Modeling Earth Systems and Environment (2022) 8:1449–1460
https://doi.org/10.1007/s40808-021-01166-9

REVIEW ARTICLE

Application of HEC-RAS and HEC-GeoRAS model for Flood Inundation Mapping, the case of Awash Bello Flood Plain, Upper Awash River Basin, Oromiya Regional State, Ethiopia

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Received: 13 November 2020 / Accepted: 16 April 2021 / Published online: 7 May 2021

Abstract

Flood is the devastating natural events as it causes massive destructive of life, economy and infrastructure. The main objective of this study was flood inundation mapping using HEC-RAS model: the case of Awash Bello flood plain, Upper Awash River basin, Ethiopia. River geometry, annual peak flood, and boundary conditions are the most important input parameters for RAS preprocessing. The river cross-sections along the flood plain were extracted using HEC-Geo RAS. Annual peak flood frequency analysis for different recurrence intervals (i.e., 2, 5, 10, 25, 50, and 100 years) was computed using the calibrated and validated HEC-HMS model based on a 25 years (1990–2015) hydro-meteorological data collected from Ministry of Water Resources Irrigation and Electricity and National Meteorological Agency, respectively. The model result depicted the flood extreme value for the respective recurrence interval was 526, 610, 828.8, 1072.8, 1263.6, and 1461.3 m^3/s, respectively. For more reliability, the HEC-HMS model outputs were compared with the flood extreme value obtained from Log Pearson type-III, General Pareto and Gumbel extreme value distribution function and it was found the HEC-HMS model result for every recurrence interval was higher than the extreme value distribution function outputs. After verifying the acceptability of the HEC-HMS model result, the verified peak flood was inserted into HEC-RAS model and flood inundation mapping for different recurrence intervals were executed. The HEC-RAS model outcome indicated that the flood inundation mapping area for 2, 5, 10, 25, 50, and 100-year recurrence intervals, respectively, was 71.475, 76.630, 89.150, 100.290, 105.160, and 109.462 km^2. Finally, it was realized that the whole Awash Bello flood plain is under the influence of flood inundation due to the intensive rainfall event.

Keywords Awash Bello · Flood frequency analysis · Flood inundation mapping · HEC-HMS · HEC-RAS · Arc GIS

Introduction

Flood is undoubtedly the most devastating, widespread, and frequent natural hazard of the world that produces many socioeconomic and environmental consequences within the affected floodplains. As the study conducted by (Aris 2003; Getahun and Gebre 2015) stated, floods can be defined as the surplus water beyond the carrying capacity of the river channel, lakes, ponds, reservoirs, drainage system, dam and any other water-related structures, whereby it inundates the area of the land outside water bodies. Flood is the combined result of hydrological and meteorological processes that makes it one of the most destructive natural events. It is a natural phenomenon that temporary inundates surface of the land outside the water body owing to bursting and overtopping of water in the natural or artificial channel. Furthermore, rising up of ground water table due to heavy and prolonged rainfall have significant contribution to the emergence of this catastrophic events (Wisner et al. 2004; Martini and Loat 2007; Santos et al. 2014). Flood is among the disastrous natural outcomes as it causes terrible and costly damage to lives including human, infrastructure, and the environment as a whole. As per the study conducted by (Abon et al. (2015)) indicated, about 196 million people in more than 90 countries were exposed to catastrophic flooding problem now a day and hence it was attracting the eyes of numerous researchers all over the world. At present, flood

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is highly affecting worldwide people than any other catastrophic events (Banks et al. 2014). Hence, it is important to thoughtfully considering floods and risks accompanying to it to hand over the probable destruction. Flood damage control include flood forecasting and warning systems, flood inundation mapping, preparation and implementation of flood mitigation and adaptation strategies alternatives those have becoming more important all over the world (Pedro et al. 2015; Dale et al. 2012; Santos and Tavares 2015; Son et al. 2015; Adams and Pagano 2016; Santillan et al. 2016). Flood is non-stopping and frequently occurring natural events in floodplains of monsoon rainfall areas like Ethiopia, where over 80% of annual precipitation falls in the four wet consecutive months (Sanyal and Lu 2005; Gashaw and Legesse 2011). (Abon et al. 2015) stated that flood is one of the most harmful natural disasters in the world, and therefore, it needs excellent attention especially in the area that redundantly affected by flooding problem such as Awash and rift valley regions of Ethiopia.

According to Getahun and Gebre (2015), Ethiopia generally faced two types of flood. These are floods due to excess and prolonged rainfall that contribute to the flood in the main and tributaries of the river and floods owing to the unexpected release of excess amount of water from reservoir or dam. The flood in Awash River basin is due to the excess precipitation that occurred in the highland of the basin, (Getahun and Gebre 2015). The present fluctuating climatic condition is one of the driving force behind such extreme events and it plays a significant contribution in increasing the heavy rainfall that latter generates unusual flood in the whole basin. Flooding will occur when the watershed system receives unusual high rainfall intensity or the prolonged rainfall event so that the stream flow rate exceeds the channel capacity (Kania et al. 2015). Awash Bello flood plain is the primary flood vulnerable area of Awash River basin among those flood plains accompanying extreme flood magnitude generated from the prolonged and intensive precipitation especially, from month of June to September (Kefeyale (2003)). It is a flat plain and suitable area for a variety of agricultural activity as a result of which it was densely populated by ample of farmers. However, during the specified months, i.e., from June to September, this flood plain is completely inundated due to the flood over flowing the Awash river. As a consequence of this, a number of households were imposing to be displaced from their homeland frequently, and they were exposed to homelessness, food insecurity, and other related problems.

In addition, many animals and different infrastructures were damaged due to such catastrophic natural events (Kefeyale 2003). For the rehabilitation and sustainable livelihood of the householders, emergency action should be taken by the government body and Awash Basin Development Authority (BDA). Through mapping the inundation area and identifying the flood concentration center of the flood plain, this study has vital role for the better achievement of flood mitigation action to be taken. It can be used as the best indicator of flood mitigation alternatives. There are two most widely used flood mitigation strategies. The first strategy is the structural strategy that completely based on the application of engineering and technology. It is the physical structure constructed along the flood plain at side of the river bank to avoid flood overflowing. The second flood mitigation strategy is the conceptual or non-structural flood mitigation strategy that mainly encompasses flood time computation and early flood warning systems. Owing to financial capacity, the implementation of the former flood mitigation strategy is difficult in the developing countries like Ethiopia while the latter is the only option where the construction of structural mitigation strategy is not possible.

