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Linking Drought Intensity with Rice Yield in Nagaland

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ABSTRACT

Background: Rainfall being one of the most important factors of production for rainfed *kharif* rice, occurrence of drought may have serious implication on rice yield. Hence, this study is an attempt to understand the linkage between drought and yield of rice in Phek and Dimapur district of Nagaland where rice is the primary crop.

Methods: Reconnaissance Drought Index was calculated using gridded daily rainfall (0.25° X 0.25°) and temperature (1° X 1°) (°=degree) data for the year of 1975-2013.

Result: The annual mean temperature has increased by 0.03°C in Phek and Dimapur district during the study period. The increasing linear trends for annual temperatures are significant whereas, the linear trend for annual rainfall shows decreasing but insignificant trend. About 38.46% and 41.02% of the 39 years under study were 'Normal condition-dry' in Phek in Dimapur district, respectively. Moderate and severe drought occurred more frequently in Dimapur than Phek. After 1994, majority of the years were drought years and the frequency of occurrence was higher in Dimapur. The drought occurrences negatively impacted the rice yields and the rice yield may reduce by 13.85% in normal condition dry to 18.45% in extreme drought condition.

Key words: Potential evapo-transpiration, Rainfall, Reconnaissance drought index, Rice.

INTRODUCTION

Climate change is one of the most conversed topics of the present day due to its huge potential to impact the environment, the agriculture sector and the society. The impact is considered to be severe in developing countries like India where most of the people depend on agriculture (Mendelsohn *et al.*, 2006). The consequences of climate change are expected to go beyond the food production and likely to affect the food system including availability of food, access to food, utilisation of food and stability of food *etc.* (Joshi, 2015). The variation in rainfall and diverse temperature situation and lack of adaptive potentials add more to the burden of climate change. Over the years, the global temperature has been increasing by 0.74% (IPCC, 2007). The global summary report of the National Centers of Environmental Information confirms that 2014 was the most hottest year since the record kept from the year 1880 (NOAA, 2015). The India Meteorological Department (IMD), Pune reported rise of annual mean temperature by 0.56°C in between 1901 and 2009. The annual mean temperature has been above normal since 1990 (IMD, 2009). In another study, Goswami *et al.* (2006) estimated that India's surface temperature increased by 0.08°C during 1969-2005.

Increasing temperature enhances evapo-transpiration and other physiological processes. This coupled with late monsoon or deviation in rainfall adversely affects the soil moisture content and induces drought like situation. Drought is defined as a prolonged absence or marked deficiency of precipitation (IPCC, 2001). The IMD, Pune has classified drought into meteorological drought, hydrological drought, agricultural drought and socio-economic drought. Globally the occurrence of drought has been increasing (IPCC 2007a). Zarch *et al*. (2011) reported that 28% of the Iranian territories were under extreme drought, 31 per cent under severe drought and 26 per cent were affected by moderate drought during the hydrological year of 1999-2000. Studies also reported occurrence of drought in Bhavnagar of Gujarat (Shah *et al*., 2013); Palamau in Jharkhand (Sah and Singh, 2011) and Bellary region of Karnataka (Adhikari *et al.*, 2012). Severe drought stress during reproductive stage can lead to complete crop failure (Nguyen, 2011).

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Drought in North Eastern Himalayan region of India

The Central Research Institute for Dryland Agriculture (CRIDA) has identified 17 districts from the North Eastern (NE) states which are vulnerable to climate change (Venkateswarlu *et al.*, 2012). Seven districts among them *viz.*, Senapati and Imphal East in Manipur; Ri-Bhoi and West Garo Hills in Meghalaya; Phek, Dimapur and Mokokchung in Nagaland are vulnerable to drought. Tirap and West Siang in Arunachal Pradesh; and Lunglei in Mizoram are identified as the water stressed districts. In 2015 monsoon rainfall was deficit by 58%, 33% and 30% in Nagaland, Meghalaya and Manipur, respectively, as on 12th August (GoI, 2015). Majority of the population in NE India depends on agriculture and over 60% of the crop area is under rainfed (GoI, 2011).

