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The Rainfall Regime and its Variability in the Malaprabha River Basin of Karnataka State, India

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Abstract: ***Among the climatic elements, rainfall is the first index ever thought of by farmers and climatic analyzers, as it is the most important single factor that determines the cropping pattern of an area in general and the type of crop to be cultivated and its success or failure. Information on the spatial variability and temporal trends of mean rainfall is essential for efficient management of water resources in general and agriculture. We have analyzed the rainfall data of the Malaprabha river basin, a larger river sub - basin in the Krishna basin, South India, which plays a significant role in agricultural development and, accordingly, in the overall development of some talukas of Belagavi, Bagalakot, Dharwad, and Gadag districts of Karnataka state. The impact of climate change on spatial and temporal patterns of rainfall over smaller spatial scales is clearly noticed in this analysis. Monthly, seasonal, and annual rainy days and rainfall data series of the Malaprabha basin were computed using daily rainfall data from 1971 to 2013 from fifty - eight rain gauge stations located in and around the talukas of the Malaprabha river basin. It was followed by the computation of the mean monthly, seasonal, and annual Standard Deviation (SD), Standard Error (SE), and Coefficient of Variation (CV) through the SPSS package. The statistical methods adopted by Bhargava (1977) are used for the analysis of annual mean rainfall, rainfall intensity, rainfall variability, and rainfall ratio. The coefficient of variation indicates the amount of fluctuation in rainfall recorded over a long period of time from the mean values. Temporal changes in the monthly, seasonal, and annual rainfall were also analyzed by a one - way ANOWA test to confirm the significance of the observed trends. Overall, an insignificant decrease in annual rainfall over the Malaprabha river basin has been observed during the study period.***

Keywords: Rainfall distribution, Variability, Trend, ANOWA test and River basin

1. Introduction

Mother Earth is the home planet of mankind. It is a unique planet in the solar system because it can sustain life. But now, our planet is suffering from various problems like pollution, global warming, climatic changes, etc. So, it is our duty to diffuse knowledge among the masses about these problems and save the mother earth not only for us but also for a brighter, better, and longer future generation. Among the climatic elements, rainfall is the first index ever thought of by farmers and climatic analyzers, as it is the most important single factor that determines the cropping pattern of an area in general and the type of crop to be cultivated and its success or failure in particular. Water is the real elixir of life; irrigation is the fountain of civilization. The availability of surface water resources in a region must be carefully evaluated by a systematic study of the distribution, variability, and trends of rainfall. Knowledge of the spatial variability and temporal trends of mean rainfall is essential for efficient management of water resources and agriculture.

The evaluation of surface water resources is an important aspect of understanding the nature of vegetation and the peculiarities of its variations for the planning and development of agriculture (Subash et al., 2012). It plays an important role in the development of agriculture, hydrology, and especially water resource management. It is well established that water supply to a region is primarily through precipitation, and water loss is entirely due to evaporation and evapotranspiration. The wetness and dryness of a region are determined by the magnitudes of water balance elements (Thornthwaite and Mathur, 1955).

India is a developing country where agriculture is the main economic activity. With an increasing population and decreasing per capita availability of water, there is a need for careful planning and utilization of water resources. A study on water resources planning and development has been developed for the river basins (Akhter et al., 2013). India is in a tropical zone; its agricultural planning and utilization of water depend on monsoon rainfall; more than 75% of rainfall occurs during the monsoon season; monsoon rainfall is uneven both in time and space. So, it is an important factor in evolving the rainfall analysis. Thus, the Indian economy is inextricably linked with the monsoon, and its prosperity is entirely dependent on the amount of rainfall received during the monsoon period.

2. Review of Literature

Several researchers have studied the distribution, variability, and trends of rainfall at global, regional, and basinal scales. Mainly Jagannathan and Parthasarathy (1973), Mooley and Parthasarathy (1983), Thapliyal and Kulshrestha (1991), Parthasarathy et al. (1995), Smith (2000), Guhathakurta, and Rajeevan (2008). Krishnakumar et al. (2008) studied temporal (monthly, seasonal, and annual) rainfall trends in the twentieth century over Kerala, India, and reported a significant decrease in rainfall during the southwest monsoon and an increase during the post - monsoon season. Anandakumar et al. (2008) studied the spatial variation and seasonal behaviour of rainfall patterns in the lower Bhavani River basin, Tamil Nadu, India, and attempted to analyse the occurrence and distribution of rainfall in the basin. I. M. Rathod and S. Aruchamy (2010) have analysed the rainfall variations in Coimbatore district, Tamil Nadu, India. They have analysed the monthly, annual, and seasonal rainfall, rainfall variability, and precipitation ratio of the Coimbatore district, Tamil Nadu. Sivapragasam et al. (2013) studied rainfall trends at the basin scale over the Tamarabarani basin

in Tamil Nadu, India. Chakraborty et al. (2013) tried to study the spatial and temporal variability of rainfall at Seonath subbasin in Chhattisgarh State for 49 years (1960–2008).

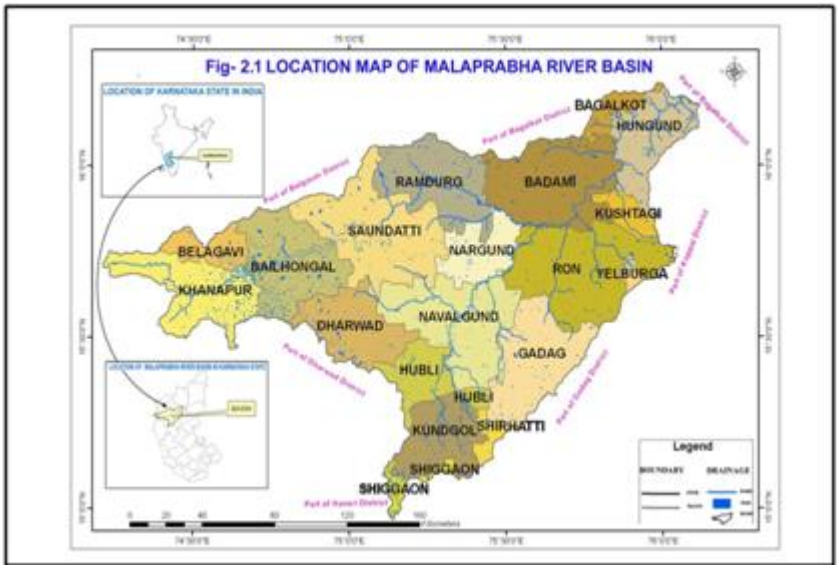
Recently, S. Sushant, K. Balasubramani, and K. Kumaraswamy (2015) studied the spatio - temporal analysis of rainfall distribution and variability in the twentieth century over the Cauvery basin, south India, and concluded that the coefficient of variation shows more significant fluctuations during the winter than other seasons. Long - term changes in rainfall have been determined by A significant decreasing trend in the winter rainfall and an increasing trend in the post - monsoon season with insignificant levels have been inferred based on the Mann - Kendall rank statistics and linear trend.

The Indian summer monsoons are a harbinger of hope for farmers. The southwest monsoon brings the maximum rainfall from the west, precipitating most of the moisture on the windward side of the coast of Karnataka state. After crossing the ranges, the monsoonal wind currents move towards the interior, but with lesser intensity and precipitating towards the east. This factor introduces considerable spatial variation in the amount of rainfall. As the monsoon currents move inside the peninsula, it loses much of its moisture, and as the slope of the country is towards the east coast, the conditions become unfavorable for heavy precipitation except due to depressions and cyclonic storms that develop in the Bay of Bengal. This status results in the east of the Western Ghats of the Karnataka state, in the rain shadow area, being semi - arid and hence drought prone. With this insight, despite providing sustenance to a large geographical area, the rainfall trends of the Malaprabha river basin have not yet been studied considering changing climatic status. Therefore, in the present study, we have tried to appreciate the rainfall regime and its variability in the talukas of the Malaprabha river basin.

3. Study Area

The Malaprabha river basin of Karnataka state is approximately triangular in shape and located in the extreme western part of the Krishna basin. It lies between 15^0 05^l 02^{ll} to 16^0 20^l 19^{ll} North latitudes and 740 05l 43ll to 760 05l 33ll East longitudes, covering an area of 11549 sq. km, out of which 3880 sq. km are in Belgaum (33.59%), 1950 sq. km in Bagalakot (16.89%), 2739 sq. km in Dharwad (23.72%), 2657 sq. km in Gadag, 220 sq. km in Koppal, and 103 sq. Topographically, the Malaprabha river basin presents two important divisions, viz., the Western Ghats and the typical eastern part of the Deccan/Karnataka plateau, with distinct characteristics. The plateau has two natural sub - divisions, the Semi - Malnad and the Northern Maidan, which include the northern upland, or the Deccan trap, of the state. An exhumed structure with superimposed drainage is also responsible for the sharp relief in the Kaladgi sandstones, in which Ghataprabha forms a waterfall near Gokak and the Malaprabha forms a gorge near Saundatti (Spate and Learmonth, 1967). The river Malaprabha is the most important right - bank tributary of the river Krishna. The Benni Hall, Hire Hall, and others are the principal tributaries of the Malaprabha River.

