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Potential risks of climate variability on rice cultivation regions in the Mekong Delta, Vietnam[1]

Riscos potenciais da variabilidade climática nas regiões de cultivo de arroz no Delta do Mekong, Vietnã

T. K. H. Dinh[2] & T. A. Dang[2,3]*

[1] Research developed at Institute of Biochemical Technology and Environment, Vinh University-4300
[2] University of Science, Ho Chi Minh City, Vietnam-70000
[3] Vietnam National University, Ho Chi Minh City, Vietnam-70000

HIGHLIGHTS:

Dry weather seasons overwhelmed the wet weather seasons across the Mekong Delta.
The 2014-2016 dry weather season was the driest, occurring in 75% of the Mekong Delta.
Coastal rice-producing regions are known by abundant water, but had significant downward trend in rainfall in recent years.

ABSTRACT: In recent decades, the rice cultivation regions in the Mekong Delta have continuously suffered from unprecedented weather events due to a decline in rainfall as part of climate variability. The aim of this study was to perform a comprehensive exploration of the rainfall characteristics across the area, applying the Rainfall Anomaly Index (RAI), Spearman Rho test and Sen slope estimator to help track the weather as well as provide warnings on the potential risks caused by alterations in rainfall amounts. For this goal, the rainfall data sequences at 14 national observation stations across the Mekong Delta were collected for the 1984 - 2019 period. Results indicated that the dry weather seasons occurred more frequently during the normally wet weather seasons. Four typical dry weather seasons were identified for the 1997 - 1998, 2002 - 2004, 2014 - 2016, and 2018 - 2019 periods. Among these, the 2014 - 2016 period was the driest, with 9 out of 12 stations in the area being extremely dry and RAI risk peaks as high as -4.86 at the Moc Hoa station in the province of Long An. A weather trend of decreasing rainfall was evident, mainly in the coastal sub-regions. The discovery of changing rainfall trends is valuable for predicting future climate variability.

Key words: climate change, RAI, Spearman Rho tests, weather seasons

RESUMO: Nas últimas décadas, as regiões de cultivo de arroz no Delta do Mekong têm sofrido continuamente eventos climáticos sem precedentes devido ao declínio das chuvas como parte da variabilidade climática. O objetivo do estudo foi realizar uma exploração abrangente das características da chuva em toda a área, aplicando o Índice de Anomalia de Precipitação (RAI), o teste Rho de Spearman e a inclinação de Sen para ajudar a rastrear, bem como alertar sobre os riscos potenciais causados pela alteração na precipitação. Para este objetivo, foram coletadas sequências de dados de precipitação em 14 estações nacionais de observação em todo o Delta do Mekong no período de 1984 - 2019. Os resultados indicaram que a estação de clima seco passou a existir mais frequentemente na estação de clima normalmente úmido. Quatro estações típicas de clima seco foram definidas para os períodos de 1997 - 1998, 2002 - 2004, 2014 - 2016 e 2018 - 2019 períodos. Dentre esses, o período de 2014 - 2016 foi registrado como o mais seco com 9 das 12 estações da área extremamente secas e o pico de risco do RAI de até -4,86 na estação Moc Hoa na provincia de Long An. A tendência climática é evidente na diminuição da precipitação, ocorrendo principalmente nas sub-regiões costeiras. A descoberta das tendências das mudanças nas chuvas é valiosa para prever a variabilidade climática futura.

Palavras-chave: mudanças climáticas, RAI, testes Rho de Spearman, estações climáticas

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* Corresponding author - E-mail: dtan@hcmus.edu.vn
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Introduction

Drought is known as a natural disaster that often appears from a persistent deficiency of rainfall compared with the average value over a long time period (Mayowa et al., 2015; Becker et al., 2021), leading to a lack of freshwater for serving life, agricultural activities, and other sectors (CGIAR, 2015; Zarch et al., 2015). Unlike other natural disasters, drought comes silently, but its consequences are extremely large (Miyan, 2015). In Vietnam, drought represents the most extreme natural threat to the socio-economic sector, and especially to agricultural production (Dang, 2021). For example, when the worst drought event in over 90 years hit Vietnam from 2014 to 2016, the government declared a drought emergency in 18 provinces in Vietnam, causing great losses to the agricultural sector (Lee & Dang, 2019). The emergence of severe droughts in the Mekong Delta has resulted in huge crop failures, with 90% of sowed fields perishing in the drought-impacted regions (RCSA, 2016; Dang, 2021). More recently, Vietnam recorded an extreme drought event in 2019 in 5 of 13 provinces in the Mekong Delta, and an emergency was declared. This devastating drought damaged up to 30% of 29,900 ha rice, 4,566 ha of shrimp, and approximately 43,583 ha of forest. According to Gocic & Trajkovic (2013), the frequency, severity, and duration of drought can be attributed to changes in rainfall. Rainfall deficiency resulting in drought, leads to large global economic losses each year in the agricultural sector (UNVN, 2020; Junges et al., 2019). Hence, studies on rainfall characteristics provide useful information that can help to better manage water resources for domestic use and especially plant crop irrigation (UNVN, 2020; Carvalho et al., 2020).

Although studies on rainfall characteristics have been conducted in the Mekong Delta in recent years, a comprehensive study of the trends and rainfall characteristics is still lacking. A deep understanding of rainfall characteristics across the growing regions can track drought as well as provide the essential quality information. The aim of this study was to comprehensively examine the weather characteristics across the Mekong Delta to contribute to early warning as well as monitoring of the weather risks mainly caused by alterationss in rainfall.