The deviation in rainfall and unfavourable shifts in climate can potentially endanger the food security of the people (Kumar *et al.,* 2011). Hence, this paper is an attempt to analyze the drought situation and estimate its impact on rice yield in Phek and Dimapur districts of Nagaland.

Methodology

Description of the study area

The study was conducted in the state of Nagaland (25.6^{0}N and 27.4°N latitude and 93.20°E and 95.15°E longitude), one of the seven NE states of India. Topographically, the state is mountainous and the altitude varies from 194 m to 3048 m above mean sea level (AMSL) (GoN, 2013). Nagaland has a population of 19.80 lakh, out of which 71.14% of the population are lives in rural areas (Census, 2011). The population density in the state is 119 per sq.km. The sex ratio is at 931: 1000 (female: male) and the literacy rate is at 79.55 % (GoN, 2013). *Dhansiri*, *Doyang*, *Dikhu* and *Milak* rivers flow westward into the Brahmaputra whereas, *Tizu* river flows towards east and joins the Chindwin river in Burma (GoN, 2013). Nagaland experiences wide variations in climate at different altitudes. The state receives an average annual rainfall of 1,800 mm to 2,500 mm, primarily concentrated in the months of May to September. The average temperature ranges from 21°C to 40°C. In winter, temperatures generally drop to 3°C to 4°C, but frost is common at high elevations (GoN, 2013).

Agriculture is the largest source of livelihood for majority of the people of Nagaland. Agriculture contributes 28.71% to the Net State Domestic Product (NSDP) (GoN, 2012) and employs 70% of the population. The main agricultural produce in the state includes rice, maize, soybeans *etc*. About 80% of the cropped area is under rice crop (GoN, 2013). It is also a hub to many horticultural crops like orange, pineapple *etc.* Cash crops like potato are also grown in some parts of the state. The people mainly depend on rain for cultivating crops. The total irrigated area in the state is only 0.09 mha, which is only 18.92% of the total cultivated area of 0.48 m ha (GoN, 2013).

Dimapur district is located at 25.5°N latitude and 93.5°E longitude at an altitude of 260 m AMSL. Rice is the main crop in the district and covers an area of 9470 ha under *jhum* and 36720 ha under wet land transplanted rice cultivation (WTRC) (GoN, 2013). Phek district lies between 25.75°N latitude and 94.50°E longitude at an altitude of 1524 m AMSL. The economy of Phek district is predominantly agrarian, where about 80.84% of the people practice terrace cultivation.

Data

The daily rainfall (0.25° X 0.25°) and temperature (1° X 1°) data were retrieved from gridded India Meteorological Department (IMD) data set for the period of 1975-2013 to estimate the drought intensity in Nagaland. Rice yield data was accessed from Directorate of Economics and Statistics, Ministry of Agricultural Cooperation and Farmers Welfare. The available rice yield data for Phek and Dimapur district pertains to 1990-2013 and 2000-2013, respectively.

Analytical techniques

Drought analysis

There are various indices like Standardised Precipitation Index (SPI), Palmer's Drought Index *etc.* which are used to measure drought but a number of researchers preffered Reconnaissance Drought Index (RDI) (Zarch *et al*., 2011; Kusre and Lalringliana, 2014) as it is more sensitive and suitable in case of changing environment (Tsakiris *et al.*, 2006). RDI was first presented in the co-ordinating meeting of the Mediterranean Drought Preparedness and Mitigation Planning (MEDROPLAN) (Tsakiris and Vangelis, 2004).

The RDI (α_k) was calculated for the ith year based on the monthly rainfall or seasonal rainfall (*i.e.,* June to September is monsoon; October to December is post-monsoon; and January to May is pre-monsoon). The formula is given as,

$$\text{Reconnaissance Drought Index } (\alpha_i) = \frac{\sum_{j=1} P_{ij}}{\sum_{j=1}^{k} PET_{ij}} \quad i=1 \text{ to } n.......(i)$$

Where,

P_{ij} = Precipitation of jth month in ith year; PET_{ij} = Potential Evapo-transpiration of jth month in ith year; n = Number of years of the available data; i = year ($1 \leq i \leq 39$) and j = months ($1 \leq k \leq 12$).

