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Rainfall Pattern Analysis in the Three Major Valley Systems of Bengaluru

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Abstract Bengaluru has three major valley systems, i.e., Vrishabhavathi Valley (V-Valley), Hebbal Valley and Kormangala-Challaghatta Valley (K-C Valley) which are the repositories of many lakes. Due to the increasing population, urbanization and industrialization, the lakes and their drainage areas are being encroached. Bengaluru is facing the problem of flooding. Hence, the rainfall analysis is very important to understand the rainfall pattern, trend as well as its quantity. Rainfall analysis helps to predict urban floods. In the present study, the Taluk level station rainfall data was collected from Karnataka State Natural Disaster Monitoring Cell (KSNDMC) for the period of 50 years from 1971 to 2020 and the same was analyzed for monthly, seasonal and annual periods using the Thiessen polygon method. Based on the monthly rainfall analysis carried out in the valley systems, it is observed that the highest rainfall occurs during the month of September, i.e., nearly 20% of the total annual rainfall, whereas the January month contributes the least amount of rainfall. Based on the seasonal rainfall analysis, it is known that the South-West Monsoon contributes to the highest percentage of rainfall when compared to other two season. The South-West Monsoon contributed to nearly 54.7%, 55% and 55.4% of the total annual rainfall in the Hebbal Valley, K-C Valley and Vrishabhavathi Valley respectively. The normal average annual rainfall is observed to be 830.1mm, 890.2mm and 1002.2mm respectively for Hebbal Valley, K-C Valley and Vrishabhavathi Valley when calculated from the past 50 years data (1971 to 2020). Hebbal Valley has received a lowest rainfall of 455mm during 2012 and Vrishabhavathi Valley has recorded the highest rainfall of 1556.2mm during 2005. When analyzed annually, it was observed that the highest rainfall of 1321.2 mm (2005) and lowest rainfall of 455mm (2012) was recorded in the Hebbal Valley. In the K-C Valley, the maximum rainfall observed was 1225.3mm (2004) and the minimum rainfall of 623.9mm was observed (1985). In the Vrishabhavathi Valley, the highest rainfall of 1556.2mm (2005) was recorded and the least rainfall of 551.3mm (2012) was recorded. Since all the valleys are located spatially adjacent to each other, they experience similar kinds *of* monthly and seasonal rainfall pattern. The rainfall pattern in the three valleys shows an increasing trend.

Keywords: *Hebbal valley, Kormangala-Challaghatta Valley (K-C Valley), Vrishabhavathi Valley(V-Valley), Rainfall analysis, Thiessen Polygon, Monsoon etc*

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1. Introduction

Bengaluru has three major valley systems, i.e., Vrishabhavathi Valley, Hebbal Valley and Kormangala-Challaghatta Valley which are the repositories of lakes. These lakes form a cascaded system and when a lake fills, the excess water is outpoured into the next lake in the lower series. These lakes play a vital role in supporting life and ensure ground water recharge. Due to surplus population, urbanization and industrialization, the lake and its beds are encroached leading to loss of their interconnectivity. Bengaluru is facing the problem of flooding. Hence, the rainfall analysis/precipitation analysis is very important to understand the rainfall pattern, trend as well as its volume.

Precipitation is an important meteorological event in the Hydrological cycle. The variation in precipitation over space and times creates serious problems of floods and droughts. Precipitation may occur in liquid form(as rain, drizzle) or solid form (hail, snow, dew, frost etc). Rain is the precipitation of liquid water in which the drops are generally greater than 0.5mm in size. A part of rainfall reaches back to atmosphere by the process of evaporation, some part of it is intercepted by the vegetation and the rest reaches the ground surface (throughfall). The water that reaches the ground surface may get infiltrated or may be disposed as surface runoff finally joining water bodies/streams. Some portion of it directly falls on water bodies or streams. "Weather" is the state of atmosphere with respect to temperature, wind, humidity, cloudiness etc over a short period of time and "Climate" of a region is the aggregate of the weather relatively over a long period of time. The Indian Meteorological department (IMD), classifies seasons into four seasons namely Winter Season (January and February), Pre-monsoon season (March, April and May), South-west Monsoon(June, July, August and September) and North-East Monsoon (October, November and December).

2. Study Area

The three major valley systems comprises of Vrishabhavathi Valley (V-Valley), Hebbal Valley and Kormangala-Challaghatta Valley (K-C valley). The Vrishabhavathi Valley is one of the three major valleys in Bengaluru which forms a part of the Arkavathi River basin, a tributary of the River Kaveri. It has a catchment area of 382.5 Sq Kms and housing 88 lakes approximately when digitized on SOI topographical maps (1:50,000 scale). It is identified as the largest valley amongst the three major valleys. V-Valley is located in the Districts of Bengaluru Urban and Ramanagara. The Hebbal Valley is one of the three major valleys in Bengaluru draining into River Dakshina Pinakini. The Hebbal valley has a catchment area of 311.26 Sq Kms and 74 lakes approximately. It is located in the District of Bengaluru Urban and is also a repository of many lakes. The Koramangala-Challaghatta Valley is also one of the major valleys of Bengaluru with a catchment area of 289.68 Sq Kms and 85 lakes approximately. It is also located in the districts of Bengaluru Urban and Bengaluru Rural and finally drains into Dakshina Pinakini River similar to the streams of Hebbal Valley.

