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Quantitative precipitation forecast for the Godavari basin using the synoptic analogue method

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सार – **वर्तमान अध्ययन में, हमने वर्ष** 2012-2019 **के लिए सिनॉप्टिक एनालॉग विधि का उपयोग करके गोदावरी नदी-जलग्रहण क्षेत्र के प्रत्येक उप-जलग्रहण क्षेत्र में वर्षा की घटना की आवृत्ति का आकलन किया है। क्षेत्रीय औसत वर्षा** (AAP) **की आवृत्ति का उपयोग करते हुए, मॉडल को वर्ष** 2020 **की सिनॉप्टिक स्थितियों के** AAP **के लिए सत्यापित किया गया है। मॉडल ने** 2020 **के मॉनसून ऋतु के लिए** 62% **सही प्रेक्षण दिया है और यह** 50-100 **और** >100 **परिघटनाओं के लिए** 90% **सही अनुमान दिया है।** AAP **की परिघटनाओं की आवृत्ति का उपयोग करते हुए, हमने उप-बेसिन में होने वाली सिनॉप्टिक परिघटनाओं की प्रतिशत संभाव्यता का आकलन किया है। यह मॉडल क्षेत्र की सिनॉप्टिक स्थितियों की जानकारी प्रदान करने के लिए आम तौर पर** 24 **घंटे से पहले मात्रात्मक वर्षा पूर्वानुमान देने के लिए सटीक होता है जिससे बाढ़ पूर्वानुमानकर्ताओं को** 48 **घंटे पूर्व का पूर्वानुमान देने और अंतिम उपयोगकर्ताओं जैसे केंद्रीय जल आयोग और आपदा प्रबंधन प्राधिकरणों के लिए यह बहुत उपयोगी साबित होता है।**

ABSTRACT. In the present study, we have constructed a frequency of occurrence of rainfall over each sub-catchment of the Godavari river catchment using the synoptic analogue method for the years 2012-2019. Using the frequency of the Areal Average Precipitation (AAP), the model is verified for the AAP of the synoptic situations for the year 2020. The model has observed a 62% correct for the monsoon season 2020 and it gives a 90% correct for 50-100 and >100 AAP events. Using the frequency of the AAP events, we have constructed the percentage probability of the AAP of the synoptic events which occur over the sub-basin. This model is generally accurate for the generation of QPF before the 24hr when providing the synoptic conditions over the region, which will be very helpful to facilitate the 48hr forecast to the flood forecasters and end-users like the central water commission and disaster management authorities.

Key words – Quantitative precipitation, Rainfall, Synoptic situation.

