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Floodplain Modelling of Awetu River Sub-Basin, Jimma, Oromia, Ethiopia

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Abstract

Proper estimation and management of flood play significant roles in the design of hydraulic structures and environmental protection. However, in Ethiopia, understanding of flood magnitude estimation and management is not achieved advanced stage. Because of this, many property and life have been damaged in Jimma town frequently. The objective of the study was Floodplain modeling of Awetu River using HEC RAS Model. Here, hydrological and DEM data were used as input data. The hydrological data was used to estimate a flood magnitude of the river by using lognormal distribution corresponding to different years return periods. All geometric data prepared from DEM by using HEC-Geo RAS and exported to HEC RAS. The steady state model simulation carried out by using input data and also the floodplain delineation map was done. The result shows that the river cross section stations 17603, 6001 and 417 are the most vulnerable to flooding area on the right and left side of the river bank. Notably, the downstream part, starting from Jimma University Agricultural College research area to Bishishe, and surrounding are more exposed to flooding. The inundation areas corresponding to 5 and 1000 year return periods are 130.7 and 185.2ha with 19.8 and 21.2m maximum depth respectively. Therefore, the respective body should wide and clear the river channel filled by waste materials and construct necessary structures along the river bank.

1. Introduction

River flooding is a natural events and part of the hydrological cycle of rainfall, surface and groundwater flow and storage. Floods occur whenever the capacity of the natural or man-made drainage system cannot cope up with the volume of water generated by rainfall from the basin [1]. With prolonged rain falling over broad areas rivers are fed by a network of ditches, streams, and tributaries and flow build up to the point where the normal channel is overwhelmed and water floods onto surrounding areas. On large rivers, flooding occurs a considerable period after the Rainfall and last for a long time as the large volumes of water drain out of the catchment[2, 3]. This flood needs proper management to make sensible and fair decisions related to flooding events[4],[5].

A floodplain management is a new and applied method of river engineering and is essential for the estimation of flood hazards[6],[7]. However, life and property have been affected in developing countries because the floodplain management is not correctly executed with consideration of spatial and temporal events. Ethiopia is one of the natural hazard- prone (drought, flood etc.) countries in Sub-Saharan Africa. The impact of drought and flood coupled with poverty and high population growth let many people become victims for various disasters[8, 9]. For instance, in Ethiopia, rainfall attributed to the summer rains has led to extensive flooding. It is estimated that about 18,628 households (93,140 people) have been affected , of which 7,270 households (36,350 people) have been displaced from their home [10]. It has direct impacts on the human and animals lives and contributes to the modification of a fragile ecosystem through land degradation. Low-income communities usually settle on flood-prone areas of a town mainly because of rapid urbanization and population increase. And besides this, the poor drainage system of the town also intensify the risk of flooding as well[11],[12]. The reduction of green areas and the increase in the impervious area in urban areas generate more surface runoff even from regular storms and the situations will be the worst when poor people settle in the regions vulnerable to flooding such as riverside and low-lying floodplains[13],[14],[15].

Because of the above reasons and extreme climate events like increment of precipitation in summer season [16], Addis Ababa is vulnerable to riverine as well as flash floods [17].Also, on 5 August 2006, torrential rains caused the Dechatu River to burst its banks, causing severe flash flooding in the region of Dire Dawa [18]. According to the report by the United Nations Office for the Coordination of Humanitarian Affairs on August7, 2006 (http://www.ifrc.org/), 300 people were displaced and 200 dead. Similarly, in Jimma town about 150 households have been displaced and suffered by flood frequently occurring through the year because of the mentioned causes and lack of proper collection and disposal system of both solid and liquid wastes in the town [19], [20].

The majority of flood disasters' victims are poor people living in a nearby stretch of floodplain [21].In addition, big productive business and infrastructures have been damaged due to extreme rainfall coming from upstream highland during rainy seasons as shown in figure1.1.

