A climatological feature with forecasting aspect of
heavy rainfall events over Kolkata

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सार – इस शोध-पत्र में कोलकाता में हुई भारी वर्षा के जलवायविक अभिलक्षणों और पूर्वानुमान के पहलुओं का अध्ययन वर्ष 1974 से 2007 तक के 34 वर्षों के आँकड़ों के आधार पर करने का प्रयास किया गया है। इसमें 184 घटनाओं का पता लगाया गया और कोलकाता में भारी वर्षा की घटना के लिए अनुकूल सिनॉप्टिक प्रणाली और विवेचित सूचकांक (क्रिटिकल इंडेक्स) सहित विभिन्न प्रकार के विश्लेषण के अनुसार आँकड़ा सैट तैयार किया गया। औसत वर्षा की घटना प्रति वर्ष 5.4 घटना देखी गई है। मासिक वितरण से जुलाई माह में सबसे अधिक 26 प्रतिशत घटनाएँ, इसके बाद सितंबर माह में 20 प्रतिशत, अगस्त माह में 17 प्रतिशत और जून माह में 14 प्रतिशत घटनाएँ होने का पता चलता है। मौसमी वितरण सामान्यतः मानसून ऋतु के दौरान अधिकतम 77 प्रतिशत घटना को दर्शाता है इसके बाद मानसूनोत्तर ऋतु में 14 प्रतिशत और मानसून पूर्व ऋतु में 0.9 प्रतिशत घटना को दर्शाता है। सिनॉप्टिक विश्लेषण से यह पता चला है कि निम्न अवदाब प्रणाली (एल.पी.एस.) के कारण भारी वर्षा की घटनाएँ अधिक हुई है। 167 मामलों (जून से अक्तूबर तक) का अध्ययन करने से यह पता चला है कि जब किसी क्षेत्र में कोई भी एक अनुकूल सिनॉप्टिक स्थिति बनती है और डी. पी. डी.–पवन–पी. डब्ल्यू.–डब्ल्यू एस. सूचकांक विवेचित (क्रिटिकल) मान पर पहुँची है तो कोलकाता और उपनगरीय क्षेत्रों में भारी से भारी वर्षा हुई है।

ABSTRACT. In this paper an attempt has been made to study climatological characteristics and forecasting aspects of heavy rainfall over Kolkata for data of 34 years of period from 1974 to 2007. Total 184 events has been found out and the data set has been subjected to various types of analysis along with favourable synoptic system and critical index for occurrence of heavy rainfall over Kolkata. Average occurrence is found as 5.4 events per year. Monthly distribution shows maximum of 26% events in July followed by September 20%, August17% and June as 14%. Seasonal distribution naturally indicates maximum of 77% occurrence during monsoon followed by post-monsoon with 14% and pre-monsoon with 09 %. Synoptic analysis revealed that majority of heavy rainfall events occurred due to low pressure system (LPS). Study of 167 cases (during June to October) suggests that when any one of the favourable synoptic condition prevailed over the region and DPD-Wind-PW-WS index reaches a critical value, heavy to very heavy rain occurred over Kolkata and suburban areas.

Key words – Heavy rainfall, Low pressure system (LPS), DPD.

1. Introduction

Any rainfall amount of around 70 mm or more with a moderate to high intensity in the vicinity of Kolkata can lead to a flood like situation causing damage to property, human life and water logging in low-lying areas. Many Meteorologists have studied heavy rainfall analysis at different city considering the geographical and synoptic conditions. An attempt to forecast heavy rainfall has been made by Lal (1992), in the river basin Teesta by Lahiri (1981) and over Delhi and neighbourhood by Ghosh

