]. To compute the water surface level, the model needs to know the starting water level at the start and end of reaches that are not connected and at junctions to other reaches (boundary conditions). For a steady flow analysis, four types of boundary conditions are available, namely known water surface level, critical depth, normal depth, and rating curve [27,30]. The critical depth option was selected in this study; the model will calculate the critical flow depth for the first cross-section along a reach from the cross-section profile and water volumes from the first two cross-sections using the Froude formula [27,30].The steady flow water surface profiles module is used for calculating water surface profiles for steady, gradually varying flow using supercritical, subcritical and mixed flow regimes [27,30].The model solves an energy loss equation between two cross-sections using friction and contract/expansion coefficients [27,30]. The output data of HEC-RAS model are water surface profile variations for different flow rates with varied recurrence intervals in desired lengths of the river, current velocity values, normal depth, critical depth, and hydraulic properties and parameters in the river.

The HEC-GeoRAS assists the ArcGIS in providing pre-processing, direct support, and post-processing functionality before and after the hydraulic analysis. For pre-processing, both HEC-GeoRAS and ArcGIS packages should preprocess data, but HEC-GeoRAS provides the extra capability to capture the geometric data according to the HEC-RAS format required for the hydraulic modeling. The HEC-GeoRAS exports and imports the spatial data to different formats between ArcGIS and HEC-RAS by using a data exchange format called a RAS GIS File [37,38].

Data and Data Analysis

The raster rainfall file for the Awash River Basin with average annual rainfall (1971-2007) was collected from the National Meteorological Agency (NMA), Ethiopia. The soil type and stream flow data were collected from the Ministry of Water and Energy, Ethiopia. The digital elevation model (DEM) and land use were also downloaded from the United States Geological Survey (USGS) and the Corn Land Cover Facility (GLCF), respectively. The daily stream flow data was collected from the five available gauging stations, i.e.Melka Kuntrie, Hombole,MelkaWorer, Adaitu, and Dubti from the Upper, Middle and Lower parts of the Awash River Basin as shown in Figure 4.

Some of the selected gauging stations for this study had missing data for a few days or months. The missing data percentage for Hombole and Melka Kuntrie gauging station was zero. The Dubti gauging station missed 3% of data. Data analysis could not be carried out with missing values, so that periods of missing data had to be filled in by using inverse distance weighting. The inverse distance weighting method was applied for estimating the missing data [39,40].

The mean monthly stream flow for the selected gauging stations along the Awash River Basin presented in Figure 5. The highest stream flow for the selected gauging is in Kiremt season, which is the main

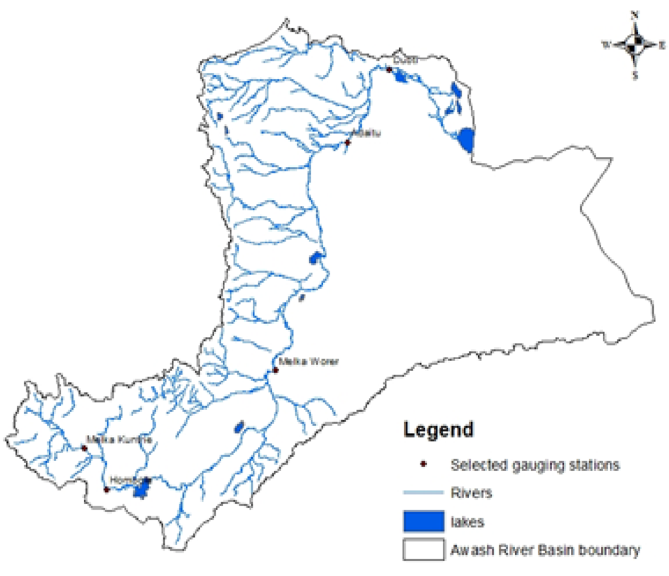

Figure 4: Selected gauging stations along the Awash River.

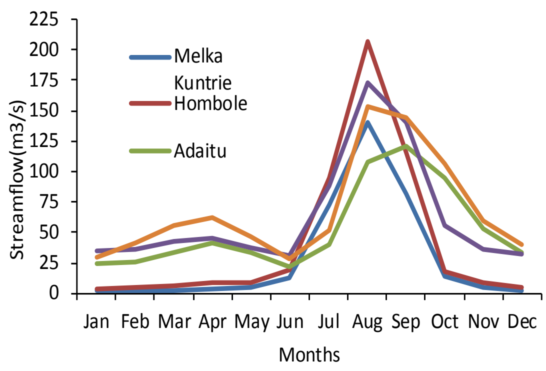

Figure 5: Long years mean monthly stream flow in the selected gauging stations along the whole Awash River

