



Variability of Rainfall in Bangalore city-Mapping of hourly variation of heavy rainfall event

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Abstract: This paper deals with study of Rainfall characteristics of Bangalore city, the capital of Karnataka state. Taluk wise rainfall data for 50 years is analyzed for various statistical analysis. The paper also highlights the variability of rainfall in Bangalore city. Bangalore city has suffered during the 2014 rains. The city witnessed a record breaking rainfall of 140mm /day during the month of October.. Variability of rainfall is better appreciated if the resolution of the rainfall measurement is enhanced. . Bangalore has been identified as one of its kind in the country to have established a dense network of 100 Telemetric Rain Gauge stations within 800 sq km city area to Monitor Rainfall. The Daily and hourly variation of one particular heavy rain event is displayed in this paper to appreciate the resolution of the rainfall data.

Key words: Rainfall, variability, Monitor rainfall, High rain event, Bangalore

I. Introduction

Variability in the rainfall pattern needs to be understood, as it is the key input for flood forecast and hydrological modelling. It is an important issue in the hydrological science (Atmospheric Research 137 (2014) 176–182). Bangalore was once called the garden city. Due to rapid urbanisation the city has transformed to a concrete bunch. Due to global warming and increased human activities, the climate of the city is varying. The city used to experience a temperature from min 15 deg in winter to max of 33deg in summer. The annual rainfall is about 920mm. The climatic condition now has gone beyond extremes, the city has suffered an extreme heat of 40deg during the April May in 2014 to a coldest of 10deg during October and November. Bangalore receives rainfall from both the northeast and the southwest monsoons and the wettest months are September, October and August.. The city received a record breaking rainfall of 140mm/ day during 2014 October which is more than 20% of the annual rainfall in a single day. Such a variability needs to be understood. Hence the present paper brings about the summary of the statistical variation and indicates the value of high resolution sensors to study the rainfall variability.

II. Materials and Methods

II.1. Study Area

The study area is the Bangalore urban district. the municipal corporation is called the BBMP. The statistical analysis is done for the Bangalore Urban district and the high resolution variability shall be displayed for the BBMP (city area) area. Bangalore is the capital of Karnataka state in India. The Bangalore city has an area of 800 sq km.

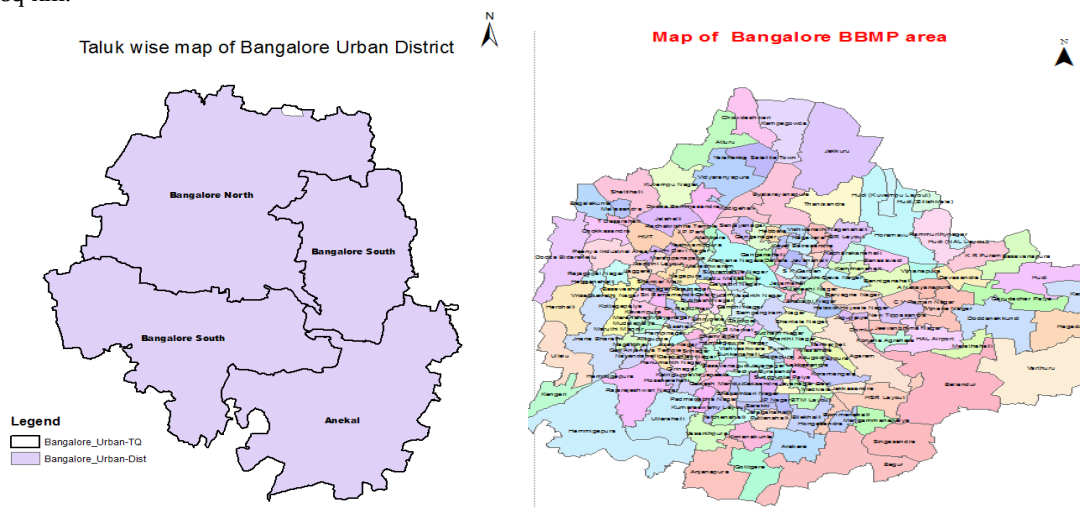


Fig. 1: Map showing the taluks of Bangalore Urban and Bangalore BBMP (city)

II.2. Rainfall data and Statistical Analysis for Historical data

Daily Rainfall data is collected from 1963-2013 .For statistical characteristics the taluk wise data for 50 years for Bangalore North and Bangalore south is considered . In order to understand the daily and hourly variation of heavy rain events hourly data for the 2014 is considered.The entire data set is carefully checked and missing data is filled from the nearby stations.

Mean Vs Normals

The mean monthly rainfall is calculated and compared with the normals.The following table gives the comparison.

Taluk	Month	Mean(mm)	Normal(mm)	Taluk	Month	Mean (mm)	Normal(mm)
Bangalore North	Jan	1.213725	2	Bangalore South	Jan	1.364	2
	Feb	5.662549	7		Feb	6.172	8
	Mar	10.84294	8		Mar	14.23167	10
	Apr	50.07353	37.2		Apr	42.80505	39.6
	May	109.7623	98.1		May	102.5917	110.3
	Jun	85.46961	71		Jun	84.06147	72.9
	Jul	115.4322	92		Jul	92.8494	99
	Aug	134.8437	129.3		Aug	118.0824	117.3
	Sep	177.808	170		Sep	173.5902	179.1
	Oct	161.6351	152		Oct	147.3396	163.3
	Nov	63.47078	50.8		Nov	60.0346	60.3
	Dec	20.59957	15.1		Dec	14.67079	17.2

Table 1: Table showing comparison of Mean and Normal rainfall

Most of the rain water goes as surface runoff .Precipitation here is usually short duration , high intensity rainfall The rainest months are during september and october.The average rainfall recorded in a month is as given in the table :1. The maximum rainfall recorded during the month of october is 178.9mm and minimum is 9.6 mm as shown in table:2. Hence the rainiest month is october.

Highest and Lowest Rainfall

Month	Highest Rainfall(mm)	Lowest Rainfall (mm)
Jan	24.2	0
Feb	42.5	0
March	94.5	0
April	108.6	0
May	116.9	0.8
June	103.76	0
July	123.5	3.5
Aug	103	3.6
Sep	108.4	9.6
Oct	178.9	2.9
Nov	105.6	0
Dec	71.3	0