Material and Methods

The Mekong Delta is situated in the southern part of Vietnam, spanning the latitudes 8° 34' - 11° 10' N and longitudes 104° 25' - 106° 48' E (Figure 1) for a total land area of around 40,547 km², approximately 1.7 million ha of which are agricultural production land (Vu et al., 2017). The area is a delta-shaped region with two sides surrounded by the sea, and its territory is covered by fertile plains, a few hills, and mountains (Vu-Thanh et al., 2014). The terrain lowers from north to south with elevations varying from 0.5 to 3.5 m mean sea level, while the highest mountain peak is 705 m (Son & Bae, 2015).

The climate is mostly dominated by Asian monsoon systems, with a gradual transition between the two main monsoon circulations, namely the southwest and northeast

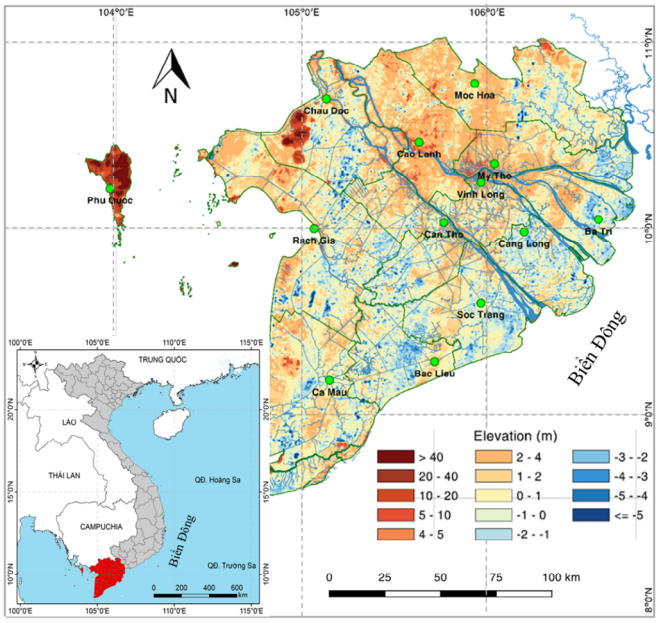


Figure 1. The study area, with rainfall observation stations marked by green circles

monsoons. The southwest monsoon lasts from May to October and brings abundant moisture from the Bay of Bengal, resulting in hot, very humid air and abundant rainfall, while the northeast monsoon (November to April) comes from the Asian continent, with dry air, heat, and little rainfall (Lee & Dang, 2019). The air temperature of the area ranges from 26.5 to 29.3 °C, and the mean annual rainfall varies from 1287.6 to 2832.8 mm, 80% of which is concentrated during the wet season (Lee & Dang, 2019). To conduct this research, monthly rainfall data sequences from 14 national normal observation stations in the Mekong Delta were collected for the period from 1984 to 2019 (Table 1). All the data were collected from the National Center for Hydrometeorological Forecasting (NCHF). The database quality was verified, with missing samples accounting for less than 10%, and each station's data was assessed for randomness, autocorrelation, and homogeneity to ensure the reliability of the statistical analysis.

The Spearman Rho test is known as a non-parametric statistical method for assessing the strength and direction of associations present in the relationship between two data

Table 1. Geographical descriptions of rainfall observation stations in the study area

No.	Station	Province	Latitude (N)	Longitude (E)	Period
1	Chau Doc	An Giang	10° 42'	105° 08'	1984-2019
2	Cao Lanh	Dong Thap	10° 28'	105° 38'	1984-2019
3	Rach Gia	Kien Giang	10° 00'	105° 04'	1984-2019
4	Can Tho	Can Tho	10° 02'	105° 46'	1984-2019
5	Vi Thanh	Hau Giang	09° 49'	105° 27'	1984-2019
6	Soc Trang	Soc Trang	09° 36'	105° 58'	1984-2019
7	Vinh Long	Vinh Long	10° 15'	105° 58'	1984-2019
8	My Tho	Tien Giang	10° 21'	106° 24'	1984-2019
9	Ba Tri	Ben Tre	10° 03'	106° 36'	1984-2019
10	Cang Long	Tra Vinh	09° 59'	106° 12'	1984-2019
11	Moc Hoa	Long An	10° 47'	105° 56'	1984-2019
12	Ca Mau	Ca Mau	09° 11'	105° 09'	1984-2019
13	Bac Lieu	Bac Lieu	09° 17'	105° 43'	1984-2019
14	Phu Quoc	Kien Giang	10° 13'	103° 58'	1984-2019

series (Gocic & Trajkovic, 2013). The input data series can be continuous or ordinal, but they need to have a monotonic relationship. The Spearman Rho test is widely used for measuring continuous data series and is also known as a method for measuring the absence of a trend change. In most practical applications, the Spearman Rho test is applied for measuring the strength of association between two data series. The statistic standardized test (Z_D) is obtained based on the following expression:

$$Z_D = D\sqrt{\frac{n-2}{1-D^2}} \quad (1)$$

With D in Eq. 1 defined based on the expression

$$D = \frac{1-\left\{6\sum_{i=1}^{n}\left[R(X_i)-i\right]^2\right\}}{n\left(n^2-1\right)} \quad (2)$$

where:

n - the number of observed data sequences;

i - the order of the elements in the observation data sequence; and,

R(Xi) - the rank of the ith observation data point.

If the Z_D value in Eq. 1 is positive, it implies that the observed data sequence has an upward trend; otherwise, it implies a downward trend (Gocic & Trajkovic, 2013). At the 0.05 significance level, the null hypothesis of no trend is rejected if $|Z_D| > 2.08$.

The Sen slope estimator was established by Kendall (1975) to detect the change trend of observed data sequences (Yue et al., 2002) as well as to define the true slope of an existing trend. The linear slope (d_k) is calculated as

$$d_k = \frac{x_i - x_j}{i-j} \quad (3)$$

where:

X - denotes the observed data sequences;

k - the number of the observed data sequence; and,

i and j - the indices in the observed data sequences.

