551.509.324 : 551.577.37 : 556.51

# QUANTITATIVE PRECIPITATION FORECAST FOR MAHI BASIN BASED ON SYNOPTIC ANALOGUE METHOD

1. 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). Similar efforts have been made by others to issue QPF by synoptic analogue method, *viz.*, Ray and Sahu (1998), Ray and Patel (2000), Ram and Kaur (2004), Ali *et al*. (2011) over river catchments of Narmada, upper Yamuna river and lower Yamuna respectively. In the present paper efforts have been made to clarify the various synoptic systems & their locations which are accountable for the average areal Precipitation in range of 11-25, 26-50, 51-100 & above 100 mm during SW monsoon period in Mahi river catchment. After conducting the study for 10 years, results were drawn based on synoptic analogue method for issue of QPF of river Mahi Basin. Similar studies have been done by Singh *et.al*. (1995) for river Pun Pun in Patna and Lal *et al*. (1983) and Abbi *et al*. (1979) for river Gomti catchment & Bhagirathi catchment respectively.

2. River Mahi is one of the major west flowing interstate river of India draining in to Gulf of Cambay. The basin is bounded on the north & northwest by Aravalli Hills on the East by ridge separating it from the Chambal basin, on the South by the Vindhyas & on the west by Gulf of Cambay. The basin has a maximum width of about 250 km. The river Mahi originates on the Northern slope of Vindhyas near the village of Sardarpur in Dhar district of Madhya Pradesh at an elevation of 500 m above mean sea level. Its length is 583 km & it traverses through the state of M. P., Rajasthan & Gujarat. The river Mahi drains an area of 34,842 sq km. State wise distribution of drainage area is shown below:

| *Name of State* | *Drainage area* | *River length* | *% Area* |
|---|---|---|---|
| Madhya Pradesh | 6695 sq km | 167 km | 19.22 |
| Rajasthan | 16453 sq km | 174 km | 47.22 |
| Gujarat | 11694 sq km | 242 km | 33.56 |
| Total | 34842 sq km | 583 km | 100 % |


**Fig. 1(a).** Map showing rivers and dams of Mahi Basin

The basin is divided by CWC into two zones (*i*) Mahi Upper basin and (*ii*) Mahi Lower basin [Fig. 1(a)]. These are further divided for convenience into six sub catchments (A, B, C, D, E, F). The sub-basin A and C falls in N W Madhya Pradesh B and D in Rajasthan and are in Upper Basin, while sub-basin E and F fall in Gujarat state and are also in lower basin [Fig. 1(b)]. The average rainfall of the basin is 808 mm by the southwest (SW) monsoon which sets in by middle of June and withdraws by the last week of September. Sub-basin E gets the highest average rainfall of 935.3 mm followed by 871.4 mm in sub-basin A and 869.3 mm in sub-basin D. The seasonal monthly averages are shown in Table 1. Sub basins A and C get highest rainfall in July followed by August while all other sub-basins get highest rainfall in August followed by July.

3. The synoptic situations during southwest monsoon season based on 0000 UTC upper air and 0300 UTC surface charts were taken from Gujarat daily weather reports and India daily weather report (IDWR). Sub basin-wise Average Areal Precipitation (AAP) calculated daily during the period 15$^{th}$ June to 15$^{th}$ October has been utilized for the same period. The various synoptic systems responsible for >10 mm rainfalls 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 ≥ 11 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

