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Estimation of peak flood discharge using rational method and Manning equation in Junbedia jorh microwatershed, Bankura district, West Bengal, India

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Abstract

The present paper deals with the calculation of peak flood discharge by two important hydrological models- 'Rational Method' and Manning Equation' in Junbedia Jorh microwatershed near Bankura town of West Bengal. The study applied 'IMD 1/3rd Rule' for calculation of short duration rainfall from daily rainfall data and 'hydraulic radius' for calculation of Manning value based on data derived from the field by Auto Level and GPS survey. The result shows that the peak discharge of the jorh during its record rainfall of September, 2021 was 69 m^3s^{-1} rendering the lower part of the catchment more than 12 hours of waterlogging. The Manning equation estimated the discharge at 45 m^3s^{-1} with consequent nineteen hours of waterlogging. It is found that the results so obtained by model estimations have fairly matched with the questionnaire survey results in almost 240 households in the most flood affected area of the catchment.

Keywords: Hydraulic Radius, IMD 1/3 Rule, Junbedia Jorh, Manning Equation, Peak Flood Discharge, Rational Method, Runoff Coefficient, Time of Concentration

1. Introduction

Flood has been an important hazard which takes a heavy toll on the human life and property in recent years. Flood may be defined as the sudden rise in the level of water of rivers, seas, lakes or sewages due to high amount of rainfall within a very short span of time, storm surges on the seas or lakes. There are many different types of flood like river flood, coastal flood, lake flood, sewage flood, etc. [1]. Among them, river flooding is one of the most important flood hazard in the world which is mainly attributed to the high intensity rainfall, dam outburst or glacial lake outburst flood (GLOF). Urban flooding is basically caused by unprecedented growth of urbanization with consequent infrastructural development and growth of concretization. The growth of roads, railways, concrete pavements together increases the peak discharge rate in the catchment. The term 'peak discharge' can be defined as the concentrated flow of water after a certain time of high intensity rainfall in the upper catchment area of a watershed which causes flood like situation in the lower catchment due to overtopping of bankfull discharge of water. In addition to that, the river becomes increasingly encroached by the growth of settlements with consequent decrease of discharge capacity of the main river. These factors ultimately lead to flood situation and make people more vulnerable.

West Bengal is highly flood affected state of India particularly during monsoon season. Almost all its districts except Purulia are affected by recurring flood events. Nearly 42% of the total geographical area of the state is flood affected [2]. Bankura district is no excxeption. Nearly 10 blocks (Sarenga, Raipur, Indas, Patrasayer, Kotulpur, Joypur, Sonamukhi, Barjora, Mejia and part of Bankura-I) out of 22 blocks of the district are flood affected [3]. Bankura town- the administrative headquarter of the district has recently in the flood prone map of West Bengal where during last two decades almost 8 flood events occurred with varied intensity. In last five years, every year breaks the record of the last year's depth and duration of flood. Every year in the late monsoon, the electronic and print media are being flooded with the news headlines of Bankura flood mainly caused by Gandheswari River and its right bank small tributary rivulet locally known as Junbedia Jorh.

The present paper attempts to estimate the peak discharge of this jorh (Bengali local dialectic term for rivulet) flowing through the northern border of Bankura municipal town of the western part of West Bengal. During the last decade, the recurring flood inundation by this small rivulet particularly during monsoon has been a great concern to the urban planners and engineers. The absence of flow during summer and sudden flash flood situation during monsoon has restricted the instrumental measurement of discharge in this rivulet. Accuraate estimation of discharge and the calculation of basin runoff volume are necessary for any hydrological project [4]. Therefore, the paper deals mainly with the indirect calculation of peak discharge [5] by applying two different mathematical models. Hydrologists also use Geomorphological Instantaneous Unit Hydrograph (GIUH) as an alternative method of estimating peak discharge for an ungauged river. Supraja et al [6] worked in Palar Sub Basin of Andhra Pradesh, Bhaskar et al [7] compared two different models to estimate peak discharge in Jira river subcatchment in eastern India. In an another study Roy et al [2] attempted to calculate peak discharge by three different geomorphic based hydrological models- Manning's equation, Kinematic Wave Parameter (KWP) and SCS Curve Number (CN) methods for Kunur river basin in Birbhum district of West Bengal. Blagojevic et al [8] on the other hand attempted to estimate peak flood discharge of very small catchments with less than 32 km^2 area in Bosnia and Herzegovina applying GIS techniques. All these studies applied either mathematical models or GIS based methods to estimate peak flood discharge after an high intensity rainfall in a small catchment.

2. Study Area

The Junbedia Jorh microwatershed is located in the north-western part of Bankura town of West Bengal. The jorh (rivulet) is the right bank tributary of Gandheswari River of Dwarakeswar River basin, flowing from north-west to south-east direction. It has a total area of 8.48 km^2 stretching from 23°13′30″ N to 23°16′45″ N latitude and 87°00″ E to 87°06″ E longitude (Fig-1). The watershed covers almost seven mouzas viz. Keshra, Panchbagha, Badra, Adhorjabandh, Khudsole-1, Khudsole-2 and Junbedia. Out of these seven mouzas Khudsole-1 and Khudsole-2 are included in Bankura municipality (ward no.11). Geologically, the watershed is a part of eastern extension of Chhotanagpur plateau, one of the oldest plateaus of the world and hence the basement complex of the area is mainly composed of granite and gneiss. However, on the uppermost part of this igneous rock, sporadic alluvial deposits are found. The elevation of the entire basin ranges between 78 m and 125 m with an average slope of below 5° in WNW to ESE direction. The main rivulet is very small with a length of 6.69 km originating from Keshra and finally flows into Gandheswari river near Palashtala carrying the rainwater of the newly added urbanized area in the south and predominantly rural area with agricultural land use in the north. Therefore, locally it is significant in terms of the amount of discharge particularly during the monsoon. The catchment is composed of 36% of urban settlement, followed by 31% of agricultural, 14% of orchard and plantation, 11% of wasteland and nearly 4% of major and minor roads and other infrastructures. It is found from the survey that the urbanization in this periphery area is a recent phenomenon. Nearly 80% of the houses constructed in this region is between 2010 and 2020. The unplanned urbanization, rapid encroachment of the main channel, dumping of the building as well as other domestic wastes on the channel bed have significantly diminished the discharge capacity of the jorh with consequent waterlogging during short period of high intensity rainfall. In spite of urbanization being a recent phenomenon, the area looks mature as most of the houses are double storied. The survey among 240 households shows nearly 56% of them in the region particularly in its lower catchment are double storied. This may be attributed to the resilience developed against the regular waterlogging in the area.

