Hydrological Analysis For The Proposed Bridge At South Wollo Ethiopia

Birhanu Haile Gedamu, Vijaykumar Nagappa

Abstract: The main purpose of this study is to investigate the geomorphological data, soil properties and land use for the bridge and based on the field observation and analysis, to know the rainfall intensity and to obtaining different return period of flood magnitudes and catchment area for the Mechela river for the determination of required sizes of opening for the waterway at various watercourses and design parameters of bridge. The study area is located in South Wollo Ethiopia which connects main leg Ambo Woreda rural village with Weynamba Leghida. Study area is full of flat terrain, the elevation of the Mechela river bridge project varies from 1800m to 3000m above mean sea level. The mean annual rainfall of the study area ranges between 400mm-799mm. The study results are analytically manipulated by hydraulic Model HEC-RAS (Version-4) software and GIS Software's like ArcGIS.

Index Terms: HEC-RAS, Rainfall, Flood, Bridge, River.

1. INTRODUCTION

Bridges are very expensive structures, Millions of Birr are spending for the construction, but most of them are does not last longer life therefore a hydrological and hydraulics detail investigation is required for the proper design and construction of bridges [1, 2]. There is need of hydraulics and hydrological analysis before start of bridge construction. The results obtained from the analysis and by keeping in a view of suitable free board value the construction of bridge has to be fixed [3]. The river flood accompanied by storms are one of the major devastations and had caused damages properties and lives more [4]. Hydrological projects often result in many far-reaching environmental changes [5] analysis and comparison of the hydrological calculations of bridge design flood flow at different frequency in condition in the same main river system [6]. In HEC-RAS Model for analysis of control of flood and in the peak river flood records were used for inputs into HEC-RAS model to find the expected flood [7]. River floodplains are among the most species-rich and productive ecosystems necessary data were collected including cross sections areas, hydrological data, hydrometric stations data, etc. at the river the HEC-RAS software models used for analysis [8, 9]. In the hydrologic analysis the flood hydrograph of the catchment area was developed using time distribution coefficient method hydrologic Engineering Centre's Hydrologic Modelling System [10]. A river flood is an unusually high stage, it is a water overflow of outside the river boundaries [11]. The country Ethiopia is located in Africa, its area is more than one million square kilometers and its latitude 3° North of the equator and from 33° North to latitude 15° East to 48° East longitudes. The population of the country is 77.1 million approximately with an annual growth rate of 2.4% [12]. Every year for flood control and flood forecasting millions of Birr is spending [13]. Friction slope is a very important parameter in the river flow its value must be chosen very carefully [14]

- *Birhanu Haile Gedamu is currently Lecturer in the Department of Hydraulics and Water Resource Engineering, Kombolcha Institute of Technology Wollo University, Kombolcha, Ethiopia, PH: +251913652129. E-mail: belay144@mail.com*
- *Vijaykumar Nagappa is currently Lecturer in the Department of Civil Engineering, Kombolcha Institute of Technology Wollo University, Kombolcha, Ethiopia, PH: +251967518946. E-mail: vijaykumarnagnaik@mail.com*

Most of the people directly depends on the river basins water for their livelihoods, including hydropower, domestic supply, irrigation, industries etc. [15]. Flood profile information collected by flood modeling is an accurate engineering tool [16]. For the flood warming practical applications past flood data and station elevations were chosen as variables [17]. HEC-RAS model software used with ArcGIS combination to obtain results and prepare different return periods [18]. The water wave progressed downstream side because of flood flow variation with respect to time [19]. For the estimation of error and to determine capacity potential of the river the HEC-RAS model was tested suitable one [20]. From the rainfall the peak discharge from the river flow can be obtained from generated unit hydrographs [21].

2 STUDY AREA

The proposed Mechela bridge project is found in South Wollo of the Amhara Regional State. The proposed bridge connects main leg Ambo Woreda rural village with Weynamba Leghida Woreda village. The project area is full of flat terrain based on data collected using hand held GPS and total station instrument the Mechela river bridge project area elevation varies from 1800m to 3000m above mean sea level.