Gauging Stations	Lon	Lat	Area (km²)	Stream flow		Missing data	
				Start year	End year	Stream flow length of day	%
Hombole	38:47	8:23	7656.0	1975	2008	1	0
Melka Kuntrie	38:36	8:42	4456.0	1966	2008	43	0
MelkaWorer	39:51	8:51	31183.0	1973	2009	245	2
Adaitu	40:47	11: 8	52836.0	1980	2003	78	1
Dubti	41: 7	11:42	66308.0	1972	2009	245	3

Table 1: List of selected gauging stations used for this study in the Awash River Basin, including percentage of missing data.

rainy season in the Awash River Basin. The two downstream gauging stations, Dubti and Adaitu showed rather high stream flow in October, November, and December relative to the upper or middle basins gauging stations (Table 1).

Floodplain HEC-GeoRAS/HEC-RAS data analysis

The ArcGIS extension of HEC-GeoRAS was used to extract the complete geometric datasets of the river from TIN for the HEC-RAS input (Figure 6). There are several rules and procedures in the HEC-GeoRAS/HEC-RAS manual regarding how to digitize or create the river geometry components. For example, the cross section lines must be drawn from the left bank to the right bank looking downstream, the cross section lines should be perpendicular to the flow direction, should not intersect, and should intersect the centerline.

The final HEC-GeoRAS output river geometric data of the Awash River Basin that was imported into HEC-RAS model is presented in **Error! Reference source not found.** The HEC-RAS has the ability to import 3Driver schematic and cross section data created in the GIS extension of the HEC-GeoRAS. Whereas, the HEC-RAS model only utilizes 2D data during the computations, the 3D information is used in the program for visualization purposes (Figure 7).

Finally, the selected stream flow values for different return period must be entered manually. For the 95% exceedance flow, there is a high likelihood of occurrence of a flood along the river. However, there was no historical high flow data for validation. Based on previous studies [41-45] 95% exceedance flow has been used to generate inundation extent with different return periods. During the field survey in this study, some GPS coordinate points were collected, where there was inundation in the previous years in the upper part of the river basin to validate the spatial extent of flooded areas. The daily stream flow at the gauging station ranked to extract the 95-percent exceedance high flow to be used in the HEC-RAS with different return period as shown in Figure 8.

Flood hazard factor analysis

The major flood generating factors used for flood hazard assessment are slope, elevation, average rainfall, drainage density, land use, and soil type. The flood generating raster layers have been classified based on their flooding capacity of the area according to previous studies [46-50].

The DEM was converted into slope and elevation raster layers using the ArcGIS conversion tool. The lower the slope value is the flatter the terrain and in the same way the higher the slope value is the steeper the terrain. Based on their susceptibility to flooding; slope and elevation have been classified into five classes (Figure 9). In the classification process, an area at the lowest elevation and slope, very highly affected by flood and then ranked to class 5, which is less than 605 m and <4%, respectively. Following the very high hazard class, there was a class high (605-856 m) ranked 4, class moderate (856-1455 m) ranked 3, class low (1455-1991 m) ranked 2 and class very low ranked 1 (>1991 m). In case of slope, there is class high (4-13%) ranked 4, moderate (13-31%) ranked 3, low (31-74%) ranked 2 and class very low ranked 1 (>74%) (Figure 9). Different breaking values were checked based on the expert knowledge, local information and the 3rdpossible realization, was selected for slope and elevation hazard map

The average rainfall, raster layer was classified into five classes. The long-year mean rainfall pattern indicated that there is high precipitation in the west highlands, northwest and southwest peripheries, while there is low rainfall in the east lowlands of the river basin (Figure 10, right). In the classification process an area with higher rainfall, is very highly affected by flood and then ranked as class 5, which is greater than 879 mm/year. Following the very high hazard class, there is a class high (745-879 mm/year) ranked as class 4, moderate (586-745 mm/year) ranked as class 3, low (435-586 mm/year) ranked as class 2 and very low ranked as class 1 (<435 mm/year) Figure 10, right.The DEM was used to compute the drainage density (Valleys) using the spatial analyst extension. However, all the valleys do not necessary carry water. The drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. The line density module calculates a magnitude per unit area from polyline features that fall within a radius around each cell. The drainage density layer was classified in five classes. In the classification process an area with a higher drainage density is very highly affected by flood and then ranked as class 5, which is greater than 3.15 km/km². Following the very high hazard class, there is high (1.97-3.15 km/km²) ranked as class 4, moderate (1.25-1.97 km/km²) ranked as class 3, low (0.056-1.25km/km²) ranked as class 2 and very low ranked as class 1 (<0.056 km/km²) (Figure 10, left).

