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Assessment of Meteorological Drought Using Different Indices in Cambodian Mekong Delta

Raksmey Ang, Chantha Oeurng [*], Ty Sok

Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Russian Ferderation Blvd., P.O. Box 86, Phnom Penh, Cambodia.

Abstract: *Drought is one of the main natural disasters that have affected agriculture and rice production in Cambodia. The main objective of this study is to assess the drought in the Cambodia Mekong Delta using different drought indices (Standardized Precipitation Index (SPI), Percent Normal Index (PNI) and Decile Index (DI). The results showed that Index (PCI) values ranged from 14.79 to 16.69, meaning that the rainfall pattern of the study area is seasonality in distribution. Based on the calculated drought indices: SPI, PNI and DI on 3– and 6– month timescale ending in June, August, and November, it is evident that the year 1987 was the most critical year associated with extreme drought occurrences. The area experienced drought in June and extended to August. June was the critical base month since all five locations usually experienced drought in this month. Droughts occurred in the early and mid rainy season, and returned to normal or wet conditions by the end of rainy season. Three of the five provinces (Svay Reang, Prey Veng and Kandal) experienced frequent droughts.*

Keywords: meteorological, drought indices, SPI, PNI, PCI, Mekong delta

1. INTRODUCTION

Cambodia's climate variability together with the country's heavy dependence on rain-fed agriculture make it vulnerable to the impacts of drought. This vulnerability is obvious in the Cambodia Mekong Delta. Over the last few decades, total annual flows of the Mekong River have experienced drought situations bringing about water shortages for rice and other upland crop production. Drought is considered to be one of the costliest threats as it can lead to diminished water supply and subsequently have adverse effects on agriculture and socioeconomic activities (Obasi, 1994; Riebsame et al., 1991). Flood and drought are the two key natural hazards which threaten Cambodia. In a normal year, usual rainfall distribution in Cambodia is from May to October with heavy rainfall from August until mid-October; with a dry spell usually taking place for about two to three weeks in between July and August. In a year when this dry period is extended, a drought could occur (RGC, 2010). The Royal Government of Cambodia (RGC) understands drought as a threat to the Cambodian economy and agricultural sector (RGC, 2010). Cambodia ranks high among the drought–prone countries in Asia–Pacific region (Steyaert et al., 1981). Effective drought indices are essential tool for sustainable water resource management as well as mitigation of some of the more adverse consequences of drought. Additionally, being aware of drought helps to ensure water resources are utilized sustainably in the future.

Drought indices are quantitative measures that characterize drought levels by assimilating data from one or several variables such as precipitation, evapotranspiration, snow pack, stream flow and other water-supply indicators into a single numerical value (Zargar et al., 2011). There are a number of indices which quantify how precipitation for a particular period has differed from historically established norms. Nowadays, there are many drought indices to help access drought severity more quickly and accurately. Some of the broadly used drought indices include SPI, PNI and DI. The SPI is based on the probability of precipitation for any time scale. It is being used in research in more than 70 countries (Svoboda et al., 2012). The SPI calculation for any location is based on the long-term precipitation record that is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 2015). Another

[*] Corresponding author: *Dr. Oeurng Chantha*
E-mail:chantha@itc.edu.kh ; Tel: +855-12-895-840; Fax: +855-23-880-369

drought index is PNI which is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. Analysis of the PNI is effective in the drought and wet time series and during a particular season (Willeke and Hosking, 1994). Therefore, arranging monthly precipitation data into deciles is another drought monitoring technique (W. J. Gibbs and Maher, 1967). By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record (W. J. Gibbs and Maher, 1967). All of these three indices are reported in units that can easily be converted into precipitation values for multiple time scales and they can all be extended back in time. Quiring et al. (2007) conducted a study to qualitatively evaluate drought index methods in Texas. And the results indicate that SPI, PNI, and DI were the most appropriate methods for monitoring meteorological drought among ten selected drought index methods. Therefore, these indices can be readily calculated for all stations in Texas that have a long record of precipitation. They recommend using the SPI, PNI and DI to monitor meteorological drought in Texas because these three indices are relatively easy to calculate, and they are transparent and easy to understand. Dogan, Berktay, and Singh (2012) conducted the study to compare multi-monthly rainfall-based drought severity indices, with application to a semi-arid closed basin. In this study, they compared PNI, DI, statistical Z-Score, China-Z Index (CZI), SPI, and Effective Drought Index (EDI) to identify drought in a semi-arid closed basin in Konya, Turkey. As a result, SPI, DI and PNI are suitable methods for monitoring drought among others. Research focused on drought monitoring for rice production in Cambodia used SPI's to identify drought in Kampong Speu province (Chhinh and Millington, 2015). Nury and Hasan (2015) analyzed drought in north-western Bangladesh using SPI and its relation to the southern oscillation index based on a three-month time scale. In a study monitoring drought in Cyprus during the 2007-2008 hydrometeorological year, Michaelides and Pashiardis (2008) used SPI to characterize drought. SPI was also applied to access drought occurrence in China, where Zhang, Xu et al. (2009) used the SPI observed changes of drought/wetness episodes in the Pearl River Basin. A study was carried out by Dogan et al. (2012) looking at multi-monthly rainfall-based drought severity indices and their application to a semi-arid closed basin. This revealed that PNI was one of the most appropriate methods for monitoring drought among others. DI was a method applied to measure rainfall deficiency in a study comparing suitable drought indices for climate change impact assessment in Australia relating to resource management (Mpelasoka et al., 2008). Based on the research work mentioned above, it is seen that SPI, PNI and DI are drought indices which were successfully applied in different parts of the world to conduct various studies related to drought assessment.