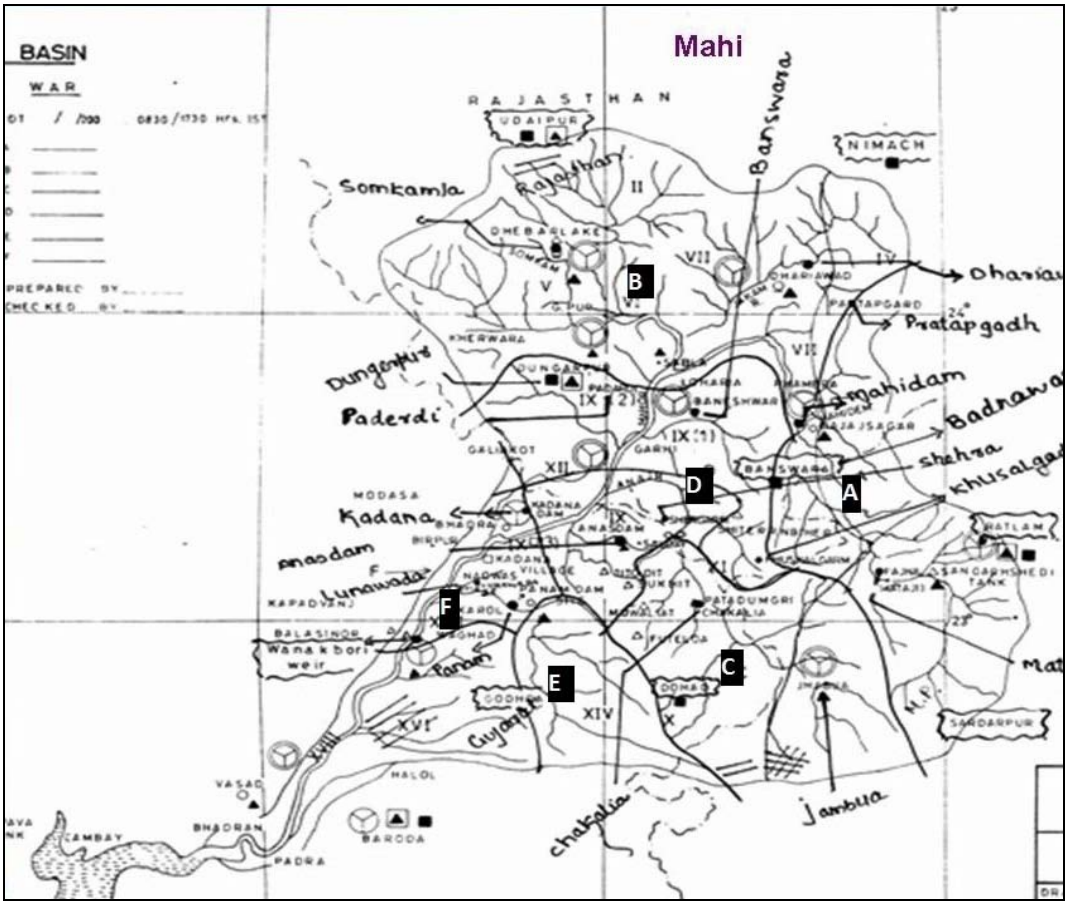


**Fig. 1(b).** Map showing sub-basins of Mahi Basin

**TABLE 1**

**Month wise average rainfall in (mm) for various sub-basins of Mahi**

| Mahi sub basins | Area (sq km) | Rainfall (mm) | | | | |
|---|---|---|---|---|---|---|
| | | June | July | August | Sept | Total |
| A | 6149 | 105.3 | 322.3 | 282.5 | 161.3 | 871.4 |
| B | 10098 | 94.5 | 265.9 | 274.3 | 107.4 | 742.1 |
| C | 4650 | 92.1 | 249.2 | 242.4 | 128.6 | 712.2 |
| D | 4623 | 104.1 | 310.2 | 328.2 | 126.7 | 869.3 |
| E | 2314 | 127.7 | 320.5 | 361.6 | 125.5 | 935.3 |
| F | 2831 | 85.2 | 260.5 | 277.6 | 99.3 | 722.5 |

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.

