Journal of Climate Change, Vol. 3, No. 1 (2017), pp. 27–35.
DOI 10.3233/JCC-170003

Droughts/Floods in Relation to El Nino/La Nina over All-India, East Uttar Pradesh and Some Stations of East Uttar Pradesh

R. Bhatla[1]*, Usha Laxmi[2] and Madhu Singh[1]

[1]Department of Geophysics, Benaras Hindu University, Varanasi, India
[2]Department of Botany, Benaras Hindu University, Varanasi, India
✉ rbhatla@bhu.ac.in

Received May 22, 2016; revised and accepted October 11, 2016

Abstract: Monsoon is the seasonal change in atmospheric circulation and precipitation associated with the asymmetric heating of land and sea. The year-to-year variability in monsoon rainfall could cause severe droughts and floods. El Nino is widely recognized as the main source of global climate variability. Thus, the interannual variation of summer rainfall over India is associated with El Nino/La Nina events. In the present study, the association between the seasonal rainfall series for all-India, East Uttar Pradesh (UP) and also their some stations with El Nino/La Nina events for the period 1971-2010 has been analyzed. The study shows that there is association of drought/flood condition with El Nino/La Nina, but it is not necessary that every drought/flood over all-India, East UP and some stations of East UP relate to the El Nino/La Nina.

Keywords: El Nino/La Nina; Drought/floods; Southwest monsoon; Interannual variability.

Introduction

Indian economy largely depends upon agriculture, and Indian agriculture is heavily dependent on the rains, especially during the summer monsoon or southwest monsoon (June to September). The inter-annual variation of rainfall is associated with El Nino and La Nina events. The El Nino is the warm phase of the El Nino Southern Oscillation (commonly called ENSO) and it is due to band of warm ocean water that develops in the central and east-central equatorial Pacific including the pacific coast off South America. On the other hand La Nina is the cold phase; it is a coupled ocean-atmosphere phenomenon that is the counterpart of El Nino.

Thapliyal and Kulshreshtha (1991), Gadgil (2003), Kriplani et al. (2003), Bhatla and Chattopadhyay (1995) and many studies relate the variability of the Indian summer monsoon rainfall on different temporal and spatial scales. There are studies by many workers over the past decade which have shown that interannual variation in many parts of the world and ENSO (El Nino Southern Ocean) events (warm event) in the tropics are generally related, for example drought in Australia, Indonesia, India and parts of Africa and the heavy rain and floods in the Pacific coast of South America (Nicholls, 1991; Ropelewski and Halpert, 1987). During an anti-ENSO or the cold event, the pattern of climatic anomalies is broadly reverse of that experienced during an ENSO event (Van Loon, 1985; Ropelewski and Halpert, 1989). Sikka (1980) for the first time relates the droughts over India with the occurrence of ENSO event. Since then there were several studies related to Indian monsoon rainfall and ENSO/anti-ENSO events (Angell,

*Corresponding Author

1981; Rasmusson and Carpanter, 1983; Mooley and Pathasarathy, 1983; Chattopadhyay and Bhatla, 1996).

Most studies suggested that there is some link between ENSO (anti-ENSO) events with droughts (floods); the relationship is not necessarily universal. Singh and Sontakke (2002) have inferred westward shift in rainfall activities and severe rainstorms over IGPs (Indo Gangetic Plains). Several studies have demonstrated that El Nino events with the warmest sea surface temperature (SST) anomalies in the central equatorial Pacific are more effective in focusing drought-producing subsidence over India than events with the warmest SSTs in the East equatorial Pacific. Different authors selected these El Nino/La Nina events based on the number of factors, e.g., Sea Surface Temperature Anomaly (SSTA) over East Pacific (Quinn et al., 1978; Rasmusson and Carpenter, 1982), Southern Oscillation Index (SOI). Halpert and Ropelewski (1992) and several others have shown atmospheric and oceanographic parameters like disruption of fishery and marine bird life off the coasts of Peru and Equador. Kriplani and Kulkarni (1997) and Kumar et al. (1999) have suggested a change in the relationship between these two phenomena, while Sahai et al. (2003) showed that there is need for more evidences.