Table 2: Table showing highest and lowest rainfall recorded in particular months

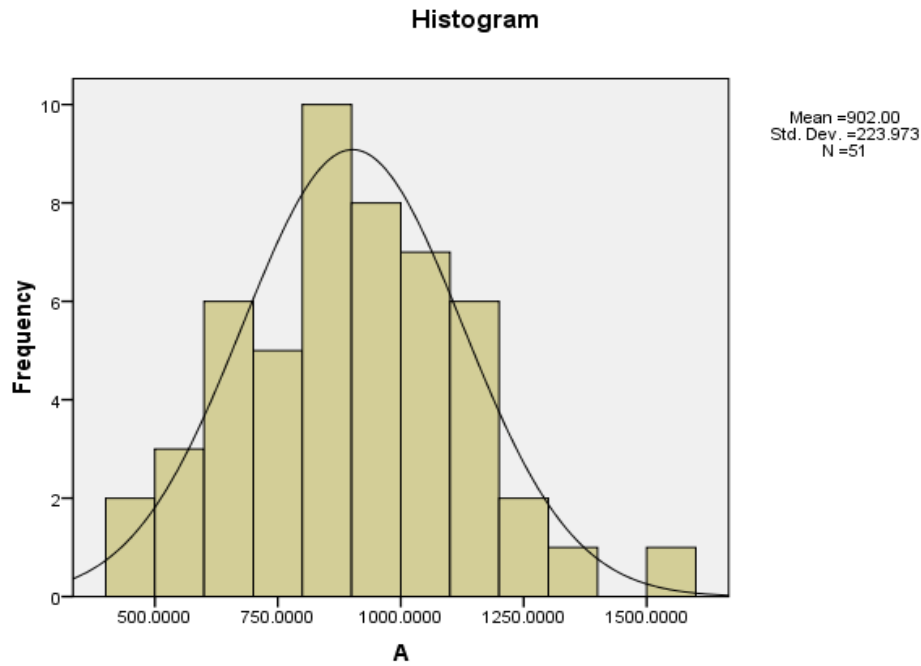
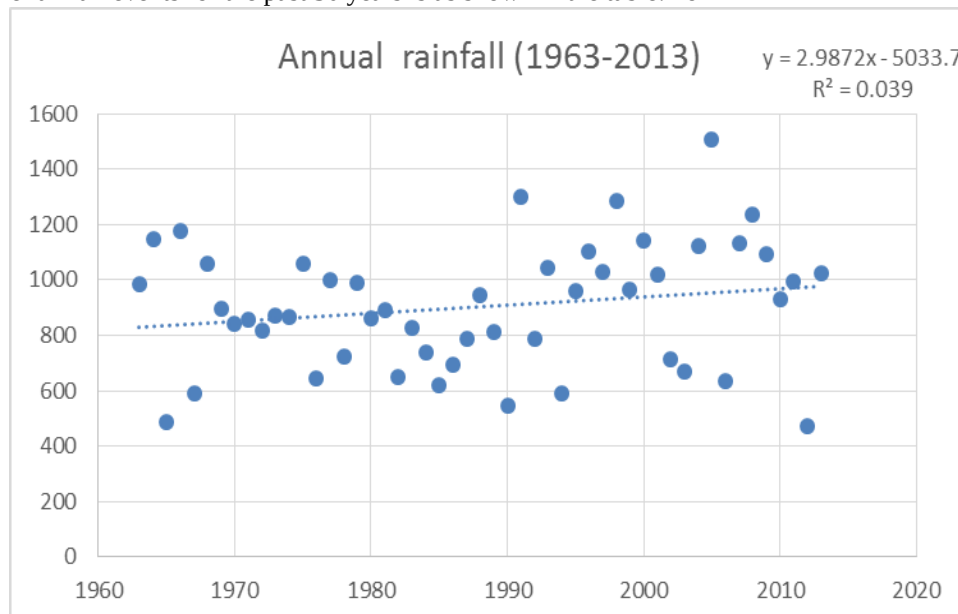


Fig. 2: Histogram of Annual daily maximum Rainfall data

Rainfall characteristics

The annual rainfall varies from 1500mm to 473mm. The annual distribution of the rainfall is as shown in the histogram (figure no2). The mean value is 902 the standard deviation is 224 the distribution is positive skewed 0.16 and the Kurtosis is negative mean compared to the normal distribution the central peak is lower and a flat distribution. The number of annual rainy days of Bangalore district varies from 34 to 165 days as shown in Table3. Trend analysis (simple regression method) for fifty years (1963 to 2013) rainfall data shows that there is increasing trend of 2.98 i.e. 3 mm per year; However considering the last 13 years (2000-2013) the trend shows there is an increase 16mm per year. Figure 3 shows the Trend Analysis of Annual rainfall of Bangalore District. The extreme rainfall events for the past 50 years is as shown in the table: no 4



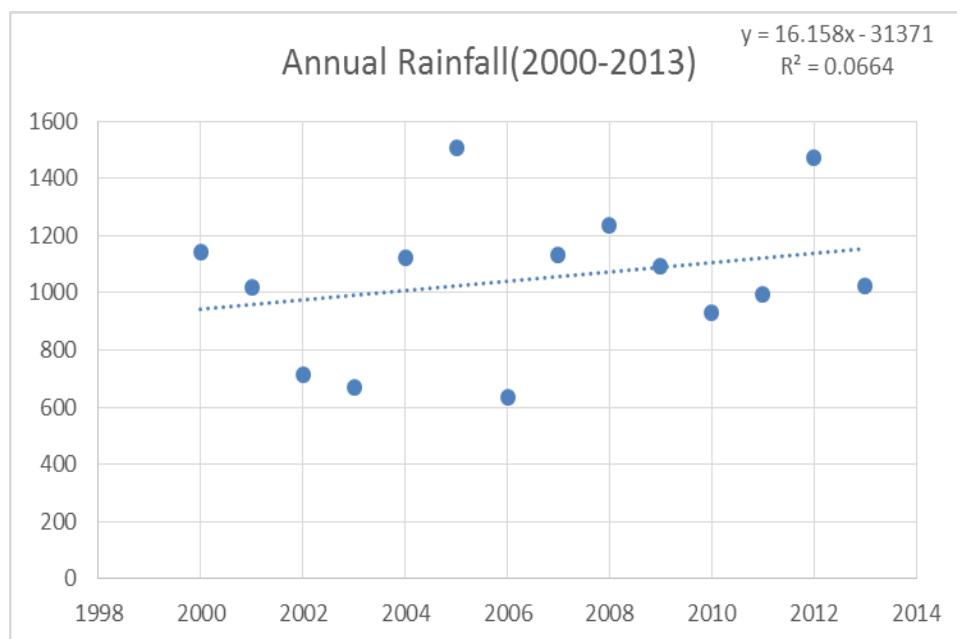


Fig. 3: Trend of Annual Rainfall Bangalore Urban District

Highest daily Rain fall events							
Bangalore North	11th Jan	1969	13.5	Bangalore South	11th jan	1967	24.2
	17th feb	2013	153		22-Feb	1986	42.5
	19th April	2001	108		16th march	2008	94.5
	26th May	2002	95		17th april	1971	64.4
	1st june	2009	84.5		26th May	2002	116.9
	18th july	1998	123.5		28th june	2013	103
	4th August	1998	92		22-Jul	1979	67.5
	30-Sep	1963	91.9		12-Aug	1996	103
	23Oct	2005	120.7		14th sep	2007	108.4
	16th nov	1991	105.6		1st oct	1997	178.9
	5th Dec	1993	66.4		15th Nov	1991	103.6
					5th Dec	1993	71.3