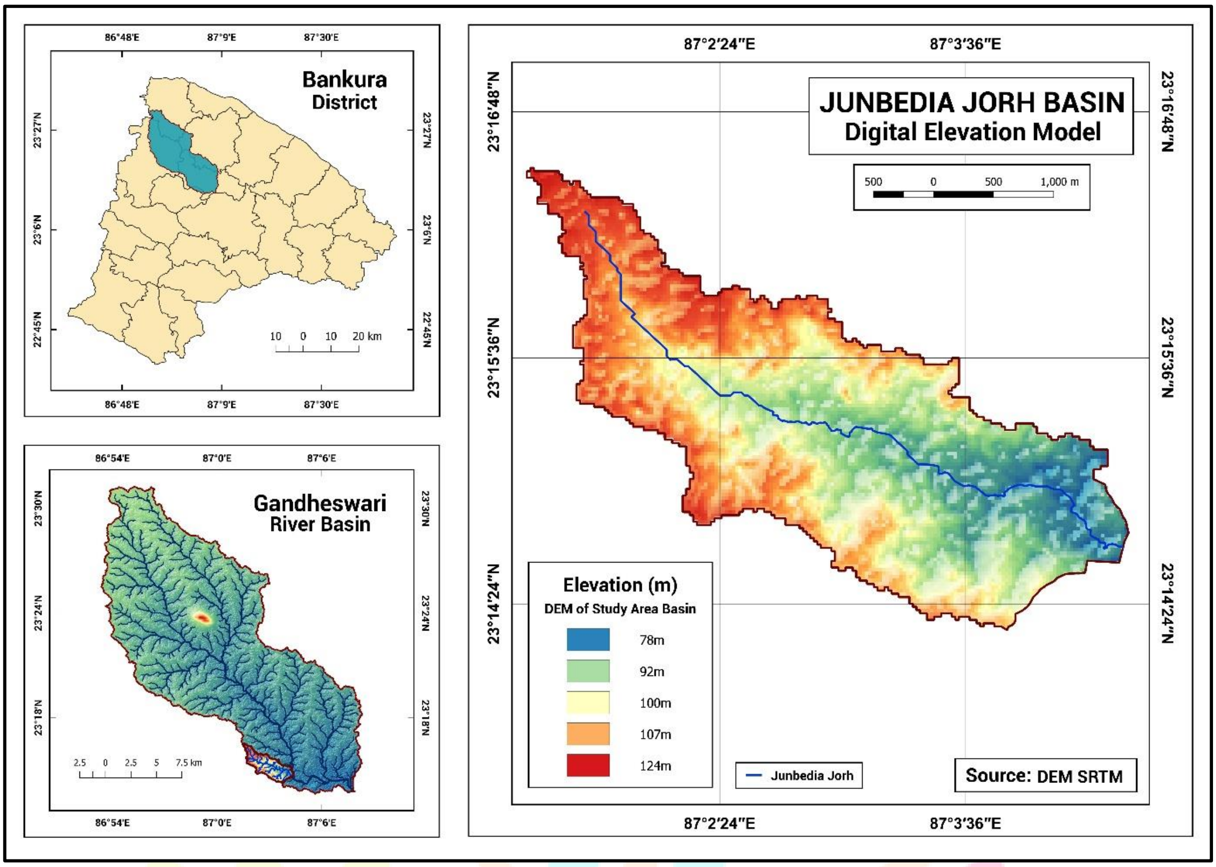


Figure 1: Location of the study area

The region falls within monsoon climate regime with maximum rainfall being concentrated in June to September. The month of July normally receives the highest rainfall with monthly mean of 336 mm [3]. However, in 29th September, 2021 the 50 year record rainfall occurred with an amount of 354 mm during 24 hour [9], causing devastating flood in the lower catchment. The morphometric analysis of the Junbedia Jorh basin has shown that the basin is of 4th order based on the stream ordering (Strahler's method) prepared from SRTM-DEM of the basin [10] with drainage density [11] of 2.74 km/km^2 and mean bifurcation ratio [12] of 2.88. The basin is elongated with the elongation ratio [12] of 0.49 and form factor [11] of 0.19. All these values suggest that the basin is not morphometrically flood prone. The survey among the old residents of Junbedia and Badra village also revealed that the basin has not been historically flood prone. Therefore, the recent regular flood events in the basin can be mainly attributed to the rapid urbanization in the area.

3. Materials and Methods

The major spatial data inputs for the study are seven mouza maps- Keshra, Panchbagha, Badra, Adhorjabandh, Khudsole-1, Khudsole-2 and Junbedia have been collected from DL&LRO office, Bankura. Topographical maps on 1:50,000 scale – 73M/3 and 73M/4 were collected from Survey of India, Kolkata office and the Shuttle Radar Topography Mission- Digital Elevation Model (SRTM-DEM) was downloaded from USGS Earth Explorer. Apart from these data, physical Auto Level (SUN DSG-240) survey was conducted in 10 sites along the jorh to prepare cross profiles of the rivulet. The coordinates of the cross profiles were obtained by a handheld GPS receiver- GPS Map 76CSx. The benchmark elevations of the first stations of each profile were taken from Google Earth elevation data duly compared with the DEM as the vertical elevation accuracy of handheld GPS is restricted. The detailed methodology can be broadly outlined into the following major steps:

3.1: Preparation of Base Map

At first, the watershed boundary is delineated in QGIS 3.16 with the SRTM-DEM [13] along with all the rivers and rivulets ordered accordingly by Strahler's method [10]. The seven mouza maps then mosaicked in AutoCAD-2018 for seamless mosaicking. In this step, it has found that the digital mosaicking of all seven mouza maps in QGIS was not perfect as the edge boundaries of the mouzas were not perfectly matched. AutoCAD in this case gave a better result with perfect matching of all the boundaries. After mosaicking the maps, all the plots under the basin are digitized and the nature of landuse of each of the plots are recorded as plot attribute keeping the Google Earth image as base layer. The landuse map is very important for the calculation of runoff coefficient of various landuse categories of the basin.

