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Flood Modeling of Jemo River Catchement in Addis Ababa City, Ethiopia

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Abstract:- Flood affects lives and livelihoods in parts of Ethiopia. The flood from the Jemo river is causing damages to river side houses, infrastructures and displacement of affected population that resulted overflow on the surface following heavy rains and inundated lowland areas in the Nifas Silk Lafto district of Addis Ababa city, Ethiopia. This research involves the integration of Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) and Hydrologic Engineering Center-River Analysis System (HEC-RAS) to develop a two-dimensional (2D) river model for flood inundation determination and mapping. The model Nash-Sutcliffe efficiency (ENS) was found to be 0.751 during calibration and 0.79 during validation and the coefficient of determination (R^2) was found to be 0.786 during calibration and 0.801 during validation. The HEC -RAS model was calibrated by comparing the results of the water level in each selected cross section obtained by the model with the observed historic flood mark levels of the year 2010 and 2013. The peak estimated time series discharge of HEC HMS model result was used to simulate the unsteady state of flow to determine flood extent, water depth and velocity of the study river. Flood hazard vulnerable areas both left and right side of the Jemo river delineated for the return periods 2, 5, 10, 25, 50 and 100 years. The research showed community houses ranging from mud houses to regular story buildings can be affected during each return period maximum flooding event. Jemo river flow capacity also checked at different cross sections and less carrying capacity sections identified for recommended flood protection measures like dyke and retaining masonry walls construction to tackle the flooding impact and avoid possible erosion of the river banks.

Key words: Hydrodynamic model, HEC RAS 2D flood modeling, RAS Mapper, GIS, HEC HMS, Jemo river

1.INTRODUCTION

Flooding is the most common natural hazard that can happen any time in wide variety of locations due to high intensity rainfall events. Floods can be explained as excess flows exceeding the transporting capacity of River channel, lakes, ponds, reservoirs, damage system, dam and any other water bodies, whereby water inundates outside water body areas [1]. Flood affects lives and livelihoods in parts of Ethiopia. Especially during the rainy season (June-September), the major perennial rivers as well as their numerous tributaries forming the country’s drainage systems carry their peak discharges. Floods are already having very large impacts on cities and smaller urban centers in many African nations for instance the floods in Mozambique in 2000 which included heavy floods in Maputo, the floods in Algiers in 2001(with around 900 people killed, and 45,000 affected); heavy rains in East Africa in 2002 that brought floods and mudslides forcing tens of thousands to leave their homes in Rwanda and the very serious floods in Port Harcourt and in Addis Ababa in 2006 [2].

Flash flood from the Jemo river is causing damages to houses, infrastructures and threat to loss of life for human beings every year in Nifas silk lafto sub city of Addis Ababa city. The need for delineating flood risk areas and determining its magnitude is quite important in order to take required protection measures.

HEC-HMS and HEC-RAS Computer modeling software is used for determination of river characteristics as well as delineation of flood affected areas to indicate the extent of flooding arising from the river considering different return periods.

2. MATERIALS AND METHODS

2.1 Description of the study area

The Jemo river catchment is located between 8^{0}57.192’ N Latitude and 38^{0}40.923’ and 38^{0}43.728’ Longitude, the river catchment delineated and covers an area of 12.67km^2. The main river course is located centrally in the catchment generally creating a V-shaped terrain profile.

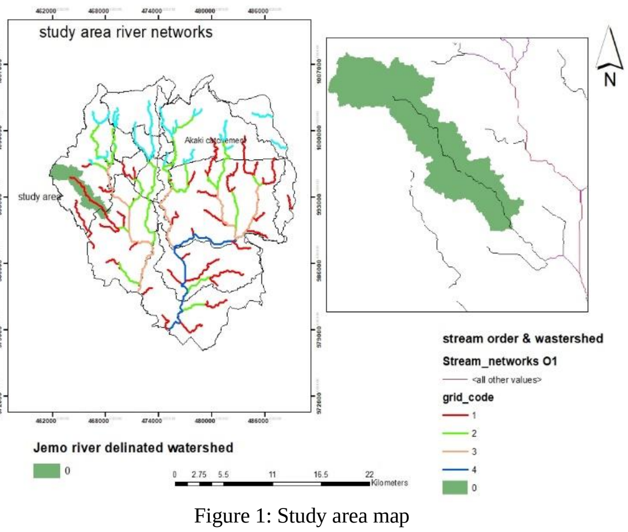

Figure 1: Study area map

2.2 HEC-HMS model setup

The Hydrologic Engineering Center’s Hydrological Modeling System (HEC-HMS) has four main model components: basin model, meteorological model, control specifications and input data (time series, paired data and gridded data). The Basin Model, for instance, contains information relevant to the physical attributes of the model, such as basin areas, river reach connectivity, or reservoir data. Likewise, the Meteorological Model holds rainfall data. The Control Specifications section contains information pertinent to the timing of the model such as when a storm occurred and what type of time interval is to be used in the model, etc. Finally, the input data component stores parameters and boundary conditions for basin and meteorological models [3].

