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Estimation of Design Flood for Rivers of Saurashtra Region contributing into the Gulf of Khambhat

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ABSTRACTS

Design flood has been estimated for rivers of Saurashtra region contributing into the Gulf of Khambhat using deterministic as well as statistical approach for planning, design and management of hydraulic structures. By comparing the results obtained by these approaches, one can easily estimate the flow rate or peak discharge to a given design return period and can establish the suitability of approach for this study area. Nine river basins with 20 dams of Saurashtra region were analyzed in this study. Though Saurashtra is one of the most water scarce regions of India yet it suffers from the flooding problem, as the numbers of rainy days are very less and the rainfall intensity is very high. Due to being a regulated basin, dam wise study was preferred. Deterministic approach was carried out using synthetic unit hydrograph (SUH) and regional flood formulae (RFF) methods for subzone-3a provided in Central Water Commission (CWC) report, 2001. Statistical approach was carried out using Rainfall frequency analysis employing Gumbel's EV1distribution. As there is no spill by these hydraulic structures and the annual flood data for the nine river sites are heavily affected by the storage dams in the upstream. Hence these data violate the basic principle of virgin flow. Hence the analysis of these data was not attempted further. The main objective of study was to carry out the rainfall frequency analysis for these river basins to get 24 hour rainfall for a return period of 25, 50 and 100 years for an individual basin instead of using the value obtained by iso-pluvial map to estimate the design flood. The overall results reveals that due to construction of number of dams in 9 river basins, design flood estimation on each dam by using deterministic approach is more feasible. Revised design floods using SUH and RFF method on the basis of estimated rainfall indicates over-estimated and under-estimated design floods. Since the percentage difference is very less between revised SUH and revised RFF method. So, for safety purpose one with higher value should be used.

Keywords: Design flood, Digital Elevation Model (DEM), Geographic Information System (GIS), Soil and Water Assessment Tool (SWAT) model, Synthetic Unit Hydrograph (SUH); Regional Flood Formulae (RFF); Gumbel's EV1; rainfall frequency.

INTRODUCTION

Flood, a natural disaster is responsible for loss of life and property world over. Floods damage property and endanger the lives of humans and animals and also affect the environment and aquatic life negatively. Floods have been occurring repeatedly in India. Approximately 40 million ha area (12%) in India has been identified as flood prone[18]. For mitigating the flood disasters, various structural and non-structural measures are adopted. Structural measures include protection works and flood embankments while non-structural measures include flood forecasting, flood warning and flood plain zoning. Design flood estimates are required for the design of various hydraulic structures such as weirs, barrages, dams, embankment etc. and flood protection / relief schemes[5, 14]. Flood forecasts are required for operation of various flood control structures, for taking emergency measures such as maintenance of flood levees, evacuating the people to safe localities etc. Whenever rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable flood estimates directly. In such situation, flood formulae developed for the region are one of the alternative methods for estimation of design floods, particularly for small-to-medium catchments. The conventional flood formulae developed for different regions of India are empirical in nature and do not provide estimates for a desired return period.

