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Characterization of drought in a hill city- Shillong using standardized precipitation index

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ABSTRACT

The water stress situation in a high rainfall hill city- Shillong, Meghalaya during 1983 to 2010 was investigated using standardized precipitation index (SPI). The SPIs were computed on sliding timescales of 1- and 2- months to represent short term moisture stress (STMS); 3- and 6- months to represents agricultural drought and 12-, 24- and 36- months to represent hydrological drought. Yearly and monsoon droughts as well as drought spells were also determined. The monsoon months in the area contributes more than 75% to the annual rainfall and droughts during monsoon months are well correlated with annual droughts. Frequency of drought events and drought durations indicated are inversely proportional and directly proportional to the timescale of SPI, respectively. The study revealed that STMS ranged from 1 to 11 months, agricultural droughts ranged from 1 to 13 months and hydrological droughts ranged from 11 to 62 months. Among the STMS indicator, the SPI2 has shown longest drought spell of 11 months between July, 1990 and May, 1991. Similarly, for agricultural drought, the longest drought spell was given by SPI6 which was started in the month of June, 1998 and lasted till June, 1999. Further, hydrological drought given by SPI24 that starts on July, 1995 and lasted until September, 2000 for over 5 years was of the extreme nature. The authors however, concluded that, water crisis in Shillong is manageable with proper soil moisture conservation and water harvesting techniques.

1. Introduction

Droughts and floods are the two extremes of rainfall distribution, in which, its deficiency causes droughts while its abundance causes floods. Droughts, unlike other natural hazards such as floods, cyclones, earthquakes, landslides, forest fires, etc., built up rather slowly without being noticed and its impact span for a very long time (Taggu and Shrivastava 2018). Droughts, like all other natural hazards, also adversely affect the human and animal lives, its economy as well as the environment. One of the major effects of widespread drought is the population migration from drought affected areas to a safer place. According to 4th assessment report of Intergovernmental Panel on Climate Change (IPCC), the migration of people has increased in drought affected areas (IPCC 2007). Many people in different countries especially in rural areas, used migration as their coping strategy, which definitely is not among the feasible solutions in the long run.

Drought may be defined as widespread hydro-meteorological syndrome (Gupta *et al.* 2011) which is caused by occurrence of rainfall far below its normal value. A longer run of deficit rainfall for several months may lead to various forms of droughts such as short-term moisture stress, agricultural, hydrological, socio-economic and ecological droughts. In any case, the droughts are characterized by its severity, onset, duration and the spatial extent of spread. The impacts of droughts persisted for a very long period of time and therefore it become utmost important especially in the agricultural sector in which it directly affects the food production. Failing to notice shortage of moisture in agricultural crops due to deficient rainfall in rainfed areas will directly impact the agricultural production. Hence, early detection of drought especially meteorological drought is utmost important in rainfed areas. Droughts generally produce huge stress on environment limiting the rain-fed agriculture (Singh and Kumar 2009). Approximately, one-third of India total geographical areas is experiencing drought in recent decades (Roy and Hirway 2007; Mishra and Singh 2010).

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Northeast region of India is blessed with high rainfall and enormous number of rivers including the mighty Brahmaputra River. However, due to its rugged terrain in most parts, it becomes difficult to explore and tap its surface as well as groundwater resources. In the recent past, this region has witnessed a discernible shift of climate change and its impacts such as change in pattern of seasonal rainfall, reduced water level in the rivers, loss of springs in various foothills, etc. The Meghalaya, one of the states in northeast India, which also embodied the two rainiest places in the world- Mausynram and Cherrapunjee, receives ample amount of rainfall and yet often (Sahu 2005). Due to lack of rainfall in the recent years, various paddy fields (where ponded water existed during rainy season) in Meghalaya, were now transformed into playgrounds. The water situation in the Meghalaya is a case of – "scarcity amidst plenty" brought by many factors such as decrease in rainfall in the last few decades, uncontrolled water runoff due to steep slope, increase in water demands due to population growth besides demands from agriculture, transportation, mining and industries. Shortage of water in the state has become a chronic phenomenon in the recent years.

Drought studies are very limited for the north-eastern region. (Jhajaria *et al.* 2007) assessed drought proneness at Guwahati (a city in north east India) using percentage departure of rainfall from its normal. Similar approach was adopted by (Shrivatava *et al.* 2008) to assess the meteorological droughts in North Lakhimpur district of Assam. They have classified a week or a month to be drought if the receiving rainfall is less than 50% of its normal, a drought year as a year receiving rainfall is less than the value of normal minus its standard deviation and termed a seasonal drought if the receiving rainfall is less than the value of normal minus twice standard deviation. (Parida and Oinam 2015) determined and compared the unprecedented drought in north east India with droughts in western India and concluded that the probability of drought occurrences in northeast India was found to be higher than that of western India. (Das *et al.* 2009) have reported that the Meghalaya has experienced rainfall deficiencies of 23%, 32% and 56% from its normal respectively in the years 2005, 2006 and 2009. Ray *et al.* (2013; 2013a; 2014; and 2015) assessed the meteorological drought condition in Shillong, Tura, East Garo Hills and Cherrapunjee of Meghalaya respectively. Most of the researches carried out in the north-eastern part of India are based on departure of rainfall from its normal value. Drought indices which represent and quantified drought severity in terms of numerical value were hardly tried in this region. Many drought indices have been developed over the years and used by researchers around the world. (Kusre and Lalringliana 2014) assessed winter droughts (October to March) persistent in East Sikkim district using a simple drought indicator- reconnaissance drought index (RDI). Their study is quite important because most of the north-eastern part of India have similar terrain like East Sikkim where proper water storage mechanism is absent and rainfall in the region are rapidly washed out from the area due to steep slope. Amongst the drought indices, the standardized precipitation index is a popular choice of the researchers (Agnew 2000; Pandey *et al.* 2018; Nosrati and Zareiee 2011; Kumar *et al.* 2012; Shah *et al.* 2015; Sabau *et al.* 2015; Habibia *et al.* 2018; Thakur *et al.* 2019; Pei *et al.* 2020). Keeping in view the importance of water and chronic water shortage situation at Shillong, the capital of Meghalaya, we have attempted to investigate the drought situation using a robust drought indicator- the standardized precipitation index (SPI) on sliding time scale, so as to reflect the STMS, agricultural and hydrological droughts.