Finally, the true slope (β) is estimated based on the median of the linear slope.

$$\beta = \text{Median } d_k \quad (4)$$

With confidence levels of 95%, the null hypothesis of no trend is rejected if the Sen slope value is $|Zs| > 1.96$.

The Rainfall Anomaly Index (RAI) was created by Van-rooy (1965) for the purpose of analyzing the frequency and intensity of historical rainfall sequences by comparing the average values of observed rainfall sequences with the average values of the 10 highest or lowest rainfall data samples (Hänsel et al., 2016). An area is called slightly, moderately, very, or extremely wet if the RAI values vary from 0.50 to more than 3.00, whereas the area is considered to have a rainfall deficit if the RAI value varies from -0.50 to less than -3.00 (Table 2). RAI is calculated as follows:

$$RAI = \pm 3\left[\frac{(p-\bar{p})}{\bar{x}-\bar{p}}\right] \quad (5)$$

where:

p and $\bar{p}$ - the rainfall value and average value of the observed rainfall data sequences, respectively; and,

$\bar{x}$ - the average value of the 10 highest or lowest rainfall data samples.

Table 2. Classification scale of Rainfall Anomaly Index (RAI) values (Hänsel et al., 2016)

RAI values	Category
≥ 3.00	Extremely wet
2.00 to 2.99	Very wet
1.00 to 1.99	Moderately wet
0.50 to 0.99	Slightly wet
-0.49 to 0.49	Near normal
-0.99 to -0.50	Slight dry
-0.99 to -1.99	Moderately dry
-2.99 to -2.00	Very dry
≤ -3.00	Extremely dry

Results and Discussion

The monthly rainfall sequences in the 1984 - 2019 period at 14 national normal observation stations across the area were converted to annual rainfall values to detect homogeneity with the Pettitt test, the Standard Normal Homogeneity Test (SNHT) and Buishand test. At a 95% confidence level, the critical values for 12 of the rainfall stations after applying the Pettitt test, the SNHT test and Buishand test were larger than the values of α while those for the Vi Thanh and Phu Quoc stations recorded values less than α (Table 3). This means that the rainfall data sequences at the Vi Thanh (Figure 2A) and Phu Quoc (Figure 2B) stations were interrupted.

Basic features such as the minimum, maximum, coefficient of variation (CV), and standard deviation (SD) of the rainfall data sequences at 12 of the assessed observation stations across

Table 3. Results of the homogeneity tests for rainfall sequences from 1984 to 2019

Station	Pettitt test		SNHT test		Buishand test	
	K_N	p-value	T_0	p-value	Q	p-value
Chau Doc	96	0.508	1.742	0.920	3.585	0.840
Can Tho	118	0.911	1.611	0.050	3.932	0.759
Cao Lanh	117	0.974	3.096	0.606	5.665	0.323
Rach Gia	62	0.309	3.147	0.130	3.351	0.328
Soc Trang	105	0.720	4.367	0.352	5.410	0.297
My Tho	134	0.221	4.988	0.253	5.630	0.223
Vi Thanh	198	0.178	8.976	0.048	6.458	0.175
Bac Lieu	148	0.164	6.004	0.216	6.679	0.106
Ba Tri	187	0.159	5.344	0.228	7.262	0.108
Vinh Long	109	0.820	5.023	0.292	5.143	0.378
Cang Long	80	0.959	3.153	0.578	4.612	0.428
Moc Hoa	137	0.243	6.943	0.076	6.346	0.145
Ca Mau	230	0.077	6.776	0.153	7.728	0.080
Phu Quoc	170	0.133	8.383	0.042	6.103	0.209

K_N - Pettitt test value; To - SNHT test value; Q - Buishand test value; SNHT - Standard Normal Homogeneity Test

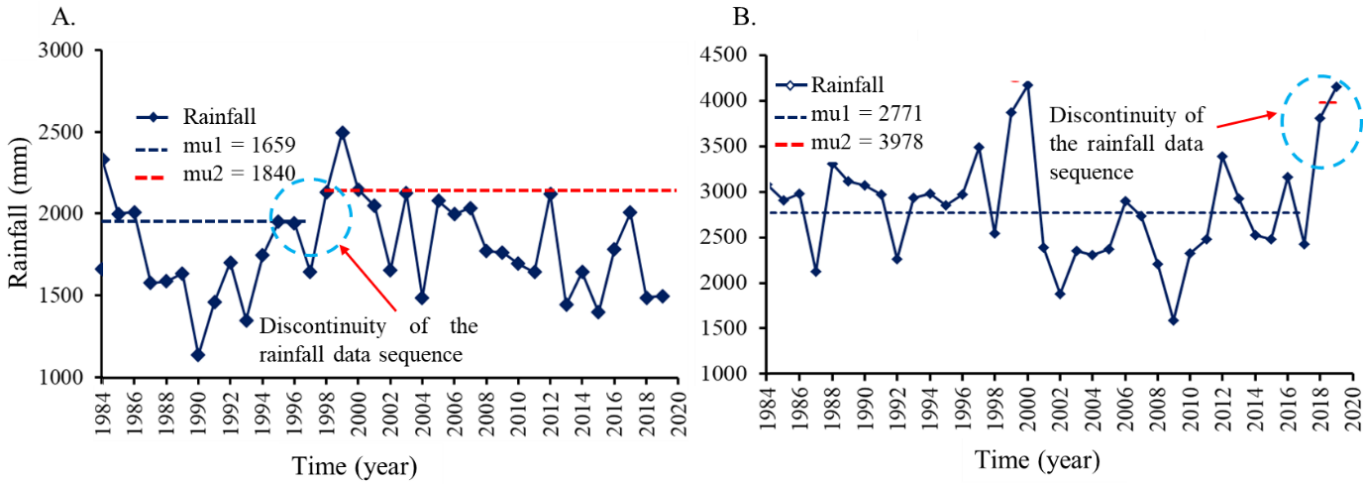


Figure 2. Results of the assessed rainfall data sequences at (A) Vi Thanh station and (B) Phu Quoc station during the 1984 - 2019 period