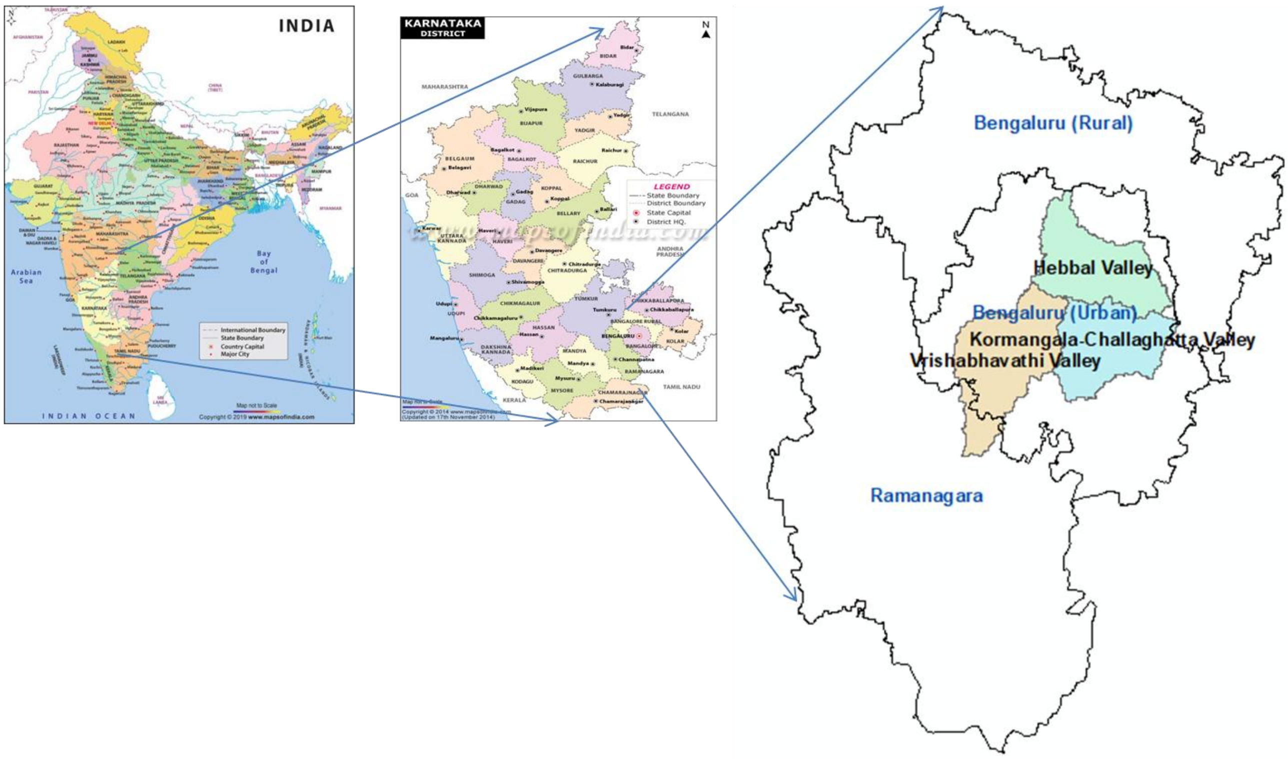

Figure 1. The Three major Valley Systems around Bengaluru: Vrishabhavathi Valley, Kormanagala -Challaghatta Valley and Hebbal Valley

3. Material and Methods

In the present study, the rainfall analysis was done in the three major valley systems i.e. Hebbal Valley, Kormangala-Challaghatta valley and Vrishabhavathi Valley using Thiessen polygon method for monthly, seasonal and annual period. The Taluk level station rainfall data was collected from Karnataka State Natural Disaster Monitoring Cell (KSNDMC) for the period of 50 years from 1971 to 2020 and the same was analyzed. Hebbal Valley rainfall analysis was carried out using KSNDMC point rainfall data of six rain gauge stations (Taluk level) namely Bangalore North, Bangalore East, Devanahalli, Doddaballapura, Hosakote and Nelamangala. Kormangala-Challaghatta Valley rainfall analysis was carried out using three rain gauge station's data namely Bangalore North, Bangalore East and Bangalore South. Vrishabhavathi Valley was carried out using five rain gauge station's data namely Bangalore North, Bangalore South, Nelamangala, Ramanagara and Magadi stations. Monthly, seasonal and annual rainfall analysis were carried out.

3.1. Monthly Rainfall Analysis

The point rainfall data of 50 years (1971 to 2020) was collected from KSNDMC and analyzed using weighted area average method. The daily rainfall data of each station was multiplied with Thiessen coefficient to get weighted average rainfall and monthly data was obtained by adding daily rainfall data. Using this data the percentage contribution of rainfall during each month, maximum and minimum contributing months were calculated.

3.2. Seasonal Rainfall Analysis

The rainfall data was analyzed for three seasons as Pre-Monsoon (January-May), South-West Monsoon (June to September) and North-East Monsoon (October-December). The seasonal rainfall percentage contribution and the season contributing highest rainfall were calculated.

3.3. Annual Rainfall Analysis

The Annual actual rainfall data was obtained by adding monthly rainfall data and the normal mean rainfall was calculated. Based on this data the rainfall deviation was calculated using the formula:

$$Rainfall\ Deviation = \frac{\begin{pmatrix} Annual\ Actual\ Rainfall \\ -Normal\ Mean\ Rainfall \end{pmatrix}}{Normal\ mean\ Rainfall} * 100$$

Rainfall was classified into different categories based on the Indian Meteorological Department (IMD) Rainfall distribution classification.

4. Results and Discussion

In the present study, Thiessen polygon method is used to estimate the rainfall in the three major valley systems. The Thiessen polygon generated for the study area using the KSNDMC rain gauge stations are represented in the Figure below.