The overall aim of this study focuses on using various drought indices to assess meteorological drought in the Cambodia Mekong Delta, a drought-prone region of Cambodia. This study will follow two main objectives:

- firstly, to statistically analyze rainfall distribution characteristics in the Cambodia Mekong Delta,
- and next to quantify both drought severity and frequency.

2. METHODOLOGY

2.1 Study area

Mekong Delta study area covers the Mekong River from midway between Kratie and Kampong Cham province to the border of Cambodia and Vietnam, excluding the drainage area of the Tonle Sap River and Lake. Most of the areas is affected by Mekong River floodwater (Fig. 1). The total area of the study area is of 35,839 km^2 (ADB, 2014). The elevation throughout the basin is generally low-lying lands with gentle slopes (Fig. 1). Agricultural paddy land heavily dominates the basin area with some forests in the upper part. The average annual rainfall varies from 800 mm to 1,800 mm. The northern upstream region around Kampong Cham has an annual rainfall between 1,000 mm and 2,200 mm. In the eastern part of the basin, the rainfall increases slightly. Annual rainfall variation was observed from 1,000 mm to 2,100 mm in Prey Veng and Svay Rieng province. The dry season encompasses six months, November to April. During these months the average total rainfall is only 173 mm, 14% of the annual total (ADB, 2014).

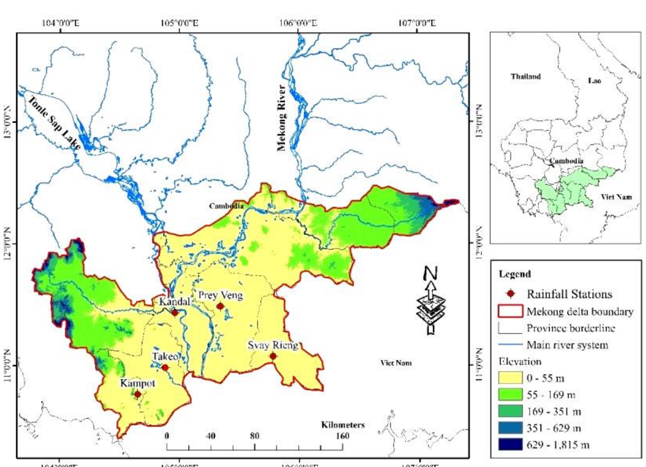


Fig. 1. Cambodia Mekong delta and rainfall station

2.2 Data collection

A minimum data set of 20 to 30 years of monthly precipitation values is the required to access drought using the three selected indices. Ideally, one needs at least 20-30 years of monthly values, with 50-60 years (or more) being optimal and preferred (Guttman, 1998). There are several rainfall stations located in the study area, but only five stations (Kampot, Takeo, Kandal, Svay Reang, and Prey Veng) have rainfall data which was recorded in a period (≥ 28 years) sufficient the present study (Fig. 1). All of the rainfall data from rain gauge stations which were collected for the study were retrieved from the Ministry of Water Resources and Meteorology (MOWRAM). The description of the five rainfall stations in the study area are provided in Table 1.

2.3 Statistical analysis of rainfall distribution characteristics

It is essential to understand rainfall variability to optimally manage the scarce water resources under continuous strain due to increasing water demands as a result of population growth and economic development (Herath and Ratnayake, 2004). Nyatuame et al., (2014) describes a statistical analysis of the spatial and temporal variability of rainfall, one of the scientific approaches which is used to identify the characterization of water sources in water resources management.

Table 1: Rainfall station description

No	Station ID	Coordinates		Province	Data availability	Number of year
		Latitude	Longitude			
1	100401	10.617	104.217	Kampot	1985-2012	28
2	100420	10.992	104.791	Takeo	1985-2012	28
3	110409	11.433	104.967	Kandal	1984-2014	31
4	110503	11.083	105.783	Svay Reang	1981-2012	32
5	110521	11.490	105.340	Prey Veng	1984-2012	29

This analysis was performed to assess any significant difference among the five stations within months and years by studying the data. Tables and graphs were constructed to illustrate the changing trends within the months and years for the specified period. The statistical analysis was used to determine the measure of central tendency and dispersion. Michiels et al. (1992), another crucial consideration is the quantification of how rainfall is distributed through the year. Annual rainfall distribution within a cetain period might be vary since rainfall distribution in each year is irregular. The Precipitation Concentration Index (PCI) was chosen to quantify the temporal variation of the rainfall. A simple measure of rainfall variability over a certain period of a year is the standard deviation (SD) of the data set sampled from the population, but its value depends upon the actual amount of rainfall observed and hence, does not seem to be applicable for comparative studies (Thenkabail et al., 2004). To overcome this problem, the coefficient of variance (CV) is commonly used Eq. (1).

$$CV = 100 \times \frac{SD}{\overline{P_i}} \quad (1)$$

where SD is the standard deviation and $\overline{P_i}$ is the arithmetic mean of the monthly rainfall of the year.
In an attempt to define the monthly heterogeneity of rainfall, Modified version of PCI (Oliver, 1980), derived from the Index of Employment Diversification (J. P. Gibbs and Martin, 1962) was used. The PCI is defined in Eq.(2) and its classification is illustrated in Table2:

$$PCI = 100 \times \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \quad (2)$$

