Flood Estimation for Rivers of Saurashtra Region Contributing into Gulf of Khambhat

Priyanka Kumari and N. K. Goel
Department of Hydrology
Indian Institute of Technology Roorkee
Roorkee-247667, India

***Abstract* — Water, as the most valuable part of the earth, is the major requirement for survival of life. Utilization of water resource is abruptly rising due to urbanization and development of civilization. For the design and planning of water resources structures design flood estimates are required. In the present study design floods have been estimated the 20 dams located in 9 river basinsnamely Wadhavan-Bhogavo, Limbdi-bhogavo, Sukhbhadar, Utavali, Padalio, Khalkhalia, Ghelo, Keri and Kalubhar of Saurashtra region. These rivers of Saurashtra region are contributing into the Gulf of Khambhat. 90 m SRTM Digital Elevation Model (DEM) has been used to estimate physiographic catchment characteristics of each basin. 25, 50 and 100 years return period design floods have been estimated using synthetic unit hydrograph and regional flood frequency relationships developed by CWC. The results suggest that the design floods given by the Synthetic Unit Hydrograph (SUH) approach may be more appropriate as the complete shape of the hydrograph may be obtained. The limitation of the study is that same values of rainfall have been used for the entire region, which may vary from one basin to another basin. The flood estimates of the present study shall be helpful to verify the existing design floods of the dams.**

Keywords*— *Flood design, Synthetic unit hydrograph, Saurashtra, Digital elevation model

I. INTRODUCTION (*HEADING 1*)

Gujarat, one of the states of India, has inland boundaries as well as coastal boundaries. It is divided in to four parts namely (1) North Gujarat, (2) CentralGujarat, (3) South Gujarat, and (4) Saurashtra and Kutch. It shares boundaries with states of Rajasthan, Madhya Pradesh and Maharashtra. The rivers of Gujarat join Arabian Sea which has got two Gulfs namely Gulf of Khambhat and Gulf ofKutch.

The state of Gujarat has seen many damaging floods in the past. Almost all the major rivers in Gujarat pass through a wide stretch of very flat terrain before reaching the sea. These flat low lands of lower river basins are prone to flooding because of flat terrain and poor drainage.

Occasional cyclones and depressions are responsible for heavy rainfall in the parts of Saurashtra, Kutch, central and northern Gujarat. Gujarat has seen many disasters like Muchchhu II dam failure in 1979, loss of life and damage of property in years like 1927, 1970, 1979, 2003, 2005, 2006, 2007, 2009, 2012, 2013 and 2014. The Figure 1 shows the flood prone areas of Gujarat.

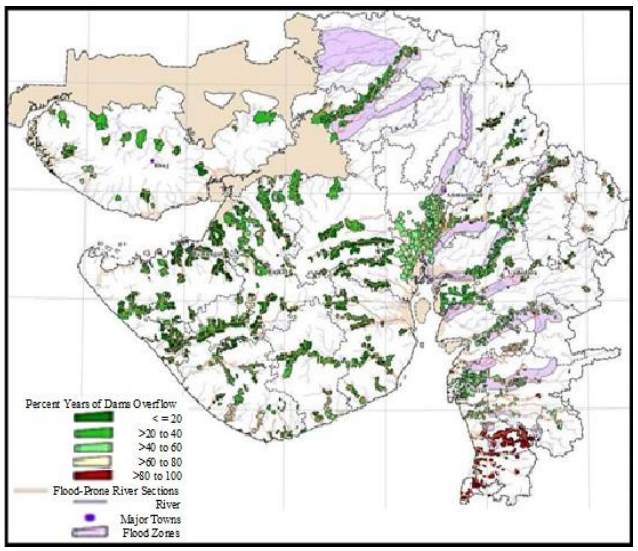

FIGURE 1: FLOOD PRONE AREAS OF GUJARAT

(Source: Gujarat State Disaster Management Authority)

1) PROBLEMS OF SAURASHTRA REGION

Though Saurashtra region is one of the most water scarce regions of India, yet it suffers from the flooding problem, in spite of having lesser rainy days. The rainfall intensity usually is very high in this region. The topography of this region is of inverse bowl type that makes the water collection further difficult. It has highest point of 200 feet above the mean sea level.Typical problems of Saurashtra region are insufficient and inequitable water availability, erratic rainfall, Salinity Ingress in coastal areas and ground water depletion.

