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QPF model for Sabarmati basin based on Synoptic analogue method

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सार – इस शोध–पत्र में दक्षिण पश्चिमी मानसून अवधि के दौरान दस वर्षों के आँकड़ों (2000–2009) के आधार पर साबरमती बेसिन के लिए परिमाणात्मक वर्षण पूर्वानुमान (क्यू. पी. एफ.) जारी करने के लिए सिनॉप्टिक अनुरूप मॉडल प्रतिपादित किया गया। वर्ष 2010 के दौरान अनुकूल सिनॉप्टिक स्थितियों के लिए वास्तविक औसत क्षेत्रीय वर्षा (ए. ए. पी.) के साथ इस निदर्श की जाँच की गई। इस मॉडल का निष्पादन 71 प्रतिशत तक सही प्रतिशत (पी. सी.) पाया गया। एक अथवा दो स्तरों पर स्थितियाँ तंत्र की तीव्रता में विविधता विशेषकर बेसिन (एस. 3) में उपरितन वायु परिचालन के कारण हुई है। केन्द्रीय जल आयोग के बाढ़ का पूर्वानुमान करने वालों के लिए सिनॉप्टिक अनुरूप मॉडल 24 घंटे पहले सही क्यू. पी. एफ. तैयार करने में सक्षम हो सका है।

ABSTRACT. The paper formulates a synoptic analogue model for issuing Quantitative Precipitation Forecast (QPF) for Sabarmati basin based on 10 years data (2000-2009) during southwest monsoon period. The model was verified with the actual Average Areal Precipitation (AAP) for the corresponding synoptic situations during 2010.The performance of the model were observed Percentage Correct (PC) up to 71%. The cases out by one or two stage were due to variation in the intensity of the system especially upper air circulation (S3) over the basin. The synoptic analogue model was able to generate accurate QPF 24 hrs in advance to facilitate flood forecasters of Central Water Commission.

Key words – AAP, QPF, Synoptic analogue model, Sabarmati.

1. Introduction

Various deterministic models (Numerical Weather Prediction), even the high resolution ones are unable to produce reliable QPF, to be used directly for flood forecasting. The problem of QPF needs to be tackled by methodologies based on statistical probabilistic approach. The Synoptic analogue technique is based upon the concept of analogy applied in meteorology and exploits the reliable representation of large scale hydrodynamic variables, like geo-potential fields to derive precipitation forecast indirectly. The method is based on the philosophy that the weather behaves in such a way that the present initial conditions, if found to be similar to a past situation, will evolve in a similar fashion and it is easy to find good analogues over a small area, even if the data-set available is short (Roebber and Bosart, 1998). The synoptic analogue model can be simply implemented and is capable of quickly generating objective forecasts; furthermore it does not rely upon complex and subtle reasoning inherent in physical/statistical methods (Radinovic, 1975; Bergen and Harnack, 1982; Toth, 1989), yielding a real solution to a difficult problem and not introducing any simplification over the physics of the atmosphere. Singh *et al.*, (1995) did a similar study for river Pun Pun in Patna. Lal *et al.*, (1983) and Abbi *et al.*, (1979) also studied QPF by synoptic analogue method for Gomti catchment & Bhagirathi catchment respectively. Similar efforts have been made by others to issue QPF by synoptic analogue method, *viz*., Ray and Patel (2000); Ram and Kaur (2004) and Ali *et al*., (2011) over river catchments of Narmada, Upper Yamuna River and Lower Yamuna respectively. In the similar manner an attempt has been made to identify the different synoptic systems and their locations which are responsible for Average Areal Precipitation (AAP) in the ranges 11-25, 26-50, 51-100 and > 100 mm during the southwest monsoon season over Sabarmati Basin for the period 2000-2009 and then preparation of a synoptic analogue model accordingly.