the study area during the 1984 - 2019 period are presented in Table 4. Accordingly, the minimum rainfall was recorded in the northwest part of the Mekong Delta, with the lowest amount of 691.5 mm at the Chau Doc station, while the highest value is detected at the Phu Quoc station, with up to 4164.5 mm and an average annual rainfall of approximately 1780 mm. For the CV, the whole study area recorded high CVs of up to 90%. Within the study area, the highest CV value was at the Ba Tri station up to 96.4%, while the lowest was at the Rach Gia station (85.40%). This implies that the rainfall data sequences at all observed stations have a high level of dispersion around their mean values. The mean SD varied from 208.9 at the Can Tho station to 335.3 at the Moc Hoa station.

The annual trends of the rainfall sequences analyzed by applying the Spearman Rho test and Sen slope estimate are shown in Figure 3. According to the results, a slight upward/downward trend was recorded at the Chau Doc, Can Tho, Cao Lanh, Cang Long, and Vinh Long stations (Figures 3A, B, C, I, K) while at the Ba Tri, My Tho, and Bac Lieu stations, a significant upward trend was observed (Figures 3F, G, H), with Z_D = 1.019 - 1.082 and β = 3.14 - 5.62, respectively (Table 5).

In contrart, a significant downward trend was recorded at the Moc Hoa, Rach Gia, Soc Trang, and Ca Mau stations (Figures 3D, E, J, L), with Z_D values ranging from -2.067 to -2.046 and β values from -7.52 to -5.86. Similar findings were reported by Lee & Dang (2019), who reported a decreasing trend in annual rainfall in the southern and southeast coastal areas of the Mekong Delta detected for the period 1984 - 2015.

Table 4. Annual rainfall features at the observation stations in the 1984 - 2019 period

Station	Min	Max	Mean	CV	SD	Skewness	Kurtosis
	(mm)			(%)			
Chau Doc	691.5	1920.9	1287.6	92.4	299.5	1.047	1.146
Cao Lanh	996.0	2387.8	1467.9	90.4	277.8	0.811	0.155
My Tho	757.7	1884.2	1454.2	96.0	238.2	0.670	-0.432
Moc Hoa	998.8	2420.9	1620.8	92.9	335.3	1.126	1.599
Vinh Long	1028.2	1893.1	1467.2	87.8	190.9	0.554	-0.628
Ba Tri	1031.3	2238.2	1500.6	96.4	260.7	0.678	-0.355
Can Tho	1160.2	2134.6	1601.9	93.6	208.9	0.563	-0.388
Vi Thanh	1140.1	2496.3	1778.9	91.2	290.8	0.129	-0.352
Cang Long	1200.1	2041.4	1612.1	93.3	224.3	0.511	-0.888
Soc Trang	1354.6	2754.2	1889.5	91.2	306.8	0.476	-0.773
Bac Lieu	1381.0	2821.3	1939.8	93.4	299.8	0.579	-0.519
Rach Gia	1528.6	2895.3	2117.3	85.4	356.2	0.701	0.202
Ca Mau	1905.7	3549.4	2375.6	85.9	302.9	0.560	-0.442
Phu Quoc	1587.1	4164.5	2832.8	88.5	574.4	1.102	1.899

Min - Minimum rainfall; Max - Maximum rainfall; Mean - Mean rainfall; CV - Coefficient of variation; SD - Standard deviation

The analysis of the RAI at all stations across the area is shown in Figure 4 and Table 6. These results show that during the 432 month period (1984 - 2019), there were 202 months with dry weather conditions (representing 47.2%), 176 months with wet weather conditions (41.1%), and only 50 months (11.7%) of near-normal weather conditions (Table 6). Specifically, at the Chau Doc, Can Tho, Cao Lanh, Cang Long, Ba Tri, Vinh Long, Moc Hoa, and Ca Mau stations, a dry season dominated the study area (Figures 4A, B, C, H, I, J, K, L), whereas a wet season dominated at the Rach Gia, Soc Trang, and Bac Lieu stations (Figures 4D, E, G). Only the My Tho station recorded the same number of months with dry and wet weather (Figure 4F).

During the 202 months of dry weather recorded, there were 47 (22.9%), 64 (31.3%), 49 (24.8%) and 42 months (20.9%) classified as slightly, moderately, very, and extremely dry weather, respectively (Figure 5). The highest number of slightly and moderately dry weather months were recorded at the Ca Mau (84 months) and at the Vinh Long (132 months) stations, respectively, while the highest number of very and extremely dry weather months were recorded at the Cao Lanh (84 months) and Soc Trang (96 months) stations, respectively.