3.2: Estimation of Peak Discharge by Rational Method

Runoff is the excess flow of water on the ground after rain water, storm water, melt water or any other sources of surface water. In a river basin, runoff takes place soon after the rainfall and flows through the channels and ultimately departs from the catchment through the main outlet. The amount of runoff can be calculated if the basin area and the amount of daily rainfall are known. There are various methods of runoff calculation for a basin area, such as unit hydrograph method, empirical method and semi-empirical method. All these methods require similar kind of data particularly rainfall intensity, depth and duration of rainfall in a basin area. Therefore, daily rainfall data are required for the simulation of hydrological processes [15]. The use of a particular method of runoff calculation is largely determined by the desired objective, available data, size of the basin etc. After considering the availability of data for an ungauged river with a very small catchment, a semi-empirical method, popularly known as rational method has been used.

The rational method of runoff calculation considers uniform rainfall intensity within a reasonably high duration. It takes into account 't_c' = time of concentration of rainfall i.e., the time taken for a drop of water from the furthest part of the catchment to reach the outlet [14]. This method also envisages that if the rainfall continues beyond 't_c', the runoff will be constant and at the peak value. It is assumed that the runoff begins at the commencement of the storm and increases linearly to the peak value. The peak value is sustained till the end of the storm and gradually decreases linearly to zero. Hence, the peak becomes flat. By this method, the peak discharge can be calculated by the following formula:

$$Qp = 2.78\, C\, (i_{tc.p})\, A$$

Where,

Qp = Peak discharge (m^3s^{-1})

C = Coefficient of runoff. If the land use and land cover of the basin is of mixed type, then weighted equivalent runoff coefficient (Ce) has to be calculated as under;

$$Ce = \frac{\sum_1^n C_i A_i}{A}$$

where, A_i = Area of ith land use category

C_i = Runoff coefficient of ith land use category

A = Total basin area = $A_1+A_2+A_3+ \ldots\ldots +A_n$

$i_{tc.p}$ = The mean intensity of rainfall (cm/hr) for a duration equal to 't_c' and at exceedence probability *P.*

The *(tc.p)* can be calculated by using Kirpich's formula as:

$$tc = \frac{0.01947 L^{0.77}}{S^{0.385}} \text{ min.}$$

where, L = Maximum length of travel of stream in meters

S = Slope of the whole catchment ($S = \frac{\Delta H}{L}$)

A = Basin area in km^2

Table 1: Value for Runoff Coefficient in Land Use Categories.		
Sl. No.	Land use category	Runoff Coefficient (C)
1	Residential	0.40
2	Urban orchard/ Plantation	0.10
3	Wasteland (sandy)	0.20
4	Agricultural (flat)	0.50
5	Road	0.82
6	Waterbody	00
Source: Based on Report on Runoff Calculations, Mustansiriyah University, Baghdad, 2019 [13]		

3.2.1: Database

The total catchment area is 8.48 km^2 and the maximum length of travel of water (maximum stream length) is calculated to be 6.6852 km. The vertical interval between the highest and the lowest point of the catchment remains 47 m (ΔH = 125-78) and hence the average slope being 0.007 (47/ 6.6852). The maximum depth of daily (24 hour period) rainfall in the catchment is represented in the table-2:

Table 2: Duration of Rainfall (Assumed & Actual)					
Duration (hours)	24	24	24	24	24
Maximum amount of rainfall (mm)	175#	220#	354*	450#	525#
* Actual Record Rainfall of 29th September, 2021 during last 50 years [9] # Assumed rainfall below and above the record rainfall					

3.2.2: Calculation of Peak Discharge

The volume of peak discharge at the Junbedia Jorh outlet at Gandheswari River near Palashtala can be determined by the formula $Qp = 2.78\ C\ (i_{tc.p})\ A$.

3.2.3: Calculation of tc (time of Concentration)

The time of concentration (t_c) is the time taken for the first drop of water falling on the furthest part of the catchment to reach the outlet. After this time, the discharge will be at the peak rate. It is variable and dependent on the shape and general slope of the basin. Generally, the elongated basins have higher 't_c' than the circular basins. It is the ratio between the length of the master stream and slope of the catchment and numerically represented as:

$$tc = \frac{0.01947L^{0.77}}{S^{0.385}} \text{ min.}$$

$$= \frac{0.01947*(6685)^{0.77}}{(0.007)^{0.385}} \text{ min.}$$

= 115.97 min.

= 116 min.

3.2.4: Calculation of hourly duration of rainfall

As the hourly duration of rainfall is not available, the IMD 1/3rd Rule has been applied to estimate the hourly duration of rainfall from the daily rainfall data by the following formula [16]:

$P_t = P_{24}\,(t/24)^{1/3}$

Where, P_t = Rainfall in mm at 't' hours duration

P_{24} = Daily rainfall in mm

t = Shorter duration in hours

Table 3: Calculation of Hourly Rainfall applying IMD 1/3rd Rule.

Duration (minutes)		30	60	90	120	150	180
Duration (hours)		0.5	1.0	1.5	2.0	2.5	3.0
Maximum Rainfall (mm)	175	48.16	60.68	69.46	76.44	82.35	87.51
	220	60.54	76.28	87.32	96.10	103.52	110.01
	354	97.42	122.70	140.50	154.64	166.58	177.01
	450	123.84	156.02	178.60	196.57	211.75	225.02
	525	144.48	182.03	208.37	229.93	247.04	262.52

Source: Calculated by the Authors

3.2.5: Calculation of maximum depth of rainfall for 116 min duration

From the Table-3, the maximum depth of rainfall for 116 min duration can be calculated as the duration of rainfall are represented. In order of magnitude, the 116 min duration actually lies between 90-120 min. Therefore, by using simple interpolation $\left(\frac{d_1}{D_1} = \frac{d_2}{D_2}\right)$, the maximum depth of rainfall corresponding to each of the daily rainfalls are converted into shorter duration rainfall (see table-4).