Table: 4 Table showing highest daily rainfall events

Taluk	year	Jan	Feb	March	April	May	June	July	august	Sep	oct	Nov	Dec	Tota; Rainy days
bangalore north	1963	0	0	0	6	5	4	8	15	11	11	1	2	63
bangalore north	1964	0	0	0	1	5	7	10	8	7	7	8	1	54
bangalore north	1965	0	0	2	3	3	4	7	13	6	1	2	4	45
bangalore north	1966	0	0	0	1	5	7	10	8	7	7	8	1	54
bangalore north	1967	0	0	2	3	3	4	7	13	6	1	2	4	45
bangalore north	1968	0	0	1	2	2	3	10	5	11	8	8	3	53
bangalore north	1969	1	0	1	2	3	7	12	6	3	7	2	5	49
bangalore north	1970	0	0	0	3	8	5	8	3	15	6	3	1	52
bangalore north	1971	0	0	0	1	10	5	9	10	6	10	5	3	59
bangalore north	1972	0	0	0	2	5	5	6	12	13	11	5	5	64
bangalore north	1973	0	0	0	3	9	5	13	21	13	17	4	6	91
bangalore north	1974	0	0	1	6	12	1	14	11	12	11	3	0	71
bangalore north	1975	0	1	1	2	12	7	13	13	13	13	4	1	80
bangalore north	1976	1	0	0	6	3	0	7	12	6	5	9	1	50
bangalore north	1977	0	2	2	3	12	8	12	12	11	18	13	0	93
bangalore north	1978	0	3	0	6	5	4	8	11	14	3	8	6	68
bangalore north	1979	0	5	0	2	10	14	10	6	10	8	6	0	71
bangalore north	1980	0	0	2	3	9	2	11	2	10	8	6	0	53
bangalore north	1981	0	0	1	2	7	1	6	14	13	13	2	3	62
bangalore north	1982	0	0	0	0	6	5	5	5	6	4	3	0	34
bangalore north	1983	0	0	0	2	9	14	15	26	21	9	4	8	108
bangalore north	1984	2	6	4	4	9	13	22	9	17	12	7	2	107
bangalore north	1985	1	0	2	6	7	12	16	17	20	8	9	3	101
bangalore north	1986	3	3	0	4	11	14	11	17	17	8	8	2	98
bangalore north	1987	0	0	1	6	8	12	7	21	18	15	13	8	109
bangalore north	1988	0	1	3	16	10	7	22	24	21	6	2	3	115
bangalore north	1989	0	0	3	4	9	10	19	19	15	9	3	1	92
bangalore north	1990	1	0	1	4	12	12	12	22	10	12	3	2	91
bangalore north	1991	0	0	0	10	12	18	16	17	16	12	5	0	106
bangalore north	1992	0	0	0	4	8	19	14	19	15	17	10	0	106
bangalore north	1993	0	0	5	5	10	11	13	18	14	19	7	4	106
bangalore north	1994	0	1	0	2	12	15	19	18	9	22	8	3	109
bangalore north	1995	3	0	1	5	13	13	20	22	18	19	2	0	116
bangalore north	1996	0	0	0	9	10	14	13	19	20	12	2	11	110
bangalore north	1997	1	0	6	6	4	13	13	13	13	10	18	7	104
bangalore north	1998	0	0	1	7	6	13	15	19	20	17	10	7	115
bangalore north	1999	0	1	0	7	18	10	22	11	15	21	6	4	115
bangalore north	2000	0	3	0	9	12	20	13	23	16	15	3	3	117
bangalore north	2001	1	0	1	12	6	7	16	19	17	15	6	4	104
bangalore north	2002	0	0	0	1	10	13	11	17	9	13	4	1	79
bangalore north	2003	0	1	4	9	2	10	16	22	12	16	3	1	96
bangalore north	2004	2	1	2	12	14	13	24	19	20	20	8	0	135
bangalore north	2005	1	1	1	12	12	11	24	19	17	24	14	7	143
bangalore north	2006	1	0	6	5	16	17	11	17	11	9	7	1	101
bangalore north	2007	0	0	0	6	9	11	16	18	16	15	6	6	103
bangalore north	2008	0	3	11	4	14	7	18	26	9	20	8	1	121
bangalore north	2009	0	0	4	7	10	8	10	11	20	6	13	3	92
bangalore north	2010	0	0	1	7	13	10	17	18	14	11	12	3	106
bangalore north	2011	0	2	1	10	13	15	21	28	15	17	10	7	139
bangalore north	2012	1	0	2	6	12	11	17	20	15	17	9	6	116
bangalore north	2013	0	6	4	9	12	18	24	27	25	20	15	5	165
		19	40	77	267	457	489	693	795	688	615	337	159	