2. Materials and Methods

2.1 Study area and data

The study area, Shillong is the capital hill city of Meghalaya, which is located at 25°34' N latitude and 91°53' E longitude (Fig.1). It is the most populated city in Meghalaya, comprising of 27 municipal wards, covering a geographical area of 10.36 square kilometres, and situated upon a plateau elevated to 1497 m above mean sea level. The climate is subtropical. In order to quantify the occurrence of drought in the city, the monthly rainfall data from 1983 to 2010 of

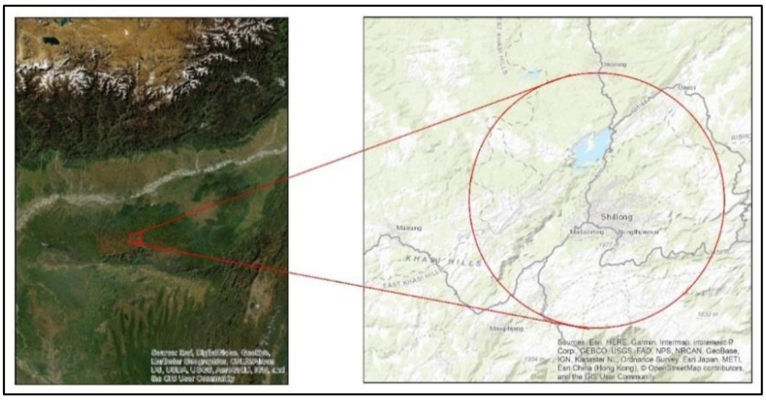

Figure 1. Study area: Shillong, Meghalaya.

Shillong were acquired from Indian Council of Agricultural Research (ICAR) centre at Barapani. Although, only rainfall data is required for the quantification of drought, other meteorological data such as maximum and minimum temperature, and evaporation data were also studied for better understanding of the climate of the study area.

2.2 Methods

The Standardized Precipitation Index (SPI) was developed by (Mckee *et al.* 1993). The SPI is simple, easy to calculate and statistically relevant, and requires precipitation as the only input parameter. It quantifies the precipitation deficit for multiple timescales such as 1-, 2-, 3-, 6-,12-, 24-, 36-, 48-, and so on months. (Mckee *et al.* 1993) classified drought according to SPI values as shown in Table 1. The SPI is also flexible to use other variables like streamflow discharge, snowpack, groundwater level, reservoir level and soil moisture (Keyantash and National Center for Atmospheric Research Staff 2018). This allows SPI to be used for various other monitoring activities. One of the major advantages of the SPI is that it can also be used to monitor wet as well as dry periods since the SPI is normally distributed and thus wet and dry climate are represented in a similar way.

A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less and the drought event ends when the SPI becomes positive. The timescales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short timescale while groundwater, streamflow and reservoir storage reflect the longer-term precipitation anomalies. So, for example, one may want to look at a 1- or 2-month SPI for short term moisture stress (STMS), anywhere from 3-month to 6-month SPI for agricultural drought, and something like 6-month up to 48-month SPI for hydrological drought analyses (NDMC 2018) and applications. In this study, we determined the SPI at Shillong from 1983 to 2010 using a software- SPI Generator developed by National Drought Mitigation Center (NDMC 2018). The SPI calculated with this software is based on gamma distribution of historical rainfall records. We determined the SPI values at 1- and 2-month timescales to represent STMS; 3- and 6- month timescales to represent agricultural droughts and 12-, 24- and 36- month timescale to represent hydrological droughts in the study area. Also, annual and monsoon months (June to October; 5 months) SPI values were determined to see how the droughts have been evolving in the study area year after year. Severity, onset and duration are the three major characteristics of droughts. Considering this, we also determined the drought period at the timescales mentioned above.

Table 1. Drought classification according to SPI values after Mckee *et al.* 1993

Drought Class	**SPI values**
Extremely wet	>2
Very wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Near normal	-0.99 to 0.99
Moderately dry	-1.0 to -1.49
Severely dry	-1.5 to -1.99
Extremely dry	<-2

3. Results and Discussion

The basic statistical analysis was carried out in the precipitation data at Shillong from 1983 to 2010. The mean (normal), extreme values (minimum and maximum), standard deviation, coefficient of variation and percentage contribution of rainfall are illustrated in Table 2 for various months of the year, annual and monsoon months. The average annual rainfall at Shillong was found as 2409.9 mm in which five monsoon months (June to October) contributes 75.4 % (1817 mm). The month of December in Shillong received the least amount of rainfall followed by January, February and March. On the other hand, the highest normal rainfall of 439 mm was observed in July followed by June (408.3 mm), September (355.9 mm) and August (345 mm). The coefficient of variation for monsoon months and annual are found lesser than those observed in individual months. The months of December, January and February have higher probability of drought occurrence as the standard deviation in these months are higher than the normal rainfall. Lack of water storages in the preceding months owing to steep slopy terrain make these months more vulnerable.

In order to understand the temporal variation in the climate of Shillong, monthly and yearly variation of various meteorological data are plotted as shown in Fig. 2 and Fig. 3. The meteorological variables include rainfall (PRECIP, mm), maximum temperature (TMAX, ºC), minimum temperature (TMIN, ºC), temperature range (TRNGE, ºC) and evaporation (EVAP, mm). The mean monthly maximum temperature remains constant throughout the year while the mean monthly minimum temperature varies considerably. During the months of winter- November, December, January, February and March, higher diurnal temperature variation was observed than the rest of the months. As a result, temperature range (TRNGE) are lower during monsoon seasons. The yearly variation showed that TRNGE and TMIN remains constant over the years while TMAX drops slightly in the later part of the study period. Pan evaporation was found highest in the month of April (4.4 mm) followed by March (4 mm) and May (3.4 mm). This may be attributed to the stronger wind speed during this period in the study area. Monsoon months have relatively low evaporation. The yearly variation of pan evaporation clearly shows decreasing pattern towards the end of the study period. The rainfall pattern in the study area started to build up in March and attains peak in the month of July. More than 90% of the annual rainfall were received during the months from April to October in the study area. The yearly variation of rainfall started to diminish from 1992 and again rise after 1998. This analysis of monthly and yearly variation of rainfall in the study area will be helpful in better understanding the droughts indicated by the SPI, later in the following sections.