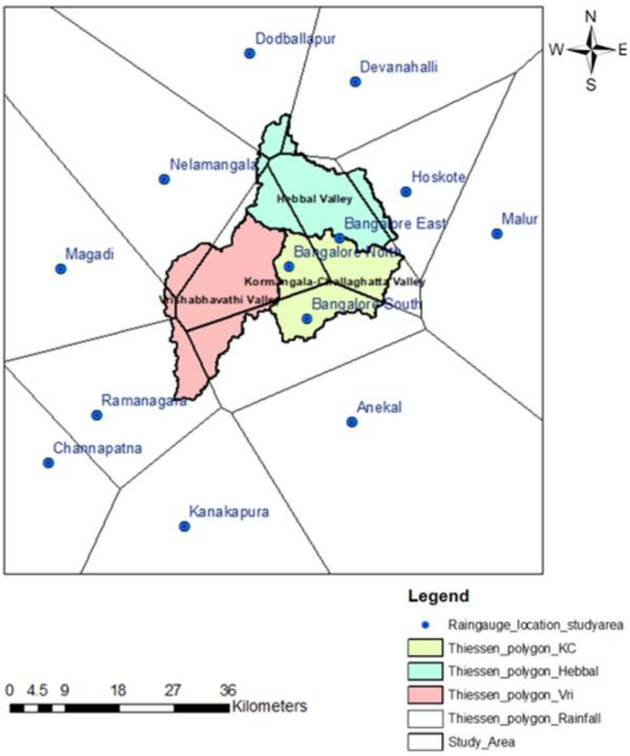

Figure 2. Thiessen polygon generated for the study area along with rain gauge station locations

4.1. Monthly Rainfall Analysis

The point rainfall data of 50 years i.e. from 1971 to 2020 was collected from KSNDMC and analyzed using weighted area average method. The analysis shows that the Hebbal Valley receives maximum monthly average rainfall of 168.7mm and 145.4 mm during the months of September and October respectively. The least monthly weighted average mean rainfall is observed during the month of January i.e. 1.4mm. The K-C Valley receives maximum monthly average rainfall of 180.0 mm and 153.0 mm during the months of September and October respectively. The least monthly weighted average mean rainfall is observed during the month of January i.e. 1.4mm. The Vrishabhavathi Valley receives maximum monthly average rainfall of 205.3 mm and 168.6 mm during the months of September and October respectively. The least monthly weighted average mean rainfall is observed during the month of January i.e. 1.4mm. All the three valleys show similar monthly mean rainfall pattern since these valleys are located spatially adjacent to each other. In all the three valleys we can observe highest monthly mean rainfall during September and least during January.

Table 1. Monthly mean rainfall in mm (50 years mean)

Months	Hebbal Valley (Monthly mean Rainfall in mm)	K-C (Monthly mean Rainfall in mm)	V-Valley (Monthly mean Rainfall in mm)
Jan	1.4	1.4	1.4
Feb	5.8	6.3	6.2
Mar	15	16.4	16.9
Apr	43.9	47.2	57.2
May	98.5	107	121.9
Jun	78.9	87.7	94.4
Jul	90.2	96.9	111.2
Aug	115.7	125	144.8
Sep	168.7	180	205.3
Oct	145.4	153	168.6
Nov	52.1	53.9	58.8
Dec	13.9	15.2	15.5

The contribution of rainfall percentage from each month was calculated and is shown in the form of pie charts below.

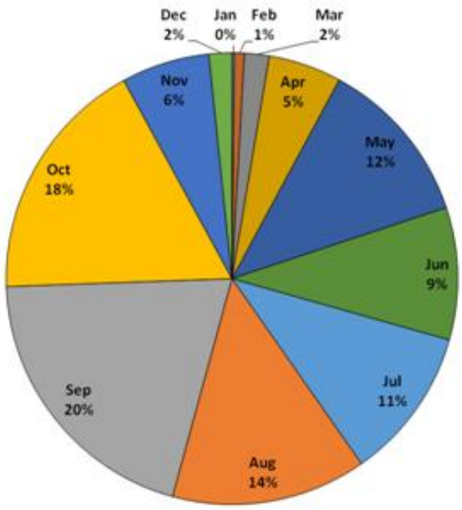

Figure 3. Pie chart representing the monthly rainfall percentage contribution in the Hebbal Valley

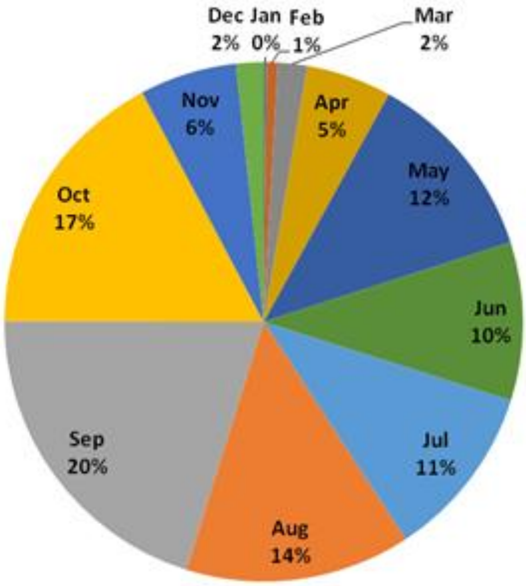

Figure 4. Pie chart representing the monthly rainfall percentage contribution in the K-C Valley

