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Some Studies on the Frequency of Extreme Weather Events over India

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ABSTRACT

The authors of the present paper studied some aspects of hydro and agrometeorological phenomena in terms of humidness, dryness and crop growing periods over India. Revised water balance model is used to obtain the above and the results are examined during the two half centuries i.e 1901 to 1950 and 1951 to 1995 in delineating the climate change impacts over India. Palmer Drought Severity Index (PDSI) for All India is related to aridity and humidity indices to understand the dry and wet spells over India. The paper also holds its stand on the analysis and the trends of thermo and hygric components such as precipitation, maximum and minimum temperatures, water need, actual evapotranspiration and soil moisture for All India. The return rates of All India maximum and minimum rainfall and temperatures are obtained for different time intervals using Extreme Value Analysis, that might be useful in assessing the impact and thereby to plan over the risk management for the better environmental and thus the human sustainability.

Keywords: Crop growing periods, Extreme value analysis, Drought indices, Water balance elements, PDSI.

INTRODUCTION

The regional climate of India is influenced by the southwest and northeast monsoon systems that govern the India's economy. Kumar et al. (1994) reported that the warming trend over India eas 0.57°C per 100 years and is expected to increase 1.4°C to 5.8°C by 2010 over the globe (Intergovernemtnal Panel on Climate Change (IPCC), Sathaye *et al.* (2006)). In addition to the abnormal inter-annual, seasonal and intra-seasonal variations in the climate indices, the extreme weather events such as floods, droughts, heat and cold waves are known to create adverse effects in widely separated areas of Asia (Karl *et al.,* 1995, World Health Organization Report, 2007). The total flood prone area in India is about 40 m ha which is 12.16% of total land area (Mirza and Ericksen, 1996). The western parts of Rajasthan and the Kutchh region of Gujarath are chronically drought affected. Drought conditions have also been reported in Karnataka, Orissa, Andhra Pradesh and Bihar states of India (Sharma and Smakhtin, 2004). Sarma and Kumar (2006) reported that during the year 2002, the western part of Andhra Pradesh experienced a severe drought situation. At least half of the failures of the Indian monsoon systems since 1871 have occurred during El Nino years (Webester *et al.,* 1998; De *et al.,* 2005). In 1996, IPCC concluded that the flood related consequences of climate change may be as serious and widely distributed as the adverse impacts of

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droughts over the globe. Sarma (2006) studied the probable maximum values of humidity, aridity and climate shifts from the water balance concept in the moist subhumid and dry climate of south India. But, the present investigation deals with monthly indices of humid and drought events in detail. Sarma and Srinivas (2005) investigation on the trend analysis of the normalized 30-year seasonal climate indices of aridity, humidity and moisture status with cold and warm phases of ENSO revealed that aridity is decreasing with increase and decrease trends in Southern Oscillation Index (SOI) and Nino 3 Sea Surface Temperatures (Nino 3 SST) respectively accompanied by improved humidness and moisture status for All India. Sarma and Kumar (2009) highlighted the trends of water balance elements for different geographical regions of Andhra Pradesh and reported the moisture recycling during El Nino and La Nina events. Sarma and Kumar (2006) calculated the crop growing periods over Andhra Pradesh using rainfall and water need and reported that the number of humid days that are subjected by the crop during its growth is reduced in the case of El Nino years. Sarma and Kumar (2007) also reported the rainfall and soil wetness response to ENSO year of 2002 on a daily basis and found the considerable impact of ENSO over these elements. Sarma and Kumar (2005) studied the spatial distribution of water budget elements and reported the deficient rainfall being taken place during the El Nino year 2002 compared to the normal in Andhra Pradesh. Houghton *et al.* (2001) reported that during the period 1900 to 1995, the frequency of the droughts are increased in parts of Asia. Therefore, the present investigation addresses this aspect from the water balance angle in the study of the frequency of the varied humid and drought events for All India in the 20^{th} century.

The extreme event impacts on agriculture can be traced on the growing seasons of the crops and consequently the crop yields. For the expected range of global warming that can be predicted by the scientists, the regional and local impacts on agricultural yields is to increase rapidly. According to Hulme (1996), the variations that have to takeplace in the precipitation and temperature will alter the distribution of agro-ecological zones and the growing seasons of the crops. Rosenzweig and Hillel (1995) reported the increase of the length in growing seasons in middle and higher latitude as a result of higher temperatures. Naylor *et al.* (2001) highlighted that the El Nino and La Nina events affect the timing of planting and result in crop production. The present paper pays attention to addressing the length of the growing periods for All India during distinct epochs along with the ENSO/LNSO events.

MATERIALS AND METHODS

The main data source for this study is from Indian Institute of Tropical Meteorology (IITM) developed data sets. The daily rainfall data has been collected from 305 rain gauges distributed in India and are averaged on a monthly basis and published in the website www.tropmet.res.in (Mooley *et al.,* 1981; Parthasarathy *et al.,* 1987; 1993, 1995, 1995; Pant and Kumar, 1997) from 1871 to 2003. The monthly mean temperatures which are the mean of day maximum and day minimum temperatures for the period 1901 to 1990 are also available in the same website where rainfall data is collected.

The 2.5°x2.5° gridded Palmer Drought Severity Index (PDSI) is retrieved from the website http://www.drought.unl.edu on All India scale for the present study. The classification of PDSI is given in the Table 1. The water deficit (WD) and water surplus (WS) and moisture storage (S_T) are simulated from the revised water balance model of Thornthwaite and Mather (1955) with the inputs of monthly rainfall (P) and temperature (T) for All India.