Table 2: Classification of the Precipitation Concentration Indices (Oliver, 1980)

Precipitation Concentration Indices Values	Categories
<10	Uniform distribution
11 – 15	Moderate seasonal distribution
16 – 20	Seasonal distribution
>20	Strong seasonal distribution

2.4. Drought index values computation

The three drought indices values: SPI, DI and PNI were calculated for the timescale of three and six months ending in June, August, and November for precipitation data recorded from the five rainfall stations in the study area (Table 3). A 3-month timescale of SPI reflects short and medium-term moisture conditions that are useful for primary agricultural regions like Cambodia, and provides a seasonal estimation of precipitation as well. A 3-month SPI at the end of August would capture precipitation trends during the important reproductive and early grain-filling stages for both corn and soybeans. Meanwhile, the 3-month SPI at the end of May or June gives an indication of soil moisture conditions as the growing season begins (WMO, 2012). The 6-month SPI indicates seasonal to medium-term trends in precipitation. A 6-month SPI can be very effective in characterising the precipitation over different seasons (WMO, 2012). According to Chhinh and Millington (2015), the time periods developed around the three months listed above relate to the average rainfall pattern, particularly the onset of the monsoon and key aspects of monsoon variability and paddy rice growth.

The 3 or 6-month timescale provides a comparison of the precipitation for that period with the same 3 or 6-month period for all the years included in the historical record.

Table 3: Time periods for which SPI, DI and PNI values were calculated and base month

Base Month	3-Month Timescale	6-Month Timescale
June	April– June	January– June
August	June –August	March – August
November	September –November	June – November

2.4.1 Standard Precipitation Index (SPI)

McKee et al. (1993) developed SPI for monitoring drought conditions based on rainfall. Precipitation is the only required input parameter (Guttman, 1998). The SPI is computed by dividing the difference between the normalized seasonal precipitation and its long-term seasonal mean by the standard deviation. The normalized seasonal precipitation is determined by SPI tool. SPI can be defined as shown in Eq. (3).

$$SPI = \frac{X_i - \overline{X}}{S} \tag{3}$$

where X_i is the normalized monthly rainfall amount, $\overline{X}$ and S are the mean and standard deviation of rainfall calculated from the entire time series of monthly values.

McKee et al. (1993) used the classification system shown in Table 4 to define drought intensities resulting from the SPI.

Table 4: The Categorization of SPI, DI and PNI values

Categories	SPI	PNI (%)	Deciles (%)
Extremely Wet	≥ 2.0		≥ 90
Very Wet	1.5 to 1.99	≥110 [a]	80 – 90
Moderately Wet	1.0 to 1.49		70 – 80
Near Normal	-.99 to .99	80 – 110	30 – 70
Moderately Dry	-1.0 to -1.49	55 – 80	20 – 30
Severely Dry	-1.5 to -1.99	40 – 55	10 – 20
Extremely Dry	≤ -2	≤ 40	≤ 10

[a] *All high values of PNI (representing wet conditions) are categorized as one 'wet' class.*

2.4.2. Percent Normal Index (PNI)

The PNI is one of the simplest measurements of rainfall for a location. It is calculated by dividing actual precipitation by normal precipitation and multiplying by 100%. The classification of PNI is presented in Table 4. The percent normal index can be calculated by equation Eq. (4).

$$PNI = \frac{P_i}{\overline{P}} \times 100 \tag{4}$$

2.4.3. Deciles index (DI)

Arranging monthly precipitation data into deciles is another drought monitoring technique. Gibbs and Maher (1967) divided the distribution of occurrences over a long-term precipitation record into tenths. The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record (Table 4). The formula of DI can be illustrated as Eq. (5).

$$P_i = \frac{i}{n+1} \times 100 \quad (5)$$

Where, P_i is probability of rain in number i^{th}, and n is number of rainfall data.

3. Results and discussion

3.1. Rainfall distribution characteristics

3.1.1. Monthly rainfall distribution characteristics

The monthly rainfall data of each month during the study period (1980s – 2010s) obtained from fives selected rainfall stations were used to identify rainfall distribution characteristics of Cambodia Mekong Delta. Table 5 reveals that October had the highest standard deviation. The highest amount of average monthly rainfall was also recorded in October with the value of 253 mm, while the lowest was in February at 9 mm. The precipitation changes from month to month are considerable throughout the years. When the standard deviation values are examined, it is observed that the standard deviation values of most months (January, February, March, and December) are higher than the monthly average rainfall of these months. This relation indicates that the deviation from the normal distribution cannot be ignored. This fact is supported by CV of these months which are over or close to one. These show that in the study area, the precipitation values are much different from the average.