bangalore South	1963	0	0	0	6	6	11	14	22	10	11	7	7	94
bangalore South	1964	0	0	0	1	10	11	17	14	17	8	11	2	91
bangalore South	1965	0	0	2	3	2	8	8	19	5	2	10	7	66
bangalore South	1966	0	0	0	1	6	12	17	12	20	15	10	0	93
bangalore South	1967	0	0	2	3	6	10	17	13	8	7	5	5	76
bangalore South	1968	0	0	1	2	14	15	22	15	22	12	6	6	115
bangalore South	1969	1	0	1	2	12	7	18	15	10	14	10	7	97
bangalore South	1970	0	0	0	3	14	11	15	17	11	12	6	1	90
bangalore South	1971	0	0	0	1	14	2	15	15	11	5	2	2	67
bangalore South	1972	0	0	0	2	9	12	10	13	15	12	1	5	79
bangalore South	1973	0	0	0	3	3	15	14	18	15	14	3	5	90
bangalore South	1974	0	0	1	6	13	13	18	16	17	12	5	0	101
bangalore South	1975	0	1	1	2	15	15	20	20	16	21	8	1	120
bangalore South	1976	1	0	0	6	4	6	18	20	9	4	14	1	83
bangalore South	1977	0	2	2	3	18	13	17	13	13	19	14	0	114
bangalore South	1978	0	3	0	6	8	14	18	19	13	13	6	9	109
bangalore South	1979	0	5	0	2	8	18	11	11	23	7	19	0	104
bangalore South	1980	0	0	2	3	13	10	14	15	13	9	8	1	88
bangalore South	1981	0	0	1	2	10	4	11	20	17	15	7	5	92
bangalore South	1982	0	0	0	0	7	11	12	12	8	5	8	0	63
bangalore South	1983	0	0	0	2	7	15	14	24	19	10	1	6	98
bangalore South	1984	2	6	4	4	5	13	21	9	14	11	5	2	96
bangalore South	1985	1	0	2	6	8	13	13	12	19	8	7	1	90
bangalore South	1986	3	3	0	4	10	13	11	18	20	6	0	0	88
bangalore South	1987	0	0	1	6	5	11	5	18	12	15	11	13	97
bangalore South	1988	0	1	3	16	7	3	19	23	17	6	2	3	100
bangalore South	1989	0	0	3	4	7	11	16	18	15	7	3	1	85
bangalore South	1990	1	0	1	4	9	16	14	17	8	11	8	2	91
bangalore South	1991	0	0	0	10	13	18	14	18	17	10	8	0	108
bangalore South	1992	0	0	0	4	11	19	8	20	12	14	9	2	99
bangalore South	1993	0	0	5	5	8	12	15	17	10	22	10	4	108
bangalore South	1994	0	1	0	2	9	10	19	15	7	21	7	3	94
bangalore South	1995	3	0	1	5	11	12	17	20	14	15	1	0	99
bangalore South	1996	0	0	0	9	8	14	10	15	22	14	4	10	106
bangalore South	1997	1	0	6	6	7	18	16	18	15	11	16	5	119
bangalore South	1998	0	0	1	7	6	10	14	20	17	14	10	6	105
bangalore South	1999	0	1	0	7	14	11	13	11	13	20	6	3	99
bangalore South	2000	0	3	0	9	13	16	11	25	15	13	3	4	112
bangalore South	2001	1	0	1	12	4	10	12	16	16	13	4	3	92
bangalore South	2002	0	0	0	1	12	9	9	11	9	12	5	1	69
bangalore South	2003	0	1	4	9	2	9	14	20	9	12	4	1	85
bangalore South	2004	2	1	2	12	16	14	19	17	19	20	6	0	128
bangalore South	2005	1	1	1	12	12	11	22	15	15	20	15	7	132
bangalore South	2006	1	0	6	5	10	15	9	12	9	8	9	0	84
bangalore South	2007	0	0	0	6	10	11	14	18	14	15	4	6	98
bangalore South	2008	0	3	11	4	14	7	19	19	8	20	6	0	111
bangalore South	2009	0	0	4	7	16	13	11	12	22	8	17	4	114
bangalore South	2010	0	0	1	7	18	10	19	17	16	14	11	3	116
bangalore South	2011	0	2	1	10	11	15	21	26	13	16	9	1	125
bangalore South	2012	1	0	2	6	10	7	12	19	10	15	12	4	98
bangalore South	2013	0	6	4	9	10	16	22	25	22	15	15	7	151
		19	40	77	267	495	600	759	864	721	633	388	166	

Table 3: Table showing number of rainy days

From the above table it is evident that there is increase in the rainfall during the recent years and due to climate change there is a large variability in the rainfall pattern.

III. High rain event a case study_Bangalore city (BBMP)

From 2009 onwards Rainfall data is available for every 15min interval for more number of stations. The increase in the variability of rainfall calls for a demand for high resolution data to better understand the phenomenon, as rainfall variability has key applications.

Network of Rain gauge stations in Bangalore BBMP

We have initiated a project in association with civic authorities to monitor, model and forecast urban flooding for Bangalore. Rainfall is being monitored through 100 GPRS enabled Telemetric Rain Gauges at a density 1 to 8 sq km area in the city which is a unique model in the country. Meso-scale Rainfall forecast and high intensity and heavy rainfall alerts are being generated and sent to the concerned authorities at near-real time.



Fig. 4: Newspaper clipping of recent rains during 2014 October

IV. High Rain event _23rd sep 2014 for Bangalore BBMP

A heavy rain event on September 23rd is considered and the daily rainfall (8.30a.m to 8.30a.m) on that day is as shown in fig: 5 the map indicates the variation of the daily rainfall through the city. A table of Rainfall values in the same fig is indicating the values crossing 35.5mm of rain on that day. Any rainfall value crossing 35.5mm is considered as rather heavy rain, indicated in light blue colour. Any rainfall value exceeding 64.5mm is a heavy rain.

On 23rd sept more than 30% of city experienced heavy rains. The hourly variations of the same rain is displayed below.

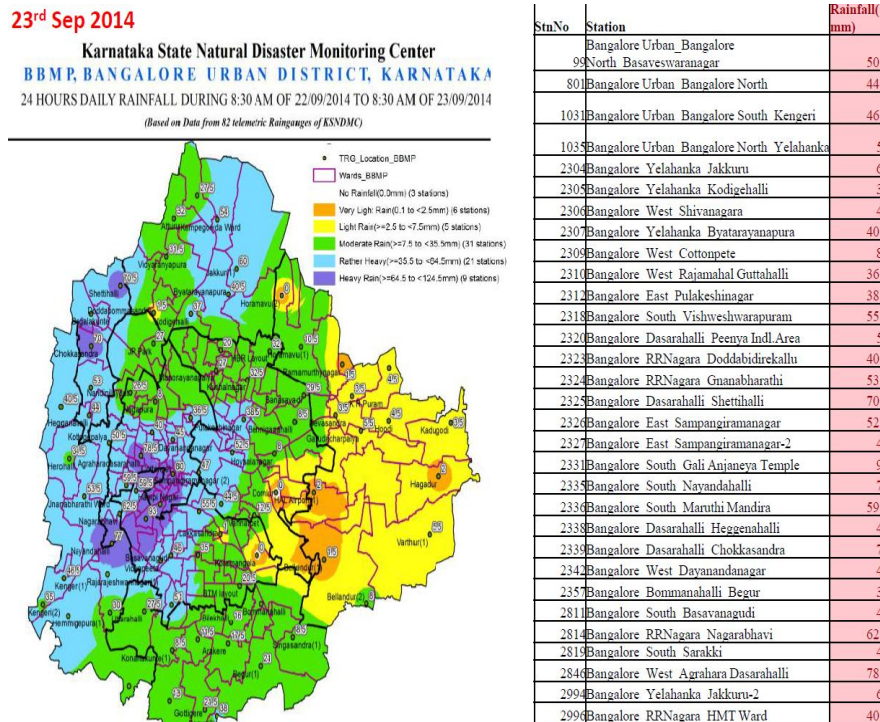
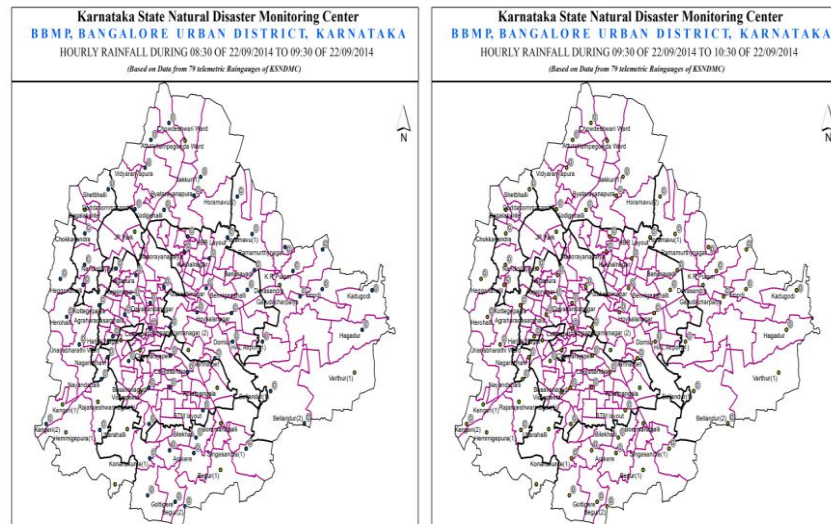