The entire river basin experiences a semi - arid type of climate, spread in the hilly, Northern dry, and Northern Transition zones of the agro - Climatic Zones of Karnataka State, and it is very warm during the summer, especially in April and May, with temperatures ranging between 350 and 400 °C in the eastern part of the river basin. The annual normal rainfall of the Malaprabha basin area is over 759 mm spread over 50 days, which receives monsoon rainfall as much as our nation with slight variations. Deep black cotton soils are ubiquitous in the basin area. Jowar, besides other drought - resistant inferior small millet crops, is traditionally the predominant crop. Geographically, deep black cotton soils, Unpredictable monsoonal rainfall, droughts, and famines are part of the lives of people in the study region.



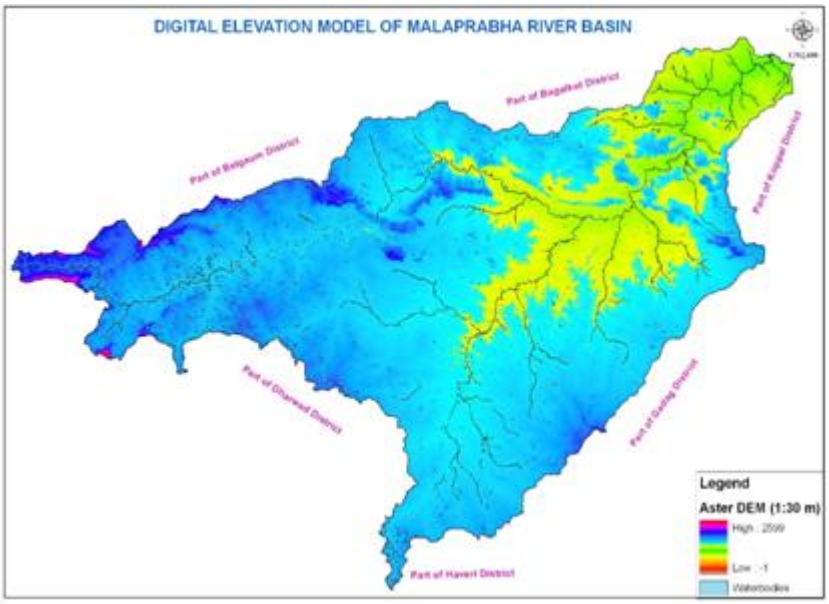


Figure 1: Location of Study Area in India and in Karnataka State and Talukas in Malaprabha River Basin

The present study is a natural region that occupies 6.02 percent of the Karnataka state. As per the 2011 census, the population of the Malaprabha river basin is 3.38 million (5.53% of the state's total population), of which 77.66 percent are rural and 22.34 percent are urban. The dominance of rural populations makes the regional economy mainly agrarian. The basin's 68.37% of the workforce (61.75% of males and 79.55% of females), however, is still dependent on agriculture and its allied activities for their livelihood. The economic development and prosperity of the masses depend mainly on agriculture.

4. Objectives

The present study has been undertaken with the following specific objectives:

- To study the rainfall characteristics of the talukas of the basin area on the basis of mean monthly and annual rainfall from 1971 to 2013.
- To analyse the long - term (1971–2013) spatial distribution of rainfall in the basin area,
- To appreciate the south - west monsoon season and annual rainfall through the mean annual, intensity, variability, and rainfall ratio of the talukas of the basin area and illustrate the presentation of results by way of diagrams and maps.
- To analyse the temporal changes in the south - west monsoon season and annual rainfall by deviation of rainfall from normal and one ANOWA test to confirm the significance of the observed trends among the talukas of the basin area and
- To suggest appropriate strategies to reduce the impact of regional inequalities in rainfall on the sustainable development of river basins.

5. Materials and Methods

The methodology has been divided into three major sections: data collection and input, data processing, and presentation of output. The present study is based on secondary sources of data, and though the study area is a natural region, the taluka has been taken as the unit of study. The rainfall (mm) data over the Malaprabha River Basin for the period from 1971 to 2013 has been obtained from the Directorate, Department of Economics and Statistics, Rainfall Division (DES), Bangalore. Monthly, seasonal, and annual rainy days and rainfall data series of the Malaprabha basin were computed using daily rainfall data from fifty - eight rain gauge stations located in and around the talukas of the Malaprabha river basin. It was followed by the computation of the mean monthly, seasonal, and annual Standard Deviation (SD), Standard Error (SE), and Coefficient of Variation (CV) through the SPSS package. The statistical methods adopted by Bhargava (1977) are used for the analysis of annual mean rainfall, rainfall intensity, rainfall variability, and rainfall ratio. The coefficient of variation indicates the amount of fluctuation in rainfall recorded over a long period of time from the mean values.

The coefficient of variation of annual precipitation is an index of climatic risk, indicating a likelihood of fluctuations in reservoir storage or crop yield from year to year. Agriculturally, it is perhaps a more crucial statistic for marginal areas than in either very dry areas, where farming practices have adapted to variability, or wet areas, where relatively lower inter - annual variability is generally expected. Contrary to these general perceptions, no perceptible spatio - temporal variations were observed, which prompted the examiner to find out the long - term trends with the help of average rainfall graphs constructed with the trend line. Temporal changes in the monthly, seasonal, and annual rainfall were also analysed by a one - way ANOWA test to confirm the significance of the observed trends. According to the Radhakrishna et al. (1974) Method, the U. S. Geological Method (1962), Seghal's' (1970), and the Krishna Rao (1970) method, rainfall recharge, specific yield, and the ground water resources of the basin are also worked out.

6. Result and Discussion

6.1 Rainfall Characteristics of the MRB

The average monthly, seasonal, and annual rainfall characteristics over the long term for 58 rain gauge stations in the Malaprabha river basin area are presented in Table 1 and Fig.2. The observations and inferences from these are discussed as follows: The average annual normal rainfall was 736.77 mm in the river basin from 1971 to 2013, with a standard deviation of 504.41 mm. The coefficient of variation of annual rainfall is 68.59 percent, indicating that it is highly variable. The variation in rainfall is found in every month, with the intensity of rainfall gradually increasing from March to July and suddenly decreasing from August to September. Rainfall during July is the highest (135.89 mm) and contributes 18.44% of annual rainfall (736.77 mm), followed by September (17.53%), June (17.17%), August (15.78%), and October (13.60%). Thus, the high intensity trends are noticed in the months of July and September, and these months get the highest rainfall, which reaches its maximum peak and also starts to decrease from December onwards. Least amounts of rainfall are observed during the month of February (1.06 mm), followed by January (1.50 mm), which contribute only 0.15 and 0.20 % to the annual rainfall, respectively [Fig.2]. The coefficient of variation is highest in March (299.54%), followed by December (228.48%) and January (225.29%), and the least during July (32.87%) and August (33.33%). The contribution of the seasonal rainfall to the annual rainfall is highest during the monsoon period (68.91%), followed by the post - monsoon period (18.16%), the pre - monsoon period (12.58%), and the winter period (0.35%) in decreasing order. A non - significant relationship between SD and CV has been observed during the months of highest rainfall (July and September).

Table 1: Mean Monthly, Seasonal and Annual Rainfall Statistics (SD, SE & CV) of Malaprabha River Basin from 1971 to 2013

Months Seasons/ Annual	Min	Max	Mean	SD	SE	CV	% contribution to Annual Rainfall
January	0.00	15.24	1.50	3.37	0.51	225.29	0.20
February	0.00	13.36	1.06	2.31	0.35	217.00	0.15
March	0.00	138.23	7.05	21.13	3.22	299.54	0.95
April	0.03	71.54	27.43	15.99	2.44	58.31	3.73
May	4.50	124.20	58.19	29.01	4.42	49.86	7.90
June	54.39	303.82	126.52	48.49	7.40	38.33	17.17
July	42.88	244.79	135.89	44.66	6.81	32.87	18.44
August	33.63	206.77	116.21	38.73	5.91	33.33	15.78
September	33.39	289.88	129.09	65.01	9.91	50.36	17.53
October	17.11	224.34	100.19	51.75	7.89	51.66	13.60
November	0.00	121.22	29.67	33.24	5.07	112.02	4.03
December	0.00	37.80	3.97	9.07	1.38	228.48	0.54
Seasons;							
Cold (Jan - Feb)	0.00	15.2	2.56	8.04	0.34	318.32	0.35
Hot (Mar - May)	35.6	205.8	92.67	51.58	2.18	55.78	12.58
S - W (Jun - Sep)	244.7	822.2	507.71	494.30	20.91	97.58	68.91
N - E (Oct - Dec)	30.9	280.7	133.83	73.70	3.12	55.09	18.16
Annual	451.22	1052.58	736.77	504.41	21.33	68.59	100.0