Flood inundation mapping is the basics for the conceptual flood mitigation measures. For proper flood risk management and flood damage rehabilitation, flood extent area identification is the prerequisite that can be done through flood inundation mapping. Therefore, the main objective of this study was flood inundation mapping based on Hydrologic Engineering Center's River Analysis System (HEC-RAS). HEC-RAS is hydraulic modeling software developed by the U.S. Army Corps of Engineer's Hydrologic Engineering Center River Analysis System. Many researchers have been used HEC-RAS model for flood inundation mapping and flood hazard assessment in different areas of the world. According to Merz et al. (Merz et al. 2007), flood inundation mapping is the useful tool assisting for flood hazard management and flood extent area identification. HEC-RAS is the best computer programming software widely applicable for the successful flood inundation mapping. Several critical parameters are required for performing flood inundation mapping using HEC-RAS. These are topographic data, discharge data (profiles), Manning's roughness coefficient, and river geometric cross-section (such as river centerline, flow path lines, river bank lines, XS cut line), bridge data, and physical watershed parameters (Banks et al. 2014). Flood inundation mapping requires forecasting of the behavior of stream flow and hydrological events along the flood plain under question for various recurrence intervals and the knowledge to convert the forecasted peak flood into the plan-view extent of the floodplain [29].

The HEC-RAS can also model flooding events and produce water surface profiles over the length of the modeled stream. Through the help of GIS extension Geo Spatial River Analysis System (HEC-Geo RAS), those water surface profiles can easily be converted to flood inundation maps. By understanding the extent of flooding and flood inundation area, decision makers can make choices about how to best allocate resources to prepare for emergencies action and to improve the quality of life generally. For this study, HEC-RAS together with HEC-Geo RAS was used for flood inundation mapping. The software is capable of performing one-dimensional (1-D) steady and unsteady-flow modeling and comprises a graphical user interface (GUI), separate hydraulic analysis components, data storage, and management capabilities as well as graphics and reporting facilities (HEC, 2010b).

Methodology

Study area

Awash Bello flood plain is one of the frequently flood-affected areas found in the upper part of Awash River basin, Oromiya, Ethiopia. It is found to the southwest of the basin in the upper part near the source of Awash River between 8^{o}0′0′′ and 9^{o}1′0′′ N Latitude and 38^{o}0′0″ to 38o50′0′′ E Longitude on a geographical basis (Fig. 1) at a distance of 55 km from Addis Ababa. It obtains annual average precipitation of 829 mm during the dry season and 1267 mm during the rainy season with the minimum monthly average precipitation of 5 mm to maximum monthly average precipitation 210 mm, and the maximum and minimum average temperatures of 25.56 °C and 8.99 °C, respectively. It is a flood plain under intensive agricultural activities and highly populated area.

Study flow chart

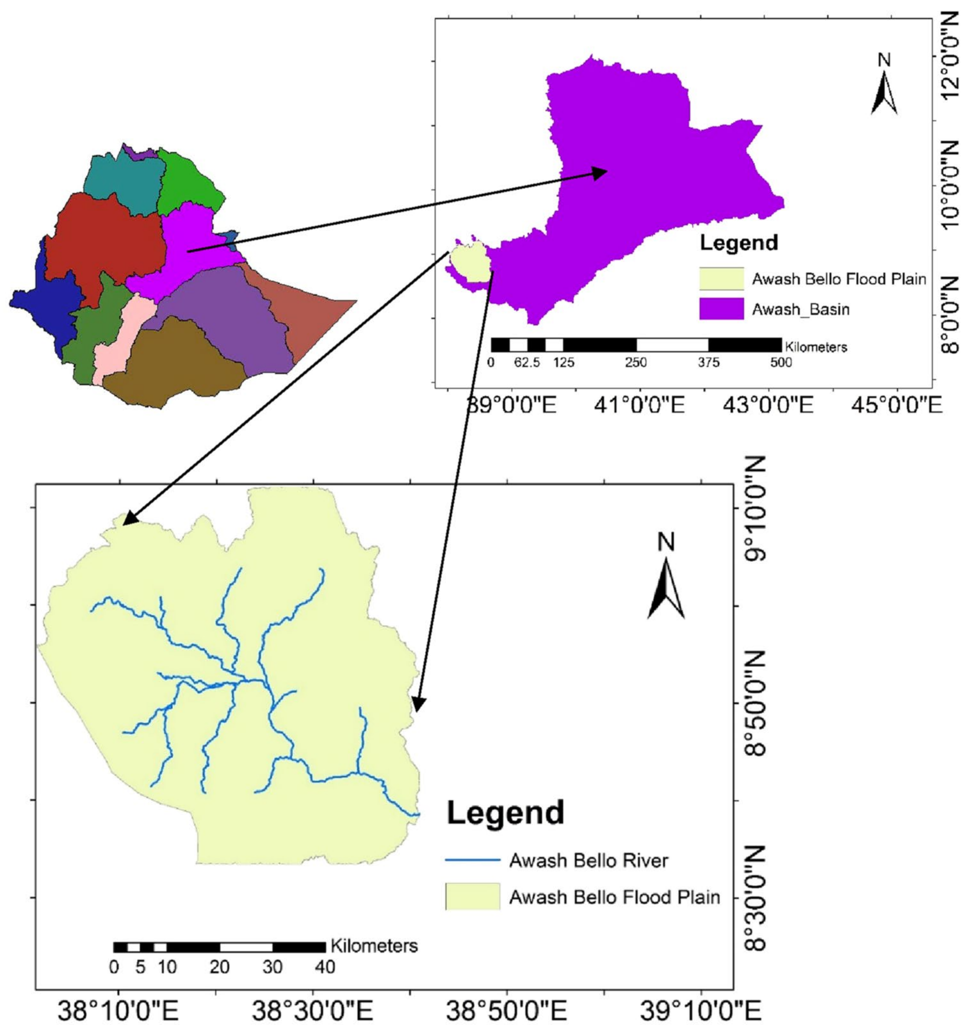
The overall procedures that were undertaken from the beginning up to the end of the HEC-RAS model are expressed as in the Fig. 2.