Table 1. PDSI classification

PDSI	Status
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

The monthly humidity (I_{MH}), aridity (I_{MA}) and the soil wetness (S_{WT}) in percentage are obtained from the following expressions

I_{HM}= (WS/PE)×100

I_{MA}= (WD/PE)×100

S_{WT}= (S_T/F_C)×100

Where, F_C is the field capacity of area under consideration.

To understand the degree of severity of drought and humid events, the categorization given in Table 2 is used as per the schema of Sarma and Srinivas (2005). The basis for this classification is annual aridity and humidity indices. The severity of drought and humid events in dry and moist climates obtained from the percentage departures of the median and further the standard deviations are calculated and with the help of range in standard deviations, the following categorization is made. Since the standard deviation is the indication of interannual variability, the variability in the aridity and humidity indices will replicate the drought and humid events over that particular region.

Table 2. Classification of degree of severity of drought and humid events

Limit	Drought
0–½ S	Slight
½ S–S	Moderate
S–2S	Severe
≥ 2S	Very severe
Limit	Humid
0–S	Moderate
S–2S	Very Humid
≥ 2S	High Humid

where S is the standard deviation for the respective time series.

To obtain an idea whether the available soil water is in match with the water need of the crop, the moisture adequacy concept which is defined as the percentage ratio of actual evapotanspiration to that of the potential evapotranspiration can be used. This concept is extensively used in conjunction with the crop, forestry and agricultural land use studies (Subrahmanyam *et al.,* 1963, Sarma 1983). Sarma and Kumar (2006) extended the application of moisture adequacy concept to understand the vegetation condition incorporating Integrated Normalized Difference Vegetation Index (INDVI). It is worth mentioning here that Petrasovits (1984) also reported a similar expression which is a ratio of actual evapotranspiration (AE) to potential evapotranspiraion (PE) to determine the agro-hydropotential of the region under consideration in terms of occurrence of droughts of varied intensities and for which the following scheme was suggested. The parameters AE and PE are derived from the water balance model for All India to obtain the moisture adequacy. The scheme of Petrasovits (1984) is followed in delineating the various grades of Agro-Hydro Potential. The index lies between 0 and 1 and the categorization is given in Table 3.

The agro-ecological model of Food and Agricultural Organization (FAO) proposed by Higgins and Kassam (1981) is employed to determine the length of the growing period which is the sum of the humid, moist and dry days during the season of crop growth and the categorization of various periods is as follows,

$P > PE$ -------- Humid period

$\frac{1}{2} PE < P < PE$ -------- Moist period

$\frac{1}{4}PE < P < \frac{1}{2}PE$-------- Moderately dry period

$P < \frac{1}{4} PET$ -------- Dry period

The dry and wet spell events in terms of aridity and humidity for All India derived on a monthly basis from the scheme of water balance model are compared with that of

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Table 3. Classification of Agro-Hydro Potential

AHP	Explanation
1.0 - 0.8	The water scarcity of the plant stand is only theoretical, because the water supply to the plants is continuous and not limited
0.8-0.5	The water demand satisfying ability of the area is still continuous, but it is getting increasingly restricted
0.5-0.3	The water scarcity is becoming high, the water supply to the plants is periodical and restricting, therefore water-stress develops
< 0.3	Strong water stress occurs, causing considerable biomass and yield deficiency, and when this stage lasts long - also the death of the plant.

PDSI and further subjected to correlation and regression analysis to obtain the relation and the degree of difference in the severity of the spells obtained from these two methods.

An attempt is made to analyze the All India annual rainfall and temperature using extreme value analysis and the Gumbel statistical theory (Gumbel, 1954) for extremes to obtain the return periods for the possible exceedance.

The standard Gumbel Distribution is as follows

$G(x)= \exp(-\exp(-(x-a)/b))$

Where, a and b are location and scale parameters and are estimated by means of numerical solver after getting the following equations.

$b= -b(n^{-1}\Sigma\exp(-x_i/b))$ and $b-n^{-1}\Sigma x_i+\Sigma(x_i\exp(-x_i/b))/\Sigma(\exp(-x_i/b))= 0$

Where, $i= 1\ldots n$ and n is the number of observations for the variate under consideration.

RESULTS AND DISCUSSION

Trends of the All India Water Budget Elements

Figures 1-(a-e) depict the variability (100 as mean value in all figures) in All India annual rainfall (1871 to 2003), mean minimum and maximum temperatures, potential evapotranspiration and soil wetness for the period 1901 to 1995, respectively. Right from 1871 to 1895, the variability in annual rainfall is above the normal and it is altered during the periods 1895 to 1920 and 1920 to 1960. However, during the period of 1960 to 2003, nearly 55% of the cases maintained less rainfall compared to the normal values. As a whole, the annual rainfall trend over India is not showing any significant trend as reported by Kumar *et al.* (2002). The annual rainfall of All India recorded a hike and depletion of 24 and 25% of the normal during the extremities of 1917 and 1899, respectively.

From Figures 1 (b and c), it is observed that both temperatures yielded an increasing trend with the variance of 0.2 for minimum temperature and 0.3 for maximum temperature, but the variability in the former is high compared to the minimum. Nearly 53% of the cases during the study period 1901 to 1950, fell below the long term mean where as it is 85% during 1951 to 1990.

