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HEC-HMS based mathematical model for Sabarmati and Mahi river basin and land cover analysis using Q-GIS

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Abstract

Mathematical models are quite commonly used powerful tool in the hydrology for predicting and managing the water in various environments. Applications of rainfall runoff mathematical modeling highlights its unique contributions to different fields. In the present study hydrological rainfall runoff modelling has been performed for two major river basinsi.e. Sabarmati river basin and Mahi river basin.Standard frequency distribution methods Gumbel's method and lognormal method has been deployed in IDF analysis. For this the mathematical HEC-HMS based model development and analysis has been extensively performed and LULC analysis has been done using GIS tool. The aim of the study is to carry out hydrological modelling for river basins. Comparative LULC analysis has been performed for both the river basins. Agriculture area is around 47% in both the basins. The basic problem within the study area is the to use the rainfall water effectively and in optimized manner. Rainfall analysis has been done andIntensity-Duration-frequency curve has been developed for both the river basins. Here deployment of HEC-HMS software is done for performing hydrological modelling.Runoff developed for a recurrence period of 50 years with 12-hr time is obtained as 2817 cumecs and runoff for a recurrence interval period of 50 years with 24-hr time is obtained as 3292 cumecs for the Sabarmati river basin. LULC classes based dominancy has been devised for both the river basins. Study shows the evaluation of water resources potential of the study area which can be used in various purposes.

Subject Classification: *34-XX, 65U20, 81T80,60G15, 60G25, 68T01, 68T10, 97R40.*

Keywords: *IDF Curve, Rainfall, Runoff, HEC-HMS, Land Use, Sabarmati.*

1. Introduction

In the rainfall runoff modelling Intensity, duration and frequency curves (IDF curves) have its own importance [1]. Abulohom et al. [1] developed the rainfall runoff model for their study area. IDF curves shows the potential of runoff and has modelling importance [2]. AlHassoun [2] developed a formulae to measure Rainfall Intensity in his study area. Gumbel's Distribution: In the theory of statics and probability, Gumble's distribution (generalized extreme distribution value Type-I) can be applied for modeling highest or lowest value distribution for a group of samples with different distributions [3]. Distribution of scattered values has its own importance [4]. The values in sorting i.e. high to low or low t high needs to be identified [5]. The below equation estimates the precipitation frequency R_t for every duration with a certain recurrence interval t_r (in a year) [6].

$$R_t = R_{mean} + G_T S, \tag{1}$$

where R_t is frequency of rainfall in mili meter for each duration, S is the standard deviation of rainfall data, R_{mean} is the mean annual precipitation, and G_T is the Gumbel frequency factor given by equation [7]. It has its own value and importance [8],

$$G_T = \frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{t_r}{t_r+1}\right)\right]\right\} \tag{2}$$

here, Gumbel frequency factor, t_r is recurrence interval (2, 5, 10, 25, 50, and 100) years. Lee et al. [9] developed the rainfall runoff model for large catchment. Then, the rainfall intensity I_T (in mm/h) for recurrence interval t_r is obtained by below equation [9]. Recurrence interval has its own dominance [10]. Liu, Yang, and Fan Sun [10] studied about the sensitivity in the runoff modelling.

$$I_T = \frac{Pt}{T_D} \tag{3}$$

Here T_D is the time duration expressed in hour.

Lognormal Method [11]: Similar procedure for Log Pearson Type III method (i.e., logarithm values of the statistical variables) using normal G_T that was used in Gumbel method as discussed earlier [12]. O'Loughlin, Geoffrey, et al. (1996) discussed the rainfall runoff modelling and processes [13]. Statistical modelling needs the distribution approaches to be adopted [14]. Log pearson method is widely used method [15]. Lognormal method has wide research and statistical importance [16]. Singh [17] studied the development of computer models and mathematical models for watershed [17]. Singh [18] emphasized the use of intelligent approaches in modelling hydrology phenomena. Hydrological process and rainfall runoff modelling has been well described technically by Chow et al. [19]. Zhang et al. [20] calibrated the rainfall runoff models using global optimization techniques. Cirilo, José Almir, et al. [21] worked for the semi arid region by developing a rainfall-runoff model and also analyzed its applications.

Objectives of present is to evaluate the hydrological rainfall runoff modelling and its hydrological water yield performance using suitable approach for two river basins. The second aim is to compare the LULC characteristics with diversity of both the river basins. The paper is organized in the four sections, in this present section basic introduction, literature review and objectives are depicted. In the next section study are and methodology is being described. In the third section data analysis and land use land cover analysis has been described. In the last session results and conclusions has been mentioned.