(1970). Study on heavy rainfall over Kerala in October 1999 has been done by Lakshminarayan & Rajamohan (2003), over Madhya Pradesh for period 1977-1987 by Dube & Balakrishnan (1992) and in and around Jaipur by Ganeshan & Prasad (1985). Recently Kumar *et al.* (2007) has attempted to forecast heavy rainfall over Mumbai. They concluded that when the low level westerly at 850 hPa reported ≥ 30 knots by Minicoy/Aminidivi islands or any other station along the west coast of peninsular India from Thiruvananthapuram to Mumbai during monsoon season then DPD ≤5° C upto 400 hPa confirmed the
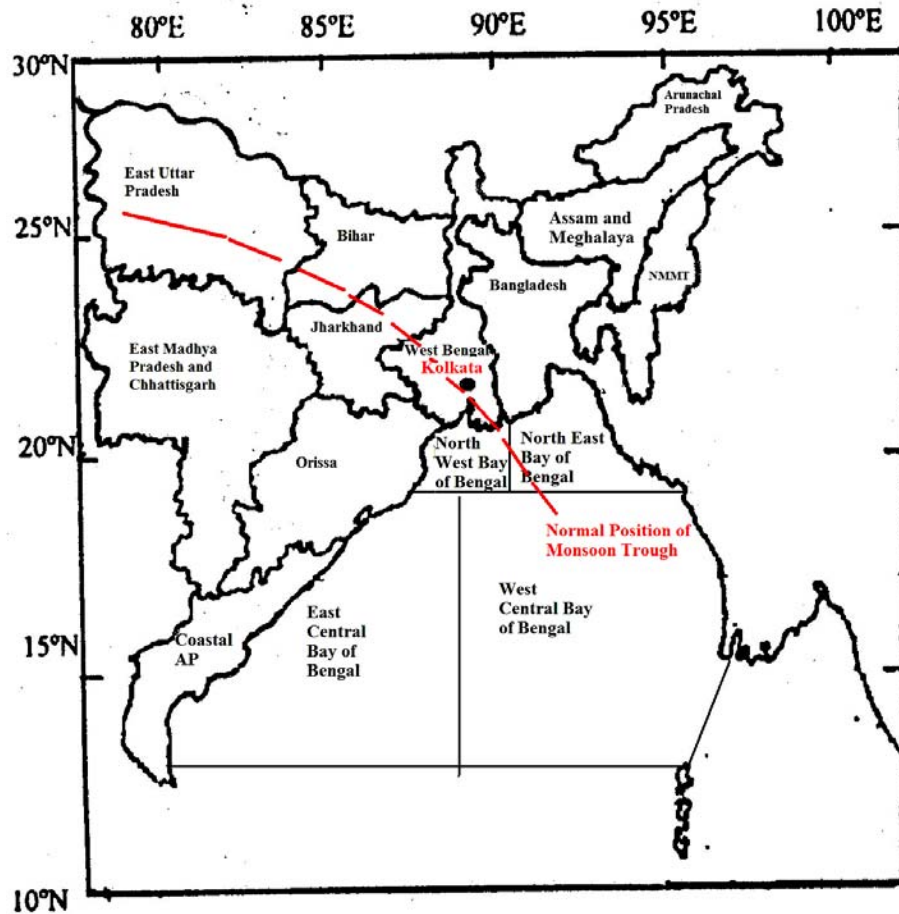
Fig. 1. Geographical location of Kolkata

accumulation of huge moisture for the heavy to very heavy rainfall over Mumbai during next 24 hours. Srinivasan *et al.* (1972) had observed that a weak monsoon is characterized by a sharp decrease of humidity with height (particularly between 850 and 650 hPa), while on day of strong monsoon the wet bulb curve particularly follows saturated adiabat. Rao (1976) had observed that DPD is generally 4° C or less during active monsoon with the average DPD at Mumbai during weak monsoon as high as 10° C. In this paper the authors have attempted to bring out a detail climatological features of 'Heavy Rain' over Kolkata.

2.   Data and methodology

Precipitation data originated from Kolkata (Alipore and Dumdum Observatory) of Regional Meteorological Centre (RMC), Kolkata during the period 1974-2007 has been collected. All month available data has been investigated. A rainfall event is defined heavy if accumulated sum of precipitation from 0300 UTC of the previous day to 0300 UTC of the measurement day is at least 65 mm. In this paper, we considered a heavy rainfall event over Kolkata if any one of the two station recorded heavy rainfall and other station got at least rather heavy rainfall (4-6 cm). As such total 184 events have been identified during the period under consideration which is inclusive of all seasons. The upper air RS/RW data of MO, Kolkata for the period under study has been collected from University of Wyoming Upper Air website.