Data processing

Geometric data

Hydraulic modeling of HEC-RAS requires numerous geometric data to configure the flood plain physical

Fig. 1 Location map of awash bello flood plain



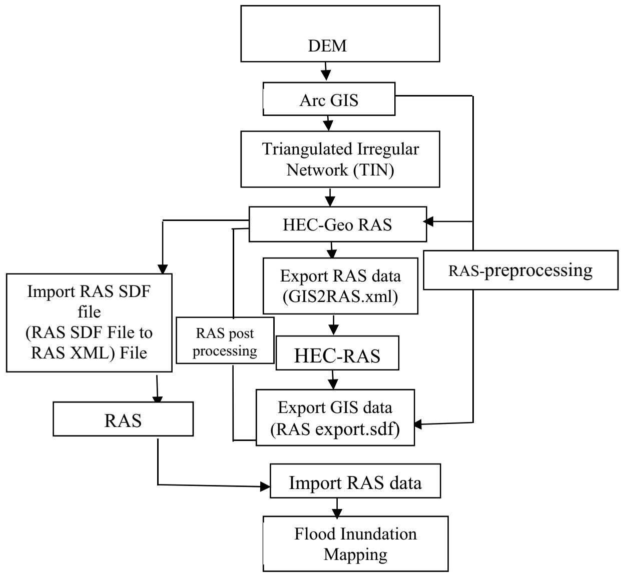


Fig. 2 Flow diagram of HEC-RAS model

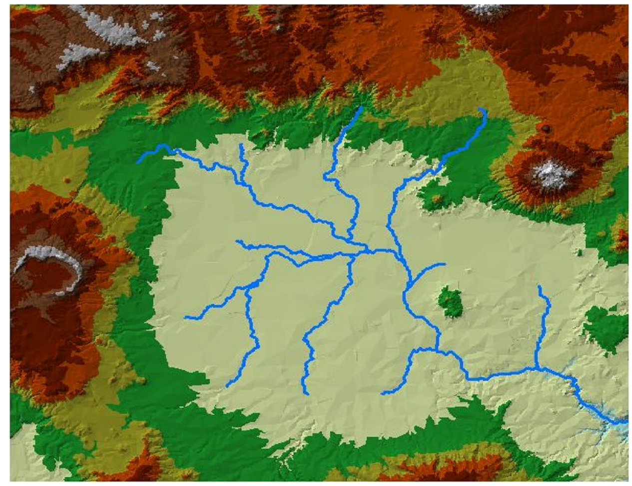


Fig. 3 Terrain TIN of Awash Bello flood plain

characteristics into the model. To accurately transform the actual flood coverage area of the flood plain, the proper geometric and topographic data utilization is strongly advised. For proper flood inundation mapping, high-resolution digital elevation model (DEM) required. To achieve this objective, high-resolution DEM with a dimension of 12.5 m × 12.5 m was downloaded from Alaska Satellite Facility (https://vertex.dac.asf.alska.edu). This high-resolution DEM was used in Arc GIS and its extension geospatial river analysis system HEC-Geo RAS to extract river geometric cross-section such as river centerline, flow path lines, river bank lines, XS cut lines, and Manning's roughness coefficient.

Flow data

For flood inundation mapping or flood risk assessment or flood hazard plotting, the extreme flood value computation is the primary steps (Permatasari et al. 2017; Noor et al. 2018). According to Shakirudeen and Saheed (Shakirudeen and Saheed 2014), flood inundation mapping is a process-based task that follows the pattern of the outcome of flood frequency analysis within a defined catchment (flood plain). River analysis system (RAS) requires flow data (profile) to plot the flood inundated area of the flood plain. For the purpose of this objectives, 25 years (1990–2015) hydro-meteorological data were collected from Ethiopian Ministry of Water Resources, Irrigation and Electricity (MoWRIE) and Ethiopian Meteorological Agency, respectively, and then processed in HEC-HMS model.

The rainfall depth of different duration was taken from the calibrated and validated HEC-HMS model. Then the maximum annual rainfall depth was picked out of the computed result and reinserted to the model to compute the peak flood. Using the storm frequency option provided in the HEC-HMS model, the extreme flood magnitude for 2, 5, 10, 25, 50 and 100 years' recurrence interval was undertaken. Log Pearson Type-III, General Pareto and Gumbel's extreme value distribution functions were used for verifying the model output.

The non-parametric statistic used to ascertain the fitness of either Log Pearson Type-III, General Pareto or Gumbel's extreme value distribution function measure is Chi-square statistic for inundation mapping (Shakirudeen and Saheed 2014). Here, for goodness of fit test measure, Chi-square was preferred due to its essential numerical characteristics for test of association and homogeneity which is the vital basis for validation of the selected techniques for the comparison.

RAS preprocessing

The primary function of HEC-RAS model is to compute surface water elevation in the river along the flood plain. From the beginning up to the end, the flood inundation process passes through two very crucial steps, i.e., RAS preprocessing and RAS post-process. River analysis system preprocessing is the first stage in the process of flood inundation mapping. It is the process from Arc GIS to the HEC-RAS model through an Arc GIS and HEC-RAS model interface called HEC-Geo RAS. At this stage, to extract river cross-section, HEC-RAS requires terrain Triangular Irregular Network (TIN). This was achieved through converting DEM to terrain TIN using the conversion toolbox provided in ArcGIS (Fig. 3).

