MAUSAM, **61**, 2 (April 2010), 187-196

551.579 : 551.577.3 : 556.51

Study of rainfall departure over catchments of Bihar plains

T. N. JHA and R. D. RAM

India Meteorological Department, New Delhi – 110 003, India

(*Received 16 September 2009, Modified 22 December 2009*)

e mail : tilanand@yahoo.in

सार – मानसून ऋतु मे कोसी, कमला/बागमती/अधवारा और गंडक/बूढ़ी गंडक में वर्षा प्रत्यंतर और परिवर्तिता का अध्ययन करने के लिए 60 वर्षों के दैनिक वर्षा के केन्द्रवार आँकड़ों का उपयोग किया गया है। वर्षा प्रत्यन्तर और परिवर्तिता के गुणांक का आकलन करने के लिए केन्द्र और जलग्रहण क्षेत्रवार वर्षा समय श्रृंखलाएँ बनाई गई हैं। अधिकतम, सामान्य, न्यून और विरल वर्षा वितरण में उनके प्रभाव का आकलन करने के लिए परसेनटाइल विश्लेषण के आधार पर दक्षिणी दोलन सूचकांक (एस. ओ. आई.), बहुचर एनसो सूचकांक (एम. ई. आई.) और एनसो तीव्रता का उपयोग किया गया है। इससे प्राप्त हुए परिणामों से पता चला है कि अन्य जलग्रहण क्षेत्रों की तुलना में कोसी में परिवर्तिता अधिक है। सामान्य वर्षा की प्रायिकता 0.75 और एल निनों और ला निना वर्ष में जलग्रहण क्षेत्रों में विरल वर्षा की कोई संभावना नहीं पाई गई है। इसी तरह मिश्रित वर्ष में सामान्य, न्यून, अधिकतम वर्षा की प्रायिकता क्रमशः 0.67, 0.18 और 0.15 पाई गई। एस. ओ. आई. एक मुख्य प्राचल रहा जिससे एल निनो और ला निना वर्ष में प्रत्यंतर में सुधार का पता चला है। विशेष रूप से क्षीण और तीव्र मध्यम ला निना में क्रमशः न्यून और अधिक वर्षा का आकलन करने के लिए मिश्रित वर्ष में एनसो तीव्रता सहित एम. ई. आई. अधिक स्पष्ट रहे हैं।

ABSTRACT. Station wise daily rainfall data of sixty years is used to study rainfall departure and variability in Kosi, Kamala/Bagmati/Adhwara and Gandak/Burhi Gandak catchments during monsoon season. Station and catchment wise rainfall time series have been made to compute rainfall departure and Coefficient of Variation (CV). Southern Oscillation Index (SOI), Multivariate ENSO Index (MEI) and ENSO strength based on percentile analysis are used to ascertain their impact on rainfall distribution in the category as excess, normal, deficient and scanty. Results indicate that the variability is greater over Kosi as compared to the other catchments. Probability of normal rainfall is found 0.75 and there is no possibility of scanty rain over the catchments during El Nino and La Nina year. Similarly probabilities of normal, deficient, excess rainfall are found as 0.67, 0.18 and 0.15 respectively during mixed year. SOI has emerged as principal parameter which modifies the departure during El Nino and La Nina year. MEI along with ENSO strength are more prominent during mixed year particularly to ascertain deficient and excess rain in weak and strong- moderate La Nina respectively .

Key words − Coefficient of variation, Rainfall departure, Southern oscillation index, Multivariate ENSO index, Probability, Deficient and scanty rainfall.

1. Introduction

Agriculture output mainly depends on monsoon rainfall in India. Despite high level water infrastructure investment, Bihar's agriculture yield still remains variable which is driven by highly variable weather sequences in the catchments and adjoining areas with Nepal during south west monsoon season. North south oscillation of monsoon trough in association with propagating upper air westerly trough produces plenty of rainfall in Bihar plains. Gandak catchment receives widespread rainfall from low pressure area/depression when the systems move northwestwards from the Bay of Bengal and the Kamala and the Kosi catchments receive the same rain when the systems move north northwestwards and recurve. Jenamani and Dash (2005) studied role of synoptic and semi permanent system during different phases of EL Nino *vis-a-vis* Indian monsoon rainfall and found that highest monsoon rainfall is strongly correlated with highest number of monsoon disturbances and trough days. It is observed that the findings do not conform with rainfall pattern in the catchments. It is observed that circulation pattern and movement of synoptic systems deviate from normal position and affects spatial distribution of rainfall. Historically average above (below) Indian monsoon rainfall has been generally connected with cold (warm) phase of ENSO but it is still less clear in regional, catchments and sub catchment scale (WMO, 1999). Several studies have been made to relate performance of Indian summer monsoon and its