2. Methodology

The Sabarmati River Basin (Figure 1), originating from the Aravalli Range in Rajasthan, extends for approximately 371 kilometers before merging into the Gulf of Khambhat in Gujarat. Covering a vast expanse of around 21,674 square kilometers, the Sabarmati Basin meanders through Gujarat and parts of Rajasthan. The Mahi River Basin as depicted in Figure 2, originating in the Madhya Pradesh hills, stretches over an impressive length of approximately 583 kilometers. Covering an expansive area of approximately 34,799 square kilometers, the Mahi Basin encompasses parts of Madhya Pradesh, Rajasthan, and Gujarat.

2.2 *HEC-HMS Based Methodology and tool*

Modeling of rainfall and streamflow using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software typically involves key steps to model the conversion of rainfall to runoff in a watershed. A general methodology for performing rainfall-runoff modeling with HEC-HMS:

(A) Data Collection and Preparation, (B) Define Study Area and Watershed Boundaries, (C) Create a Project in HEC-HMS, (E) Quality

Figure 1

Sabarmati Basin

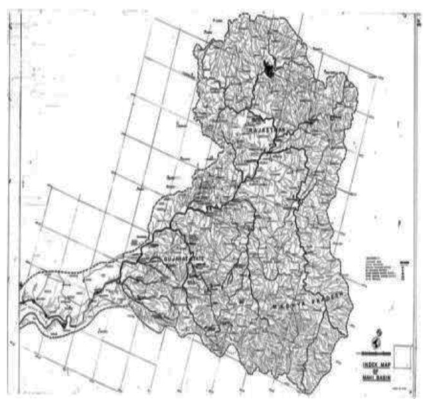

Figure 2

Mahi river Basin

Assurance for Finalization and Implementation. HEC-HMS is a powerful tool for rainfall-runoff modeling andrequires a good understanding of hydrological principles.

2.3 *Data Collection and Analysis*

Data Collection & Analysis: Required data has been obtained from State water data center, Gandhinagar and Central water commission (CWC) for research. Data Acquisition (Data Sources) For this study Landsat 9 data with spatial resolution of 30m had been used with 5 bands (Blue, green, Red, NIR & SWIR1). The mean monthly analysis and mean annual analysis has been performed for the rain gauge stations in both river basins (Figure 3 & 4). An empirical reduction formula prepared by India Meteorological department (IMD) as shown below for rainfall analysis, This formulae is very much useful wherever the hourly data is not available or has not gauged for the station.

$$R_t = R_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \tag{4}$$

where R_t is the asked precipitation depth t-hour duration in milimeter, R_{24} is the daily precipitation in mili meter, and t represents the duration of rainfall in hour for which the precipitation depth is asked.

Exceedance analysis for return period has been performed and IDF curve has been generated for both river basin gauge stations. Table 1 shows the return period and no. of exceedance analysis for 5 stations where as figure 5 shows the IDF curve for one rain gauge. The same analysis has been performed for all the rain gauge stations of Sabarmati and Mahi river basin. For regression of IDF curve Sherman equation is used, i.e.

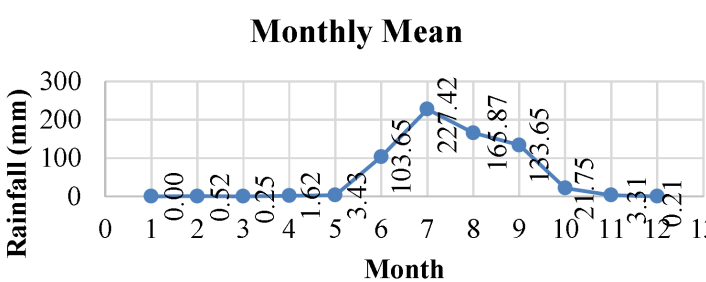

Figure 3

Monthly means for Sabarmati station for last 30 years (1991-2020)

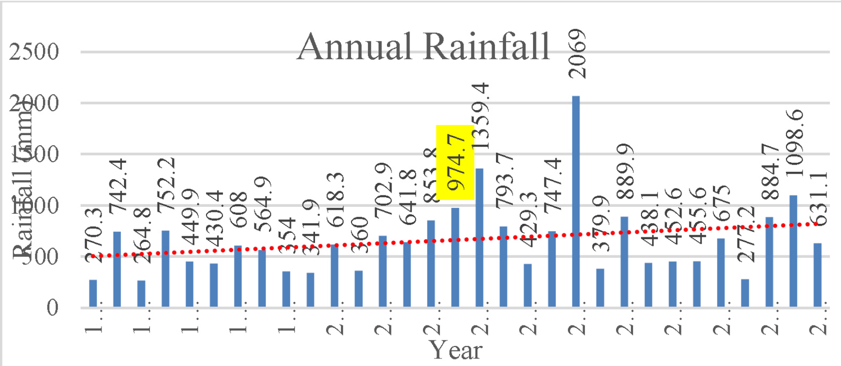

Figure 4

Annual Mean of Sabarmati Station

$$i = \frac{a}{(b+d)^c} \tag{5}$$

Where, i is rainfall intensity, d is duration of rainfall and a, b, c are the regression parameters determined by the least square method. Different a,b,c values are regressed for different return periods T.