Fig. 5: Daily rainfall map from 8.30a.m of 22/9/2014-8.30a.m of 23/9/2014



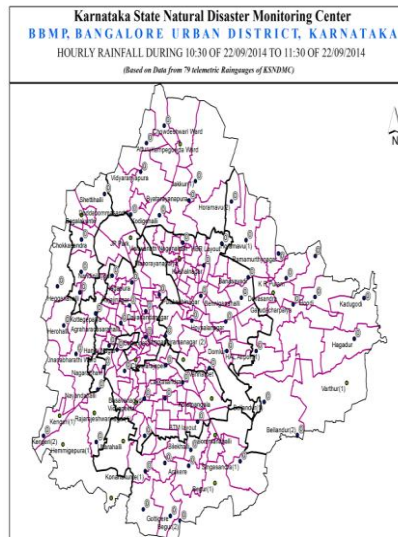
8.30-9.30 am of 23rd Sep

9.30-10.30 am of 23rd Sep

10.30-11.30 am of 23rd Sep

• TRG_Location_BBMP
Wards_BBMP
No Rainfall(0.0mm) (79 stations)

• TRG_Location_BBMP
Wards_BBMP
No Rainfall(0.0mm) (79 stations)



Legend
• TRG_Location_BBMP
Wards_BBMP
No Rainfall(0.0mm) (79 stations)

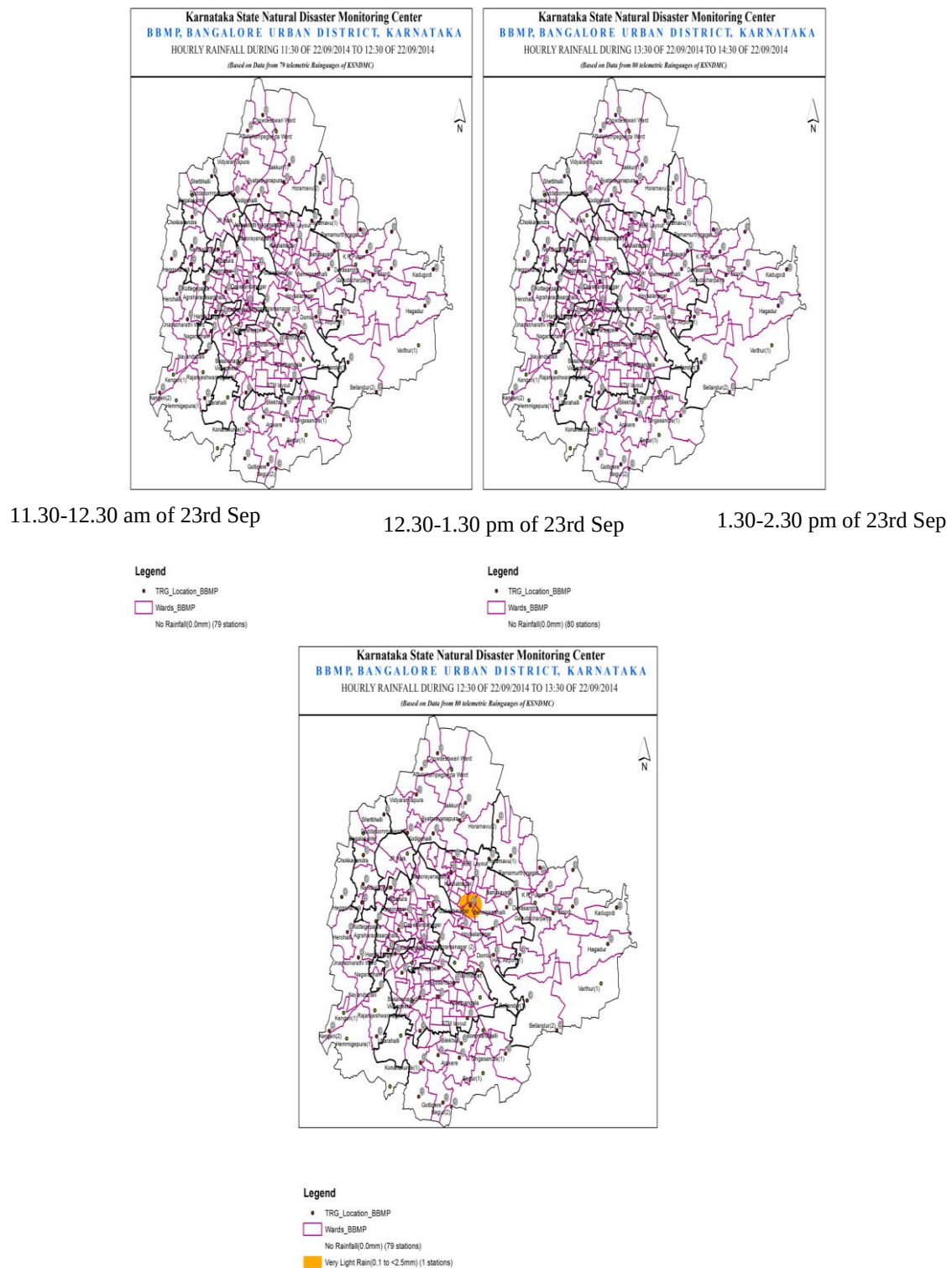
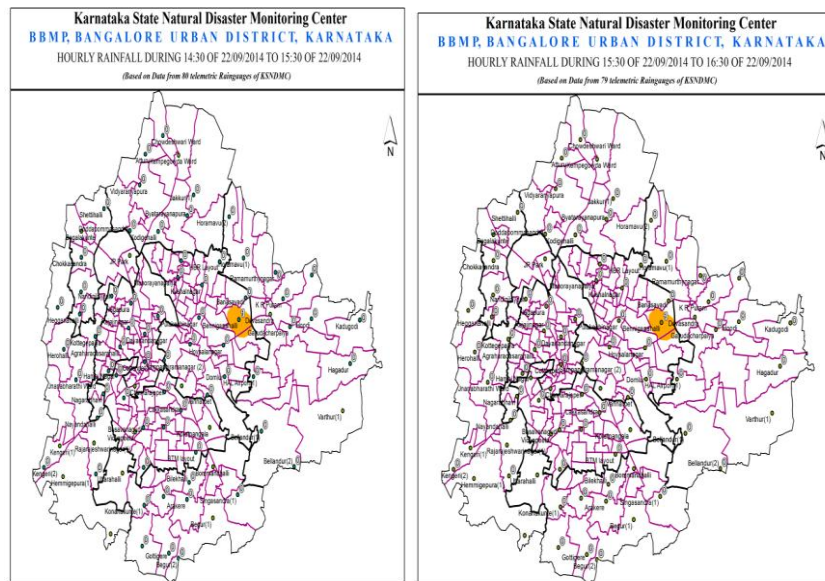