Although there is a wide range of soil types, five main soil classes were distinguished based on the hydrologic soil grouping system of Ministry of Water and Energy, Ethiopia. PellicVertisols, Chromic Vertisols, Chromic Luvisols, Euthric Nitosols, and Lithosols [46]. The Vertisols are the dominant soil type in the Awash River Basin. These, five groups of soil types were converted into raster and reclassified based on the flood generating capacity. The soil type that has a very high capacity to generate a very high flood rate is ranked as class 5, high ranked as class 4, moderate ranked as class 3, low ranked as class 2 and very low ranked as class 1. Therefore, PellicVertisols are assumed to have a very high flooding capacity class 5, Chromic Vertisols are assigned as high class 4, Chromic Luvisols are assigned as moderate class 3, Euthric Nitosols are assigned as a low class 2, and Lithosols are assumed to have a very low flooding capacity class 1 (Figure 11, top). The land use

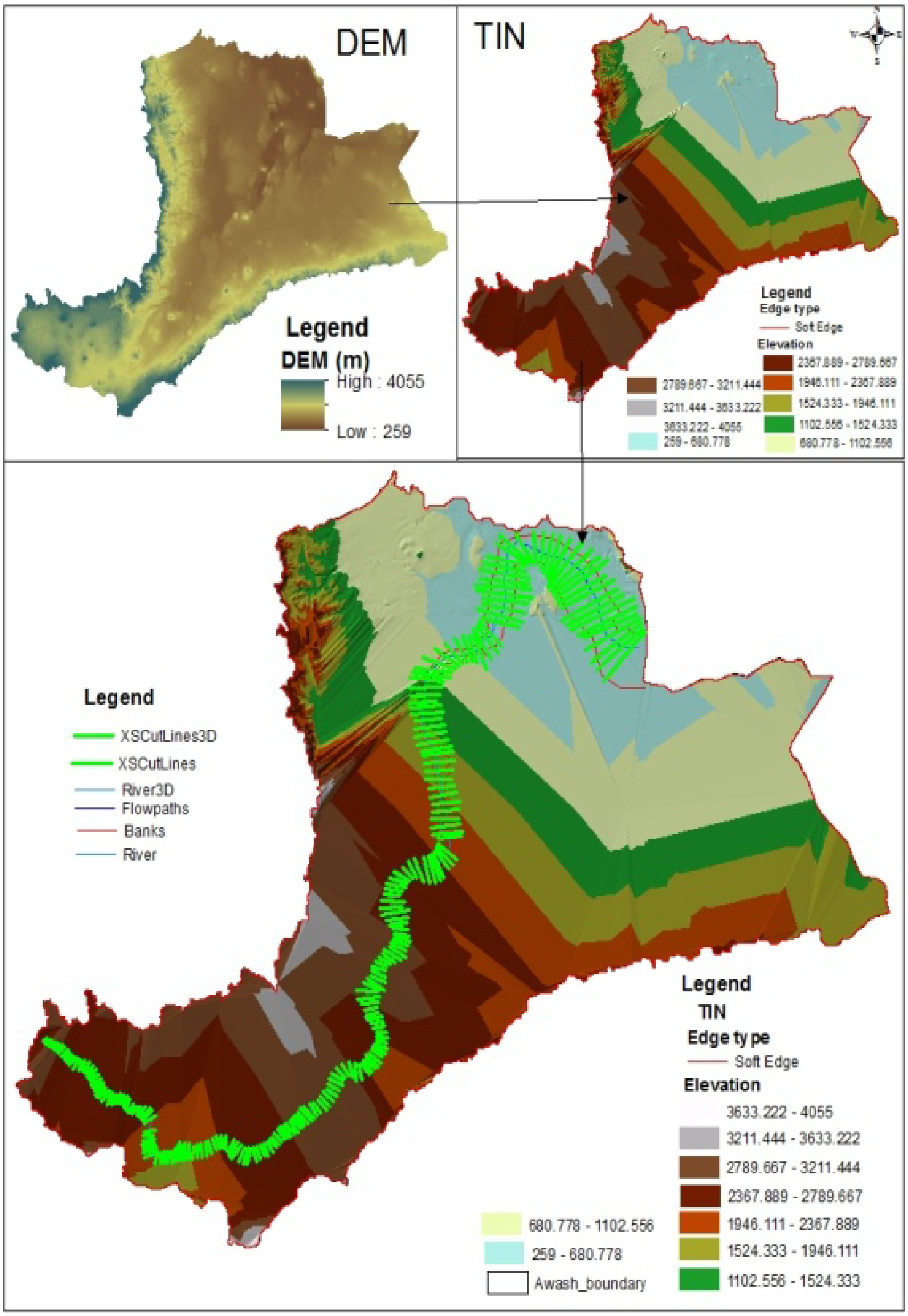

Figure 6: The Awash River Basin geometry data preparation using HEC-GeoRAS.