Table 2. Descriptive statistics of rainfall at Shillong during 1983-2010

Month	Normal (mm)	Extreme Value Minimum (mm)	Extreme Value Maximum (mm)	Standard Deviation (mm)	Coefficient of Variation (%)	Percentage Contribution (%)
January	15.2	0	84.7	17.9	21.2	0.6
February	22.5	0	117.9	27.8	23.5	0.9
March	49.5	3.6	161.7	37.2	23	2.1
April	144.5	16.1	379.2	89.1	23.5	6
May	283.7	82.1	640.5	110.1	17.2	11.8
June	408.3	131.2	738	150.2	20.4	16.9
July	439	114.9	935.2	192.2	20.5	18.2
August	345	134.8	594.7	123.2	20.7	14.3
September	355.9	158.3	511.7	85.8	16.8	14.8
October	268.8	112.9	603.7	127.7	21.2	11.2
November	64	0	206.8	56.4	27.3	2.7
December	13.5	0	57.7	16.3	28.3	0.6
Monsoon	1817	1241.8	2283.6	299.7	16.5	75.4
Annual	2409.9	1808.2	3322.6	360.7	15	-

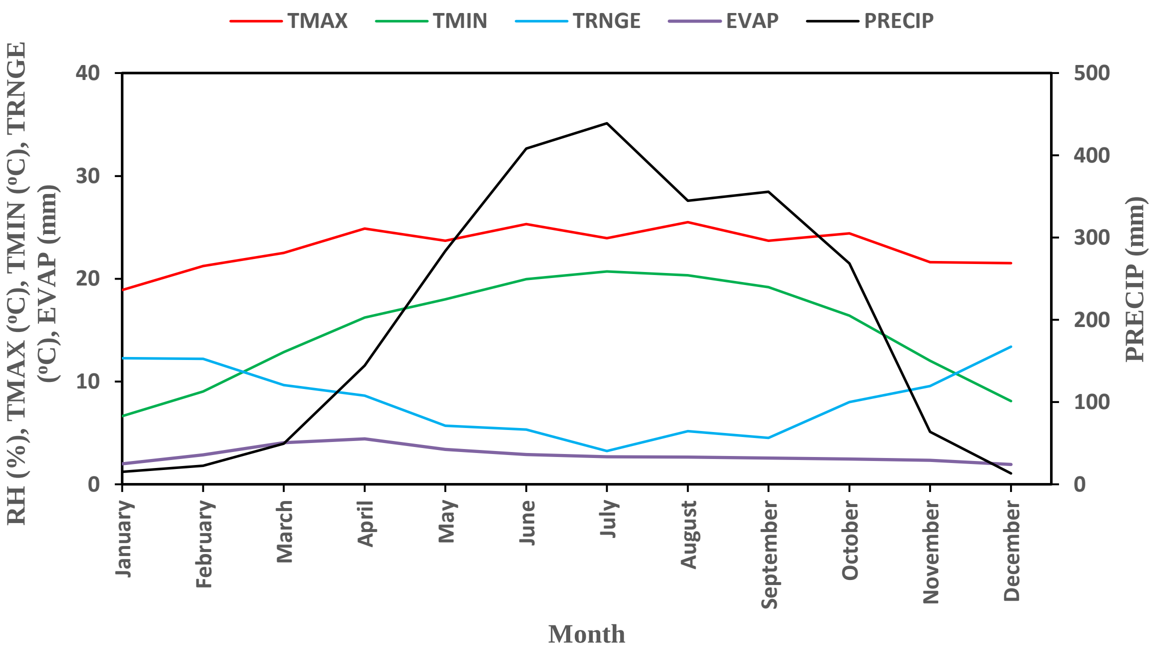

Figure 2. Monthly variation of meteorological variables at Shillong.

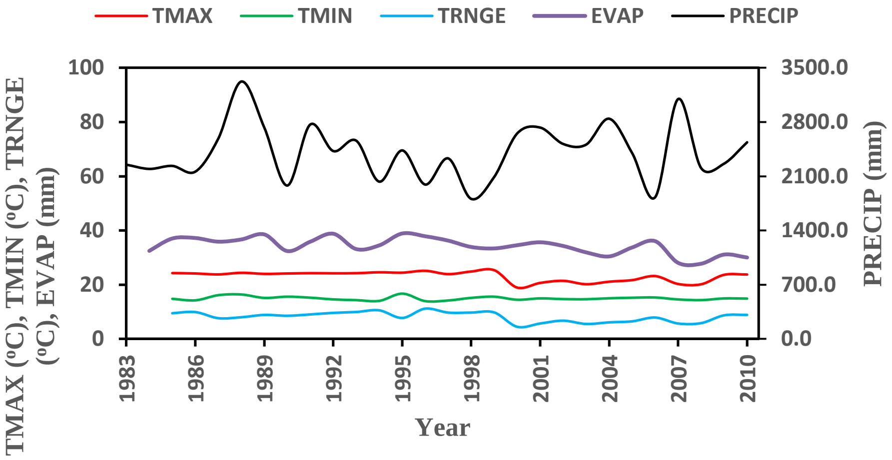

Figure 3. Yearly variation of meteorological variables at Shillong.