In consistency with the increased trends in temperature as mentioned previously, All India PE too showed a rising trend and reached a 10% deviation in the year 1994. A perceptible increase in All India PE with a slope 0.05 is evidenced in the second half of the 20th century and the same is reported by Ross and Elliott (2001) that the increased atmospheric water vapor indicates the increment in PE for the past two decades i.e from 1973 to 1995 over the globe.

During 1901 to 1950, the All India soil wetness maintained an increasing trend with a minimum of 54% in the 1918 to a maximum of 35% of the normal in the year 1917. But the case is different as the year 1995 is reached. The soil moisture decreased

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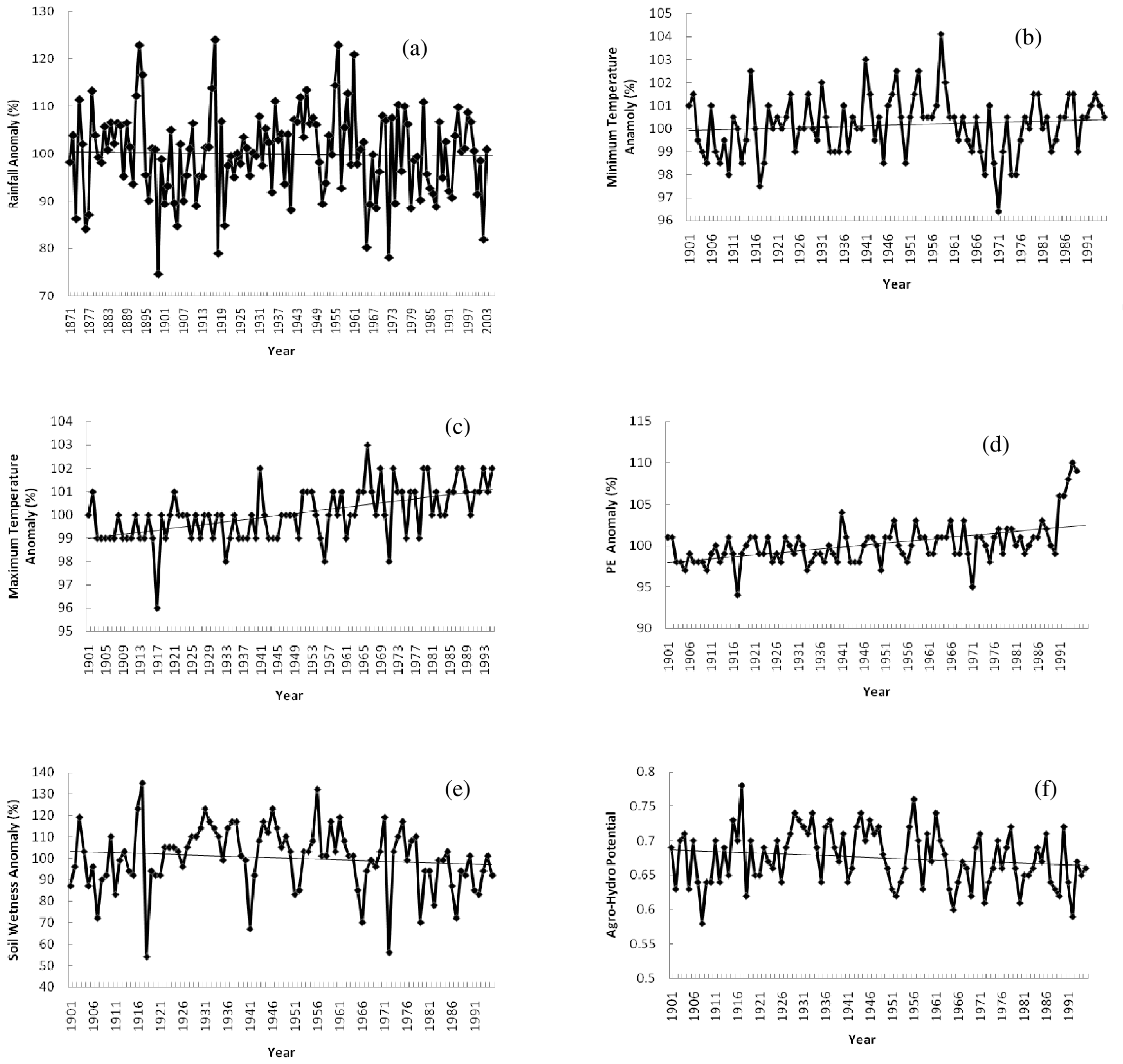

Figure 1. Trend and anomalies of All India **a)** annual rainfall: 1871 to 2003, **b)** annual minimum temperature: 1901 to 1995, **c)** annual maximum temperature: 1901 to 1995, **d)** Potential Evapotranspiration (PE): 1901 to 1995, **e)** Soil Wetness (S_{WT}): 1901 to 1995, **f)** Agro-Hydro Potential (AHP): 1901 to 1995.

rapidly from 1950 and especially from 1979 to 1995 so that only on three occasions, it was above the normal.

Agro–Hydro Potential of All India

Figure 1-f shows the trend in agro-hydro potential for All India for the period 1901 to 1995. AHP displayed an increasing trend during the first half century but started to decrease from 1951 to 1995. The index AHP, registered maximum at the year 1917 (extreme wet monsoon) to the value of 0.8 which is the indication that the plant is in continuous supply of water and harbored a minimum of 0.58 in the year 1908. The first half century witnessed one case recorded below AHP of 0.6, 27 years registered, an AHP of 0.6 to 0.7 and 22 years of 0.7 to 0.8. These figures are changed considerably in the second half century i.e one below 0.6, 34 cases between 0.6 and 0.7 and only 10 cases registered between 0.7 and 0.8 from which,

it is known that during the period of 1951 to 1995, the AHP values dropped and an increased water deficit occurred compared to the 1901-1950 period. The interesting feature is that in this study, no single year except 1917, showed more than 0.8 of AHP, which means that there is always water demand for the crops during entire period of 1901 to 1950.