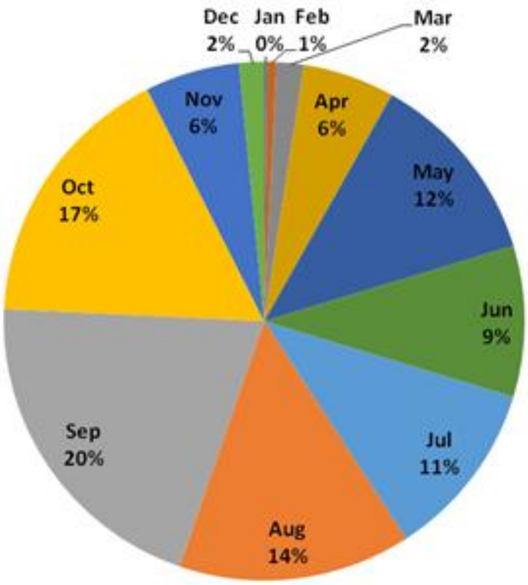

Figure 5. Pie chart representing the monthly rainfall percentage contribution in the Vrishabhavathi Valley

4.2. Seasonal Rainfall Analysis

The rainfall data was analyzed for three seasons as Pre-Monsoon (January-May), South-West Monsoon (June to September) and North-East Monsoon (October-December). In the Hebbal Valley region, the pre-monsoon rainfall contributed to 19.8% of the total rainfall, South-West Monsoon (S-W Monsoon) contributed to 54.7% of the total rainfall and the North-East Monsoon (N-E Monsoon) contributed to 25.5% of the total rainfall. In the K-C Valley region, the pre-monsoon rainfall contributed to 20% of the total rainfall, S-W Monsoon contributed to 55% of the total rainfall and N-E Monsoon contributed to 25% of the total rainfall. In the Vrishabhavathi Valley region, the pre-monsoon contributed to 20.3% of the total rainfall, S-W Monsoon contributed to 55.4% of the total rainfall and N-E Monsoon contributed to 24.2% of the total rainfall. The South-west monsoon contributes to highest percentage of rainfall in all the three valleys, which holds good for the Bengaluru District as well as the Karnataka State. The seasonal rainfall percentage contribution is tabulated in the Table 2 below.

Table 2. Seasonal Rainfall Contribution (%) in the three major valley systems

Season	Rainfall Contribution(%)		
	Hebbal Valley	Kormangala-Challaghatta Valley	Vrishabhavathi Valley
Pre-Monsoon	19.8	20	20.3
South-west Monsoon	54.7	55	55.4
Post-Monsoon	25.5	25	24.2

Table 3. Annual actual rainfall in mm

Year	**Annual actual rainfall in mm**		
	Hebbal Valley	**K-C Valley**	**Vrishabhavathi Valley**
1971	823.9	837.4	1011.8
1972	800.9	869.2	1012.6
1973	868.7	899	1081.1
1974	863.2	926.5	988.2
1975	980.8	897.8	1285.1
1976	688	815.1	785.8
1977	914.9	884.4	1148.1
1978	719.4	800.6	924.8
1979	876.6	829.9	1109
1980	586.4	706.3	806.5
1981	749.2	774.4	855.3
1982	672	733.8	716.3
1983	717.6	765.4	996.1
1984	666.3	674.4	742
1985	547.8	623.9	622
1986	670.6	711.9	882.8
1987	739.8	818	867.1
1988	868.9	867.4	1074.6
1989	728.9	718.1	866.2
1990	533.1	820.5	573
1991	1210.7	1083	1323.9
1992	722.1	873.5	937.7
1993	1001.3	875.6	1141.7
1994	572	676.8	640.7
1995	830.7	952.4	1004.5
1996	967.3	1141.5	1183.3
1997	1036.8	1108	1055.9
1998	1127.6	1128.3	1431.1
1999	894.9	981.5	1123.8
2000	1005.8	1063.4	1288.9
2001	938.8	879.9	1090.4
2002	609.2	668.5	741.2
2003	589.5	820.7	753
2004	1037.5	1225.3	1213.6
2005	1321.2	1147.2	1556.2
2006	552.1	773.6	691.1
2007	989.1	1133.9	1187.9
2008	1119.7	1151.9	1344.3
2009	915.6	938.6	1000.8
2010	851.3	922.6	1031.1
2011	875.5	762.3	975.7
2012	455.8	673.7	551.3
2013	925.1	872.6	1053.9
2014	619.1	854.8	849.2
2015	1072.8	963.5	1252.7
2016	618.5	978.1	776
2017	1160.4	1152	1434.8
2018	709.6	793.3	940.7
2019	738	967.3	988.7
2020	989.2	971.7	1195
Normal Mean Rainfall in mm	830.1	890.2	1002.2

4.3. Annual Rainfall Analysis

The Annual actual rainfall data was obtained by adding monthly rainfall data. The annual actual rainfall data is tabulated in the Table 3 and also represented in the form of bar diagrams.

The normal rainfall calculated for the period of 50 years (1971 to 2020) is 830.1mm, 890.2mm and 1002.2mm respectively for the Hebbal Valley, K-C valley and Vrishabhavathi Valley. In the Hebbal Valley the highest rainfall of 1321.2 mm was observed in the year 2005 and the lowest rainfall was observed during 2012 as 455mm. In the K-C Valley, the maximum rainfall of 1225.3mm was observed in the year 2004 and the minimum rainfall of 623.9mm was observed during 1985. In the Vrishabhavathi Valley, the highest rainfall of 1556.2 was recorded in the year 2005 and the least rainfall of 551.3mm was recorded during 2012. The Annual actual rainfall from 1971 to 2020 in the three major valleys are shown in the form of bar diagrams and the rainfall trend shows an increasing pattern in all the three valley systems.