Table 5: Statistical summary of monthly rainfall data

Parameter (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	74	81	160	275	349	356	383	430	496	560	273	124
Min	0	0	0	6	23	38	40	50	81	44	0	0
Range	74	81	160	269	326	318	344	379	415	516	273	124
Mean	12	9	40	94	147	161	186	202	236	253	100	23
SD	20	18	48	67	85	78	87	87	92	117	78	33
Skewness	2.00	3.00	1.44	0.98	0.49	0.56	0.44	0.48	0.99	0.75	0.61	2.04
CV	1.74	2.16	1.28	0.71	0.57	0.49	0.46	0.43	0.40	0.48	0.79	1.54
Median	1	3	22	83	140	156	177	187	223	238	82	8
Kurtosis	3.42	10.13	1.39	0.98	0.15	0.40	-0.19	0.93	1.81	2.24	-0.19	4.44

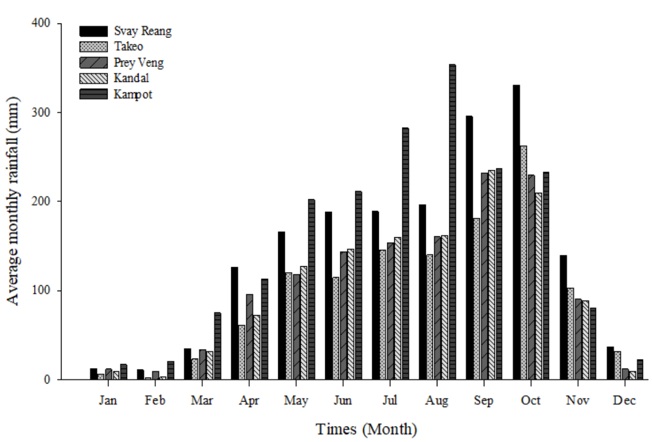


Fig. 2. The average monthly rainfall of the five stations

From the analysis, it was observed that rainfall is usually at its peak between August and October (Fig. 2). The month with the lowest rainfall is February followed by January and December. From Fig. 2, rain starts to fall in May until October and covers 80% of the total annual rainfall (rainy season). The remaining months (November – April) made up 20% of the total annual rainfall (dry season).

3.1.2. Annual rainfall distribution characteristics

The rainfall data obtained from fives stations including

Kampot, Takeo, Kandal, Svay Reang, and Prey Veng was used to assess rainfall distribution characteristics of the Cambodia Mekong Delta within the years during the study period (1980s – 2010s). From Table 6, the year with the highest annual rainfall was 1982, which recorded an amount of 2320 mm with a corresponding highest mean value of 193 mm. The record indicated the highest standard deviation was

179 mm. The data was skewed right with the positive value of skewness, meaning the rainfall distribution is flat. This observation was supported by the negative value of kurtosis. However, the maximum annual rainfall standard deviation occurred in 1983, with a value of 179 mm. This means the rainfall was highly dispersed or there was inconsistency in the rainfall pattern in 1983, with the corresponding highest range value of 593 mm. This observation again was buttressed by the highest variance, with the value of 32203 mm. Therefore, the lowest annual rainfall occurred in 1981 with an amount of 1104 mm and a corresponding annual mean value of 92 mm. Table 7 illustrates the information about CV and PCI values corresponding to PCI classification of annual rainfall of the five stations during the study period between 1980s –2014. It is seen that the CV values of all stations are similar to each other with the being between 0.14 and 0.26. Additionally, since the CV of each of the five stations are less than 0.5, indicating the changes of precipitation from year to year in these stations are low. PCI values of the five stations are similar to each other considering the period of study. PCI values range from 14.79 to 16.69. According to Table 2, these values suggest a moderate seasonal to seasonal distribution of rainfall.

Table 6: Descriptive statistics of annual rainfall data

Year	Annual (mm)	Mean (mm)	Median (mm)	SD (mm)	Variance (mm)	Skewness	Kurtosis	Min (mm)	Max (mm)	Range (mm)
1981	1104	92	68	89	7973	0.82	-0.20	0.00	278	278
1982	2320	193	161	179	32088	0.47	-1.13	0.00	491	491
1983	1995	166	141	179	32203	1.18	1.60	0.00	593	593
1984	1099	92	63	103	11456	1.22	2.40	0.00	341	341
1985	1482	123	121	111	12936	0.41	-0.74	0.00	321	321
1986	1577	131	107	127	19739	0.71	-0.60	1.68	360	359
1987	1233	103	61	121	16231	1.11	0.63	0.00	354	354
1988	1286	107	100	90	8462	0.49	-0.65	1.36	261	260
1989	1360	113	107	110	12286	0.97	0.88	0.04	357	357
1990	1251	104	84	100	10714	0.76	-0.15	0.00	307	307
1991	1245	104	70	115	14866	0.69	-0.78	0.04	317	317
1992	1200	100	61	112	14501	0.81	-0.45	0.78	316	315
1993	1456	121	103	121	15562	0.91	0.49	0.00	375	375
1994	1525	127	99	133	18952	1.19	1.51	1.08	426	425
1995	1569	131	119	125	16484	0.86	0.25	0.00	390	390
1996	1683	140	123	123	15651	0.52	-0.79	1.26	373	372
1997	1401	117	103	104	11443	0.66	-0.52	0.46	314	314
1998	1517	126	105	114	13655	0.57	-0.07	1.90	343	341
1999	1636	136	124	117	14070	0.76	0.49	3.80	374	370
2000	1681	140	128	108	11667	0.56	0.18	7.02	341	334
2001	1571	131	111	111	12807	1.13	1.42	0.76	385	384
2002	1355	113	104	97	9590	0.31	-1.00	0.00	276	276
2003	1484	124	78	129	17774	0.81	-0.64	0.00	354	354
2004	1278	107	105	94	9175	0.39	-0.78	0.00	274	274
2005	1480	123	92	124	16385	0.95	0.31	0.00	389	389
2006	1517	126	124	120	16655	0.56	-0.88	1.48	338	337
2007	1408	117	91	113	13419	0.80	0.17	0.00	345	345
2008	1713	143	131	98	9653	0.29	-0.83	14.46	306	292
2009	1381	115	113	106	12284	0.52	-0.74	0.00	307	307
2010	1608	134	100	140	20820	1.42	2.73	0.00	482	482
2011	1562	130	120	114	13231	0.42	-1.06	0.12	332	332
2012	1632	136	128	110	12705	0.48	-0.52	5.58	334	328
2013	1307	109	93	99	9844	0.28	-1.55	0.00	254	254
2014	1198	100	123	80	6330	-0.17	-1.74	0.00	208	208