of the study area was classified into five main classes and converted into a raster layer. Based on the flood generating characteristics of the land use type, cultivated bare land was assigned as very high flooding (class 5), crop/vegetation land as high (class 4), open to closed vegetation/grass land as moderate (class 3), shrub land as low (class 2) and forest land as very low (class1) as shown in Figure 11.

The rasterized and classified flood generating factors (Figures 9, 10 and 11) have to be weighted. In this study Saaty`s approach was used based Analytic Hierarchy Process (AHP), where a pair-wise comparison was prepared for each map using a nine point importance scale (Table 2). According to Saaty, (1980) AHP is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information. It is a methodology to systematically determine the relative importance of a set of activities or criteria by pair wise comparison [47].

Weighting method is used to prioritize the relative importance of each factor relative to another factor. The larger the weight, the more important is the factor in weighted overlay relative to the other factors. The relative comparisons between the six raster layers were performed based on iteration. The IDRISI 32 software was used to

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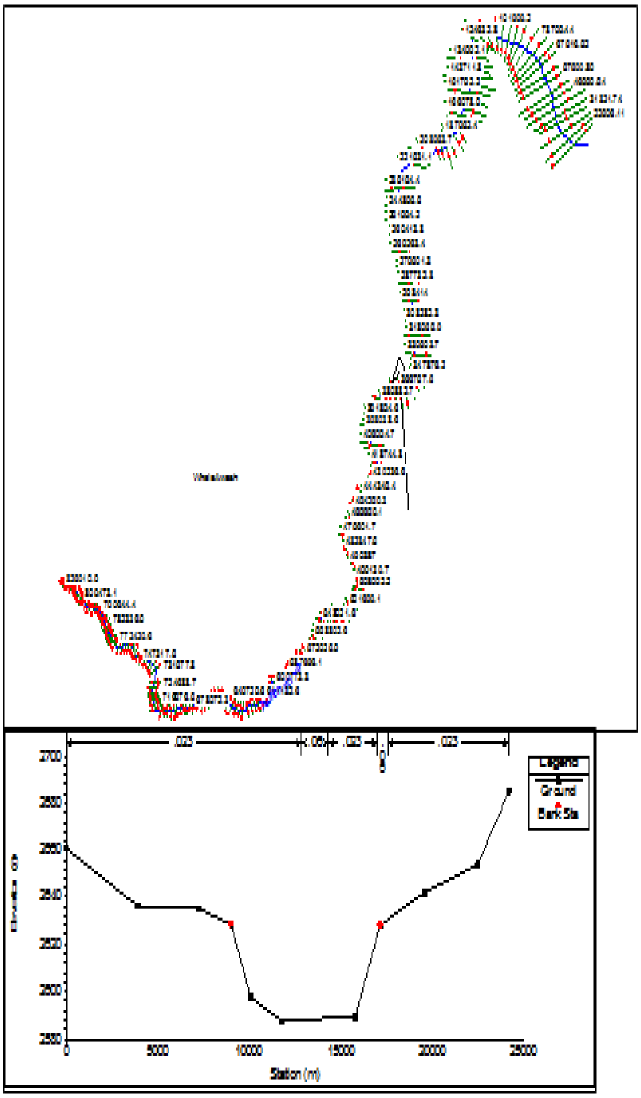

Figure 7: The Awash River Basin river geometry (top) and a sample cross section (bottom) from 558802.6 river station using the HEC-RAS Model; the arrow in the top figure indicates the general flow direction.

calculate hierarchical weights for all layers based on the given pair-wise comparison (Table 3). A consistency ratio values less than 0.1 is acceptable. The calculated consistency ratio was 0.03 that shows that the given pair-wise weights are accepted. The pair-wise comparison indicated a high weight for the elevation followed by the drainage density; slope, rainfall, land use, and soil type (Table 4).