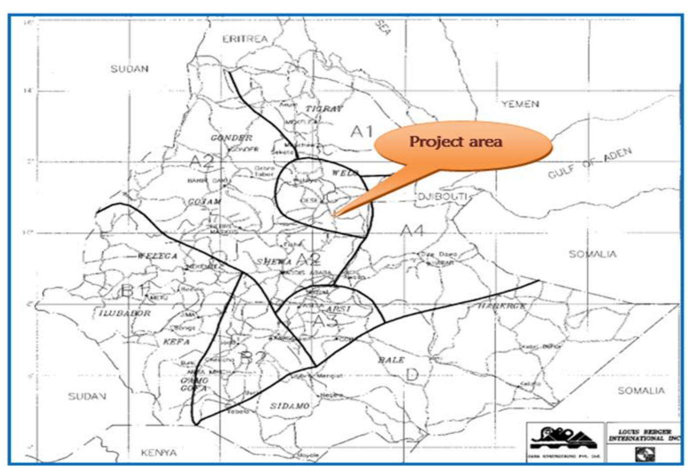

***Fig.** 1. Location of project area*

3 METHODOLOGY

For hydrologic and hydraulic analysis there are various modelling methods are there but choosing the best method is very important, the following methods have adopted for the investigations are as follows.

3.1 The Rational Method

This method is more accurate for calculating the design of storm, peak run-off for up to 50hecter (0.5 km^2) areas [2].

The rational formula is expressed as,

$$Q = 0.278C\ I\ A \quad (1)$$

Where,

Q = Maximum rate of runoff, m^3/sec
C = Run-off coefficient
I = Rainfall intensity, mm/Hour
A = Catchment Area km^2

3.2 Time of Concentration (T_c)

The rainfall intensity used in the rational method is determined from the time of concentration.

$$T_c = 0.0147L^{1.155}\ H^{-0.385} \quad (2)$$

Where,
Tc = Time of concentration, minutes
L = Maximum length of flow, m
H = Elevation difference between outlet, m

3.3 Soil Conservation Service (SCS) method

Soil Conservation Service method is developed by the U. S. Soil Conservation Service for estimation of run-off rates, runoff factor, time of concentration, rainfall intensity and catchment area. The Soil Conservation Service run-off equation is used for calculating direct run-off from 24-hour storm rainfall [2].

The equation is,

$$Q = (P - I_a) \wedge 2/ ((P - I_a) + S) \quad (3)$$

Where,

Q = Direct accumulated run-off, mm
P = Accumulated rainfall, mm
Ia = Initial abstraction, mm
Ia = 0.2*S
S = Maximum retention potential, mm
S=25400/(CN-254)
Where, CN has a range of 0 to 100

3.4 Estimation of Peak Discharge

It is used for the estimation of the peak discharge in Soil Conservation Service method.

$$q_p = q_u\ A\ Q \quad (4)$$

Where,
q_p = peak discharge, m^3/sec
q_u = unit peak discharge, $m^3/s/km^2$/mm
$q_u = 10 \wedge (Co + C1log_{tc} + C2\ (log_{tc})\wedge 2)$
A = Drainage area, km2
Q = Depth of run-off, mm
Where C_o, C_1 and C_2 = Regression coefficients given in table for various I_a/P ratios
∝ = Unit conversion factor equal to 0.000431 in SI unit.

TABLE 1 *COEFFICIENTS OF PEAK DISCHARGE (SOIL CONSERVATION SERVICE METHOD)*

Rainfall Type	I_a/P	C_0	C_1	C_2
I	0.1	2.3055	-0.51429	-0.1175
	0.2	2.23537	-0.50387	-0.08929
	0.25	2.18219	-0.48488	-0.06589
	0.3	2.10624	-0.45695	-0.02835
	0.35	2.00303	-0.40769	0.01983
	0.4	1.87733	-0.32274	0.05754
	0.45	1.76312	-0.15644	0.00453
	0.5	1.67889	-0.0693	0
IA	0.1	2.0325	-0.31583	-0.13748
	0.2	1.91978	-0.28215	-0.0702
	0.25	1.83842	-0.25543	-0.02597
	0.3	1.72657	-0.19826	0.02633
	0.5	1.63417	-0.091	0
	0.1	2.0325	-0.31583	-0.13748
	0.2	1.91978	-0.28215	-0.0702
	0.25	1.83842	-0.25543	-0.02597
	0.3	1.72657	-0.19826	0.02633
II	0.1	2.55323	-0.61512	-0.16403
	0.3	2.46532	-0.62257	-0.11657
	0.35	2.41896	-0.61594	-0.0882
	0.4	2.36409	-0.59857	-0.05621
	0.45	2.29238	-0.57005	-0.02281
	0.5	2.20282	-0.51599	-0.01259
	0.1	2.55323	-0.61512	-0.16403
	0.3	2.46532	-0.62257	-0.11657
	0.35	2.41896	-0.61594	-0.0882
III	0.1	2.47317	-0.51848	-0.17083
	0.3	2.39628	-0.51202	-0.13245
	0.35	2.35477	-0.49735	-0.11985
	0.4	2.30726	-0.46541	-0.11094
	0.45	2.24876	-0.41314	-0.11508
	0.5	2.17772	-0.36803	-0.09525
	0.1	2.47317	-0.51848	-0.17083
	0.3	2.39628	-0.51202	-0.13245
	0.35	2.35477	-0.49735	-0.11985