2) BROAD OBJECTIVE OF THE STUDY

The broad objective of the present study is to estimate design floods for various structures in the 9 river basins namely Wadhavan-Bhogavo, Limbdi-bhogavo, Sukhbhadar, Utavali, Padalio, Khalkhalia, Keri, Ghelo and Kalubharof Saurashtra region which are joining Gulf of Khambhatusing deterministic and statistical approaches. These estimates shall help in dam rehabilitation and improvement.

II. STUDY AREA

The nine river basins, namely Wadhwan-Bhogavo, Limbdi-Bhogavo, Sukhbhadar, Utavali, Padalio, Khalkhalia, Keri, Ghelo, Kalubhar, related to the study area lie in Northern

part of Saurashtra region (Fig. 2; Table 1). Out of the above nine river basins Wadhwan-Bhogavo and Limbdi-Bhogavo drain into low level muddy plains lying adjacent to Sabarmati river basin.The area covered by Saurashtra region is 59,360 Km^2, out of which 9000 Km^2 area is covered under study. Suarashtra basin lies between latitude 20˚N to 24˚N and longitude 69˚E to 73˚E. There are 20 dams in these river basins (Table 2).

Figure 2: River map of Gujarat

Table 1: Details of River Basins

S.No.	Basin Name	Catchment area (km^2)	Length (km)	Eq.Slope (m/km)
1	Wadhavan-Bhogavo	1517	128	1.19
2	Limbdi-Bhogavo	915	118	1.4
3	Sukhbhadar	1774	145	0.997
4	Utavali	1206	98	0.751
5	Padalio	311	50	0.779
6	Khalkhalia	436	47	0.779
7	Keri	556	110	1.537
8	Ghelo	626	94	1.565
9	Kalubhar	2047	90	1.42

Table 2: Details of dams in 9 River Basins

S.N.	Name of River	Name of the Dam	Area (km^2)	River Length (km)	Eq. Slope (m/km)
1	Wadhwan-Bhogavo	WB I	389	50	1.86
		WB II	159	14	1.22
		WB III	303	24	1.81
2	Limbdi-Bhogavo	LB I	329	33	1.727
		LB II	201	19	2.142
		LB III	192	36	1.504
3	Sukhbhadar	Sukhbhadar	591	45	3.211
		Goma	165	24	1.937
4	Utavali	Khambhada	255	40	3.332
		Senthali	62	18	2.431
5	Keri	Bhimdad	126	24	2.931
		Gala	169	26	3.892
6	Ghelo	GheloSomnath	56	12	5.662
		GheloItaria	111	16	3.681
		Limbali	142	27	3.427
		Navagam	60	15	1.988
7	Kalubhar	Kalubhar	592	46	2.47
		Rangholi	397	31	2.570
		Malpara	114	23	3.139
8	Padalio	Bhambhan	66	14	3.66

III. DATA AVAILABILITY

There are 13 rain gauge stations and 9 Gauge and discharge(G&D) sites in these river basins (Fig. 3 and Table 3 and 4.). These data were collected from IMD and Kalpasar Department of Gujarat