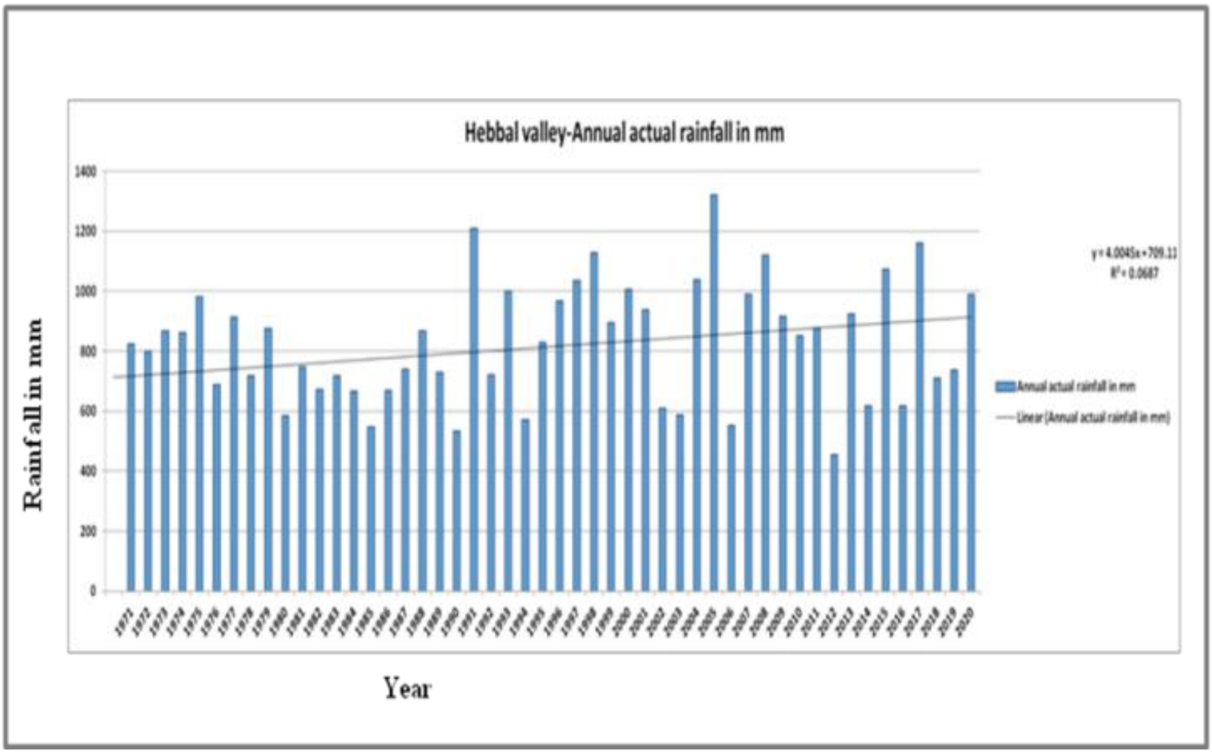

Figure 6. Hebbal Valley- Annual actual rainfall (in mm)

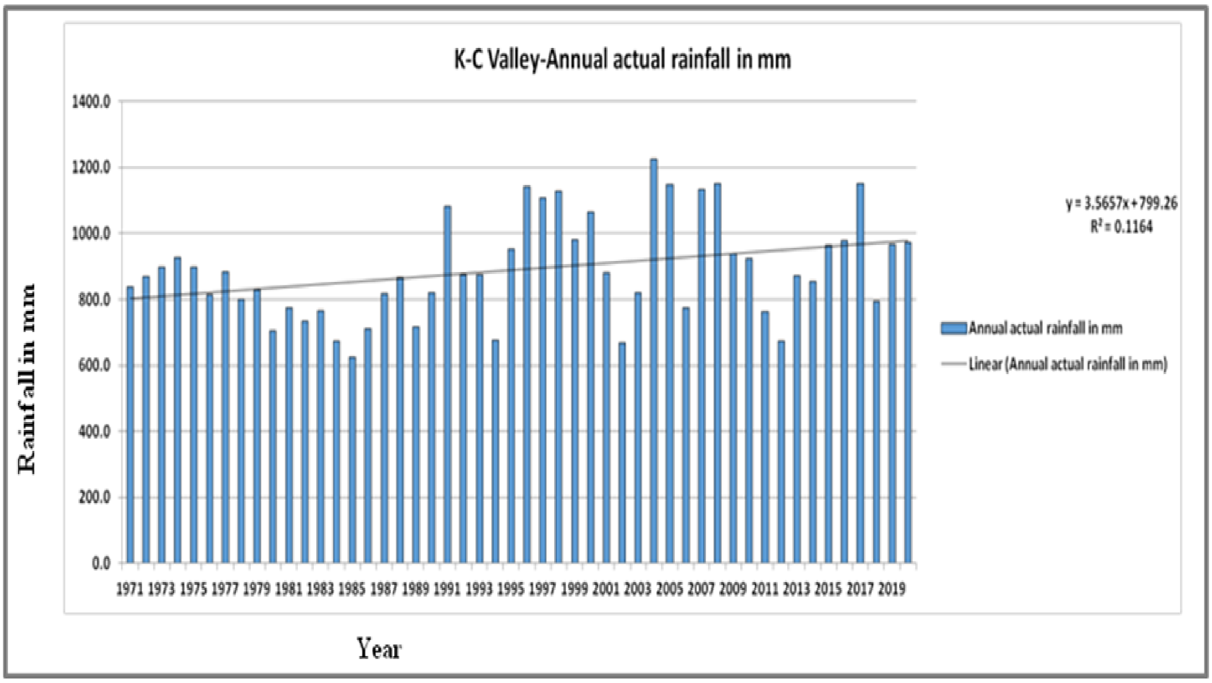

Figure 7. K-C Valley- Annual actual rainfall (in mm)