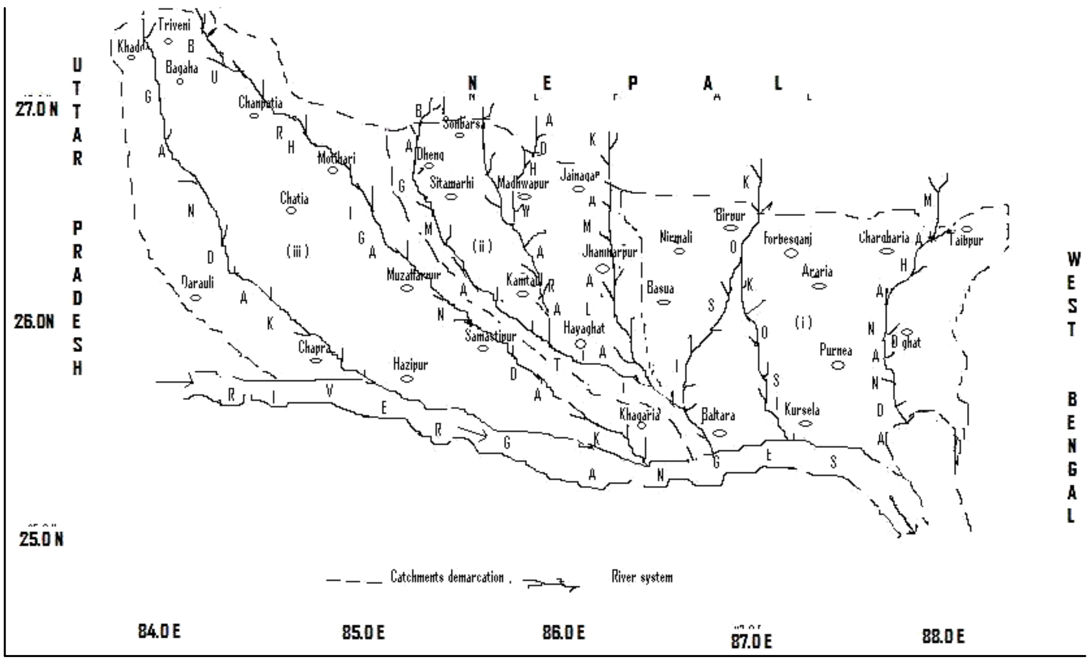

Fig. 1. Catchment area (i) Kosi (ii) Kamala/Bagmati/Adhwara and (iii) Gandak/Burhi Gandak

connection with El Nino and southern oscillation (Mooley and Parthasarthy, 1984; Parthsarthy and Pant, 1985 and Ropelewski and Halpert, 1987). Sontakke and Singh (1996) presented a time series of rainfall dividing India in six homogenous zones but within the zones there are number of incoherent catchment of high variability of rainfall due to regional and local complexities; *viz*., geography, topography and diverse atmospheric processes. Singh (2001) has shown that lag correlation with multivariate ENSO index and Southern Oscillation Index (SOI) is insignificant over Bihar plains during the monsoon season and also found that ENSO does not have any adverse impact on monsoonal rain in eastern India. Studies have been made to ascertain relation of El Nino particularly with drought (Kane, 2004) and found that deficient and scanty rainfall is connected with negative SOI. Kripalani and Kulkarni (1997) found that there was no one-to-one correspondence between monsoon rainfall and El Nino because peak of EL Nino/La Nina phases do not coincide with monsoonal peak. Chattopadhyay and Bhatla (1996) showed simultaneous significant correlation of SOI, *i.e*., Tahiti minus Darwin pressure with performance of Indian monsoon. Indeed, El Nino phenomenon is associated with flood and drought and is linked to the weather disturbances in many locations around the earth. Kirtman and Shukla (2000) has shown that SOI and monsoon rainfall relation is still very complex.

No study has been made to connect catchment rainfall with S O I , therefore , the main objective of the paper is to study rainfall departure in El Nino, La Nina year in Kosi, Kamala/Bagmati/Adhwara and the Gandak/Burhi Gandak catchments during monsoon season using SOI, MEI and strength of ENSO.

2. Physiography of catchments

Fig. 1 shows catchment of Kosi, Kamala/Bagmati/ Adhwara and Gandak/Burhi Gandak. The catchments are situated between Lat. 25.0° - 27.5° N and Long. 83.5° - 88.5° E and boundary of each catchment has been demarcated by dotted line.

The Kosi, the Kamala, the Bagmati and the Gandak originate from the Himalayas, plains and hills in Nepal, the Adhwara and the Burhi Gandak originate from elevated area of Sitamarhi and Someshwar hills of West Champaran district in Bihar respectively. The catchment area of Kosi, Kamala/Bagmati/Adhawara and Gandak/ Burhi Gandak are 13940, 5542 and 17658 sq km respectively. The Kosi, the Gandak and the Burhi Gandak merged with the Ganges at Kursela, Hazipur and Khagaria respectively and the Kamala and the Bagmati with the Kosi at Baltara. The most of their run off is built up in upper catchments and adjoining areas of Indo-Nepal border. The landscape of the catchments is mainly dominated by level plains and soil is mainly alluvial and marshy. About 40 % of total area of Bihar lies within these catchments where 50 % percentage of total population is generally affected due to flood/heavy rain every year. 95% of annual rainfall is received during June - September and the largest amount of surface water is drained into the Ganges. Mean maximum, minimum temperature and relative humidity vary in the range 33-34° C, 25-26° C and 78 - 82 % respectively. The streams of the rivers follow curvilinear path and become turbulent during monsoon season. At time the rivers swell beyond danger level culminating breach of embankments. Economic losses based on 1950-90 data indicate that the aggregate tangible loss is estimated about Rs. 35 crores per year during monsoon due to flood and heavy rain. Hereafter, the Kosi, Kamala/Bagmati/Adhwara and Gandak/Burhi Gandak catchment will be referred collectively as entire basin.