Watershed delineation done at selected river outlet and required physical parameters for the HEC HMS model collected.

2.3 HEC -RAS Model Development

The three steps to run the Hydrologic engineering center river analysis system (HEC RAS) model are pre-processing of data, modeling phase, and post processing of data [4].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 river cross section at each location will be opened and geometric data called by Geographical information system (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 of the study area.

The discharge values for different return periods can be entered manually for unsteady flow. The roughness coefficients (Manning's coefficient) and boundary conditions were added to the model. The values selected for manning's coefficient were 0.05 and 0.17,

for the stream channel and overflow banks, respectively referring Ethiopian roads authority (ERA) standard document and fixed during calibration. The model was run for mixed flow regime conditions and unsteady flow water surface profile computations. The iterative solution of the energy equation, using the standard step method, solved the unsteady flow, while Manning's equation and contraction/expansion coefficients determined head losses before applying the computation process the model set up for boundary condition. There are various methods of boundary condition used. The method used in this paper is the Normal depth at the downstream end of the reach. The model calculates the depth from the given elevation data and discharge. Finally, the plan must be established for each model simulation.

2.4 Terrain Preprocessing

2.4.1 HEC-GeoHMS

HEC GeoHMS allows to preprocess terrain in two approaches either step by step or batch mode. In this research step by step process was used in order to examine out puts and made necessary corrections.

HEC-GeoHMS is a set of ArcGIS tools specifically designed to process geospatial data and create input for the HEC-HMS. HEC-GeoHMS provides the connection for translating GIS spatial information in to model files for HEC-HMS. The GIS capability is for data formatting, processing and coordinate transformation. Currently, HEC-GeoHMS operates on DEM to derive sub-basin delineation and to prepare a number of hydrologic units. HEC-HMS supports these hydrologic inputs as starting point for hydrologic modeling.

3. MODEL CALIBRATION AND VALIDATION

3.1 Model calibration

3.1.1 HEC HMS model calibration

A total of Sixteen years' (2000-2015) metrological data and Twenty-seven-years' (1989-2015) was collected from Ministry of Water, Irrigation and Energy and National Metrological Agency respectively and Nine years' data (2000 to 2008) are used for calibration. Validation of the model was done for the year's (2008-2015)

3.1.2 HEC RAS model calibration

In the calibration, Manning's coefficient "n" was altered continually until the variations between observed and simulated flood water level marks for the year 2010 and 2013 were within the acceptable limits. The calibration was performed by comparing the results of the water level in each selected cross section obtained by the model with the observed historic flood mark levels of the year 2010 and 2013.By starting with an initial value of manning's roughness coefficient suggested by ERA technical manual, the n value was altered until the differences between observed and simulation water levels became small as far as possible. So, the outcomes of the HEC-RAS model for distinct values of n were compared with the observed water surface profile.

$$RMSD = \frac{\sqrt{\sum_{i=1}^{N}(Y_{i\,sim} - Y_{i\,obs})^2}}{N} \qquad \ldots\ldots (1)$$

Equation-51

Where, RMSD is the root mean square deviation

$Y_{i\,obs}$ is simulated water depth at cross section i

$Y_{i\,obs}$ is observed flood mark depth at cross section i

N is the total number of data (total number of cross sections).

3.2 HEC HMS & HEC RAS model evaluation

The performance of selected model was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (ENS) were the goodness of fit measures used to evaluate model prediction. The R^2 value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, ENS is approximately1. If the ENS is between 0 and 1, it indicates deviations between measured and predicted values. If ENS is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction. The R^2 and ENS values are explained in equations below.

$$r^2 = \frac{\sum [(qsi - qs)(qoi - qo)]^2}{\sum (qsi - qs)^2 x \sum_{i=1}^{n} (qoi - qo)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

qsi: - is the simulated value, qoi: - is the measured values, qs: - is the average simulated value and qo: - is the average measured value

The ENS simulation efficiency for n time steps is calculated as:

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$$\sum ENS = 1 - \frac{\sum_{i=1}^{n} (qoi-qsi))^2}{\sum_{i=1}^{n} (qoi-qo)^{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: qsi is the simulated value and qoi is the measured value.