A recent study (Bhatla et al., 2015) relates the possible association between Indo-Gangetic rainfall and El Nino/La Nina events. However, in the present study, an attempt has been made to analyze the seasonal rainfall series for all-India, east Uttar Pradesh (UP) and some stations of east UP during time period 1971-2010 and examine its association with El Nino and La Nina to see the impact of El Nino/La Nina in the smaller scale over India.

Data and Methodology

The summer monsoon or southwest monsoon (June to September) rainfall data over all-India and east Uttar Pradesh (UP) was obtained from the website (www.tropmet.res.in). The rainfall data over some stations of East UP viz. Varanasi, Lucknow, Allahabad, Gorakhpur and Bahraich (Figure 1) were taken from India Meteorological Department. The rainfall series for all-India, east UP and some stations of east UP were used for the period 1971-2010. To identify the flood, drought and normal monsoon years for all-India, the following criteria have been used:

I. Flood: Percentage departure of realized rainfall is >10% of the Long Period Average.
II. Drought: Percentage departure of realized rainfall is <10% of the Long Period Average.
III. Normal: Percentage departure of realized rainfall is within ±10% of the Long Period Average.

To identify the flood, drought and normal monsoon years for east Uttar Pradesh and the selected stations, the following criteria have been used:

I. Flood: Percentage departure of realized rainfall from normal rainfall is +20% or more.
II. Drought: Percentage departure of realized rainfall from normal rainfall is <20%.
III. Normal: Percentage departure of realized rainfall from normal rainfall is between –19% to +19%.

For the purpose of association between different categories of rainfall for all-India, East UP and some stations of the region during the period 1971-2010 with El Nino/La Nina, the El Nino and La Nina years for the period 1971-2010 have been taken from the website (https://www.longpaddock.qld.gov.au/products/australiasvariableclimate/ensoyearclassification.html).

Results and Analysis

Rainfall Analyses and Its Association with El Nino/La Nina over All-India

Figure 2 shows the percentage departure of monsoon season rainfall over all-India during the period of 1971-2010. It has been found that there were eight drought years (1972, 1979, 1982, 1986, 1987, 2002, 2004 and 2009) and five flood years (1975, 1983, 1988, 1994 and 2007) and rest 17 years were normal monsoon years. There were the 13 El Nino years (1972, 1977, 1982, 1987, 1991, 1992, 1993, 1994, 2002, 2004, 2006, 2009 and 1994), 11 La Nina years (1971, 1973, 1974, 1975, 1988, 1996, 1998, 2000, 2007, 2008 and 2010) during the period 1971-2010 and the rest 16 years were neutral years. However, the El Nino (single asterisks) and La Nina (double asterisks) are also marked in Table 1, for its association with drought and flood years respectively.

It has been observed that six drought years viz. 1972, 1982, 1987, 2002, 2004 and 2009 out of the total eight years were associated with El Nino and rest two drought years, 1979 and 1986 were neutral years (Table 1). Further, it has been found that three floods 1975, 1988 and 2007 were associated with La Nina years. However, the year 1994 was identified as flood year in spite of El Nino year. The year 1983 was identified as flood year and it was neutral year. Thus, it has been observed that 75% of droughts were associated with El Nino and rest 25% droughts were associated with neutral years and no