Over the entire study, the 2014 - 2016 period was identified as having the driest weather, with 12 out of 12 stations undergoing slightly to extremely dry weather and peak RAI values varying from -8.16 to -3.88 (Table 7). For the wet weather periods, the 176 months with wet weather were classified as slightly, moderately, very, and extremely wet for approximately 35 (19.1%), 52 (28.3%), 51 (27.6%), and 38 (25.0%) months, respectively (Figure 6). Specifically, the greatest number of slightly and moderately wet weather months at the Ba Tri station (60 months) and at the Bac Lieu and Moc Hoa stations (84 months each), respectively. The least amount of slightly wet weather (24 months) was recorded at the Chau Doc, Vinh Long, Cang Long, Moc Hoa, and Ca Mau

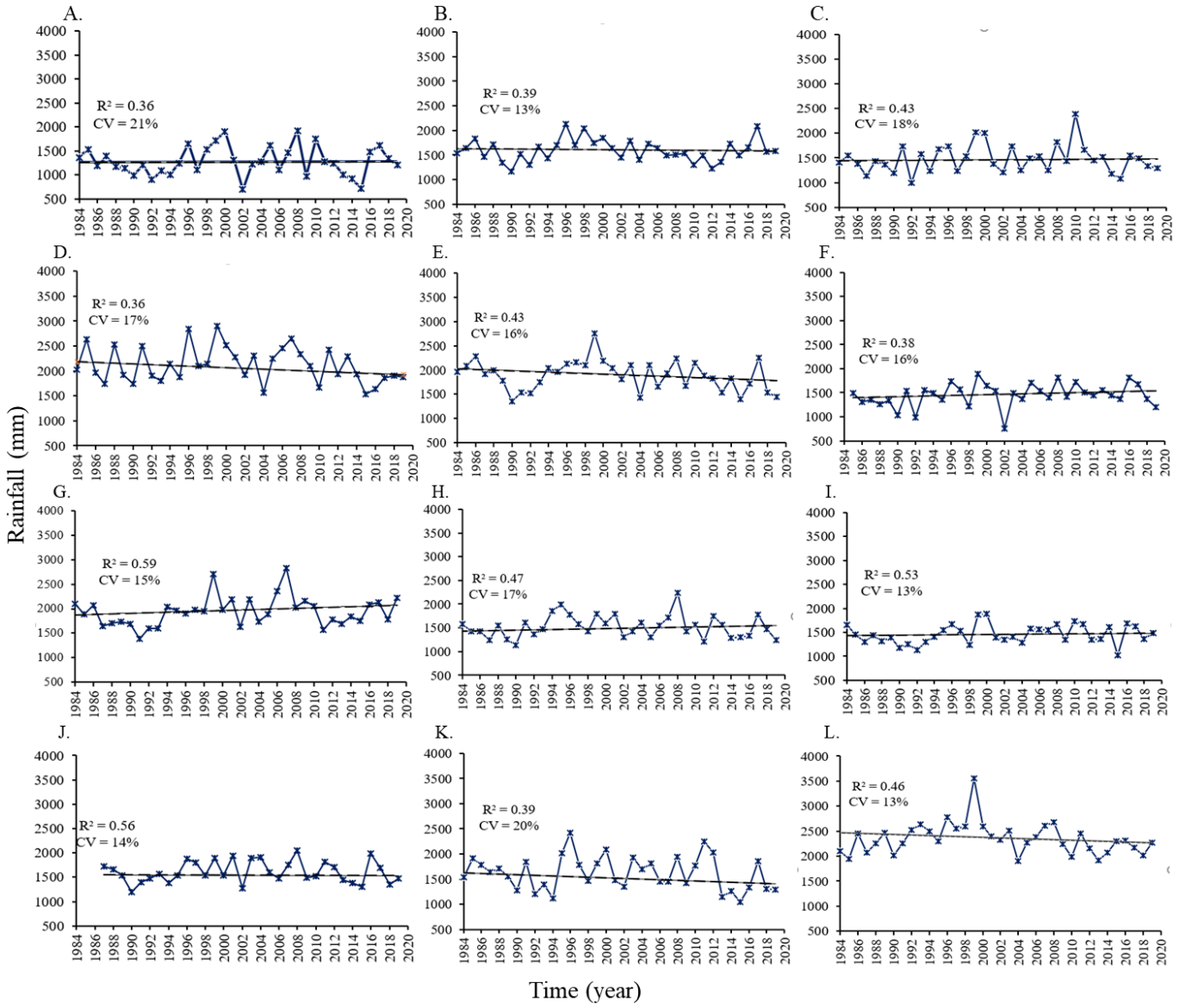


Figure 3. Rainfall trends in the study area at stations (A) Chau Doc, (B) Can Tho, (C) Cao Lanh, (D) Moc Hoa, (E) Rach Gia, (F) My Tho, (G) Bac Lieu, (H) Ba Tri, (I) Cang Long, (J) Soc Trang, (K) Vinh Long, and (L) Ca Mau for the period 1984 - 2019

Table 5. Analyses of rainfall sequences across the area for the period 1984 - 2019

Station	Spearman Rho		Sen slope	Trend
	Z_D	p-value	β	
Chau Doc	0.008	0.879	0.280	Upward
Can Tho	-0.014	0.800	-1.200	Downward
Cao Lanh	0.020	0.720	1.133	Upward
Rach Gia	-2.046	0.424	-7.527	Downward
Soc Trang	-2.067	0.244	-6.853	Downward
My Tho	1.019	0.732	4.300	Upward
Bac Lieu	1.082	0.972	5.624	Upward
Ba Tri	1.029	0.613	3.145	Upward
Vinh Long	0.006	0.907	1.425	Upward
Cang Long	-0.006	0.917	-0.427	Downward
Moc Hoa	-2.053	0.356	-6.386	Downward
Ca Mau	-2.058	0.310	-5.865	Downward

Z_D - Statistic standardized test; p - Critical value; β - True slope value

stations, and the least amount of moderately wet weather (12 months) was recorded at the Ba Tri station.

For very wet weather, the Rach Gia, Soc Trang, Bac Lieu, Ba Tri, Vinh Long, Moc Hoa, and Ca Mau stations had the highest amount, with an average of 60 months (30%), while at the Chau Doc, Can Tho, My Tho, and Cang Long stations recorded the least amount 36 months (22%). For extremely wet weather, the My Tho, and Cang Long stations each recorded 60 months (35.8%), with peak RAI values up to 5.04, while the Ca Mau station had the least amount relative to the other stations in the Mekong Delta (Figure 6).