3.1 Drought characterization using SPIs

The aggregates of rainfall for 1-, 2-, 3-, 6-, 12-, 24- and 36- months reflects the availability of the different water resources. In this study, we determined the SPI values on these sliding months so as to reflect different water resources in the study area. We have chosen 1- and 2-month SPI for short term moisture stress (STMS); 3- and 6- month SPI for agricultural drought and 12-, 24- and 36- month SPI for hydrological drought. The STMS, agricultural and hydrological droughts represented by various SPIs at Shillong are presented in Fig. 4, Fig. 5 and Fig. 6. Table 3 illustrated the number of drought (moderate, severe and extreme) months for each year from 1983 to 2010 given by various SPIs. This table showed how many months had shortage of rainfall in each corresponding years at various time scale. SPI1 and SPI2 showed that in the year 1999, 5 of the 12 months are under water stressed at Shillong. In the year 2006, SPI3 determined 5 months to be under water stressed while according to the SPI6, 7 months are under droughts. In case of SPI3, 5 months of the year 2006 are also under drought conditions. According to SPI12, 7 months of the year 1998 were under droughts. All the months of 1999 are under stressed according to SPI24 and SPI36. All the months in the year 2000 were also under drought conditions as per the SPI36.

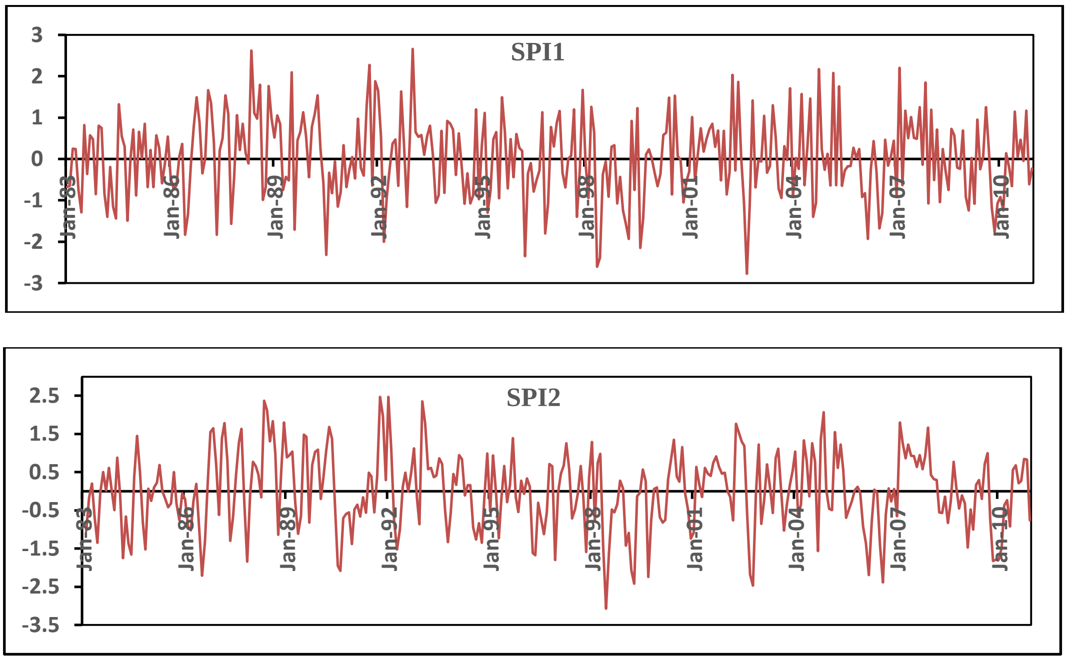

Figure 4. Short term moisture stress represented by SPI1 and SPI2.

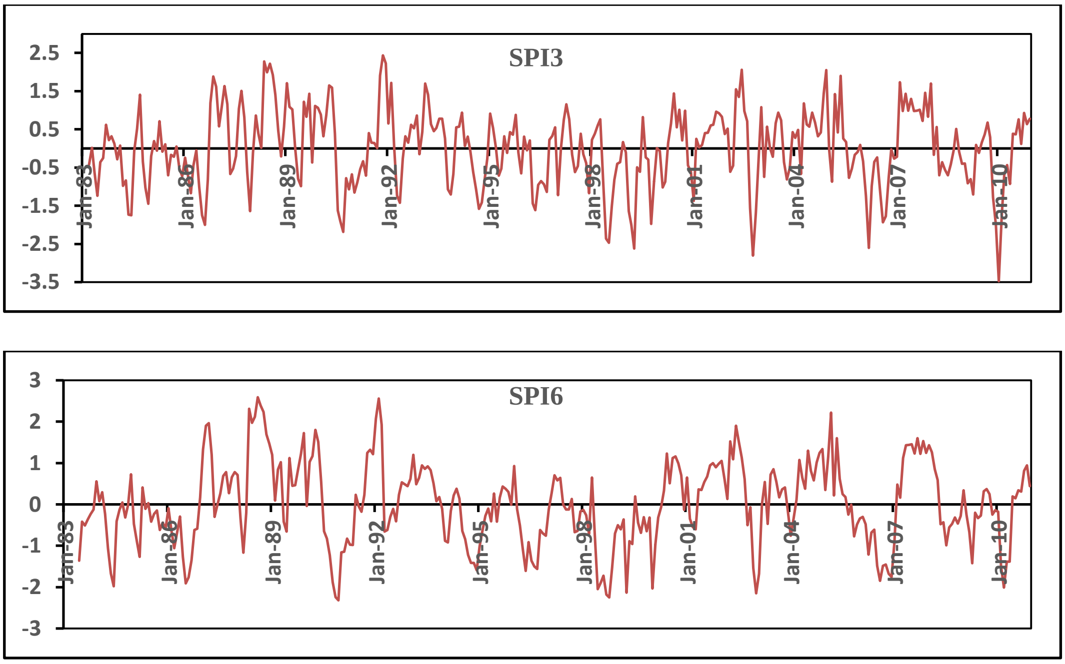

Figure 5. Agricultural droughts in Shillong represented by SPI3 and SPI6.