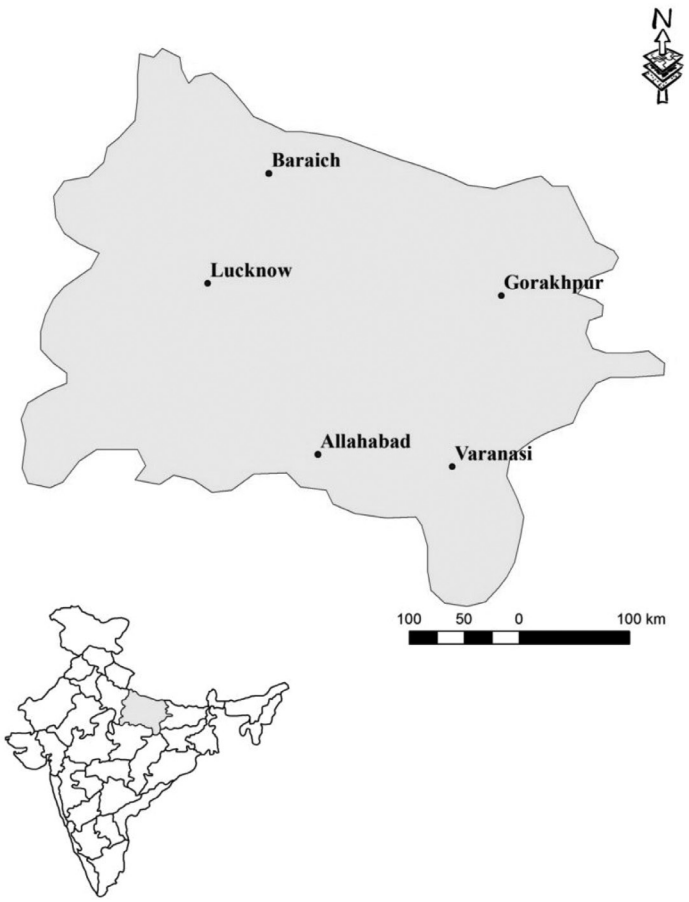

Figure 1: Location map of the study area.

drought years were associated with La Nina (Table 2). Table 2 also shows that 60% of floods were associated with La Nina, 20% of floods associated with El Nino and rest 20% with neutral years. The normal monsoon years may be associated with El Nino with about 25% of chance or La Nina with about 30% of chances (Table 2). It is interesting to note that no drought years are associated with La Nina, while flood years might be associated with La Nina and El Nino (with little chances of 20%). It can also be shown that about 50% of El Nino years were associated with drought years; only about 8% of El Nino years were associated with flood years while 42% were normal monsoon years over all-India. While, about 30% of the La Nina years were related to floods, about 10% related to El Nino years and rest 60% associated with normal monsoon years.

Rainfall Analyses and Its Association with El Nino/ La Nina over East Uttar Pradesh

Figure 3 shows the percentage departure of monsoon season rainfall over east Uttar Pradesh. During the period 1971-2010, eight droughts (1972, 1977, 1979, 1987, 1991, 2002, 2009 and 2010), and six floods (1971, 1975, 1980, 1981, 1990 and 2008) and rest 26 years were found to be associated with normal monsoon years.

Table 1 shows that six drought (out of eight) years were associated with El Nino years. The only year 2010 was identified as a drought year in spite of La Nina condition. Interestingly, east UP has experienced drought in the year 1979 in spite of neutral condition of El Nino/La Nina. Further, it has been found that three flood years 1971, 1975 and 2008 were associated with La Nina years and rest three floods 1980, 1981 and 1990 were associated with neutral condition. It can also be observed from Table 1 that about 50% of El Nino years were associated with drought years, only about 8% of El Nino years were associated with flood years while 42% were normal monsoon years over east Uttar Pradesh (same as all-India). It has been observed that there were 75% of droughts associated with El Nino, about 12% droughts associated with La Nina and rest of about 13% drought associated with neutral condition (Table 2). Table 2 also suggests that 50% of floods were related to La Nina, rest 50% with neutral condition of El