Drought and Humid Events over All India

Figures 2-(a-d) demonstrate the variations in the monthly index of aridity for the month of June and humidity for July, August and September, respectively. Nearly 80% of the annual rainfall over India is received during the south-west monsoon period i.e from June to September (Ramesh and Yadava 2005). Therefore, the study of aridity and humid events was confined to southwest monsoon period. The inter-monthly variability in June is very high compared to other months. Table 4 illustrates the frequency of occurrence of drought and humid events in percentage over India. Since the study is focused on evaluating the frequency of occurrence of extreme events, the authors

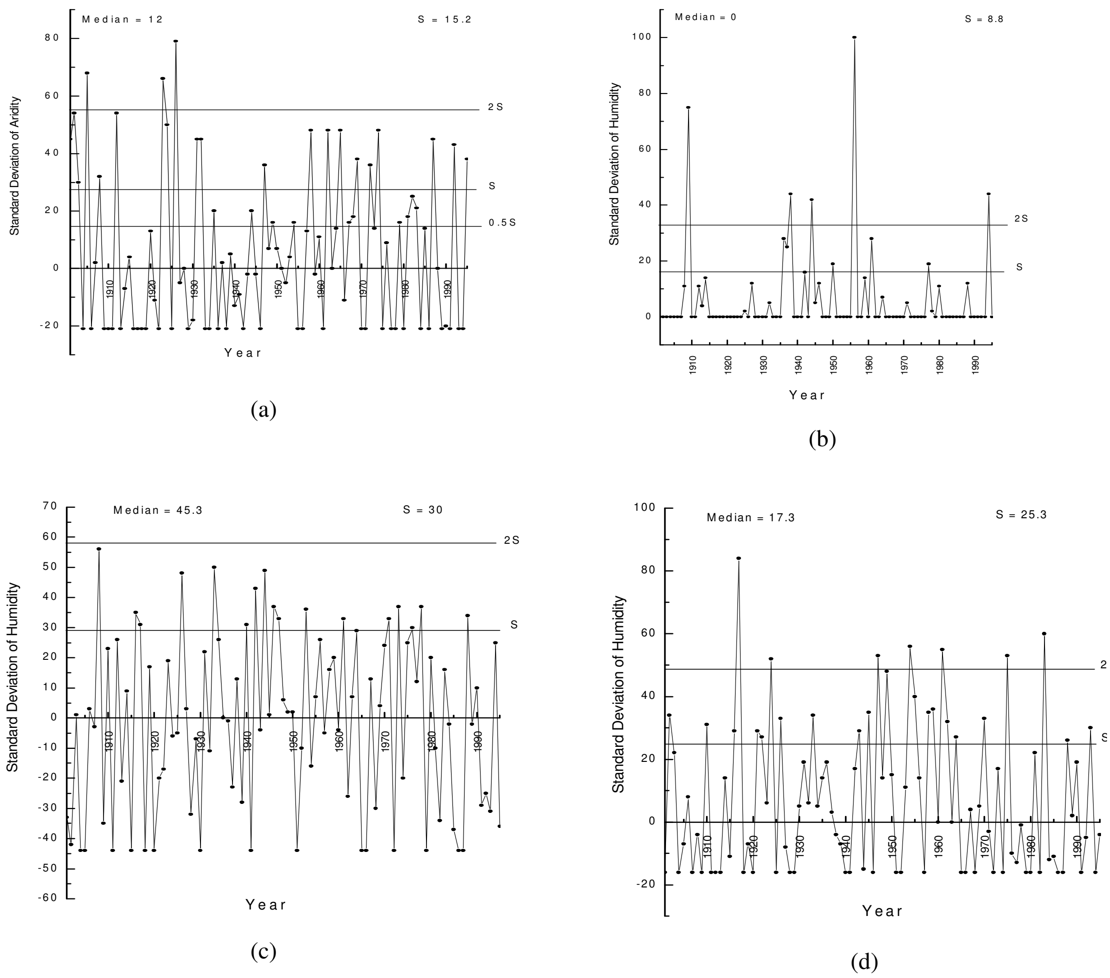

Figure 2-a) All India Aridity for June: 1901 to 1995, All India Humidity for **b)** July: 1901 to 1995, **c)** August: 1901 to 1995, **d)** September: 1901 to 1995.

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Table 4. Frequency of occurrence of drought and humid events in % over India.

	Slight Dry		Moderately Dry		Severely Dry	
	1901-50	1951-95	1901-50	1951-95	1901-50	1951-95
June	70	64	6	18	18	18
	Moderately Humid		Very Humid		Highly Humid	
July	86	91	8	8	6	5
August	78	82	22	18	0	0
September	74	74	20	18	6	8

were interested in investigating the drought events in June month and humid events in the remaining months of the south-west monsoon where one can capture higher numbers of humid events.

From the analysis, it is observed that in the second half of the 20th century, the percentage frequency of slight category events is decreased from 70 to 64%, whereas the moderate events increased in the second half from 6 to 18%. The events of very humid category, showed a decreasing trend in the second half century from 8% to 4.5% in the month of July, 20 to 18% in the month of August and 22 to 18% in September. The highly humid category decreased to 4.5% from 6% in July with no change in September.