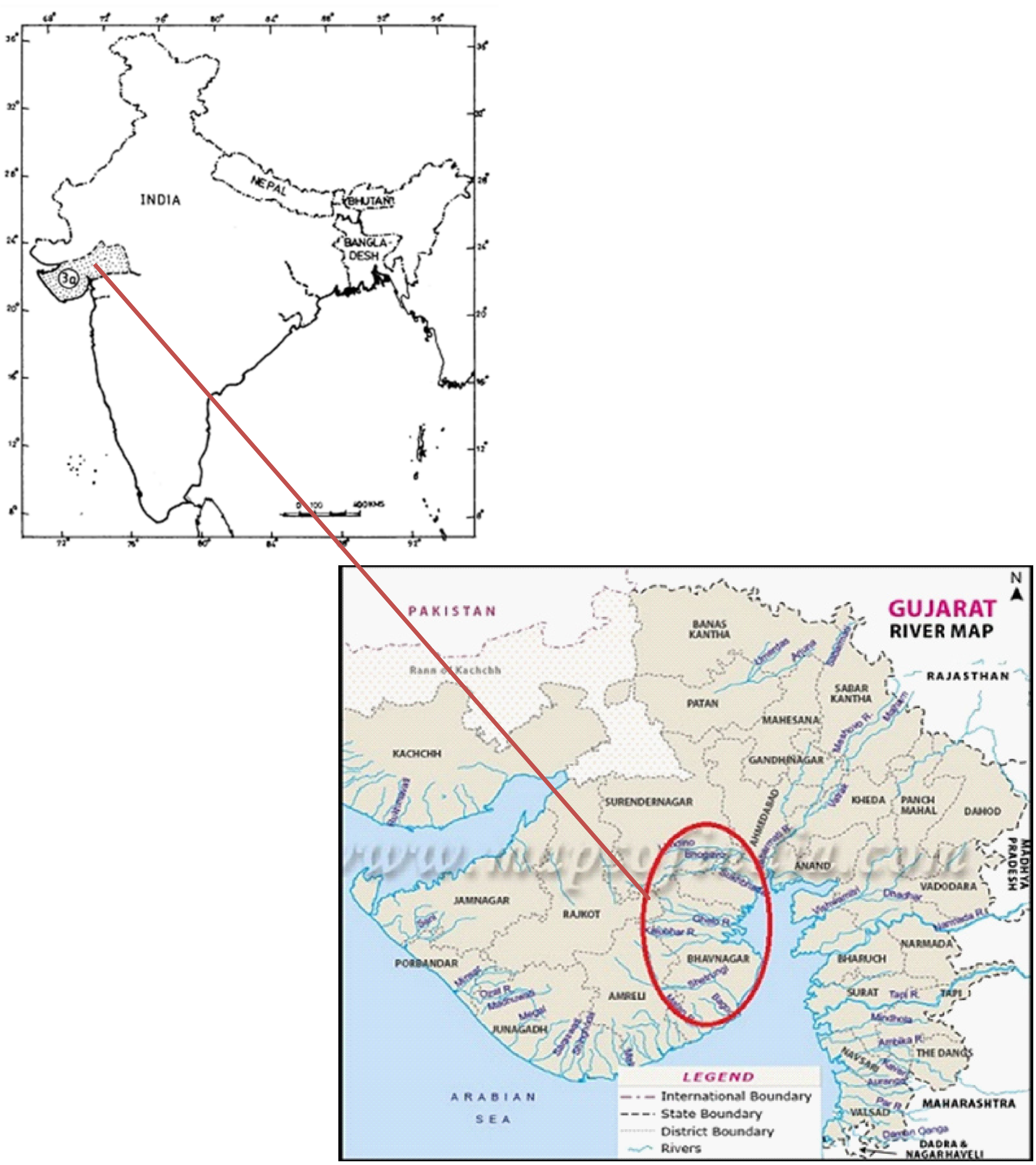

Fig. 1: Location map of study area a) Subzone 3(a) of India b) River map of Gujarat (Source: Gujarat State Disaster Management Authority)

A number of studies have been carried out for estimation of design floods for various structures by different Indian organizations. Among these the prominent studies are carried out jointly by the Central Water Commission (CWC), Research Designs and Standards Organization (RDSO), and India Meteorological Department (IMD) using the method based on synthetic unit hydrograph and design rainfall, considering physiographic and meteorological characteristics for estimation of design floods[3] and regional flood frequency studies carried out by RDSO using the USGS and pooled curve methods[12] for various hydro-meteorological subzones of India. The concept of the geomorphologic instantaneous unit hydrograph (GIUH) was introduced by Rodriguez-Iturbe and Valdes[17]. The topographic and geometric properties of the watershed and its drainage channel network are reflected by geomorphology[6]. Snyder (1938) proposed synthetic unit hydrograph approach (SUH) for ungauged basin[21]. A desirable method should satisfy the requirements of universal acceptability; ease in use with a minimum of data; robustness in nature; and reliability[14]. Now a days GIS and remote sensing techniques are being used extensively to monitor the disasters like droughts and floods[7].

Practically in the design of all hydrologic structures the peak flow that can be expected with an assigned frequency (say 1 in 100 years) is of primary importance to adequately design the structure to accommodate its effect. The design of bridges, culvert waterways and spillways for dams and estimation of scour at a hydraulic structure are some examples wherein flood-peak values are required. To estimate the magnitude of a flood peak