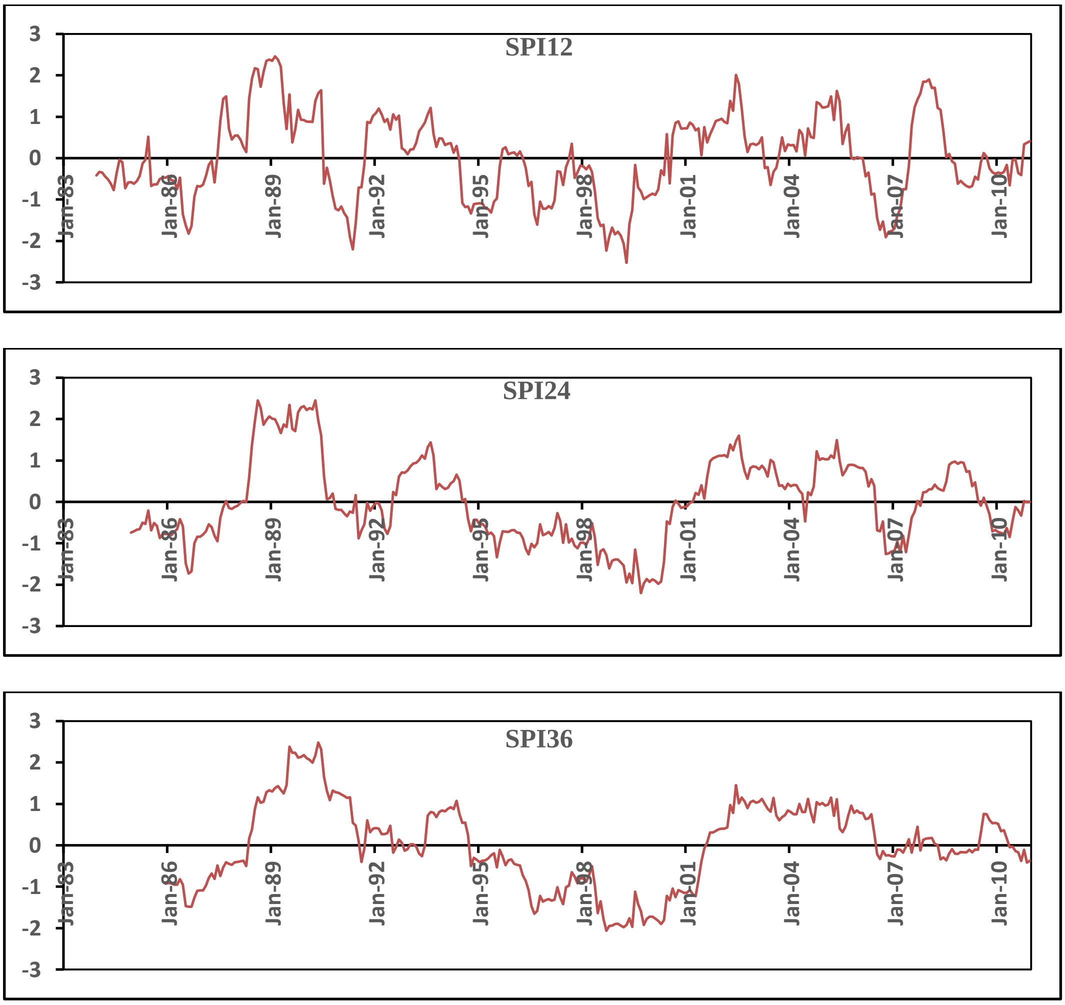

Figure 6. Hydrological droughts in Shillong represented by SPI12, SPI24 and SPI36.

The short-term moisture stress represented by SPI1 and SPI2, illustrated in Fig. 4, has multiple spikes of positive and negative SPI values while hydrological droughts represented by SPI12, SPI24 and SPI36, illustrated in Fig. 6, has very less positive and negative SPI nodes. The agricultural droughts represented in Fig. 5 has lesser spikes than STMS and more spikes than hydrological droughts. These results indicated that STMS persisted for short duration while agricultural and hydrological droughts persisted for longer duration. The SPI36 values, in Fig. 6 from 1995 up to the year end of 2000, are negative indicating water stressed hydrologically. However, at shorter time scales such as the SPI1 and SPI2, there are series of positive and negative values during the same period. This indicate that the rainfall occurred during this period was sufficient to recuperate from short term moisture stress and to some extent agricultural droughts but remains insufficient for recuperating the hydrological droughts. The study also observed that the number of a drought spell which starts when SPI touches a value of -1 and ceases when SPI becomes positive after a continuous run of negative values, decreases as timescale increases. On the other hand, another aspect of drought i.e., drought duration increases as timescale increases. The number of droughts months that had occurred during each calendar month over the years from 1983 to 2010 has been illustrated in Table 4. The table revealed that drought occurrences at Shillong are not concentrated during winter months when the rainfall is scanty, instead, all months of the year are vulnerable for water stress as illustrated by the SPI at different timescales.

Table 3. Number of drought months in each year from 1983 to 2010 at Shillong

Year	SPI1	SPI2	SPI3	SPI6	SPI12	SPI24	SPI36
1983	1	2	1	1	-	-	-
1984	4	4	4	3	0	-	-
1985	0	0	0	1	0	0	-
1986	2	3	4	5	4	4	6
1987	2	2	1	0	0	0	1
1988	0	1	0	1	0	0	0
1989	1	1	0	0	0	0	0
1990	2	3	4	4	2	0	0
1991	0	0	1	2	6	0	0
1992	2	2	2	0	0	0	0
1993	1	1	2	0	0	0	0
1994	2	2	3	4	6	0	0
1995	1	1	0	1	6	1	0
1996	3	4	3	5	5	5	7
1997	1	1	2	0	3	2	7
1998	3	3	3	6	7	8	7
1999	5	5	4	1	6	12	12
2000	1	1	1	1	0	5	12
2001	0	1	1	0	0	0	4
2002	3	2	3	1	0	0	0
2003	0	1	0	2	0	0	0
2004	2	1	0	0	0	0	0
2005	0	0	0	0	0	0	0
2006	3	4	5	7	6	3	0
2007	1	0	0	0	3	3	0
2008	1	0	0	0	0	0	0
2009	5	4	3	1	0	0	0
2010	1	2	2	4	0	0	0