The proposed model of this study was calibrated by adjusting sensitive parameters and validation was done using observed data of the existing gaging station.

4.RESULTS AND DISCUSSIONS

4.1 Study area basin characteristics

ARC-GIS 10.4 modeling software is used to delineate catchment for different river system in the Big Akaki and Jemo river at selected outlet catchment and hydrological, physical parameters and spatial information of the catchments were obtained. Road Networks, houses and buildings as well as vegetation cover of the catchment is digitized and corresponding areas is calculated.

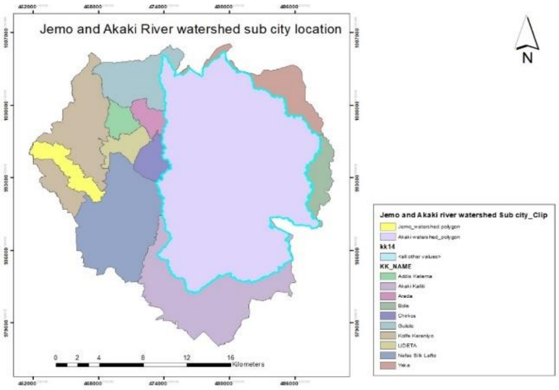


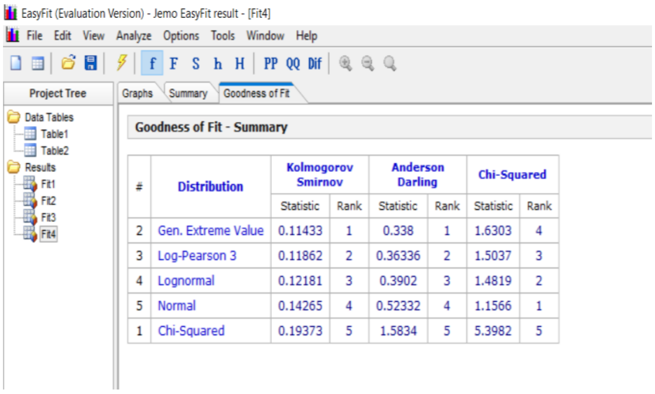
Figure 2: Study area watershed delineation

Hydrological parameters of the study area extracted and curve number (CN), water shed area, soil types obtained and used to run the model. The study area soil, land use characteristics and curve number (CN) were extracted during terrain processing using GIS extensions (Arc Hydro and HEC-GeoHMS).

4.2 Best fit flood probability distribution

The test statistic for yearly maximum precipitation and discharge data of selected study area outlet was analyzed using EasyFit software and best fit probability distributions among Normal, Log Normal, General Extreme Value, Chi-Squared and Log Pearson 3 identified.

The five probability distributions were compared using Kolmogorove Smirnov,Anderson Darling and Chi-Squared test statistic using EasyFit software. The rank with respective test statistic listed and accordingly, General Extreme Value distribution rank first using Kolmogorov Smirnov and Anderson Darling statistic and Normal distribution rank first using Chi-Squared statistic



#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
2	Gen. Extreme Value	0.11433	1	0.338	1	1.6303	4
3	Log-Pearson 3	0.11862	2	0.36336	2	1.5037	3
4	Lognormal	0.12181	3	0.3902	3	1.4819	2
5	Normal	0.14265	4	0.52332	4	1.1566	1
1	Chi-Squared	0.19373	5	1.5834	5	5.3982	5

Figure 3: Goodness of fit comparison

4.2 HEC HMS hydrological model result

4.2.1 Calibration and Validation

Calibration is adjusting of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. The calibration of HEC-HMS for this particular study area was carried out using nine years from 2000-2008 daily rainfall and daily stream flow data of nearby Akaki river.

Optimization of the parameter values was carried out within the allowable ranges recommended by the US Army corps of Engineers Hydrologic Engineering Center [5]. Coefficient of determination(R^2) (0.68 to 0.88 for Calibration and 0.62 to 0.86 for Validation and Nash-Sutcliffe efficiency (ENS) 0.5 to 0.88 for Calibration and 0.61 to 0.85 for Validation).