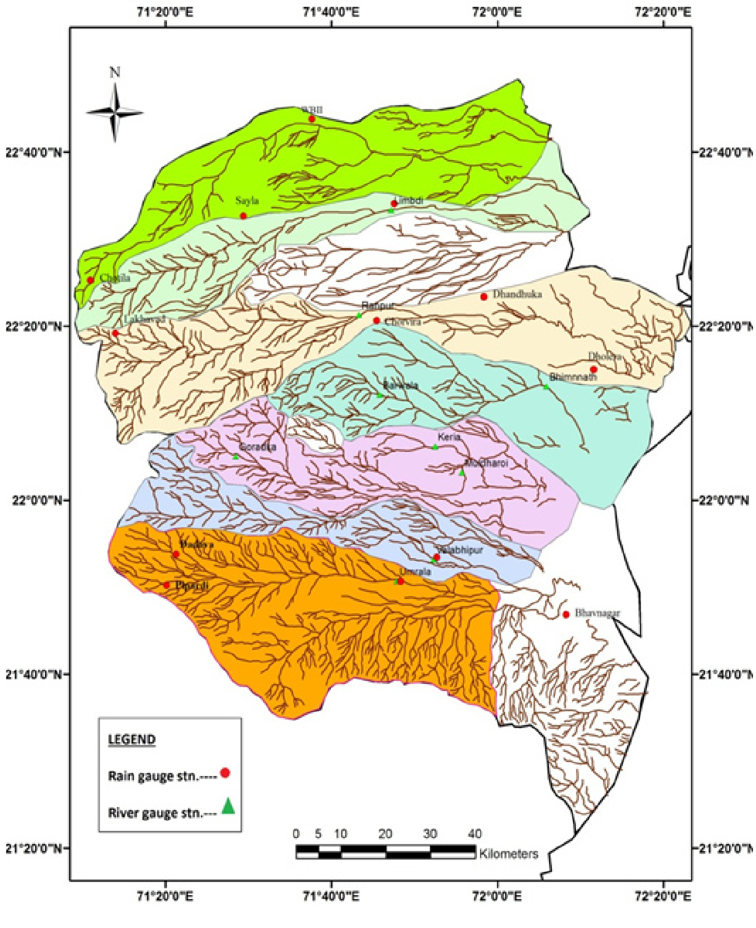

Fig. 2: Location of G&D sites and rain-gauge in river basin map

the following methods are available: (1) Rational method; (2) Empirical method; (3) Unit-hydrograph technique and (4) Flood-frequency studies[10]. The use of a particular method depends upon (i) the desired objective, (ii) the available data and (iii) the importance of the project. Further, the rational method is applicable only to small-size (<50 km^2) catchments and the unit-hydrograph method is normally restricted to moderate-size catchments with areas less than 5000 (km^2)[13, 15].

In present study, design floods for various structures in the 9 river basins namely Wadhavan-Bhogavo, Limbdi-bhogavo, Sukhbhadar, Utavali, Padalio, Khalkhalia, Ghelo, Keri and Kalubhar have been estimated. Deterministic approach based on unit hydrograph theory developed by CWC[4] and statistical approaches based on frequency analysis has been used for the design flood estimation.

Study area and data availability

Saurashtra basin is a region of western India, located on the Arabian Sea coast of state of Gujarat. Saurashtra is bounded on three sides by waters of sea, namely in the north by the Gulf of Kutch with some part by the little Rann, in the west and south by the Arabian Sea and in the South-East by the Gulf of Khambhat; while in the east is the Mainland of Gujarat and are shown in Figure[1,8,9,19]. The area covered by Saurashtra region is 59,360 sq. km. of which 9000 sq. km. area is under study[20]. Suarashtra basin lies between latitude 20°N to 24°N and longitude 69°E to 73°E. The rivers of Saurashtra region under study are: Wadhavan-Bhogavo, Limbdi-Bhogavo, Sukhbhadar, Utavali, Khalkhalia, Padalio, Keri, Ghelo and Kalubhar. There are 20 dams situated in these river basins. Details of river basins and dam situated in these river basins are shown in Table 1 and 4. Basin maps with dam site are shown in Figure 3 to 10.

There are 13 rain gauge stations and 9 G&D stations in these river basins which are shown in Figure 2**.** The rainfall data are collected from IMD as well as Kalpasar Department and G&D data are collected from Kalpasar Department of Gujarat. Details of G&D stations and raingauge stations are shown in Table 2 and 3. For Synthetic Unit Hydrograph analysis, data related to catchment like river length, catchment area and equivalent slope are required and the same are computed using SWAT model and Arc-GIS. SRTM data of 90 m resolution are used for this purpose.

METHODOLOGY

In this study, deterministic approach based on unit hydrograph theory and statistical approaches based on frequency analysis are used for design flood estimation.

Deterministic Approach

Due to paucity of data, regional approach based on synthetic unit hydrograph developed by Central Water Commission (CWC), 1987 has been used[2]. The study area falls under the subzone 3(a).

Synthetic Unit Hydrograph (SUH) method

The following relationship for SUH method has been developed by CWC (1987):

Table 1: Details of River Basins

Sr.No.	Basin Name	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

$t_p = 0.433(L/S_c)^{0.704}$ ...(1)
$q_p = 1.161/(t_p)^{0.635}$ ...(2)
$T_B = 8.3758(t_p)^{0.512}$ ...(3)
$W_{50} = 2.284/(q_p)^{1.00}$ ...(4)
$Q_p = q_p * A$ ...(5)
$W_{75} = 1.331/(q_p)^{0.991}$ ...(6)
$WR_{50} = 0.827/(q_p)^{1.023}$ ...(7)
$WR_{75} = 0.561/(q_p)^{1.037}$ ...(8)
$T_m = t_p + 0.5$ ...(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 cumec 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.