3.5 Manning's Formula

This method deploys the hydraulic characteristics of the stream influencing the maximum discharge, such as velocity of flow, slope of the stream, cross sectional area of the stream and shape and roughness of the stream [2].

$$Q = 1/n \quad R \wedge (2/3) \quad S \wedge (1/2) \quad A \quad (5)$$

Where,
Q = Total discharge m^3/sec
n = Manning's roughness coefficient
R = Hydraulic mean depth (m)
S = Longitudinal bed slope in %
A = Cross-sectional flow area in m^2
P = Wetted perimeter in m

3.6 Design Criteria for Bridge

The following criteria has been used for the hydraulic analysis for the bridge design. Backwater: Backwater up to 0.5m in duration of up to100-year flood is established. Clearance: For the design of bridge a minimum clearance has been used from the below table.

TABLE 2 FREE *BOARD RECOMMENDATION AS PER ERA - 2013*

Discharge Q (m^3/s)	Freeboard (m)
0 – 3.0	0.3
3.0 -30	0.6
30 -300	0.9
0 – 3.0	0.3

3.7 GIS Software
The hydrological and hydraulic analysis has also done by using GIS Software's like Arc View. The Complete Digital Elevation Model (DEM) of Ethiopia (30m x 30m DEM) together with GIS shape files such as GIS data of land use, Soil Types etc.

3.8 HEC-RAS Hydraulic Model Software
The main objective of the HEC-RAS program is quite simple to compute water surface elevations at all locations of interest for either a given set of flow data (steady flow simulation), or by routing hydrographs through the system (unsteady flow simulation).

4 RESULT AND DISCUSSION

4.1 Catchment Area Delineation
Each sizes of catchment area are established by using Arc view GIS software and catchment area of each watershed on the whole route corridor has delineated from DEM- Digital Elevation Model data and topographic map 1:50,000.

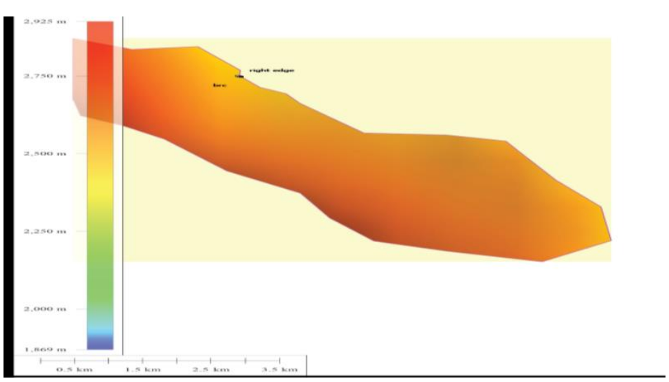

Figure 2. *Catchment Area Delineation*

4.2 HCE-RAS Analysis
Hydrological analysis of river such as flow of river, discharge capacity and depth of flow is determined by using HCE-RAS model software as shown in Fig.3 and also water surface elevation determined as shown in Fig. 4 as the main channel distance is 800m and the water surface elevation is almost 1822m.