Fig. 5: Hourly rainfall maps from 8.30a.m of 23/09/2014 to 2:30 p.m of 23/09/2014



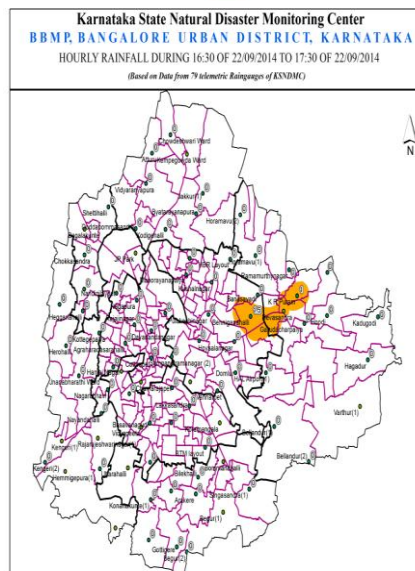
2.30-3.30 pm of 23rd Sep

3.30-4.30 pm of 23rd Sep

4.30-5.30 pm of 23rd Sep

Legend
 • TRG_Location_BBMP
 Wards_BBMP
 No Rainfall(0.0mm) (79 stations)
 Very Light Rain(0.1 to <2.5mm) (1 stations)

Legenda
 • TRG_Location_BBMP
 Wards_BBMP
 No Rainfall(0.0mm) (78 stations)
 Very Light Rain(0.1 to <2.5mm) (1 stations)



Legend
 • TRG_Location_BBMP
 Wards_BBMP
 No Rainfall(0.0mm) (77 stations)
 Very Light Rain(0.1 to <2.5mm) (2 stations)

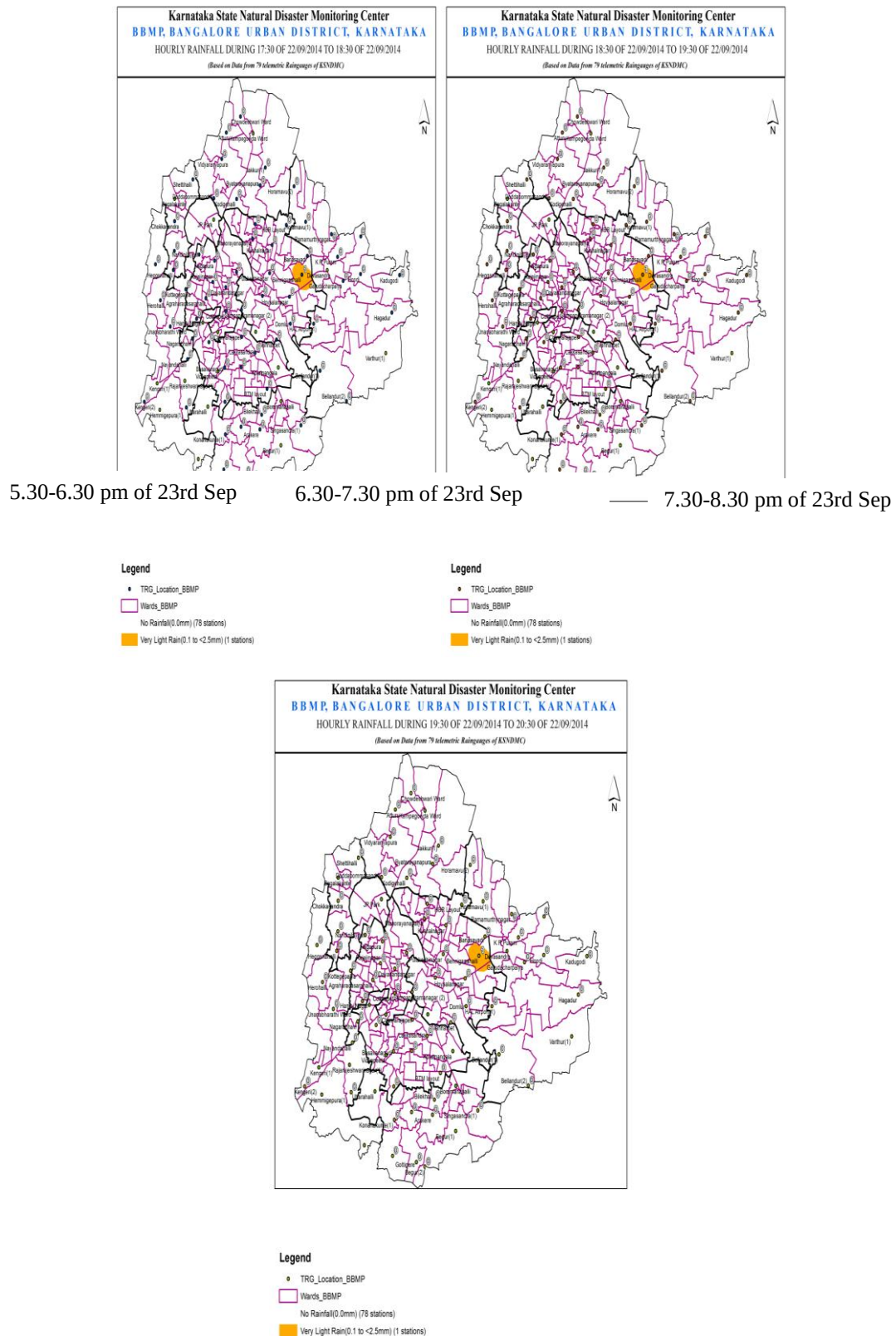
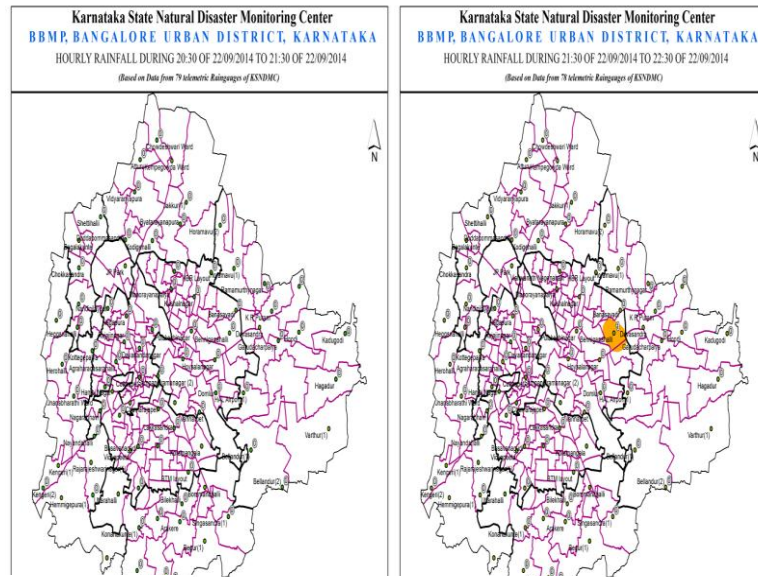