Regional flood formulae method

The regional flood formulae have been developed by CWC to estimate 25, 50 and 100 year return period flood values. The meteorological variability has been accounted from region to region in these formulae. The others factors such as shape of the catchment, slope of the stream etc, which have influence on the peak, have also been included in these formulae thereby improving over most of the limitations of the empirical / rational formula. Thus to estimate design flood for sub-zone 3(a), Regional flood formula is given as[2]:

$$Q_T = \frac{\left(a * A^b * S^c * R_t^d\right)}{L^e} \quad ...(10)$$

Where,
a, b, c, d and e are coefficient and the value of this coefficient is provided in CWC report.
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
Thus,

$$Q_{25} = 1.005 * A^{(0.978)} * S^{(0.25)} * R_t^{(1.19)} / L^{(0.618)} \quad ...(11)$$

$$Q_{50} = 1.164 * A^{(0.947)} * S^{(0.242)} * R_t^{(1.143)} / L^{(0.566)} \quad ...(12)$$

$$Q_{100} = 1.161 * A^{(0.96)} * S^{(0.241)} * R_t^{(1.126)} / L^{(0.568)} \quad ...(13)$$

Statistical Approach

The statistical approach, otherwise also called frequency analysis, may be performed on the past recorded data of annual peak data series.

Table 2: Details of G&D stations of Saurashtra region

Sr. No.	Station Name	Longitude	Latitude	Type	Data Availability (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' 1.2"	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

Frequency analysis is carried out on the available record of annual flood peak discharge or annual rainfall events of the region.

Frequency Analysis for individual gauged sites

Frequency analysis study interprets a past record of events to predict the future probabilities of occurrence and estimate the magnitude of an event corresponding to a specific return period[1]. If the event records are of sufficient length and reliability, they may yield satisfactory estimates. The method, however, does not provide a hydrograph shape but gives only a peak discharge of known frequency. The processed data series are to be analysed to ensure that the fundamental assumption of frequency analysis are satisfied. The data series is to be checked for randomness, presence of trend and outliers. The presence of trend is tested by using Kendall's rank correlation test and Turning point test. The presence of randomness and outliers is tested by Anderson's correlogram test and Chow test respectively. Detailed at site flood frequency analysis is carried out by using various distributions like Normal, Log-Normal, Pearson type III, Log-Pearson type III, Gumbel's Extreme value distribution[9]. Gumbel EV1 is the commonly used distributions and the details about these distributions are given below[1,15,16].

Gumbel EV-1 type distribution

It is one of the most commonly used distributions in flood frequency analysis and was introduced by Gumbel in 1941. It is widely used for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc. It is the double exponential distribution (known as Gumbel's distribution or extreme value type 1 or Gumbel's EV-1 distribution). The CDF of EV-1 distribution is defined as