Fig. 1(a). Map showing sub basins of Sabarmati Basin

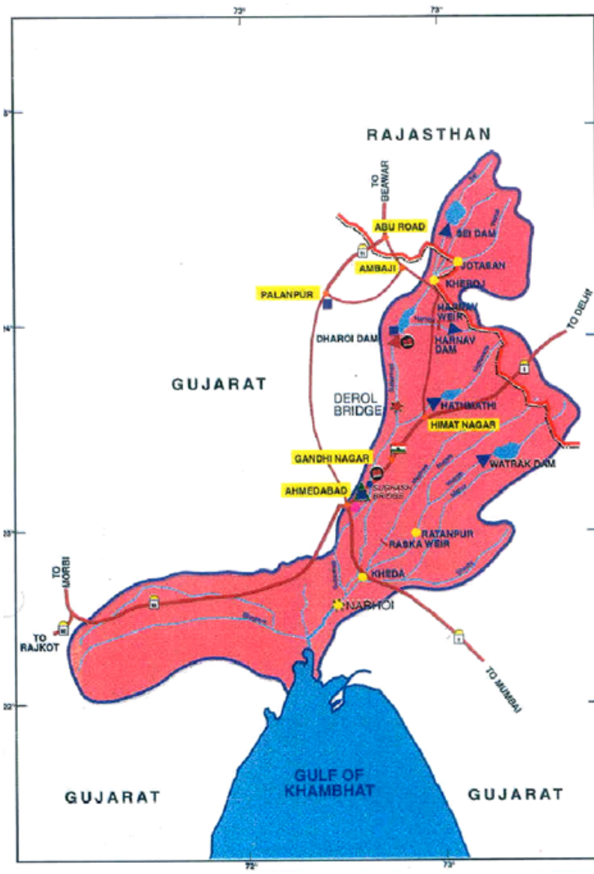

Fig. 1(b). Map showing rivers and dams of Sabarmati basin

2. Description of the study area

River Sabarmati is one of the major west flowing rivers in Sabarmati Basin, meeting the Arabian Sea in Gulf of Cambay. It rises in the Aravali hills at latitude 20° 40' N and longitude 73° 20' E in Rajasthan at an elevation of 762 m above msl. The river flows through Rajasthan for about 48 km & through Gujarat for 323 km length & then falls into Gulf of Cambay. Sabarmati River rises in the Aravali hills, which roughly mark the western boundary of Udaipur District, *i.e.*, Mount Abu area, and flows in a south-westerly direction. The main tributaries of river Sabarmati with their drainage area are Sei (331.66 sq km), Wakal (1,893 sq km), Harnav (865 sq km), Hathmati (1,574 sq km) & Watrak (1,114 sq km) [Fig. 1(b)]. The Sabarmati basin has a maximum length of 300 km and maximum width of 105 km. The total catchment area of the basin is 21,674 sq km out of which, 4124 sq km lies in Rajasthan State and the remaining 18550 sq km in Gujarat State. It lies between east longitudes of 72° 15' to 73° 49' and north latitudes of 22° 15' to 24° 53'. Sabarmati basin is bounded on the north & northeast by Aravali hills, on the east by the ridge separating it from the Mahi basin, on the south by the Gulf of Cambay & on the west by ridge separating it from the basins of the rivers draining into Rann of Kutch & the Gulf of Cambay. Sabarmati River Basin extends over parts of Udaipur, Sirohi, Pali and Dungarpur Districts. Orographically, the western part of the basin is marked by hilly terrain belonging to the Aravali chain. East of the hills lies a narrow alluvial plain with a gentle eastward slope. The important soil types found in the basin are black, alluvial and sandy soils. The cultivable area of the basin is about 1.55 million hectare. The various rivers which are included in Sabarmati basin (except river Sabarmati) are Watrak, Meshwo, Hathmati, Guhai, Harnav, Waidy, Shedhi and Mazam. Major existing projects on Sabarmati basin are: Sei Dam, Harnav-I, Harnav-II, Dharoi Dam, Hathmati, Guhai, Meshwo, Mazam, Watrak, Waidy, Raska Weir, Moti Fatewadi and Vasna Barrage. The basin is divided by CWC into two zones. (*i*) Upper basin and (*ii*) Lower basin [Fig. 1(a)]. These are further divided for convenience into four sub basins (A, B, C, D). The sub-basin A falls in Rajasthan state and is in Upper Basin, Sub-basin B and C fall in Gujarat state and are also in Upper Basin while sub-