During the study period, 1998 - 2000 was the wettest weather phase, with 9 out of 12 stations sufferring from moderately to extremely wet weather, with peak RAI values varying from 4.94 to 10.56 (Table 7).

The results of the RAI analysis of the typical weather seasons across the area in the 1984 - 2019 period are shown in Figure 7. The results show that during the study period, four typical dry weather seasons occurred in the Mekong Delta: 1989 - 1991, 2002 - 2004, 2015 - 2016, and 2018 - 2019. Specifically, for the 1989 - 1991 period, 12 out of 12 provinces recorded slightly to extremely dry weather, with peak RAI values ranging from -4.94 to -2.50. Prolonged drought of up to 40 consecutive months were recorded at the Chau Doc, Bac Lieu, and Vinh Long seasons (Figures 7B, C, I). For the 2002 - 2004 period,

Figure 4. Percentage distribution of weather seasons across the study area at stations (A) Chau Doc, (B) Can Tho, (C) Cao Lanh, (D) Rach Gia, (E) Soc Trang, (F) My Tho, (G) Bac Lieu, (H) Ba Tri, (I) Vinh Long, (J) Cang Long, (K) Moc Hoa (L) Ca Mau for the period 1984 - 2019

Table 6. Analyzed weather seasons based on the Rainfall Anomaly Index (RAI) across the area for the period 1984 - 2019

Station	Wet season		Normal		Dry season	
	Number of wet months	(%)	Number of near normal months	(%)	Number of dry months	(%)
Chau Doc	144	33.3	84	19.4	204	47.2
Can Tho	180	41.8	60	13.9	192	44.3
Cao Lanh	156	36.1	84	19.4	192	44.4
Rach Gia	204	47.2	36	8.3	192	44.4
Soc Trang	204	47.1	36	8.3	192	44.5
My Tho	180	42.9	60	14.3	180	42.9
Bac Lieu	204	47.2	48	11.1	180	41.7
Ba Tri	168	38.9	48	11.1	216	50.0
Vinh Long	168	38.9	24	5.6	240	55.6
Cang Long	156	39.4	48	12.1	192	48.5
Moc Hoa	204	47.2	12	2.8	216	50.0
Ca Mau	144	33.3	60	13.9	228	52.8
Average	176	41.1	50	11.7	202	47.2

10 out of 12 stations in the Mekong Delta experienced slightly to extremely dry weather, with peak RAI values varying from -4.94 to 2.27. The My Tho station suffered the driest weather as shown by its RAI risk peak of -4.94 (Figure 7L).

For the 2014 - 2015 period, 9 out of 12 stations (except for My Tho, Can Tho, and Bac Lieu stations) experienced slightly

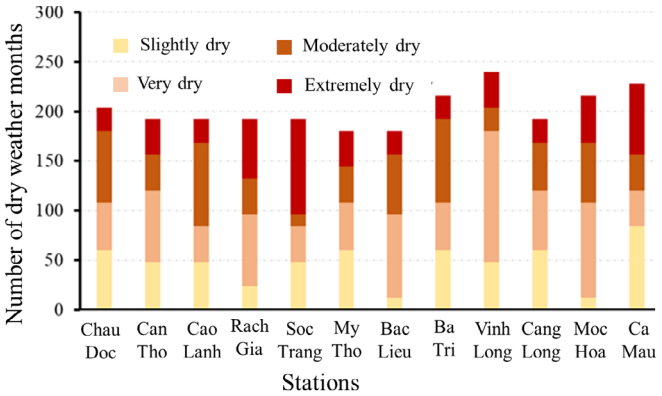


Figure 5. Distribution of the Rainfall Anomaly Index (RAI) for dry weather across the area for the period 1984 - 2019

to extremely dry weather conditions, with peak RAI values varying from -4.86 to -1.25 (Figures 7A, C, F, L); the Vinh Long station had the driest weather, with a risk peak up to -4.86 (Figure 7I). Although, the My Tho, Can Tho, and Bac Lieu stations appeared to have no dry weather, the RAI values for those stations were negative, which means the weather in those provinces was transiting from normal conditions to a dry season.

For the 2018 - 2019 period, the entire Mekong Delta recorded slightly to extremely dry weather at 8 out of 12

Table 7. Characteristics of the Rainfall Anomaly Index (RAI) for the weather seasons across the area for the period 1984 - 2019

Station	Number of dry weather months				Peak value and occurred year		Number of wet weather months				Peak value and occurred year	
	S	M	V	E	Peak	Year	S	M	V	E	Peak	Year
Chau Doc	60	48	72	24	-4.56	2002	24	48	36	36	4.94	2008
Can Tho	48	72	36	36	-4.90	1990	48	60	36	36	6.03	1996
Cao Lanh	48	36	84	24	-4.12	1992	48	24	48	36	6.79	2010
Rach Gia	24	72	36	60	-4.67	2015	48	48	60	48	5.03	1999
Soc Trang	48	36	12	96	-4.70	1990	36	72	60	36	7.59	1999
My Tho	60	48	36	36	-8.16	2002	24	60	36	60	5.04	1999
Bac Lieu	12	84	60	24	-6.95	1999	36	84	60	24	8.15	2007
Ba Tri	60	48	84	24	-3.88	1990	60	12	60	36	7.02	2008
Vinh Long	48	132	24	36	-4.86	2015	24	48	60	36	5.54	2016
Cang Long	60	60	48	24	-4.39	1990	24	36	36	60	4.61	2008
Moc Hoa	12	96	60	48	-4.14	2015	24	84	60	36	5.85	1996
Ca Mau	84	36	36	72	-4.09	2004	24	48	60	12	10.56	1999
Average	47	64	49	42	-5.20	-	35	52	51	38	6.42	-