3.2.6: Calculation of average intensity ($i_{tc.p}$)

Average intensity of rainfall ($i_{tc.p}$) from the daily rainfall data can be calculated for the particular duration by the following formula;

$$\text{Average intensity } (i_{tc.p}) = \frac{Depth\ of\ rainfall\ in\ cm}{Duration\ of\ rainfall\ in\ hour}$$

The result so obtained are entered in the Table-4.

Table 4: Calculation of Maximum Depth of Rainfall and Average Intensity.

Maximum Daily Rainfall (mm)	Maximum Depth of Rainfall for 116 min duration (mm)	Average Intensity ($i_{tc.p}$) (in cm/hour)
175	75.51	3.91
220	94.93	4.91
354	152.75	7.90
450	194.17	10.04
525	226.54	11.72
Source: Calculated by the Authors		

3.2.7: Calculation of weighted runoff coefficient (Ce)

As the Junbedia Jorh basin has mixed land use pattern, the single runoff coefficient is not suitable and will not give accurate runoff estimate. Therefore, a land use map has been prepared from the high resolution Google Earth image matching each and every plot of seven mouzas under the study area. (See Table-5 and Figure-2)

Table 5: Area of Land Use Categories

Land use category	Residential	Orchard/plantation	Wasteland	Agricultural	Road	Waterbody	Others
Area in km^2	3.1343	1.1721	1.0387	2.6874	0.2850	0.1311	0.0322
Source: Based on Google earth image							

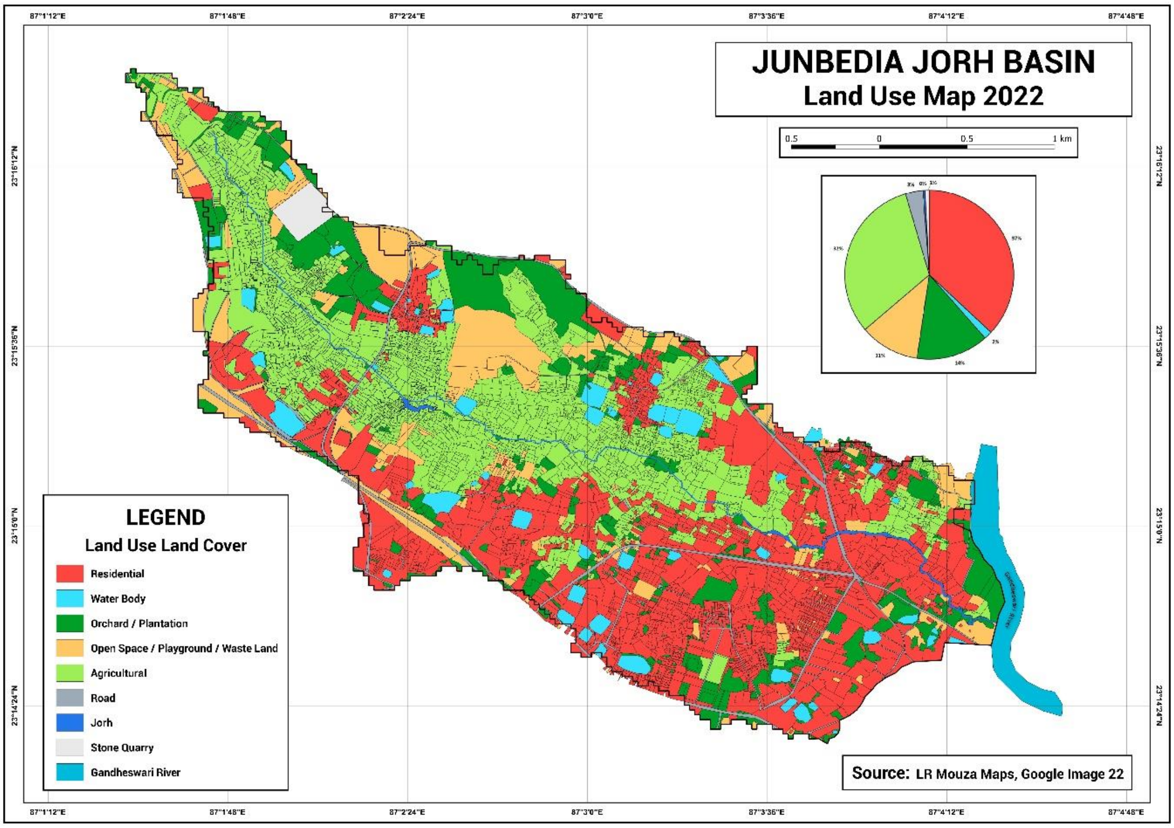


Figure-2: General Landuse of Junbedia Jorh Microwatershed

The table-5 shows the entire catchment is composed of six major landuse categories, the area of which is calculated in QGIS 3.16. In such case of non-homogeneous catchment [14], weighted equivalent runoff coefficient has to be applied for better result as under:

$$Ce = \frac{\sum_{1}^{N} C_i A_i}{A}$$

$$= \frac{(0.40*3.1343)+(0.10*1.1721)+(0.20*1.0387)+(0.5*2.6874)+(0.82*0.2850)+(00*0.1311)}{8.4808}$$

$$= 0.3721$$

3.2.8: Calculation of peak discharge (m^3s^{-1}) and runoff volume (m^3) in different value of daily rainfall

Finally with all the calculated values, peak discharge at the outlet of the jorh and the volume of runoff in the entire catchment have been worked out by the following formula and the results are entered in the Table-6.

$$Qp = 2.78\, C\, (i_{tc.p})\, A \text{ m}^3\text{s}^{-1}$$

Table 6: Calculation of Peak Discharge and Runoff Volume.