The computed Eigen Vector values were used as coefficient for the respective flood factors that is elevation, land use, rainfall, drainage density, slope and soil type layers to be combined in weighted overlay in ArcGIS to generate the final flood hazard map of the Awash River Basin using the following equation:

Flood hazard=0.439 × [Elevation]+0.239 × [Drainage density]+0.134 × [Slope]+0.092 × [Rainfall]+0.059 × [Land use]+0.038 × [Soil type]

Result and Discussion

Flood hazard map

The flood hazard assessment map was produced by flood generating factors, such as slope, elevation, rainfall, drainage density, land use, and soil type in the Awash River Basin using GIS along with multi-criteria AHP techniques and a weighted overlay.

The flood hazard assessment map shows that 2103 km^2, 35406 km^2, 59272 km^2, 162829 km^2 and 1492 km^2 were correspond to very high, high, moderate, low, and very low flood hazard, respectively (Table 5). The hazard map indicates that the high and very high flood hazard threats are in the downstream part of the basin, which is low-lying flat areas of the Awash River basin (Figure 12). The moderate flood hazard covers the largest area, which is 52%.There is a low and very low flood hazard probability in the west highlands that is the upper part of river basin, in the northwest and southwest peripheries.

The arid and semi-arid low land of the Afar region with mostly grazing land is within the high to very high flood hazard zones. The low-lying areas along the entire Awash River and some agricultural land use types are also somehow within the high to very high flood hazard zones.

Inundation area

The inundation area map along the Awash River was produced by

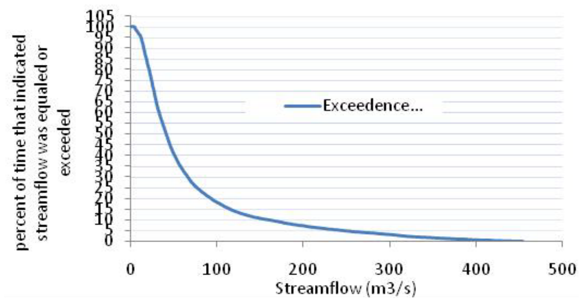

Figure 8: Daily mean flow frequency duration curve for the Awash River Basin at Dubti gauging station.

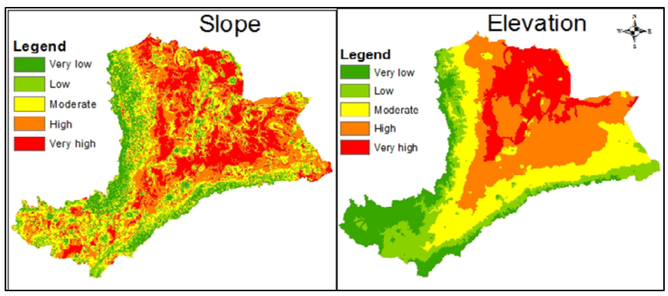

Figure 9: Susceptibility to flooding: rating of slope (left) and elevation (right).

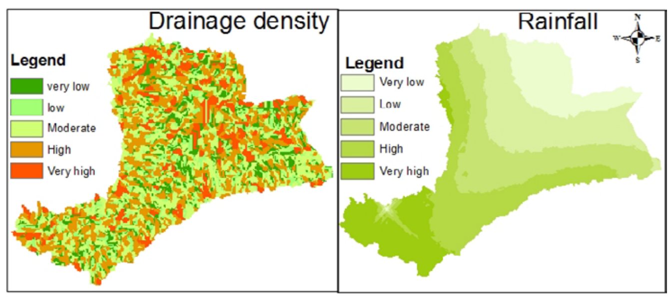

Figure 10: Susceptibility to flooding: rating of drainage density (left) and rainfall (right).

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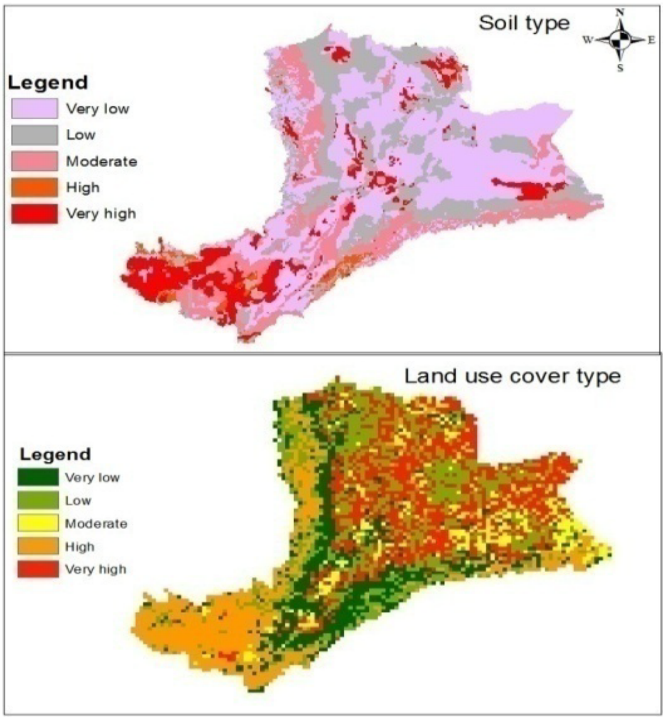

Figure 11: Susceptibility to flooding: rating of soil type (top) and land use cover type (bottom).