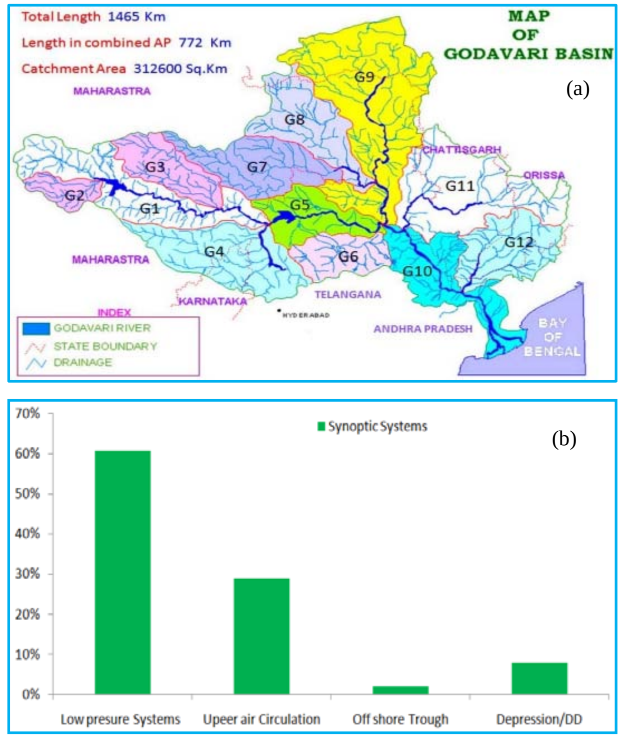
1. Introduction

The synoptic analogue method is one of the helpful tools for issuing the QPF (Quantitative Precipitation Forecast) over a sub-basin in the River Basin. It is based on synoptic systems and their locations, which are responsible for rainfall over the river basins. This method is based on how the weather behaves in such a way that the present initial conditions, if found to be similar to a past situation, will evolve similarly and it is easy to find good analogues over a small area (Roebber and Bosart, 1998). Several scientists have been studied by others to issue QPF (Quantitative Precipitation Forecast) by synoptic analogue method, *viz*., Singh *et al*. (1995), Ray and Sahu (1998), Ray and Patel (2000), Ram and Kaur (2004), Ali *et al*. (2011), Kamaljit Ray *et al*. (2012) over the river catchments of Narmada, upper Yamuna, Mahi and lower Yamuna, respectively. In the present study, we construct the frequency of occurrence table of heavy rainfall where the areal average precipitation (AAP) is more than 11-25, 26-50, 51-100 and above 100 mm during the Southwest monsoon period of the Godavari River Catchment and the probability of occurrence due to the synoptic systems over the Godavari River Basin for the years from 2012-2019 (Hydromet Manual, 2010). After constructing the frequency and probability of occurrence of rainfall events for the next 8 years based on the analogue method, the QPF for the Godavari catchment for the year 2020 was issued. The verification results are also presented here.

The Godavari is India's second-longest river after the Ganga. It has its source in Triambakeshwar, Maharashtra. It starts in Maharashtra and flows east for 1,465 kilometers (910 mi), emptying into the Bay of Bengal (Fig. 1). The basin lies in the Deccan plateau and is situated between latitude 16°16'00" North and 22°36' 00" North and longitude 73°26'00" East and 83°07'00" East. The Godavari river basins receive maximum rainfall in the south-west monsoon season. The monsoon current strikes the west coast of the peninsula from the west of the Sahyadri rage, the barrier ranging from 600m to 2100m in height. While crossing the barrier, the monsoon current deposits all moisture on the windward side of the Konkan, a small portion of Madhya Maharashtra, *i.e.*, the Upper Godavari sub-basin. The monsoon current follows the eastward slope of the country from the crest of the Western Ghats, so conditions in the interior basin of maximum heavy rainfall are associated with depressions and low-pressure systems forming in the Bay of Bengal and Arabian Sea. January and February are dry seasons; they receive a maximum of 15 mm of rainfall. The pre-monsoon and post-monsoon receive 20-50 mm of rain due to the thunderstorms and the cyclone forming in the Bay of Bengal. A maximum of 600-1200m of rainfall is received in the monsoon season. The river Godavari spreads in the states of Maharashtra (152199 sq km) (48.6%), Andhra Pradesh & Telangana (73201 sq km) (23.4%), Madhya Pradesh (65255 sq km) (10.0%), Chhattisgarh (10.9%), Odisha (17752 sq km) (5.7%) and Karnataka (4405 sq km) (1.4%), and Pondicherry (Yanam) through its extensive network of tributaries.

2. Data and methodology

According to the CWC, the Godavari River basin is divided into three sections: (*i*) Upper Godavari Division, (*ii*) Wainganga Division; and (*iii*) Lower Godavari Division. These are further subdivided into the 12 sub-catchments (G1-G12) shown in Fig. 1(a). The average annual rainfall in the Godavari River basin ranges from 850 to 1200 mm. The months of June-September have seen the most rainfall (650-1100 mm), accounting for 80% of the total (monsoon season). The monsoon season, followed by the post-monsoon season, produces 10% of the annual rainfall with a range of 91-160mm in the pre-monsoon season, that is from March to May, and 4% (20-80mm) of the annual rainfall in the winter (Jan-Feb) season (Sravani *et al.*, 2021). As a result, the monsoon season is the predominant flood season in the Godavari River Basin. The Flood Met Centre in Hyderabad collects point-by-point rainfall data and generates the Areal Average Precipitation for the monsoon season. We obtained the AAP data for this analysis from the FMO Hyderabad. The synoptic conditions were derived from



Figs. 1(a&b). (a) Map of Godavari Basin and (b) Major Synoptic Systems in Godavari Basin

the Meteorological Centre Hyderabad's daily weather reports at 0000 UTC for upper air charts and at 0003 UTC for surface charts. AAP should indeed be computed daily for each sub-basin based on the previous day's synoptic conditions. Areal Average Precipitation (AAP) in the ranges of 11-25, 26-50, 51-100 and > 100 mm during the South West monsoon season over a specific sub-basin.