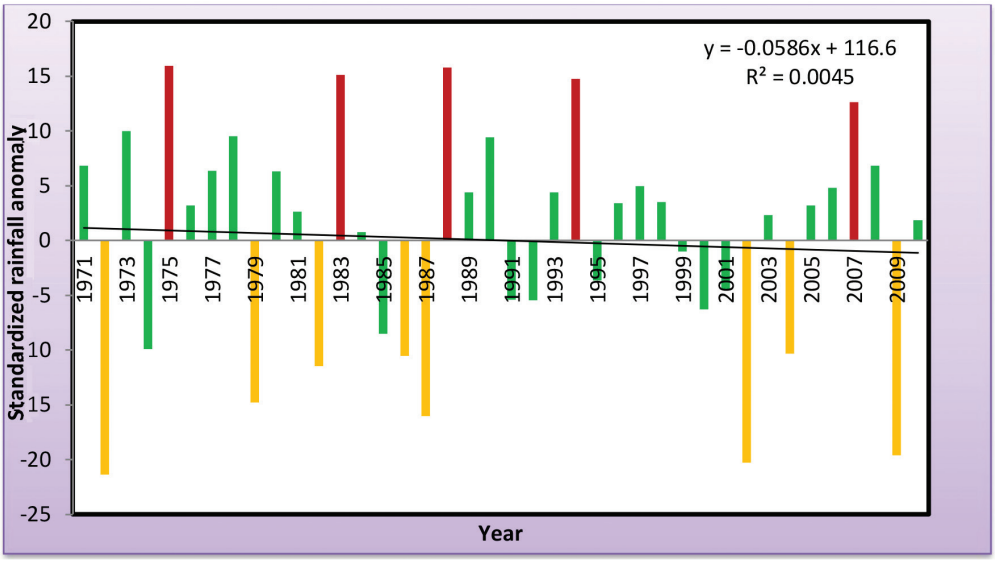

Figure 2: Standardized rainfall anomaly over all-India for monsoon season (June-September) during the period 1971 to 2010. The normal years are shown by green coloured bars, drought years shown by red coloured bars and flood years are shown by yellow coloured bars.

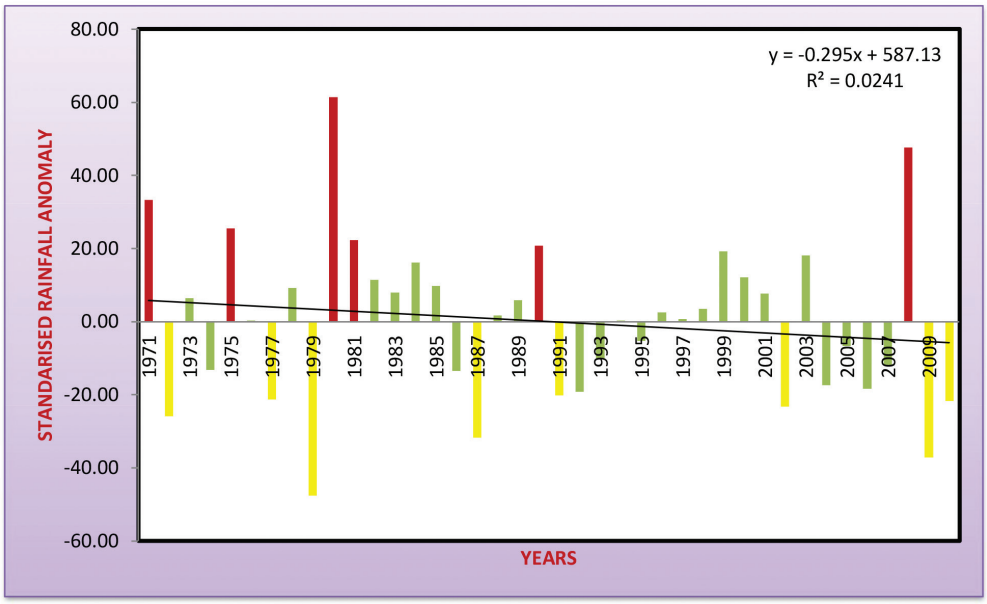

Figure 3: Standardized monsoon season (June-September) rainfall anomaly during the period 1971 to 2010 over east U.P. The normal years are shown by green coloured bars, drought years shown by red coloured bars and flood years are shown by yellow coloured bars.

Nino/La Nina and no flood years were associated with El Nino. However, the normal monsoon years might be associated with El Nino or La Nina with about 27% of chances (Table 2).

When standardized rainfall anomaly over east UP has been compared with standardized rainfall anomaly of all-India, it has been found that not every drought over east UP is associated with drought condition over India and same condition hold true for floods also. Also, the impact of El Nino and La Nina over all-India shows variation from its impact on east UP.