Average monthly distribution is shown to identify peak month of occurrence of these events along with seasonal distribution. In order to determine the synoptic
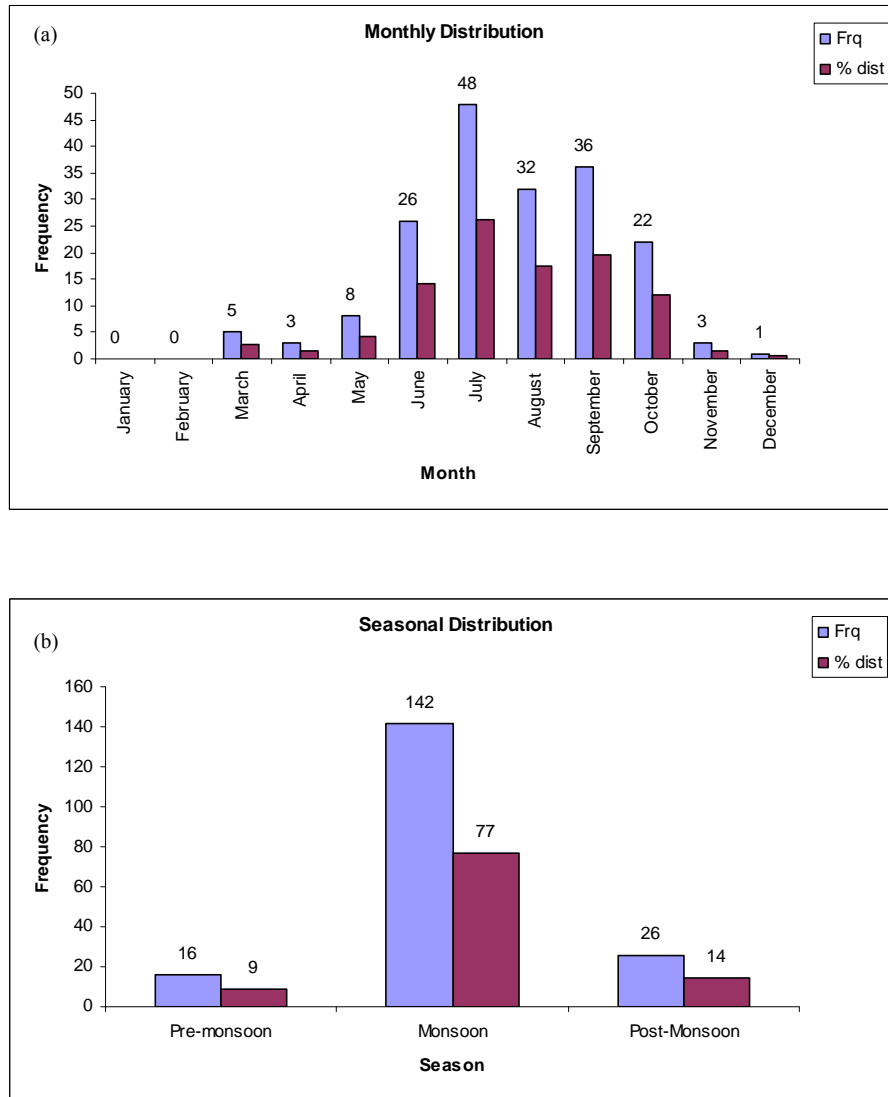
Figs. 2 (a&b). Monthly and seasonal distribution of heavy rainfall over Kolkata

system associated with heavy rainfall events at Kolkata, the Daily Weather Report (DWR) inference of RMC Kolkata has been explored to determine the favourable position of Low Pressure System (LPS), Upper Air System (UAS), Monsoon Trough (MT) and convection during the entire period under consideration.