Less important				Equally important
extremely	Very strong	Strongly	moderately	
1/9	1/7	1/5	1/3	1

Table 2: Satty's scale (weight) for pair-wise comparison of flood factors [51].

	Elevation	Drainage density	Slope	Rainfall	Land use	Soil type
Elevation	1					
Drainage density	1/5	1				
Slope	1/3	1/3	1			
Rainfall	1/5	1/5	1/3	1		
Land use	1/5	1/7	1/5	1/3	1	
Soil type	1/7	1/7	1/5	1/3	1/3	1

Table 3: The weights for the pair-wise comparison matrix of flood generating factors in the Awash River Basin.

Elevation	0.439
Drainage density	0.239
Slope	0.134
Rainfall	0.092
Land use	0.059
Soil type	0.038

Table 4: The Eigen Vector weights of each flood factor obtained after the pair-wise comparison.

Flood hazard level	Area (km²)	Percent
Very high	2103	1.8%
High	35406	30.9%
Moderate	59272	51.7%
Low	16289	14.2%
Very low	1492	1.3%

Table 5: The Awash River Basin flood hazard level area coverage and percent change.

5% highest flow from the selected five gauging stations for different return periods using HEC-GeoRAS/HEC-RAS model**.** The HEC-GeoRAS/HEC-RAS model considers a high flow from a gauging station in a specific return period as representative flow along the river.

The Ministry of Water and Energy reported that there are some areas along the Awash River Basin that have been frequently flooded after the main rainy season, such as around Dubti down to the Lake Abe, between Debele and Gewane around Lake Yardi and 30 km north of the Awash town [51,52]. The inundated areas indicated by HEC-GeoRAS/HEC-RAS model are similar to that of the areas in the report from the Ministry of Water and Energy. The seasonally flooded areas along the Awash River Basin are the town of Debel near the Lake Yardi, the lower plains around Dubti down to Lake Abe and north of awash town in the vicinity of MelkaWorer. These areas have been flooded for all return periods5, 10, 25, 50, and 100, though the flooded areas were different from period to period. The flooded area for the 100 recurrence interval was high relative to other return periods (Table 6).

The flooded area was high particularly from town Dubti down to Lake Abe for all return periods (Figures 13-17). The inundated areas in the Upper and Middle Awash River Basin are low in most of the times as compared to downstream. Based on the field investigation and land use maps most of the area close to the River Awash is agricultural land. A small part of these areas that are very close to the River might be flooded after the main rainy season.

The 100 year return period flood plain map using the flow data from the Melka Kuntrie gauging station indicated a large inundated floodplain in the lower part of the Awash River Basin that approximately covers 139 km^2 and in the upper and middle part of the Awash River Basin the flooded area approximately covers 26 km^2 (Figure 13).

The 50 year return period floodplain map using the flow data from the Hombole gauging station indicated a large inundated floodplain in the lower part of the Awash River Basin that approximately covers 108 km^2 and in the upper and middle part of the Awash River Basin the flooded area approximately covers 21 km^2 (Figure 14).

The 25 year return period floodplain map using the flow data from the MelkaWorer gauging station indicated a large inundated floodplain in the lower part of the Awash River Basin that approximately covers 54 km^2 and in the upper and middle part of the Awash River Basin the flooded area approximately covers 22 km^2 (Figure 15).

The 10 year return period floodplain map using the flow data from the Adaitu gauging station indicated a large inundated floodplain in the lower part of the Awash River Basin that approximately covers 48 km^2 and in the upper and middle part of the Awash River Basin the flooded area approximately covers 20 km^2 (Figure 16).

The 5 year return period floodplain map using the flow data from the Dubti gauging station indicated a large inundated floodplain in the lower part of the Awash River Basin that approximately covers 24 km^2 and in the upper and middle part of the Awash River Basin the flooded area approximately covers 17 km^2 (Figure 17).