Potential evapo-transpiration (PET) is the amount of evaporation that would occur if a sufficient water source is available. Studying or inclusion of PET improves the study of risk in agriculture (Tsakiris *et al.*, 2006). The PET was calculated using Hargreaves equation as suggested by Hargreaves and Allen (2003) and the formula is given as:

$$ET_0 = 0.0023H_0\,(T_{max}-T_{min})^{0.5}\,(T_{mean}+17.8) \quad .... (ii)$$

Where,

ET_0 = Potential evapo-transpiration (mm/day); H_0 = Extra-terrestrial radiation (mm/day); T_{max}= Daily maximum temperature; T_{min} = Daily minimum temperature and T_{mean} = Daily mean temperature.

Standardized RDI (RDI_{std}) was calculated to classify the drought years and wet years from the available secondary data using the following formula:

$$RDI_{std} = \frac{Y_k - \bar{Y}_k}{\alpha_k} \quad .... (iii)$$

Where,

Y_k = ln α_k; $\bar{Y}_k$ = Arithmetic mean; α_k = Standard deviation

The drought was classified following Kusre and Lalringliana (2014). The values from -0.50 to -0.99 was characterised as "mild drought" and >0.1 was regarded as "no drought" (McKee *et al*., 1993). After standardization, the RDI was normalised so as to bring their values under a suitable range *i.e.*, 0-1 range. Normalised RDI (RDI_n) is the drought exposure index for the farms.

Effect of drought on rice yield

We have regressed yield and log of yield of rice on RDI_{std} or drought dummy and time. The models are as below:

$Y=a+b*RDI_{std}+Time+U_i$ .... (iv

$Y = a +b*Drought + Time + U_i$ .... (v)

Where,

a = intercept, b = slope coefficient, Drought = Dummy (wet and Normal condition–dry = 0, Moderate drought = 1, Severe drought = 2, Extreme drought = 3) and U_i = stochastic error term.

RESULTS AND DISCUSSION

Annual temperature

The annual mean temperature in Phek district (23.98^{0}C) was higher than in Dimapur (22.81^{0}C) during 1975-2013 (Table 1). The lower extremes for annual minimum temperature were 17.23^{0}C in Dimapur and 18.11^{0}C in Phek district. The upper extremes were 29.28^{0}C in Dimapur and 30.91^{0}C in Phek for annual maximum temperature. The highest difference (3.64^{0}C) between lower and upper extreme was recorded for annual maximum temperature in Dimapur and the lowest difference (1.29^{0}C) was for minimum temperature in Dimapur. The calculated coefficient of variations (CV) reveals that the inter year variation was highest for average annual minimum temperatures in both the districts, though the difference in CV values for the annual minimum, maximum and mean temperatures were negligible (Table 1). The linear trends in annual mean, minimum and maximum temperatures are increasing and significant (P<0.01) in both the districts. The annual maximum temperature has increased by 0.31^{0}C and 0.28^{0}C per decade whereas the annual minimum temperature has increased by 0.20^{0}C and 0.19^{0}C per decade in Phek and Dimapur district, respectively during 1975-2013 (Table 1). Chakraborty *et al.* (2014) reported a dissimilar pattern of changes among the stations; places *viz.*, Basar in Arunachal Pradesh, Imphal in Manipur and Gangtok in Sikkim where the mean temperature was lower, i.e., those places which are climatologically cooler, the increase in temperature is significant. Increasing trend in temperature was also observed in Assam (Jhajharia and Singh, 2010; Jain *et al.*, 2013) and Meghalaya subdivision (Jain *et al*., 2013).