With the help of RAS Geometry menu provided in the HEC-Geo RAS, river geometry parameters such as stream centerline, bank line, flow path line, and XS cut lines were extracted from the topographic terrain model, i.e., from the TIN (**Fig. 4**). Except the XS cut lines, the other river

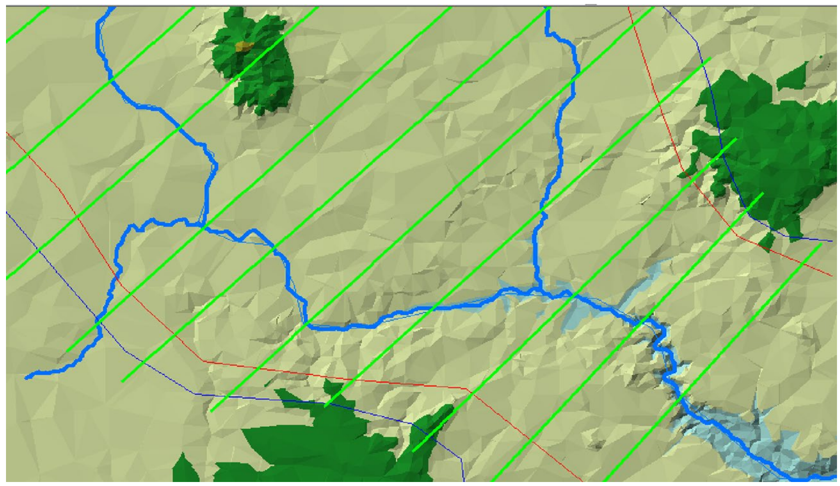


Fig. 4 River geometric cross-section

geometries were drawn from upstream to downstream along the river centerline while the XS cut line were drawn across the river centerline at a random distance from upstream to downstream. Delineation of river cross-section into the model is tedious and time consuming, it must be done carefully with great attention.

The XS cut line must be drawn in such a way that it must be cross the stream centerline exactly once, the bank lines exactly twice (left and right), and the flow paths exactly three times (left, right and centerline) and they should not intersect each other. After the successful extraction and necessary adjustment, stream centerline and XS cut lines attribute were computed. These are important for river length measurement and river station computation. The other very essential parameter provided in RAS Geometry is XS cut line attribute and this comprises river/reach name, stationing, bank station, downstream length and elevation. Computing all the river geometries carefully, the extracted river geometry shape file was exported to HEC-RAS from Arc GIS using ‘Export RAS data’ option provided in HEC-Geo RAS (Fig. 5). This exported river geometry cross-section shape file incorporates the overall properties of the river along the flood plain into the HEC-RAS model and can be used as the basic input data for flood inundation mapping.

Exporting river geometry shape file into HEC-RAS model, the other data such as flow data (profile), boundary condition and Manning’s roughness coefficient were added to develop the plan view of the water surface elevation. The HEC-RAS model have a capability of performing steady or unsteady state flow condition for 1-D, 2-D or 3-D flow. However, steady flow condition is widely applicable for flood inundation mapping (Niraj and Suresh 2017). Therefore, 1-D steady-state flow condition was performed for this study. The maximum flood value already developed by the calibrated and validated HEC-HMS model for different recurrence intervals (2, 5, 10, 25, 50 and 100 years) was used for flow data (RAS profile) and inserted into the HEC-RAS model. Numerous authors working on the flood inundation

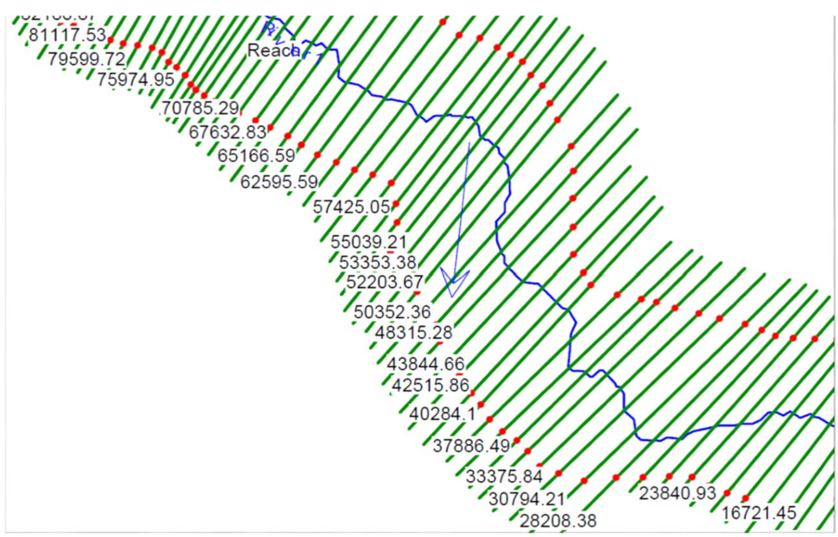


Fig. 5 Geometric cross-section at different river stations

mapping and flood hazard assessment have computed annual maximum flood and flood frequency analysis using different flood frequency analysis techniques. But within this study, peak flood frequency analysis was conducted through the calibrated and validated HEC-HMS model. Then, the result of the model was compared with annual maximum flood of three flood frequency analysis techniques (i.e., Log Pearson type-III, General Pareto and Gumbel's extreme value distribution function). This process is to verify the acceptability of annual maximum flood obtained from the model. This is the new concept that this study may contribute for the scientific community.

To estimate the correct water surface elevation, the role of Manning's roughness coefficient n is very high and it is strongly advised to consider the appropriate n value. According to the HEC-RAS manual used for this study (USACE 2016), one of the best criteria used for n value consideration is river channel description. This includes natural channel, lined channel, and excavated channel. Since the river along the Awash Bello flood plain is just natural channel that subtend by the flood plain, the first criteria was used to assign n value for left, right and bottom of the channel. Accordingly, similar n value of 0.025 was assigned for left and right channels while 0.035 was assigned for channel bottom.

After flow data and Manning's n value were applied into the model, critical depth both for upstream and downstream was chosen as a boundary condition. Then, the combination of sub and super critical (mixed) flow regime was selected to integrate type of flow regime in the river and then the HEC-RAS model was run. After the successful running of the HEC-RAS model, the result of the developed water surface for all flow profile together with the entire river cross-section was exported back to the Arc GIS using Export GIS data option given in the HEC-RAS model.

Postprocessing

RAS postprocessing is the back process from HEC-RAS to the Arc GIS. After the HEC-RAS model was correctly developed with all necessary adjustment, the GIS data were exported to Arc GIS work environment in *'file.sdf'* format. Then, the HEC-Geo RAS *'Import RAS sdf.file'* was selected to convert GIS data from *'file.sdf'* to *'file.xml'* file format so that the GIS can recognize it. Generally, Fig. 6 shows the general procedures that were undertaken in the RAS postprocessing.