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

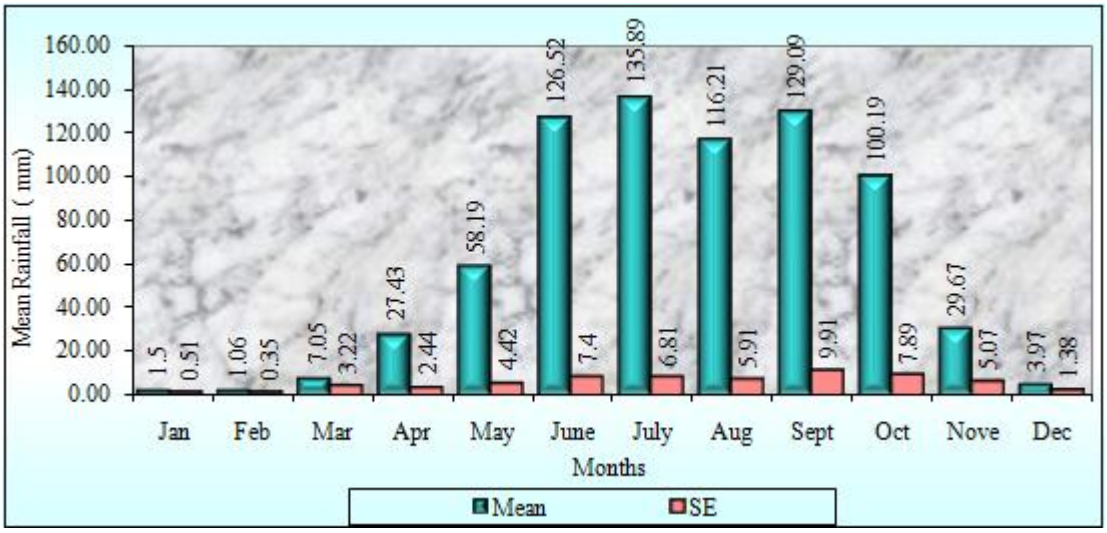


Figure 2: Mean Monthly & Standard Error of Rainfall in Malaprabha Basin (1971-2013)

6.2 Spatial Distribution of Rainfall

In the Malaprabha river basin, there are fifty - eight rain gauge stations with records extending over 43 years. The distribution of these stations is good, which enables us to draw a consistent and reliable picture of the rainfall in the basin. In Table 3, the number of rain gauges and the normal monthly and annual rainfall of each taluka are given. The normal rainfall in each month as a percentage of the annual average along with the average number of rainy days are also included in the table.

Table 3: Taluka - wise Mean Monthly Rainfall, Percentage of the Annual Rainfall and Rainy Days of Malaprabha River Basin from 1971 to 2013 (mm)

S. No.	Taluka	Variables	R. G. No	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Bailhongal	Rainfall	14	0.9	0.7	6.6	24.6	57.1	122.6	135.9	98.0	108.7	95.3	28.8	4.02	683.3
		%[#]	11	0.1	0.1	1.0	3.6	8.4	17.9	19.9	14.3	15.9	13.9	4.2	0.6	100.0
		R. Days		0.1	0.1	0.4	1.8	3.5	8.5	10.8	9.0	6.8	5.3	1.8	0.2	48.3
2	Khanapur	Rainfall	14	0.9	0.4	7.1	21.0	40.7	492.9	777.9	546.7	201.9	111.8	24.7	2.5	2228.6
		%	6	0.0	0.0	0.3	0.9	1.8	22.1	34.9	24.5	9.1	5.0	1.1	0.1	100.0
		R. Days		0.1	0.0	0.4	1.7	2.8	16.4	22.7	20.7	11.4	6.6	1.6	0.1	84.4
3	Ramadurga	Rainfall	6	0.9	1.0	6.8	15.6	50.9	81.8	49.4	54.0	118.4	95.4	27.6	3.6	505.4
		%	4	0.2	0.2	1.4	3.1	10.1	16.2	9.8	10.7	23.4	18.9	5.5	0.7	100.0
		R. Days		0.1	0.1	0.4	1.3	2.9	4.8	4.3	4.4	5.9	5.0	1.5	0.3	30.8
4	Saundatti	Rainfall	10	1.3	1.2	7.1	20.8	57.4	83.4	63.4	48.4	114.0	94.7	27.1	3.3	522.1
		%	6	0.3	0.2	1.4	4.0	11.0	16.0	12.1	9.3	21.8	18.1	5.2	0.6	100.0
		R. Days		0.1	0.1	0.4	1.7	3.5	5.6	5.8	4.9	6.4	4.9	1.6	0.3	35.2
5	Badami	Rainfall	6	1.5	1.0	5.8	20.0	52.5	81.1	63.1	76.7	131.5	100.4	25.1	4.5	563.2
		%	4	0.3	0.2	1.0	3.6	9.3	14.4	11.2	13.6	23.4	17.8	4.5	0.8	100.0
		R. Days		0.1	0.1	0.3	1.7	3.5	5.3	5.4	5.7	7.0	5.5	1.5	0.3	36.5
6	Hunagund	Rainfall	8	2.8	1.0	6.6	15.7	59.0	83.1	65.3	91.0	138.4	119.1	25.0	5.4	612.5
		%	4	0.5	0.2	1.1	2.6	9.6	13.6	10.7	14.9	22.6	19.4	4.1	0.9	100.0
		R. Days		0.1	0.1	0.4	1.2	3.4	4.9	5.3	6.1	7.0	5.5	1.6	0.3	35.9
7	Gadag	Rainfall	6	0.8	0.7	9.3	31.0	61.4	85.7	63.9	74.2	116.9	96.7	34.9	5.5	581.0
		%	3	0.1	0.1	1.6	5.3	10.6	14.8	11.0	12.8	20.1	16.6	6.0	0.9	100.0
		R. Days		0.1	0.1	0.5	2.3	4.2	5.7	5.7	6.4	7.1	5.6	1.9	0.3	39.8
8	Naragund	Rainfall	3	1.9	0.6	6.2	20.9	47.4	75.6	50.1	63.2	128.2	92.4	29.7	3.6	519.8
		%	2	0.4	0.1	1.2	4.0	9.1	14.6	9.6	12.2	24.7	17.8	5.7	0.7	100.0
		R. Days		0.1	0.1	0.3	1.6	3.1	5.1	4.8	4.9	6.2	4.8	1.7	0.4	33.0
9	Ron	Rainfall	4	4.2	1.1	7.3	26.9	62.8	90.4	70.4	90.9	146.7	108.7	27.3	5.2	641.9
		%	3	0.6	0.2	1.1	4.2	9.8	14.1	11.0	14.2	22.9	16.9	4.3	0.8	100.0
		R. Days		0.2	0.1	0.4	1.7	3.6	5.4	5.8	6.3	7.0	5.4	1.4	0.4	37.4
10	Dharwad	Rainfall	10	1.6	1.2	8.8	47.9	74.6	148.0	170.9	132.0	122.6	107.4	32.3	4.3	851.6
		%	6	0.2	0.1	1.0	5.6	8.8	17.4	20.1	15.5	14.4	12.6	3.8	0.5	100.0
		R. Days		0.1	0.1	0.6	3.1	4.5	10.3	13.8	12.1	7.9	6.3	2.0	0.3	61.0
11	Hubli	Rainfall	5	0.8	1.2	5.9	33.0	61.4	111.6	97.3	83.1	98.4	91.7	28.4	3.3	616.1
		%	4	0.1	0.2	1.0	5.4	10.0	18.1	15.8	13.5	16.0	14.9	4.6	0.5	100.0
		R. Days		0.1	0.1	0.5	2.6	4.0	8.2	9.6	8.1	6.7	5.6	1.8	0.3	47.6
12	Kundagol	Rainfall	2	0.7	2.4	6.5	44.5	65.3	95.9	89.3	79.2	105.2	90.4	42.4	3.7	625.3
		%	2	0.1	0.4	1.0	7.1	10.4	15.3	14.3	12.7	16.8	14.5	6.8	0.6	100.0
		R. Days		0.1	0.1	0.5	2.9	4.3	8.0	9.2	8.3	7.4	5.9	2.1	0.3	49.3
13	Navalgund	Rainfall	5	1.2	0.8	7.6	33.1	64.9	90.2	68.7	70.2	139.1	96.6	34.0	2.7	609.0
		%	3	0.2	0.1	1.2	5.4	10.7	14.8	11.3	11.5	22.8	15.9	5.6	0.4	100.0
		R. Days		0.1	0.1	0.4	2.6	4.2	6.0	6.6	6.1	7.2	5.9	1.9	0.2	41.3
MRB		Rainfall	93	1.5	1.1	7.1	27.4	58.2	126.5	135.9	116.2	129.1	100.2	29.7	4.0	736.8
		%	58	0.2	0.1	1.0	3.7	7.9	17.2	18.4	15.8	17.5	13.6	4.0	0.5	100.0
		R. Days		0.1	0.1	0.4	2.0	3.7	7.2	8.4	7.9	7.2	5.6	1.7	0.3	44.7
MRB Seasonal				Winter		Summer			South West Monsoon				North East Monsoon			Total
		Rainfall		2.56		92.67			507.71				133.83			736.8
		%		0.35		12.58			68.91				18.16			100.0
		R. Days		0.18		6.10			30.83				7.55			44.66

(#: - Monthly rainfall as percentage of annual)
Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore Karnataka State.