Table 1

No. of time exceedance as per return period

[A: Intensity (mm/hr) and B: No. of time Exceeds]

Return Period	Station N. 1		Station N. 2		Station N. 3		Station N. 4		Station N. 5	
	A	B	A	B	A	B	A	B	A	B
2 Year	30.0	168	32.4	166	44.3	159	36.0	193	44.1	165
5 Year	50.4	70	48.3	75	68.8	72	57.9	86	67.7	70
10 Year	63.9	37	58.8	55	84.9	48	72.4	53	83.4	46
25 Year	80.9	19	72.2	35	105.3	29	90.6	27	103.1	20
50 Year	93.6	16	82.0	24	120.5	17	104.2	14	117.8	17
75 Year	100.9	15	87.8	20	129.3	13	112.1	10	126.3	14
100 Year	106.2	12	91.8	16	135.5	13	117.7	7	132.3	13
500 Year	135.2	7	114.5	11	170.3	4	148.8	3	165.9	8

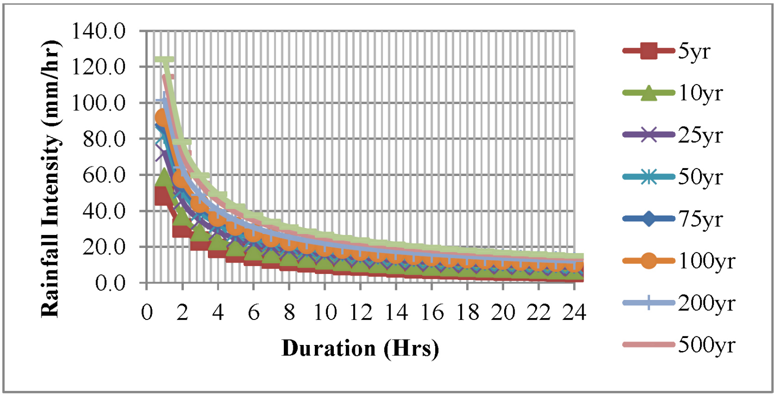

Figure 5

ID-Freq. curve for station no. 2 (Sabarmati Basin)

The IDF curve has been prepared and DEM is developed for both the basins in Q-GIS software which is used in preparing LULC. Figure 6 shows the results of Mahi river basin discharge on map.

Figure 6

River basin discharge results in HEC-HMS

3. Results and Discussion

3.1 *Runoff potential as per IDF*

Evaluation of the IDF curves has been performed for the developed models and then HEC HMS has been used for rainfall-runoff modelling.

Table 2

Runoff developed for the Sabarmati and Mahi basin

Sabarmati Discharge from Rainfall Runoff Modelling		Mahi Discharge from Rainfall Runoff Modelling	
RP_Storm	**Q (m3/s)**	**RP_Storm**	**Q (m3/s)**
50yr_4hr	1900.7	50yr_4hr	1466.5
50yr_8hr	2508.3	50yr_8hr	1573.9
50yr_12hr	2816.7	50yr_12hr	1462.7
50yr_24hr	2809.5	50yr_24hr	1181.9
100yr_4hr	2244.6	100yr_4hr	1748.7
100yr_8hr	2938.5	100yr_8hr	1873.8
100yr_12hr	3291.8	100yr_12hr	1737.8
100yr_24hr	3262.7	100yr_24hr	1399.3

After performing the return period analysis, curve number method has been deployed with requisite data to model the parameters. The runoff developed has been shown in the below Table 2 for both river basins.

3.2 *LULC Analysis*

Land use land cover analysis has been performed and compared for both the river basins. Table 3 shows the detailed classification and comparison of the modelled data in Q-GIS for both the river basins.