$$F(x) = \exp\left[-\exp(-(x-u)/\alpha)\right] \quad ...(14)$$

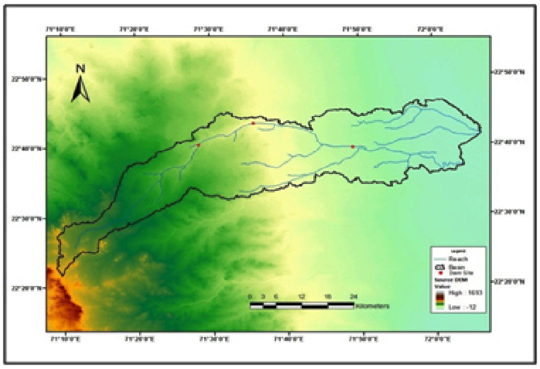

Fig. 3: Basin map of Wadhavan-Bhogav

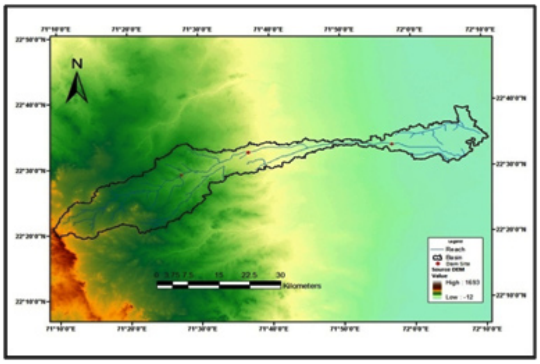

Fig. 4: Basin map of Limbdi-Bhogavo

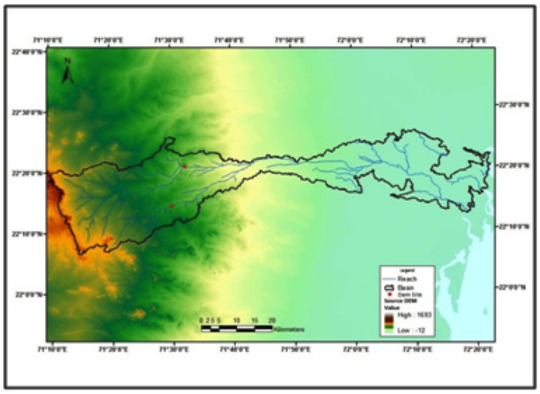

Fig. 5: Basin map of Sukhbhadar

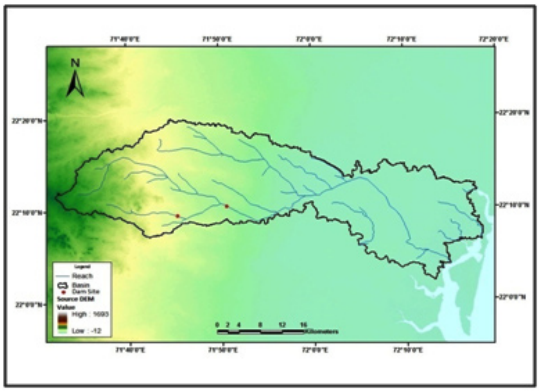

Fig. 6: Basin map of Utavali

Where, u and a are the location and scale parameters of the distribution.

Using method of moments, u and a are obtained by following equation:

$$\bar{x} = u + 0.5772\alpha \quad ...(15)$$

$$s_x^2 * 6 = \pi^2 \alpha^2 \quad ...(16)$$

Where, $\bar{x}$ and S_X are mean and standard deviation of the variate X.

Equation (16) can be written in the reduced variate form as

$F(y) = \exp(-\exp(-Y_T))$ ...(17)

Where,

$$Y_T = \frac{(x-u)}{\alpha} \quad ...(18)$$

The reduced variate Y_T can be written in terms of return period, T, by replacing F(x) by 1-1/T as

$Y_T = -\ln(-\ln(1-(1/T))$ ...(19)

$$= -\ln\left(\ln\left(\frac{T}{T-1}\right)\right) \quad ...(20)$$

Thus,

$X_T = u + a * Y_T$ ...(21)

Regional flood frequency analysis

Kumar (2009), developed the Regional flood frequency relationship using L-moment approach for ungauged catchments for 17 Subzones hydro-meteorologically homogeneous. Out of 17 subzones, Saurashtra region falls under Subzone 3(a) and the relationship for this subzone developed by Kumar (2009) is given as follows[11]:

$Q_T = C_T * A^b$ ...(22)

Where,

Q_T = Flood estimate for an ungauged catchment in m^3/s for T year return period

C_T = a regional coefficient

A = Catchment area in km^2

b = a regional coefficient, for subzone 3(a) this value is 0.383.