The HEC-Geo RAS's RAS mapping alternative has two options. These are water surface generation and flood plain delineation or flood inundation mapping. The HEC-Geo RAS with help of Arc GIS was automatically developed the water surface TIN for all the aforementioned flood frequency intervals by running water surface generation option in the RAS mapping. After the water surface TIN for all the flood

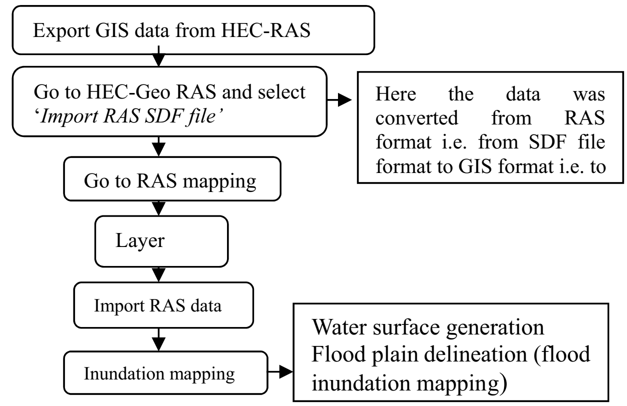


Fig. 6 RAS postprocessing flow chart

recurrence intervals were generated correctly, the flood inundation map of the Awash Bello flood plain was developed by integrating water surface TIN and the Awash Bello flood plain terrain TIN developed previously.

Results and discussion

Flood frequency

Flood inundation mapping is the function of extreme flood magnitude of different recurrence intervals that can be computed by various flood extreme value distribution techniques or models. Estimating peak flood discharge and their intensity are the primary tasks for Hydrologists and meteorologists for the reliable flood inundation mapping (Narayan et al. 2018). Herein this study, the extreme flood values of various recurrence intervals (i.e., for 2, 5, 10, 25, 50, and 100 years) from which the flood inundation mapping was drawn were computed using the calibrated and validated Hydrologic Modeling System (HEC-HMS). Even though there are numerous alternative techniques for peak discharge computation, the calibrated and validated HEC-HMS model is becoming more advanced and acceptable in the area of peak discharge determination than other extreme flood distribution function (Jazuri et al. 2016). This is because HEC-HMS model is a physically based semi-distributed model and it considers diverse watershed physical parameters that hinder the magnitude of the over land flow.

To utilize this vital property of the HEC-HMS model, 24-h rainfall depth was sorted out from the calibrated and validated outcome of the model and it was used into storm frequency option provided in the HEC-HMS to develop peak flood for the aforementioned recurrence interval. By the successful accomplish of this process, the model result shows that the maximum flood value that will be detected after 100 years was found to be 1461.3 m^3/s while the minimum value that will be noticed after 2 years was 526 m^3/s (**Table 1**). To be more confidential with the peak flood value obtained from HEC-HMS model, it essential to compare the model result with the value from different flood frequency methods. Different researchers have done this to obtain reliable results. For instance, Narayan et al. (Narayan et al. 2018) compared flood frequency results obtained from the HEC-HMS model with the peak flood value from two flood frequency analysis techniques, i.e., from Log Pearson type-III and Gumbel's extreme value distribution functions and he found that the model output is slightly higher than the result of extreme value distribution function. Finally, they were suggested that HEC-HMS model result was more reliable when related with the actual conditions of the study area than the results from the two flood frequency techniques.

For the case of this study, yearly maximum from the model outcomes were used in EasyFit 5.6 statistical software and best fit test was undertaken as tabulated in Table 2. From the identified goodness of fit test, Chi-square goodness of fit test was selected and based on the rank given to each flood frequency distribution function under this goodness of fit test, three flood frequency distribution functions were preferred. These are Log Pearson type-III, General Pareto and Gumbel distribution functions (Table 2).

Having identified the three most suitable flood frequency distribution functions for the data used, flood extreme values for the respective recurrence interval were computed. The final result of the computation indicated that result of Log Pearson type-III nearly approached the model result than of the remaining two extreme value distribution functions (Table 3).

As the scatter chart illustrated on the Fig. 7, graph of Log Pearson type-III was slightly below the graph of HEC-HMS model which mean that Log Pearson type-III is more suitable for the study area with the data utilized. On the other hand, graph of Gumbel's extreme value distribution function of is highly below the graph of the model and this indicates that Gumbel's extreme value distribution function is less suitable for the study area with the data under consideration.

Flood inundation map

Owing to the intensive agricultural activity and poor land use management taking place from the long time up to date, the whole Awash River basin was becoming the frequent flood-affected area (Sintayehu 2015). For example, the sudden flood over spread of the Dire Dawa town at the midnight of August 6, 2006 was one of the worst of the flood events occurred in the lower Awash River basin of Ethiopia (Yirga 2016) and this study indicated that most part of the Awash Bello flood plain is under flood inundation problem like some other areas of the River basin. Many researchers (Sintayehu 2015; Yirga 2016) have conducted flood inundation mapping and flood hazard assessment in the lower part of the basin and they were put forward their conclusion that the whole Awash river basin was at risk due to the frequent

Table 1 24-h rainfall depth and peak flood frequency analysis from HEC-HMS model

S/no	Return period (year)	24-h rainfall depth (mm)	Peak flow (m^3/s)
1	2	51.92	526
2	5	65.52	610
3	10	74.45	828.8
4	25	85.7	1072.8
5	50	94.07	1263.6
6	100	102.45	1461.3

Table 3 HEC-HMS model result comparison with different extreme value distribution function

Return period (year)	HEC-HMS	Gumbel	Pearson type 3	Gen. Pareto
2	526.0	472	516	492
5	610.0	559	595	590
10	828.8	617	793	721
25	1072.8	690	998	853
50	1263.6	743	1190	983
100	1461.3	797	1397	1121

Table 2 EasyFit 5.6 statistical software output for statistical distribution function

S/no	Distribution	Kolmo.smirnov		Anderson Darling		Chi square	
		Statistics	Rank	Statistics	Rank	Statistics	Rank
1	Gamma	0.2629	6	1.4185	2	1.9613	6
2	Gamma (3p)	0.2692	5	1.0441	6	0.6869	7
3	Gen.Pareto	0.1966	3	4.1073	7	2.5898	2
4	Gumbel	0.2939	2	2.2549	1	2.0596	3
5	Log Pearson	0.2946	7	1.42	5	1.4091	4
6	Log Normal	0.2884	1	1.4073	3	–	5
7	Log Pearson 3	0.2061	4	0.7841	4	0.2346	1