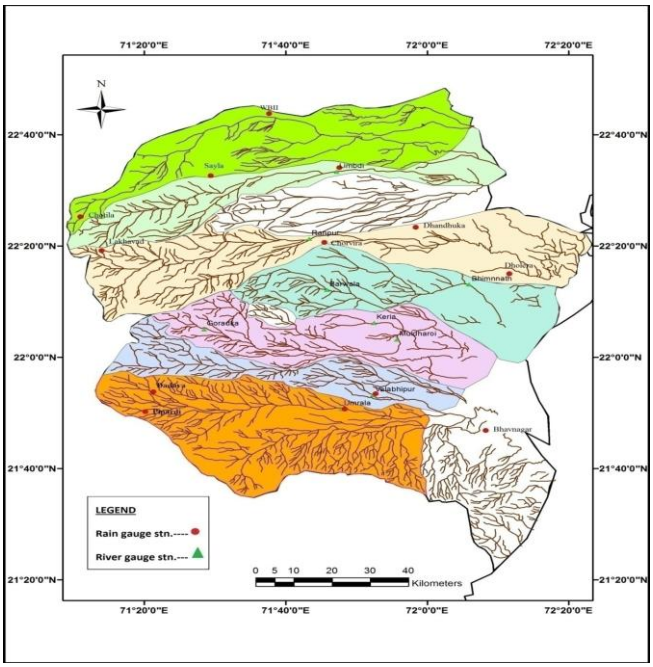

FIG-3: LOCATION OF G&D SITES AND RAINGAUGE IN RIVER BASIN MAP

Table 3: Details of G&D stations of Saurashtra region

S.No.	Station Name	Longitude	Lattitude	Type	DataAbvailability (Years)	River Basin
1	Limbdi	71˚43'8.39"	22˚33'28.79"	Daily	1991-2011	Limbdi
2	Ranpur	71˚43'29.99"	22˚ 21' 18"	Daily	1991-2010	Sukhbhadar
3	Bhimnnath	72˚ 5' 59.99"	22˚ 13' 1.19"	Daily	1999-2010	Utavali
4	Barwala	71˚ 46' 8.4"	22˚12'10.79"	Daily	1991-2009	Utavali
5	Keria	71˚ 52' 33.6"	22˚ 6' 7.2"	Daily	1991-2010	Padalio
6	Muldharoi	71˚55'51.59"	22˚3'14.39"	Daily	1997-2010	Padalio
7	Goradka	71˚ 28' 26.4"	22˚ 5'20.39"	Daily	1991-2010	Keri
8	Vallabhipur	71˚ 52' 22.8"	21˚ 53'9.59"	Daily	1991-2010	Ghelo
9	Umrala	71˚ 47' 56.4"	21˚ 50'56.4"	Daily	1991-2008	Kalubhar

Table 4: Details of Rain gauge stations of Saurashtra region

S. No.	Station Name	Longitude	Lattitude	Type of Data	Data Availability (Years)	River Basin
1	WB II	71˚31' 58.8"	22˚43' 55.19"	Hourly	1906-2003	WB
2	Sayla	71˚27' 21.6"	22˚32' 42"	Hourly	1969-2003	WB
3	Chotila	71˚12' 46.79"	22˚25' 15.59"	Hourly	1968-2003	WB
4	Limbdi	71˚43' 19.19"	22˚34' 15.6"	Hourly	1991-2010	Limbdi
5	Dhandhuka	71˚ 58'29.99"	22˚ 23'27.59"	Hourly	1901-2006	Sukhbhadar
6	Chorvira	71˚ 45'28.79"	22˚ 20' 45.6"	Hourly	1991-2010	Sukhbhadar
7	Lakhavad	71˚ 31'55.19"	22˚ 19' 12"	Hourly	1982-2010	Sukhbhadar
8	Dholera	72˚11'41.99"	22˚15'7.19"	Hourly	1901-2006	Sukhbhadar
9	Bhavnagar	72˚ 8' 13.2"	21˚ 46' 55.2"	Hourly	1901-2006	Kalubhar
10	Vallavipur	71˚52'44.4"	21˚53'27.59"	Hourly	1960-2003	Ghelo
11	Umrala	71˚48' 21.59"	21˚ 50' 38.4"	Hourly	1961-2007	Kalubhar
12	Dedava	71˚21' 18"	21˚53' 45.6"	Hourly	1982-2010	Kalubhar
13	Pipardi	71˚20' 9.59"	21˚50' 9.59"	Hourly	1983-2007	Kalubhar