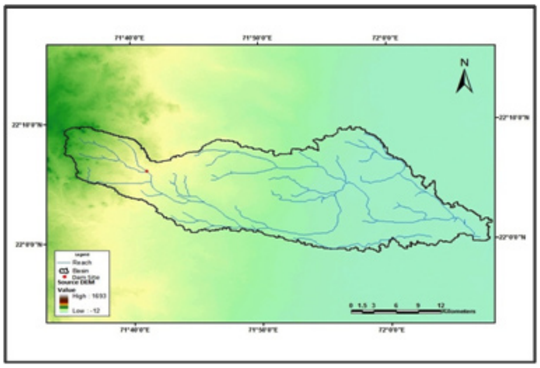

Fig. 7: Basinmap of Padalio and Khalkhalia

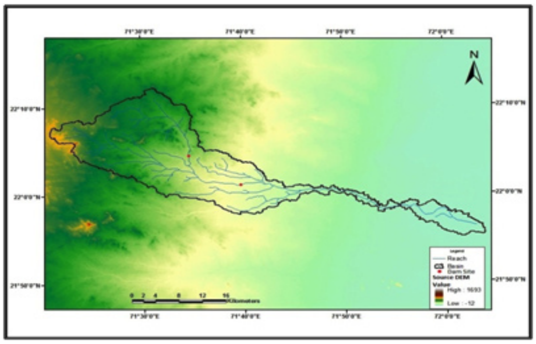

Fig. 8: Basin map of Keri

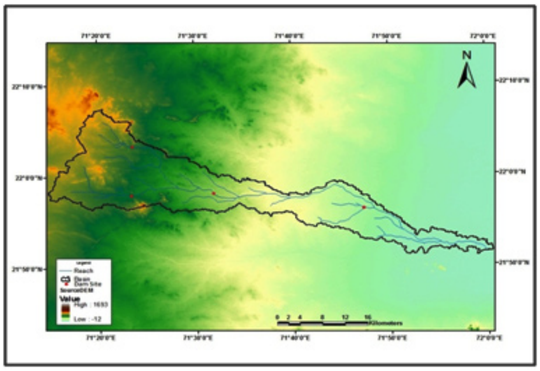

Fig. 9: Basin map of Ghelo

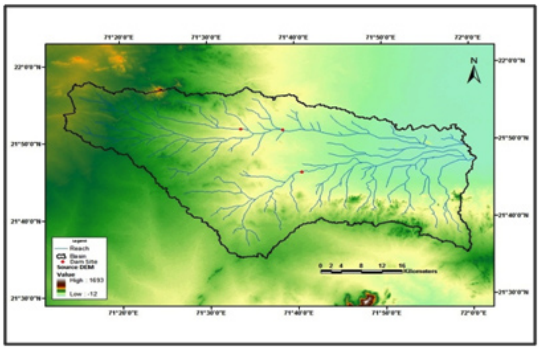

Fig. 10: Basin map of Kalubhar

Table 3: Details of Rain gauge stations of Saurashtra region

Sr. No.	Station Name	Longitude	Latitude	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

Table 4: Details of Dam with river-wise

Sr. No.	Name of River	Name of the Dam	Location		Area (km^2)	River Length (km)	Eq. Slope (m/km)
			Longitude	Latitude			
1	Wadhwan-Bhogavo	WB I	71°28'57.7"	22°40'49.6"	389	50	1.86
		WB II	71°36'26.8"	22°43'17.2"	159	14	1.22
		WB III	71°48'50.0"	22°39'45.6"	303	24	1.81
2	Limbdi-Bhogavo	LB I	71°27' 21.6"	22°28' 48"	329	33	1.727
		LB II	71°36' 39.6"	22°32' 34.8"	201	19	2.142
		LB III	71°56' 45.6"	22°33' 17.9"	192	36	1.504
3	Sukhbhadar	Sukhbhadar	71°32' 13.2"	22°20' 45.6"	591	45	1.937
		Goma	71°30' 3.6"	22°14' 23.9"	165	24	3.211
4	Utavali	Khambhada	71°50' 41.9"	22°10' 22.8"	255	40	2.431
		Senthali	71°44' 27.6"	22°9' 43.2"	62	18	3.332
5	Keri	Bhimdad	71°34' 37.2"	22°4' 51.6"	126	24	2.931
		Gala	71°34' 22.8"	22°2' 45.6"	169	26	3.892
6	Ghelo	GheloSomnath	71°24' 7.2"	22°3' 10.8"	56	12	5.662
		GheloItaria	71°23' 49.2"	21°58' 4.8"	111	16	3.681
		Limbali	71°31' 48"	21°58' 8.4"	142	27	3.427
		Navagam	71°47' 24"	21°56' 20.4"	60	15	1.988
7	Kalubhar	Kalubhar	71°38' 27.6"	21°51' 28.8"	592	46	3.139
		Rangholi	71°39' 35.9"	21°45' 36"	397	31	2.570
		Malpara	71°32' 56.4"	21°51' 39.6"	114	23	2.470
8	Padalio	Bhambhan	71°41' 6"	22°6' 0"	66	14	3.66

Value of C_T for Various return period for Subzone 3(a) are shown in Table 5.

RESULTS AND DISCUSSION

In this study initially the above approach are used for 20 dams as well as for 9 river basins on the basis of 24 hour rainfall for T year return period given in the iso-pluvial map. After rainfall frequency analysis, it is revised only for dams because these basins are heavily affected by dams situated on upstream. The result obtained by the above approach by the use of 24 hour rainfall for a T year return period given in the iso-pluvial map (IMD, Pune) are shown in Table 6 and 7 as well as developed by rainfall frequency analysis for basin wise are shown in Table 8 and 9. From Table 6, it can be seen that design flood estimates for return period of 25, 50 and 100 years for dams namely Wadhavan-Bhogavo, Limbdi-Bhogavo, Sukhbhadar, Utavali, Khalkhalia, Padalio, Keri and Kalubhar are underestimating except Ghelo which is overestimating when compares with the result obtained from Table 8. The reason behind this variation in result is the use of value T year return period 24 hour rainfall. By rainfall frequency analysis it has been found that the river basins namely Wadhavan-Bhogavo, Limbdi-Bhogavo, Sukhbhadar and Kalubhar have higher value of rainfall from what

Table 5: Value of C_T for Various return period for Subzone 3(a)

Coeff. (b)	C_T for Subzone 3(a) Return Period (Years)				
	2	10	25	50	100
0.383	23.283	68.862	94.629	114.058	133.488