Maximum Daily Rainfall (mm)	Weighted Runoff Coefficient (C)	Average Intensity of Rainfall (cm/hr.) ($i_{tc.p}$)	Basin Area (km²) (A)	Maximum Peak Discharge (m^3s^{-1}) ($Qp = 2.78\, C\, (i_{tc.p})\, A$)	Volume of Runoff (m³) (max. daily rainfall × A)
175	0.3721	3.91	8.4808	34.30	14,84,140
220		4.91		43.07	18,65,776
354		7.9		69.31	30,02,203

450		10.04		88.08	38,16,360
525		11.72		102.82	44,52,420
Source: Calculated by the Authors					

3.3: Estimation of Peak Discharge by Manning Equation

Manning Equation is another indirect method of estimating peak discharge of open channels [4]. According to Chow [17], Benson and Dalrymple [18], Summerfield [19] and many other hydrologists, Manning Equation is a suitable method of peak discharge estimation for an ungauged open channel. The application of hydraulic radius in it has made the Manning equation as the most powerful tool for the estimation of peak discharge for any channel shape. It also requires a number of calculations and determination of coefficients. The equation defines the mean channel flow velocity (v) as:

$$V = \frac{K\,(R_h^{\frac{2}{3}} \times S^{\frac{1}{2}})}{n}$$

Where, V = Channel flow in m/sec = Peak discharge

K = Constant (1.0 for Metric units and 1.46 for British units)

R_h = Hydraulic radius in meters ($R_h = A/P$)

S = Slope of the channel under consideration

n = Manning roughness coefficient

[According to V.T. Chow [17], the Manning roughness coefficient generally ranges between 0.025 – 0.060 if the Channel bed lacks boulders and vegetation cover to redirect channel flow. According to Simons and Richardson [20], if the channel bed is characterized by dunes and such kind of obstructions, the Manning roughness coefficient will vary between 0.018 and 0.035. For the present channel, as two types of channel bed roughness is found the Manning roughness coefficient is taken to be 0.035.]

3.3.1: Calculation of Hydraulic Radius

Hydraulic radius represents the efficiency of the channel. It determines the amount of discharge through a particular cross-sectional area at a specific time. It is the ratio between cross-sectional area of a channel and its wetted perimeter. Mathematically it is represented by:

$$R_h = A/P$$

Where, R_h = Hydraulic radius in meter

A = Cross sectional area of the channel through which bank-full discharge takes place

P = Wetted perimeter i.e., the cross-sectional length of the river which remains wet during its bank-full capacity (cumulative lengths of all the lines along the river bed including its two inclined sides)

In the present study of Junbedia Jorh microwatershed ten cross profiles are drawn with the data directly obtained from field measurements by Auto Level. For the collection of coordinates of each of the cross-sectional points, handheld GPS - Garmin GPS Map 76 CSx has been used. The benchmark heights of the starting points of each profile were taken from Google earth elevation data. After collecting all the field data, reduced levels of all of the points were calculated on the basis of benchmark heights. All the profiles were then plotted in spreadsheet to have an idea of the shape of the profiles (see fig-3).

3.3.1.1: Calculation of Cross Sectional Area

As the profiles revealed irregular geometric shapes, the cross-sectional areas of all the profiles have been calculated as under:

Cross Sectional Area = Area above the Curve

Area above the Curve = (Total area of the Curve – Area under the Curve)

The area under each of the curves can be calculated in spreadsheet by applying simple integration formula:

Area under the Curve = Sum of areas of rectangles under the Curve (Fig. 4a)

Area of each rectangle = $\left(\frac{y_1+y_2}{2}\right) \times (x_2 - x_1)$

For the profiles, the distance is plotted on x-axis while the reduced levels (RL) on the y-axis. The origin of x-axis is always kept as ‘0’, but the origin of y-axis is variable which is based on the datum or baseline of the profiles.