TABLE 1

Rain-gauge stations in various sub-basins of Sabarmati

Sabarmati sub-basins	A	B	C	D
Raingauge stations	Jotasan (CWC)	Danta (DRMS)	Ahmedabad (IMD)	Bayad (DRMS)
	Saidam(CWC)	Harnaveir (CWC)	Bhiloda (DRMS)	Dhansura (CWC)
	Udaipur (IMD)	Kheroj (CWC)	Derol Bridge (CWC)	Dholka (DRMS)
			Dharoi (DRMS)	Kapadvanj (DRMS)
			Gandhinagar (DRMS)	Kheda (CWC)
			Hathmati (CWC)	Meghraj (DRMS)
			Idar (IMD)	Modasa (DRMS)
			Mansa (DRMS)	Nadiad (DRMS)
			Vijapur (DRMS)	Prantij (DRMS)
			Vijaynagar (DRMS)	Raskaveir (CWC)
				Ratanpur (CWC)
				V.V.Nagar (IMD)
				Watrak Dam (CWC)

TABLE 2

Month wise average rainfall in mm for various sub-basins of Sabarmati

Sabarmati sub-basin	Rainfall in mm					Area in sq km
	June	July	August	September	Total	
A	64.3	231.9	193.5	89.8	579.5	3650
B	83.7	303.3	248.4	112.3	747.7	2226
C	114.3	304.6	255.0	107.9	781.9	5199
D	122.4	299.8	278.3	108.8	809.3	10599

basin D falls in Gujarat and covers the entire Lower Basin and some part of Upper Basin. The average rainfall of the basin is 787.5 mm by the southwest (SW) monsoon which sets in by middle of June and withdraws by the last week of September. Sub-basin D gets the highest average rainfall of 809.3 mm followed by 781.9 mm in sub-basin C and 747.7 mm in sub-basin B. Sub-basin A gets lowest, *i.e.*, 579.5 mm of average rainfall during southwest monsoon. The seasonal monthly averages are shown in Table 2. All sub basins get highest rainfall in July followed by August.

3. Data and methodology

In order to apply synoptic analogue technique over Sabarmati basin, various synoptic situations during southwest monsoon season for 10 years period (2000-2009), based upon 0000 UTC upper air charts and 0300 UTC surface charts in relation to different ranges of rainfall have been categorized using Gujarat daily weather report and Indian Daily Weather Reports. The rainstorm ranges 11-25, 26-50, 51-100 mm and more than 100 mm have been considered for matching with different synoptic

TABLE 3

Frequency of occurrence of AAR more than 10 mm for various synoptic conditions and locations

Sabarmati	A					B					C					D					GT
	11-25	26-50	51-100	>100	Total	11-25	26-50	51-100	>100	Total	11-25	26-50	51-100	>100	Total	11-25	26-50	51-100	>100	Total	
S11	12	0	1	-	**13**	8	2	1	-	**11**	5	4	1	-	**10**	4	7	1	-	**12**	**46**
S12	1	2	2		**5**	0	2	3	1	**6**	2	0	5	1	**8**	0	4	2	-	**6**	**25**
S13	0	0	0	3	**3**	0	0	0	2	**2**	0	0	0	-	**0**	0	0	0	-	**0**	**5**
S14	0	0	0	-	**0**	1	0	0	-	**1**	0	0	0	-	**0**	0	0	0	-	**0**	**1**
Total	**13**	**2**	**3**	**3**	**21**	**9**	**4**	**4**	**3**	**20**	**7**	**4**	**6**	**1**	**18**	**4**	**11**	**3**	**0**	**18**	**77**
S21	18	6	0		**24**	12	5	1		**18**	9	5	1	-	**15**	12	4	1		**17**	**74**
S22	15	14	8	-	**37**	14	15	9	-	**38**	7	20	10	1	**38**	14	14	6		**34**	**147**
S23	7	5	0	2	**14**	7	6	1	2	**16**	5	3	4	2	**14**	8	3	1	4	**16**	**60**
S24	3	0	0	1	**4**	1	1	1	1	**4**	0	1	0	1	**2**	2	2	1	1	**6**	**16**
Total	**43**	**25**	**8**	**3**	**79**	**34**	**27**	**12**	**3**	**76**	**21**	**29**	**15**	**4**	**69**	**36**	**23**	**9**	**5**	**73**	**297**
S31	2	0	0	-	**2**	2	1	0	-	**3**	1	1	0	-	**2**	3	0	0	-	**3**	**10**
S32	10	5	0	-	**15**	9	5	1	-	**15**	13	1	0	-	**14**	8	1	0	-	**9**	**53**
S33	22	8	1	-	**31**	18	11	0	-	**29**	23	5	0	-	**28**	16	4	0	1	**21**	**109**
S34	27	9	0	-	**36**	24	10	1	-	**35**	25	14	3		**42**	28	23	4	2	**57**	**170**
Total	**61**	**22**	**1**	**0**	**84**	**53**	**27**	**2**	**0**	**82**	**62**	**21**	**3**	**0**	**86**	**55**	**28**	**4**	**3**	**90**	**342**
G.T	**117**	**49**	**12**	**6**	**184**	**96**	**58**	**18**	**6**	**178**	**90**	**54**	**24**	**5**	**173**	**95**	**62**	**16**	**8**	**181**	**716**