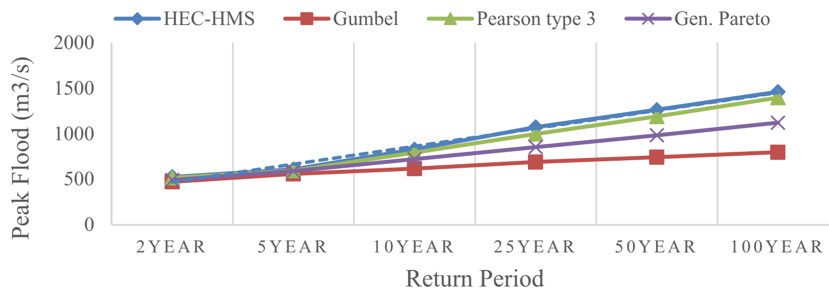


Fig. 7 Graphical comparison of flood frequency analysis

flood damage. Awash Bello flood plain is among the flood-affected area of the Awash River basin located in the upper part.

Shape file representation of the flood plain was developed from the river geometries along the flood plain. These river geometries were extracted from the high-resolution Triangulated Irregular Network using HEC-Geo RAS and Arc GIS. The integration of flow data with the flood plain shape file was undertaken in HEC-RAS model to develop plan view of the flood plain. From the integrated plan view of the flood plain, water surface elevation for different flood frequency recurrence intervals was developed. From this plan view of the water surface elevation along the flood plain, it was found that the maximum and minimum water surface elevations were found at river station of 49,422 and 47,139, and it ranges from 6800 to 6700 ft, respectively (Figs. 8, 9).

The developed water surface elevation plan view was exported to HEC-Geo RAS and Arc GIS work environment, and then water surface TIN generation and flood inundation mapping were undertaken. Water surface TIN generation for all flood recurrence intervals was enabled to be computed and the HEC-Geo RAS has automatically generated these water surface TIN. These Water surface TIN were the same in shape for recurrence interval but they were different in the generated water surface elevation. As a sample, the water surface TIN for 2-year (a) and 100-year (b) recurrence intervals, respectively, is shown in Fig. 10.

As it can be seen from the map of water surface TIN shown in Fig. 10, the water surface elevation along the flood plain for 2-year and 100-year flood recurrence intervals were varied from 2102 to 1901 m and 2103–1904 m, respectively. This means that the water surface elevation decreases from upstream to downstream of the flood plain. After the successful generation of water surface TIN for all flood recurrence interval, the generated water surface TIN and the terrain TIN were integrated to demarcate flood inundation area of the flood plain. This was done using the flood delineation option provided in the RAS mapping of HEC-Geo RAS.

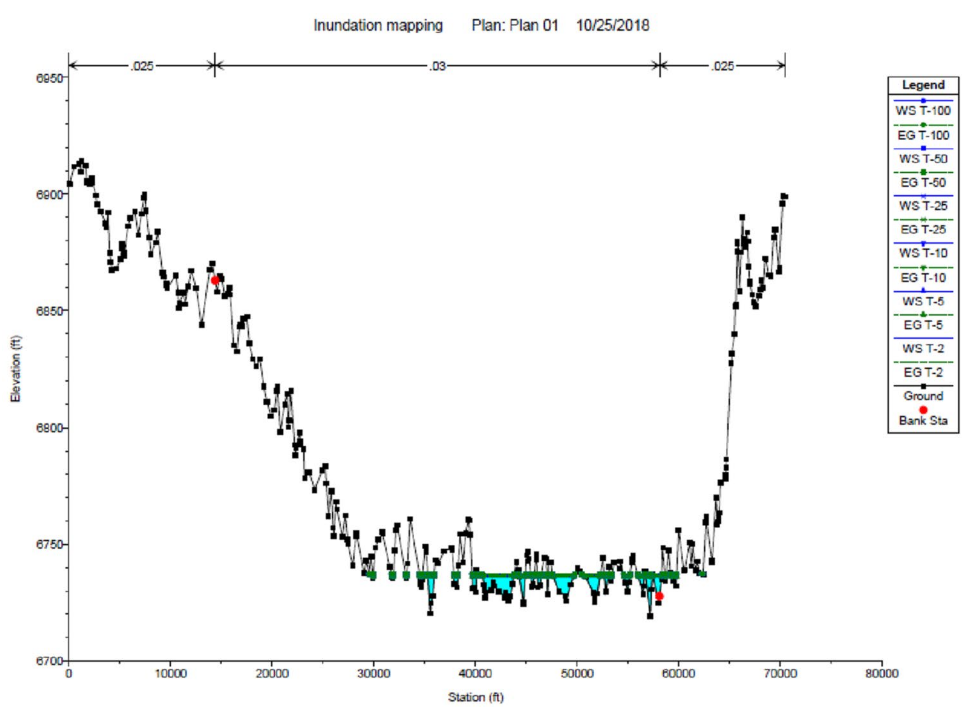
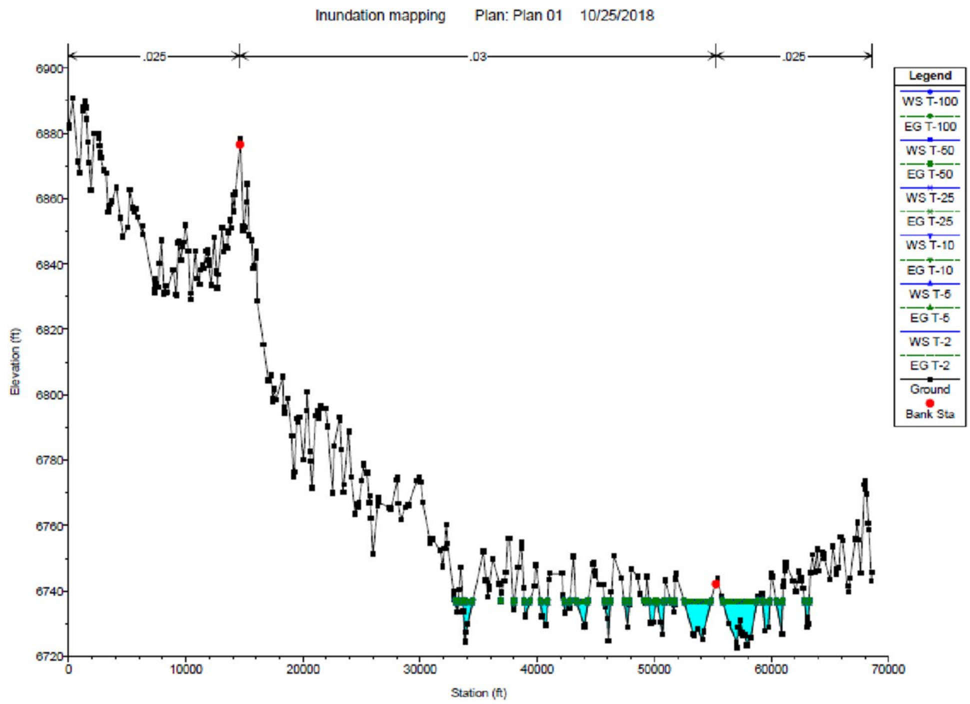