Table 4. Number of drought months in each calendar months during the period 1983-2010

Month	SPI1	SPI2	SPI3	SPI6	SPI12	SPI24	SPI36
January	0	3	4	4	5	3	5
February	3	5	4	3	5	3	4
March	5	4	3	4	5	3	4
April	4	5	4	6	3	2	4
May	3	6	3	3	3	4	3
June	4	3	4	4	5	3	5
July	4	4	4	4	4	5	6
August	5	5	5	4	5	4	5
September	5	4	5	6	5	4	5
October	5	4	4	4	4	5	5
November	5	4	5	4	5	4	5
December	4	4	4	4	5	3	5

The SPI values for monsoon as well as annual total rainfall were determined on yearly basis and are plotted in Fig. 7. During the analysis of the results, the drought years at Shillong are observed in 1990, 1994, 1996, 1998 and 2006. Similarly, the monsoon of the years 1990, 1994, 1998 and 2006 are under drought conditions. As can be seen in the graph (Fig. 7), the drought years of 1990, 1994 and 2006 are solely responsible by the shortage of rainfall during monsoon months indicated by high drought value of SPImonsoon. The monsoonal drought of 1990 is under the extreme drought category and the rainfall received during non-monsoon months was not enough to recover from drought situation. One of the interesting observations is that in the in the year 2002, the SPImonsoon was negative while SPIannual was positive, indicating that the rainfall in non-monsoon months were able to recover the water situation from acute to surplus. The comparison of these two SPI graphs also revealed that the monsoon of 1996 which was considered normal although acute in rainfall had no support of rainfall from other months and therefore, in this particular year, SPI goes beyond -1 indicating a moderate drought year.

3.2 Drought spells in Shillong during 1983-2010

A drought spell or a drought event is a period of continuous water stress situation. In this study, a drought spell starts when SPI touches -1 i.e., when SPI turns moderate drought, and ends when SPI becomes positive i.e., no water stress condition. Drought spells in Shillong, based on the various SPIs, are determined and illustrated in the tables. Table 5 represents the short-term moisture stress spells while Table 6 and Table 7 represent the agricultural and hydrological drought spells in Shillong respectively. In the tables, the peaks represent the severity of the drought and are used to define whether the drought is either moderate, severe or extreme nature. And the magnitudes in these tables represent the sum of all the SPI values during a drought spell. The results showed that there were 29 each STMS spells in Shillong as per the SPI1 and SPI2. The drought spells for STMS are of short duration ranging from 1 to 6 months for SPI1 and from 1 to 11 months for SPI2. According to the SPI1, the number of moderate, severe and extreme drought spells are respectively 14, 9 and 6. It can be observed that mean drought duration for extreme cases is higher than moderate and severe drought cases. And according to the SPI2, the number of moderate, severe and extreme drought spells are respectively 12, 9 and 8. The longest spell of STMS

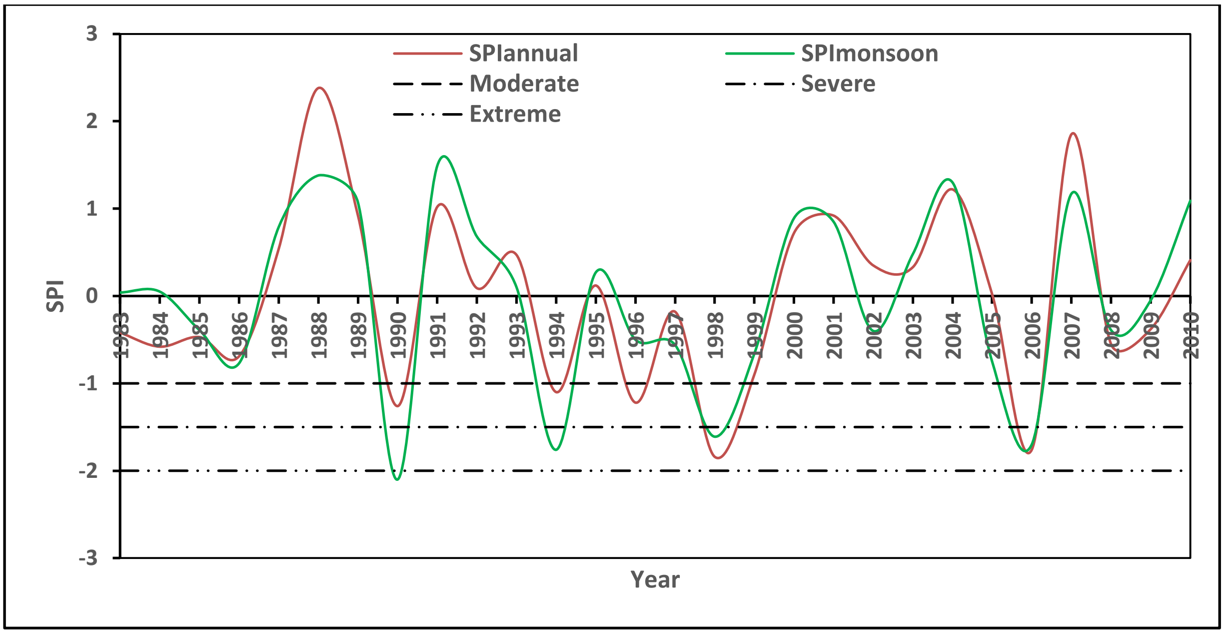

Figure 7. Annual and monsoon drought in Shillong during 1983 to 2010.

was observed from July, 1990 and continued till May, 1991 for 11 months. The drought observed in this period is of extreme nature and the drought magnitude is -9.46. The SPI3 has shown 9 moderate, 5 severe and 7 extreme drought spells while SPI6 has shown 4 moderate, 5 severe and 5 extreme drought spells. Longer spells are observed in agricultural drought as compare to short term moisture stress. The drought spells as per the SPI3 ranges from 1 to 12 months while it ranges from 1 to 13 as per the SPI6. The mean drought duration for extreme cases is also found higher than those of moderate and severe drought cases. Few notable extreme agricultural droughts in Shillong are Mar-1986 to Sep-1986 (lasted for 7 months), Jul-1990 to May-1991 (lasted for 11 months), Jun-1998 to Jun-1999 (lasted for 13 months), Feb-2006 to Jan-2007 (lasted for 12 months) and Nov-2009 to May-2010 (lasted for 7 months). The severe most agricultural drought in terms of severity is the drought of Nov-2009 to May-2010 which lasted for 7 months. The highest magnitude of drought was observed during the drought of Jun-1998 to Jun-1999 that reaches a drought peak of SPI = -2.25 and accumulates a drought magnitude of -17.77 over 13 months.