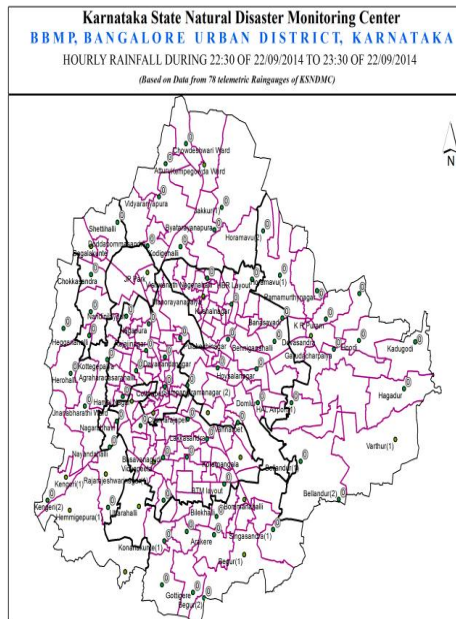
Fig. 5: Hourly rainfall maps from 2.30p.m of 23/09/2014 to 8.30p.m of 23/09/2014



8.30-9.30 pm of 23rd Sep 9.30-10.30 pm of 23rd Sep 10.30-11.30 pm of 23rd Sep

Legend
 • TRG_Location_BBMP
 Wards_BBMP
 No Rainfall(0.0mm) (79 stations)

Legend
 • TRG_Location_BBMP
 Wards_BBMP
 No Rainfall(0.0mm) (77 stations)
 Very Light Rain(0.1 to <2.5mm) (1 stations)



Legend
 • TRG_Location_BBMP
 Wards_BBMP
 No Rainfall(0.0mm) (78 stations)

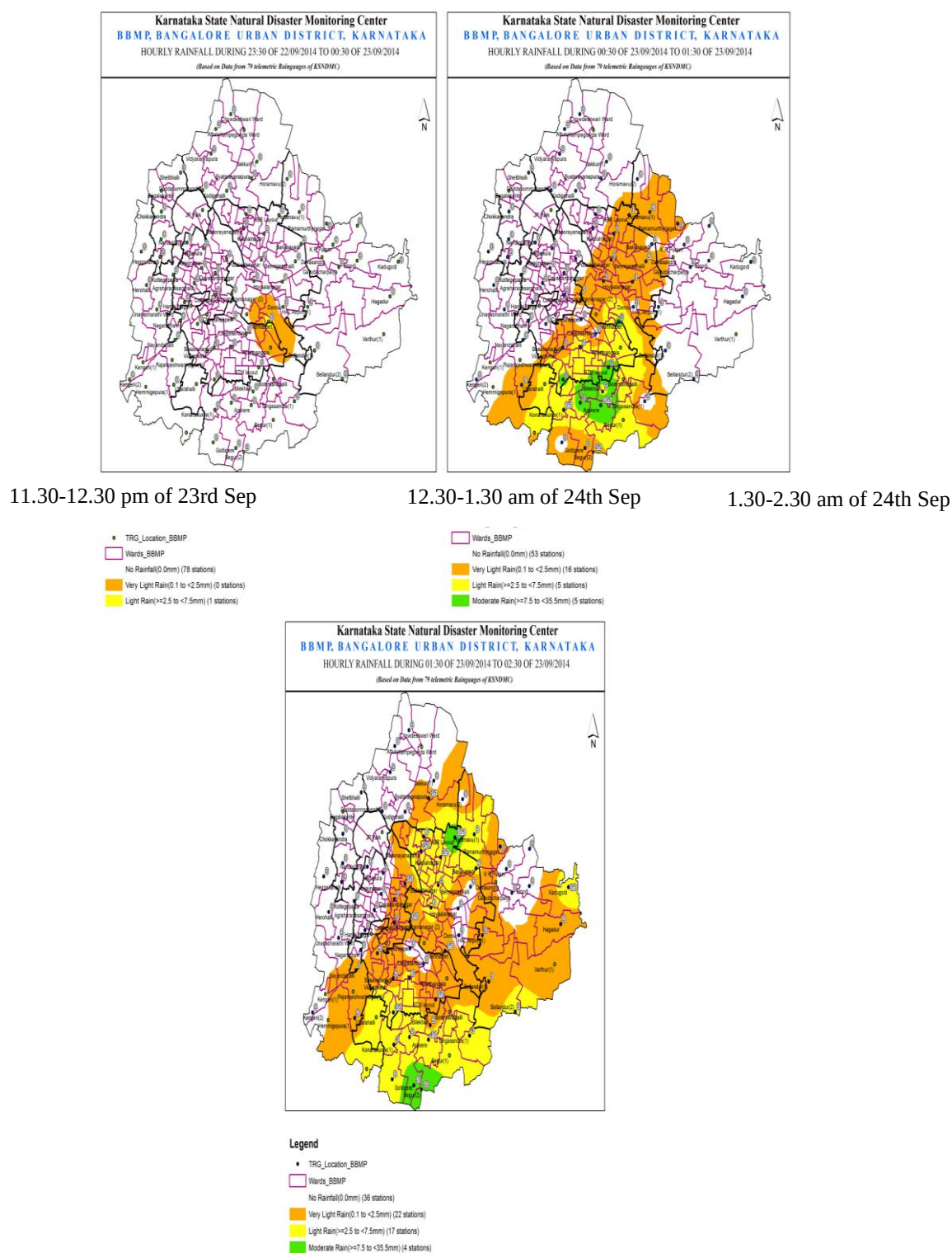


Fig. 6: Hourly rainfall maps from 8.30 p.m of 23/09/2014 to 2:30 a.m of 24/09/2014