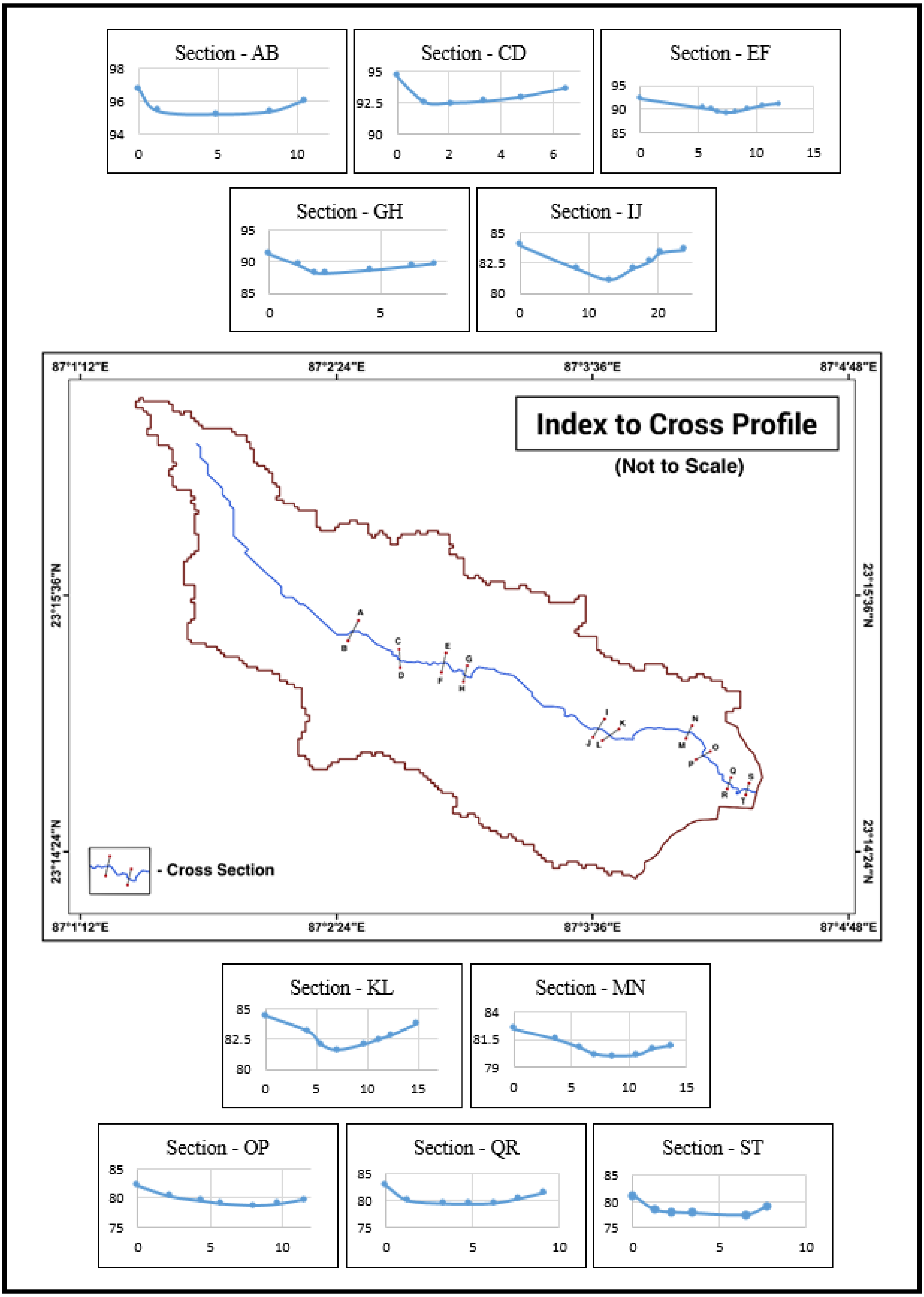
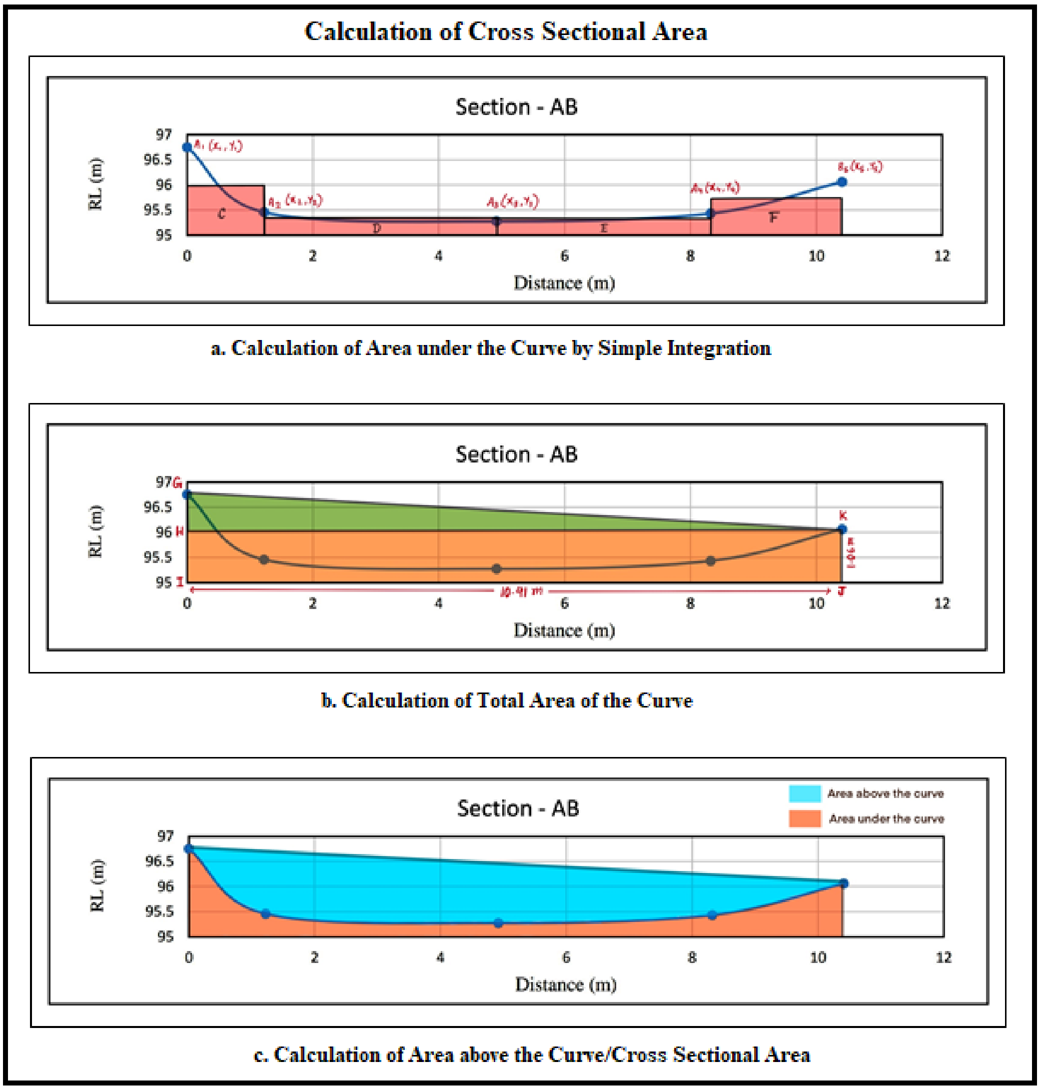


Figure 3: Cross Profiles of Junbedia Jorh

The table-7 represents the assignments of coordinates to each of the points and figure-4a represents the transformation of the curve into 4 rectangles (C,D,E and F) by integration. Therefore, the total area of the 4 rectangles will give the total area under the curve. In this way, the total area under the curve AB is calculated to be 5.480175 m^2. The process is repeated for other 9 cross sections.

Table 7: Assignment of Coordinates of Section 'AB'.				
Station	Distance (m)	Cumulative distance (m) (x)	RL (m)	RL (if base is 95) (m) (y)
A_1	0	0 (x_1)	96.755	1.755 (y_1)
A_2	1.22	1.22 (x_2)	95.46	0.46 (y_2)
A_3	3.7	4.92 (x_3)	95.275	0.275 (y_3)
A_4	3.4	8.32 (x_4)	95.435	0.435 (y_4)
B_5	2.09	10.41 (x_5)	96.06	1.06 (y_5)
Source: Assigned by the Authors				



a. Calculation of Area under the Curve by Simple Integration

b. Calculation of Total Area of the Curve

c. Calculation of Area above the Curve/Cross Sectional Area

Figure 4: Calculation of Cross Sectional Area

To calculate the total area of the curve, the profiles have been divided in two regular geometric shapes- one perfect rectangle and the other perfect right triangle. The areas of these two shapes have been calculated by (length x breadth) in case of rectangular area (HIJK) and (1/2 x base x height) for right triangle area (GHK) in figure-4b. In this way, the total area of the profile AB has been calculated to be 14.652075 m^2. Thus, area above the curve AB can be worked out as (14.652075 – 5.480175) m^2 = 9.1719 m^2 (figure-4c). This is the cross sectional area of the section AB. The same process is repeated for other 9 cross sections.