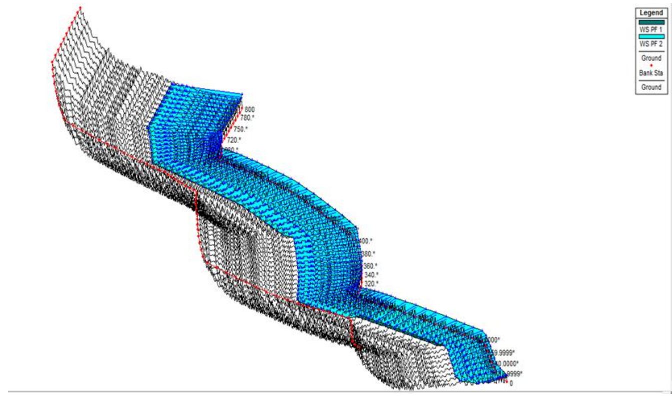

Figure 3*. Mechela River Flow Layout*

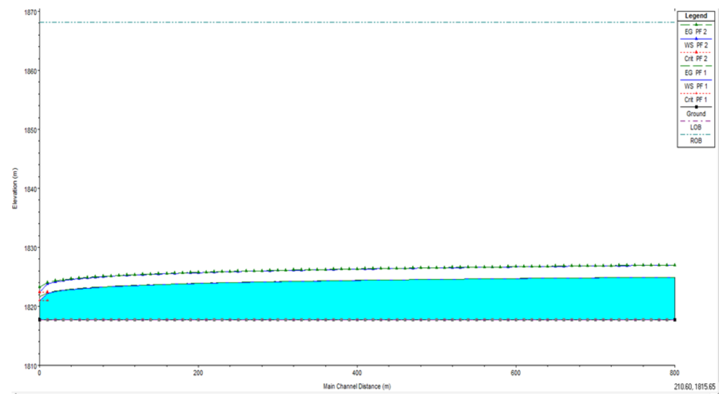

Figure 4*. Water surface elevation of Mechela River*

4.3 Hydrological Assessment
Following the preliminary hydrologic and hydraulics investigations has been carried out at Mechela river. In this investigation physically the location of bridge has been identified. The summary of recommended hydrologic and hydraulic analysis is presented in the Table 3 below.

TABLE 3 *SUMMARY OF HYDROLOGY AND HYDRAULICS OF BRIDGE*

S. No	Station	50yr. Peak Discharge Q (m^3/s)	100yr. Peak Discharge Q (m^3/s)	Recommended size		Remark
				Span (m)	Height (m)	
1		159.263	182.6	15	3.85	Including free board

4.4 Mechela River Bridge Project Hydrology investigation
A detail hydrological investigation has been carried out for the design of bridge. Hydrologic soil grouping is classified by the Ministry of Water Resources Metadata Bases (Shape files) with 1:50000 scale. The Hydrologic soil grouping for each catchment is identified from examination of available soil maps and physical assessment done on site. Accordingly, 81.1% of the catchment areas were Eutric cambisols, 11% Eutricleptosols and the remaining 7.9% was covered by Eutric regosols as shown in Table 6. From condition survey and Ministry of water resources metadata (land use Shapes files)

the Mechela bridge project passes through predominantly covered with agricultural land and some parts is grass pasture and shrubs as shown in Table 7. Field observations and topographic map of scale 1:50000 show that the general watershed that drains across the Mechela bridge project crossing mountainous terrain. Curve numbers shall be selected only after a field inspection of the catchment area and a review of cover type and soil maps as shown in Table 8. Geologically the Mechela bridge project, river catchments area is present sand, flood basalt, silt gravel, surma basalts and teltel. The climate along the project route is categorized as dega in which it is characterized by Minimum temperature and low relative humidity. The mean annual rainfall of the area ranges between 1500mm-3000mm, the major rainy seasons of project area is during Kiremet (June -September) in which its amount ranges between 400-799mm and during Belg times (February -may) and between times (October-January) it ranges between 50-99mm mean annual rainfall distribution as shown in Fig. 5.