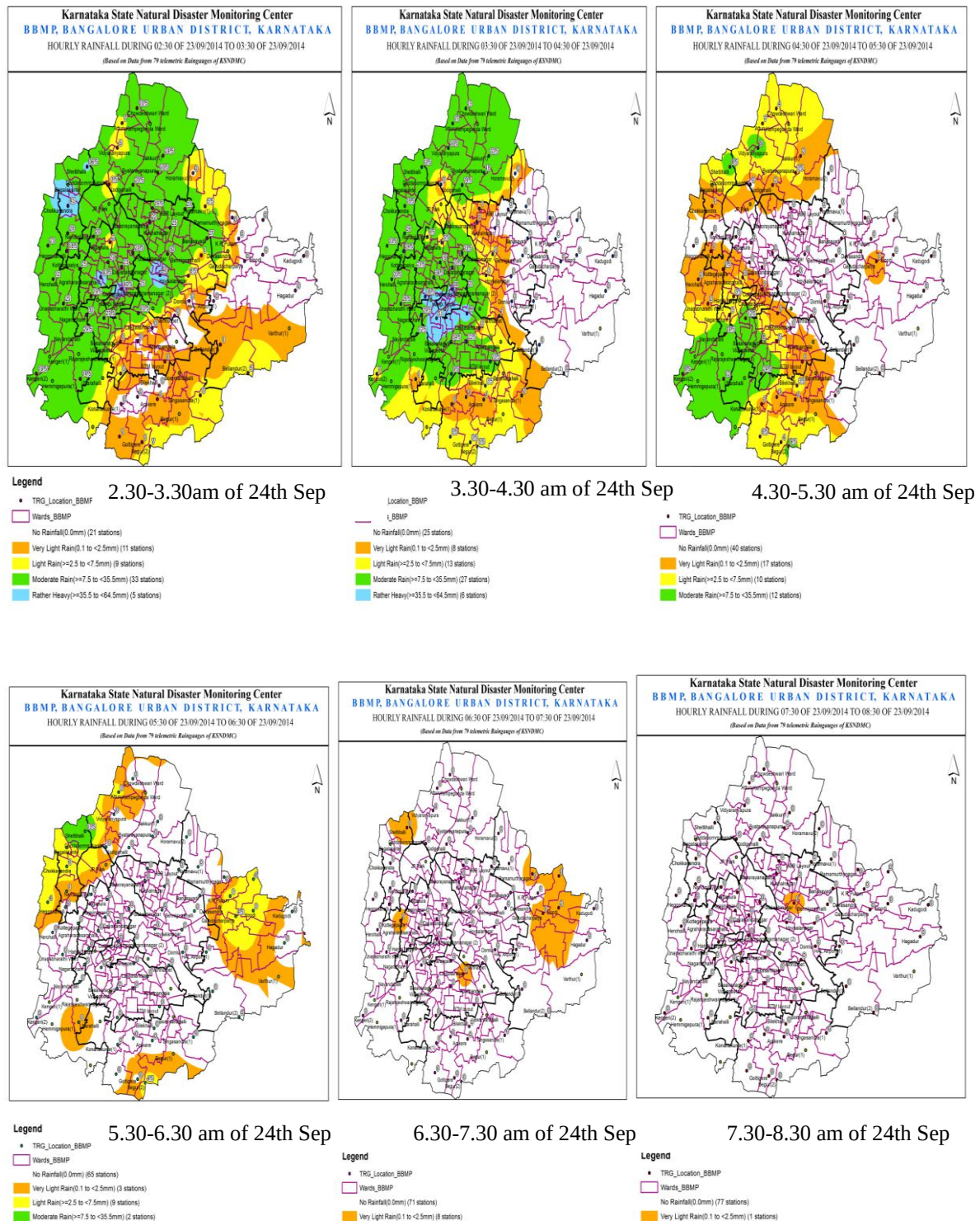
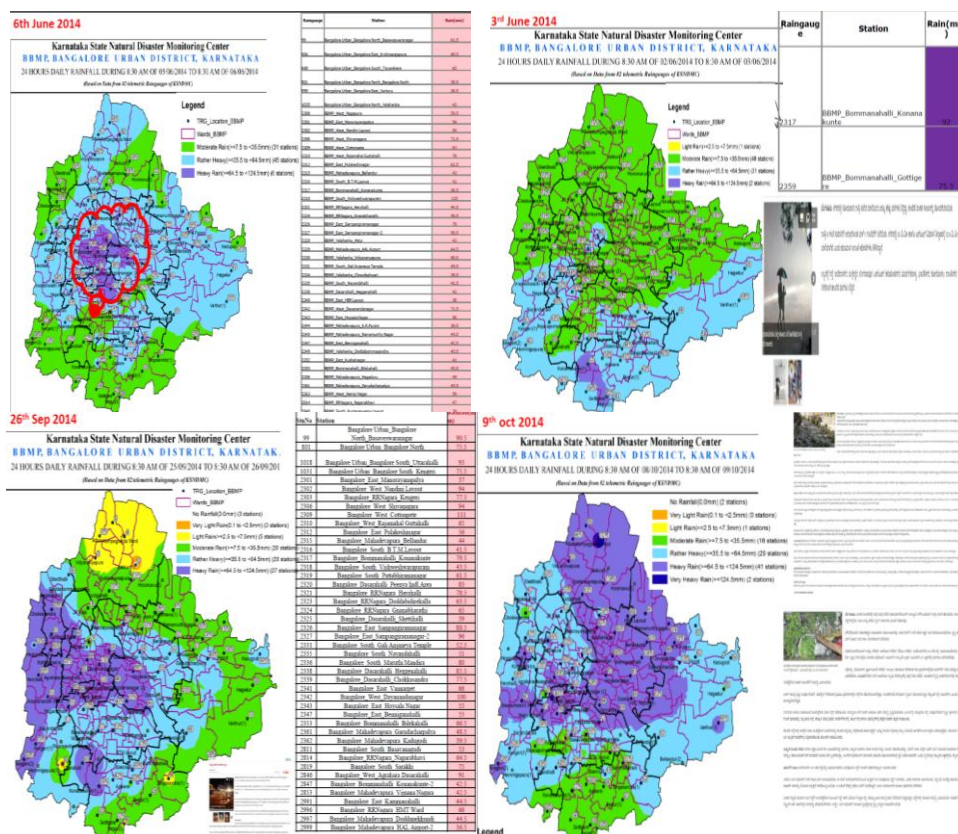


Fig. 7: Hourly rainfall maps from 2.30p.m of 24/9/2014 to 8.30a.m of 24/09/2014

Observations

It is to be noted that many such rain events are studied during the monsoon, the studies mainly reveal that the variability does exist during the rains, rainfall in the city occurs mainly during the evening to late night hours. The core built up and the law laying areas are inundated quickly. the rainfall intensity is more in the core areas than compared to the outskirts. The reason for such high intensity short duration rains are being studied. some of the heavy rain event maps are displayed below



Conclusion

The statistical analysis was carried out with fewer rain gauge data for the Bangalore district, highlighted the rainfall variability. Further the higher resolution sensor data and a larger network of the data proved that the city is highly susceptible to rainfall variability.

References

- [1] Wikipedia
- [2] (Atmospheric Research 137 (2014) 176–182)
- [3] Master plan BBMP
- [4] Ahasan, M.N., Chowdhary, M.A.M., Quadir, D.A., 2010. Variability and trends of summer monsoon rainfall over Bangladesh. J. Hydrol. Meteorol. 7 (1), 1–17.
- [5] Ahasan, M.N., Chowdhary, M.A.M., Quadir, D.A., 2011. Simulation of a heavy rainfall event on 14 September 2004 over Dhaka, Bangladesh using MM5 Model. J. Sci. Res. 3 (2), 261–270.

Acknowledgements

KSNDMC: Karnataka State Natural Disaster Monitoring Centre BBMP: Bruhat Bengaluru Mahanagara Palika