Discussion

The elevation, land use, soil type, rainfall, and slope have been used to derive the flood hazard map using a GIS and Analytical Hierarchical Process (AHP), i.e. multi-criteria decision-making techniques for appropriate land use planning in flood prone areas [47-49]. The flood hazard caused by the extreme discharges of the main rivers is expected to increase due to the climate change [53]. A study in selected regions of Ghana using available topographical, land cover and demographic

Return period	Melka Kuntrie		Hombole		MelkaWorer		Adaitu		Dubti	
	Flooded	Stream flow	Flooded	Stream flow	Flooded	Stream flow	Flooded	Stream flow	Flooded	Stream flow
100	165	944	154	803	101	547	117	1007	119	452
50	134	542	129	622	97	387	107	707	103	443
25	89	390	87	531	76	348	84	602	73	437
10	72	323	63	426	57	321	68	480	62	418
5	44	261	32	382	27	300	38	375	41	350

Table 6: Flooded area (km^2) and stream flow (m^3/s) using HEC-GeoRAS/HEC-RAS model simulated with different return periods for a number of gauging stations.

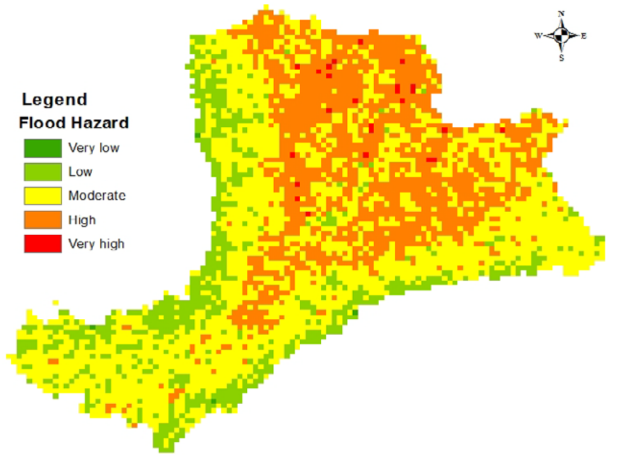

Figure 12: Flood hazard map of the Awash River Basin.

Figure 13: Flooded area for the 100 year return period based on stream flow from Melka Kuntrie gauging station.

data along with GIS indicated that most of agricultural areas were in the high flood hazard zone [8]. A study carried out in the Thach Han River basin, based on different environmental factors showed that there was high flood hazard threat in the downstream area of the river basin [54]. Based on a flood hazard study in the Ribb and Meki Rivers, the flood generating factors were developed in a GIS environment along with multi-criteria decision making techniques. The study indicated that land use change, which involved intensification of agricultural activities increased the overflow magnitude that caused high flood hazard zone in downstream part of the river basins [50]. The flooded area in the Ribb River for the return periods 2, 10, 50 and 100 years was 13 km^2, 19 km^2, 21 km^2, and 23 km^2, respectively. The Ribb River stream flow value was 92 m^3/s, 202 m^3/s, 273 m^3/s, and 308 m^3/s for return periods of 2, 10, 50 and 100, respectively [55]. Based on the flood hazard study in the Dire Dawa town the very low, low, moderate, high, and very high flood hazards zones were estimated 88, 989, 1381, 217, and 61 ha, respectively. Moreover, the study indicated that 100% cultivated, 96% open land, 85% sand deposit, 83% built up area and 75% open shrub land faces low to moderate flood hazard and the 16% built up areas was categorized into high to very high hazard [56].

The flooding due to excessive rainfall in a short period is a challenge in the Kankai River Basin (Nepal), so that based on the study in the river basin the flood prone areas were identified and the flood hazard zone was 59 km^2 and 60 km^2 for the 25 and 50 year return period flood, respectively. The Kankai River Basin hazard prone area considerably increased from the 25 year return period flood to the 50 year return period flood and the agricultural land was the most affected by high flood hazard zone [57]. Due to the climate change the intense rainfall has increased tremendously causing floods in the Susan River (Ghana), so that GIS together with HEC-RAS has been used for flood hazard mapping and approximately 3 km^2 area was flooded along the low-lying area of the river with 10 year return period peak flow [31]. Based on the flood hazard study in the Elbe River the width of inundated corridor for the flood with a return period of 100 years was 1000 m across the Elbe River and the settlements were by far the most flooded by this event [58]. The study of a flood hazard map using GIS environment along with multi-criteria decision making techniques in the Vamanapuram River Basin showed that the flooded areas are likely to increase due to climate change, which are caused by high intensity of rainfall as well as to inappropriate river management [59]. The GIS and HEC-RAS based River Flood Hazard Mapping in the Kayuara River Basin indicated that the rainfall event had more impact on the river flood hazard than the land use change [60].