Rainfall Analyses and Its Association with El Nino/ La Nina over Different Stations of East Uttar Pradesh

It has been observed that there were five years, 1972, 1979, 1988, 2004 and 2010 associated with drought years and seven years, 1971, 1973, 1978, 1987, 1995,

Table 1: Years of drought (D), flood (F) and normal (N) monsoon and its association with El Nino (single asterisk) and La Nina (double asterisk) over all-India, east UP and some stations of east UP

Years	*All-India*	*East UP*	*Varanasi*	*Lucknow*	*Allahabad*	*Gorakhpur*	*Bahraich*
1971**	N	F	F	F	F	N	F
1972*	D	D	D	N	D	D	D
1973**	N	N	F	N	D	N	N
1974**	N	N	N	D	D	D	D
1975**	F	F	N	F	N	D	F
1976	N	N	N	N	N	D	D
1977*	N	N	N	N	N	D	D
1978	N	N	F	F	N	N	N
1979	D	D	D	D	D	D	N
1980	N	F	N	F	F	F	F
1981	N	F	N	F	F	N	F
1982*	D	N	N	F	F	D	D
1983	F	N	N	D	D	N	N
1984	N	N	N	D	N	F	F
1985	N	N	N	F	N	F	F
1986	D	N	N	N	N	D	D
1987*	D	D	F	D	D	N	D
1988**	F	N	D	F	N	F	D
1989	N	N	N	D	D	F	N
1990	N	F	N	N	F	D	F
1991*	N	D	N	F	F	N	N
1992*	N	N	N	D	D	D	N
1993*	N	N	N	D	D	N	N
1994*	F	N	N	N	N	N	D
1995	N	N	F	D	N	N	D
1996**	N	N	N	D	N	N	N
1997*	N	N	N	N	N	D	N
1998**	N	N	N	D	F	N	N
1999	N	N	F	D	F	D	N
2000**	N	N	N	F	F	F	F
2001	N	N	F	D	N	F	N
2002*	D	D	N	N	D	D	D
2003	N	N	N	N	N	N	N
2004*	D	N	D	D	N	N	N
2005	N	N	N	D	N	N	N
2006*	N	N	N	N	D	N	N
2007**	F	N	N	D	N	N	N
2008**	N	F	N	F	F	F	F
2009*	D	D	N	N	N	N	N
2010**	N	D	D	N	D	F	D

*El Nino **La Nina

Table 2: Overall association of El Nino/La Nina with drought/flood during the period 1971-2010

Region	*No. of flood years*	*Association with El Nino event*	*Association with La Nina event*	*No. of drought years*	*Association with El Nino event*	*Association with La Nina event*	*No. of normal years*	*Association with El Nino event*	*Association with La Nina event*
All-India	5	1(20%)	3(60%)	8	6(75%)	0	27	6(22.22%)	8(29.62%)
East UP	6	0	3(50%)	8	6(75%)	1(12.5%)	26	7(26.92%)	7(26.92%)
Varanasi	7	1(14.29%)	2(28.57%)	5	2(40%)	2(40%)	28	10(35.71%)	7(25%)
Lucknow	11	2(18.18%)	5(45.45%)	16	4(25%)	4(25%)	13	7(53.84%)	2(15.38%)
Allahabad	10	2(20%)	4(40%)	12	6(50%)	3(25%)	18	5(27.78%)	4(22.22%)
Gorakhpur	9	0	4(44.44%)	13	6(46.15%)	2(15.38%)	18	7(38.89%)	5(27.78%)
Bahraich	9	0	4(44.44%)	12	6(50%)	3(25%)	19	7(36.84%)	4(21.05%)

1999 and 2001 associated with flood years over Varanasi (Table 1). Further, it has been observed that there were two drought years 1972 and 2004 associated with El Nino years. Interestingly, the drought years 1988 and 2010 were associated with La Nina years. Although, the year 1979 was neither an El Nino nor the La Nina year, it was associated with drought condition over Varanasi. Table 1 also shows that out of seven, two flood years 1971 and 1973 were associated with La Nina condition. However, the year 1987 was identified as a flood year in spite of El Nino condition and rest four floods 1978, 1995, 1999 and 2001 were found to be associated with normal condition. Thus, it has been observed that there were 40% of drought years associated with each El Nino and La Nina events and rest 20% of drought years were not associated with El Nino/La Nina events over Varanasi during the period 1971 to 2010 (Table 2).