The Nash-Sutcliffe efficiency (ENS) was found to be 0.751 during calibration and 0.79 during validation. The stochastic nature of precipitation effect on the simulated hydrograph was handled by stochastic calibration. In the stochastic calibration observed and simulated discharge time series were arranged in descending order and the objective function, $\Sigma(Q_{obs}-Q_{sim})^2$ was minimized by observing the plot of observed and simulated discharge.

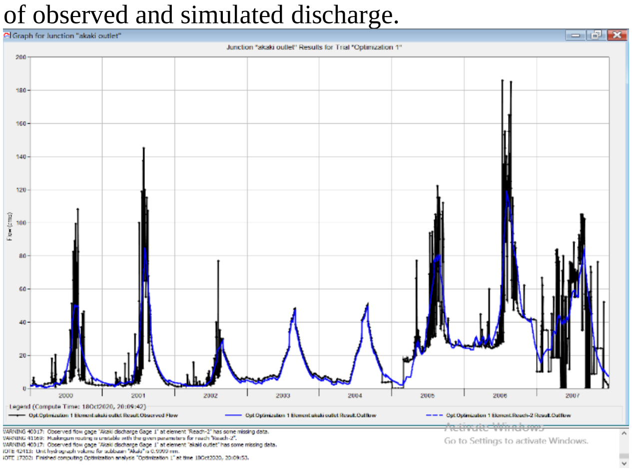


Figure 4: Observed and Simulated flow time series

Observed flow and simulated flow time series graph obtained during calibration and validation was significantly within the recommended Nash-Sutcliffe efficiency and the time series graph matches with the observed flow.

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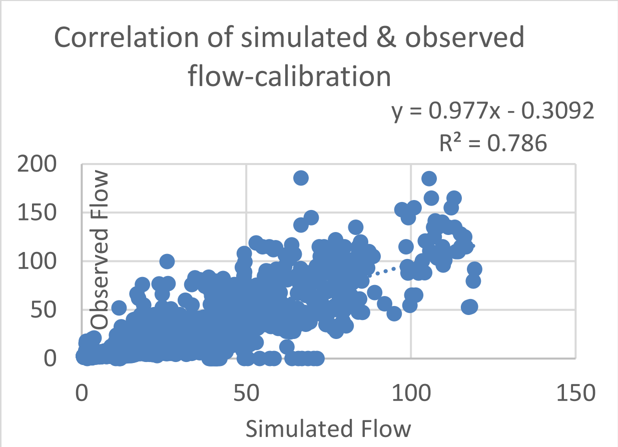

Figure 5: Correlation of flow (calibration)

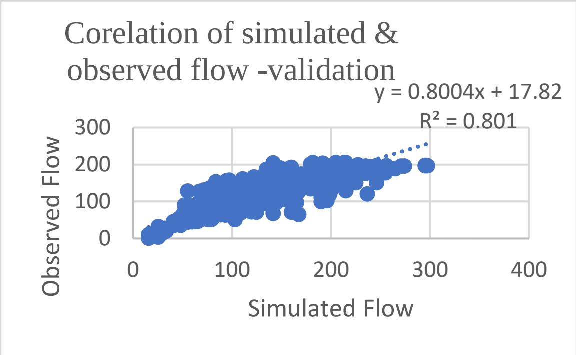

Figure 6: Correlation of flow (validation)

The coefficient of determination (R^2) was found to be 0.786 (Figure 4) during calibration and 0.801 during validation (Figure 5). The relationship of simulated and observed flow found to be good and coefficient of determination and Nash-Sutcliffe matches as per the standard indicated above.

4.2 HEC HMS model result

The calibrated and validated HEC HMS model was used to estimate peak flood magnitude of the Jemo river selected outlet area using rainfall depth calculated by the best fit distribution for respective return periods. The 24hour depth frequency curve values were used from the Ethiopian Roads Authority drainage manual [6]. Accordingly, the output of the peak flow result for each return period was found as in the below Table 1.

Return Period, years	Peak flood, M^3/s
2	39.2
5	43.8
10	47
25	51.2
50	54.3
100	57.5

Table 1: HEC HMS peak flow result

4.3 HEC RAS model result

The outcomes of the HEC-RAS model for different values of Manning's roughness coefficient (n) were compared with the observed historic water surface flood level marks collected from specific site which occurred during the year 2010 and 2013 as shown in the Table 2 and represented in Figure 7.