3. Data and methodology

Daily rainfall data of hydromet stations namely Galgalia, Taibpur, Chargharia, Dhengraghat, Araria, Basua, Nirmali, Purnea, Manihari and Kursela of Kosi; Kamtaul, Jhanjharpur, Hayaghat, Benibad, Madhwapur, Jainagar and Sonbarsa of Kamala/Bagmati/Adhwara and Triveni, Chatia, Bagaha, Chanpatia, Samastipur, L B Ghat, Rewaghat, Motihari, Muzaffarpur, Rosera, Darauli, Chapra, Khagaria and Sikanderpur of Gandak/Burhi Gandak catchments have been obtained from National data centre, IMD, Pune from 1930-1990 for the month of June, July, August and September. A computer program in Fortran has been made to compute monthly and seasonal rainfall for each station utilizing available data. Catchment wise monthly and seasonal rainfall have also been computed from the station data set. Similarly seasonal rainfall time series for entire basin is computed using monthly rainfall of all the three catchments. Mean monthly and seasonal rainfall are computed in respect of each catchment to derive C.V. (Pillai and Bagavathi 2003). Finally percentage departure from the mean seasonal rainfall is computed from actual rainfall in respect of each catchment and for the entire basin using the formula as given below.

$$\% \text{ Departure} = (A - N) / N * 100 \quad (1)$$

Where, A = Actual seasonal rainfall and N = Mean Seasonal Rainfall (MSR).

The percentage departure has been classified in the category excess, normal, deficient, scanty according to criteria adopted in India Meteorological Department (Hydromet division); *viz.*, excess +20 % or more, normal +19 to -19 %, deficient -20 to -59 % and Scanty -60 to -99 %.

SOI of Australian Bureau of Meteorology which ranges from about -35 to +35 is used to analyze percentage departure which is calculated using the formula as given below.

$$SOI = 10 (Pdiff - Pdiffav) / SD (Pdiff) \quad (2)$$

Where, Pdiff = (average Tahiti MSLP for the month) - (average Darwin MSLP for the month), Pdiffav = long term average of Pdiff for the month and SD (Pdiff) = long term standard deviation of Pdiff for the month. Magnitude of monthly SOI has been examined for each year and classification has been made as follows.

(*i*) El Nino year : when SOI is negative during all the four months.

(*ii*) La Nina year : when SOI is positive during all the four months and

(*iii*) Mixed year : when SOI is negative in any month out of the four month.

As per above classification, 1930, 1932, 1940, 1941, 1946, 1953, 1963, 1965, 1969, 1972, 1977, 1982 and 1987 are El Nino, 1931, 1938, 1945, 1947, 1950, 1955, 1956, 1964, 1967, 1971, 1973, 1974, 1975, 1978 and 1981 are La Nina year and remaining are mixed year.

MEI may be more informative than SOI because it is based on observed variables in tropical pacific; *viz.*, sea level pressure, zonal and meridional wind, surface wind, sea surface temperature, surface air temperature and total cloudiness fraction in the sky. So, available MEI from 1950 to 1990 has also been down loaded from website (usclivar) with a view to examine ENSO impact on rainfall departure. In order to explain complexities of rainfall distribution on catchment scale, strength of ENSO is used based on percentile analysis (Gergis and Fowler, 2009) which are defined as

Extreme	=	90^{th},
Very strong	=	$70\text{-}90^{th}$,
Strong	=	$50\text{-}70^{th}$,
Moderate	=	$50\text{-}30^{th}$ and
Weak	<	30^{th} percentiles.

Decimal parts of rainfall have been rounded off as per meteorological convention. In the next section the Kosi, Kamala/Bagmati/Adhwara and Gandak/Burhi Gandak catchments will be referred as zone I, zone II and zone III respectively.

4. Results and discussion

Figs. 2-4 show actual seasonal rainfall time series for zone I, II and III respectively and Fig. 5 shows