Comparative Study of Aridity and Humidity Indices with Palmer Drought Severity Index

All India monthly aridity indices of June and the humidity indices of July, August and September are correlated with All India Palmer Drought Severity Index (PDSI) for the period 1940 to 1995 to understand the category of climate stress over India. Figures 3-(a-d) depict the variability of PDSI and aridity and humidity over India. In the month of June 1969 (Figure 3-a), PDSI recorded the maximum value of -2.3 (moderate drought) and the corresponding aridity index is 33. The relation showed a good negative correlation of -0.55 with 0.01 level of significance which means that as the aridity increases, the PDSI decrease i.e it approaches negative values that show drought conditions over the country. July registered a moderately wet situation from PDSI i.e. +2.5 in the year 1956 while the corresponding humidity value is 57 and in the year 1966, the PDSI reached a moderately dry condition while the humidity value is zero from the water balance model. The correlation for the month of July is +0.43 with 0.01 level of significance from which it can be inferred that as the humidity increases PDSI increases leading to wet conditions of the region under consideration. The month of August revealed some interesting features over India; PDSI varied from -2.9 in the year 1987 (ENSO year) to a value of +1.4 in the year 1975 (good monsoon year of India) while the humidity varied from 0 and 71 respectively. It can be observed from Figure 3 that in the month of August, the interannual variability of both PDSI and humidity are more comparable to previous months. The Pearson correlation for this month is +0.65 with 0.01 level of significance. The PDSI for September varied from a severe drought situation of -3.1 in the year 1987 (ENSO year) to +2.3 in the year 1975 (good monsoon year) for a humidity index value of 0 and 74, respectively and the correlation in this case is +0.69 with 0.01 level of significance. The regression expressions along with the variance values for the retrieval of aridity and humidity using PDSI are presented in the Table 5.

Aridity and Humidity Indices in Relation to ENSO

The aridity and humidity indices of the respective months of monsoon season are

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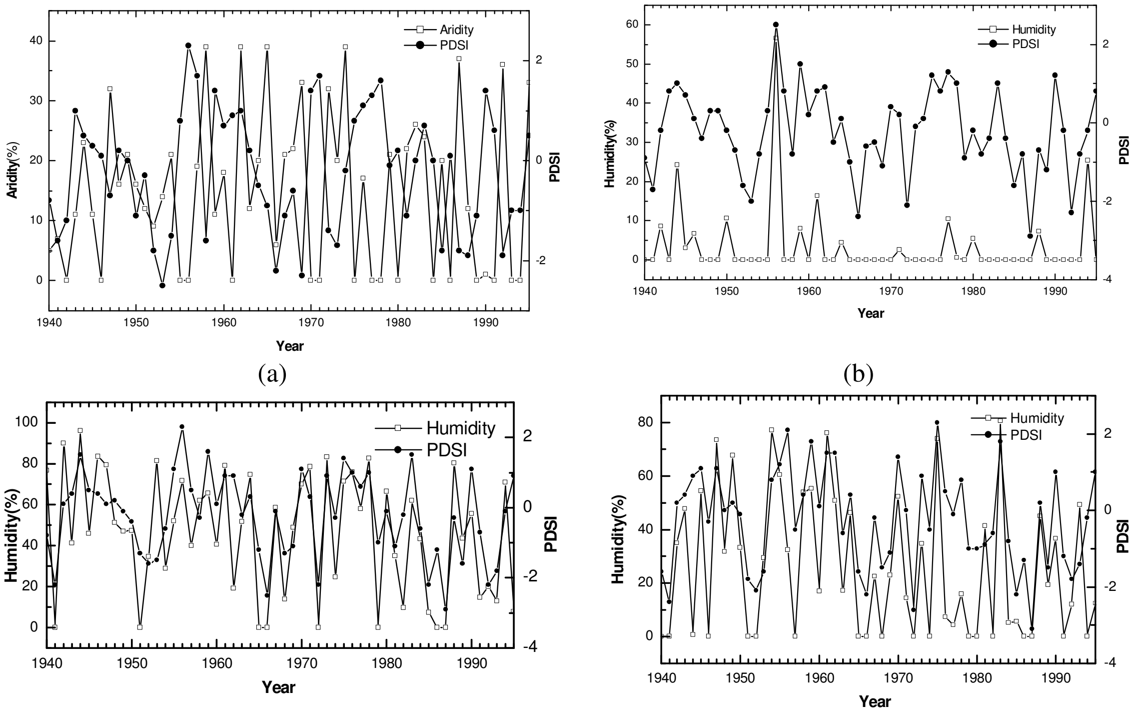

(a) (b)

(c) (d)

Figure 3-a) Time series of Aridity (%) and PDSI for June: 1940 to 1995, Time series of Humidity (%) and PDSI for **b)** July: 1940 to 1995, **c)** August: 1940 to 1995, **d)** September: 1940 to 1995.

correlated with the El Nino Southern Oscillation index. The relation revealed that as the SOI, increases, the aridity decreases with a decrease in Nino 3 Sea surface temperature. The Pearson correlation coefficients for aridity with SOI and Nino 3 SST for the month of June during 1901 to 1950 are –0.23 and +0.009 which are statistically insignificant while for 1951 to 1995, the correlations are –0.50 and +0.46 that are significant at 0.01 percent level. The correlation coefficients of humidity indices with SOI and SST for the month of August 1901 to 1950 are +0.33 (significant at 0.05 level) and –0.42 (significant at 0.01 level), respectively. However, for the second half of the 20th century, the correlation values are +0.56 (significant at 0.01 level) and –0.52 (significant at 0.01 level). The September humidity correlations are also indicated as +0.51 (significant at 0.01 level) and +0.61 (significant at 0.01 level) with SOI and –0.42 and –0.56 having a 0.01 level of significance for the periods 1901 to 1950 and 1951 to 1995, respectively. From the analysis of correlations, it can be inferred that during the first half century (1901 to 1950), the impact of SOI and Nino 3 SST on monthly aridity and humidity indices was less compared to the second half century (1951 to 1995).