Table 7: CV and PCI values of annual rainfall of the five stations (1980s-2010s)

Station Name	CV	PCI Value	PCI Classification
Svay Reang	0.14	14.79	Moderate seasonal distribution
Takeo	0.26	16.69	Seasonal distribution
Prey Veng	0.26	15.85	Seasonal distribution
Kandal	0.20	15.38	Seasonal distribution
Kampot	0.20	14.95	Moderate seasonal distribution

3.2. Drought severity

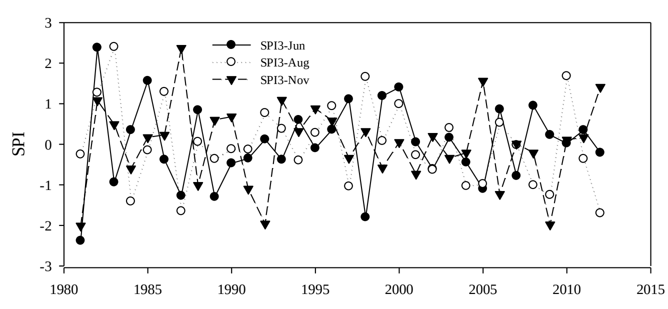
In this study, three drought indices namely, SPI, PNI and DI were selected to access drought severity for the timescale of three and six months in Mekong Delta of Cambodia. As can be seen in the previous section, the 3-month timescale reflects short and medium-term moisture conditions and provides a seasonal estimation of precipitation, while the 6-month timescale indicates seasonal to medium-term trends in precipitation and can be very effective in showing the precipitation over distinct seasons.

3.2.1. Three-month timescale

The time series of SPI values on a 3-month timescale for each of the five stations is shown in Fig. 3 It is seen that drought often occurred in 1987 for all stations, indicating that 1987 was the driest year during the study period (1980s – 2010s). The Svay Reang station experienced moderate drought in June 1987 and prolonged to August, shifting from moderate to severe drought. More significantly, extreme drought occurred in the Takeo station for both base months – June and August (1987). Likewise, the Svay Reang, Takeo and Prey Veng stations underwent extreme drought in June 1987 and moderate drought in August of the same year. August 1987 had negative SPI values indicating dry conditions and conform to the fact that most farmers argue that August coincides with the Kuon Rodow Prang (dry spell). Lastly, there were severe drought occurrences in the Kandal and Kampot station during June and August 1987, respectively. To be consistent with this finding, the study carried out by (Chhinh and Millington, 2015) on "Drought Monitoring for Rice Production in Cambodia" revealed that 1987 was a dry year and where no month had more than 200 mm of rainfall during this year.

3.2.2. Six-month timescale

Similar to tree-month timescale SPI values, 1987 was the driest year during the study period (1980s – 2010s) for all stations except Kampot station for six-month timescale SPI values (Fig. 4). Again, the Svay Reang station experienced moderate drought in June 1987 and extended to August (Kuon Rodow Prang dry spell), changing from moderate to extreme drought. Surprisingly, in the Takeo station, there were both severe and extreme drought in all three different base months (June, August and November) showing it experienced less rainfall for nearly the whole year. Like the 3-month SPI values, the Prey Veng and Kandal station underwent drought in two base months (June and August) making a change from extreme to severe drought and severe to extreme drought, respectively.