Table 6: Design flood (Cumec) for 20 dams

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
Suhkbhadar	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

recommended by IMD Pune while Ghelo river basin has lower value. T year return period 24 hour rainfall recommended by IMD Pune for these river basins is: R_{25} = 20 cm, R_{50} = 24 cm and R_{100} = 28cm. Since only 5 basins namely Wadhavan-Bhogavo, Limbdi-Bhogavo, Sukhbhadar, Ghelo and Kalubhar have sufficient rainfall data availability so by using Gumbel EV1 distribution T year return period 24 hour rainfall are estimated for 5 river basins and are shown in Table 8. Thus this estimated value of 24 hour rainfall for return period of 25, 50 and 100 years is used to revise design floods for the dams present in these river basins. Revised design floods for dams in these river basins for return period of 25, 50 and 100 years are computed and tabulated in Table 9 and from Table 9 it is found that the % difference is very less between revised SUH and revised RFF method.

By using the relationship developed by Kumar (2009), the design flood estimates for return period of 25, 50 and 100 years for dams and rivers are computed below in Table 10 and 11. From Table 10 and 11 it is found that the % difference is very large between L-moment and revised SUH method. L-moment method underestimates the design floods for dams as well as river basins.

The annual flood data for the nine river sites are heavily affected by the storage dams in the upstream. Hence these data violate the basic principle of virgin flow. Hence the flood frequency analysis of these data was not attempted further.

CONCLUSIONS

After the analysis of these river basins and dams situated on it, the following conclusions are drawn:

- For the study area, 24 hr rainfall for the return period of 25, 50 and 100 years are different

Table 7: Design flood (Cumec) for 9 river basins

Sr. No.	Basin Name	SUH Method			RFF method		
		Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}
1	Wadhavan-Bhogavo	2710.72	3472.33	4228.19	2473.45	3129.90	3832.12
2	Limbdi-Bhogavo	1832.21	2326.2	2821.62	1638.00	2095.30	2548.53
3	Sukhbhadar	3192.12	4068.33	4947.0	2519.04	3200.88	3926.56
4	Utavali	2208.94	2686.26	3101.49	2085.64	2630.09	3213.83
5	Padalio	754.38	952.94	1149.27	1178.52	1480.72	1787.92
6	Khalkhalia	1032.13	1319.2	1572.23	815.14	1038.28	1248.04
7	Keri	1306.05	1635.35	1971.73	1237.48	1581.81	1912.50
8	Ghelo	1413.24	1791.38	2170.07	1337.6	1709.47	2069.72
9	Kalubhar	3862.14	4952.84	5334.61	4274.00	5256.78	6464.61

Table 8: 24 hour Rainfall (cm) for T year return period for river basins

Sr. No.	Basin Name	R_{25}		R_{50}		R_{100}	
		After analysis	As per Iso-pluvial map	After analysis	As per Isopluvial map	After analysis	As per Isopluvial map
1	Wadhavan-Bhogavo	25	20	28	24	32	28
2	Limbdi-Bhogavo	34	20	38	24	41	28
3	Sukhbhadar	21	20	25	24	28	28
4	Ghelo	18	20	21	24	23	28
5	Kalubhar	21	20	24	24	27	28

Table 9: Revised design flood for T year return period by SUH and RFF methods for dams

Basin Name	Dam	Revised SUH Q_{25}	Revised RFF Q_{25}	% Difference	Revised SUH Q_{50}	Revised RFF Q_{50}	% Difference	Revised SUH Q_{100}	Revised RFF Q_{100}	% Difference
Wadavan-	WB I	1758.15	1644.75	-6.89	2007.38	1882.22	-6.65	2332.77	2206.38	-5.73
Bhogavo	WB II	1105.27	1355.08	18.44	1109.87	1550.72	28.43	1280.18	1817.79	29.57
	WB III	1982.51	2013.79	1.55	1745.24	2304.54	24.27	2302.02	2701.44	14.79
Limbdi-	LB I	2391.5	2603.66	8.15	2424.82	2972.12	18.41	2942.72	3253.40	9.55
Bhogavo	LB II	2047.6	2433.12	15.84	2306.44	2777.45	16.96	2499.89	3040.30	17.77
	LB III	1371.24	1381.06	0.71	1549.98	1576.50	1.68	1683.35	1725.70	2.45
Suhkbhadar	Goma	918.3	1042.31	11.90	1091.95	1282.64	14.87	1497.79	1467.82	-2.04
	Sukhbhadar	1803.22	2169.29	16.88	1907.3	2669.47	28.55	3050.28	3054.88	0.15
Ghelo	Somnath	501.66	533.31	5.93	592.77	640.68	7.48	652.5	713.93	8.60
	Itaria	693.38	782.73	11.42	704.42	940.33	25.09	968.15	1047.84	7.61
	Limbali	794.52	707.99	-12.22	945.06	850.53	-11.11	1044.94	947.78	-10.25
	Navagam	345.59	382.61	9.68	410.77	459.64	10.63	454.17	512.19	11.33
Kalubhar	Malpara	761.68	741.16	-2.77	882.32	868.80	-1.56	1003.66	999.52	-0.41
	Rangholi	1981.18	1986.30	0.26	2307.04	2328.39	0.92	2336.22	2678.72	12.79
	Kalubhar	2018.97	2277.86	11.37	2370.23	2670.16	11.23	2724.11	3071.92	11.32