Table 2 also concludes that about 29% of floods were related with La Nina years, and very less association (15%) were found with El Nino years and rest, 56% of flood years were neither El Nino nor La Nina events over Varanasi. It can also be observed from Table 1 that about 15% of El Nino years were associated with drought years, only about 8% of El Nino years were associated with flood years while 77% were normal monsoon years over Varanasi. However, 18% of La Nina events were associated with droughts or floods over Varanasi while 64% were normal monsoon years. When association of El Nino/La Nina with drought/floods years in Varanasi has been compared with east UP, it has been found that not every drought over Varanasi was associated with drought condition over east UP and same condition held true for floods also. Also, the impact of El Nino and La Nina over Varanasi shows its variation from its behaviour over east UP.

Table 1 shows the drought and flood years over Lucknow during the period 1971 to 2010. The El Nino (single asterisk) and La Nina (double asterisk) marked in Table 1 for its association with drought and flood years respectively. It can be observed from Table 1 that there were 16 droughts (1974, 1979, 1983, 1984, 1987, 1989, 1992, 1993, 1995, 1996, 1998, 1999, 2001, 2004, 2005 and 2007), 11 flood years (1971, 1975, 1978, 1980, 1981, 1982, 1985, 1988, 1991, 2000 and 2008) and rest 13 years were associated with normal monsoon years. It has been observed that there were four drought years viz. 1987, 1992, 1993 and 2004 associated with El Nino but there are four years 1974, 1996, 1998 and 2007 identified as drought years while they were La Nina years. However, rest of the eight drought years viz. 1979, 1983, 1984, 1989, 1995, 1999, 2001 and 2005 were neither associated with El Nino nor with La Nina. Table 1 also shows that there were five flood years viz. 1971, 1975, 1988, 2000 and 2008 associated with La Nina but there were years 1982 and 1991 identified as flood while they were El Nino years. Thus, it has been observed that there were 25% of droughts associated with El Nino, 25% of the droughts were associated with La Nina and rest 50% droughts were neither El Nino nor La Nina. It also implies that 45% of floods were La Nina years, 18% of floods were El Nino years and rests 37% were neither El Nino nor La Nina. The above discussion results that occurrence of droughts over Lucknow might be associated with El Nino or La Nina, but the probability of floods were more with La Nina events than El Nino.

The El Nino (single asterisk) and La Nina (double asterisk) marked and its association with drought and flood years during the period 1971 to 2010 over Allahabad are shown in Table 1. It has been found that

there were 12 drought years, and rests 19 years were normal years. Further, it has been observed that there were six drought years (1972, 1987, 1992, 1993, 2002 and 2006) out of 12 drought years associated with El Nino but there were years 1973, 1974 and 2010, identified as drought years while they were La Nina years. However, rest of the drought years 1979, 1983 and 1989 were not associated with El Nino/La Nina. There were four flood years, 1971, 1998, 2000 and 2008 associated with La Nina but there were years 1982 and 1991 identified as flood; however, they were El Nino years. While, rest four years 1980, 1981, 1990 and 1999 were not El Nino/La Nina. Thus, it has been observed that there were 50% of drought years linked with El Nino and 25% La Nina-droughts (Table 2). Table 2 also indicates that 40% of flood years linked with La Nina and 20% with El Nino and rest 40% of floods were not associated with La Nina/El Nino. It is also observed from Table 2 that out of 13 El Nino years six were drought years, two were flood years and rest five were normal monsoon years. However, out of 11 La Nina years, three were associated with flood, four were drought and rest four normal monsoon years.

There were 13 drought years, nine flood years and rest 18 normal years found over Gorakhpur during 1971-2010 (Table 1). It is observed that six drought years (1972, 1977, 1982, 1992, 1997 and 2002) out of 13 drought years were El Nino years but the years 1974 and 1975 both were identified as drought years while they were associated with La Nina years. While, rest five drought years, 1976, 1979, 1986, 1990 and 1999 were not associated with El Nino or La Nina. However, the four flood years, 1988, 2000, 2008 and 2010 were associated with La Nina and rest five flood years 1980, 1984, 1985, 1989 and 2001 were not El Nino/La Nina years. Table 2 also shows that about 46% of droughts were El Nino years, 15% of droughts were La Nina years. While, there are about 45% of flood years which were La Nina years and no flood years were related to El Nino years. It can be also seen from Table 1 that out of 13 El- Nino years, six were drought years and seven were normal years while no El Nino years were flood years. However, out of 11 La Nina years four were flood, two were drought and rest five were normal monsoon years.