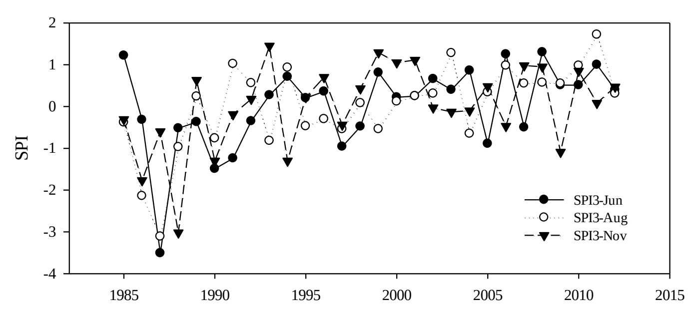
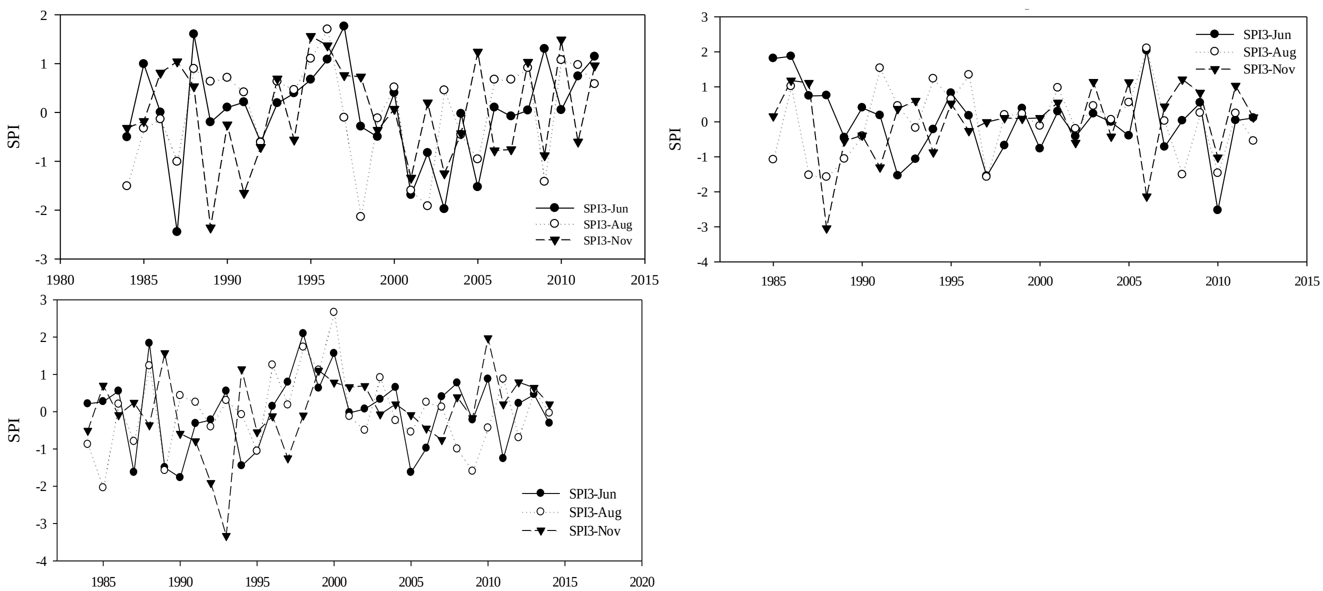


Fig. 3. Three-month timescale SPI values for June, August and November of (a) Svay Reang, (b) Takeo, (c) Prey Veng, (d) Kandal and (e) Kampot Station