3. Methodology

There are three primary rain-bearing synoptic systems in the Godavari river basin region [Fig. 1(b)], which are:

(*i*) Deep Depressions & Depressions

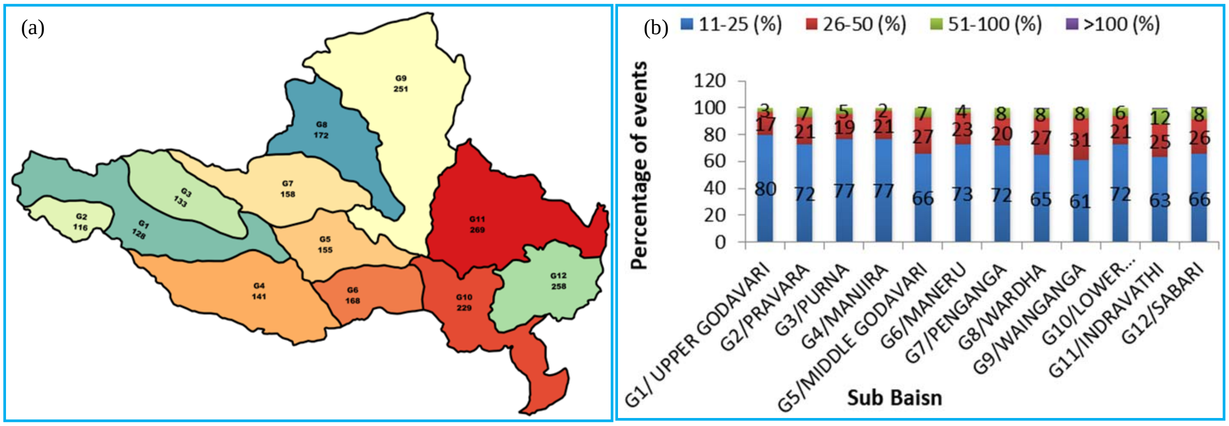
(*ii*) Well-Marked low pressures/Low Pressures

(*iii*) Troughs/Upper Air Circulations/Offshore Troughs

The Godavari River Basin covers a vast area and consists of 12 sub-basins. The catchments are there and those cover the subdivisions like:

(*i*) Madhya Maharashtra

(*ii*) Marathwada



Figs. 2(a&b). Shows the (a) Total no. of Rainfall Events and (b) percentage of Events of various rainfall range categories over the Godavari basin

(*iii*) North Interior Karnataka

(*iv*) Vidarbha

(*v*) Chhattisgarh

(*vi*) Telangana

(*vii*) Coastal Andhra Pradesh

(*viii*) A few parts of Odisha

(*ix*) Some parts of East Madhya Pradesh

The Godavari basin, with its twelve sub-catchments, a total of 9 subdivisions, was classified into three different places in terms of the creation and migration of the synoptic systems across the area:

(*i*) Marathwada, Madhya Maharashtra, North Interior Karnataka and adjoining areas.

(*ii*) East Madhya Pradesh, Vidharbha, Telangana and adjoining areas.

(*iii*) Chhattisgarh, Odisha, Coastal Andhra Pradesh and adjoining areas.

We developed the following matrix format in which the synoptic systems flow through the areas/regions of the sub catchments. The Matrix is in the form of Sij and it contains information on the type and area/location of the synoptic system over the sub catchments.

Sij Matrix form where, I = Synoptic Situation Category (1, 2, or 3...) J = Synoptic System over Area/Location (1, 2, 3...).

S11 : Depressions and Deep Depressions over Marathwada, Madhya Maharashtra, North Interior Karnataka and adjoining areas.

S12 : Depressions & Deep Depressions over East Madhyapradesh, Vidharbha, Telangana and adjoining areas.

S13 : Depressions and Deep Depressions over Chhattisgarh, Odisha, Coastal Andhra Pradesh and adjoining areas.

S21 : Low pressures and well-marked low pressures over Marathwada, Madhya Maharashtra, North Interior Karnataka and adjoining areas.

S22 : Low pressures and well-marked low pressures over East Madhyapradesh, Vidharbha, Telangana and adjoining areas.

S23 : Low pressure & well-marked Low pressure over Chhattisgarh, Odisha, Coastal Andhra Pradesh and adjoining areas.

S31 : Upper Air Cyclonic Circulations over Marathwada, Madhya Maharashtra, North Interior Karnataka and adjoining areas.

S32 : Upper Air Cyclonic Circulations over East Madhyapradesh, Vidharbha, Telangana and adjoining areas.

S33 : Upper Air Cyclonic Circulations over Chhattisgarh, Odisha, Coastal Andhra Pradesh and adjoining areas.