Figure 1.1 Flash flood of Awetu River in Jimma Town surrounding Bishishe

It will cause to serious flooding problem which affects the population life and property settling on the river bank. To prevent as such hydrological event of the flooding problem in urban and rural areas, it is important to understand that hydrological response of the catchment using different hydraulic and hydrologic models.
Hydraulic and hydrologic models can quantify the magnitude of flood and forecast, identify the most causes of the flood and identify the most prone area of the flood to make its management easy. Through the integration of the GIS extension, HEC-Geo RAS and HEC-RAS, engineers can use an available DEM by converting to triangular irregular networks (TIN) to build the geometric file for an HEC-RAS model[7, 22]. And the Geo RAS extension has primitive import and export capabilities to smooth the transition between creating the geometric file, simulating the model and displaying the results. Also, it is used to delineation floodplain quickly with greater accuracy and a flow depth grid representing to the user the level of inundation of any area in the model [23] .
Recently, several scholars have been used HEC-RAS with integration GIS tool for floodplain modeling and mapping of a River as worldwide and Ethiopia. For instance, flood inundation map was developed for case study of Edirne city in Turkey[24] and a case study of Nakhon Ratchasima municipality, Thailand[25]. Also, three-dimensional simulation of a centennial flood of Mohammedia city inthe river of El Maleh was developed for different return periods in Morocco[26].
In the same manner, the models have been applied in Ethiopia basins at different time and space for flood modeling and mapping study [4, 8, 16, 27-29]. But Awetu River floodplain modeling has not studied by another researcher. Therefore, this research was conducted to model Awetu River floodplain by using a hydraulic model called HEC-RAS with the integration of GIS and HEC -Geo RAS model to save lives and properties settling on the bank of the river.

1.1 Description of Study Area

Jimma Town is one of the biggest and dominant political, Economic, cultural and historical towns in the Oromia Regional State and southern part of the country (Ethiopia), which has been, founded the late 1830s. Jimma town is locally known as the town of Aba Jiffar. It is situated 350kms from Finfine on the high way of Mettu - Gambella at an altitude of 1620 m.a.s.l. geographically; the town is located 7° 40'N latitude and 36°60'E longitudes. As per the master plan of the city, the total area of land town is 4623 (46.23km2) Hectare. Two major rivers are flowing through the town: Awetu, which bisects the center of the town and Kito, which flows at the western end. This study was conducted to Awetu River which flows through the center of Jimma town and contributes to Boye wetland.

2. Material and Methods

2.1 Data Collection Process and Analysis

The use of any model must be preceded by data collection. The input data types were collected from different organizations, literature, and websites. Spatial data (Digital Elevation Model) and hydrological data were the primary input data type used in this study. The detail description of these data is given below.