Table 8: Hydraulic Radius of Junbedia Jorh.			
Cross Sections	Cross Sectional Area (m^2)	Perimeter (m)	Hydraulic Radius (m)

AB	9.1719	11.069	0.8286114
CD	7.670975	7.9994	0.9589438
EF	13.85683	13.0458	1.0621675
GH	10.3377	9.272	1.1149374
IJ	36.07505	24.2844	1.4855236
KL	19.88835	15.9316	1.2483586
MN	11.2474	14.2288	0.7904672
OP	14.9971	13.6209	1.1010359
QR	17.50833	11.3841	1.537963
ST	14.74405	10.3675	1.4221413
Source: Calculated by the Authors			

The Table-8 represents variable hydraulic radius along the entire course of Junbedia Jorh. It shows that the hydraulic radius is the highest (1.54) along the profile 'QR' in Junbedia mouza. The best fit curve in Figure-5 shows a rising tendency of hydraulic radius from source to the outlet of the Jorh. Therefore, it can be concluded that the Junbedia Jorh gradually opens its mouth towards its outlet with a sharp drop in Junbedia area. It signifies the fact that the efficiency of the Jorh gradually increases towards its outlet, which means the excess flood water in every rainy season up to a certain amount is efficiently discharged into the Gandheswari river. The backflow of Gandheswari river is primarily responsible for Junbedia flood.

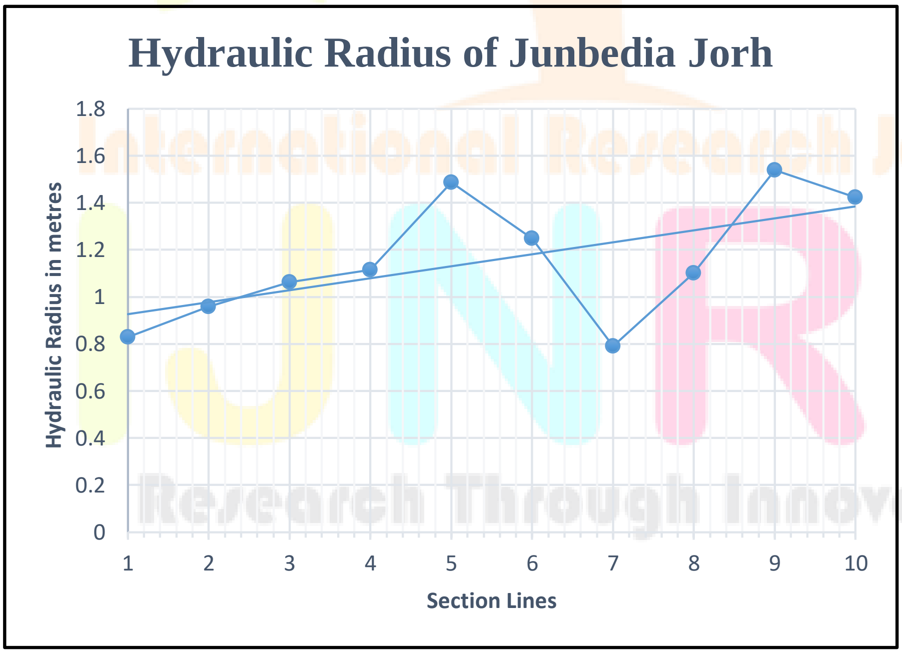


Figure 5: Hydraulic Radius

3.3.1.2: Calculation of Manning Value and Discharge Capacity

The table-9 shows the calculated Manning value for all the 10 cross profiles along the Junbedia Jorh. The value ranges between 0.77 and 3.47. The lowest value is found in Junbedia upper part where hydraulic radius is also minimum because of encroachment of the channel by rapid urbanization as well as dumping of building or other domestic wastes. The highest value of 3.47 is found in Khudsole lower where the channel is found to be narrow and deep. The discharge capacity of the Jorh has also been calculated simply by multiplying the Manning value with the cross sectional area. In terms of discharge capacity Junbedia upper again shows the lowest capacity of nearly 9 m^3s^{-1} whereas Khudsole upper has the highest capacity to outflow water with nearly 95 m^3s^{-1}. The outlet of the Jorh at Gandheswari river near Palashtala lower is moderate with the value of 34 m^3s^{-1}. This value is the most

Table 9: Calculation of Manning Value and Discharge Capacity of Junbedia Jorh.

Sl. No.	Sites	Cross Sections	Hydraulic Radius (Rh) in metres	Slope (s) in m/m	Manning Value (v=m/s)	Cross Sectional Area (m^2)	Discharge Capacity (m^3/s)
1	Keshra Upper	A (23°15'23.83"/ 87°02'27.58") B (23°15'24.20"/ 87°02'27.49")	0.82861144	0.006	1.952427	9.1719	17.9074676
2	Keshra Middle	C (23°15'18.27"/ 87°02'41.40") D (23°15'18.16"/ 87°02'41.50")	0.9589438	0.006	2.152136	7.670975	16.5089804
3	Keshra Lower	E (23°15'17.03"/ 87°02'54.09") F (23°15'16.84"/ 87°02'54.02")	1.06216752	0.005	2.103192	13.856825	29.1435667
4	Adhorjo-bandh	G (23°15'13.93"/ 87°03'00.02") H (23°15'13.85"/ 87°03'00.03")	1.11493745	0.004	1.942953	10.3377	20.0856648
5	Khudsole Upper	I (23°14'58.00"/ 87°03'40.02") J (23°14'57.00"/ 87°03'39.03")	1.48552363	0.005	2.630288	36.07505	94.8877777
6	Khudsole Lower	K (23°14'56.46"/ 87°03'41.54") L (23°14'56.40"/ 87°03'40.00")	1.24835861	0.011	3.474198	19.88835	69.0960614
7	Junbedia Upper	M(23°14'57.09"/ 87°04'03.23") N (23°14'57.49"/ 87°04'03.23")	0.79046722	0.001	0.772422	11.2474	8.68773716
8	Junbedia Lower	O (23°14'51.08"/ 87°04'06.92") P (23°14'57.84"/ 87°04'06.53")	1.10103591	0.002	1.362431	14.9971	20.4325183
9	Palashtala Upper	Q (23°14'43.21"/ 87°04'14.47") R (23°14'42.88"/ 87°04'14.39")	1.53796304	0.003	2.085082	17.508325	36.5062969
10	Palashtala Lower	S (23°14'41.48"/ 87°04'19.29") T (23°14'41.29"/ 87°04'19.19")	1.42214131	0.004	2.285198	14.74405	33.6930697
Average Values			1.533	0.0047	2.604208	17.1	44.5319553