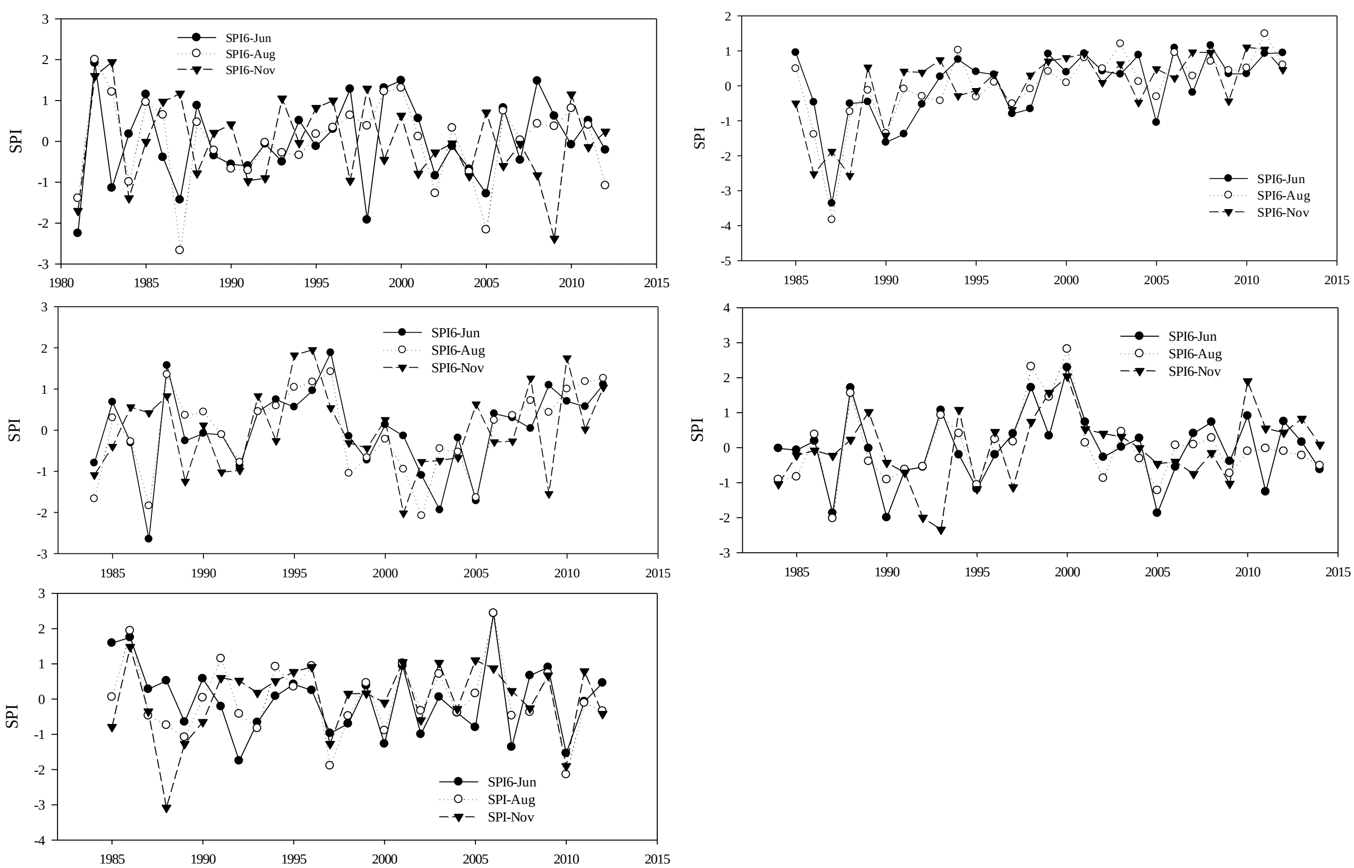


Fig. 4. Six-month timescale SPI values for June, August and November of (a) Svay Reang, (b) Takeo, (c) Prey Veng, (d) Kandal and (e) Kampot Station

3.3. Drought frequency

3.3.1. Three-month timescale

Fig. 5 shows the frequencies of dry months during the study period for the 3-month timescale according to SPI, DI, and PNI. These three methods feature classification into three typical dry conditions: moderately dry, severely dry and extremely dry. Unlike DI, the number of drought frequency indicated by PNI is slightly different from SPI. The Svay Reang station most frequently experienced drought (18 times) followed by the Kandal and Prey Veng station which is indicated by SPI.

3.3.2. Six-month timescale

Drought frequency for the 6-month timescale based on three drought indices between 1980s and 2010s is illustrated in Fig. 6. The number of drought occurrence of each station are similar to each other and given by SPI, PNI and DI. Unlike the 3-month timescale, PNI gives the highest drought frequency followed by DI. Similar to the 3-month timescale, PNI indicates that the Takeo, Prey Veng and Kandal station more frequently underwent drought events compared to the others. PNI and DI have a similar number of drought occurrence over the five stations.