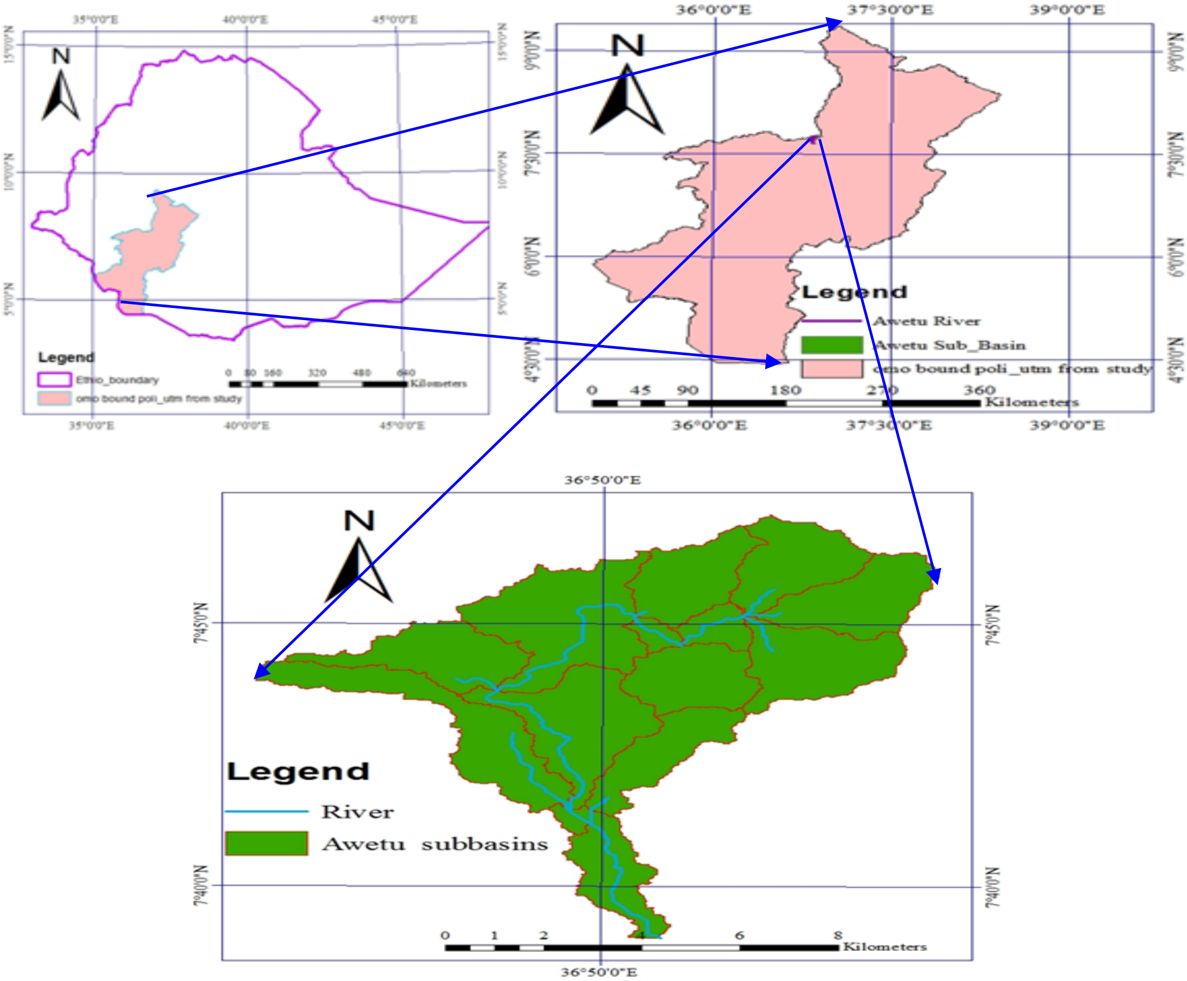

Figure: 1.2 Map of Study Area

2.1.1 Digital Elevation Model

Topography was defined by a DEM which describes the elevation any point in a given catchment area at a specific spatial resolution. This high resolution of DEM 12.5mx12.5m was downloaded from the website of https://www.asf.alaska.edu/ and projected properly. The projection of the DEM data was made using the Arc toolbox operation in Arc GIS10.1. The projected coordinate system parameters of the study area are GCS-Adindan and UTM zone 37N projection. The required spatial datasets were projected to the same projection called Adindan UTM Zone 37 N, which is the transverse Mercator projection parameters for Ethiopia, using ArcGIS 10.1.

2.1.2. **Geometric Data Preparation**

Geometric data is one of the vital information regarding the geometrical information of a specific river stretch. The DEM was uploaded to HEC Geo RAS 10.1 of Arc GIS extension to generate geometric data. The geometrical data of river was prepared using a tool called HEC-Geo RAS which assists in preparing input file as well as post-processing of the HEC-RAS results in the GIS environment. The crucial layers that were created by HEC Geo RAS are the stream centerline, flow path centerlines, main channel banks, and cross section cut lines as RAS layers. These all parameters were used to establish a series of cross-sections along the stream. Finally, these geometric data were saved to interest director and exported to HEC RAS.

2.1.3. Hydrological Data

The hydrological data is required as input for HEC RAS model to steady and unsteady river flow analysis as per research objective. For this study, daily hydrological data (1982-2006) was collected with some missing data of stream flow from the hydrology department of Ministry of Water, Irrigation, and Energy (MoWIE) of Ethiopia. The missing data were filled by linear regression using XLstat2017 tool (http://www.xlstat.com). After the consistency of hydrological data was checked, statistical frequency analysis was carried out by lognormal distribution function based on the procedure frequency analysis [30]. Accordingly, flood magnitudes of the Awetu River were estimated corresponding to 5, 10, 25, 50,100 and 1000 years return periods.

2.2. HEC -RAS Model Development

HEC-RAS and HEC-GeoRAS (Geospatial River Analysis System), an extension of HEC-RAS were used to simulate flash floods in the Awetu River Basin. HEC-RAS was developed by the Hydraulic Engineering Centre, a part of the Institute for Water Resources, U.S. Army Corps of Engineers [31]. The Research Institute developed several programs for river modeling in 1965. The first version of HEC-RAS was released in 1995 to assist in analyses of rivers, streams, and channels. The software HEC-RAS is an integrated system of software that can simulate the water flow in rivers and channels using a numerical model. This software is one dimensional which means that there is no direct modeling of the hydraulic effects of the transverse profiles. [32].The most importance of HEC- RAS model is to estimate the water surface profiles of flash flood events to simulate and create flood inundation maps. The water surface profile calculation is based on the one-dimensional energy equation as per HEC- RAS manual[33]. In this study, three steps have been followed to run hydraulic or hydrologic modeling (HEC -RAS) with aid of the GIS environment. These steps are Pre-processing of data, Modeling phase, and Post-processing of data [34].The first step in developing hydraulic model HEC -RAS is to establish which directory the researcher wishes to work in and enter a title for the new project. Then, the cross section was opened and geometric data called by GIS format and edited. And all RAS layers like stream center line, bank lines; bank stations, flow path center lines, cross-section cut lines, and others were generated from DEM or triangular irregular networks (TIN). Flow data of the river was entered to the model corresponding to the return periods as shown in table 3.1below.