Table 1 shows the drought, flood and normal monsoon years during the period 1971 to 2010 for Bahraich. The El Nino (single asterisk) and La Nina (double asterisk) marked in Table 1 for its association with drought and flood years, respectively. It shows that there were 12 drought years (1972, 1974, 1976, 1977, 1982, 1986, 1987, 1988, 1994, 1995, 2002 and 2010), nine flood years (1971, 1975, 1980, 1981, 1984, 1985, 1990 2000 and 2008) and 19 normal monsoon years. Further, it has been observed that out of 12 drought years, six drought years were associated with El Nino but there were years 1974, 1988 and 2010 identified as drought years while they were La Nina years and three drought years, 1976, 1986 and 1995 were not associated with El Nino/La Nina. There were four flood years, 1971, 1975, 2000 and 2008 associated with La Nina and rest five years 1980, 1981, 1984, 1985 and 1990 associated with normal monsoon rainfall years. Thus, it has been observed that there were 50% of droughts associated with El Nino, 25% of droughts associated with La Nina and rest 25% of droughts were not El Nino/La Nina (Table 2). Table 2 also shows that about 45% of floods were associated with La Nina and no flood years were El Nino year. It can also be discussed that out of 13 El Nino years, six years were drought and seven years were normal monsoon years. It is interesting to note that no El Nino years experienced flood over Bahraich. However, out of 11 La Nina years, four years were flood and normal monsoon years each, while three were drought years.

Conclusions

The following conclusions may be drawn from the above discussion:

- The El Nino-drought association is found to be 75% and La Nina-flood association is found to be 60% over all-India. The year 1994 was identified as flood year in spite of El Nino condition and there was not a single drought year to be associated with La Nina condition over all-India. Most of the El Nino years are either drought years or normal years, while most of La Nina years are either flood years or normal monsoon years over all-India.
- Interestingly, looking at the relation between El Nino/La Nina and Indian droughts/floods since 1971 to 2010, it is observed that India faced eight droughts/five floods and six of these droughts were in El Nino years and two droughts associated with normal years. And, three of these floods were in La Nina years, one in El Nino years and one flood year was associated with normal year. This indicates that there may not be a one-to-one relationship between El Nino/La Nina and Indian droughts/floods.

- In the case of east UP, since 1971 to 2010, there were eight droughts/six floods and six of these droughts were in El Nino years and one was in La Nina year, and three of these floods were in La Nina years, rest were associated with normal years. Thus it also indicates that there may not be a one-to-one relationship between El Nino/La Nina and east UP drought/floods.
- Further, the association between drought (flood) and El Nino (flood) year is analyzed over five stations of east Uttar Pradesh to access the impact of El Nino/La-Nino on regional scale. The pattern of El Nino-drought and La Nina-flood association is very much non-descriptive over Varanasi. The year 1987 was identified as a flood year over Varanasi whereas drought condition prevailed over all-India, east Uttar Pradesh and its other four stations (except Gorakhpur) and the year 1988 was a drought year in spite of flood condition over all-India and some stations of east UP. The result also showed equal association (40% cases) between droughts and El Nino/La Nina years. However, flood-La Nina year associations were found to be 29% and flood-El Nino association were found to be 14%. The normal monsoon years were found to be associated with El Nino years in 36% cases and 25% with La Nina years.
- The El Nino-droughts associations were higher (50%) over Allahabad, Bahraich and Gorakhpur and least (25%) over Lucknow. However, La Nina-flood association is more over all stations of east UP except Varanasi.
- From the study of rainfall variability over all-India, east Uttar Pradesh and some of their stations, it has been observed that there is maximum probability of drought/flood condition associated with El Nino/ La Nina but it is not necessary that every drought/ flood over all-India, east Uttar Pradesh and some of the other stations must be associated with El Nino/La Nina or vice versa. So, the micro-scale studies are also appreciated for proper mitigation and sustainable development of a given place.