Table 2: Observed and simulated water level

i	Cross section	Flood Water Level Observed	Water level simulated		
			Simulated for n=0.17	Simulated for n=0.05	Simulated for n=0.01
1	3314	2271.150	2272.850	2271.713	2271.781
2	3146	2266.000	2266.150	2265.972	2265.898
3	2829	2264.720	2264.640	2264.695	2264.654
4	2578	2260.820	2261.031	2261.000	2261.003
5	2202	2256.370	2256.461	2256.061	2255.011
6	1877	2251.240	2252.000	2251.450	2253.000
7	1142	2240.350	2240.102	2240.121	2240.123
8	902	2238.870	2239.843	2239.651	2239.843
9	685	2235.720	2235.501	2235.479	2235.446
10	304	2230.000	2230.531	2230.500	2230.530
11	183	2229.750	2230.512	2230.542	2230.512
12	11	2229.300	2229.678	2229.664	2229.652

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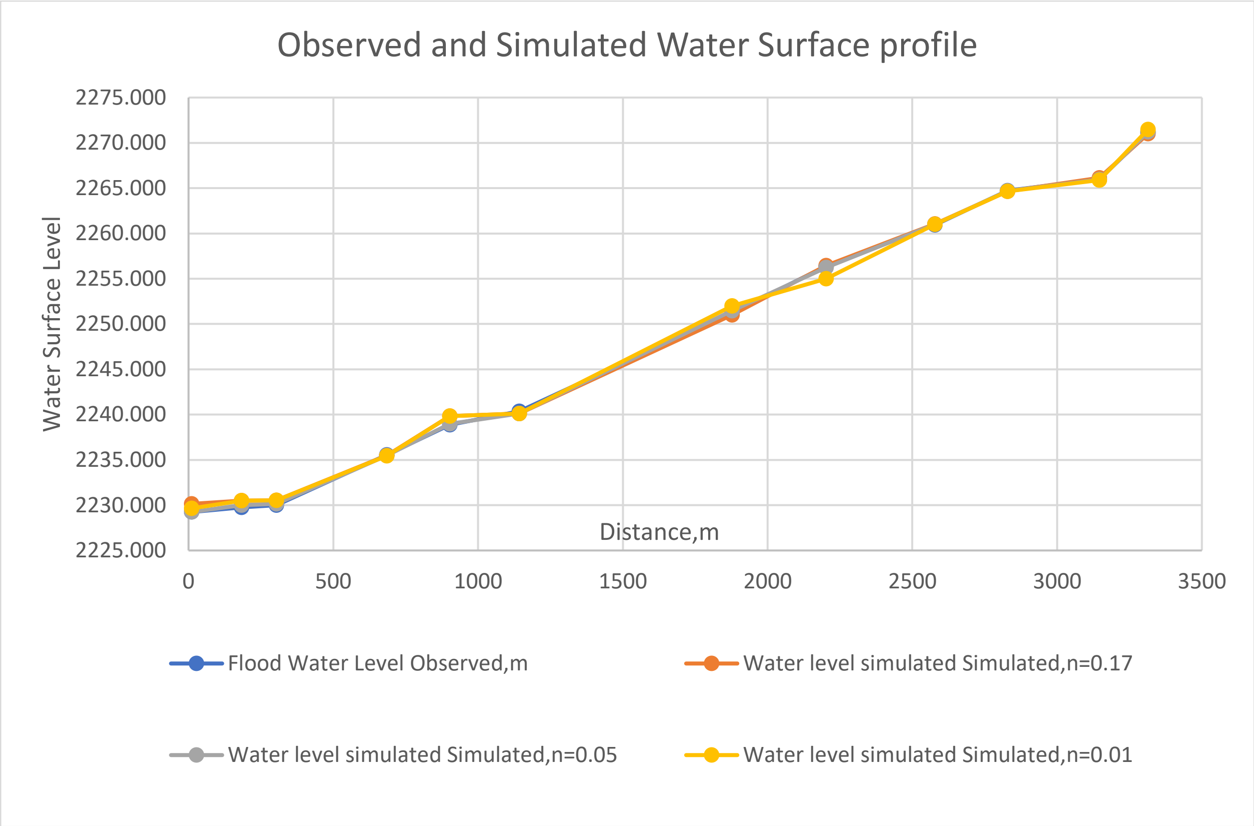

Figure 7: Observed and simulated water surface profile

The root means square deviation (RMSD) was tested between observed and simulated water surface elevations as shown in the Table 3.