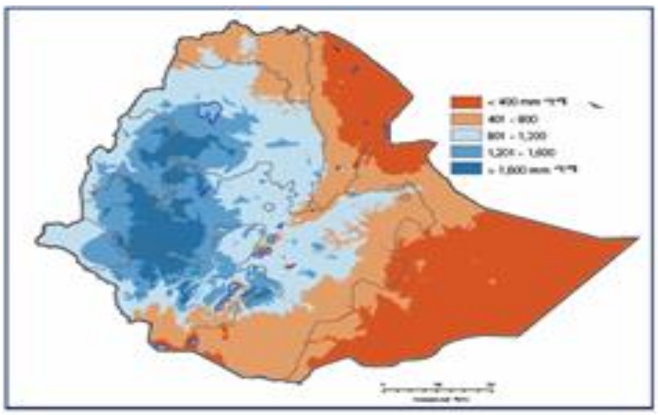

Figure 5. *Annual Rainfall Distribution of Ethiopia*

The mean annual temperature of the area falls between 13˚c to 30˚c, which is categorized in cool temperate (altitude from 1800-3000m). According to ERA (2013) Drainage Manual the project road is located in rainfall regime C rainfall intensity was taken from the manual as shown in Table 4.

TABLE 4 *24HOUR RAINFALL DEPTH*

Region		24-Hour depth (mm) v/s Frequency (years)					
		2	5	10	25	50	100
A1	A4	79	93	113	127	142	142
A2	A3	67	79	95	107	118	118
B	C	84	98	92.52	101.48	110.5	110.5
D		67	89	105	127	144	161
Hayke		74	106	131	163	187	211

TABLE 5 *MECHELA BRIDGE DESIGN FLOOD USING USSCS*

Return period (years)	qu (Unit peak discharge) m³/s/km²/mm	Catchment Area (km²)	Q depth of runoff (mm)	$q_p = q_u$ A Q
25	0.11019	28.218	43.953	136.66
50	0.11019	28.218	51.221	159.263
100	0.11019	28.218	58.726	182.600

TABLE 6 *MECHELA BRIDGE SOIL DETAIL*

S. No	Item	Area (km²)	Percentage %	Hydrological soil group
1	Eutric cambisols	22.881	81.09	B
2	Eutric Regosols	2.227	7.89	A
3	Eutric leptosols	3.11	11.02	D
Total		28.218	100.00	

TABLE 7 *MECHELA BRIDGE LAND USE*

S. No	Item	Area (sq.km)	Percentage %	Land cover	Curve number
1	Agricultural	20.62	73.07	Dominantly cultivated	80
2	Open shrub land	7.598	26.93	Shrub land	79
Total		Total	28.218	100.00	

TABLE 8. *MECHELA BRIDGE CURVE NUMBER*

Item	Area	CN	Product
Agricultural	20.62	80	1649.6
Open shrub land	7.598	79	600.242
Total	28.218		2249.84
Average curve number CN			79.73

TABLE 9 *MECHELA BRIDGE CATCHMENT MAXIMUM POTENTIAL RETENTION (S)*

25400	CN	254	
	79.73		
	318.5722	S	64.6

TABLE 10 *MECHELA BRIDGE CATCHMENT INITIAL ABSTRACTION (I_a)*

I_a = 0.2S	P25	P50	P100	I_a/P25	I_a/P50	I_a/P100
12.91	92.52	101.48	110.5	0.139	0.127	0.117

TABLE 11 *MECHELA BRIDGE DIRECT RUNOFF IN mm DEPTH*

S	0.2S	0.8S	P25	Q25	P 50	Q50	P100	Q100
64.572	12.91445	51.65779	92.52	43.95298	101.48	51.220911	110.5	58.73
	153.1378		6337.044		7843.857		9522.94	
			144.1778				162.1578	

TABLE 12 *MECHELA BRIDGE TIME CONCENTRATION FOR OVER LAND FLOW*

				C Values					
Length (km)	Min Elv	Max Elv	Slope= H/1000 x L	Town or Paved area	Open shurb land	Agricultural	CVL	S^0.5	$T_c=0.604(C_v L/S^{0.5})$
					7.598	20.62			
2.6154	2479.775	2747.412	0.1023		0.1700	0.2000	0.5020	0.3199	0.75
					1.29166	4.124	1.29166		
						5.4			
				CV weighted		0.19			

TABLE 13 *MECHELA BRIDGE TIME CONCENTRATION FOR DEFINED WATER COURSE*

Length (km)	Elevation 0.85L (m)	Elevation 0.1L(m)	S_{av} = ($H_{0.85L}$ - $H_{0.10L}$) / (1000) x (0.75 x L)	1000 x S_{av}	0.87 x L^2	$Tc= (0.87L^2/1000 \times S_{av})^{0.385}$
6.184	2675.5	2487.62	0.0405	40.509	33.27	0.93
	5.2564	187.88				
	5256.4	4638				
				Total T_c	$T_{c1}+T_{c2}$	1.67