IV. METHODOLOGY

Central Water Commission (CWC) has published flood estimation reports for various zones and subzones of India. Basin related to Saurashtra region of Gujarat is covered in subzone 3(a). In these reports the relationships for synthetic unit hydrograph (SUH) parameters like time to peak (t_p), peak discharge per unit area (q_p), width of hydrograph at 50% of peak discharge (W_{50}) and width of hydrograph at 75% of peak discharge (W_{75}) etc. have been developed based on the catchment characteristics. Apart from SUH relationships, CWC (2000) has also developed regional flood frequency formulae and enveloping values for the estimation of design flood.

A. SUH Relationships

The following relationships have been developed by CWC (1987) for subzone 3a.

$$t_p = 0.433 * (L / S_c)^{0.704} \quad (1)$$

$$q_p = 1.161 / (t_p)^{0.635} \quad (2)$$

$$W_{50} = 2.284 / (q_p)^{1} \quad (3)$$

$$W_{75} = 1.331 / (q_p)^{0.991} \quad (4)$$

$$W_{R50} = 0.827 / (q_p)^{1.023}$$

$$W_{R75} = 0.561 / (q_p)^{1.037}$$

$$T_B = 8.3758 * (t_p)^{0.512}$$

$$T_m = t_p + 0.5$$

$$Q_p = q_p * A \quad (9)$$

Where,

A = Total catchment area in km^2

L = Length of longest main stream along the river course in km

S_c = Equivalent stream slope in m/km

t_p= Time from the centre of effective rainfall duration to the peak in hr.

q_p = Peak rate of discharge in cumecs per sq. km.

Q_p = Peak discharge of U.G. in m^3/s

T_B = Base width of U.G. in hr.

T_m = time from the start of rise to the peak of U.G. in hr.

W_{50} = Width of U.G. measured at 50% of peak discharge ordinate in hr.

W_{75} = Width of U.G. measured at 75% of peak discharge ordinate in hr.

W_{R50} = Width of rising limb of U.G. measured at 50% of peak discharge ordinate in hr.

W_{R75} = Width of rising limb of U.G. measured at 75% of peak discharge ordinate in hr.

Various steps to estimate the design flood hydrograph are described as under:

1. Preparation of catchment area plan of the un-gauged catchment.
2. Determination of physiographic parameters i.e. the catchment area (A), the length of the longest stream (L) and equivalent Stream slope (S_c).
3. Determination of 1-hour SUH parameters i.e. peak discharge per km^2. (q_p), the peak discharge (Q_p), the basin lag (t_p), thepeak time of U.G. (T_m), widths of the U.G. at 50% and 75% of Q_p (i.e. W_{50} and W_{75}), widths of the rising limb of U.G. at 50% and 75% of Q_n (i.e. W_{R50} and $W_{R\,75}$) and time base of U.G.(T_B).
4. Drawing of a SUH.
5. Estimation of design storm duration (T_D or T_B).
6. Estimation of point rainfall and areal rainfall to obtain design storm duration (T_D).
7. Distribution of areal rainfall during design storm duration (T_D) to obtain rainfall increments for unit duration intervals.
8. Estimation of effective rainfall units after substraction of prescribed design loss rate for this zone from rainfall increments.
9. Estimation of base flow (q_b).
10. Calculation of design flood peak.
11. Calculation of design flood hydrograph.