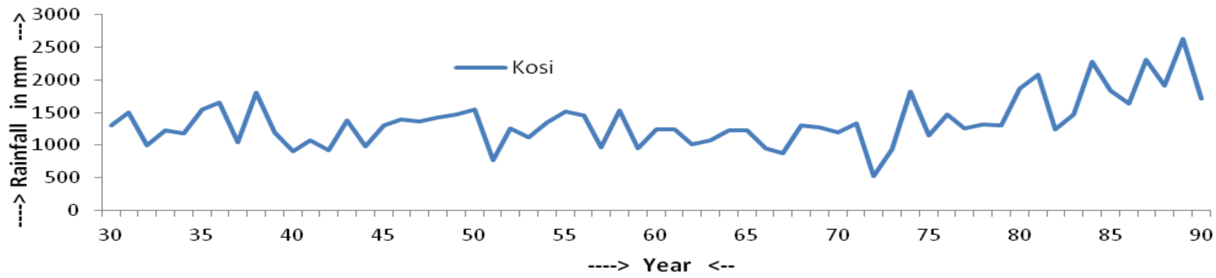

Fig. 2. Time series of rainfall Kosi catchment

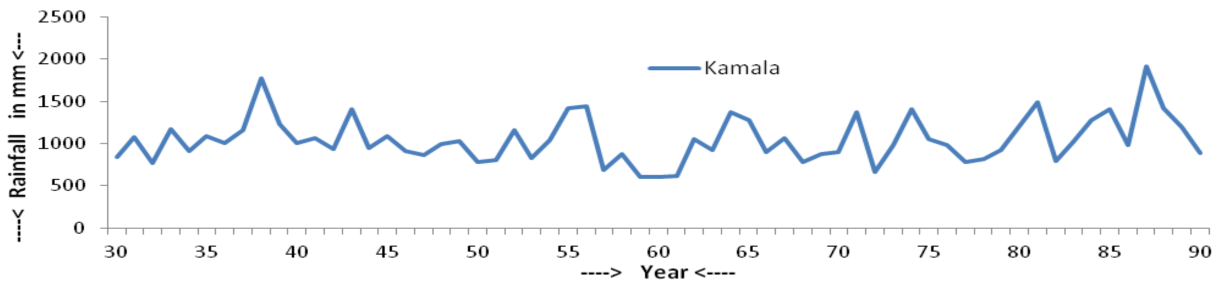

Fig. 3. Time series of rainfall in Kamala/Bagmati/Adhawara catchment

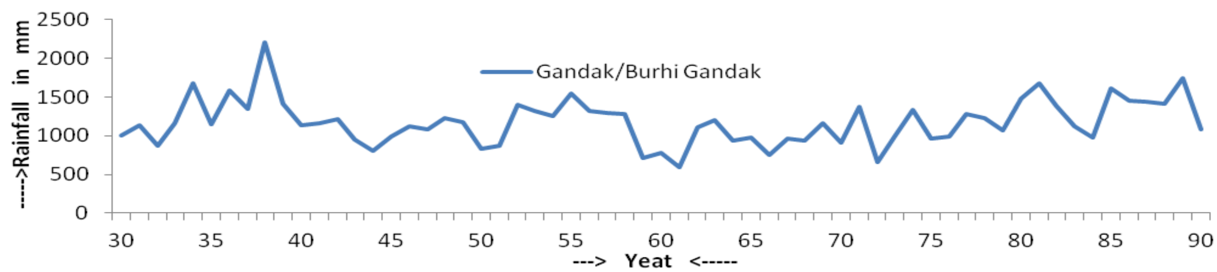

Fig. 4. Time series of rainfall in Gandak/Burhi Gandak catchment

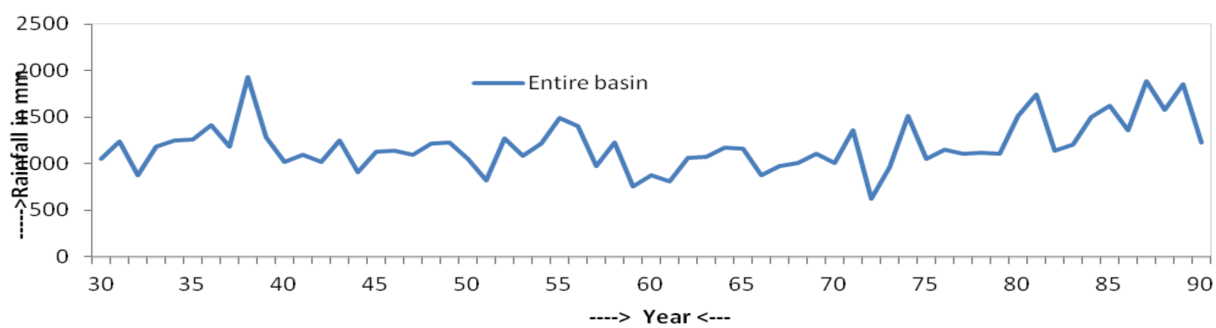

Fig. 5. Time series of rainfall for entire basin

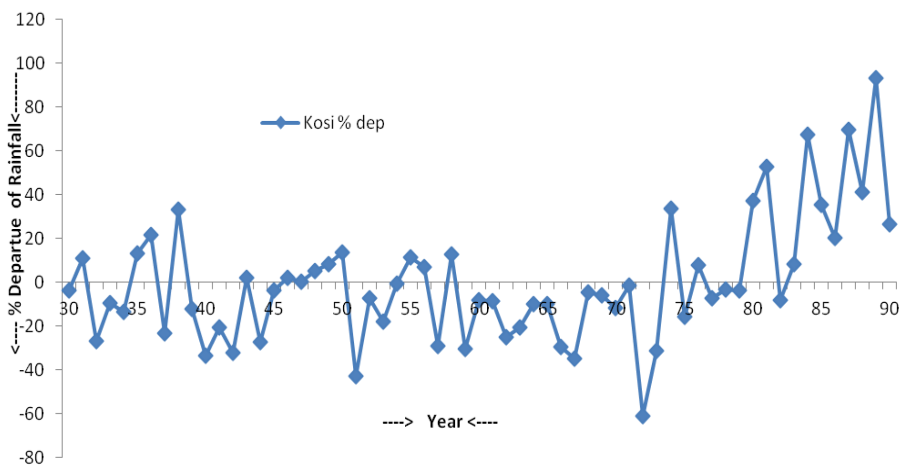

Fig. 6. Yearly percentage departure from normal of Kosi catchment

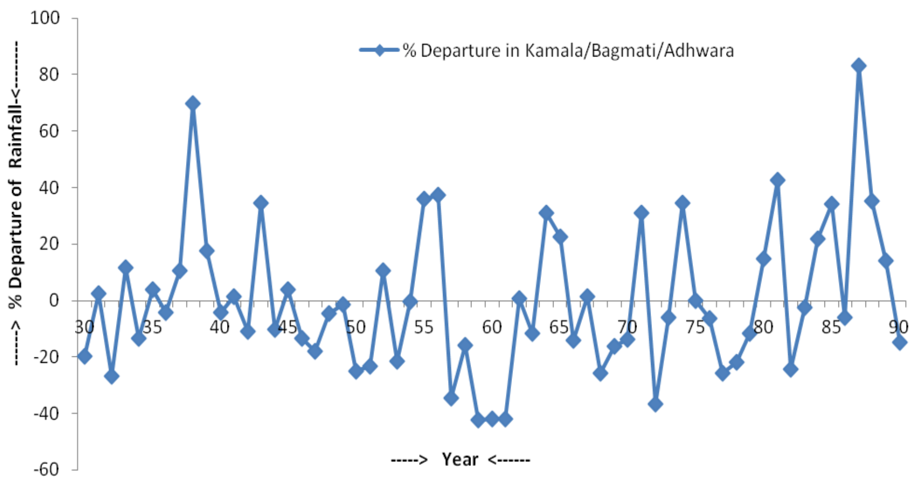

Fig. 7. Yearly percentage departure of Kamala/Bagmati/Adhwara catchment

the same for entire basin. The highest rainfall is found 2307 and 1919 mm in zone I and II during the year1987 and the same is found 2207, 1931 mm for zone III and entire basin in the year 1938 respectively. During July 1987 monsoon trough was running from Rajasthan to Assam across Bihar with embedded upper air cyclonic circulation over Bihar from 11 July 1987 to 2 August 1987 as well as two depression passed across Jharkhand and adjoining areas of Bihar close to Chaibasa during the month of August and September (IDWR-1987). Four depressions formed over north west Bay and adjoining areas during the monsoon months in 1938 and under its influence monsoon was active over Bihar plains (IDWR - 1938). The lowest rainfall is found as 532, 664, 662 and 620 mm in zone I, II, III and entire basin respectively in the year 1972 because one after another four depression formed in the North West Bay of Bengal and all the systems moved westwards across Orissa and Chhattisgarh. Hence, break monsoon was observed rarely for a short period of 2-3 days. The highest and the lowest rainfall over the catchments are attributed to the direction of movement of weather system across the catchments. One can see from the figures that actual rainfall has increased in all the three catchments alongwith entire basin from 1975 to 1989. It is to be noted that the period is under impact of mixed phase except 1982 and 1987. In addition to 3-4 years El Nino oscillation in equatorial Pacific, there are also inter decadal and perhaps centennial oscillation. They are all interacting in such a way that relation has not yet been understood (Asnani, 2001).