Extreme Value Analysis

The objective of the extreme value analysis

Table 5. Regressions for aridity and humidity indices using PDSI.

Month	Regression expression	Variance
June	I_{MA}= *9.74–5.81(PDSI)*	0.21
July	I_{MH}= *4.32+3.64(PDSI)*	0.24
August	I_{MH}= *49.38+16.19(PDSI)*	0.48
September	I_{MH}= *28.78+13.76(PDSI)*	0.49

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is to model the derived monthly hydroclimatic elements to allow generalizations on the likely recurrence of these events. A considerable number of statistical researches have been carried out on the studies of extremes of weather variables (Buishand 1991; Katz et al. 2002). This type of analysis is essential and helpful in management of risks such as drought and floods. The return period is the average time within which a given variable will be exceeded just once. The probable return periods of the maximum and minimum temperatures and maximum and minimum rainfalls (once in 5 years) are evaluated using Extreme Value Analysis and the probable distribution of these extreme values for different return periods are studied. From the design values of the return periods, it can be observed that as the return period increases, the mode of intensity of the variable increases. The extreme values for the return periods of 10, 20, 50, 100, 500 and 1,000 years are obtained by using two parameter methods (Gumbel) such as Method of Moment – Theoretical (MTM), Method of Quantiles (MQ), Method of Probability-weighted Moments (MPM) and Maximum Likelihood Method (MLM).

From the Figures 4-(a-d), it can be noticed that the variability in the hydroclimatic variables is very high for the respective return periods.

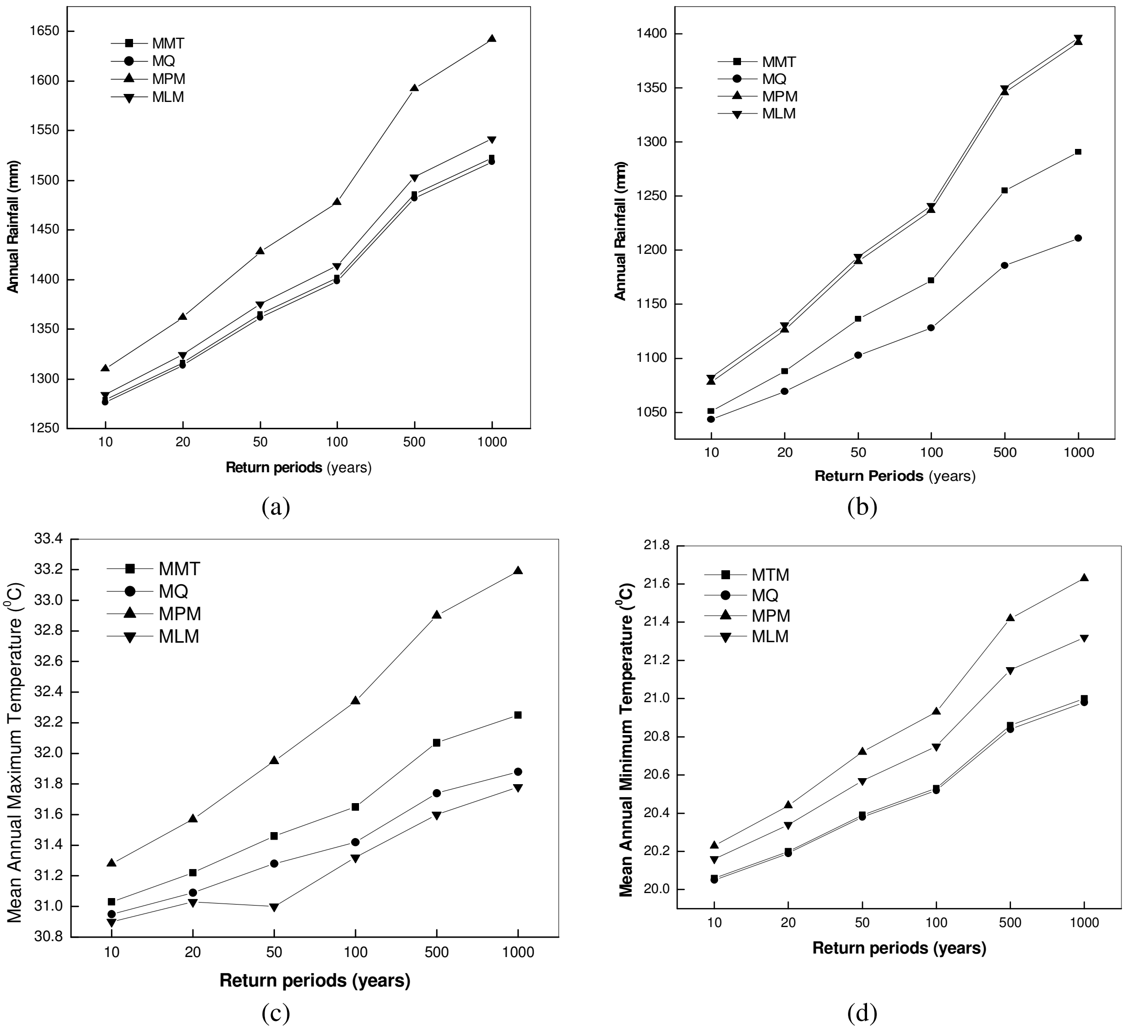

Figure 4. Extreme distribution of **a)** maximum annual rainfall for different return periods. **b)** minimum annual rainfall for different return periods and External distribution of mean **c)** annual maximum temperature for different return periods , **d)** minimum temperature for different period periods.