Annual rainfall

The average annual rainfall was comparatively higher in Phek (1630.67 mm) than in Dimapur (1491.88 mm) district during 1975-2013 (Fig 1). Phek district registered a minimum of 1154.70 mm of annual rainfall (-29%) in 2006 and a maximum of 2521.40 mm (+35%) in 1993. Dimapur experienced a minimum of 948.20 mm average annual rainfall (-36%) in 2012 and a maximum of 2248.80 mm (+34%) in 1993. The inter year variations in rainfall was about 18-19% in the study area but the patterns were similar for both the districts. The annual rainfall has decreased by 2.77 mm and 2.91 mm per annum in Phek and Dimapur district, respectively but the linear trends are not significant (Table 2). Chakraborty *et al*. (2017) also reported insignificant negative trend in monsoon rainfall for Umiam in Meghalaya. Similar finding was reported by Jain *et al*. (2013) for Assam and Meghalaya sub-division for the period of 1871-2008.

Extra-terrestrial radiation (H_0) and Potential evapo-transpiration (PET)

The value of H_0 depends on latitude. As both the districts falls under the same latitude, hence, calculated H_0 was same for them. Each day of the year has a single value of H_0 and the calculated average value was 13.38 mm/day for the study period. The estimated average PET was higher (1509.14 mm/year) in Phek than in Dimapur (1441.05 mm/year). The maximum PET was observed in the year of 2012 in Phek and in 2013 in Dimapur district (Fig. 1). The annual PET in both the districts has increased significantly (P<0.05) over the years during the period 1975-2013 which may be due to raising temperature (Table 2).

Relationship between the weather variables

The correlation between the variables reveals that the PET was positively related with temperatures implying that the PET was higher in warmer years. The rainfall was negatively correlated with temperatures indicates that the hotter years experienced lesser rainfall. Rainfall was also negatively correlated to PET which has its link through the temperatures. It means that the years with higher rainfall were relatively cooler and hence, the PET was lower (Table 3).

Reconnaissance drought index (RDI)

The years of the study were classified based on the calculated RDI_{std} to analyze the occurrence of drought in the study area. Majority of the 39 years under study *i.e.*, 38.46% in Phek and 41.02% in Dimapur were in the class of Normal condition-dry (Table 4). This indicates that mild

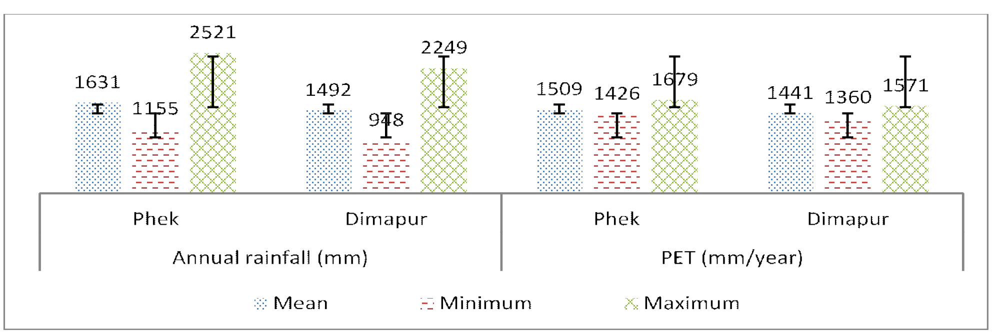

Fig 1: Annual rainfall and PET in Phek and Dimapur during 1975-2013.

Table 1: Summary statistics and linear trends for annual temperature (^{0}C) during 1975-2013.

Particulars	Phek			Dimapur		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Average (^{0}C)	18.71	23.98	29.25	17.75	22.81	27.83
CV (%)	2.29	1.96	2.12	2.19	1.97	2.02
Lower extreme (^{0}C)	18.11	23.11	28.02	17.23	21.97	26.64
Upper extreme (^{0}C)	19.65	25.03	30.91	18.52	23.75	29.28
Range (^{0}C)	1.54	1.92	2.89	1.29	1.78	3.64
Slope coefficient	0.020**	0.027**	0.031**	0.019**	0.025**	0.028**
P value	0.00	0.00	0.00	0.00	0.00	0.00

** indicates p<0.01

Note: Figures in bracket indicate p value

Table 2: Instability and linear trend in H_0, annual rainfall and PET during 1975-2013.