A total of 460 occasions of rainfall > 10 mm have been considered for the Mahi river basin, with each sub-basin having 72-87 instances of rainfall in same categories 11-25, 26-50, 51-100, >100 (Table 3.). It was found that maximum number of occasions of rainfall over the catchment are due to Low pressure/Well marked Low pressure area (65%) and out of these 92% cases are due to Low pressure/Well marked Low pressure over Madhya Pradesh. The next important synoptic situation is the Upper air cyclonic circulation (33%). The deep depression/depression contributes remaining 2%.

**TABLE 2**

**Instances of Average Areal Precipitation (AAP) more than 100 mm (sub-basin wise) during the period 2000-2009**

| S. No. | Date | Sub- basin | AAP | Synoptic condition | S. No. | Date | Sub basin | AAP | Synoptic condition |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 Aug 01 | E | 113.1 | DNA | 20 | 01 Aug 06 | B | 112.1 | S11 and S23 |
| 2 | 3 Sep 02 | C | 112.5 | S12 | 21 | 08 Aug 06 | E | 114.6 | S22, originated as DD on 2nd in NW Bay |
| | | | | | | | F | 258.3 | |
| 3 | 22 Jun 03 | E | 114.3 | S32 | 23 | 11 Aug 06 | A | 101.2 | S22 |
| | | | | | | | E | 101.3 | |
| 4 | 28 Jul 03 | A | 117.1 | | 25 | 12 Aug 06 | A | 115.5 | S11 and S23 |
| | | B | 101.6 | S11 and S33 | | | C | 121.8 | |
| | | C | 114.9 | | | | F | 161.1 | |
| | | D | 106.6 | | | | | | |
| 8 | 24 Aug 03 | F | 148.2 | | 28 | 19 Aug 06 | A | 139.3 | S12 and S24 |
| | | | | | | | B | 131.6 | |
| 9 | 06 Aug 04 | C | 103.8 | S22 and S34 | 30 | 07 Sep 06 | A | 157.6 | S22, originated as Depression in NW Bay on 3rd |
| | | F | 109.7 | | | | D | 171.1 | |
| | | | | | | | F | 123.2 | |
| 11 | 13 Aug 04 | D | 103.4 | S21 and S34 | 33 | 03 Jul 07 | F | 149.7 | S23, originated as DD |
| 12 | 28 Jul 05 | A | 227.5 | S22 | 34 | 09 Jul 07 | A | 221.8 | S11 |
| | | B | 180.8 | | | | B | 144.0 | |
| | | C | 144.1 | | | | D | 254.9 | |
| | | D | 161.3 | | | | F | 108.5 | |
| 16 | 22 Jul 06 | A | 226.7 | S22 | 38 | 09 Aug 07 | F | 106.6 | S22 |
| | | D | 128.4 | | | | D | 100.6 | |
| 18 | 29 Jul 06 | E | 101.2 | S22 | 40 | 29 Aug 09 | D | 121.5 | |
| | | F | 214.6 | | | | | | |