systems in the present study. Rainfall data have been collected from 30 stations (CWC, IMD and Daily Rainfall Measuring Scheme (Table 1) and daily average areal precipitation (AAP) of sub-basins has been computed using Thiess an Polygon method. Synoptic analogue model for Sabarmati basin was earlier prepared by Ray and Sahu (1998) using data for the period (1986-1995).

After going through the daily synoptic conditions which lead to rainfall over the Sabarmati basin, it was found that the basin gets rainfall due to low pressure areas/depressions that develop over Bay of Bengal and then travel in NW'ly direction along the monsoon trough. The basin also gets rainfall due to upper air cyclonic circulations that develop over Gujarat, as induced effect of western disturbances or midtropospheric cyclonic circulations that develop over Arabian Sea and adjoining Gujarat region. The low pressure area or depression in different sub-divisions starting from east M. P to Gujarat region/East Rajasthan (depending upon the position of monsoon trough) give rainfall in various ranges over the basin. The synoptic conditions also indicate that the offshore trough along west coast gets activated as soon as a low pressure area develops over Bay of Bengal and then as it approaches East M. P. Sabarmati basin gets rainfall in 11-25 mm category, therefore east M.P. was also considered important for low rainfall over the basin.

Thus, various synoptic systems responsible for > 10mm rainfall are:

S1 Deep Depression/Depression

S2 Well marked Low pressure area/Low pressure area

S3 Upper air Cyclonic circulation

The following four sub-divisions are considered influential in causing rain > 10 mm over the basin

Z1 East Madhya Pradesh and adjoining

Z2 West Madhya Pradesh and adjoining

Z3 East Rajasthan and adjoining

Z4 Gujarat Region and adjoining

According to the above classification symbol Sij stands for system Si situated in sub-division/Zone j. For example S11 stands for depression/deep depression over East Madhya Pradesh and adjoining.

4. Results and discussion

CWC, Gandhinagar has divided Sabarmati basin in two catchments (*i*) Upper Catchment (A, B, C sub-basin)

TABLE 4

Instances of average areal precipitation (AAP) more than 100 mm (sub-basin wise) during the period 2000-2009

S. No.	Date	Sub-basin	AAR	Synoptic System
1	14 Jul 2000	D	127.7	S22
2	28 Jul 2003	C	118.8	S11 and S23
3	01 Aug 2005	B	104.7	S11 and S33
4	02 Aug 2005	A	114.7	S22
5	24 Sep 2005	A	103.2	S22
6	29 Jul 2006	D	106.6	S22
7	30 Jul 2006	D	105.6	S22
8	01 Aug 2006	A	117.2	S11 and S23
		B	104.8	
9	08 Aug 2006	D	104.1	S22 , originated as deep depression on 2nd in NW Bay
10	12 Aug 2006	C	106.1	S11 and S23
		D	129.1	
11	19 Aug 2006	A	112.5	S12 and S24
		B	133.4	
12	20 Aug 2006	A	224.8	S23, originated as depression on 16th
		B	113.4	
13	07 Sep 2006	B	123.4	S22, originated as depression in NW Bay on 3rd
		C	127.6	
		D	129.5	
14	03 Jul 2007	C	134.0	S23, originated as deep depression on 28th June in NW Bay
		D	115.9	
15	04 Jul 2007	A	189.9	S23 but originated as deep depression on 28th June in NW Bay
		B	129.3	
16	13 Aug 2008	C	119.1	S22
		D	179.3	