The situation in upper level thermodynamics of has been studied using upper air RS/RW data of MO, Kolkata during the five month from June to October in which 167 cases out of 184 have occurred. 115 RS/RW data were available out of 167 days of heavy rainfall events. Four parameters have been considered for this study namely

Dew Point Depression (DPD), Precipitable water, veering and backing of wind and vertical wind shear between 850 hPa and 500 hPa.

The dew point depression (DPD) is the difference between the temperature and dew point temperature at a certain height in the atmosphere. It is used to signify the presence of relative humidity in upper level. Dew point depression values are used in the study and forecasting of severe convective storms. Again, the total precipitable water (TPW) which is the amount of water vapour in a column from the surface of the earth to space is also used
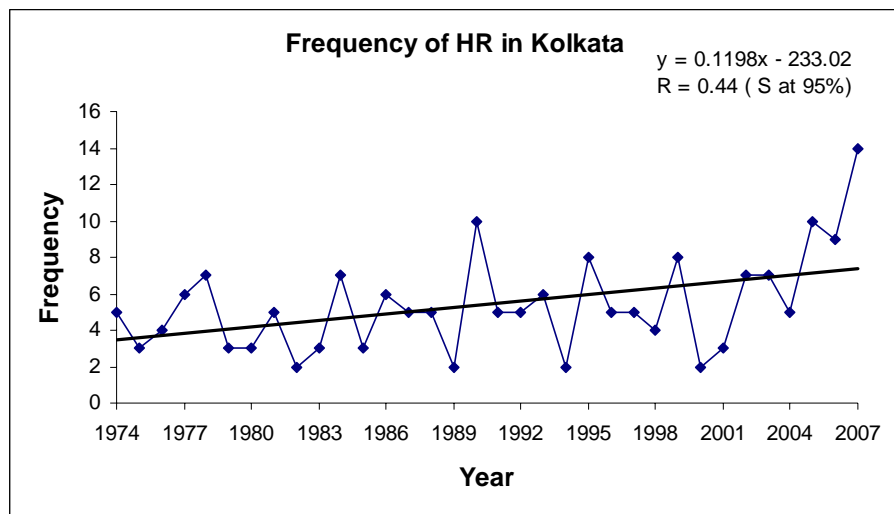
Fig. 3. Annual frequency of heavy rainfall over Kolkata

by forecasters to predict heavy precipitation. Vertical wind shear and veering of wind is also an important tool for forecasting of heavy rainfall events**.**

In this present study DPD ≤ 5° C from 0.3 km asl to 500 hPa, veering/backing of wind from 850 hPa to 500 hPa / 700 hPa, precipitable water has been examined along with vertical wind shear between 850 hPa and 500 hPa has been critically analysed for the day of heavy rainfall events taking the RS/RW data of MO, Kolkata. Weightage for each sub-division of the four parameters has been assigned on the basis of occurrence of heavy rainfall cases under a particular category out of the total number of HY rainfall occasions. Arithmetic mean has been used for finding an index for each subdivision of the four parameters.

3. Results and discussions

General aspects of analysis of 184 events have been discussed such as monthly and seasonal distribution, trend analysis and synoptic systems along with critical index for occurrences of heavy rainfall events.

3.1. *Monthly and seasonal distribution*

Fig. 2(a) shows monthly distribution of 'Heavy Rain Spells'. Naturally during monsoon season under the very active phase July designate maximum number of events as 48 (26%) out of 184 events. June, August and September however shows 26 (14%), 32 (17%) and 36 (20%) respectively. In the month of October systems like

depression or cyclonic storm over the region plays major role for these events with 12% occurrence whereas in the month of May system like cyclonic storm/convection play significant role for these events with 4% occurrence. March, April, November and December shows rare occurrences of heavy rainfall events. Months like January and February shows zero events. Fig. 2(b) depicts the seasonal distribution of these events for monsoon, post and Pre-monsoon season. Monsoon contributing the maximum 77% followed by post-monsoon with 14% and pre-monsoon with only 9% of occurrence. It is well known fact that during pre-monsoon season thunderstorm is a significant phenomenon of this region causing heavy to very falls in a short duration.