The annual average rainfall of the Malaprabha river basin area is over 736.8 mm spread over 44.7 days. However, its spatial and temporal distribution are not uniform. The normal annual rainfall was about 505.3 mm spread over 30.8 days in Ramadurga taluka, whereas 2228.6 mm of rainfall spread over 84.4 days in Khanapur taluka of the river basin area. The details of taluka - wise altitude, annual average rainy days, and rainfall for 1971–2013, and actual rainy days and rainfall of the Malaprabha river basin in 2013 have been presented in the following Table 4.

Table 4: Altitude, Annual Average Rainy Days and Rainfall and Actual Rainy Days and Rainfall of Malaprabha River Basin, Karnataka State, 1971 - 2013

S. No	Taluka	Altitude above MSL (in mts)	Annual Average Rainy Days & Rainfall (1971 to 2013)		Annual Actual Rainy Days & Rainfall in 2013	
			No. of Rainy Days	Rainfall (in mms)	No. of Rainy Days	Rainfall (in mms)
1	Khanapur	800	84.4	2228.6	89.5	1588.8
2	Bailhongal	715	48.3	683.3	57.0	673.6
3	Saundatti	710	35.2	522.1	29.3	382.0
4	Ramadurga	652	30.8	505.4	34.4	505.6
5	Badami	625	36.5	563.2	32.0	464.5
6	Hunagund	625	35.9	612.6	40.6	595.6
7	Ron	549	37.4	641.9	29.3	480.3
8	Gadag	671	39.8	581.0	49.5	697.0
9	Naragund	609	33.0	519.8	28.0	480.5
10	Dharwad	715	61.0	851.6	66.9	788.4
11	Navalgund	623	41.3	609.0	43.7	588.3
12	Hubli	620	47.6	616.1	59.3	617.3
13	Kundagol	624	49.3	625.3	46.5	472.0
Total River Basin Area		657	44.7	736.8	46.6	641.1

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

The actual average rainfall received in the river basin area during the year 2013 was about 641.1 mm spread over 46.6 days, which is 14.93 percent less than the average rainfall (736.8 mm) and falls under the normal category**.** The actual rainfall varies from as low as 382.0 mm spread over 29.3 days at Saundatti taluka to as high as 1588.8 mm spread over 89.5 days at Khanapur taluka of the river basin area. The rainfall of all talukas in the basin area has been classified into four categories, mainly as Excess (**E**), Normal (**N**), Deficit (**D**), and Scanty (S), as per the following criteria:

- ***Excess (E):*** + 20% and above the average Rainfall (884.2 mm and above).
- ***Normal (N):*** - 20% to +20% of the average Rainfall (589.4 mm to 884.2 mm)
- ***Deficit (D):*** - 20% to - 40% of the average Rainfall (442 mm to 589.4 mm)
- ***Scanty (S):*** - 40% and below the average Rainfall (442 mm and below)

Based on the above criteria, among the talukas of the river basin, Khanapur taluka receives more rainfall and is considered excess (***E)***, whereas Bailhongal, Hunagund, Ron, Dharwad, Hubli, Kundagol, and Navalgund talukas fall under ***Normal (N),*** followed by Ramadurga, Saundatti, Badami, Gadag, and Naragund talukas under ***Deficit (D)***. ***Scanty (S)*** category rainfall talukas are absent in the study area.

The south - west monsoon sets in the basin area in the first week of June and is replaced by the north - east monsoon in October and November. The western part receives 50 to 70 percent of the rainfall in the south - west monsoon months (June to September), and the rest of the basin receives about 50 to 60 percent of the rainfall. The study area receives about 5 to 15 percent of the rainfall during October and November. In the western half of the basin, there is a primary maximum in July and a secondary maximum in October, while in the eastern half, September and October are the rainiest months of the year. As one goes west, the secondary maximum is less significant, and most of the rainfall occurs during the south - west monsoon period from June to September. The rainfall of any place measured over consecutive years shows a very considerable variation from one year to another. The distribution of the annual rainfall of the basin is shown in Table 5, which was prepared based on the data available for the study (1971–2013).

Table 5: Distribution of Annual Rainfall of the MRB, 1971 to 2013

Range of Rainfall (in mms)	Frequency (No. of Years)	Range of Rainfall (in mms)	Frequency (No. of Years)
Less than 500	01	800 - 900	08
500 – 600	07	900 - 1000	05
600 – 700	06	More than 1000	01
700 - 800	15		43

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

Table 6: Variations of Decadal Averages of Rainfall of the MRB, 1971 to 2013

Decadal Period	Mean Rainfall (in mms)	Difference form long period	Decadal Mean as % of Average
1971 - 80	725.3	- 11.5	98.44
1981 - 90	690.1	- 46.7	93.66
1991 - 2000	795.6	+58.8	107.98
2001 - 10	765.8	+29.0	103.93
2011 - 13	637.0	- 99.8	86.45
Mean Rainfall (1971 – 2013)		736.8	

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

Table 6 explains that the least average amount of rainfall was observed during the decades of 1981–1990 (690.1 mm) and 2011–13 (637.0 mm), respectively, in the river basin. None of the above differences is, however, significant statistically, indicating that there has been no change in the annual rainfall of the basin during the 43 - year period. The lowest rainfall of the basin during the study period was 451.2 mm in 2003 (61.2 % of average), and the highest rainfall of the basin during the study period was 1052.6 mm in 2009 (142.9 % of average), giving a range of 81.7 percent of average.

There have been 12 years when rainfall was less than 90 percent of the average and only 8 occasions when it was less than 75 percent of the average. On 23 (54 percent)

occasions, rainfall was above average. Instances of two or more consecutive years when rainfall was within 75 percent of the average in the basin are noticed only once, i. e., 1971–1972 of the entire study period. There was no sequence of even two consecutive years when the basin's average annual rainfall was less than 90 percent of the average. Continuous years of drought for the basin are rare. There is also no periodicity in rainfall. Individual talukas show some interesting features. Table 7 gives the frequency distribution of annual rainfall in ·the individual talukas, and Table 8 also explains the taluka - wise means, extremes, and variability of the annual rainfall in the basin.

Rainfall is highly variable in the eastern part of the basin, where it ranges from 28 to 31 percent. In the central part of the basin, it varies from 23 to 27 percent, and in the remaining part of the basin, it is less than 23 percent. It decreases to 18 percent in the western parts of the district. The higher the coefficient of variability, the greater the variation, which results in uncertainty in rainfall. During the 43 years from 1971 to 2013, the highest annual rainfall recorded at the individual talukas varied from 157 percent to about 248 percent of the average. The lowest recorded has varied from 37 percent to 55 percent of the average.

According to general practice, annual rainfall within 20 percent of the average is called as normal, and 20 to 25 percent is considered a slight excess or defect. Table 9 indicates for each of· the talukas two or more consecutive years when the annual rainfall was below 90 percent of the average and below 75 percent of the average. It is of interest to notice that all the stations have had sequences of two or more years when rainfall was less than 90 percent.