A frequency table has been prepared using the afore mentioned Matrix Format, the AAP values gathered

TABLE 1 (a)

Frequency table of occurrence of AAP in different ranges for various synoptic conditions and locations for the upper Godavari division (G1, G2, G3 and G4)

Godavari Basin	Frequency of occurrence of AAP in the G1 Basin					Frequency of occurrence of AAP in the G2 Basin					Frequency of occurrence of AAP in the G3 Basin					Frequency of occurrence of AAP in the G4 Basin				
Synop. Condition	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	13	4	1	0	18	16	3	2	0	21	15	4	2	0	21	7	1	0	0	8
S12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	4
S13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tot	13	4	1	0	18	16	3	2	0	21	15	4	2	0	21	11	1	0	0	12
S21	45	12	2	0	59	31	6	4	0	41	42	11	3	0	56	29	13	3	0	45
S22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	4	0	0	17
S23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tot	45	12	2	0	59	31	6	4	0	41	42	11	3	0	56	42	17	3	0	62
S31	44	6	1	0	51	37	15	2	0	54	45	10	1	0	56	42	12	0	0	54
S32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	13
S33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tot	44	6	1	0	51	37	15	2	0	54	45	10	1	0	56	55	12	0	0	67
G tot	102	22	4	0	128	84	24	8	0	116	102	25	6	0	133	108	30	3	0	141

TABLE 1 (b)

Frequency table of occurrence of AAP in different ranges for various synoptic conditions and locations for the middle Godavari division (G5, G6, G7 and G8)

Godavari Basin	Frequency of occurrence of AAP in the G5 Basin					Frequency of occurrence of AAP in the G6 Basin					Frequency of occurrence of AAP in the G7 Basin					Frequency of occurrence of AAP in the G8 Basin				
Synop. Condition	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
S12	2	3	0	0	5	12	5	2	0	19	14	7	5	0	26	19	6	7	0	32
S13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tot	2	3	0	0	5	12	5	2	0	19	14	7	5	0	26	19	6	7	1	33
S21	0	2	0	0	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
S22	47	19	10	0	76	59	20	4	0	83	48	14	8	0	70	45	27	6	0	78
S23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tot	47	21	10	0	78	59	20	4	1	84	48	14	8	0	70	45	27	6	0	78
S31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S32	53	18	1	0	72	51	14	0	0	65	51	11	0	0	62	48	13	0	0	61
S33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tot	53	18	1	0	72	51	14	0	0	65	51	11	0	0	62	48	13	0	0	61
G tot	102	42	11	0	155	122	39	6	1	168	113	32	13	0	158	112	46	13	1	172

TABLE 1 (c)

Frequency table of occurrence of AAP in different ranges for various synoptic conditions and locations for the middle Godavari division (G9, G10, G11 and G12)

Godavari Basin	Frequency of occurrence of AAP in the G9 Basin					Frequency of occurrence of AAP in the G10 Basin					Frequency of occurrence of AAP in the G11 Basin					Frequency of occurrence of AAP in the G12 Basin				
Synop. Condition	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S12	17	16	7	0	40	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0
S13	1	2	0	0	3	19	6	5	0	30	15	9	10	1	35	22	6	7	1	36
tot	18	18	7	0	43	21	6	5	0	32	15	9	10	1	35	22	6	7	1	36
S21	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
S22	62	30	11	0	103	3	0	1	0	4	0	0	1	0	1	0	0	1	0	1
S23	13	6	1	0	20	83	26	6	0	115	82	46	16	0	144	71	42	10	0	123
tot	75	36	12	0	123	86	26	7	0	119	82	46	17	1	146	71	42	11	0	124
S31	0	0	0	0	0	0	0	0	0	0	0	0	0	116	116	0	0	0	0	0
S32	53	21	0	0	74	4	0	0	0	4	0	0	0	0	0	0	0	0	0	0
S33	7	3	1	0	11	55	17	2	0	74	72	8	4	0	84	76	19	3	0	98
tot	60	24	1	0	85	59	17	2	0	78	72	8	4	116	200	76	19	3	0	98
tot	153	78	20	0	251	166	49	14	0	229	169	63	31	118	381	169	67	21	1	258

from the FMO Hyderabad and when the synoptic systems are in the Sij regions/areas.

Using the frequency table, we calculated the probability of rainfall in various ranges over a specific sub-basin for each Sij.

$$\text{Probablity of Sij} = \frac{\text{Total frequenccy of particular AAP category over a particular sub-basin}}{\text{Total number of all category over a particular sub-basin}}$$

AAP on a specific day in a specific sub-basin can be categorized based on the previous day's synoptic conditions.