S – Slightly; M - Moderately; V - Very; E - Extremely

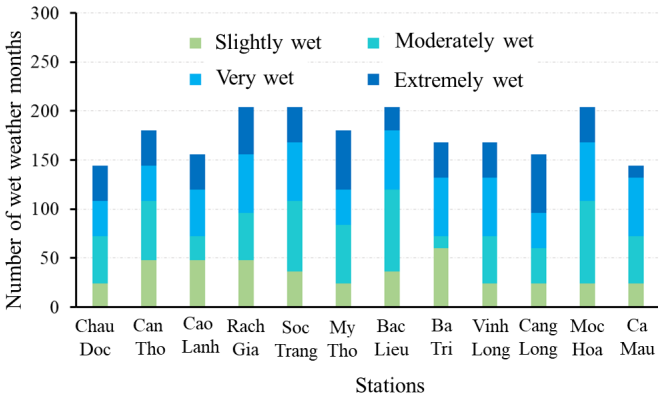


Figure 6. Distribution of the Rainfall Anomaly Index (RAI) for wet weather across the area during the period 1984 - 2019

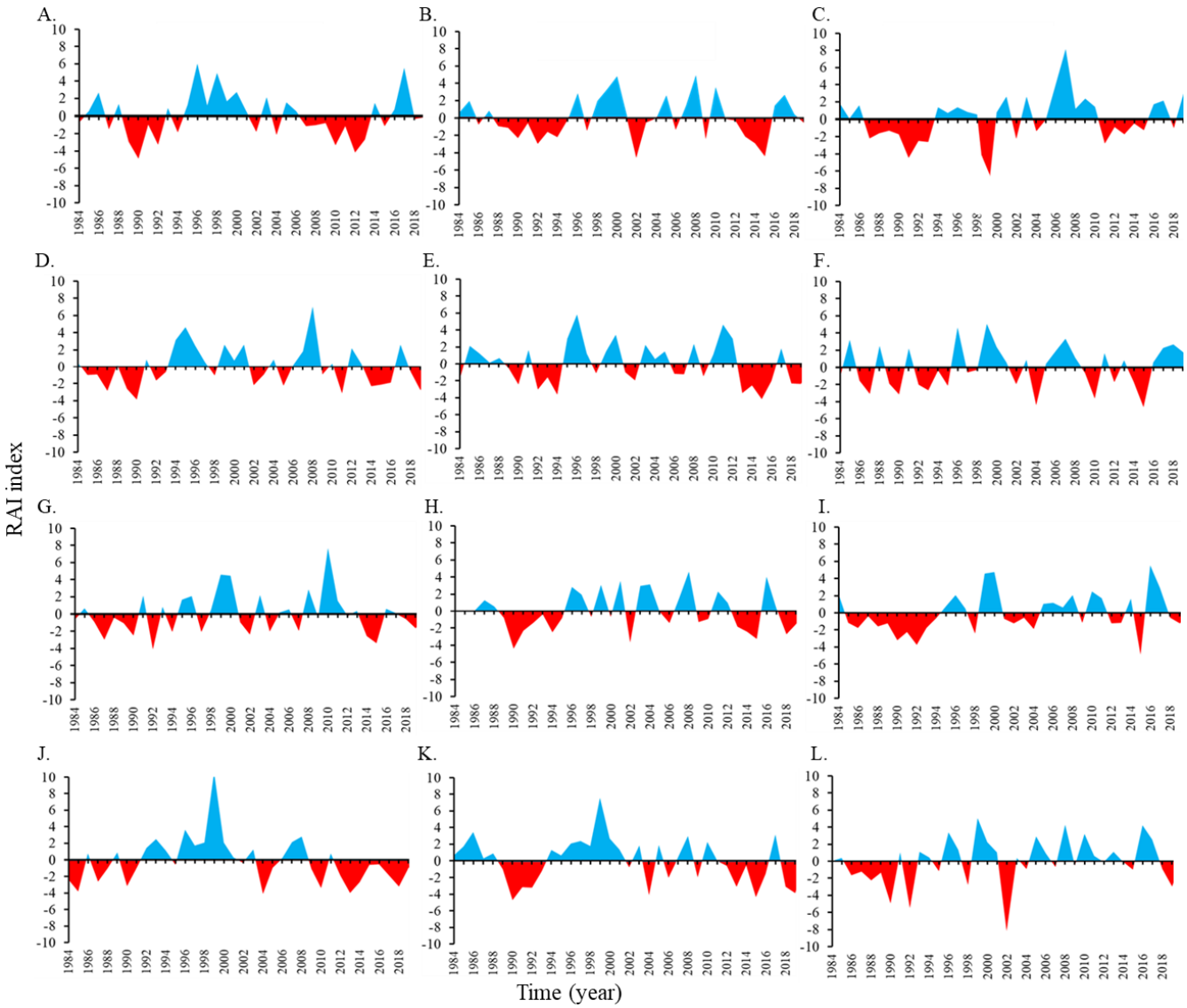
observation stations (Figures 7D, E, G, H, I, J, K, L). The severity of the weather varied from slightly to extremely dry, with peak RAI values equal to -0.55 and -3.89, respectively. During this period, the Soc Trang station had the driest weather, with an RAI risk peak of -3.89 (Figure 7K).

In the Mekong Delta, low-lying coastal provinces often use rainfall as the primary source of irrigation water in addition to fresh water from channels and rivers. Our results indicate a significant downward trend in rainfall in the Kien Giang, Soc Trang, and Ca Mau provinces, where the rice-growing areas are mainly based on rainfall. Therefore, these areas have a potential risk of water shortages, resulting in increased production costs especially during the winter-spring crop season, and a rice productivity decline, which would indirectly contribute to threatening the food security of the region and Vietnam as a whole.