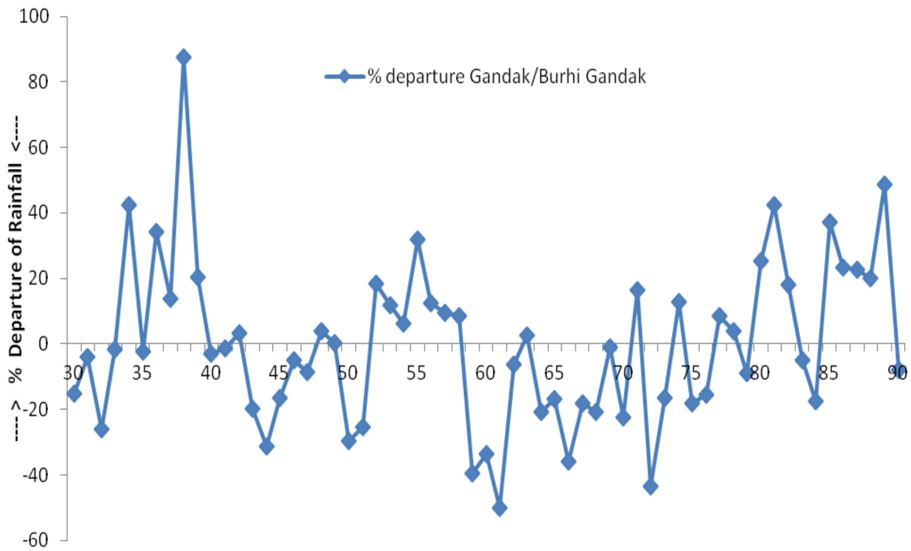

Fig. 8. Yearly percentage departure of Gandak/Burhi Gandak catchment

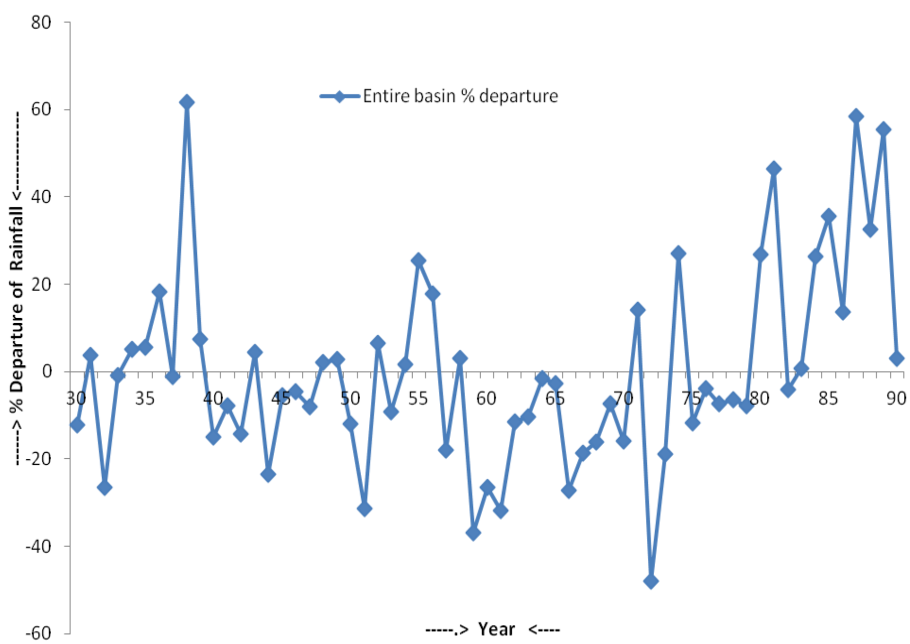

Fig. 9. Yearly percentage departure for entire basin

Utilizing actual rainfall of the catchments, MSR have been worked out as 1360, 1044 and 1178, 1195 mm for zone I, II, III and entire basin respectively.

Table 2 shows mean monthly rainfall and C. V. of zone I, II and III. It is found that the highest rainfall occurred in zone I and the lowest in zone II during the monsoon month. Comparing C.V. of of the catchments one can find that the variability is least in zone III. The highest variability in zone I is attributed to the topography of the catchment and monsoon trough. At time low pressure area and cyclonic circulation recurve in September and remain stationary for 2-3 days which causes widespread and heavy rain in zone I and II. Station wise actual monthly and seasonal rainfall have also been analyzed and the highest MSR is found

TABLE 1

Southern Oscillation Index (S.O.I.) and Multivariate ENSO Index (M.E.I.) during June - September

	SOI				MEI				
Year	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep	Remark
1930	-5.5	-4.3	-1.8	-7					N
1931	18.8	9.4	0.1	5.1					N
1932	-4.7	-5	-6.9	-8.8					D
1938	18	18.5	13	7.5					E
1940	-19.3	-15.4	-18.5	-19.6					N
1941	-14.4	-20.6	-19.1	-8.2					N
1945	8.3	3.5	11.7	8.7					N
1946	-9.6	-10.2	-4.4	-16					N
1947	2.6	9.4	7.2	11.7					N
1950	26.9	21.1	12.3	6.9	-1.37	-1.31	-1.06	-0.59	N
1953	-2.3	-1	-17.3	-13	0.24	0.43	0.26	0.56	N
1955	16.4	19.2	14.9	14.1	-2.25	-1.88	-1.99	-1.78	E
1956	12.3	12.6	11	0.2	-1.51	-1.19	-1.11	-1.35	N
1963	-9.6	-1	-2.4	-5.2	-0.07	0.38	0.66	0.75	N
1964	7.4	6.8	14.3	14.1	-1.13	-1.38	-1.54	-1.29	N
1965	-12.8	-22.6	-11.4	-14.2	0.94	1.44	1.52	1.45	N
1967	6.6	1.6	5.9	5.1	-0.31	-0.62	-0.49	-0.7	N
1969	-0.6	-6.9	-4.4	-10.6	0.8	0.43	0.27	0.21	N
1971	2.6	1.6	14.9	15.9	-1.47	-1.24	-1.27	-1.47	N
1972	-12	-18.6	-8.9	-14.8	1.13	1.82	1.77	1.54	D
1973	12.3	6.1	12.3	13.5	-0.77	-1.07	-1.36	-1.71	N
1974	2.6	12	6.6	12.3	-0.65	-0.8	-0.69	-0.61	E
1975	15.5	21.1	20.7	22.5	-1.18	-1.5	-1.69	-1.82	N
1977	-17.7	-14.7	-12.1	-9.4	0.49	0.85	0.69	0.78	N
1978	5.8	6.1	1.4	0.8	-0.53	-0.38	-0.2	-0.35	N
1981	11.5	9.4	5.9	7.5	-0.03	-0.04	-0.14	0.14	E
1982	-20.1	-19.3	-23.6	-21.4	0.99	1.61	1.77	1.8	N
1987	-20.1	-18.6	-14	-11.2	1.93	1.83	2.01	1.89	E

N = Normal, D = Deficient and E = Excess

2093 mm at Galgalia in zone I, 1172 mm at Kamtaul in zone II and 1746 mm at Triveni in zone III. Similarly, the lowest MSR is found 1031 mm at Manihari in zone I, 968 mm at Jainagar in zone II and 973 mm at Khagaria in zone III. There is significant difference between the highest and the lowest rainfall within the catchment and the entire basin. All the station recorded the highest rainfall in the month July and lowest in June.