4. Results and discussion

Fig. 2 depicts the Godavari basin's (a) total number of rainfall events and (b) percentage of occurrences in various rainfall range groups. According to the chart, there were 2178 occurrences where AAP was larger than 10 mm for the stated synoptic circumstances (S1, S2 and S3) in the entire Godavari river basin from 2012 to 2019. Nearly 1500 AAP events are in the 11-25 range (70%), 500 events are in the 26-50 range (23 %), and 51-100 (7%), with events in the 51-100 range (7%).

The Godavari River basin is considered to be divided into the following three sections:

(*i*) Upper Godavari (source to the confluence with Manjira)

(*ii*) Wainganga (between the confluence of Manjira and Pranahita)

(*iii*) Lower Godavari (Pranahita confluence to the mouth of the sea)

Because the Godavari catchment region is so extensive, over 1465 km of it is shared by Maharashtra, Telangana, Andhra Pradesh, Odisha and Karnataka. So, in addition to a comprehensive sub-catchment study, synoptic analysis is necessary to understand and forecast the QPF over the river basin. Tables 1(a-c) show the synoptic analogue model frequency table of the occurrence of AAP in various ranges for various synoptic circumstances and locations. Upper Godavari, Pravara and Purna are sub-catchments of the upper Godavari division, which mostly encompasses the Madhya Maharashtra and Marathwada subdivisions. The maximum instances of rainfall occur in these sub-catchments due to low pressure and well-marked low pressure (45%) over the Madhya Maharashtra and Marathwada regions. The other important synoptic

TABLE 2

This show the AAP is greater than 75mm (sub-basin wise) during the period 2012-2019

S. No.	Date	Sub-Basin	AAP (mm)	Synoptic situation	S.NO2	Date3	Sub Basin4	AAP (mm)5	Synoptic situation6
1.	Aug19,2012	Indravathi (G11)	71.3	S23	29	Sep18,2015	Wardha (G8)	80.7	S12
2.	Sep05,2012	Wardha (G8)	86.3	S22	30	Jun 30, 2016	Lower Godavari (G10)	79.9	S13
3.	Sep05,2012	Wainganga (G9)	82.3	S22	31	Jul 09, 2016	Wardha (G8)	90.7	S12
4.	Jun,2013	Indravathi (G11)	99.8	S23	32	Jul 10, 2016	Indravathi (G11)	83.1	S23
5.	Jun,2013	Middle Godavari (G5)	88.4	S22	33	Jul 12, 2016	Penganga (G7)	75.9	S22
6.	Jun,2013	Penganga (G7)	83.9	S22	34	Sep24,2016	Manjira (G4)	99.3	S21
7.	Jun,2013	Wainganga (G9)	74.8	S22	35	Sep24,2016	Middle Godavari (G5)	97.1	S22
8.	Jul,2013	Maneru (G6)	135.6	S22	36	Jul 18, 2017	Indravathi (G11)	77.9	S13
9.	Jul,2013	Penganga (G7)	75.6	S22	37	Jul19,2017	Indravathi (G11)	112.4	S23
10.	Jul,2013	Wainganga (G9)	74.7	S12	38	Aug20,2017	Manjira (G4)	95.1	S21
11.	Aug,2013	Penganga (G7)	76.6	S12	39	Aug21,2017	Pravara (G2)	98.0	S21
12.	Jul 21, 2014	Indravathi (G11)	74.9	S23	40	Jul 21, 2018	Sabari (G12)	88.5	S13
13.	Jul 23, 2014	Wardha (G8)	101.5	S12	41	Aug12,2018	Middle Godavari (G5)	89.9	S22
14.	Jul 23, 2014	Wainganga (G9)	99.8	S12	42	Aug12,2018	Lower Godavari (G10)	75.9	S33
15.	Sep07,2014	Indravathi (G11)	117.7	S23	43	Aug16,2018	Indravathi (G11)	107.0	S13
16.	Oct13,2014	Sabari (G12)	170.0	Cyclonic Storm Hudud	44	Aug16,2018	Sabari (G12)	87.5	S23
17.	Jun 20, 2015	Lower Godavari (G10)	81.8	S13	45	Aug17,2018	Purna (G3)	121.6	S11
18.	Jun20,2015	Sabari (G12)	81.1	S13	46	Aug17,2018	Penganga (G7)	80.7	S12
19.	Jun 21, 2015	Lower Godavari (G10)	87.0	S13	47	Aug20,2018	Lower Godavari (G10)	84.6	S23
20.	Jun21,2015	Indravathi (G11)	114.9	S13	48	Aug21,2018	Wainganga (G9)	94.9	S22
21.	Jun 21, 2015	Sabari (G12)	97.4	S13	49	Sep12,2018	Sabari (G12)	130.7	S13
22.	Aug5,2015	Penganga (G7)	77.1	S12	50	Jul 29, 2019	Indravathi (G11)	94.1	S33
23.	Aug5,2015	Wardha (G8)	99.9	S12	51	Jul 29, 2019	Sabari (G12)	90.4	S33
24.	Sep15,2015	Sabari (G12)	75.2	S23	52	Aug02,2019	Lower Godavari (G10)	78.3	S33
25.	Sep16,2015	Indravathi (G11)	80.0	S23	53	Aug03,2019	Indravathi (G11)	77.4	S33
26.	Sep16,2015	Sabari (G12)	85.7	S23	54	Aug07,2019	Indravathi (G11)	86.1	S13
27.	Sep18,2015	Purna (G3)	83.6	S11	55	Aug07,2019	Sabari (G12)	103.7	S13
28.	Sep18,2015	Penganga (G7)	97.4	S12	56	Aug08,2019	Indravathi (G11)	94.6	S13