Acknowledgements

The authors wish to express sincere thanks to India Meteorological Department for providing the necessary data. The authors also acknowledge the Bureau of Australian Meteorology for providing the El Nino/La Nina datasets.

References

Angell, J.K., 1981. Comparison of variations in atmospheric quantities with sea surface temperature variations in the equatorial eastern Pacific. *Mon. Wea. Rev.*, **109:** 230-243.

Bhatla, R. and Chattopadhyay, J., 1995. Variability of summer monsoon rainfall and incidence of good and bad monsoon over India, 1901-1990. *Journal of Scientific Research*, **45:** 79-88.

Bhatla, R., Singh Madhu, Mall, R.K., Tripathi, A. and Raju, P.V.S., 2015. Variability of summer monsoon rainfall over Indo-Gangetic plains in relation to El Nino/La Nina. *Natural Hazards*, **78(2):** 837-853.

Chattopadhyay, J. and Bhatla, R., 1996. A reexamination of ENSO/anti-ENSO events and simultaneous performance of the Indian summer monsoon. *Mausam*, **47:** 59-66.

Gadgil, S., 2003. The Indian monsoon and its variability. *Annu. Rev. Earth Planet. Sci.*, **31:** 429-461.

Halpert, M.S. and Ropelewski, C.F., 1992. Surface temperature patterns associated with the Southern Oscillation. *J. Climate*, 577-593.

Kriplani, R.H., Kulkarni, A., Sabade, S.S. and Khandekar, M.L., 2003. Indian Monsoon Variability in Global Warming Scenario. *Nat. Hazards*, **29:** 189-206.

Kripalani, R.H. and Kulkarni, A., 1997. Impact of El Niño/ La Niña on the Indian Monsoon: A New Perspective. *Weather*, **52:** 39-46.

Kumar, K.K., Rajgopalan, B. and Mark, Cane A., 1999. On the weakening relationship between Indian monsoon and ENSO. *Science*, **284:** 2156-2159.

Mooley, D.A. and Parthasarathy, B., 1983. Indian summer monsoon and El Nino. *PAGEOPH*, **121:** 339-352.

Nicholls, N., 1991. Teleconnection and Health. Teleconnection linking worldwide climate anomalies. M.A. Glantz, R.W. Katz and N. Nicholls (Eds). Cambridge University Press.

Quinn, W.H., Zopf, D.O., Short, K.S. and Kuo Yang, R.T.O., 1978. Historical trends and statistics of the Southern Oscillation, El Nino and Indonesian droughts. *Fish. Bull.*, **76:** 663-678.

Rasmusson, E.M. and Carpenter, T.H., 1982. Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Nino. *Mon. Wea. Rev.*, **110:** 354-384.

Rasmusson, E.M. and Carpenter, T.H., 1983. The relationship between eastern equatorial Pacific sea surface temperature and rainfall over India and Sri Lanka. *Mon. Wea. Rev.*, **111:** 517-528.

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

Ropelewski, C.F. and Halpert, M.S., 1989. Precipitation patterns associated with the high index phase of the Southern Oscillation. *J. Climate*, **2:** 268-284.

Sahai, A.K., Pattanaik, D.R., Satyan, V. and Grimm, M. Alice, 2003. Teleconnections in recent time and prediction of Indian summer monsoon rainfall. *Met. Atmos. Phys*., **84:** 217-227.

Sikka, D.R., 1980. Some aspects of large-scale fluctuation of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters. *Proc. Acad. Sci. (Earth and Planetary Sci.)*, **89:** 179-195.

Singh, N. and Sontakke, N.A., 2002. On Climate Fluctuations and Environmental Changes of the Indo-Gangetic Plains, India. *Climatic Change*, **52:** 287-313.

Thapliyal, V. and Kulshrestha, S.M., 1991. Climate change and trends over India. *Mausam*, **42:** 333-338.

Van Loon, H. and Shea, D.J., 1985. The Southern Oscillation Part IV: The precursors south of 15.5° to the extremes of the oscillation. *Mon. Wea. Rev.*, **113:** 2063-2074.