Also, manning coefficient of the main channel, leftover bank and right over bank, contraction coefficient, expansion coefficient and boundary condition were entered to the new HEC RAS project developed step by step as per the HEC- RAS manual, to simulate steady-state flow successfully. In the present study, when the software output data was exported, it created two files namely xml and sdf, which were used for more operations in the model and the data quality was checked by graphical cross sections editor tool for each cross-sections.

After modeling in HEC-RAS, results were interred into Arc View and by using HEC-geoRAS and cross-section tools extensions, flood zones and its areas was extracted. HEC-GeoRAS was used to extract water surface profile data from HEC-RAS and incorporate it into a floodplain map in GIS [35].The flooded area was delineated using the water surface data, and the DEM created for the basin. Finally, floodplain mapping was done by exporting output of HEC -RAS to HEC- Geo RAS Arc GIS extension. To achieve the objective of the study, the following procedures have carried out as shown figure 2.1 below.

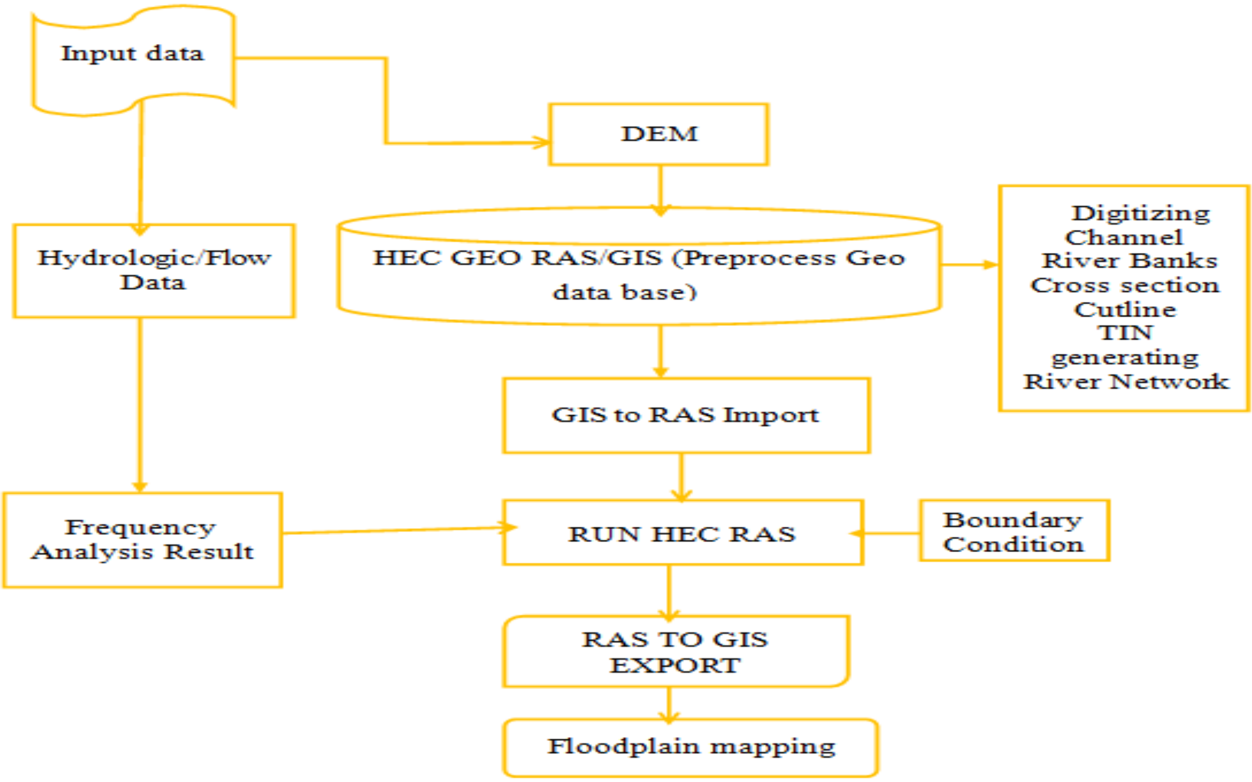

Figure 2.1 Flow Chart of Awetu River Flood Modeling

3. Results and discussion

After preparation, and consistency analyses of the maximum instant annual rates of stream flow at the considered gauged station, the Awetu River flood magnitude was determined by Log-Normal distribution function for different return periods. The simplest methodology was provided by developing a table of frequency factors and by considering the coefficient of variation Cv as zero specifically for the lognormal probability distribution function (pdf) [36] . The discharge magnitude of the river was estimated as shown in table 3.1 below and used as the model input.