conditions are the upper air cyclonic circulation and offshore trough. Approximately 37% of occasions of rainfall occur due to the formation of the upper cyclonic circulation forms over the Madhya Maharashtra and Marathwada regions. Approximately 14% of the rainfall occurs due to the movements of the offshore trough towards the Maharashtra coast region. 4% of the total cases of AAP due to depressions/deep depressions and cyclones in the Arabian Sea are 4% [Table 1(a)]. The sub-catchments of Manjira, Middle Godavari, Maneru, Penganga, Wardha and Wainganga are covered by the Marathwada, East Madhya Pradesh, Vidarbha and Telangana regions. The Wainganga/Pranahitha (G9) is the

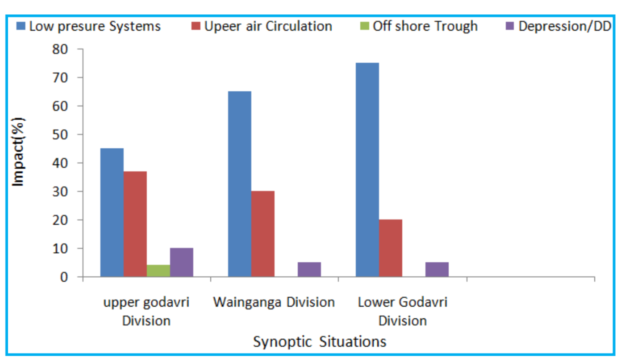


Fig. 3. Depicts the percentage of the synoptic system's influence on each of the three divisions

TABLE 3 (a&b)

Results of verification of the model for the monsoon season 2020

(a)

Month	Godavari Basin			Total
	Within the range	Out by one range	Out by two or more range	
June	212	132	15	359
July	234	126	12	372
August	236	124	12	372
September	217	131	13	360
Seasonal(Jun-Sep)	899	513	52	1463

(b)

Skill Score	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD)	0.11	0.68	0.51	0.37	0.48	--
Missing Rate (MR)	0.89	0.32	0.49	0.63	0.52	--
False alarm rate (FAR)	0.5	0.22	0.63	0.73	0.33	--
Hit rate (HR)	0.95	0.69	0.67	0.89	0.98	1
Correct Non-Occurrence	0.99	0.69	0.72	0.92	0.99	1
Critical Success Index (CSI)	0.1	0.57	0.27	0.18	0.38	--
	95	69	67	89	98	100
Heidke Skill Score (HSS)	0.17	0.36	0.21	0.25	0.54	--

largest sub-catchment that covers all three regions. The maximum instances of AAP occur due to the well-marked low pressure and low pressure over the regions. Approximately 65% of the rainfall occurs due to the passage of low pressure over the regions. Out of that 55% of rainfall activity in the category, 26-50 occur over the catchments of Manjira, Maneru, Middle Godavari, Wainganga and the passage of LOPAR/WML over the Telangana region. Nearly 30% of the intense rainfall occurs over the catchments of Wardha, Waingang/ Pranahitha and Penganga due to the passage of the WML/LOPAR over the regions of Vidarbha and East Madhya Pradesh. Another important synoptic system is the upper air circulation and shear zone over the region. There is 30% rainfall activity over the sub-catchments due to the monsoon trough and upper air circulation and shear zone. 5% of the rainfall activity over this sub-catchment was due to the depression that passed over the region. The catchments of lower Godavari, Sabari and Indrvati are under the lower Godavari division, which mainly covers the parts of Telangana, Chhattisgarh, Odisha and coastal Andhra Pradesh subdivisions. The development or crossing of WML/LOPAR over the coastal Odisha and coastal Andhra Pradesh subdivisions is responsible for the