and (*ii*) Lower catchment (D sub-basin). These catchments are reconstructed into subbasin A, B, C, D for accurate and easy calculation of Accumulated Precipitation Index (API). A total of 716 occasions of rainfall >10 mm have been considered for the Sabarmati river basin, in categories 11-25, 26-50, 51-100, >100 mm. The rainfall recorded (AAP) on a particular day in a particular sub-basin is categorized depending upon the synoptic condition prevalent on the previous day. If a low pressure forms and lies over east Madhya Pradesh and also an upper air cyclonic circulation lies over Gujarat region, than the rainfall recorded in the sub-basin is attributed to S34, *i.e.*, upper air cyclonic circulation over Gujarat region. (Table 3). It was found that maximum numbers of occasions of rainfall over the catchment are due to upper air cyclonic circulation (48%) and out of these 82% cases are due to Upper air cyclonic circulation over Gujarat region & adjoining Rajasthan. The next important synoptic situation is the Low pressure/Well marked Low pressure (41%). Out of these 80% of the rainfall events are due to Low pressure/Well marked Low pressure over Madhya Pradesh. The deep depression/ depression contributes remaining 11%. If we compare with the results given by Ray and Sahu (1998), based on data set from 1986 to 1995, the occasions of rainfall due to low pressure area has decreased from 45% to 41%, the contribution due to Upper air cyclonic circulation, has increased from 31% to 48%. The contribution of Deep Depression, Depression has also increased from 6% to 11%.

TABLE 5

QPF model for Sabarmati basin

Sub Basin	Zone	Met sub-division	S1	S2	S3
A	1	EMP & Adj	11-25	11-25	Nil
	2	WMP & Adj	>100	26-50	11-25
	3	E-RAJ. & Adj	>100	51-100	26-50
	4	GUJ. Reg & Adj	-	-	11-25
B	1	EMP & Adj	11-25	11-25	Nil
	2	WMP & Adj	>100	26-50	11-25
	3	E-RAJ. & Adj	>100	51-100	26-50
	4	GUJ. Reg & Adj	-	-	11-25
C	1	EMP & Adj	11-25	11-25	11-25
	2	WMP & Adj	51-100	26-50	11-25
	3	E-RAJ. & Adj	>100	51-100	26-50
	4	GUJ. Reg & Adj	-	-	11-25
D	1	EMP & Adj	11-25	11-25	11-25
	2	WMP & Adj	51-100	26-50	11-25
	3	E-RAJ. & Adj	>100	51-100	26-50
	4	GUJ. Reg & Adj	-	-	11-25

It was seen that rainfall in the category 11-25 mm was maximum due to upper air cyclonic circulation (60%). Upper air circulation category (S3) was also responsible for rainfall more than 50 mm in 24% cases. In these cases, it was mainly due to: (*i*) interaction of upper air westerly trough and the low level cyclonic circulation over Rajasthan and adjoining Gujarat and (*ii*) due to an upper air circulation over Rajasthan and Gujarat extending up to mid tropospheric levels. Rainfall in the category 25-50 mm is maximum due to well marked low pressure or low pressure area (47%) and next due to upper air cyclonic circulation (44%). Rainfall in the category 50-100 mm is maximum due to well marked low pressure or low pressure areas (63%). It was observed that cases of rainfall > 100 mm are maximum (42%) due to low pressure or a well marked low pressure area over west Madhya Pradesh & adjoining area and next higher 29% due to depression or deep depression over central & west M. P.