Table 3.1 Peak discharge estimated

Return periods (year)	5	10	25	50	100	1000
Peak Discharge(m^3/s)	20.72	30.24	45.25	58.71	74.17	143.02

3.1. Flood Modeling of Awetu River

In this study, steady flow was simulated along 18 km end of Awetu River, in Jimma town, Ethiopia. HEC-RAS simulation model integrated with GIS capabilities was used to meet the objective of the study. After preparing the project file, a TIN theme was extracted based on georeferenced field cross sections and topographical data to prepare the required data to be processed. Topographic map with the scale of 1:25000 and river plan with the scale of 1:1000 were applied for TIN generation using 3D analyst capability of Arc View. Also, the geometric data of the river cross-section profiles were extracted from this map as per figures 3.1, 3.2 and 3.3 shown below.

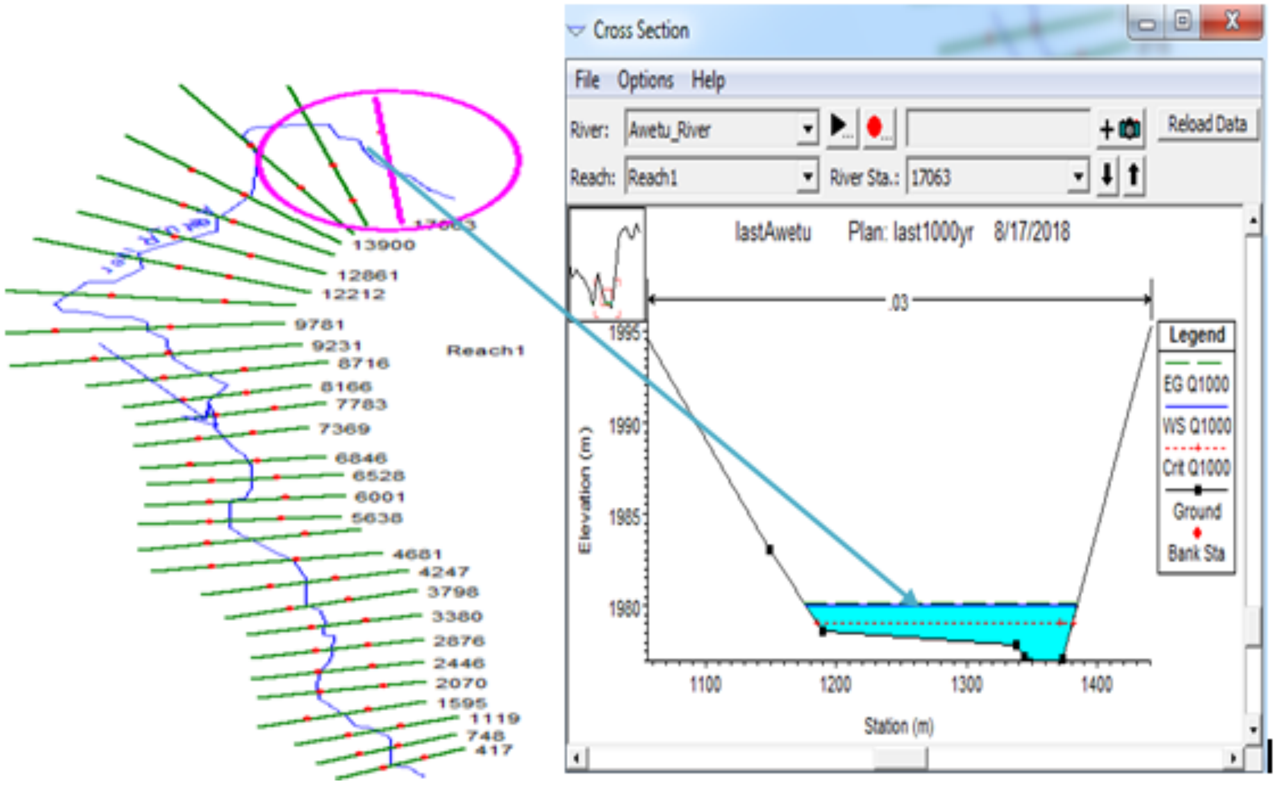

Figure3. 1 Awetu River cross section station of 17063

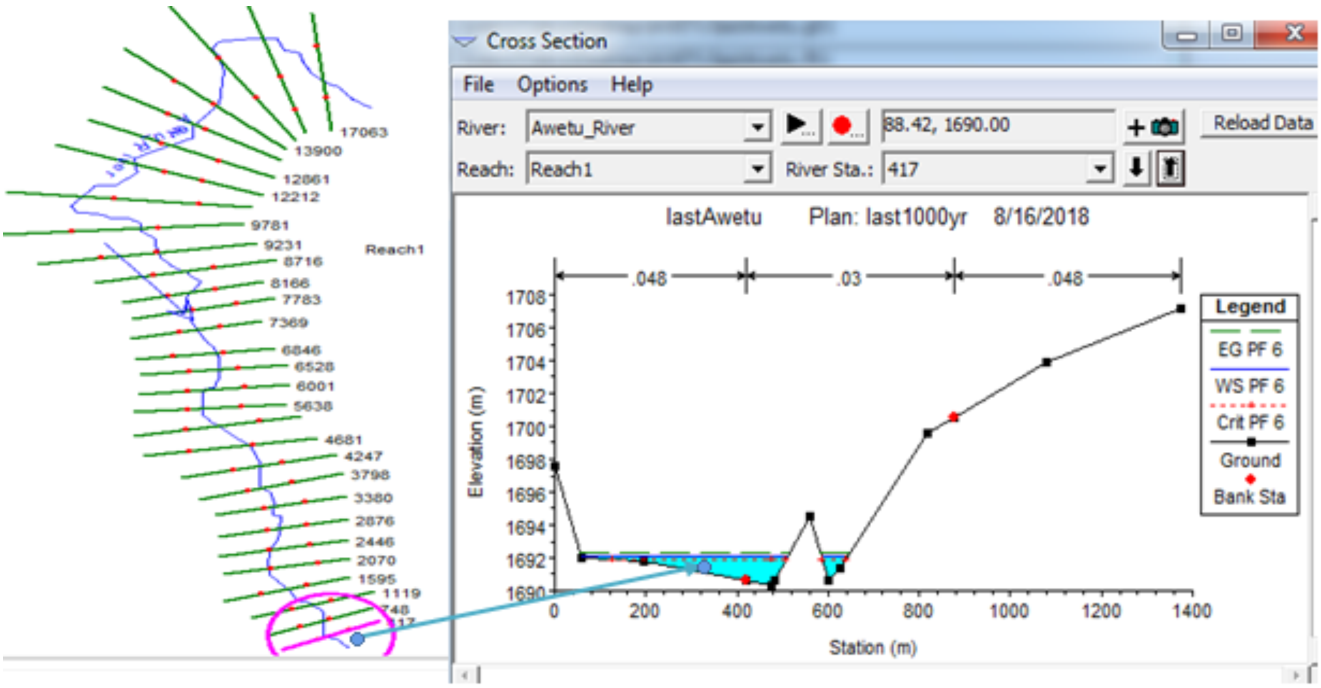

Figure 3.2 Awetu River cross section stations of 417

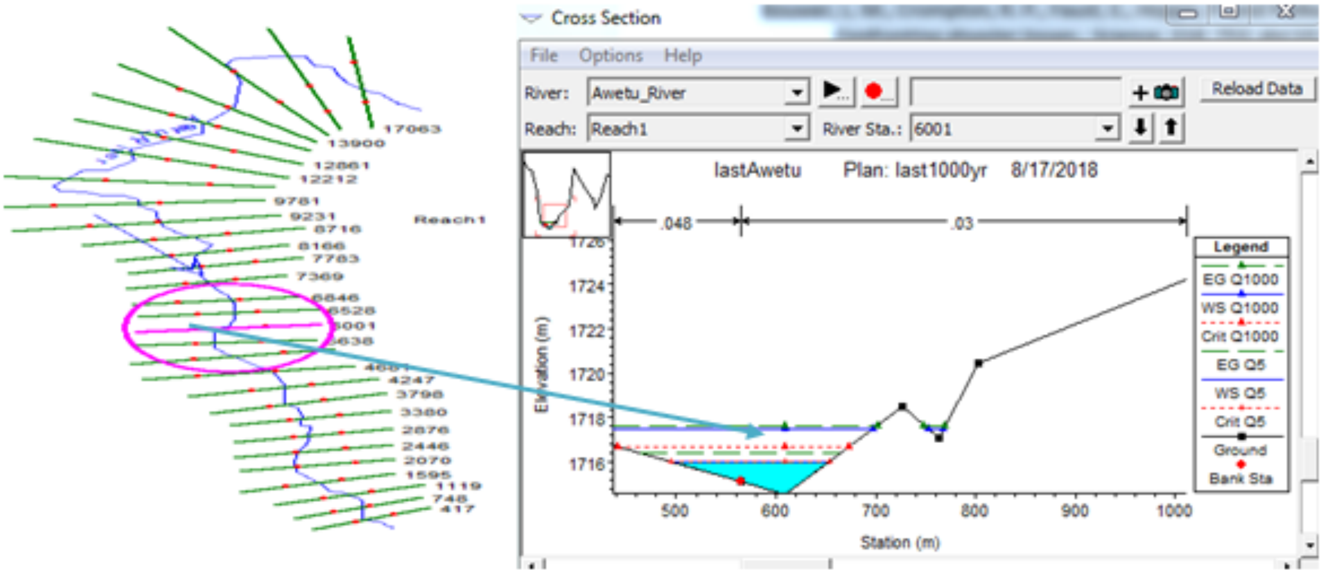

Figure 3.3 Awetu River cross section stations of 6001

For flood analysis a total of 30 cross section cut lines have been drawn and, considering a lot of cross sections water surface levels for different return period of years have been studied under the given boundary condition. The steady flow simulation of cross sections of river