Particulars	H_0	Annual rainfall (mm)		PET (mm/year)	
	(mm/day)	Phek	Dimapur	Phek	Dimapur
CV (%)	19.95	18.42	19.20	3.22	3.10
Trend	-	-2.765	-2.911	1.664*	1.508*
P value	-	(0.52)	(0.48)	(0.01)	(0.02)

* indicates p<0.05

Note: Figures in bracket indicate p value

Table 3: Correlation among the climatic variables.

Variables	Phek		Dimapur	
	Rain	*PET*	Rain	*PET*
Rain	1.00		1.00	
PET	-0.46**	1.00	-0.52**	1.00
Minimum Temperature	-0.22	0.03	-0.20	0.02
Maximum Temperature	-0.51**	0.83**	-0.54**	0.86**
Mean Temperature	-0.45**	0.61**	-0.44**	0.57**

** indicates p<0.01

drought was common in both the districts under study. The frequency of mild drought was highest during 2001-13 in Phek and during 1975-87 in Dimapur. Both the districts also faced moderate droughts but the frequency of occurrence was higher in Dimapur (17.94%) than Phek (12.82%). In Dimapur moderate drought occurred six times 1988 onwards or five time after 1995 (Fig 2). Six years were severe drought years and two years were extreme drought years (2006 and 2012) in Dimapur; extreme drought occurred only in 2006 and no severe drought was registered in Phek during the same period (Table 4). After 1994, majority of the years were drought years and the frequency of occurrence was higher in Dimapur district (Fig 2). The frequency of moderate to severe drought occurrences is also increasing in recent past in the study area. Kusre and Lalringliana (2014) found, on the basis of calculated RDI, that drought was experienced for 66.7% and 59.3% of time during October to December and January to March, respectively in East Sikkim during 1985-2012. They also observed that every three years the district experienced drought during the study period. Ray *et al.* (2012) analysed 28 years daily rainfall data of Barapani, Meghalaya and observed that the minimum number of drought occurred 5 times in 39th week, while the maximum number was observed 11 times in 28th week. The highest frequency of drought was found at a magnitude of 14 times in 28 years in December.

Effect of drought on rice yield

The calculated correlation coefficients reveal no significant correlation between drought and yield in Phek and Dimapur; but the linear association was significant (p<0.05) when the first difference form for yield was used in Dimapur (Table 5). The plotting of the observations as lines in a graph also reveals association between the yield and drought in the study area (Fig 3 and Fig 4). The time series for yields were tested for stationarity using correlogram and ADF test. The series for yield in Phek found to be non-stationary hence, converted into stationary series by taking the first difference. Then we have regressed yield, log of yield and detrended yield (*i.e*., first difference form of yield) on drought *i.e.*, drought dummy and RDI_{std}. All the models reveal that RDI_{std} has positive and significant influence on yield of rice in Phek as well as Dimapur (Table 6). The positive slope coefficients of RDI_{std} implies that as the value of RDI_{std} increase (which means moving towards wet condition) the yield increases. When drought was used as categorical variable the coefficients turned out to be negative which implies that with the increase in drought intensity the yield reduced significantly.The sensitivity of rice yield to drought intensity was evaluated using Model 4 and the results are given in Table 7. The rice yield may reduce by 28.23% in normal dry condition to 50.45% in extreme dry condition in comparison

Table 4: Classification of years across different RDI categories and periods in Phek and Dimapur during 1975-2013.