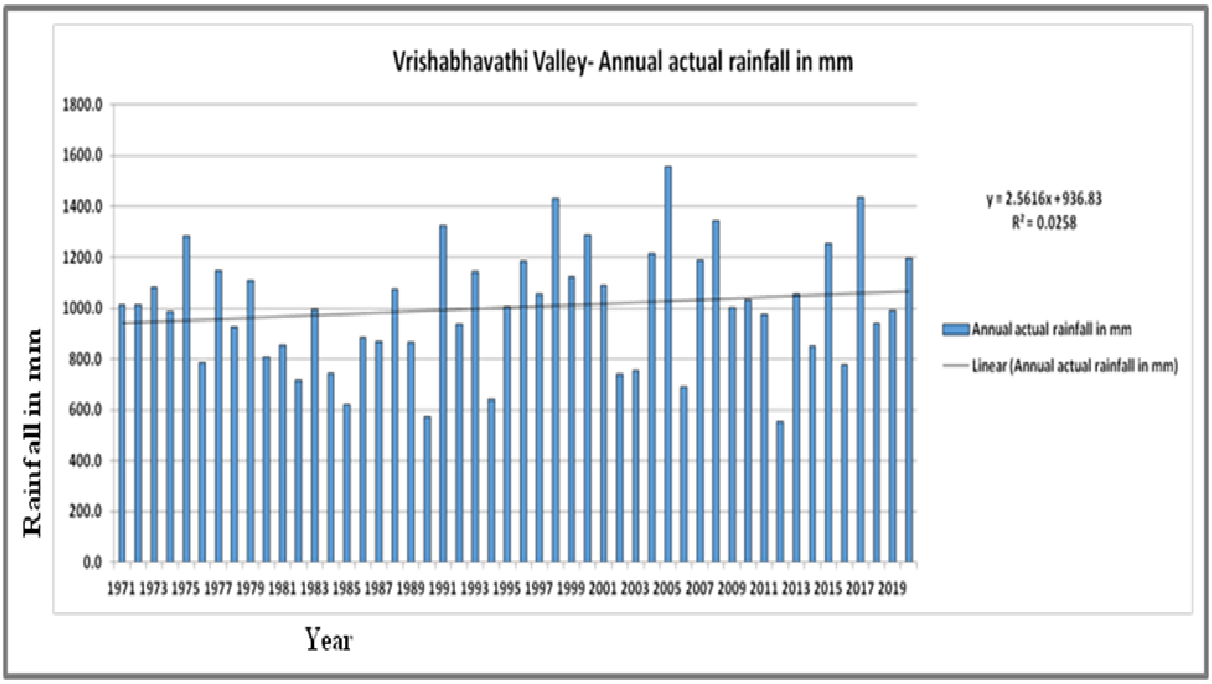

Figure 8. Vrishabhavathi Valley- Annual actual rainfall (in mm)

4.3.1. Rainfall Deviation

The below graphs represent rainfall deviation from the normal mean rainfall in the three major valleys systems around Bengaluru.

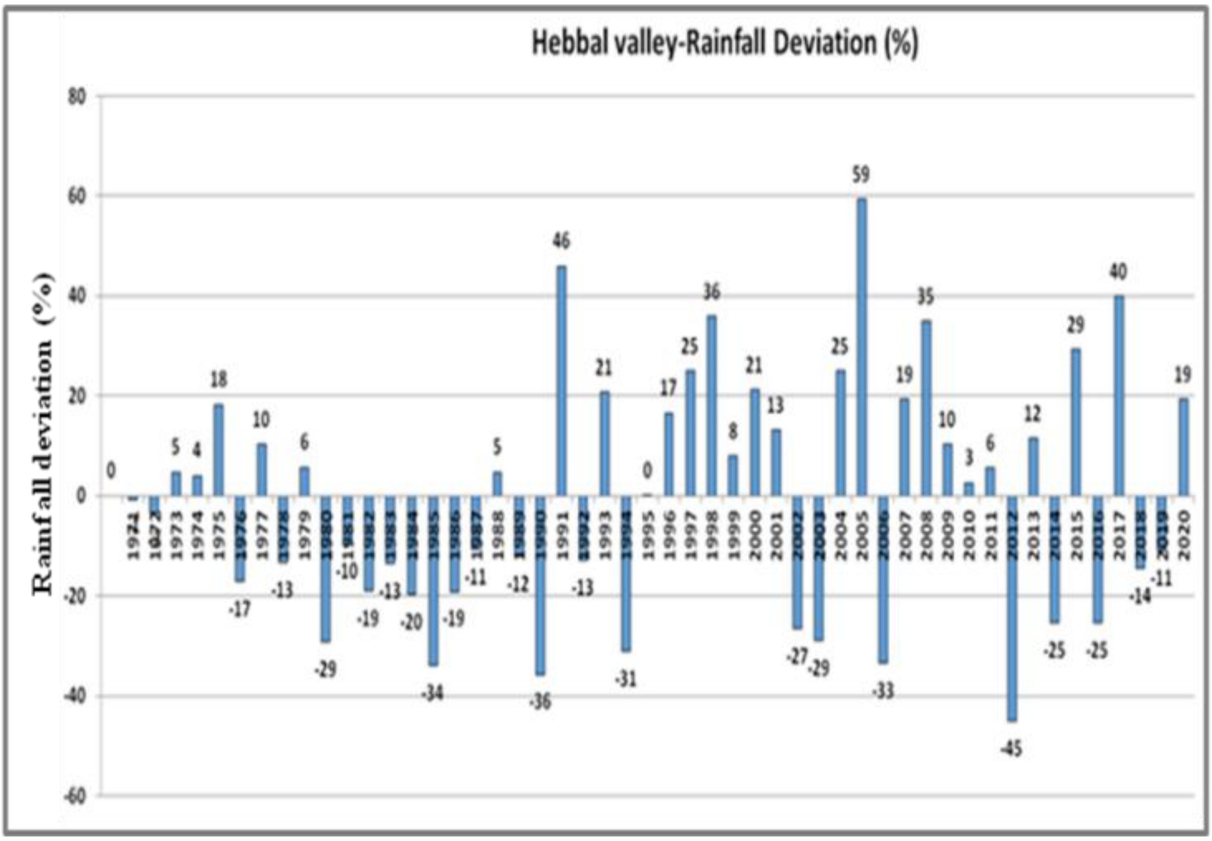

Figure 9. Percentage deviation of rainfall from normal mean rainfall in the Hebbal Valley