stations 17063, 417 and 6001 cross sections which were severe among total cross section are as shown in figures 3.1, 3.2 and 3.3 respectively. The result of simulation shows that as an increment of peak discharges used corresponding to return periods, the river starts overtopping from right-hand side bank and as well as from left side bank. The flooding problem is not only at the river stations as mentioned above, but also there is a series flooding problem along with all the river bank upstream and downstream except at small stations.

The results of the water surface calculation at different return periods in HEC-RAS software was transferred to GIS through HEC-GeoRAS extension, and flood zones were determined for each period. It is obvious that by larger flood discharge, more areas go under water, but indeed, the extent of these changes is essential, because this information could be very useful in planning land management of riverbank. As shown in table 3.2, the inundation area and flood level are increased corresponding to return periods. For example, the inundation area of 5- and 1000-year floods are 130.7 and 185.2ha with19.8 and 21.2m maximum depth of the flood respectively as shown in figure 3.4 and 3.5. It indicates that the inundation area is increased by 29.43 percentages and without much increase in flood level. Most of the overflow problem is on the right bank of the river, but especially high magnitude flooding is observed on left hand side of the river surrounding downstream part Jimma University ,Agricultural College research area and marketplace at Bishishe and near middle part as shown on figure 3.5.In the upstream part near Somodo kebele, there is more inundated area with medium flood level. It can be occurred due to a narrow of the river channel and other condition. The water surface extents from the mouth of river bank are 500m near Agricultural College research area and 200m long near Bishishe. Also,on the place where overflow was observed along the left river bank, water surface extent is equal and less than 200m length. This flood reaches the asphalt road which passes through Bishishe and near a big Muslim mosque. It shows that the capacity of

Awetu River Bank is less than the peak flood occurring during the rainy season and being the main reason for life loss and damage properties settling on the river banks. These floods come from paved lateral side of the river channel land and tributes but most percentage is generated from upstream part of the river.

According to a study conducted, Awetu River channel is mainly affected by poor management of both solid and liquid wastes in the town **[20]**. Specially, solid plastic wastes and other material are thrown to the river are blocking the river flow and being the main causes of overflow in some places.