The departures of actual rainfall in respect of zone I, II and III have been shown in Figs. 6, 7 and 8 respectively. During the El Nino years *i.e*., 1930, 1932, 1940, 1941, 1946, 1953, 1963, 1965, 1969, 1972, 1977, 1982 and 1987 departures are found -4 %, -27 %, -33 %, -21 %, 2 %, -18 %, -21 %, -10 %, -6 %, -61 %, -7%, -8 % and 70 % in zone I; -20 %, -27 %, -4 %, 1 %, -13 %, -21 %, -12 %, 22 %, -16 %, -37 %, -26 %, -24 % and 83 % in zone II and these are found -15 %, -26 %, -3 %, -1 %, -5 %, 12 %, 3 %, -17 %, -1 %, -44 %, 9 %, 18% and 23 % in zone III respectively. All the three catchments received excess rain in 1987 and deficient in 1932 and 1972. Similarly during La Nina years *i.e*., 1931, 1938, 1945, 1947, 1950, 1955, 1956, 1964, 1967, 1971, 1973, 1974, 1975, 1978 and 1981 departures are found 11 %, 33 %, -4%, 0 %, 14 %, 12 %, 7 %, -10 %, -35 %, -1 %, -31 %, 34 %, -16 %, -3 % and 53 % in zone I ; 3 %, 70 %, 4 %, -18 %, -25 %, 36 %, 38 %, 31%, 1%, 31%, -6%, 34%, 0%, -22 % and 43 % in zone II and these are -4 %, 88 %, -16 %, -8 %, -30 %, 32 %, 13 %, -21 %, -18 %, 17 %, -16 %, 13 %, -18 %, 9 % and 43 % in zone III respectively . There are excess rain in the year 1938 and 1981 and no occurrence of scanty rain during both the events. More or less number of cases of excess rain is larger in La Nina than EL Nino year . Similarly rainfall departures during mixed year are also investigated and it is found that 1951 and 1959 are deficient and 1980, 1985 and 1988 are excess rain years in all the three catchments. In this case also number of excess rain are larger in each catchment compared to El Nino year. Therefore, explicit statement can not be made that rainfall departure is likely to be normal or excess or deficient.

Fig. 9 shows rainfall departures for the entire basin. During the year 1930, 1932, 1940, 1941, 1946, 1953, 1963, 1965, 1969, 1972, 1977, 1982 and 1987 departures are found -12 %, -26 %, -15 %, -8 %, -5 %, -9 %, -10 %, -3 %, -7 %, -42 %, -7 %, -4 % and 58 % respectively. Similarly during 1931, 1938, 1945, 1947, 1950, 1955, 1956, 1964, 1967, 1971, 1973, 1974, 1975, 1978 and 1981 the same are found 4 %, 62 %, -6 %, - 8 %, -12 %, 25 %, 18 %, -1 %, -19 %, 14 %, -19 %, 27 %, -12 %, -6 % and 47 % respectively. Mostly normal rain occurred during both the events. There are two deficient cases in El Nino and none is found in La Nina year. Rainfall distribution depends on the oscillation of synoptic scale systems particularly monsoon trough over the zones (Krishnamurthy and Bhalme, 1976). Numbers of cases of excess rain are greater in La Nina than El Nino year. Similar pattern of rainfall departure is also found in mixed year on inter annual scale but there are cases of deficient

TABLE 2

Catchments mean monthly rainfall and coefficient of variation in %

Catchment Name	Month				
	Jun	Jul	Aug	Sep	C.V.
Kosi	270	514	323	253	28
Kamla/Bagmati/Adhwara	141	406	294	207	26
Gandak/Burhi/Burhi Gandak	184	422	320	252	25

rain during mixed year. Intricacy of the rainfall distribution over the entire basin may be attributed to dynamics of monsoon flow associated with synoptic conditions (Ramaswamy, 1962). Dynamically it is also found that vertical wind circulation over monsoon trough accompanying with upward moisture and convective clouds dominate over eastern India and downward motion over western India without rain (Das, 1962).

Table 1 shows SOI and MEI for the month of June, July, August and September alongwith category of rainfall departure for the entire basin during El Nino and La Nina. Positive and negative sign of SOI is exactly matching with MEI as per usual convention except in 1963 where MEI is negative in the month of June whereas SOI is negative during the all the four months. There are 10 cases of normal rainfall out of 13 events of El Nino and 11 cases of normal rainfall out of 15 events of La Nina. There is single case of excess rain in El Nino year and probability of normal, deficient and excess rainfall are found 0.77, 0.15 and 0.08 respectively while in La Nina year the probability of normal and excess are 0.73, 0.27 respectively. Similarly, there are 22 normal cases out of 32 mixed years and probability of normal, deficient and excess rainfall are 0.67, 0.18 and 0.15 respectively. In this way the departure of rainfall for each year has been examined in order to find out probability of rainfall distribution in general. There are 42 normal out of 60 years and probability has also been computed which is found 0.70, 0.13 and 0.17 for normal, deficient and excess rain respectively.