In the Hebbal Valley, it is observed that the actual rainfall is above the normal mean rainfall for 24 years and the actual rainfall is below normal mean rainfall for 25 years out of the 50 years data analyzed. Only in the year 1995 we can observe a value same as that of the normal mean rainfall data.

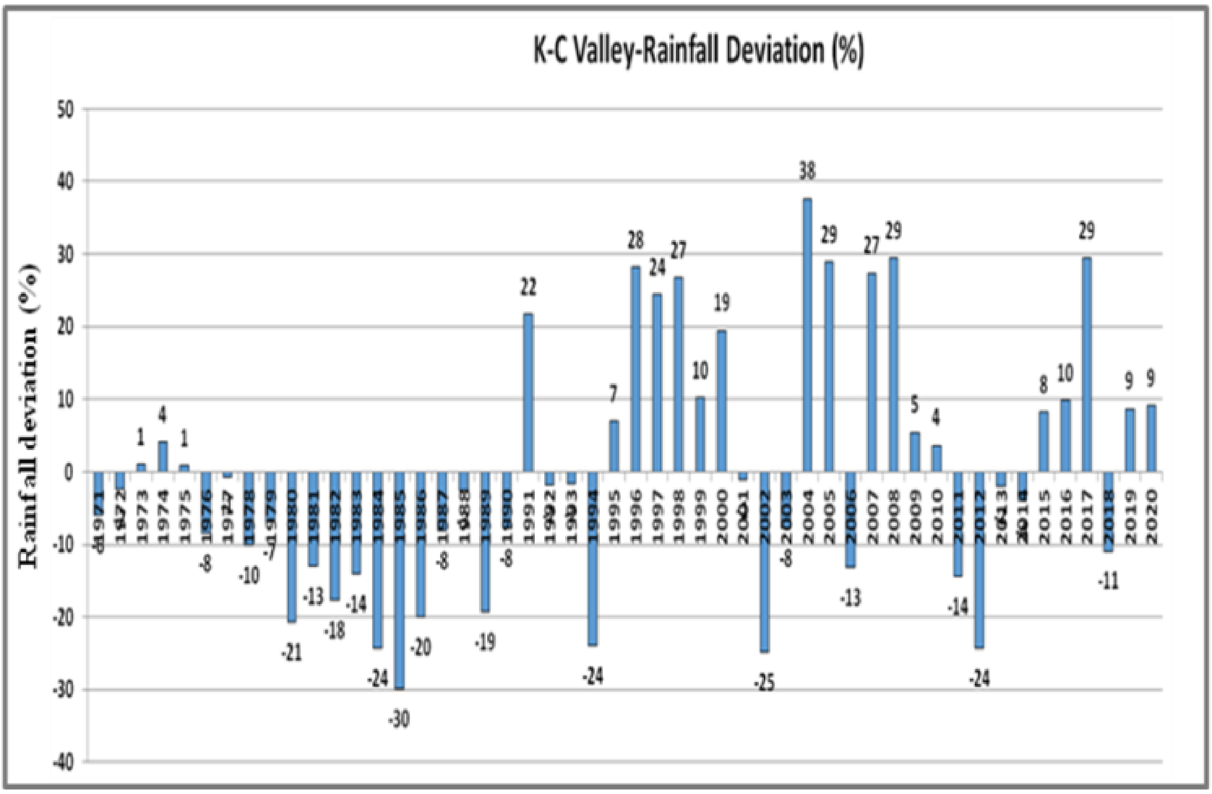

Figure 10. Percentage deviation of rainfall from normal mean rainfall in the K-C Valley

In the K-C Valley, it is observed that the annual actual rainfall is above normal mean rainfall value for 22 years and the actual rainfall is below normal mean rainfall value for 28 years out of the 50 years data analyzed.