Instances of Average Areal Precipitation (AAP) more than 100 mm (Sub-basin wise) during the period 2000-2009 have been indicated in Table 4. The years 2005, 2006, 2007 had maximum instances of rainfall greater than 100 mm. These years also had the highest number of depression/deep depressions (5, 8, and 5 respectively) as compared to other years considered in the study. Thus, it could be concluded, that the synoptic situations which will give greater than 100 mm rainfall within 24 hrs over various sub-basins of Sabarmati are:

(*i*) The low pressure or a well marked low pressure area over west Madhya Pradesh, which originated as a depression/deep depression in NW Bay and moves in NW/W direction.

(*ii*) A low pressure area or a low pressure area weakened into an upper air circulation over Rajasthan/Gujarat, followed by a depression/deep depression in Bay.

On the basis of above statistics, Synoptic analogue model was developed sub-basin-wise as shown in Table 5. The model was verified with the 116 events of rainstorm of different ranges during the year 2010 (Table 6). All cases of AAP greater than 10 mm for each sub-basin were considered as events of rainstorm. It was found that out of 116 total cases, QPF was correct for 82 cases (71%), out by one stage in 28 cases (24%) and out by two stages in 6 cases (5%). Out of theses six cases, four were due to S34 when QPF was given in the range 11-25 mm as per the model but the realized rainfall is in the range 51-100 mm. This was due to heavy rains realized in Basin C and D on

TABLE 6

Result of verification of model with AAR during monsoon period of 2010

		Model Forecast						
		0	01-10	11-25	26-50	51-100	> 100	Total
Observed	0	0	0	2	0	0	0	2
	01-10	0	0	20	0	0	0	20
	11-25	0	0	72	1	0	0	73
	26-50	0	0	6	10	0	0	16
	51-100	0	0	4	1	0	0	5
	>100	0	0	0	0	0	0	0
	Total	0	0	104	12	0	0	116

No. of occasions when realized rainfall was (*i*) within the range : 82,
(*ii*) out by one range : 28
(*iii*) out by two range or more : 06

25th and 26th July, 2010 due to cyclonic circulations over North Gujarat Region extending up to mid tropospheric level and an activated offshore trough in association with the formation of low pressure in NW Bay on 24th July 2010. In the remaining two cases no rain was realized against a forecast of 11-25 mm. The cases out by one or two stage were due to variation in the intensity of the system especially upper air circulation (S3) over the basin. In 2010 no depression had formed and thus extreme rainfall events were not there and thus could not be verified.

5. Conclusions

(*i*) The synoptic analogue model is able to generate QPF 24 hrs in advance provided the synoptic conditions are picked up correctly from synoptic charts/Model analysis.

(*ii*) The frequency of occurrence of different systems is S3 > S2 > S1.

(*iii*) It was generally observed from the study, that most of the rainfall occurred over the basin due to following synoptic conditions:

(a) Rainfall in the category 11-25 mm was maximum due to upper air cyclonic circulation over Gujarat region & adjoining Rajasthan.

(b) Well marked low pressure or low pressure area over Northwest Madhya Pradesh & adjoining area with associated upper air cyclonic circulation extending upto mid-tropospheric level was mainly responsible for the rainfall in the category 26-50 & 51-100.

(c) Well marked low pressure areas which originated as depression/deep depression in NW Bay of Bengal and moved along the monsoon trough (NW'ly OR WNW'ly direction) were solely responsible for rainfall > 100 mm in the Sabarmati basin.

From the model it could be further concluded that QPF > 100 mm can be given for a particular sub-basin of Sabarmati under following situations.

(*i*) If a well marked low pressure area or low pressure area lies over Northwest Madhya Pradesh or Southeast Rajasthan and is followed by another low pressure area or depression in Bay of Bengal or adjoining Orissa, then due to the formation of an east-west trough, QPF > 100 mm can be issued for all sub-basins.

(*ii*) If a depression/deep depression formed over Bay of Bengal travels over the normal monsoon trough then it gives >100 mm rainfall over Sabarmati sub-basins A & B as soon as it approaches West Madhya Pradesh & adjoining.

(*iii*) If the depression/deep depression forms in Bay of Bengal & travels over Monsoon trough which is south of its normal position then as soon as it approaches south west Madhya Pradesh , sub-basin C & D also get >100 mm rainfall.

(*iv*) The sub-basin C & D also get >100 mm of rainfall due to interaction of the approaching low pressure in surface & eastward moving westerly trough at 500 hPa level.

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