Fig. 8 Plan view of water surface elevation at 49,422 river station

Fig. 9 Plan view of water surface elevation at 47,139 river station



Having incorporating both water surface TIN and DEM-TIN of the flood plain, HEC-Geo RAS was delineated the flood inundation map for all flow profiles. The result indicated that the 2-year recurrence interval peak flood inundated an area of about 71 km^2 while the 100-year recurrence interval peak flood inundated an area of about 109 km^2. The maximum flood depth was 0.45 m for 2-year return period flood frequency analysis while it was about 0.489 m for 100-year flood recurrence interval (Figs. 11, 12).

Table 4 indicates the flood inundation area and flood depth for the remaining flood recurrence intervals.

In addition to the depth and areal coverage of the flood inundation mapping, flood coverage distance both in the right and left of the stream centerline was performed and it was found that the flood covers a long distance on the left side of the flood plain than on the right side looking from upstream to downstream. It extends about 15.499 km to the left of the stream centerline and about 7.884 km to the right of stream centerline for 2-year flood recurrence interval. While it covers a distance of 15.667 km on the left of the river centerline and a distance of 8.203 km on the right side of river centerline for 100-year flood recurrence interval. Therefore, special attention should be given for those householders who are living in this zone, especially for those who living at the center of the flood plain.

Alike the flood distance coverage, the flood concentration along the flood plain was varied and it was highly concentrated on the left side than on right side of the river centerline. The circled area shown on the fig (Fig. 13) shows the area of highly concentrated flood inundation. On the other hand, this area is densely populated farmland and it was occupied by a lot of farmers and many agricultural activities. Therefore, at the present, numerous farmers of this area were at risk and they need special care relative to some others farmers of the flood plain. During the summer season especially from month of June to September, this area is under large flood coverage and as a consequence, a number of households were imposing to be displaced from their homeland frequently, and they were exposed to homelessness, food insecurity, and other related problems. In addition, many animals and different infrastructures were damaged due to such catastrophic natural events (Banks et al. 2014). For the rehabilitation and sustainable livelihood of the householders, this study can be used as the ground base for emergency action strategic plan and best practicable mitigation measures.

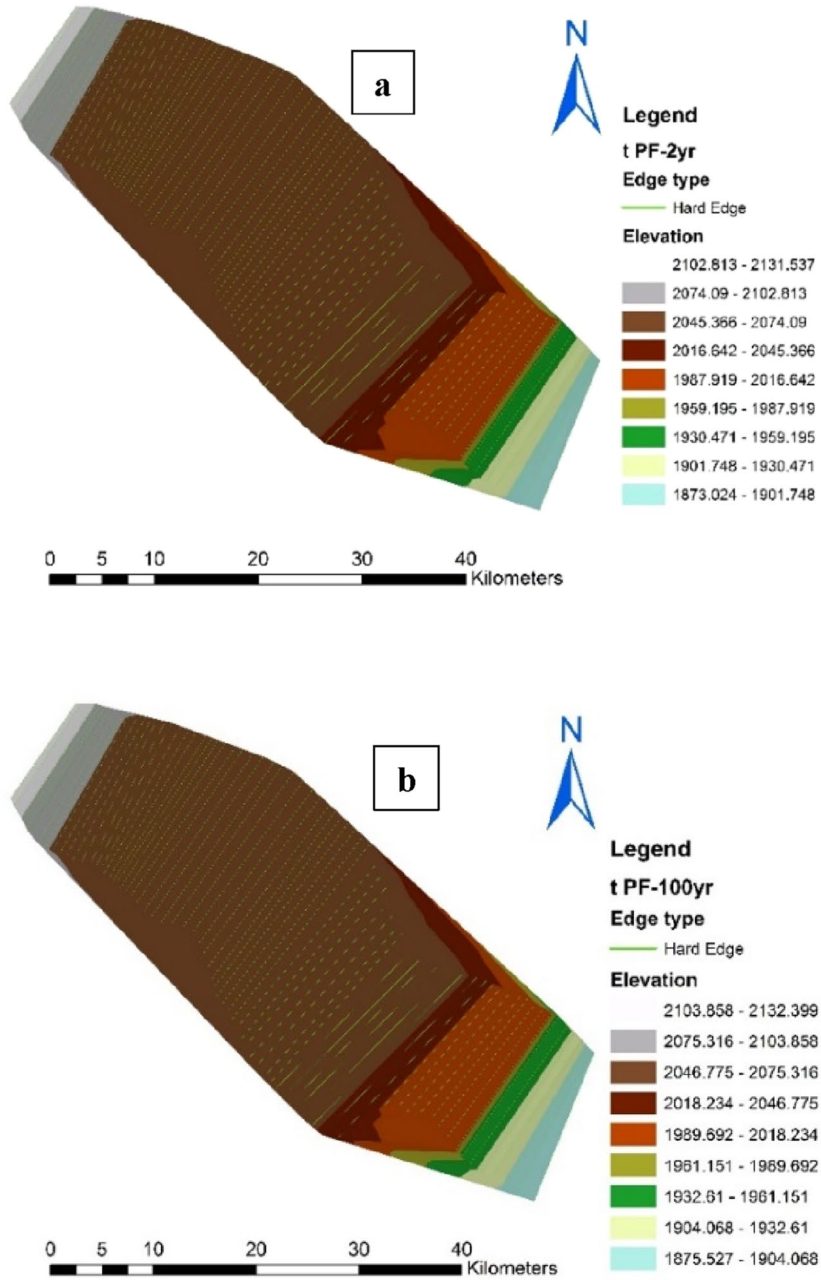


Fig. 10 Water surface TIN for 2-year (**a**) and 100-year (**b**) flood recurrence intervals