Table 9: Less than 90 & 75 Percentage of Rainfall Received Two or more Consecutive Years in the Malaprabha River Basin, 1971 to 2013

Talukas	Percentage of Rainfall Received Two or more Consecutive Years with	
	Less than 90 percent	Less than 75 percent
Khanapur	1984 - 85, 1995 - 96 &2001 - 03	1971 - 76
Bailhongal	1972 - 73, 1989 - 90 &1998 - 2000	1985 - 86 &2001 - 03
Dharwad	1986 - 87 &1988 - 89	2001 - 03
Hubli	2011 - 12	1986 - 87
Kundagol	1998 - 99	- - -
Saundatti	1971 - 72	2001 - 03 & 2012 - 13
Ramadurga	1983 - 84, 1989 - 90 &2001 - 02	1985 - 86
Badami	1988 - 89	1984 - 85 & 2002 - 03,
Hunagund	1989 - 90 &2000 - 01	1984 - 85&2002 - 03
Gadag	2011 - 12	2002 - 03
Ron	- - -	1989 - 90, 2002 - 03 & 2011 - 13
Navalgund	1971 - 72	- - -
MRB	- - -	1971 - 72

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

Table 7: Taluka - wise Frequency Distribution of Annual Rainfall of Malaprabha River Basin, 1971 to 2013

Rainfall (mms)	Khanapur	Bailhongal	Dharwad	Hubli	Kundagol	Saundatti	Ramdurga	Badami	Hunagund	Gadag	Naragund	Ron	Navalgund	MRB
	Hilly Zone	Northern Transitional Zone				Northern Dry Zone								
< 200	- -	- -	- -	- -	- -	- -	1	- -	- -	- -	1	- -	- -	- -
200 - 300	- -	- -	- -	- -	- -	1	2	2	1	- -	4	1	- -	- -
300 - 400	- -	2	- -	2	3	6	6	4	4	4	4	5	2	- -
400 - 500	- -	6	2	6	6	11	15	9	5	10	10	6	9	1
500 - 600	- -	9	2	11	11	15	9	12	11	10	14	7	13	7
600 - 700	- -	12	6	13	9	5	4	7	9	10	4	10	7	6
700 - 800	- -	3	8	7	9	4	4	6	7	6	3	5	8	15
800 - 900	- -	5	9	1	3	- -	2	2	3	2	3	2	2	8
900 - 1000	3	5	8	3	1	1	- -	- -	1	1	- -	4	1	5
1000 - 1100	- -	1	4	- -	1	- -	- -	1	2	- -	- -	3	1	1
1100 - 1200	- -	- -	2	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1200 - 1600	5	- -	2	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1600 - 2000	10	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
2000 - 2400	8	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
2400 - 2800	10	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
> 2800	7	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Total No. of Years	43	43	43	43	43	43	43	43	43	43	43	43	43	43
Mean Annual	2228.6	683.3	851.6	616.1	625.3	522.1	505.4	563.2	612.5	581.0	519.8	641.9	609.1	736.8
Mean Annual Rainy Days	84.4	48.3	61.0	47.6	49.3	35.2	30.8	36.5	35.9	39.8	33.0	37.4	41.3	44.7

Table 8: Taluka - wise Means, Extremes & Variability of Annual Rainfall of Malaprabha River Basin, 1971 to 2013

Rainfall (mms)	Khanapur	Bailhongal	Dharwad	Hubli	Kundagol	Saundatti	Ramdurga	Badami	Hunagund	Gadag	Naragund	Ron	Navalgund	MRB
Mean Rainfall	2228.6	683.3	851.6	616.1	625.3	522.1	505.4	563.2	612.5	581.0	519.8	641.9	609.1	736.8
Highest Rainfall	3795.7	1694.6	1407.1	972.1	1000.4	937.1	816.9	1031.6	1048.5	911.6	899.7	1042.7	1061.1	1052.6
Year	1994	1981	1980	1991	1991	2009	2009	2009	1975	2010	2007	1975	1974	2009
% of Mean	170.3	248.0	165.2	157.8	160.0	179.5	161.6	183.2	171.2	156.9	173.1	162.4	174.2	142.9
Lowest Rainfall	824.1	366.7	410.5	340.7	341.3	257.9	197.9	257.9	229.4	301.9	195.7	299.5	320.4	451.2
Year	1972	2001	2003	1989	2001	2012	2003	2003	1972	1990	2003	2012	2003	2003
% of Mean	37.0	53.7	48.2	55.3	54.6	49.4	39.2	45.8	37.5	52.0	37.7	46.7	52.6	61.2
S. D.	676.4	227.7	209.8	146.4	154.1	132.9	149.5	168.3	183.1	140.0	158.63	203.3	154	504.4
S. E.	103.2	34.7	32.0	22.3	23.5	20.3	22.8	25.7	27.9	21.4	24.19	31.0	23.5	21.3
Rainfall Variability	30.4	33.3	24.6	23.8	24.7	25.5	29.6	29.9	29.9	24.1	30.52	31.7	25.3	68.6
% of Rainfall in Monsoon Months	90.6	68.1	67.3	63.4	59.1	59.2	60.1	62.6	61.7	58.6	61.0	62.1	60.5	68.9
Mean Rainy days	84.4	48.3	61.0	47.6	49.3	35.2	30.8	36.5	35.9	39.8	33.0	37.4	41.3	44.7
Highest Rainy days	108.2	65.6	91.4	64.3	78.0	49.3	48.5	60.0	50.6	58	48.0	52.7	63.0	56.4
Year	2011	2010	1980	1974	1973	2010	1975	2009	1998	2010	2010	1975	1979	2010
% of Mean	128.2	135.8	149.8	135.1	158.3	140.1	157.4	164.2	140.9	145.8	145.5	140.9	152.7	126.3
Lowest Rainy days	45.8	30.7	40.3	29.5	30.0	16.3	15.8	21.0	18.7	26	10.5	22.0	24.3	31.5
Year	1976	2003	2003	1989	2001	2012	2003	1972	1972	1971	1980	2012	2003	2003
% of Mean	54.3	63.6	66.1	62.0	60.9	46.3	51.3	57.5	52.1	65.4	31.8	58.8	58.9	70.5
S. D.	14.3	10.2	10.5	8.4	10.5	7.2	7.3	9.0	7.8	7.4	8.2	7.9	7.4	6.3
S. E.	2.2	1.55	1.6	1.3	1.6	1.1	1.1	1.4	1.2	1.1	1.3	1.2	1.1	1.0
C. V.	16.9	21.1	17.3	17.7	21.3	20.4	23.8	24.7	21.6	18.7	24.7	21.2	18.0	14.1
% of Rainy days in Monsoon Months	84.3	72.7	72.2	86.6	67.0	64.5	62.8	64.2	65.0	62.5	63.5	65.1	62.8	69.0
Rainfall of Intensity	26.41	14.15	13.96	12.94	12.69	14.83	16.40	15.42	17.06	14.61	15.75	17.16	14.76	16.50
Rainfall Ratio	133.34	194.34	117.03	102.48	105.40	130.10	122.48	137.37	133.74	104.94	135.44	115.78	121.62	81.62

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State

6.3 The South - West Monsoon Season and Annual Rainfall of the MRB:

Based on the percentage contribution to the annual rainfall, the basin experiences four distinct periods of rainfall, namely, the Hot summer season from March to May, the Southwest monsoon rainfall season with strong southwest winds (June–Sept), the Northeast monsoon during October–Dec (dominant northeast wind), and the Winter season (Jan–Feb). The seasonal analysis of the mean rainfall shows that the basin received the maximum rainfall of 507.71mm (68.91%) in the southwest monsoon season. During the northeast monsoon season, it received only 133.83mm (18.16%). In the summer season, rainfall occurs at only 92.67mm (12.58%), and in the winter, the mean average rainfall is 2.56 mm (0.35%), respectively. Table 10 depicts the seasonal and annual rainfall, and Table 11 shows the Seasonal Mean Rainfall, Rainfall Intensity, variability, and ratio of the river Basin.

Table 10: Seasonal and Annual Rainfall Statistics of MRB, (1971 to 2013)

Talukas	Seasonal Distribution of Rainfall (mm)									
	Hot Weather		S - W Monsoon		N - E Monsoon		Cold Weather		Annual	
	Rainy days	Rain fall	Rainy days	Rain fall	Rainy days	Rainfall	Rainy days	Rain fall	Rainy days	Rain fall
Bailhongal	5.70	88.38	35.10	465.23	7.31	128.09	0.16	1.64	48.27	683.33
Khanapur	4.85	68.82	71.10	2019.38	8.32	139.05	0.11	1.33	84.38	2228.58
Ramadurga	4.59	73.34	19.35	303.56	6.69	126.56	0.18	1.92	30.82	505.38
Saundatti	5.56	85.31	22.71	309.10	6.75	125.08	0.21	2.56	35.22	522.05
Badami	5.59	78.35	23.44	352.47	7.31	129.95	0.19	2.46	36.53	563.23
Hunagund	5.00	81.33	23.33	377.86	7.37	149.47	0.22	3.79	35.91	612.45
Gadag	7.01	101.75	24.87	340.73	7.76	137.06	0.14	1.45	39.77	581.00
Naragund	4.99	74.54	20.97	317.13	6.90	125.66	0.15	2.44	33.00	519.77
Ron	5.70	96.94	24.36	398.44	7.10	141.29	0.25	5.23	37.41	641.90
Dharwad	8.20	131.23	44.03	573.54	8.58	143.98	0.21	2.85	61.01	851.59
Hubli	7.09	100.30	32.66	390.45	7.69	123.40	0.16	1.98	47.61	616.13
Kundagol	7.76	116.27	32.99	369.49	8.27	136.48	0.24	3.10	49.26	625.34
Navalgund	7.18	105.58	25.91	368.21	8.04	133.18	0.14	2.07	41.26	609.05
Total	6.10	92.67	30.83	507.71	7.55	133.83	0.18	2.56	44.66	736.77