Conclusion

The selected flood generating factors were processed to delineate flood hazard zone using multi criteria evaluation techniques in a GIS environment. The weights of flood generating factors were computed by pair wise comparison for final weighted overlay analysis to generate the flood hazard map. The weights for very low, low, moderate, high, and very high hazard zone were formulated based on different possible realization as well as from the knowledge of previous studies.The flood hazard assessment indicates that the low-lying areas near the Awash River, particularly in the downstream part are in the high to very high flood hazard zone. The flood hazard threats in the northwest, southwest, and west escarpment of the Awash River Basin are in the low to very low flood hazard threat zone. In particular agricultural land in the low-lying areas that is under high or very high flood hazard risk might

Figure 14: Flooded area for the 50 year return period based on stream flow from Hombole gauging station.

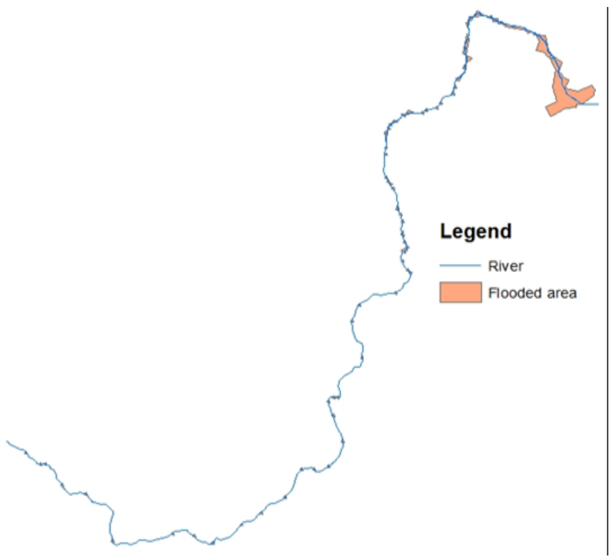

Figure 15: Flooded area for the 25 year return period based on stream flow from MelkaWorer gauging station.

be affected by the flood in the main rainy season. The poor drainage condition in the Awash River Basin particularly in the high to very high flood hazard risk zone has to be improved, land use has to be changed, and land use has to be properly managed for minimizing the flood hazard during the main rainy season.

The flooded areas along the Awash River have been delineated based on 5% highest flows for different return periods using the one-dimensional numerical model HEC-RAS, GIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and GIS. The low-lying agricultural and agro-pastoral lands along the Awash River near to the town Dubti down to Lake Abe show persistent large flooded areas for 5, 10, 25, 50, and 100 year return periods. The flooded areas along the Awash River using the Hombole gauging station peak flow were 154, 129, 87, 63, and 32 km^2 for 100, 50, 25, 10, and 5 year return periods, respectively. Due to the increased stream flow in the 100 year return period, the inundated area was high relative to other return periods. The flooded area in the upper and middle part of Awash River basin was low as compared to the lower part.

The main cause of flooding in the low-lying area along the Awash River is the intense rainfall in the main rainy season. Since it was hard to get a historical flood map or stream flow data, some GPS coordinate points that indicate historical flooded area, and literatures were used to validate the model results. The result of this report is very important as a preliminary information guide for land use planning, policy making, and investment decision as well as for security reasons.

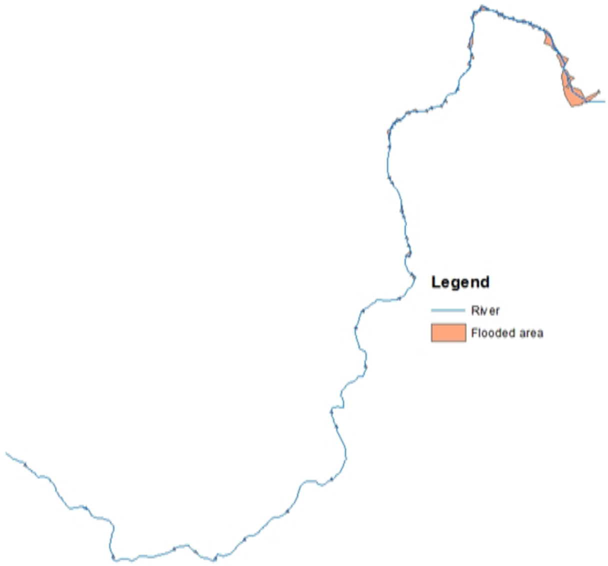

Figure 16: Flooded area for the 10 year return period based on stream flow from Adaitu gauging station.

Figure 17: Flooded area for the 5 year return period based on stream flow from Dubti gauging station.

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