Note: % Difference = $\frac{Revised\ RRF - Revised\ SUH}{Revised\ RRF}$

Table 10: Design flood for T year return period by L-moment method for dams

Basin Name	Dam	L-moment Q_{25}	Revised SUH Q_{25}	% Difference	L-moment Q_{50}	Revised SUH Q_{50}	% Difference	L-moment Q_{100}	Revised SUH Q_{100}	% Difference
Wadavan-Bhogavo	WB I	928.91	1758.15	47.17	1119.63	2007.38	44.22	1310.37	2332.77	43.83
	WB II	659.42	1105.27	40.34	794.81	1109.87	28.39	930.20	1280.18	27.34
	WB III	844.14	1982.51	57.42	1017.46	1745.24	41.70	1190.79	2302.02	48.27
Limbdi-Bhogavo	LB I	871.18	2391.5	63.57	1050.05	2424.82	56.70	1228.93	2942.72	58.24
	LB II	732.22	2047.6	64.24	882.55	2306.44	61.74	1032.90	2499.89	58.68
	LB III	708.81	1371.24	48.31	854.34	1549.98	44.88	999.88	1683.35	40.60
Suhkbhadar	Goma	668.84	918.3	27.17	806.16	1091.95	26.17	943.49	1497.79	37.01
	Sukhbhadar	1090.29	1803.22	39.54	1314.15	1907.3	31.10	1538.01	3050.28	49.58
Ghelo	Somnath	442.16	501.66	11.86	532.94	592.77	10.09	623.73	652.5	4.41
	Itaria	574.62	693.38	17.13	692.60	704.42	1.68	810.59	968.15	16.27
	Limbali	631.47	794.52	20.52	761.12	945.06	19.46	890.78	1044.94	14.75
	Navagam	454.00	345.59	-31.37	547.21	410.77	-33.22	640.43	454.17	-41.01
Kalubhar	Malpara	580.52	761.687	23.78	699.71	882.32	20.70	818.91	1003.66	18.41
	Rangholi	936.18	1981.18	52.75	1128.40	2307.04	51.09	1320.62	2336.22	43.47
	Kalubhar	1091.00	2018.97	45.96	1315.00	2370.23	44.52	1539.01	2724.11	43.50

Note: % Difference (PD) = $\frac{Revised\ SUH - (L\text{-}moment)}{Revised\ SUH}$

Table 11: Design flood for T year return period for river basins

Basin Name	Area (km²)	Return Period (years) 25			50			100		
		L-moment	SUH	PD	L-moment	SUH	PD	L-moment	SUH	PD
WB	1517	1564.38	2710.72	36	1885.57	3472.33	40	2206.78	4228.19	42
LB	915	1288.99	1832.21	21	1553.64	2326.20	25	1818.30	2821.62	29
Sukhbhadar	1774	1661.01	3192.12	34	2002.05	4068.33	37	2343.10	4947.0	40
Utavali	1206	1432.78	2208.94	31	1726.96	2686.26	34	2021.15	3101.49	37
Padalio	311	852.61	754.38	0	1027.67	952.94	1	1202.73	1149.27	3.6
Khalkhalia	436	970.39	1032.13	17	1169.63	1319.20	21	1368.88	1572.23	23
Keri	556	1065.09	1306.05	13	1283.78	1635.35	18	1502.47	1971.73	21
Ghelo	626	1114.58	1413.24	17	1343.43	1791.38	21	1572.28	2170.07	24
Kalubhar	2047	1754.62	3862.14	59	2114.87	4952.84	59	2475.14	5334.61	60

[Note: PD- % Difference]

for 9 river basins which also differs from iso-pluvial map recommended by IMD, Pune for this region.

- Revised design floods using SUH and RFF method on the basis of estimated rainfall indicates over-estimated and under-estimated design floods.
- Due to construction of number of dams in 9 river basins, design flood estimation on each dam by using deterministic approach is more feasible.
- The percentage difference is very less between revised SUH and revised RFF method. So, for safety purpose one with higher value will be used.
- Regional flood frequency relationship based on L-moment under-estimates the design floods with average percentage difference of 32.023% for dams and 28.28% for river basins.
- The reason for large average percentage difference was investigated and the data analysis reveals that there are large storages in these basins and hence application of either RFF or L-moment based methods may not be applicable.

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