B. Regional Flood FrequencyFormulae (CWC, 2000)

The regional flood frequency formulae developed by CWC for 25, 50 and 100 years return period are summarized as follows:

$$Q_{25} = 1.005 * A^{(0.978)} * S^{(0.25)} * R_t^{(1.19)}/L^{(0.618)} \quad (10)$$

$$Q_{50} = 1.164* A^{(0.947)} * S^{(0.242)} * R_t^{(1.143)}/L^{(0.566)} \quad (11)$$

$$Q_{100} = 1.161* A^{(0.96)} * S^{(0.241)} * R_t^{(1.126)}/L^{(0.568)} \quad (12)$$

The above formulae can be represented by the following equation:

$$Q_T = a * A^b * S^c * R_T^d/L^e \quad (13)$$

Where,

a, b, c, d and e are return period dependent coefficients;

Q_T = Design flood for a desired return period T in m^3/s;

A = Catchment Area in km^2;

S = Equivalent slope of main stream in m/km;

R_T= Storm depth of return period T in cm;

L = Longest length of main stream in km.

25, 50 and 100 years return period rainfall values for the region under study work out to be 20, 24 and 28cm respectively using the iso-pluvial maps prepared by IMD.

V. RESULTS AND DISCUSSION

Using SUH and regional flood frequency formulae developed by CWC, the design floods for the 20 dams are tabulated in Table 5.

It may be seen from Table 5 that the design floods given by the two approaches are comparable. The design floods given by the SUH approach may be more appropriate as the complete shape of the hydrograph may be obtained. The limitation of the study is that same values of rainfall have been used for the entire region, which may vary from one basin to another basin. However the design floods computed in the present study may be used for cross verification of the adopted design flood values for these existing dams.

Table 5: Design Floods for 20 dams using 2 approaches

Basin Name	Dam	SUH Method			RFF method		
		Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}
Wadavan-Bhogavo	WB I	1345.53	1676.05	1868.75	1261.18	1566.76	1882.22
	WB II	754.02	929.89	1105.27	1039.06	1290.82	1550.72
	WB III	1348.32	1666.65	2029.65	1544.16	1918.30	2304.54
Limbdi-Bhogavo	LB I	1303.96	1503.09	1929.6	1384.68	1720.19	2066.53
	LB II	1140.6	1389.58	1658.26	1293.99	1607.52	1931.18
	LB III	749.15	926.93	1103.8	734.48	912.44	1096.15
Sukhbhadar	Goma	1034.31	1204.52	1497.79	983.51	1221.82	1467.82
	Sukhbhadar	1789.9	2550.71	3050.28	2046.92	2542.89	3054.88
Utavali	Senthali	437.17	533.07	630.93	455.27	565.58	679.46
	Khambhada	1118.01	1380.51	1642.09	906.15	1125.71	1352.36
Padalio	Bhambhan	510.88	623.08	735.27	578.64	718.84	863.58
Keri	Bhimdad	745.08	914.13	1082.44	738.48	917.41	1102.12
	Gala	1057.66	1294.23	1531.72	1005.44	1249.05	1500.54
Ghelo	Somnath	562.15	683.43	804.03	604.54	751.02	902.24
	Itaria	830.22	1013.49	1197.47	887.28	1102.27	1324.21
	Limbali	895.08	1094.84	1251.58	802.56	997.01	1197.75
	Navagam	388.78	475.89	562.89	433.71	538.80	647.29
Kalubhar	Malpara	721.43	882.32	1044.39	699.35	868.80	1043.73
	Rangholi	1871.56	2307.04	2744.37	1874.26	2328.39	2797.20
	Kalubhar	1904.34	2370.23	2843.88	2149.38	2670.16	3207.78

VI. CONCLUSIONS

The study has been undertaken with the objective to estimate design floods for 20 dams located in rivers of Saurashtra region which are contributing into Gulf of Khambhat. SUH and regional flood frequency formulae developed by CWC have been used. The design flood estimates by the two approaches have been summarized. The design floods computed in the present study may be used for cross verification of the adopted design flood values for the existing dams, which have been investigated in this study.

REFERENCES

[1] CWC(2001), 'Manual of estimation of Design Flood', Hydrology studies Organisation, Central water Commission, New Delhi

[2] CWC (1987), 'Flood estimation report for Mahi and Sabarmati (Subzone – 3a)', Hydrology Directorate, Central Water Commission, New Delhi.