TABLE 14 *MECHELA BRIDGE UNIT PEAK DISCHARGE*

			Regression Coefficient				
Rainfall type	Return period years	I_a/P	C_0	C_1	C_2	Unit conversion factor a	T_c
II	25	0.108	2.55323	-0.6151	-0.164	0.000431	1.67
II	50	0.098	2.55323	-0.6151	-0.164	0.000431	1.67
II	100	0.090	2.55323	-0.6151	-0.164	0.000431	1.67

TABLE 15*. MECHELA BRIDGE DISCHARGE*

$Logt_c$	$C_1 \times Logt_c$	$(Logt_c)^2$	$C_2 \times (Logt_c)^2$	$C_0+C_1 \times Logt_c+C_2 \times (logt_c)^2$	$qu = \alpha \times 10^{C_0+C_1 logt_c+C_2 (logt_c)^2}$
0.223353	-0.13738	0.04988638	-0.00818137	2.40766	0.11019
0.223353	-0.13738	0.04988638	-0.00818137	2.40766	0.11019
0.223353	-0.13738	0.04988638	-0.00818137	2.40766	0.11019

TABLE 16 *MECHELA BRIDGE PROJECT HYDRAULICS*

Dimensional computation for the given Design discharge for the given return period													
Bridge span	Average Channel slope (S)	Depth of flow (m)	Manning Roughness Coefficient (n)	Side slope H: V	Area (A)		Perimeter (p)		Hydraulic Radius ®		Design Discharge Computation	
					Rectangular	Trapezoidal	Rectangular	Trapezoidal	Rectangular	Trapezoidal	Rectangular	Trapezoidal
14.6	0.016	3.25	0.07	0.5	47.45	52.73125	21.1	21.86722	2.249	2.41142897	147.174988	184.6961

Based on calculations the following parameters of the bridge has been estimated,

Depth of flow 3.25m

Bridge span Length 15m

Free board 0.6m

Total depth from river bed to bottom slab of the bridge 3.85m

5 CONCLUSION

Catchment area is determined, the catchment area delineation has been established by using GIS Software Digital Elevation Models (DEM), discharge, run-off and slope characteristics of the catchment area is calculated, water run-off quantities, drainage location, capacity and type of drainage facilities required structures are carried out using different acceptable calculation methodologies, on the size of the estimated run-off coefficient, catchment area and the run-off coefficients are determined using available information and following field reconnaissance made by hydrologist. Based on above data depth of flow 3.25m, bridge span length 15m, free board 0.6m and the total depth from river bed to bottom slab of the bridge 3.85m has been estimated. GIS Software Digital Elevation Models (DEM) and HEC-RAS software's are best Engineering tool hydrological and hydraulics analysis of river for the design of bridge.

REFERENCES

[1] Atharvi Thorat, C Shri.Srishailam, Akshay Nalawade, Sahil Gore and Sanket Lunawat, "Estimation of Hydrological and Hydraulics Parameters for Bridge Design", International Research Journal of Engineering and Technology, Vol. 6 no. 3, pp. 5039-5044, 2019.

[2] Birhanu Haile Gedamu and Vijaykumar, "Hydrological and Hydraulics investigation for the design of Bridge across Ajowa river at Wuchale town Amhara region south Wollo Ethiopia", International Journal of Civil Engineering and Technology, vol. 11, no. 5, pp. 115-124, 2020.

[3] T H M Amulya, Dhanashree, Nerlikar and Rajashri Melannavar, "Hydrological Analysis for Proposing New Bridge at Vrishabhavathi River Valley, Laggere", International Journal for Research in Applied Science & Engineering Technology, vol. 6, no. 1, pp. 743-749, 2018, doi:10.2214/ijraset.2018.1113.

[4] I Azazkhan Pathan and P G Agnihotri, "A Combined Approach For 1-D Hydrodynamic Flood Modeling by using Arc-Gis, Hec-Georas, Hec-Ras Interface – A Case Study on Purna River of Navsari City, Gujarat", International Journal of Recent Technology and Engineering, vol. 8, no. 1, pp. 1410-1417, 2019.