Category	Phek				Dimapur			
	1975 -1987	1988 -2000	2001 -2013	No of years	1975-1987	1988-2000	2001-2013	No of years
Extremely wet (≥ 2.00)	-	1992, 1993	-	2	-	-	-	0
Very wet (1.50 to 1.99)	0	0	1990-1991	2				0
Moderately wet (1.00 to 1.49)	1976			1		1990, 1992, 1993		3
Extreme to Moderate Wet	**1**	**2**	**2**	**5**	**-**	**3**	**0**	**3**
Normal condition -wet (0.01 to 0.99)	1975, 1977, 1981, 1983, 1985	1989, 1994, 1997	2001, 2004, 2007, 2008, 2010	13	1983	1989, 1991	2003, 2008	5
Normal condition -dry (0.00 to -0.99)	1978, 1982, 1986, 1987	1988, 1995, 1996, 1998, 1999, 2000	2002, 2003, 2005, 2011, 2013	15	1975, 1977, 1978, 1981, 1982, 1985 - 1986, 1987	1994, 1995, 1999, 2000	2001, 2004, 2007, 2010	16
Moderate drought (-1.00 to -1.49)	1979, 1980, 1984	-	2009, 2012	5	1980	1988, 1996 -1997	2002, 2011 2013	7
Severe drought (-1.50 to -1.99)	-	-	-	0	1976, 1979, 1984	1998	2005, 2009	6
Extreme drought (≤ -2.00)	-	-	2006	1	-	-	2006, 2012	2
Moderate to Extreme drought	**3**	**0**	**3**	**6**	**4**	**4**	**7**	**15**
Total	8	11	15	39	13	13	13	39

to 24 year average rice yield of 1.76 MT/ha in Phek. In Dimapur, the rice yield may decline by 13.85% to 30.88% in similar drought conditions in comparison to the 14 years average yield of 2.01 MT/ha. Das *et al*. (2009) also reported about 25% decline in rice yield in 2009 in drought affected areas of North-eastern (NE) region of India. Many other studies found that *Kharif* production declines if the rainfall is lower in between June to September (Webster *et al*., 1998; Selvaraju, 2003; Kumar *et al*., 2004). Siato *et al*. (2006) also observed that the average rice yield declined from 2.5 MT/ha to 1.4 MT/ha when the rainfall decreased from more than 690 mm to less than 610 mm in Laos in between the months of June to August. The time trend variable was significantly positive in all the models indicating that with the passage of time the yield has increased due to technological improvements.

Table 5: Correlation between yield and drought.

Particulars	Phek	Dimapur
Yield	-0.21	0.25
d_Yield	0.30	0.45*

* indicates $p<0.05$

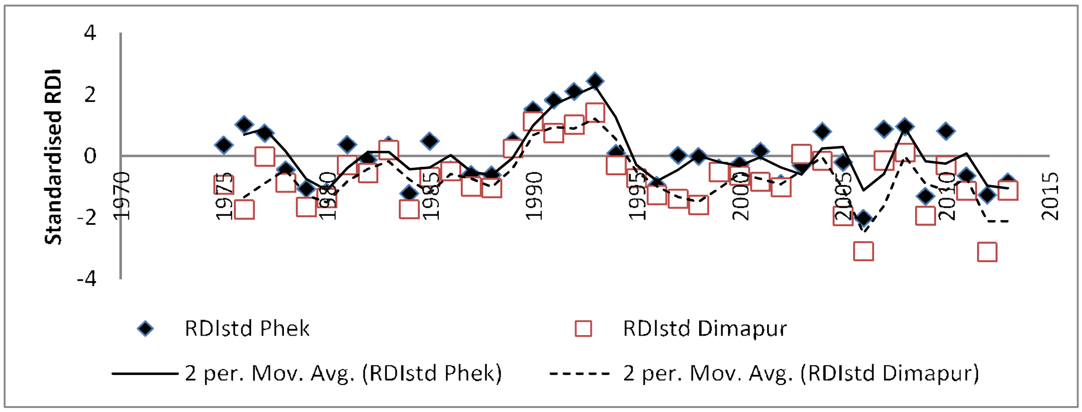

Fig 2: Trends in occurrence of droughts in Phek and Dimapur during1975-2013.

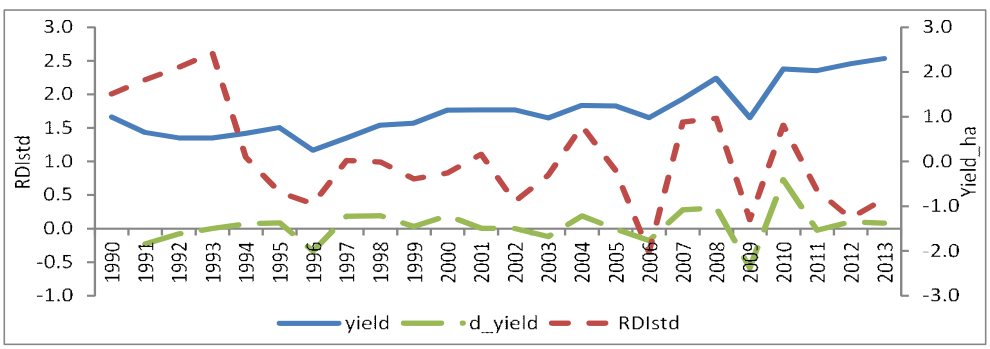

Fig 3: Time series for yield, d_yield and RDIstd in Phek during 1990-2013.