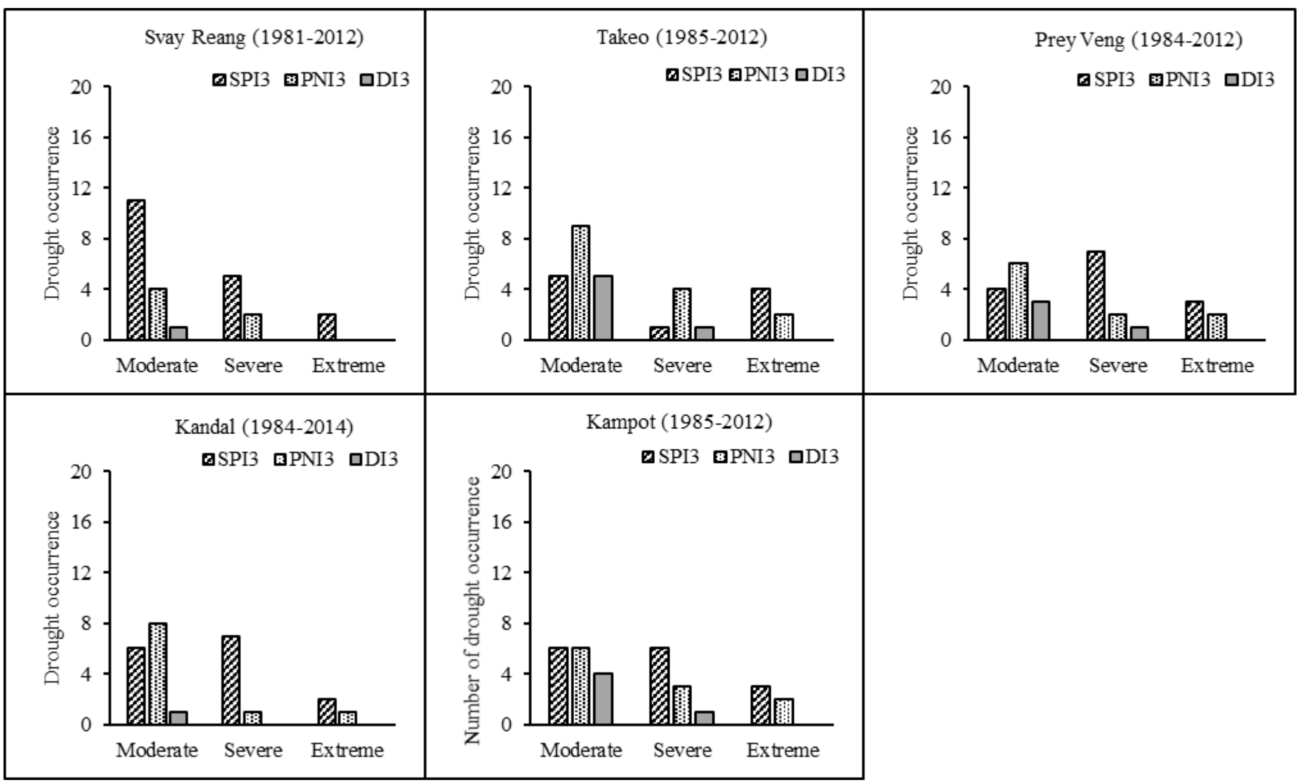


Fig. 5. Drought frequency base on three-month timescale

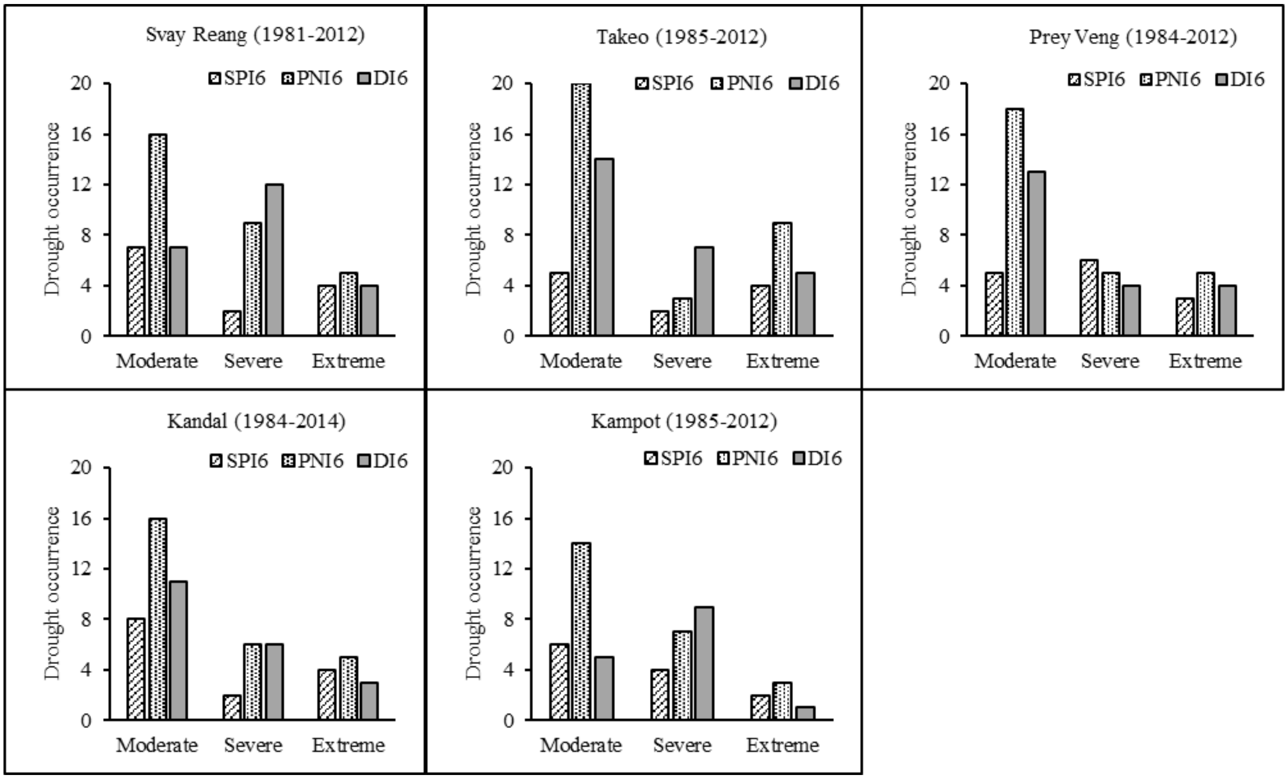


Fig. 6. Drought frequency base on six-month timescale

4. Conclusion

Cambodia's climate variability is vulnerable to the impacts of drought. This vulnerability is evident in Mekong delta, causing water shortages for rice and upland crop production. The present study, firstly, to statistically analyze rainfall distribution characteristics in the Cambodia Mekong Delta, and next to quantify both drought severity and frequency. The monthly rainfall data (1980s – 2010s) obtained from fives selected rainfall stations were used to identify rainfall distribution characteristics, and three drought indices: SPI, PNI and DI were selected to access drought severity and frequency in the study area.

- The result of monthly rainfall analysis reveals that its pattern could best be described as oscillatory. It is observed that rainfall is usually at its peak between August and October, and rain starts to fall in May until October which contributes 80% of total annual rainfall.
- However, statistical analysis of annual rainfall distribution indicates that the changes of precipitation from year to year are very low. PCI values indicate that the rainfall pattern of the study area is seasonal in distribution. Thus, it can be concluded that there are fluctuations in monthly rainfall patterns, while the variations of annual rainfall are minor.
- Based on the drought index results, it is evident that 1987 was the most critical year associated with drought occurrence. However, different parts of the basin show different patterns of dry conditions — a general dry tendency can be observed in major parts of the basin in June and August. Most of the stations show decreasing index values of November but some do not, which may be due to the extremely inhomogeneous spatial distribution of precipitation as a result of typhoon rain storms which are very common in the peak rainfall month in the basin. All stations experienced drought in June and extended to August. Droughts occurred from the early rainy season and extended to mid-rainy season, and returned to normal or wet conditions by the end of rainy season.
- Moreover, the Svay Reang, Prey Veng and Kandal station most frequently experienced drought. The small precipitation amounts over these stations during the years resulted in the highest frequency of droughts.
- The findings showed that severe droughts during this period could have detrimental impacts on rice

and other crop production in the region. Thus, this phenomenon could be taken into account to avoid possible harmful impacts on rice and other crop production. Therefore, rainwater harvesting structures should be designed to store water in rainy season for agriculture and other purposes in dry season.

- Due to the climate change in regional and global scale, the rainfall pattern in the study area might have been changing for the last decade, leading to shift time of starting and ending in rainy and dry season. Ending-month would be suggested to push ahead or bring back for future drought assessment study.

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