**TABLE 3**

**Frequency of occurrence of AAP equal to or more than 11 mm for various synoptic conditions and locations**

| Mahi Sub → Catch. | Frequency of occurrence of AAP in the Mahi sub-basin A in the range (mm) | | | | | Frequency of occurrence of AAP in the Mahi sub-basin B in the range (mm) | | | | | Frequency of occurrence of AAP in the Mahi sub-basin C in the range (mm) | | | | | Frequency of occurrence of AAP in the Mahi sub-basin D in the range (mm) | | | | | Frequency of occurrence of AAP in the Mahi sub-basin E in the range (mm) | | | | | Frequency of occurrence of AAP in the Mahi sub-basin F in the range (mm) | | | | | G.T. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Syn. Cond. ↓ | 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 | 11-25 | 26-50 | 51-100 | >100 | Total | 11-25 | 26-50 | 51-100 | >100 | Total | |
| S 11 | 2 | 0 | 2 | 2 | 6 | 2 | 0 | 0 | 2 | 4 | 3 | 2 | 1 | 2 | 8 | 2 | 1 | 1 | 1 | 5 | 3 | 0 | 0 | 0 | 3 | 3 | 0 | 1 | 1 | 5 | 31 |
| S12 | 1 | 2 | 1 | 1 | 5 | 2 | 1 | 0 | 1 | 4 | 2 | 1 | 0 | 0 | 3 | 1 | 2 | 1 | 0 | 4 | 2 | 1 | 0 | 0 | 3 | 2 | 1 | 2 | 0 | 5 | 24 |
| S13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | **3** | **2** | **3** | 3 | 11 | 4 | 1 | 0 | 3 | 8 | 5 | 3 | 1 | 2 | 11 | 3 | 3 | 2 | 1 | 9 | 5 | 1 | 0 | 0 | 6 | 5 | 1 | 3 | 1 | 10 | 55 |
| S 21 | 7 | 15 | 4 | 0 | 26 | 8 | 11 | 2 | 0 | 21 | 7 | 12 | 4 | 1 | 24 | 5 | 10 | 5 | 1 | 21 | 7 | 10 | 4 | 2 | 23 | 9 | 8 | 2 | 3 | 22 | 137 |
| S22 | 8 | 13 | 3 | 3 | 27 | 4 | 14 | 5 | 2 | 25 | 9 | 9 | 3 | 2 | 23 | 3 | 9 | 7 | 2 | 21 | 5 | 8 | 11 | 2 | 26 | 6 | 4 | 4 | 4 | 18 | 140 |
| S23 | 1 | 0 | 0 | 1 | 2 | 2 | 0 | 1 | 0 | 3 | 1 | 2 | 0 | 1 | 4 | 2 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 0 | 2 | 0 | 3 | 0 | 1 | 4 | 17 |
| S24 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 3 | 7 |
| Total | 17 | 28 | 7 | 4 | 56 | 14 | 26 | 8 | 2 | 50 | 18 | 23 | 7 | 4 | 52 | 10 | 20 | 12 | 3 | 45 | 12 | 19 | 16 | 4 | 51 | 16 | 17 | 6 | 8 | 47 | 301 |
| S 31 | 1 | 2 | 1 | 0 | 4 | 1 | 1 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 3 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 13 |
| S32 | 1 | 4 | 4 | 1 | 10 | 2 | 5 | 4 | 0 | 11 | 5 | 0 | 2 | 0 | 7 | 3 | 5 | 0 | 2 | 10 | 6 | 0 | 2 | 0 | 8 | 5 | 2 | 2 | 0 | 9 | 55 |
| S33 | 1 | 3 | 0 | 0 | 4 | 1 | 1 | 1 | 0 | 3 | 2 | 0 | 1 | 0 | 3 | 1 | 1 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 2 | 1 | 1 | 0 | 0 | 2 | 16 |
| S34 | 2 | 0 | 0 | 0 | 2 | 1 | 2 | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 0 | 3 | 2 | 1 | 0 | 0 | 3 | 3 | 1 | 3 | 0 | 7 | 20 |
| Total | 5 | 9 | 5 | 1 | 69 | 5 | 9 | 5 | 0 | 19 | 10 | 1 | 3 | 0 | 14 | 7 | 8 | 1 | 2 | 18 | 10 | 1 | 3 | 1 | 15 | 9 | 4 | 5 | 0 | 18 | 153 |
| GT | 25 | 39 | 15 | 8 | 87 | 23 | 36 | 13 | 5 | 77 | 33 | 27 | 11 | 6 | 77 | 20 | 31 | 15 | 6 | 72 | 27 | 21 | 19 | 5 | 72 | 30 | 22 | 14 | 9 | 75 | 460 |

**TABLE 4**

**Result of verification of model with AAP during monsoon period of 2010**

| Month | Mahi Basin | | | Total |
|---|---|---|---|---|
| | Within the range | Out by one range | Out by two or more range | |
| Jun | 130 | 0 | 8 | 138 |
| Jul | 94 | 67 | 25 | 186 |
| Aug | 132 | 47 | 7 | 186 |
| Sep | 138 | 35 | 7 | 180 |
| Oct | 84 | 0 | 0 | 84 |
| Seasonal | 578 (74%) | 149 (19%) | 47 (7%) | 774 |