From 1951-1990 all mixed years have been examined to ascertain impact of SOI and MEI on rainfall departure in the category excess, normal, deficient and scanty. It is found that 1952, 1954, 1957, 1958, 1962, 1968, 1970, 1976, 1979, 1983, 1986 and 1990 are normal year over the entire basin. During 1952, SOI was negative during the month of August and September while MEI was negative in the month of June, July and August and during 1970 also SOI was negative in the month July whereas MEI was negative during all the four month. During 1990, SOI was negative in the month of August and September while MEI was positive during all the four months. Similarly 1951, 1959, 1960, 1961 and 1966 are found deficient year. During 1951, SOI was found negative in the month of July, August and September while MEI was in positive during all the four months and during 1960 and 1961, SOI was negative during June only while MEI was negative during all the four months and similar is the case for both the indices during 1966. Excess rain occurred in the year 1980, 1984, 1985, 1988 and 1989. During 1984, SOI was negative in June while MEI was negative in all the four months and in 1989, SOI was negative in the month of August whereas MEI was negative in all the four months. In this way all normal, deficient and excess years have examined and found no one-to-one relation except excess rain. Obviously impact of MEI is also not clear on rainfall departure during mixed year. With a view to find distinctive signal of ENSO, the strength of the event has been considered to analyze the departure during mixed years. It is found that deficient rain occurred during weak La Nina and moderate El Nino and excess rain during very strong to moderate La Nina episode. Normal rain occurred at all ramifications of ENSO strength, *viz*., Very strong - moderate La Nina, strong - moderate El Nino.

5. Conclusions

(*i*) Variability of rainfall over Kosi is greater than Kamala/Bagmati/Adhwara and Gandak/Burhi Gandak catchment.

(*ii*) Probability of normal rain is found about 0.75 during EL Nino and La Nina year and no possibility of scanty rain over the catchments.

(*iii*) Deficient rain may be ruled out over the entire basin during La Nina year and there is least probability of excess rain during El Nino year.

(*iv*) MEI together with strength of ENSO have been found viable parameter to estimate rainfall distribution particularly for deficient and excess rain during mixed year. Normal to excess rain occurred during very strong to moderate La Nina and deficient rain during weak La Nina and strong-moderate El Nino and probability of normal, deficient and excess rain are found as 0.67, 0.18 and 0.15 respectively.

(*v*) SOI has emerged prominent indicator of rainfall departure during EL Nino and La Nina year over the catchments.

(*vi*) Water storage and drainage system may be augmented in the entire basin particularly in Kamala/Bagmati/Adhwara and Gandak catchments for water management during weak monsoon.

Acknowlegement

The authors are thankful to D.D.G.M. (Hydromet) and Director (Hydromet) for useful suggestions and cooperation for preparing this paper.

References

Asnani, G. C., 2001, “El Nino of 1997-98 and Indian summer monsoon”, **52**, 1, 57-66.

Chattopadhyay, J. and Bhatla, R., 1996, “A re-examination of ENSO/anti ENSO events and simultaneous performance of the Indian summer monsoon”, *Mausam*, **47**, 1, 59-66.

Das, P. K., 1962, “Mean vertical motion and non adiabatic heat sources over India during monsoon”, *Tellus*, **14**, 212-220.

Gergis, J. L. and Fowler, A. M., 2009, “A history of ENSO events since AD1525 : implication for future climate change”, *Climate change*, **92**, 3-4, 345-387.

I.D.W.R., 1938, “India Meteorological Department “Yeravda prison press, Poona.

I.D.W.R., 1987, “India Meteorological Department”, Pune.

Jenamani, R. K. and Dash, S. K., 2005, “A study on role of synoptic and semi permanent feature of Indian summer monsoon on its rainfall variation during different phases of El Nino”, *Mausam*, **56**, 4, 825-840.

Kane, R. P., 2004, “Relation of El Nino characteristics and timing with rainfall extreme in India and Australia”, *Mausam*, **55**, 257 -268.

Kirtman, B. P. and Shukla, J., 2000, “Influence of Indian summer monsoon on ENSO”, *Q. J. R. Meteorol. Soc*., **126**, 213-239.

Kripalani, R. H. and Kulkarni, A., 1997, “Climate impact of El Nino/La Nina on the Indian monsoon : A new perspective”, *Weather*, **52**, 39-46.

Krishnamurthy, T. N. and Bhalme, H. N., 1976, “Oscillation of monsoon systems”, *J. Atmos. Sci*., **33**, 1937-1954.

Mooley, D. A. and Parthasarthy, B., 1984, “Fluctuation in all India summer monsoon rainfall during 1971-1978”, *Climate Change*, **6**, 287-301.

Parthasarthy, B. and Pant, G. B., 1985, “Seasonal relationship between Indian summer monsoon rainfall and the southern oscillation”, *J. Cli*., **5**, 369-378.

Pillai, R. S. N. and Bagavathi, 2003, “Practical statistics”, S. Chand and Co. Ltd.

Ramaswamy, C., 1962, “Breaks in the Indian summer monsoon as a phenomenon of Interaction between easterly and westerly jet streams”, *Tellus*, **14**, 337- 349.

Ropelewski, C. F. and Halpert, M. S., 1987, "Global and regional scale precipitation pattern associated with the El-Nino/southern oscillation", *Mon. Wea. Rev*., **115**, 1606-1626.

Singh, O. P., 2001, "Multivariate ENSO Index and Indian monsoon rainfall; relationship on monthly and sub-divisional scales", *Meteorol. Atmos. Phy*., **78**, 1-9.

Sontakke, N. A. and Singh, N., 1996, "Longest instrumental regional and all India summer monsoon rainfall series using optimum observations, reconstruction and update", *Rev. Geophys*., **13**, 183-200.

World Meteorological Organisation, 1999, "Statement on status of global climate", W.M.O., No. **896**, p12.