Table 3

Land use land cover analysis details of both river basins

Sr. No.	Landuse Classes	Sabarmati River Basin LULC Analysis		Mahi River Basin LULC Analysis	
		Area (Ha)	**%**	**Area (Ha)**	**%**
1	Builtup	142634.00	4.77	56854.46	1.42
2	Waterbodies	28033.57	0.94	84751.45	2.12
3	Agriculture	1415190.45	47.30	1888869.22	47.18
4	Vegetation Patches	190002.35	6.35	325517.66	8.13
5	Shrub land	587420.31	19.63	1104970.03	27.60
6	Salineland and Barrenland	26,255.27	0.88	71,306.13	1.78

Contd...

7	Fallowland	448780.59	15.00	292158.10	7.30
8	Forest Patches	153423.30	5.13	179327.94	4.48
		Total	**2991739.82**	**100.00**	4003754.98

Figure 7 shows the LULC, DEM of Mahi and Sabarmati river basin which is extracted in GIS for performing the analysis. Figure 8 shows the LULCs map of Sabarmati and Mahi basin whereas Table 3 shows the graphical comparison of land use attributes for both the river basins.

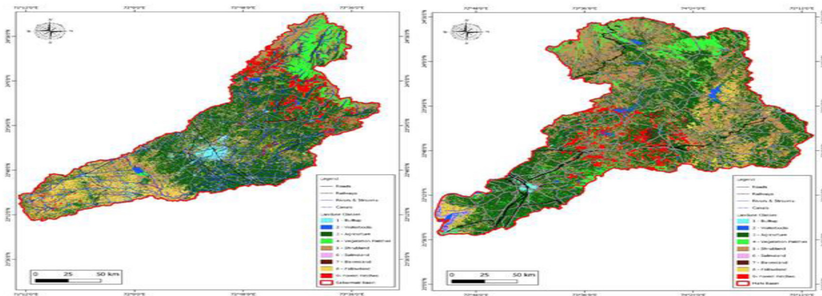

Figure 7

Detailed LULC map of Sabarmati and Mahi basin

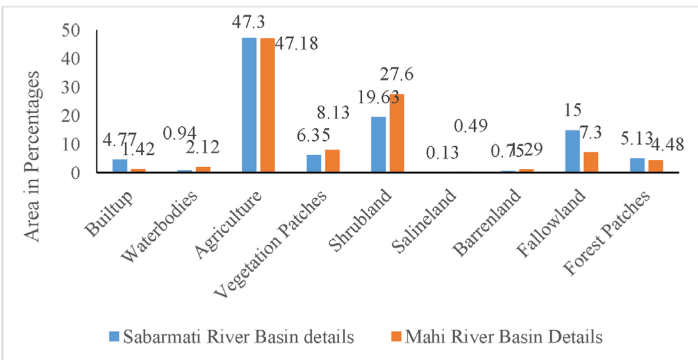

Figure 8

LULC Class wise comparison of both the basins.

3.3 *Accuracy Assessment*

The detailed producers and users accuracy has been duly calculated. The overall accuracy of the LULC analysis has been observed as 92.93 percent for the Sabarmati River Basin and 92.71 percent for the Mahi river basin for year 2022. The kappa coefficient is calibrated as 0.89 for Sabarmati basin and 0.90 for the Mahi basin. During analysis it is seen through the Q-GIS software that the producers and users accuracy for both the river basins is observed as 100 for builtup, agriculture and waterbodies whereas it is observed within 85 to 98 % in case of other LULC Class. According to this study, the runoff estimation can be done using other mathematical statistical approaches as well.

4. Conclusion

Evaluation of the hydrological Rainfall Runoff modeling has been performed for the Sabarmati and Mahi river basin. The water accumulation is more in Mahi river basin as compared to the Sabarmati River basin. Frequency analysis using standard statistical methods has been performed using Gumbel's method and lognormal method.In the present study the runoff developed for a return period of 50 years with 12-hr time is obtained as 2817 cumecs and runofffor a recurrence period of 50 years with 24-hr time is obtained as 3292 cumecs for the Sabarmati river basin. In the present study the runoff developed for a recurrence interval of 50 years with 12-hr time is obtained as 1462.7 cumecs and runoff for a return period of 50 years with 24-hr time is obtained as 1181.9 cumecs for the Mahi river basin.Land use land cover analysis of the Sabarmati and Mahi river basin has been presented in the study. Agriculture area is around 47 percent in both the basin but other criteria's and classes differs in both the basins. The waterbodies in Sabarmati river basin is 0.94 Percent whereas the waterbodies in Mahi River basin is 2.12 percent as per observation. Sabarmati river basin dominates in LULC in Built up, Fallow land and forest patches classes where as Mahi river basin dominates in the waterbodies, vegetation patches, shrublands, saline and barrenland.

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