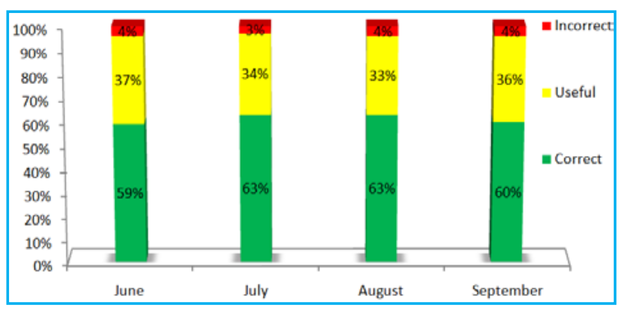


Fig. 4. Results of verification of the model for the monsoon season 2020

major synoptic conditions for the maximum occasions (75%) of rainfall that occur in sub-catchments of G10, G11 and G12. The majority of AAP instances in categories 51-100 and >100 are caused by depression/deep depression and well-marked low pressure over the coastal Odisha and coastal Andhra Pradesh subdivisions [Table 1(c)]. The largest number of occurrences when >11 mm of rainfall happened over the river watershed was due to trough and upper air cyclonic circulation over the region and the maximum number of instances when > 25 mm of rainfall occurred owing to the

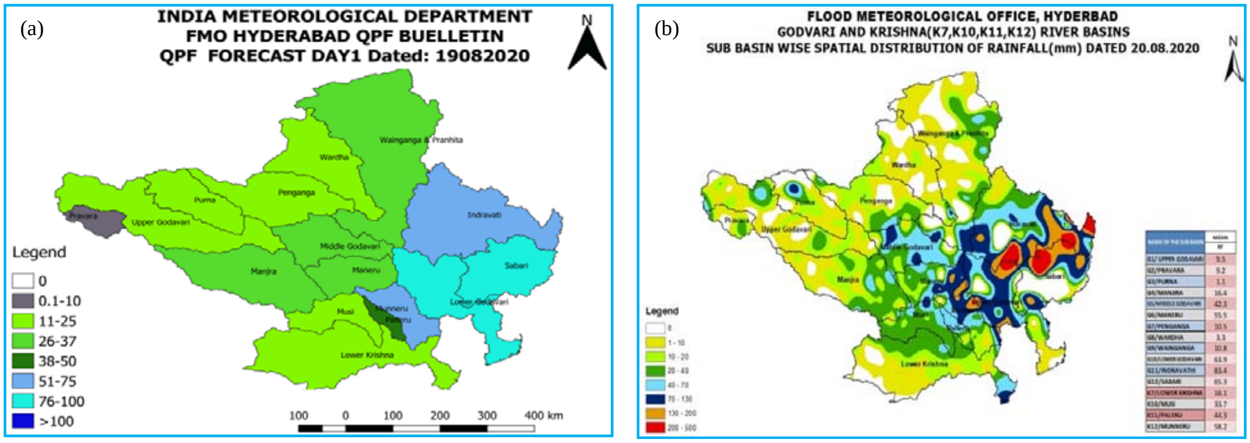
TABLE 4

Probability of the occurrence of the AAP of different ranges of Godavari river basin

Y2012 - 2019	G1				G2				G3				G4				G5				G6			
	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100
S11	25-50	5-25	0-5	0-5	76-100	5-25	5-25	0-5	50-75	5-25	5-25	0-5	50-75	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S12	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	25-50	0-5	0-5	0-5	25-50	50-75	0-5	0-5	50-75	25-50	5-25	0-5
S13	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S21	76-100	5-25	0-5	0-5	76-100	5-25	5-25	0-5	50-75	5-25	5-25	0-5	25-50	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S22	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	5-25	5-25	0-5	0-5	50-75	5-25	5-25	0-5	50-75	5-25	0-5	0-5
S23	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S31	76-100	5-25	0-5	0-5	50-75	25-50	0-5	0-5	76-100	5-25	0-5	0-5	50-75	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S32	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	5-25	0-5	0-5	0-5	50-75	5-25	0-5	0-5	76-100	5-25	0-5	0-5
S33	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5