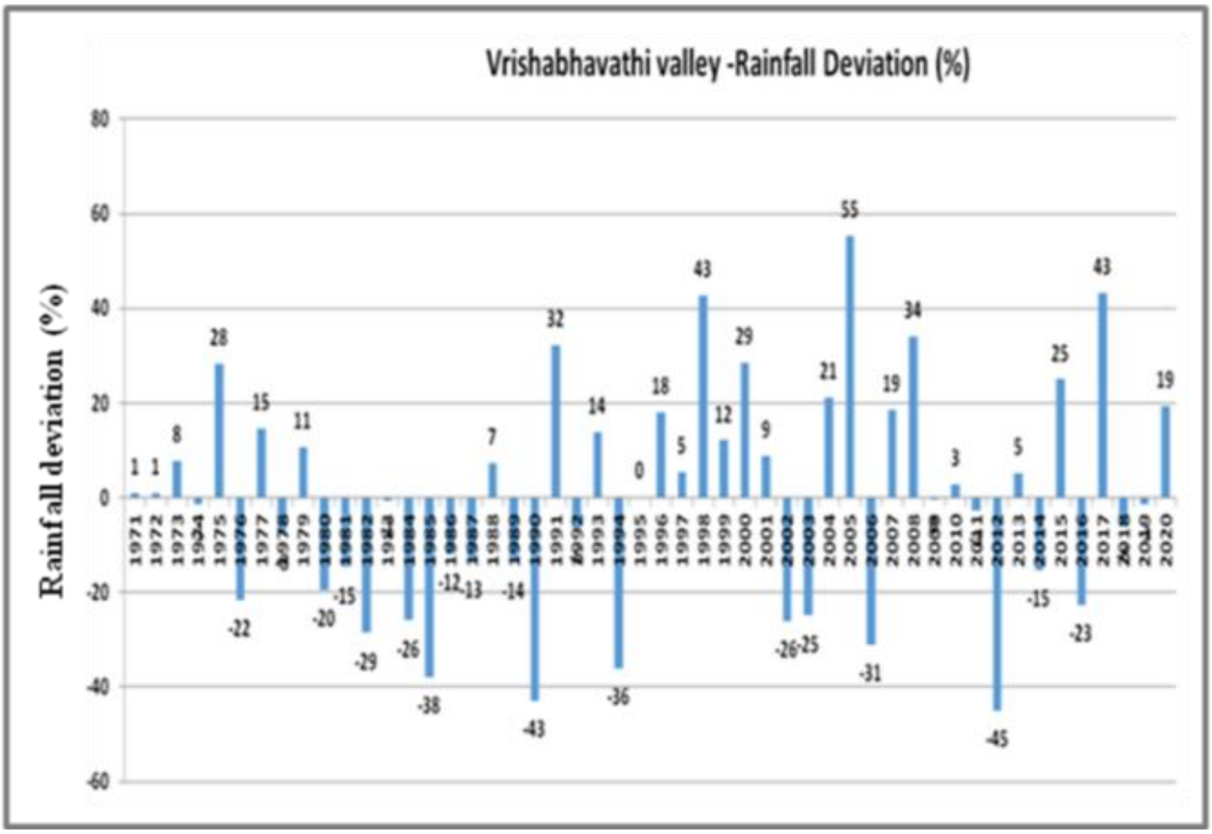

Figure 11. Percentage deviation of rainfall from normal mean rainfall in the Vrishabhavathi Valley

In the Vrishabhavathi Valley, it is observed that the actual rainfall is above the normal mean rainfall for 24 years and the actual rainfall is below normal mean rainfall value for 25 years. Only in the year 1995 we can observe a value same as that of the normal mean rainfall data.

4.3.2. Rainfall Classification Based on the Rainfall Departure from Normal mean Rainfall

Based on percentage departure of the rainfall, the annual actual rainfall has been categorized as per the Table 4 and Table 5 mentioned below.

Table 4. Rainfall distribution classification

Sl no	Percentage Departure of Rainfall	Distribution (Rainfall category)
1	+60% and above	Large Excess(LE)
2	+20% to +59%	Excess(E)
3	+19% to -19%	Normal(N)
4	-20% to -59%	Deficient(D)
5	-60% or less	Large deficient(LD)
6	-100%	No rain

Source: Indian Meteorological Department (IMD).

Table 5. Rainfall distribution classification for the three major valley systems

Sl no	Rainfall Category	Total number of years		
		Hebbal Valley	Kormangala-Challaghatta Valley	Vrishabhavathi Valley
1	Large Excess Rainfall	Nil	Nil	Nil
2	Excess Rainfall	10	9	9
3	Normal Rainfall	29	34	29
4	Deficient Rainfall	11	7	12
5	Large Deficient	Nil	Nil	Nil
6	No rainfall	Nil	Nil	Nil

From the analysis of 50 years data, it is observed that the Hebbal Valley has received normal rainfall pattern for 29years, deficient rainfall for 11 years and excess rainfall for 10 years. The K-C Valley has observed normal rainfall pattern for about 34 years, deficient rainfall for 7 years and excess rainfall for 9 years. The Vrishabhavathi Valley has observed normal rainfall pattern for 29 years, deficient rainfall for 12 years and excess rainfall for 9 years.

5. Conclusion

The increasing population, urbanization, industrialization, encroachment of lakes and their drainage areas are causing floods within the major valley systems of Bengaluru. The Rainfall data analyzed for the period of 1971 to 2020 (50 years) showed that the south-west monsoon contributes to nearly 55% of the total annual rainfall and the north-east monsoon contributes to nearly 25% of the total annual rainfall in all the three major valley systems. From the months of August (14%), September (20%) and October (17%), a rainfall amount greater than 50% of the annual rainfall can be observed, where as January (<1%) and February (1%) months contributes to least amount of rainfall. The normal annual rainfall calculated for the three Valley systems of Hebbal Valley, K-C Valley and Vrishabhavathi Valley are 830.1mm, 890.2mm and 1002.2mm respectively. Since all the valleys are spatially located closely, they experience similar kind of monthly and seasonal rainfall pattern. Comparatively, Hebbal Valley has received the lowest rainfall of 455mm during 2012 and Vrishabhavathi Valley has recorded the highest rainfall of 1556.2mm during 2005. The graph of annual rainfall pattern from1971 to 2020 shows an increasing trend of rainfall in all the three Valley systems (Figure 6, Figure 7 and Figure 8). In the span of 50 years, the valley systems have also experienced excess rainfall in a few years. Many lakes are also being fed with untreated sewage. Hence, it is very important to understand the rainfall pattern and intensity, calculate the surface runoff and map the flooding zones within the valley systems. A proper flood management strategy helps us to save lives and properties within the valley systems.

Acknowledgements

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Future Scope

Individual storm event can be studied and runoff analysis can be done.

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