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

Table 11: Seasonal Mean Rainfall, Rainfall Intensity, Rainfall Variability and Rainfall Ratio of the Malaprabha River Basin (1971 to 2013)

Sl. No	Seasons	Mean Rainfall (in mm)	Rainfall Intensity (in mm / a rainy day)	Rainfall Variability (in %)	Rainfall Ratio (in %)
1	Hot summer	92.7	15.2	55.7	183.7
2	South - west	507.7	16.5	97.4	113.7
3	North - east	133.8	17.7	55.1	186.7
4	Cold/Winter	2.56	13.9	314.1	593.8
5	MRB	736.8	16.5	68.5	81.6

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

The seasonal analysis of rainfall intensity specifies that, in the southwest monsoon season, it is 16.5mm/a rainy day. During the summer and northeast monsoon seasons, it varies from 15.2mm to 17.7 mm per rainy day. It is less than 13.9 mm of rain on a rainy day in the winter season. The rainfall variability figures are above 314.1% during the winter season. During the northeast monsoon and summer seasons, it varies from 55.1% to 55.7%. In the southwest monsoon season, the rainfall variability is less than 97.4%. The rainfall ratios of the basin are above 593.8% in the winter season. The ratio values vary from 183.66% to 186.65% in the summer and north - east monsoon seasons. During the south - west monsoon season, there is greater stability; it is 113.7%.

a) South - West Monsoon Season Rainfall Pattern (June to September):

The quantum of rainfall normally received during the Southwest monsoon season was about 68.91 percent, which is the major contributing factor to drinking water sources, agricultural activities, and power generation. Further in this season only, nearly 80 percent of the crop areas were covered. The mean seasonal rainfall during the SW monsoon was maximum in Khanapur (2019.4mm) taluka and minimum in Ramadurga (303.6mm) taluka (Table 12). The average rainfall in the basin is 507.7mm. The low rainfall zone (less than 350.00mm) was observed in Ramadurga, Saundatti Gadag, and Naragund talukas of the basin (Fig.3). The medium rainfall zone (350.00mm to 450.00mm) was witnessed in Bailhongal, Ron, Badami, Hunagund, Kundagol, Navalgund, and Hubli talukas of the basin. While Khanapur and Dharwad talukas of the basin registered in the high (more than 450.00 mm) rainfall zone during this season.

Table 12: Mean Rainfall, Rainfall Intensity, Rainfall Variability and Rainfall Ratio of the Malaprabha River Basin (1971 to 2013) (South - West Monsoon Season)

Sl. No	Talukas	Mean Rainfall (in mm)	Rainfall Intensity (in mm / a rainy day)	Rainfall Variability (in %)	Rainfall Ratio (in %)
1	Bailhongal	465.2	13.3	43.3	258.0
2	Khanapur	2019.4	28.4	30.9	136.6
3	Ramadurga	303.6	15.7	42.7	174.6
4	Saundatti	309.1	13.6	35.9	143.5
5	Badami	352.5	15.0	38.4	156.7
6	Hunagund	377.9	16.2	38.4	168.5
7	Gadag	340.7	13.7	35.4	147.1
8	Naragund	317.1	15.1	45.6	232.0
9	Ron	398.4	16.4	40.9	155.5
10	Dharwad	573.5	13.0	31.9	161.1
11	Hubli	390.5	12.0	30.5	136.6
12	Kundagol	369.5	11.2	32.3	138.0
13	Navalgund	368.2	14.2	39.1	153.1
	MRB	507.7	16.5	97.4	113.7

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

The minimum rainfall intensity (11.2mm/a rainy day) was observed in Kundagol, and the maximum intensity (28.4mm/a rainy day) was confined to Khanapur taluka, with an average of 16.5mm/a rainy day. The spatial distribution shows that low rainfall intensity (less than 15mm/a rainy day) was observed in Bailhongal, Saundatti, Gadag, Dharwad, Hubli, and Kundagol of the basin. The medium intensity (15–18 mm/a rainy day) was found in Ramadurga, Badami, Hunagund, Naragund, and Navalgund talukas of the basin. It is high (more than 18 mm/rainy day) and was found in Khanapur &Ron talukas of the basin (Fig.3).

The minimum rainfall variability observed in Hubli (30.5%) and maximum in Naragund (45.6%) talukas is an average of 97.4 percent. The spatial distribution shows that the high (more than 40%) rainfall variability was found in Bailhongal, Ramadurga, Naragund, and Ron, and the medium (35–40%) variability was found in Saundatti, Badami, Hunagund, Gadag, and Navalgund talukas of the basin. The low (less than 35%) rainfall variability was seen in Khanapur, Dharwad Hubli, and Kundagol talukas of the basin (Fig.3).

The minimum rainfall ratio value was found in Hubli (136.6%), and the maximum rainfall ratio was found in Bailhongal (258.0%) taluka, with an average of 113.7 percent. The spatial distribution shows that the ratio was less than 150 percent in Khanapur, Saundatti, Gadag, Hubli, and Kundagol talukas of the basin. It exceeds 200 percent in Bailhongal and Naragund talukas of the basin. The ratio

varied between 100 & 200 percent in the talukas of Ramadurga, Badami, Hunagund, Ron, Dharwad, & Navalgund of the basin (Fig.3).

b) The Annual Rainfall Analysis of the MRB:

The mean annual rainfall varied from 505.4mm to 2228.6mm during the study period. The minimum annual rainfall was found in Ramadurga (505.4mm) taluka and the maximum in Khanapur (2228.6mm) taluka of the basin (Table 13). The average annual rainfall in the basin is 736.8mm. The spatial distribution of the annual rainfall is shown in Fig.4.7. This map clearly depicts the decreasing trend of rainfall from the western to the eastern parts of the basin. The western margin of the study area receives higher rainfall (more than 2, 200 mm) during June–September due to orographic effects, whereas the eastern margin of the basin remains dry due to its location on the leeward side of the Western Ghats. However, the southeast part of the basin gets moderate amounts of rainfall from the northeast monsoon. Most of the drought phenomena occur in the eastern part of the river basin due to the low rainfall.

The spatial distribution shows that the low (less than 600.00mm) rainfall zone was observed in Ramadurga, Badami, Saundatti, Naragund, and Gadag talukas of the basin. The medium (600.00 to 8000.00mm) rainfall zone was confined to Bailhongal, Hunagund, Ron, Hubli, Kundagol, and Navalgund talukas of the basin. While Khanapur &Dharwad talukas of the basin registered in a high (more than 800.00 mm) rainfall zone during this season (Fig.4).

The rainfall intensity ranges from a minimum of 12.7 mm per rainy day in Kundagol taluka to a maximum of 26.4 mm per rainy day in Khanapur taluka. The average rainfall intensity is 16.5 mm per rainy day. The spatial distribution explains the high rainfall intensity (more than 17 mm/a rainy day) in Khanapur, Hunagund, and Ron talukas, the medium (15–17 mm/a rainy day) intensity in Ramadurga, Badami, and Naragund talukas, and the low (less than 15mm/a rainy day) intensity in Bailhongal, Hubli, Kundagol Saundatti, Gadag, Dharwad, and Navalgund talukas of the basin (Fig.4).

Table 13: Mean Rainfall, Rainfall Intensity, Rainfall Variability and Rainfall Ratio of the Malaprabha River Basin (1971 to 2013) (Annual)

S. No	Talukas	Mean Rainfall (in mm)	Rainfall Intensity (in mm / a rainy day)	Rainfall Variability (in %)	Rainfall Ratio (in %)
1	Bailhongal	683.3	14.2	33.3	198.7
2	Khanapur	2228.6	26.4	30.4	133.3
3	Ramadurga	505.4	16.4	29.6	122.5
4	Saundatti	522.1	14.8	25.4	130.1
5	Badami	563.2	15.4	29.9	137.4
6	Hunagund	612.5	17.1	29.9	133.7
7	Gadag	581.0	14.6	24.1	104.9
8	Naragund	519.8	15.8	30.5	135.4
9	Ron	641.9	17.2	31.7	115.8
10	Dharwad	851.6	14.0	24.6	117.0
11	Hubli	616.1	12.9	23.8	102.5
12	Kundagol	625.3	12.7	24.6	105.4
13	Navalgund	609.1	14.8	25.3	121.6
	MRB	736.8	16.5	68.5	81.6

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

The minimum rainfall variability was seen in Hubli (23.8%) and the maximum in Bailhongal (33.3%) taluka, with an average of 68.5 percent. The spatial distribution shows that the rainfall variability is less than 25 percent in Gadag, Dharwad, Hubli, and Kundagol talukas of the basin. It ranges between 25 and 30 percent in Ramadurga, Saundatti, Badami, Hunagund, and Navalgund talukas and exceeds more than 30 percent in Bailhongal, Khanapur, Naragund, and Ron talukas of the basin (Fig.4).