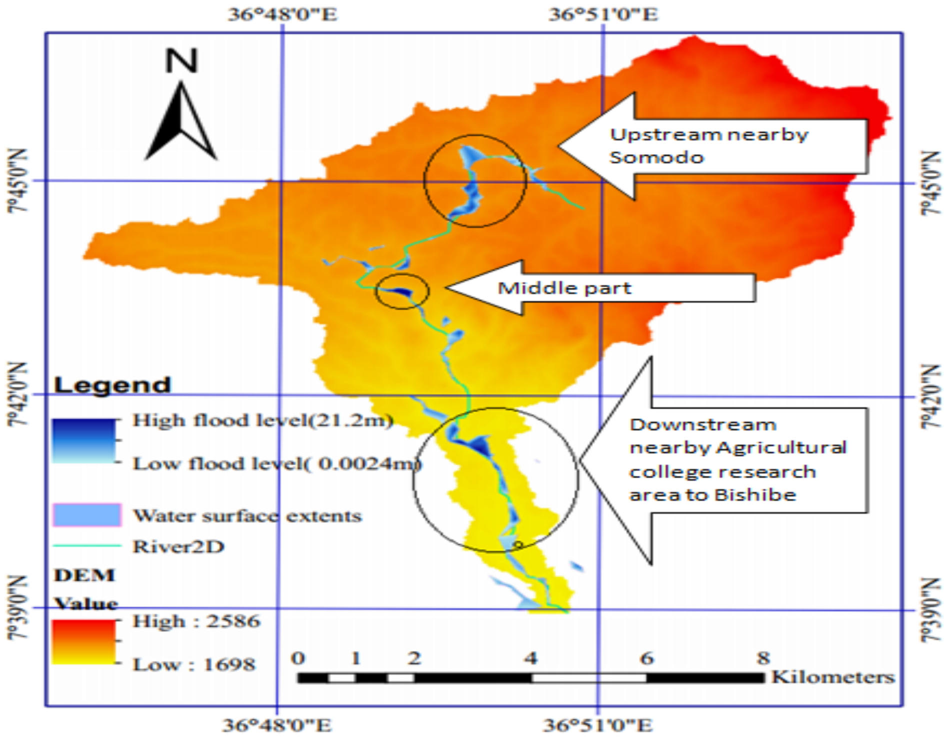

Figure 3.4 Floodplain delineated map of Awetu River for 1000 years return period

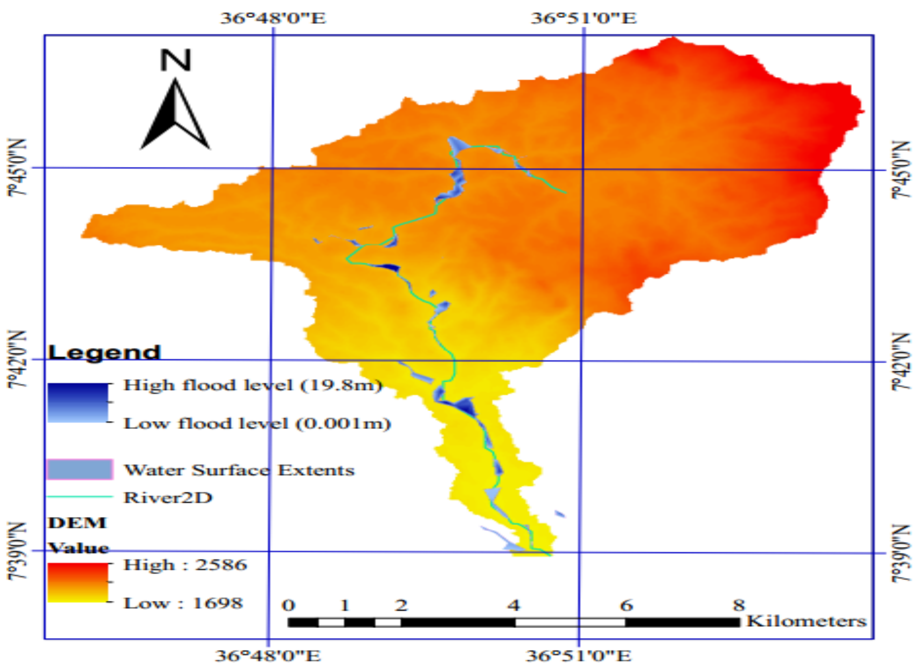

Figure 3.5 Floodplain delineated map of Awetu River for 5 years return period

Table 3.2:Area of inundated and water level

Return periods	Inundated area (ha)	Minimum water level (m)	Maximum water level(m)
5	130.7	0.001	19.8
10	137.5	0.0004	20.1
25	148.2	0.0005	20.3
50	154.2	0.0005	20.5
100	162.4	0.001	20.6
1000	185.2	0.0024	21.2

In the same manner improper design drainage system throughout the town shares some percentage for this flooding problem. Generally, it brings a serious flooding problem which can affects life of population and property settling on the river bank. Also, ecosystem damage along the river can be cause for big economic crisis .Therefore; the concerned body should give attention to a clear channel of the river and construct structural and non-structural along the river bank especially at downstream right side of the river bank. The structural measures include flood walls and levees construction, channel excavation and modification for future flood mitigation plans along the river channel. Also, it is better to relocate the population residing along the river banks.

Conclusions

In this study, HEC RAS and HEC Geo RAS Arc GIS 10.1 extension models were used for flood modelling of Awetu River. HEC Geo RAS was used to prepare and process geometric input data from high resolution of DEM and delineate floodplain map. The geometric data prepared has 30 cross sections. Also, the flood frequency analysis of Awetu River was conducted to estimate flood magnitude of the river. Flood mapping was done properly and inundation area and flood depth were identified. From the result of floodplain mapping, it is possible to conclude that there is severe flooding area along the river bank against to the return periods. Also, the result obtained indicates that both upstream and downstream right bank of the river is exposed to flooding hence the concerned body should take remedial measures along the river. As per observation made during data collection and field visit, the downstream section especially starting from recreation center on Awetu River the channel is filled by solid waste materials and this is considered as one of the factors of the flooding problem. This shows that the runoff coming to Awetu river channel from different drainage area is greater than the capacity of the river channel. Finally, it can be concluded that almost the right side of the river bank is exposed to flooding hence the remedial measures are needed to prevent loss life and damage properties.

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