Conclusions

1. The Mekong Delta area experienced four typical dry weather seasons and three wet weather seasons from 1984 to 2019, with 1999 being the driest and 2002 the wettest.

2. The dry seasons overwhelmed the wet seasons, with 202 months of dry weather versus only 176 months of wet weather.



RAI - Rainfall Anomaly Index

Figure 7. Typical weather seasons across the study area at stations (A) Can Tho, (B) Chau Doc, (C) Bac Lieu, (D) Ba Tri, (E) Moc Hoa, (F) Rach Gia, (G) Cao Lanh, (H) Cang Long, (I) Vinh Long, (J) Ca Mau, (K) Soc Trang and (L) My Tho during the period 1984 - 2019

3. The highest Rainfall Anomaly Index amplitude was 10.56 and defined the wettest period, while the driest period recorded a Rainfall Anomaly Index of -8.16. The longest period of dry weather was from 1988 to 1992, which was classified as extremely dry. The Tien Giang, Vinh Long, Bac Lieu, Soc Trang, and Tra Vinh provinces were drier in comparison to other provinces.

4. A weather trend was evident from the decrease in rainfall, wich mainly occurred in the coastal provinces.

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Literature Cited

Becker, C. C.; Streck, N. A.; Schwab, N. T.; Uhlmann, L. O.; Tomiozzo, R.; Ferraz, S. E. T. Climate risk zoning for gladiolus production under three climate change scenarios. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.297-304, 2021. https://doi.org/10.1590/1807-1929/agriambi.v25n5p297-304

Carvalho, A. A. de; Montenegro, A. A. de A.; Silva, H. P. da; Lopes, I.; Morais, J. E. F. de; Silva, T. G. F. da. Trends of rainfall and temperature in Northeast Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.15-23, 2020. https://doi.org/10.1590/1807-1929/agriambi.v24n1p15-23

CGIAR - Research Program on Climate Change. Agriculture and food security-Southeast Asia (CCAFS SEA). In assessment report: the drought crisis in the central highlands of Vietnam; CGIAR research program on climate change, agriculture, and food security (CCAFS): Hanoi, Vietnam, 2015.

Dang, T. A. Grain yield optimisation in the Plain of Reeds in the context of climate variability. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.591-596, 2021. https://doi.org/10.1590/1807-1929/agriambi.v25n9p591-596

Gocic, M.; Trajkovic, S. Analysis of precipitation and drought data in Serbia over the period 1980-2010. Journal of Hydrology, v.494, p.32-42, 2013. https://doi.org/10.1016/j.jhydrol.2013.04.044

Hänsel, S.; Schucknecht, A.; Matschullat, J. The modified rainfall anomaly index (mRAI)-is this an alternative to the Standardised Precipitation Index (SPI) in evaluating future extreme precipitation characteristics? Theoretical and Applied Climatology, v.123, p.827-844, 2016. https://doi.org/10.1007/s00704-015-1389-y

Junges, A. H.; Bremm, C.; Fontana, D. C. Rainfall climatology, variability, and trends in Veranópolis, Rio Grande do Sul, Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.160-166, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n3p160-166

Kendall, M. G. Rank Correlation Methods. New York, NY: Oxford University Press. 1975.

Lee, S. K.; Dang, T. A. Spatio temporal variations in meteorology drought over the Mekong River Delta of Vietnam in the recent decades. Paddy and Water Environment, v.17, p.35-44, 2019. https://doi.org/10.1007/s10333-018-0681-8

Mayowa, O. O.; Pour, S. H.; Shahid, S.; Mohsenipour, M.; Harun, S. B.; Heryansyah, A.; Ismail, T. Trends in rainfall and rainfall-related extremes in the east coast of peninsular Malaysia. Journal of Earth System Science, v.124, p.1609-1622, 2015. https://doi.org/10.1007/s12040-015-0639-9

Miyan, M. A. Droughts in Asian least developed countries; vulnerability and sustainability. Weather and Climate Extremes, v.7, p.8-23, 2015. https://doi.org/10.1016/j.wace.2014.06.003

RCSA - Research Centers in Southeast Asia. The drought and salinity intrusion in the Mekong River Delta of Vietnam. Assessment Report, 2016. 55p.

Son, K. H.; Bae, D. H. Drought analysis according to shifting of climate zones to arid climate zone over Asia monsoon region. Journal of Hydrology, p.529, p.1021-1029, 2015. https://doi.org/10.1016/j.jhydrol.2015.09.010

UNVN - United Nations Viet Nam. Viet Nam drought and saltwater intrusion in the mekong delta, Joint assessment report, 2020.

Van-rooy, M. P. A Rainfall Anomaly Index independent of time and space. Notos, v.14, p. 43-48, 1965.

Vu, T. M.; Raghavan, S. V.; Liong, S. Y.; Mishra, A. K. Uncertainties of gridded precipitation observations in characterizing spatio-temporal drought and wetness over Vietnam. International Journal of Climatology, v.38, p.2067-2081, 2017. https://doi.org/10.1002/joc.5317

Vu-Thanh, H.; Ngo-Duc, T.; Phan-Van, T. Evolution of meteorological drought characteristics in Vietnam during the 1961-2007 period. Theoretical and Applied Climatology, v.118, p.367-375, 2014. https://doi.org/10.1007/s00704-013-1073-z

Yue, S.; Pilon, P.; Cavadias, G. Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. Journal of Hydrology. v.259, p.254-271, 2002. https://doi.org/10.1016/S0022-1694(01)00594-7

Zarch, M. A. A.; Sivakumar, B.; Sharma, A. Droughts in a warming climate: a global assessment of SPI and RDI. Journal of Hydrology, v.526, p.183-195, 2015. https://doi.org/10.1016/j.jhydrol.2014.09.071