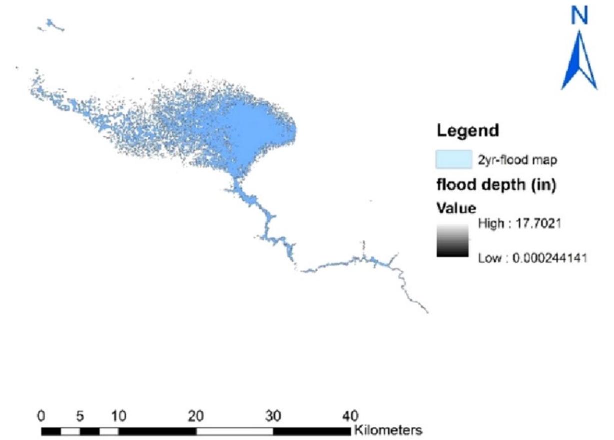


Fig. 11 Two-year recurrence interval flood inundation map

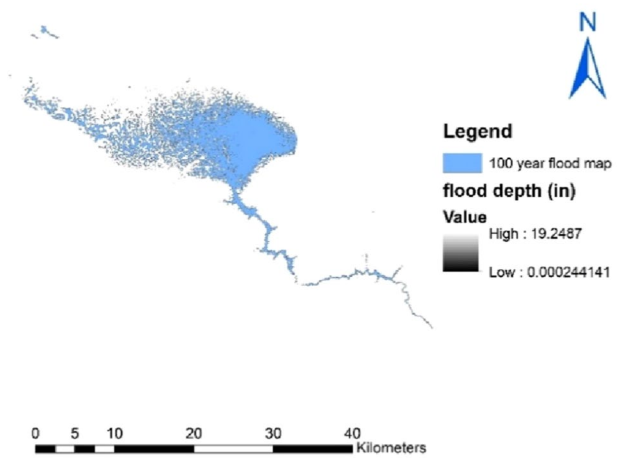


Fig. 12 100-year recurrence interval flood inundation map

Table 4 Flood inundation area and flood depth with respective peak flood

Return period (year)	Max. flood depth (m)	Peak flow (m^3/s)	Area (km^2)
2	0.450	526	71.475
5	0.457	610	76.63
10	0.475	828.8	89.15
25	0.467	1072.8	100.29
50	0.477	1263.6	105.16
100	0.489	1461.3	109.462

Conclusion

Awash Bello flood plain located in the upper part of Awash River basin, Ethiopia is found to be frequently affected by flood inundating the whole flood plain, especially during the month of June–September. To check the area of the flood plain expected to be covered during the flood inundation and depth of the flood, flood inundation mapping was conducted using HEC-RAS model.

For the successful flood inundation mapping, HEC-RAS model requires data such as flow data and river geometry, Manning's roughness coefficient and different boundary condition. Flow (RAS profile) was obtained from the calibrated and validated HEC-HMS model while river geometry was extracted from TIN of the study with help of the integration of Arc GIS and HEC-Geo RAS.

After all the necessary data were correctly inserted in the HEC-RAS model, then flood inundation mapping was developed for different recurrence intervals. The result of the model indicated that about 71 km^2 and 109 km^2 of the flood plain were inundated by the 2-year and 100-year annual maximum flood recurrence intervals, respectively. In addition, from the result of the model, it can be seen that flood from the two recurrence intervals covers long distance on the

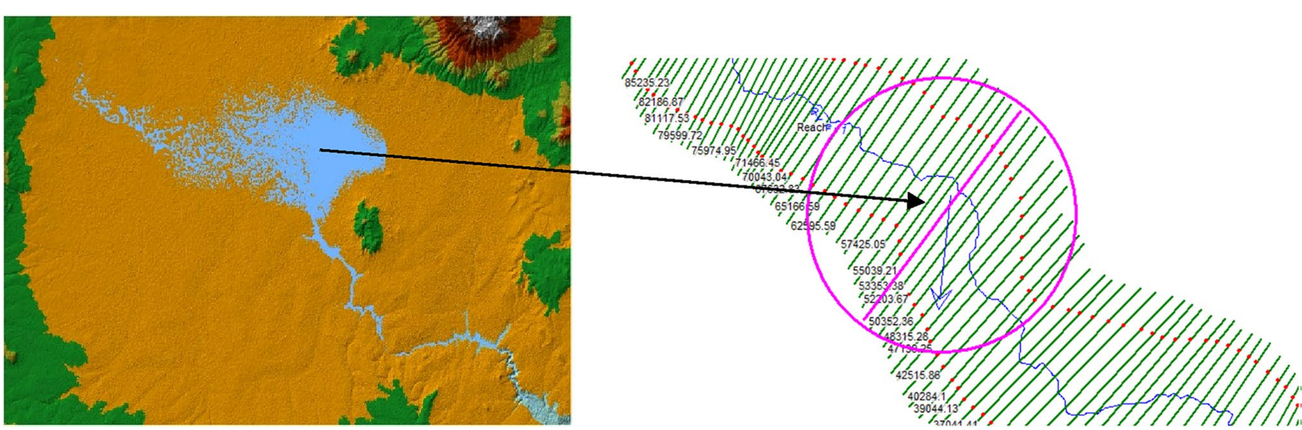


Fig. 13 Flood concentration area of Awash Bello flood plain

left side of the river centerline than on the right side seeing from upstream to downstream.

Acknowledgements Without the financial support from the Jimma University, Jimma Institute of Technology, it would not be possible to complete the study. Therefore, we, the authors, are grateful to the Jimma University, Jimma Institute of Technology for the financial support.

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