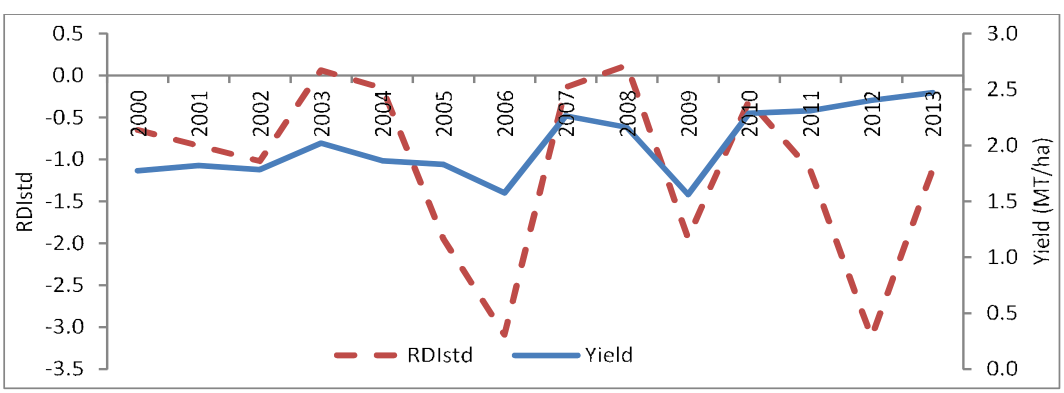

Fig 4: Time series for yield and RDI_{std} in Dimapur during 2000-2013.

Table 6: The estimated regression coefficients: Effect of drought on yield.

Variables	Model 1		Model 2	
Dependent variable = Yield (MT/ha)				
Explanatory	Phek (n=24)	Dimapur (n=14)	Phek (n=24)	Dimapur (n=14)
Const	1.07	1.71	1.21	1.67
RDI	0.10*(0.02)	0.13 *(0.04)		
Drought Dummy			-0.13*(0.02)	-0.114*(0.04)
Time	0.05**(0.00)	0.06**(0.00)	0.05**(0.00)	0.06**(0.00)
Adjust R^2	0.78	0.573	0.76	0.56

* and ** indicate p<0.05 and p<0.01, respectively

Note: Figures in bracket indicate p value

Table 7: Sensitivity analysis for rice yield using Model 2.

Drought	Yield		% change in yield	
scenarios	Phek (n=24)	Dimapur (n=14)	Phek (n=24)	Dimapur (n=14)
Normal condition-dry	1.26	1.73	28.23	13.85
Moderate drought	1.13	1.62	35.64	19.53
Severe drought	1.00	1.50	43.04	25.20
Extreme drought	0.87	1.39	50.45	30.88
Average	1.76	2.01	39.34	22.37

CONCLUSION

The paper concluded that moderate and severe drought occurred more frequently in Dimapur than Phek district of Nagaland and off let the frequencies have increased. The temperature and PET were positively correlated with drought. It has also been estimated from the regression analysis that the drought years negatively impacted the rice yield in these districts which may results to a reduction in rice yield by 13.85% in normal condition dry in Dimapur district to 18.45% in extreme drought condition in Phek district. Thus, it is a matter of concern for the research institutions in developing varieties that has significant resilience to drought. The developed varieties should also be farmers' friendly in terms of cultural operations and economic satisfaction. There is also a scope in encouraging water harvesting, efficient irrigation methods and traditional methods of farming merging with scientific methods to enhance the overall yield of rice.

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