3.2. *Trend analysis*

To study the climatology of any event to reveal significant changes with time the trend analysis has been proved to be highly useful technique. In view of its importance it has became mandatory to apply it for the different types of data sets worked out in any study. Fig. 3(a) shows trend of 'Heavy Rain Spell' events for the period 1974 to 2007, *i.e.,* for 34 years of period. The regression line and equation shows significant positive tendency with time for these events with a coefficient of correlation as + 0.44 significant at 5% level. Maximum frequency of these events is observed as 14 in 2007 and minimum as 2 in 1982, 1989, 1994 and 2000. Average frequency is seen as 5.4 events per year and out of 39 years period 13 years shows more than average and 21 shows less than or equal to average.

TABLE 1

The division of weather types bringing heavy rainfall for different basic systems in Kolkata in 1974-2007.
Relative frequencies of the heavy rain bringing events are shown

Basic System (relative frequency, %)	LPS 69			UAS 8	MT 9	CONVECTION 14
	A	B	C	D	E	F
Weather Type (relative frequency, %)	LOW 40	DEP 23	CS 6	C 8	MT/WB 9	CON 14

Note : LPS - Low Pressure System, LOW - Low Pressure Area, DEP-Depression, CS - Cyclonic Storm, UAS - Upper Air System, C - Cyclonic circulation, MT - Monsoon Trough, MT/WB - Monsoon Trough over West Bengal, CON - Convection

3.3. *Classification of the synoptic situations bringing heavy rain over Kolkata*

Geographical location of Kolkata is shown in Fig. 1. Kolkata is situated at the bank of Hooghly River and it is a coastal station very near from Bay of Bengal. Hence, Bay of Bengal affects the weather and climate of Kolkata to a great extent. Synoptic situations of all days with heavy rainfall has been analysed in order to identify similarities between them and to classify them. The main criterion of classification was based on the formation and movement of basic systems at sea level. Six basic synoptic situations with four main basic systems, appropriate for 184 days with heavy rainfall, have been analysed (Table 1). The majority of heavy precipitation events are associated with Low Pressure System (LPS). There are two dominant weather types – A (Low Pressure Area) and B (Depression) followed by type-C (Cyclonic Storm). Upper Air System (UAS) which has been consisted of cyclonic circulation extending upto MTL (type-D). Monsoon Trough (type-E) also plays an important role in the creation of the conditions for the formation of heavy rainfalls. The final group consists of convective precipitation, which is largely caused by convection and instability effects (weather type F).

Type A is associated with low pressure area (LOW) (visible both on the surface and in upper air field) that usually forms over Bay of Bengal during monsoon season (June-September) near the coast and moved along the monsoon trough and cross West Bengal coast and bring heavy rainfall over Kolkata. They usually weaken along its path and merge with the monsoon trough.

Type B is associated with depression/deep depression (visible both on the surface and in upper air field) formed over Bay of Bengal, the centre of which crosses over or near Kolkata. This depression/deep depression generally formed during monsoon season and produce not only widespread and continuous precipitation, but also strong gusty wind over Kolkata region. In most cases, heavy precipitation was registered in for 2-3 consecutive days. They usually moved along the monsoon trough and weakened along its path and merge with monsoon trough.

Type C is associated with slow moving Cyclonic Storm (CS). The majority of CS formed over Bay of Bengal/Andaman sea during post-monsoon season (October-December) and very few formed during pre-monsoon season as a LOW and intensify into a CS along its path and moved in westerly/north westerly direction and some of them cross Orissa/West Bengal coast and bring heavy to very heavy rainfall over Kolkata.

Type D is associated with upper air system which is mainly cyclonic circulation over northwest Bay of Bengal and adjoining West Bengal/Orissa coast extending upto mid-tropospheric level (MTL) during monsoon season and remains stagnant over the area and causes heavy rainfall over Kolkata.