The rainfall ratio was minimum in Hubli (102.5%) taluka and maximum in Bailhongal (198.7%) taluka, with an average of 81.6 percent. The spatial distribution depicts that the rainfall ratio is high (more than 140%) only in Bailhongal taluka; it ranges from 120–140 percent in Khanapur, Ramadurga, Saundatti, Badami, Hunagund, and Naragund talukas; and a low (120%) ratio was observed in Gadag, Ron, Dharwad, Hubli, Kundagol, and Navalgund talukas of the basin (Fig - 4).

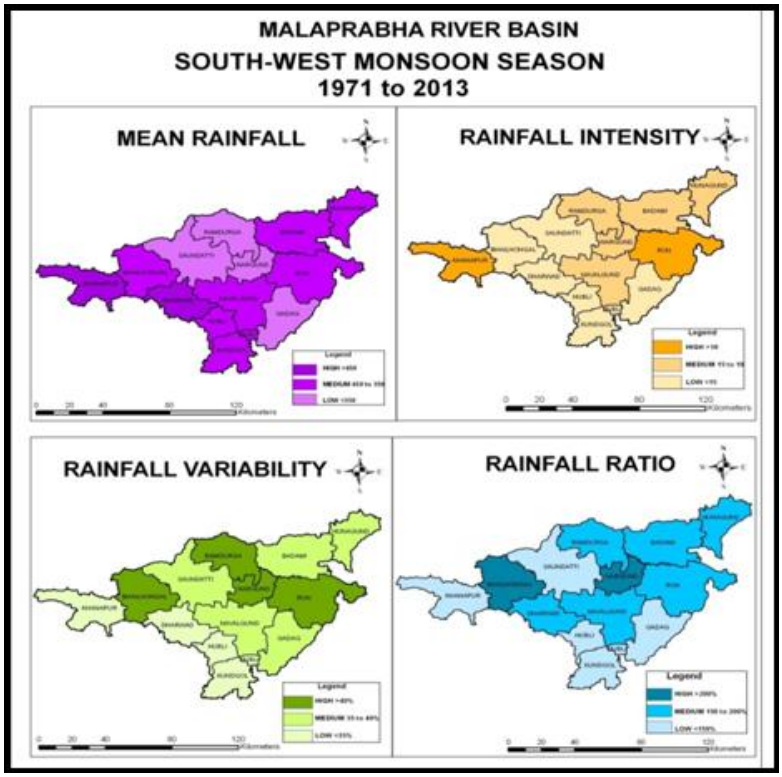


Figure 3

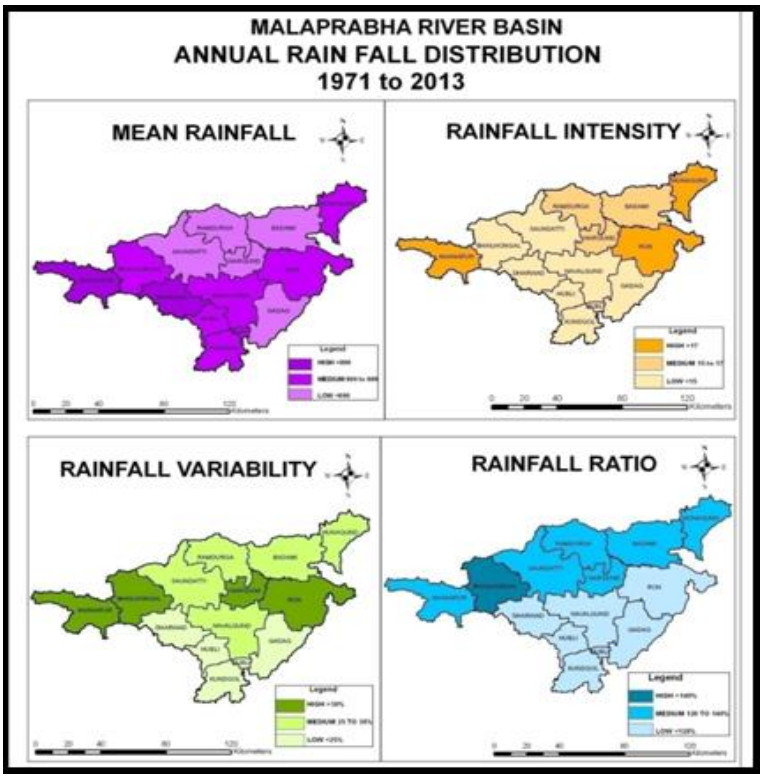


Figure 4

6.4 Departure of Rainfall from Normal Rainfall of the MRB:

Deficient or excess rainfall years are defined when the rainfall of that year departs from the normal rainfall. During the entire study period (1971–2013), there were 20 years that recorded annual rainfall below average (Fig.5). Guhathakurta and Rajeevan (2008) studied the rainfall pattern over India and found 30 years of alternating sequences of dry and wet periods. They delineated the twentieth century into (a) 1901–1930 as a dry period; (b) 1931–1960 as a wet period; (c) 1961–1990 as a dry period; and (d) 1991–2020 as a likely wet period. During the multi - decadal dry periods of 1901–1930 and 1961–1990, there were 12 years (6 years in each spell) of negative deviation of annual rainfall with more than 200 mm over the country. Similarly, during the wet period 1931–1960, there were six years of positive deviation of annual rainfall of more than 200 mm.

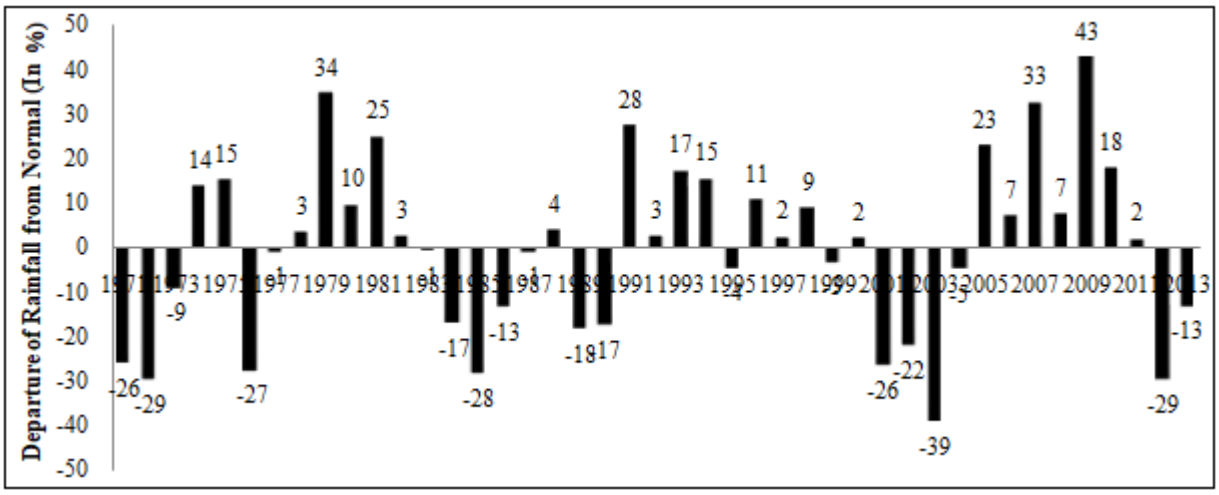


Figure 5: Departure of Rainfall from Normal Rainfall of Malaprabha River Basin; 1971-2013

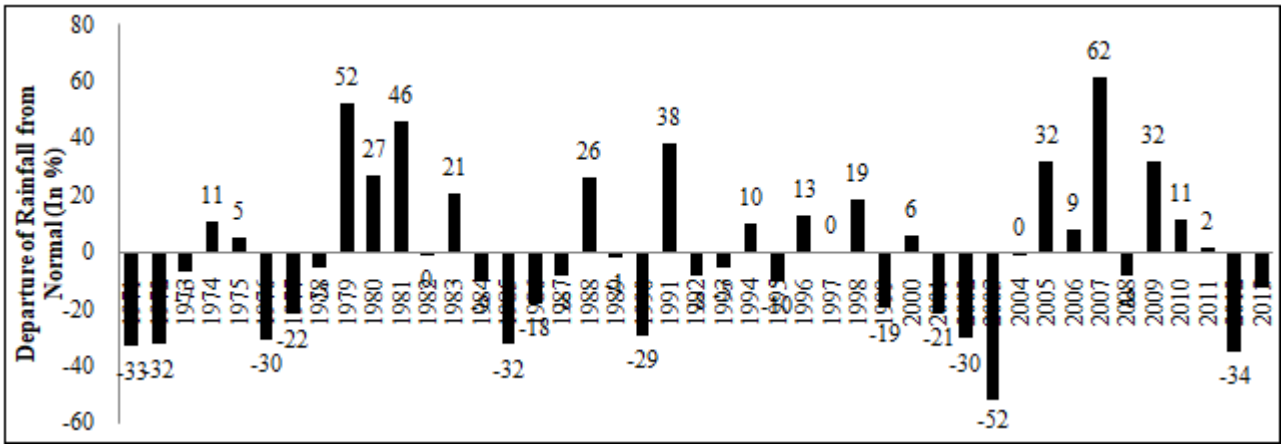


Figure 6: Departure of Rainfall from Normal Rainfall during South-West Weather Season of Malaprabha River Basin; 1971-2013

Rainfall deviation during the monsoon period had alternate positive and negative deviations from mean rainfall, but the amount of deviation was higher in the positive direction (22 years) (Fig.6). This is also validated by the one - way ANOVA test analysis (Table 14). For agricultural reasons, this declining trend is more important since agriculturalists traditionally grow more crops during this season.