[5] Dan Li, Jianyun Zhang, Guoqing Wang, XiaojunWang, Jingwei Wu, "Impact of changes in water management on hydrology and environment, A case study in North China", Journal of Hydro-environment Research, vol. 28, pp. 75-84, 2020.

[6] Hua TIAN and Jia-dong HUANG, "Hydrologic Correlation Analysis of Highway Bridge Community Along River", International Conference on Material Science and Civil Engineering, pp. 446-451, 2016.

[7] Hakim Farooq Ahmad, Akhtar Alam, M. Sultan Bhat and Shabir Ahmad, "One Dimensional Steady Flow Analysis Using HECRAS – A case of River Jhelum, Jammu and Kashmir", European Scientific Journal, vol. 12, no. 32, 2016, 340-350. doi:10.19044/esj. 2016.v12n32p340.

[8] Konstantin Ochs, Gregory Egger, Arnd Weber, Teresa Ferreira, John Ethan Householder, Matthias Schneider, "The potential natural vegetation of large river floodplains–From dynamic to static equilibrium", Journal of Hydro-environment Research, vol. 30, pp. 71-81, 2020.

[9] V Khyati Mistry, Pritika Prajapati and Bijal Chaudhri, "Determination of the stage Discharge curve using HEC-RAS", International Journal of Advance Engineering and Research Development, vol. 5, no. 5, pp. 645-649, 2018.

[10] P Sunilkumar and K O Vargheese, "Flood Modelling of Mangalam river using GIS and HEC-RAS", International Journal of Advance Research in Science and Engineering, vol. 6, no 6, pp. 159-169, 2017.

[11] Azhar Husain, "Flood Modelling by using HEC-RAS", International Journal of Engineering Trends and Technology, vol. 50, no. 1, pp. 1-7, 2017.

[12] G K Ebissa, "Hydrological Analysis and Peak Discharge Determination", Journal of Mechanical and Civil Engineering, vol. 14, no. 3, pp. 33-48, 2017.

[13] Ritica Thakur and R Deepali Vaidya, "Determination of Safe Grade Elevation by Using HEC- RAS: Case Study Mutha River", International Journal of Research in Engineering and Technology, vol. 5, no. 1, pp. 125-129, 2016.

[14] Luay Kadhim Hameed, "Calibration of Manning's Friction Factor for Rivers in Iraq Using Hydraulic Model (Al-Kufa River as Case study)", International Journal of Innovative Science, Engineering & Technology, vol. 1, no. 10, pp. 504-515, 2014.

[15] Santosh Nepal, "Impacts of climate change on the hydrological regime of the Koshi river basin in the Himalayan region", Journal of Hydro-environment Research,vol.10,pp.76-89,2006, http://dx.doi.org/10.1016/j.jher.2015.12.001.

[16] Sunil Kute, Sayali Kakad, Vrushali Bhoye, and Akshada Walunj, "Flood Modeling of River Godavari Using HEC-RAS", International Journal of Research in Engineering and Technology, vol. 3, no. 9, pp. 81-87, 2014.

[17] G Vipinkumar Yadav, Darshan Mehta and Sahita Waikhom, "Simulation of HEC- RAS model on Prediction of Flood for Lower Tapi River Basin, Surat", Journal of Emerging Technologies and Innovative Research, vol. 2, no. 11, pp. 105-112, 2015.

[18] Munjal Patel, Dr. Suvarna Shah and Er. Rajendra Shah, "Mapping Inundation due to Maximum Probable flood using GIS and HEC-RAS", National Conference on applications of Nanotechnology-February, pp. 92- 99, 2017.

[19] S. J. Chate, P. T. Nimbalkar, "Development of Flood Routing Model Using HEC-RAS Software for Mutha River in Pune City", International Journal of Engineering and Advanced Technology, vol. 8, no. 5, pp. 2302-2307, 20019.

[20] J. Imbenzi Serede, M Benedict Mutua and M James Raude, "Hydraulic Analysis of Irrigation Canals using HEC-RAS Model: A Case Study of Mwea Irrigation Scheme, Kenya", International Journal of Engineering Research & Technology, vol. 4, no. 9, pp. 989-1005, 2015.

[21] Mohammed Sharif and Azhar Husain, "Estimation of Design Flood at Kol Dam using Hydrometeorological Approach", International Journal of Environmental sciences & natural Resources, vol. 4, no. 1, pp. 005-010, 2017.