Table 5. Short term moisture stress spells in Shillong between 1983 and 2010

SPI1					SPI2				
Onset	End	Duration (months)	Peak	Magnitude	Onset	End	Duration (months)	Peak	Magnitude
01.06.83	30.06.83	1	-1.29	-1.29	01.02.83	31.03.83	2	-1.04	-1.22
01.03.84	30.06.84	4	-1.44	-4.18	01.06.83	31.07.83	2	-1.35	-1.39
01.10.84	30.11.84	2	-1.49	-1.52	01.03.84	30.06.84	4	-1.75	-5.44
01.06.86	31.08.86	3	-1.83	-3.3	01.11.84	30.11.84	1	-1.52	-1.52
01.05.87	31.05.87	1	-1.83	-1.83	01.03.86	30.04.86	2	-1.02	-1.28
01.10.87	30.11.87	2	-1.57	-2.04	01.07.86	31.08.86	2	-2.21	-3.52
01.08.89	31.08.89	1	-1.71	-1.71	01.05.87	30.06.87	2	-1.3	-1.95
01.07.90	31.12.90	6	-2.32	-5.48	01.11.87	31.12.87	2	-1.84	-1.94
01.03.92	31.05.92	3	-2	-3.16	01.10.88	31.10.88	1	-1.14	-1.14
01.11.92	30.11.92	1	-1.16	-1.16	01.05.89	30.06.89	2	-1.11	-1.74
01.09.93	31.10.93	2	-1.06	-1.93	01.07.90	31.05.91	11	-2.08	-9.46
01.07.94	31.10.94	4	-1.08	-3.38	01.04.92	31.05.92	2	-1.52	-2.52
01.03.95	30.04.95	2	-1.3	-2.07	01.10.93	30.11.93	2	-1.33	-1.87
01.04.96	30.09.96	6	-2.35	-4.39	01.08.94	30.11.94	4	-1.35	-3.59
01.11.96	31.12.96	2	-1.8	-2.87	01.04.95	31.05.95	2	-1.23	-1.42
01.10.97	30.11.97	2	-1.4	-1.67	01.04.96	30.09.96	6	-1.67	-5.97

01.05.98	30.09.98	5	-2.6	-6.33	01.12.96	31.01.97	2	-1.8	-1.84
01.12.98	30.04.99	5	-1.93	-6.24	01.11.97	30.11.97	1	-1.59	-1.59
01.08.99	30.09.99	2	-2.15	-3.6	01.05.98	31.10.98	6	-3.07	-7.52
01.11.00	31.01.01	3	-1.05	-1.9	01.01.99	30.06.99	6	-2.42	-7.16
01.08.02	31.10.02	3	-2.77	-4.91	01.09.99	31.10.99	2	-2.24	-3
01.08.04	30.09.04	2	-1.4	-2.46	01.12.00	31.01.01	2	-1.24	-2.32
01.03.06	30.04.06	2	-1.93	-2.21	01.09.02	30.11.02	3	-2.47	-4.76
01.07.06	31.08.06	2	-1.68	-3	01.09.03	31.10.03	2	-1.03	-1.37
01.12.07	31.12.07	1	-1.07	-1.07	01.09.04	30.09.04	1	-1.56	-1.56
01.04.08	30.04.08	1	-1.04	-1.04	01.02.06	30.04.06	3	-2.19	-4.36
01.02.09	28.02.09	1	-1.24	-1.24	01.07.06	30.09.06	3	-2.38	-4.41
01.04.09	30.04.09	1	-1.08	-1.08	01.02.09	30.04.09	3	-1.47	-2.94
01.10.09	28.02.10	5	-1.76	-6.16	01.11.09	31.05.10	7	-1.82	-8.38

Moderate drought
Severe drought
Extreme drought

Table 6. Agricultural drought spells in Shillong between 1983 and 2010

SPI3					SPI6				
Onset	End	Duration (months)	Peak	Magnitude	Onset	End	Duration (months)	Peak	Magnitude
01.06.83	31.08.83	3	-1.24	-1.86	01.06.83	30.11.83	6	-1.36	-3
01.05.84	31.07.84	3	-1.75	-3.55	01.04.84	31.08.84	5	-1.98	-5.25
01.11.84	31.01.85	3	-1.45	-2.67	01.03.85	31.03.85	1	-1.27	-1.27
01.03.86	30.09.86	7	-2	-7.22	01.03.86	30.11.86	9	-1.91	-9.54
01.12.87	31.01.88	2	-1.64	-1.76	01.03.88	30.04.88	2	-1.17	-1.37
01.07.90	31.05.91	11	-2.18	-11.87	01.09.90	31.05.91	9	-2.32	-12.75
01.04.92	30.06.92	3	-1.42	-2.93	01.09.94	31.05.95	9	-1.59	-8.07
01.10.93	31.12.93	3	-1.2	-2.94	01.04.96	31.01.97	10	-1.61	-10.22
01.08.94	31.12.94	5	-1.58	-5.2	01.06.98	30.06.99	13	-2.25	-17.77
01.04.96	30.09.96	6	-1.61	-6.93	01.01.00	30.04.00	4	-2.03	-3.4
01.01.97	28.02.97	2	-1.22	-1.23	01.12.02	31.03.03	4	-2.15	-5.37
01.12.97	31.12.97	1	-1.17	-1.17	01.04.06	31.01.07	10	-1.85	-13.1
01.06.98	30.11.98	6	-2.47	-7.92	01.04.09	31.07.09	4	-1.42	-2.23
01.02.99	30.06.99	5	-2.62	-7.36	01.02.10	31.05.10	4	-2.01	-6.26
01.10.99	30.11.99	2	-1.97	-2.83					
01.02.00	31.03.00	2	-1.02	-1.89					
01.01.01	31.01.01	1	-1.37	-1.37					
01.09.02	31.12.02	4	-2.8	-6.27					
01.02.06	31.01.07	12	-2.6	-11.49					
01.04.09	30.04.09	1	-1.2	-1.2					
01.11.09	31.05.10	7	-3.47	-10.59					