Table 14: Comparison of Talukas with Rainy days & Rainfall during South - West Monsoon Season& Annual of MRB from 1971 to 2013 by one way ANOVA Test

Seasons	Variables	Source of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F - value	P - value
South - West Monsoon (Jun - Sept)	Rainy days	Between talukas	100181.49	12	8348.46	147.3570	0.00001*
		Within talukas	30933.44	546	56.65		
		Total	131114.93	558			
	Rain fall	Between talukas	109298144.59	12	9108178.72	183.9117	0.00001*
		Within talukas	27040503.13	546	49524.73		
		Total	136338647.71	558			
Annual (Jan – Dec)	Rainy days	Between talukas	109016.28	12	9084.69	108.7829	0.00001*
		Within talukas	45597.61	546	83.51		
		Total	154613.89	558			
	Rain fall	Between talukas	107945738.44	12	8995478.20	144.3357	0.00001*
		Within talukas	34028530.67	546	62323.32		
		Total	141974269.11	558			

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.
*p<0.05 indicates the correlation is significant at 5% level of significance.

6.5 The Rainfall Recharge of the MRB:

The rainfall recharge of the Malaprabha river basin has been worked out using Radhakrishna *et al.*, Method (1974), U. S. Geological Method (1962), Seghal's Method (1970) and Krishna Rao (1970) Method:

According to Radhakrishna *et al. 's (*1974) method, the rainfall recharge of an area or basin is 10 percent of the rainfall. The minimum rainfall recharge was observed in Ramadurga (50.54 mm) station and the maximum in Khanapur (222.86 mm) station (Table 15), and the average annual rainfall recharge was about 73.68 mm. According to the U. S. Geological Method (1962), the annual rainfall recharge of an area or a basin is 15 percent of the annual rainfall. According to this method, the minimum annual recharge of 75.81 mm is found in Ramadurga station, and the maximum recharge of 334.29 mm is found in Khanapur station. The annual recharge of the basin is 110.52mm. Seghal (1973) has worked out groundwater recharge as G = 2.5 (P - 16) 0.5, where precipitation is in inches. According to this method, the annual rainfall recharge is relatively high. They vary from a minimum of 125.36 mm in Ramadurga station to a maximum of 537.84 mm in Khanapur station. The average annual recharge of the basin is 229.02mm.

According to Krishna Rao's (1970) method, the annual recharge is R = 0.20 (P - 400) when precipitation is between 400 mm and 600mm, R = 0.25 (P - 400) when precipitation is 600 to 1000 mm, and R = 0.35 (P - 600) when precipitation is 1000mm and above 2000mm. The annual recharge varied from 21.08 mm to 570.00 mm during the study. The minimum was seen in Ramadurga station and the maximum in Khanapur (570.00mm) station. The annual recharge of the basin is 84.19mm. The average of the four methods is worked out for each station in the Malaprabha river basin. The average annual recharge varies from a minimum of 68.19mm in Ramadurga station to a maximum of 416.25mm in Khanapur station. The average rainfall recharge of the basin is 124.35mm. Rainfall recharged is the total geographical area of the mean annual recharge of 1, 436, 118, 000 m3.

Table 15: Annual Rainfall Recharge of the Malaprabha River Basin (1971 to 2013)

S. No	Talukas	Average Annual Rainfall in mm	Radhakrishna et. al Method (1974)	U. S. Geological Method (1962)	Seghal's Method (1973)	Krishna Rao Method (1970)	Average Recharge in mm
1	Bailhongal	683.33	68.33	102.50	209.65	70.83	112.83
2	Khanapur	2228.58	222.86	334.29	537.84	570.00	416.25
3	Ramadurga	505.38	50.54	75.81	125.36	21.08	68.19
4	Saundatti	522.05	52.21	78.31	135.53	24.41	72.61
5	Badami	563.23	56.32	84.48	157.77	32.65	82.81
6	Hunagund	612.45	61.25	91.87	180.88	53.11	96.78
7	Gadag	581.00	58.10	87.15	166.49	36.20	86.98
8	Naragund	519.77	51.98	77.97	134.17	23.95	72.02
9	Ron	641.90	64.19	96.29	193.35	60.48	103.58
10	Dharwad	851.59	85.16	127.74	265.65	112.90	147.86
11	Hubli	616.13	61.61	92.42	182.46	54.03	97.63
12	Kundagol	625.34	62.53	93.80	186.41	56.33	99.77
13	Navalgund	609.05	60.91	91.36	179.34	52.26	95.97
	MRB	736.77	73.68	110.52	229.02	84.19	124.35

Source: Computed from Rainfall Data collected from DES, Rainfall Division, Bangalore, Karnataka State.

7. Conclusions

Using 43 years (1971–2013) of rainfall data, here we analyse the rainfall pattern, variability, and changes of the SW Monsoon season and annual rainfall for talukas in the Malaprabha River Basin, Karnataka state. The talukas spatial patterns are deliberated to study mean monthly, seasonal, and annual rainfall, Standard Deviation (SD), Standard Error (SE), and Coefficient of Variation (CV) rainfall. The statistical methods adopted by Bhargava (1977) are used for the analysis of annual mean rainfall, rainfall intensity, rainfall variability, and rainfall ratio. This study brought out many significant features of the rainfall pattern that can be utilised for water and agricultural management in the MRB. Some of the important findings are summarised below:

- The average annual normal rainfall was 736.8 mm in the river basin from 1971 to 2013, with a coefficient of variation of 68.59 percent, indicating that it is highly variable. Rainfall during July is the highest (135.89 mm) and contributes 18.44% of annual rainfall (736.77 mm), followed by September (17.53%), June (17.17%), August (15.78%), and October (13.60%), respectively.
- The annual average rainfall of the Malaprabha river basin area is over 736.8 mm spread over 44.7 rainy days. However, its spatial and temporal distribution are not uniform. The normal annual rainfall was about 505.3 mm spread over 30.8 days in Ramadurga taluka, whereas 2228.6 mm of rainfall spread over 84.4 days in Khanapur taluka of the river basin.
- The spatial distribution of rainfall in the basin depicts the decreasing trend of rainfall from the western part to the eastern part of the basin. The western margin of the study area receives higher rainfall with a higher number of rainy days (more than 2, 200 mm) during June–September due to the orographic effect, whereas the eastern margin of the basin remains dry due to its location on the leeward side of the Western Ghats. However, the southeast part of the basin gets moderate amounts of rainfall from the northeast monsoon. Most of the drought phenomena occur in the eastern part of the river basin due to the low rainfall and fewer rainy days.
- The rainfall intensity of the basin ranges from 12.7 mm per rainy day in Kundagol taluka to a maximum of 26.4 mm per rainy day in Khanapur taluka. The average rainfall intensity is 16.5 mm per rainy day. The minimum

rainfall variability of the basin was seen in Hubli (23.8%) and the maximum in Bailhongal (33.3%) taluka, with an average of 68.5 percent. The rainfall ratio of the basin was minimum in Hubli (102.5%) taluka and maximum in Bailhongal (198.7%) taluka, with an average of 81.6 percent.

- Rainfall deviation during the monsoon period had alternate positive and negative deviations from mean rainfall, but the amount of deviation was higher in the positive direction (22 years). During the entire study period (1971–2013), there were 20 years that recorded annual rainfall below average. This is also validated by the one - way ANOVA test analysis. For agricultural reasons, this declining trend is more important since agriculturalists traditionally grow more crops during this season.
- The average annual recharge varies from a minimum of 68.19 mm in Ramadurga station to a maximum of 416.25 mm in Khanapur station. The average rainfall recharge of the basin is 124.35 mm. Rainfall recharged is the total geographical area of the mean annual recharge of 1, 436, 118, 000 m^3.
- The entire study results i. e. south west seasonal and annual rainfall analysis can help the planners, administrators and the stake - holders (largely the agriculturalists) to strategize the development, management and utilization activities.

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