Type E is associated with monsoon trough passes through West Bengal during monsoon season and causes heavy rainfall over Kolkata.

Type F is associated with weak surface pressure field and convective precipitation during pre-monsoon season (March-May). For this weather type, the synoptic factors are insignificant and the vital ingredients for causing heavy rainfalls are local atmospheric conditions: thermal, humidity and stability characteristics. During the period of heavy rainfall generally the temperature of the cloud top is very low and vertical size of their convective cloud is extremely high.

TABLE 2

Critical index table

S. No.	Criteria	HR Cases	Total HY events	Weightage
Dew Point Depression (°C)				
1	DPD «5°C from 0.3 km to 500 hPa	90	115	0.8
2	DPD «5°C from 0.3 km to less than 500 hPa	25	115	0.2
Veering/backing of wind				
1	Veering from at least 0.9 km to 500 hPa	53	112*	0.5
2.	Veering from at least 0.9 km to 700 hPa	21	112*	0.2
3.	Veering from at least 0.9 km to less than 700 hPa or backing	38	112*	0.3
Precipitable Water (in mm)				
1	< 65	32	115	0.3
2	65-70	24	115	0.2
3	> 70	59	115	0.5
Vertical wind shear between 850 and 500 hPa (in knots)				
1	0-5	78	112*	0.7
2	6-10	21	112*	0.2
3	>10	13	112*	0.1

* Upper air winds were available for only 112 cases

3.4. *Critical index for occurrences of heavy rainfall over Kolkata*

It has been observed that PDP, different wind patterns, precipitable water contents and wind shear values of direction and speed play important role in occurrence of heavy to very heavy rainfall over Kolkata in association with favourable synoptic situation during June to October. The idea behind taking the five month from June to October for calculating a critical index is that most of the heavy rainfall occurred during these five months (167 out of 184 events) and mainly associated with LPS. Moreover, heavy rainfall during pre-monsoon seson is mainly due to local atmospheric condition and hence difficult to find critical index for such type of events.

Combining the weightage of each of the four parameters (Table 2) on the basis of DPD $\leq$ 5°C from 0.3 km asl to 500 hPa, veering/backing of wind from 850 hPa to 500 hPa/700 hPa and precipitable water along with vertical wind shear between 850 hPa and 500 hPa, an index equal to minimum critical value of 1.5 has been found necessary for occurrence of HY to VHY over Kolkata along with the favourable synoptic situation during this period (June-October).

To validate the critical index value five cases of heavy rainfall over Kolkata in 2008 has been considered.

3.4.1. *Heavy rainfall on 15-16 June 2008 over Kolkata*

Heavy rainfall has been occurred on 15-16 June, 2008 over Kolkata. Rainfall recorded at Kolkata on 16th and 17th has been 65.2 mm 114.4 mm respectively. The following synoptic situation has been observed: A LOW lay over northwest Bay off West Bengal-Orissa coast on 15/0300 UTC and intensified into a depression on 16/0300 UTC over the same area. The upper air data of 0000 UTC of 15th June 2008 and 16th June 2008 has been examined. On 15th June 2008, DPD $\leq$ 5°C has been find upto 700 hPa (D: 0.2), veering (060 15 to 095 18 knots) of wind from 850 hPa to 500 hPa (W: 0.5), precipitable water has been found to 61.4 mm (P: 0.3) and vertical wind shear from 850 hPa to 500 hPa found as 3 knots (S: 0.7). So the critical index comes to 1.7. The same has been found on 16th as DPD $\leq$ 5°C upto 400 hPa (D: 0.8), veering (035 26 to 100 14 knots) of wind from 850 hPa to 400 hPa (W: 0.5),precipitable water as 69.7 mm (P: 0.2) and vertical wind shear from 850 hPa to 500 hPa found as 04 knots (S: 0.7). So the critical index comes to 2.2.