Moderate drought
Severe drought
Extreme drought

Table 7. Hydrological drought spells in Shillong between 1983 and 2010

SPI12					SPI24				
Onset	End	Duration (months)	Peak	Magnitude	Onset	End	Duration (months)	Peak	Magnitude
01.06.86	31.05.87	12	-1.82	-10.61	01.07.86	30.09.87	14	-1.73	-12.52
01.11.90	30.09.91	11	-2.2	-13.66	01.07.95	30.09.00	62	-2.2	-70.21
01.07.94	31.08.95	14	-1.34	-15.11	01.10.06	30.09.07	11	-1.26	-10.5
01.08.96	31.08.97	13	-1.61	-11.41	SPI36				

01.06.98	31.05.00	24	-2.53	-31.11
01.07.06	30.06.07	12	-1.91	-16.16

Onset	End	Duration (months)	Peak	Magnitude
01.07.86	30.04.88	22	-1.48	-17.38
01.06.96	31.07.01	62	-2.06	-83.04

Moderate drought
Severe drought
Extreme drought

The indicators for hydrological drought- SPI12, SPI24 and SPI36 have shown 6, 3 and 2 numbers of drought spells respectively in Shillong during the study period. According to the SPI12, a moderate, three severe and two extreme drought spells are observed in Shillong. Again, according to SPI24, Shillong has been suffered with one case each of moderate, severe and extreme drought spells during 1983 to 2010. Further, according to SPI36, Shillong has experienced one spell each of moderate and extreme drought during the study period. These three SPIs are used to represent hydrological drought in the study area. The hydrological drought spells given by SPI12 ranged from 11 to 24 months while as results of SPI24 and SPI36, it ranged from 11 to 62 months and 22 to 62 months respectively. It can be interpreted that the hydrological drought in the study area ranged from about 1 year to little over 5 years. The severe most hydrological drought in Shillong in terms of drought severity was observed from June of 1998 to May of 2000. It lasted for 2 years, severe up to SPI=-2.53 and accumulate a drought magnitude of -31.11. Few notable hydrological drought spells in Shillong between 1983 and 2010 are Jun-1986 to May-1987 (lasted for a year), Nov-1990 to Sep-1991 (lasted for 11 months), Jun-1996 to Jul-2001 (lasted for more than 5 years) and Jul-2006 to Jun-2007 (lasted for a year). This study observed that as time scale increases drought events become lesser however, drought spells become longer. Again, the probability of a drought spell becoming more severe got increases as timescale increases i.e., the percentages of extreme cases rises as we move from SPI1 to SPI36.

The study found that short term moisture stress recuperates faster than the agricultural and hydrological droughts. As a result of faster recuperation, people may go unnoticed about the long-term water availability and suffered water stress in long run. The study area received over 75% rainfall during monsoon months from June to October and the analysis found that yearly droughts are well correlated with monsoon droughts. The study also found that the drought occurrences in the study area are well scattered throughout the months of the year. Looking at the amount of rainfall received at Shillong and the contribution of monsoon, most of the water crisis problem could be solved with proper rainwater harvesting techniques in the study area. Water crisis at Shillong during the months of February, March and April may be caused due to drying up of mountain springs. Water in the soil pores remains for a very long time and emerged as springs and its drying are reflected by the presence of hydrological droughts in the study area. The agricultural practices in and around the study area are rainfed and presence of agricultural droughts in the study area brings the need for storing water for irrigation use. Soil moisture conservation techniques must be introduced in the area so that rain water remains in soil for more than 3-6 months.

4. Conclusions

The mean annual rainfall at Shillong was found as 2410 mm which is very much higher than the national normal of 119 cm. The study area received over 75% of annual rainfall during monsoon season from June to October. The SPI1 and SPI2 were used to represent short term moisture stress, SPI3 and SPI6 to represent agricultural droughts and SPI12, SPI24 and SPI36 to represent hydrological drought. Droughts in the study area are not concentrated only to rainfall scanty months but also found considerable droughts during monsoon months. The monsoon droughts and annual droughts are very well correlated during the study period indicating lesser monsoon rainfall to be the major reason for droughts. As timescale increases the frequency of drought event reduces but the duration increases. Short term moisture stress in the study area ranged from 1 to 11 months, agricultural droughts ranged from 1 to 13 months and hydrological droughts ranged from 11 to 62 months. The results of the analysis signaled that water crisis in the study area is not unmanageable but with proper soil moisture conservation and water harvesting techniques, the impact of droughts can be dampened and managed. Rainfed agriculture can be depended on monsoon as drought occurred occasionally, however, in the long-term, it is unsustainable as indicated by hydrological drought indicators- SPI12, SPI24 and SPI36. The authors strongly recommended those in the water and agriculture sectors to keep in mind the results of longer scale droughts in the study area and focused on development of water harvesting solutions.

5. Future Scope

The droughts in this study are determined using precipitation data only. In future, soil moisture data and ground water data may also be incorporated to better examine the agricultural and hydrological droughts.

6. Conflict of Interest:

The materials contain in the article are the results of original work conducted by the authors, therefore, there can be no conflict of interest.

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8. Abbreviations

SPI: standardized precipitation index
STMS: short term moisture stress
IPCC: Intergovernmental Panel on Climate Change
ICAR: Indian Council of Agricultural Research
PRECIP: rainfall
TRNGE: temperature range
TMIN: minimum temperature
TMAX: maximum temperature
EVAP: evaporation