Manning's Roughness Coefficient (n)	**0.17**	**0.05**	**0.01**
RMSD	0.48387473	0.140726389	0.618011124

Table 3: RMSD for Manning's n

Manning's coefficient with low differences of RMSD were selected and used for the model.
Using ERA drainage manual left and right-side banks and channel section roughness coefficient estimated and calibrated with the HEC RAS model until historic flood marks observed and simulated water depths difference significantly reduces using root mean squared error deviation approach.
Based on the calibration result Manning coefficient of 0.05 for the channel and 0.05 and 0.17 for selected left and right river bank sides were chosen at downstream and upstream section to run the model.

4.3.1 2D flow area, water depth and water surface elevation

The river two-dimensional (2D) flow area polygon was drawn using aerial imagery and existing terrain data. The 2D flow area mesh generation made and boundary conditions fixed at upstream and downstream locations. Time series flow hydrograph output of calibrated HEC HMS model for 2,5,10,25,50 and 100 years return period was used as an input for boundary conditions for channel and 2D flow area. The unsteady state simulation model run and depth of flow, water surface elevation and velocity for different return periods of the study river area generated.

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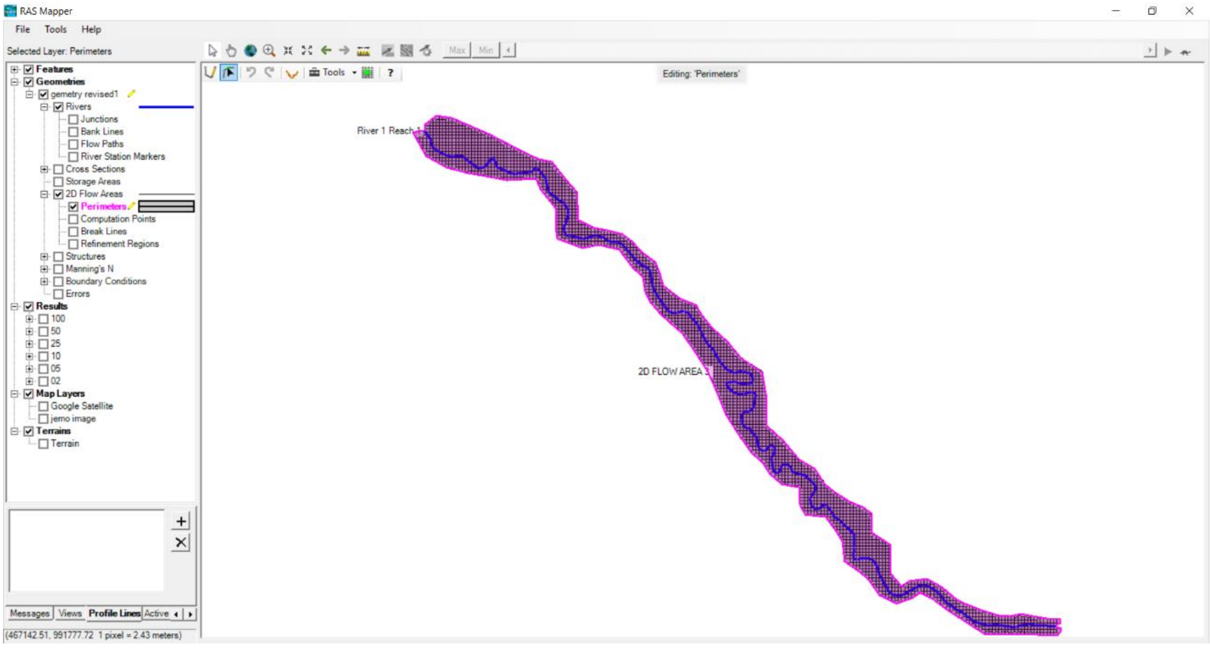