Crop Growing Periods over India

The growing periods of the crop which is the sum of humid, moist and dry days for the distinct epochs and for the extreme cases such as El Nino, La Nina, good monsoon and extreme wet monsoon years for the south-west monsoon period are presented in the Table 6. It is observed from the table that for the El Nino years, the number of humid days is considerably decreased compared with that of normal (1901 to 1995). The growing period of the crop is varied considerably for each of the 30 year periods. The growing periods of the distinct epochs revealed that during 1931 to 1960, the number of humid days when the crop underwent is more (102 days) than any other period (1931 to 1960 and 1961 to 1990). The number of humid days reached maximum during 1931 to 1960 (102 days) from 1901 to 1930 (98 days) and from then gradually decreased to 94 days during the period 1991 to 1995 then gradually decreased to 96 and 94 days during the study periods 1961 to 1990 and 1991 to 1995 respectively. In the case of extreme wet monsoon (1917) and good monsoon (1975) years, the humid, moist and dry days are 148, 29, 188 and 122, 44, 199, respectively. The authors of the present study observed the growing periods in the three major epochs (1901-1930, 1931-1960 and 1961-1990), the epoch 1931 to 1960, witnessed no considerable impact of extreme events such as El Nino and La Nina whereas in 1901 to 1930, India experienced one El Nino event (1905 year) and one extreme wet monsoon event (1917). During 1961 to 1990, four ENSO years (1965, 1972,1983 and 1987), one La Nina event (1988) and one good monsoon year (1975) occurred over India and this might be one of the causal factors for the higher number of humid days in the period of 1931 to 1960.

We attempted to study the variability of growing period for the periods 1901 to 1970 and 1971 to 1995. The selection of these periods was based on that during the past two decades, the anthropogenic emissions due to land use changes such as deforestation and increasing industrialization are predominantly increased in the atmosphere which may impact the climate of the region and in turn leave its sign on the vegetal cover that finally modulates the crop growing period. It is found that during the period 1971 to 1995, the humid days of the crop are decreased to 3% from the normal whereas it is 5% above the normal during the period 1901 to 1970. The number of moist and dry days varied accordingly with the changed scenario.

The plots from which the crop growing period is to be determined are shown in Figures 5-(a-o) for the period 1901 to 1995,

Table 6. Number of humid, moist and dry days of the crop growing period.

Period	Humid days	Moist days	Dry days (Moderate+Dry period)
1901 – 1995	93	63	209
1901 – 1970	98	61	206
1971 – 1995	90	68	207
1901 – 1930	98	55	212
1931-1960	102	61	202
1961-1990	96	49	220
1991-1995	94	56	215
1905	90	36	239
1917	148	29	188
1965	83	33	249
1972	63	65	237
1975	122	44	199
1982	72	42	251
1987	71	116	178
1988	99	30	236