Y2012 - 2019	G7				G8				G9				G10				G11				G12			
	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100	11-25	26-50	51-100	>100
S11	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S12	50-75	25-50	5-25	0-5	50-75	5-25	5-25	0-5	25-50	25-50	5-25	0-5	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S13	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	50-75	5-25	5-25	0-5	25-50	25-50	25-50	0-5	50-75	5-25	5-25	0-5
S21	50-75	5-25	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S22	0-5	0-5	0-5	0-5	50-75	25-50	5-25	0-5	50-75	5-25	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S23	50-75	5-25	5-25	0-5	0-5	0-5	0-5	0-5	5-25	0-5	0-5	0-5	50-75	5-25	5-25	0-5	50-75	25-50	5-25	0-5	50-75	25-50	5-25	0-5
S31	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	50-75	0-5	0-5	0-5	0-5
S32	76-100	5-25	0-5	0-5	76-100	5-25	0-5	0-5	50-75	5-25	0-5	0-5	5-25	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
S33	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	5-25	0-5	0-5	0-5	50-75	5-25	0-5	0-5	25-50	0-5	0-5	0-5	76-100	5-25	0-5	0-5

passage of low pressure over the region. The rainfall was highest in all catchments. Fig. 3 depicts the synoptic system's influence on each of the three divisions as a percentage. Low pressure and WML pressure systems dominate over upper air cyclonic circulations, troughs and depressions. Depressions are infrequent, but their impact is significant. It causes flooding and disasters. Table 2 shows the occurrences of AAP larger than 75mm



Figs. 5(a&b). Shows the spatial distribution maps of the comparison between the forecast QPF and observational QPF using the synoptic analogue model

(sub-basin per sub-basin) from 2012 to 2019. The greatest incidence of AAP was greater than 75 mm in 2018, 2015 and 2018 (the years 2015 and 2018 having the highest numbers and the year 2018 having the highest instances of AAP > 100 compared to the other years). The daily issued QPF for all sub-basins in the Godavari basin in the year 2020 with this synoptic analogue method has been verified with the realized AAP for the Godavari basin [Tables 4(a&b)]. It was discovered that the model observed that out of 1463 cases, 899 (62 %) were correct, 513 (35 percent) were off by one range and 52 (3%) were off by two ranges (Fig. 2). While the heavy rainfall events and the AAP are more than 51-100, the POD is more than 95 percent correct in > 100 cases. Table 4 (c) shows that the POD and HIT rate are both high. The cases that fall outside of one or two ranges are due to variations in the intensity of the systems. We chose a flood event that occurred on two consecutive days in the Indrāvati and Sabari basins on August 20-22, 2020, to understand the model's spatial distribution. Figs. 5 (a&b) shows the spatial distribution maps of the forecast *vs*. observational QPF comparison for the next 24 hours using the synoptic analogue model. Fig. 5 (a) shows the forecasted QPF in ranges, while Fig. 5 (b) shows the observed AAP. It shows that the model can generate an accurate 24-hour forecast before providing the synoptic conditions.Table 4 depicts the probability of rainfall events occurring in the Godavari River basin.

Note: Images are from operational forecast maps for the Godavari Krishna Krishna Basin (K7, K10, K11 and K12) under FMO Hyderabad jurisdiction.

5. Summary and conclusions

If the synoptic circumstances over the region are known, the synoptic analogue model is very useful for generating QPF before the 48 hr. The frequency of occurrence of synoptic systems in the Godavari basin is S2 > S3 > S1. Upper Godavari, The trough across Madhya Maharashtra and Vidharbha caused the most rainfall in the 11-25 mm range.The maximum of 11-25 is due to upper air circulation across Telangana. Low pressure and upper air cyclonic circulation across south coastal Odisha and coastal Andhra Pradesh resulted in a high of 11-25. Rainfall in the upper Godavari ranges from 26-50mm to 56-100mm due to low pressure and well-marked low pressure, which is associated with upper air cyclonic circulation up to the mid tropospheric levels and depression/deep depression across Madhya Maharashtra and Vidharbha. Over the middle Godavari division, a maximum of 26-50 mm and 56-100 mm was the maximum over low pressure and well-marked low pressure and was associated with upper air cyclonic circulation. The Telangana and Vidarbha regions in the Lower Godavari division received a maximum of 26-50mm and a 56-100mm rainfall category due to the low-pressure WML crossing over the south coastal Odisha and coastal Andhra Pradesh regions. Due to the passage of depressions and deep depressions along the coast of Andhra Pradesh, the rainfall category of > 100 mm was the largest occurrence in the lower Godavari division. Maximum rainfall was particularly high in the G11, G12 and G10 sub-basins. Maneru G6 receives the most rainfall as it moves into the land region. When a depression or deep depression crosses the Odisha coast, the Indrvati (G11) and Sabari (G12) receive the most rainfall.

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