Figure 8: 2D flow area of the Jemo river

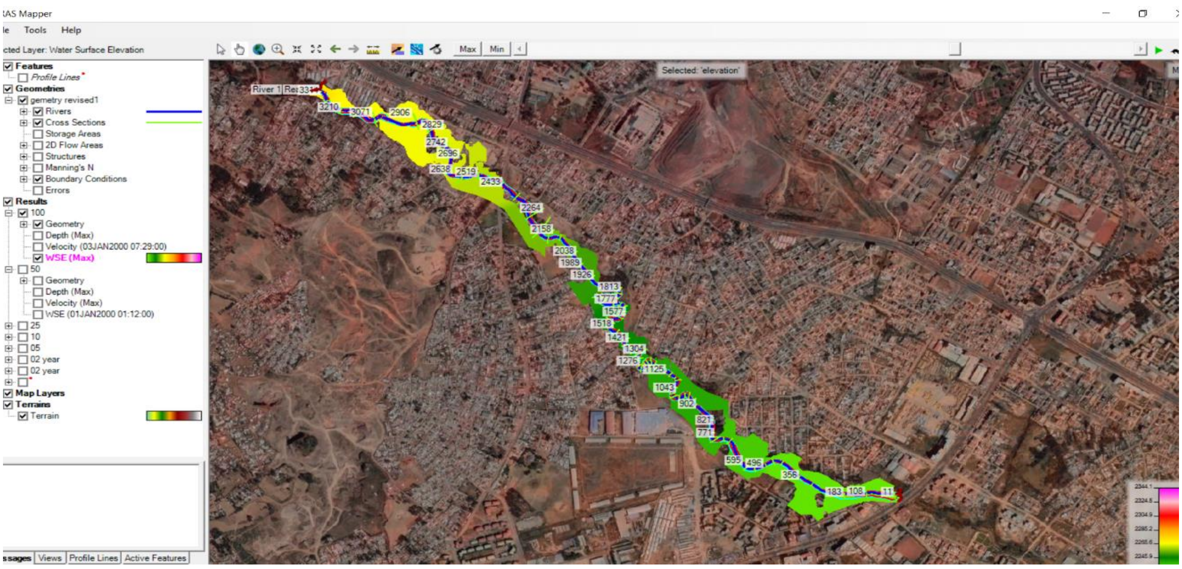

Figure 9: 100 years return period unsteady simulation water surface elevation

The 100-year return period simulated water depth simulated high at river stations 902m and 595m from selected outlet and similarly simulated water depth for 50,25,10,5 and 2 years estimated with the HEC RAS model.

The river analyzed at different cross sections and less carrying capacity of the river observed at low elevations where there are community settlements very close to the existing river.

4.3.2 Flood hazard water surface extents & velocity map

Water surface extents of the river for each return period was generated with GIS extension (HEC GeoRAS) tool. Areas flooded both left and right side of the river for respective

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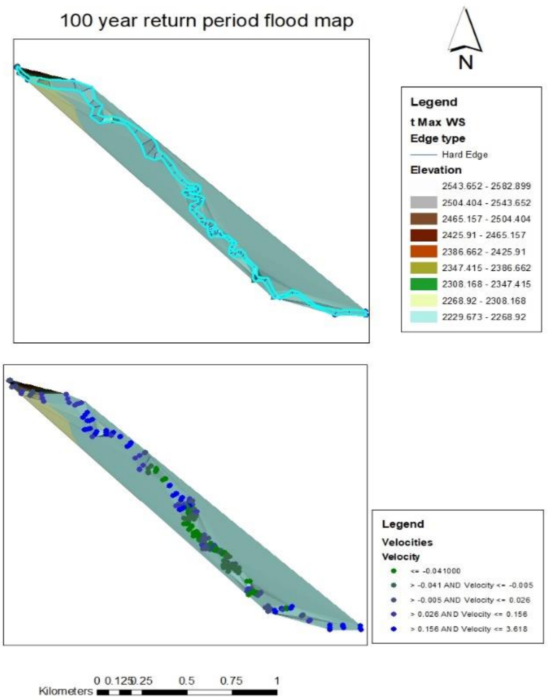

Figure 10: 100-year flood hazard and velocity map

return period delineated and shown as in the Figure 9. The 100-year return period result showed that majority of left side of the river where communities are settled in close proximity is vulnerable and can be affected by the flood. It is observed that the downstream culvert found around Anbessa Garage is overtopped by flash water during rainy season and cause problem to normal traffic movement. Storm water drainage which mark and will have great impact to erode the existing soil at concerned locations. The flood model simulated flow velocity of magnitude less than 2 m/s for major sections of the river and exclusively river stations at 183m,435m,595m,1753m and 3252m found to have flow velocity more than 2m/s and between 3-5m/s.

4.3.3 Flood hazard vulnerability

Flooding area vulnerable for different return period also identified with the model and identified as shown

With respect to river sections. Communities settled very close to the river upstream of the Jemo 01 condominium houses and newly built private houses are susceptible by the recurrence flood that can happen any time to cause potential harms to the human lives and livelihoods.