Mahi basin

| Observed range (mm) \ Forecast range in mm | 0 | 01-10 | 11-25 | 26-50 | 51-100 | >100 | Total |
|---|---|---|---|---|---|---|---|
| 0 | 367 | 58 | 17 | 1 | 0 | 0 | 443 |
| 01-10 | 25 | 153 | 26 | 12 | 0 | 0 | 216 |
| 11-25 | 10 | 17 | 44 | 18 | 0 | 0 | 89 |
| 26-50 | 4 | 2 | 5 | 14 | 0 | 0 | 25 |
| 51-100 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| >100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **406** | **230** | **93** | **45** | **0** | **0** | **774** |

PC = 74.68

| | | | | | |
|---|---|---|---|---|---|
| CSI = | 0.76 | 0.52 | 0.32 | 0.25 | 0.00 |

HSS = 0.58

It was seen that rainfall in all the categories was maximum due to Low pressure/Well marked Low pressure area. Cases of rainfall in the category 51-100 mm and in the category >100 are 75% and 92% respectively, due to depression/deep depression or well marked low pressure/low pressure areas over East Madhya Pradesh and adjoining and West Madhya Pradesh and adjoining.

Table 2 gives instances of Average Areal Precipitation (AAP) more than 100 mm (Sub basin wise) during the period 2000-2009. The years which had maximum instances of >100 mm rainfall (2005, 2006, 2007) were also the years with highest number of depression/deep depressions (5, 8, 5 respectively).

4. QPF was issued daily for all sub-basins in the year 2010 based on above method and were verified with the AAP realized for Mahi River (Table 4) and it was found that out of 774 total cases, QPF was correct for 578 cases (74%), out by one stage in 149 cases (19%) and out by two stages in 47 cases (7%). The cases out by one or two stage were due to variation in the intensity of the various systems and sometimes due to interaction with mid-tropospheric westerly trough, moving from west to east. In 2010 no depression had formed and thus extreme rainfall events were not there and thus could not be verified.

5. The synoptic analogue method is able to generate QPF 24 hrs in advance provided the synoptic conditions are picked up correctly from synoptic charts/model analysis. The frequency of occurrence of different systems is S2 > S3 > S1. It was generally observed from the study, that most of the rainfall occurred over the basin due to following synoptic conditions:

5.1. Rainfall in the category 11-25 mm was maximum due to well marked low pressure or low pressure area over East Madhya Pradesh and adjoining area and also due to upper air cyclonic circulation over Madhya Pradesh.

5.2. Rainfall in the category 26-50 & 51-100 mm was maximum due to well marked low pressure or low pressure area over Madhya Pradesh & adjoining area with associated upper air cyclonic circulation extending upto mid-tropospheric level.

5.3. Rainfall in the category more than 100 mm was mainly due to well marked low pressure areas which originated as Depression/Deep Depression in NW Bay of Bengal and moved along the monsoon trough (Northwesterly or west northwesterly direction). From the analysis it could be further concluded that QPF > 100 mm can be given for a particular sub basin of Mahi under following situations.

5.3.1. If a depression/deep depression lies over central Madhya Pradesh.

5.3.2. If a well marked low pressure or low pressure area lies over Madhya Pradesh and is followed by another low pressure area or Depression in Bay of Bengal or adjoining Odisha.

5.3.3. If a depression/deep depression formed over Bay of Bengal travels over the normal monsoon trough then it gives > 100 mm rainfall over Mahi sub-basins A & C, D as soon as it approaches West Madhya Pradesh.

5.3.4. If the depression/deep depression forms in Bay of Bengal & travels over monsoon trough which is south of its normal position then sub basin E and F get > 100 mm rainfall.

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