Source: Calculated by the Authors from Auto Level Survey Data; Coordinates were collected by Garmin GPS Map76CSx

important because with this rate the excess runoff will get discharged into Gandheswari river. However, the average discharge capacity of the jorh is 44.53 m^3s^{-1}.

4. Results and Discussion

The study has applied two semi empirical models for estimating peak flood discharge in Junbedia Jorh basin. As the catchment is very small in size, rational method is most suitable for peak discharge estimation. While the rational method gives rainfall based estimation of peak discharge, Manning equation produces discharge capacity of the jorh at any rainfall amount. The comparison of these values will help in understanding the nature of discharge during high intensity rainfall in the catchment.

4.1: Calculation of Peak Discharge by Rational Method

The estimation of peak discharge by this method involves calculation of catchment area, intensity of rainfall and runoff coefficient of the catchment. The catchment area is calculated from the SRTM-DEM in QGIS 3.16. Weighted runoff coefficient has been calculated from the six landuse categories of the basin based on the runoff coefficient of each of the landuse category [14]. For the calculation of rainfall intensity, five daily rainfall data were taken. Out of these five values, one entry of 354 mm was recorded on 29th September, 2021 which is the last 50 years' high and the other four entries were assumed rainfall figures below and above this record rainfall. The assumed values are taken here to have an idea of the peak discharge during such storm events. But to calculate $i_{tc.p}$ (intensity of rainfall during the 't_c' – time of concentration at exceedence probability p), the daily rainfall data had to be reduced to short duration rainfall equal to the 't_c'. To convert 24 hour rainfall in shorter duration, 'IMD 1/3rd Rule' is used corresponding to 't_c' (table- 3 and table-4). The calculated values show that the peak discharge increases with rising intensity of rainfall. The volume of runoff is calculated for the entire catchment and it is found that the period of waterlogging in the basin remains 12 hours after the time of peak flow at outlet of the river.

4.2: Calculation of Discharge Capacity using Manning Equation

To estimate the discharge capacity of the jorh, 10 cross sections along the jorh bed were conducted by Auto Level and a handheld GPS from the outlet towards its upstream. The field survey helps in deriving hydraulic radius at each section of the jorh and related channel geometry. The study of the 10 cross profiles show that the channel is of irregular shape. It neither resembles rectangular, parabolic or trapezoidal. Therefore, the channel cross sectional area is calculated by a different process in spreadsheet (see 3.3.1.1 subsection), applying integration formula (table-7 and figure-4). The slope is calculated from the DEM of the catchment. The table-9 shows the variable Manning value along 10 cross sections of the jorh with resulting variable discharge capacity. This may be due to the irregular channel shape. However, the average discharge capacity of the jorh has been calculated to be 44.53 m^3s^{-1}.

Table10: Discharge Capacity and Duration of Flood Water in Junbedia Jorh Basin

Maximum Daily Rainfall (mm)	Volume of Runoff (m^3/s)	Max. Peak Discharge (m^3/s) Rational Method	Discharge Capacity (m^3/s)	Max. Duration of Waterlogging (hours)
175	14,84,140	34.3	44.53	9.26
220	18,68,776	43.07		11.64
354	30,02,203	69.31		18.73
450	38,16,360	88.08		23.81
525	44,52,420	102.82		27.78

Source: Calculated by the Authors

The table-10 represents the maximum duration of waterlogging in the catchment particularly near the outlet in Junbedia mouza. If the daily rainfall remains below 220 mm which is most common during monsoon months, peak discharge calculated by rational method remains below the actual discharge capacity as estimated by Manning equation. But still there is about 9 – 12 hours of water logging in the lower catchment. The survey in the area among 240 households revealed that the waterlogging is a very common feature in the area. During the last 10 years this area was inundated slightly or moderately in almost 8 years- 2013, 2014. 2016, 2017, 2018, 2019, 2020, and 2021. However, among those years, depth and duration of flood water was highest in 2018 and 2021, causing significant damage to the properties. The amount of theoretical discharge in case of 354 mm rainfall in the catchment is about 69 m^3s^{-1} which is very high than that its capacity of about 45 m^3s^{-1} that caused about 19 hours of waterlogging. If it rains even higher than this record high, the flood situation in the catchment will become uncontrollable.

5. Conclusion

Estimation of peak flood discharge is very necessary for flood risk and vulnerability analysis as well as hydrological planning and water resource management in watersheds. The indirect method of estimating discharge is particularly relevant for ungauged rivers with small and big catchments. This method would enable hydrologists to get an approximate design discharge value for any watershed planning. Apart from this, the paper gives light on the method of calculation of hydraulic radius for open channels of irregular geometric shapes. It applies a unique method of calculating the cross sectional area of the channels with different irregular shapes by using integration formula in spreadsheets. The rainfall dependent theoretical discharge calculation as well as the actual discharge capacity will ultimately give an idea of the duration of flood or flood like situation in the watershed. Therefore, the methods used in this paper can be applied for further research in general and the findings observed may be used for future planning of this microwatershed in particular for the benefit of the local people.

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