Table 4: 100-year flooding area

River station	Flooding Area (m^2)	Remark
11 m to 821m	1809.64	Upstream of Jemo Anbessa Garage area
902m to 2433m	4310.1	Upstream of Jemo 01 condominium houses
2483m to 3314m	2106.87	
Total Area, M^2	**8,226.61 M^2 (0.82ha)**	

4.3.4 Flood damage estimate

Using HEC RAS model flood inundated area and overlaying the layer on to the latest google satellite image and Addis Ababa master plan, specific river cross sections that were affected by the flood delineated and specific areas also calculated. In order to estimate cost of flood damage an average unit price of birr 12,500 per square meter were assumed and used to estimate the probable damage that can be caused by the model flood. The following table shows residential buildings at respective river cross section that was affected by flood of more than 2m water depth and estimated cost of flood damage.

Return period	**Residential buildings area covered by flood at River cross section stations**			**Estimated unit damage price for buildings, Birr/M^2**	**Estimated residential building flood damage cost, Birr**
	183m-356m	**1926m-1518m**	**2742m-3071m**	**12,500**	
2-years	212	716	555		17,796,000.00
5-years	271.45	748	635		19,853,400.00
10-years	283	846	630		21,108,000.00
25-years	248	780	615		19,716,000.00
50-years	289	798	855		23,304,000.00
100-years	325	650	1015		23,880,000.00

Table 5: Flood damage estimate cost

The HEC RAS flood model showed that for the 2 year return period the flood can cover an area of 1,483 m^2 community properties of majority residential buildings and similarly an area of 1,654m^2 , 1,759m^2 ,1,643m^2 ,1,942 m^2,1,990m^2 can be affected by flood of return period 5,10,25,50 and 100 years respectively. Flood damage of birr 17,796,000 for 2 years return period 19,853,400 for 5 years,21,108,000 birr for 10 years ,19,716,000 birr for 25 years, 23,304,000 birr for 50 years and 23,880,000 birr for 100 years estimated in this study and the flood damage can be more of this if human life and detail livelihoods assets were considered which were not conducted in this study.

5.-CONCLUSSION

Best fit flood probability distribution for the study area identified based on how good the distribution was fitted to the data. Easy Fit software was applied to evaluate goodness of fit at various significance level. The analysis resulted the General Extreme value probability distribution as best fit probability distribution for the study area among Normal, Log Normal, Chi-Squared and Log Pearson 3 probability distributions.

The study presents a systematic approach in the preparation of Two-dimensional (2D) flood model of the Jemo River found in the Nifas Silk Lafto woreda of Addis Ababa city with the application of hydrodynamic models and GIS software. Two dimensional (2D) unsteady flood simulation was done using HEC RAS 5.0.6, Arc GIS 10.4 and HEC GeoRAS GIS extensions and HEC HMS hydrological models.

Peak flood discharge estimated using HEC-HMS software application and ERA Intensity Duration Curves for different return periods (100,50,25,10 and 2). The 100-year return period peak flood was found 57.5 m3/s and 54.3 m3/s, 51.2 m3/s, 47 m3/s, 43.8 m3/s and 39.2 m3/s for 50, 25, 10, 5 and 2-year return period respectively.

The simulated flood map showed that large flooding is observed near the sides of Jemo 01 condominium residential areas and upstream area where communities settled very near to existing river reach. The total area affected by the 100-year return period flood was 8,226.61 m^2 (0.82ha) and 10,383.18 m^2 (1.04ha), 11,383.16 m^2 (1.14ha), 11,562.84 m^2 (1.15ha), 10,527.96 m^2 (1.05ha), 8,992.74 m^2 (0.89ha) were affected areas simulated for 50, 25,10,5 and 2 years return period consecutively.

The simulated depth of water was found in between 0 to 6m for the return periods and varied along the sections depending with the specific terrain. The flow velocity upstream of Jemo 01 condominium areas and upstream sections of the reach were higher than 2.0m/s and this can lead to erosion of the soil and collapse of the existing river banks to cause further flood vulnerability of communities residing closer to the reach. The hydrologic response of the river was for the river carrying capacity of each return period was checked and locations with less carrying capacity for probable maximum flow were at low elevations and river cross sections at 1142m and 435m, 2899m,902m,595m as discussed in the result section.

The study flood model showed that communities upstream of the reach and around Jemo 01 residential areas were identified within the flooding area and can be affected badly if no immediate measure is taken to tackle the probable flooding problem. Based on the flow simulation result of this research the decision makers should consider structural measures such as construction of dike and retaining walls at low elevations along the river which would prevent the flooding caused by over toping.

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