3.4.2. *Heavy rainfall on 13 July 2008 over Kolkata*

Heavy rainfall has been occurred on 13 July 2008 over Kolkata. Rainfall recorded at Kolkata on 14th July has been 98.9 mm. The following synoptic situation has been observed: Axis of monsoon trough passes through Bihar and GWB. The upper air data of 0000 UTC of 13th July 2008 has been examined. DPD ≤ 5°C has been find upto 400 hPa (D: 0.8), veering/backing of wind has not been prominent (W: 0.3), the precipitable water has been found to 70.9 mm (P: 0.5) and vertical wind shear from 850 hPa to 500 hPa found as 14 knots (S: 0.1). So the critical index comes to 1.7.

3.4.3. *Heavy rainfall on 12 August 2008 over Kolkata*

Heavy rainfall has been occurred on 12 August 2008 over Kolkata. Rainfall recorded at Kolkata on 13th August has been 100.8 mm. The following synoptic situation has been observed: A cyclonic circulation lay over GWB and adjoining area vertically extending upto MTL. The upper air data of 0000 UTC of 12th August 2008 has been examined. DPD ≤ 5°C has been find upto 500 hPa (D: 0.8), veering (060 15 to 095 18 knots) of wind from 850 hPa to 700 hPa (W: 0.2), the precipitable water has been found to 65.6 mm (P: 0.2) and vertical wind shear from 850 hPa to 500 hPa found as 1 knots (S: 0.7). So the critical index comes to 1.9.

3.4.4. *Heavy rainfall on 26 October 2008 over Kolkata*

Heavy rainfall has been occurred on 26 October, 2008 over Kolkata. Rainfall recorded at Kolkata on 27th October has been 82.6 mm. The following synoptic situation has been observed: A deep depression lay over WC at 26/0300 UTC centered near Lat. 18.5°N Long. 87.5°E, 460 km southwest of Kolkata. Moved into a north-northwesterly direction, it intensify into a cyclonic storm RASHMI and lay over NW Bay of Bengal centered at 26/1200 UTC at Lat. 19.5°N Long. 88.0°E about 350 km south of Kolkata. The upper air data of 1200 UTC of 26th October 2008 has been examined (0000 UTC data-misda). DPD ≤ 5°C has been find upto 500 hPa (D: 0.8), veering (100 28 to 255 27 knots) of wind from 850 hPa to 500 hPa (W: 0.5), the precipitable water has been found to 50.6 mm (P: 0.3) and vertical wind shear from 850 hPa to 500 hPa found as 1 knot (S: 0.7). So the critical index comes to 2.3.

4. Conclusions

(*i*)   Monthly distribution shows maximum of 26% events in July followed by September 20%, August 17% and June as 14%. Seasonal distribution naturally indicates maximum of 77% occurrence during monsoon followed by post-monsoon with 14% and pre-monsoon with 09%.

(*ii*)   Trend analysis of 'Heavy Rain Spell' of total 184 spells over Kolkata for 34 years of period shows a significant positive tendency with coefficient of correlation as +0.44 significant at 5% level with an average 5.4 events per year.

(*iii*)   Majority of heavy rainfall has been occurred due to Low Pressure System (LPS) (69%) over Bay of Bengal in the form of LOW/depression/cyclonic storm followed by convection (14%), MT (9%) and UAS (8%). LOW/ Depression usually forms over Bay of Bengal during monsoon season (June-September) near the coast and moved along the monsoon trough and cross GWB and neighborhood coast and brings heavy rainfall over Kolkata. They usually weaken along its path and merge with the monsoon trough. The majority of CS formed over Bay of Bengal/Andaman sea during post-monsoon season (October-December) and very few formed during pre-monsoon season as a LOW and intensify into a CS along its path and moved in westerly/north westerly direction and some of them cross Orissa/West Bengal coast and bring heavy to very heavy rainfall over Kolkata.

(*iv*)   On the basis of PDP, different wind patterns, precipitable water contents and wind shear values and the weightage of the four parameters, a critical value of 1.5 has been found necessary for occurrence of HY to VHY over Kolkata along with the favourable synoptic situation during this period (June-October).

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