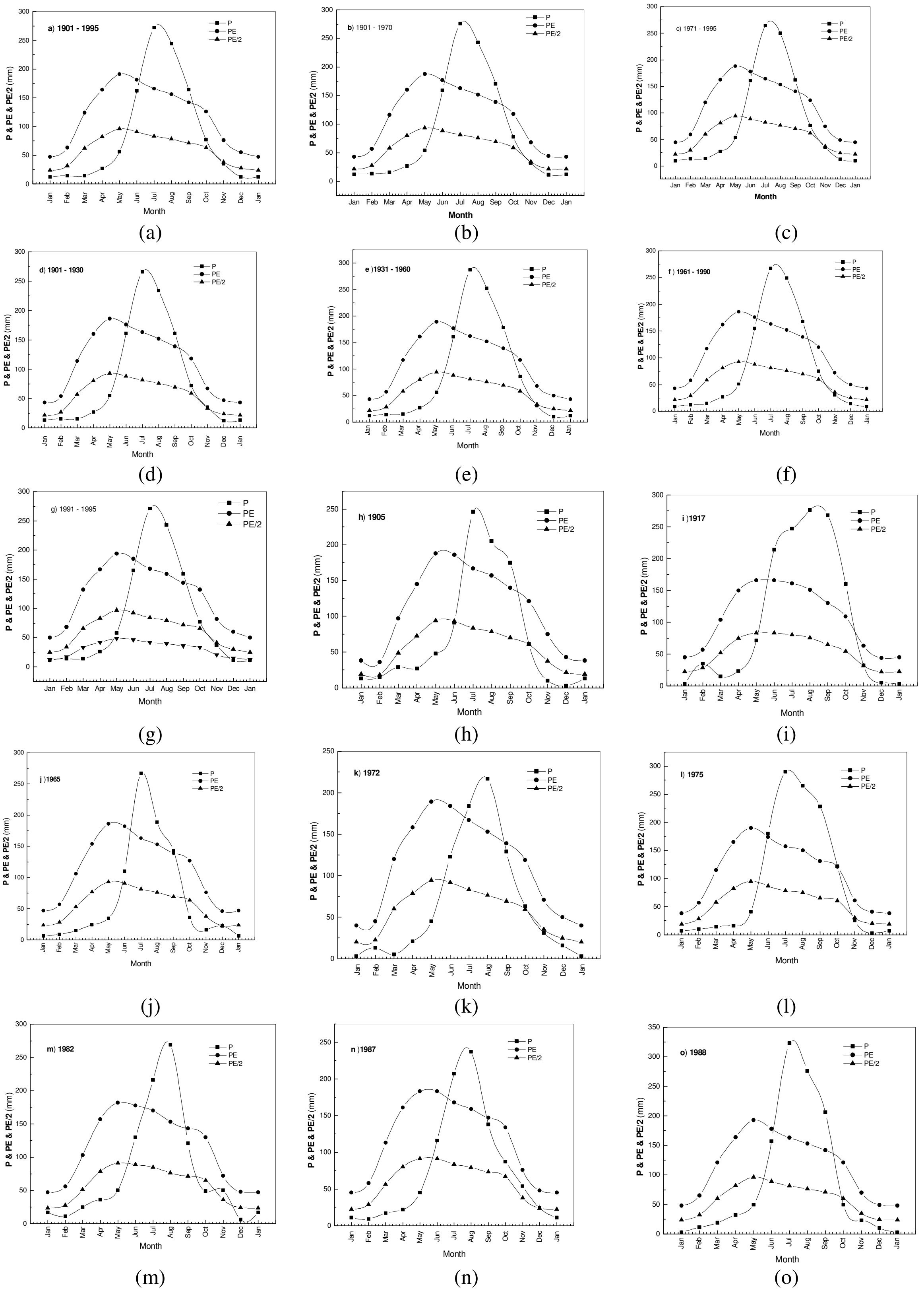

Figure 5. Length of crop growing periods: a) Long term 1901–1995, b) Epochal period 1901–1970, c) Epochal period 1971–1995, d) Epochal period 1901–1930, e) Epochal period 1931–1960, f) Epochal period 1961–1990, g) Epochal period 1991–1995, h) ENSO Year 1905 i) LNSO Year 1917, j)ENSO Year 1965, k) ENSO Year 1972, l) LNSO Year 1975.

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1901 to 1970, 1971 to 1995, 1901 to 1930, 1931 to 1960, 1961 to 1990, 1991 to 1995 and for the years 1905, 1917, 1965, 1972, 1975, 1982, 1987 and 1988. The humid period has been delayed by one week during the years 1905,1965 and further delayed by 2 more weeks during ENSO years 1972, 1982 and 1987 as compared with the normal years.

The moderate period also delayed in these years accordingly similar to the humid ones. In the case of extreme wet monsoon year, 1917, the humid period is initiated from the last week of May and it maintained the same status until the 3rd week of October. The good monsoon year, 1975, and the LNSO year, 1988, witnessed an early onset of humid as well as moderate periods.

CONCLUSIONS

The trends of All India water budget elements are examined and the results showed that though there is no significant trend in rainfall, an increasing trend in maximum temperature is observed followed by an increase in potential evapotranspiration and diminution tendency of soil wetness and agrohydro potential which clearly shows the high variability and in turn the higher frequency of occurrence of extreme events.

The comparative study of drought indices such as aridity index and humidity index with the PDSI and ENSO indices showed not only the remarkable correlation but also the interannual variability in accordance with the indices.

The extreme value analysis of temperature and rainfall implies that the rainfalls and temperatures are going to increase as the return period increases. Also the All India crop growing periods reported that the number of humid days vary significantly as the year goes deviated from the normal which means the number of humid days is very low in El Nino years whereas these days are very high during the La Nina periods.

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مطالعات بر روی فراوانی حوادث آب و هوایی شدید در هند

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چکیده

نویسندگان مقاله حاضر برخی از جنبه‌های آبی و پدیده‌های هواشناسی کشاورزی در مورد تری، خشکی و دوره‌های رشد محصول در سراسر هند را مورد مطالعه قرار داده‌اند. برای به‌دست آوردن موارد فوق، مدل تعادل آب اصلاح شده مورد استفاده واقع شد و نتایج به‌دست آمده در طول دو قرن یعنی ۱۹۰۱ تا ۱۹۵۰ و ۱۹۵۱ تا ۱۹۹۵ جهت مشخص کردن اثرات تغییرات آب و هوا در سراسر کشورهند مورد بررسی قرار گرفتند. به منظور درک بهتر دوره‌های خشک و مرطوب، رابطه شاخص شدت خشکسالی (PDSI) برای سراسرهند با شاخص‌های خشکی و رطوبت بررسی گردید. دراین مقاله همچنین تجزیه و تحلیل و روند تغییرات متغیرهای حرارتی و رطوبتی مانند بارش، حداکثر و حداقل درجه حرارت، نیاز به آب، تبخیر و تعرق واقعی و رطوبت خاک برای سراسر هند ارایه می‌شوند. نرخ-های بازگشت حداکثر و حداقل بارندگی و درجه حرارت برای فواصل زمانی مختلف با استفاده از تجزیه و تحلیل مقادیر مفرط مورد مطالعه قرار گرفتند که می‌تواند در ارزیابی اثرات و مدیریت ریسک برای پایداری بهتر محیط زیست و به تبع آن انسان، مفید باشد.