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Comparison of Meteorological Drought using SPI and SPEI

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Abstract

Drought assessment is crucial for effective water resources management in a river basin. Drought frequency has increased worldwide in recent years due to global warming. In this paper, an attempt is made to assess the meteorological drought in the Punpun river basin, India using two globally accepted drought indices namely, Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). The SPI and SPEI at 1-, 3-, 6-, 9-, and 12-month timescale were obtained to analyze the temporal variability of different drought levels. Correlation analysis of available observed data and gridded data has been carried out and the correlation coefficient was found to be 0.956. Hence gridded rainfall data from the year 1991 to 2020 is used for further analysis. Potential evapotranspiration (PET) used in the calculation of SPEI was computed by the Thornthwaite method. Water deficit was observed throughout as there is a decrease in rainfall and an increase in PET during the selected period. The results show that the period 2004 to 2006 and 2009 to 2010 years are observed as drought periods by both indices for almost all timescale. The intensity and duration of drought have increased after 2004. A negative trend of both the indices have been observed in all seasons on all timescale, which clearly shows a transition from near normal to moderately dry during the selected time period. The highest correlation between both the indices is for the 12-month scale with R^2 value 0.92 and the RMSE value 0.28. The main outcome of this study is that both SPI and SPEI show a strong correlation on same time scales adopted in this study. The dependency of SPEI on temperature is also observed in this study.

Keywords: Standardized Precipitation Index; Standardized Precipitation Evapotranspiration Index; Thornthwaite Method; Potential Evapotranspiration.

1. Introduction

Drought has been one of humanity's major natural disasters that has an impact on agricultural productivity as well as on socio-economic development. Drought occurrences have become more frequent and intense over time as the global climate has continued to warm. Drought is stated to exist if lack of water persists for longer period and its physical effect ends as the moisture/water deficiency is met. Even though the phenomenon has been explored on a global scale, its regional or even local dimension has often been ignored. Drought evaluation at the local level is required for establishing adaptation and mitigation strategies for that region. Based on the variable used to describe drought, it is divided into five categories: meteorological drought, hydrological drought, agricultural drought, socio-economic drought, and groundwater drought [1]. When a meteorological drought hits a region, it is preceded by an agricultural and hydrological drought. This study is focused on the meteorological drought, which is caused by a lack of net precipitation over the basin and is affected by climate variables. The Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) are suggested by the World Meteorological

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Organization (WMO) as basic indicators for evaluating drought intensity, duration, and spatial extent. In recent decades, the SPI index proposed by McKee et al., [2] in 1993 and the SPEI developed by Vicente-Serrano et al., [3] in 2010 has served as the foundation for drought monitoring. The SPI index is a useful tool for detecting and mapping droughts, and ArcGIS enhances the results visualization [4]. SPI is probabilistic in nature, which gives it an edge over other drought indicators in terms of risk and decision analysis. [5].

The SPI and SPEI methodologies were compared [6] and found that the SPEI method was more accurate. Harisuseno [7] found the SPI method is more suited and trustworthy for assessing drought features, which exhibits a moderately high correlation coefficient when compared to the Percent of Normal (PN) method. Surface evapotranspiration along with precipitation are the input parameters for SPEI, while precipitation is used for SPI calculation [8]. Potential evapotranspiration (PET) is increasing due to the rise in surface temperature, which results in water scarcity in the basin [9]. SPEI was more sensitive to drought assessment than SPI on the temporal scale as the conditional probability of SPEI is higher than SPI [10]. SPEI and SPI are widely used in current research and can be used together to analyze drought characteristics. Some of the main drought characteristics, such as intensity, duration, and severity has been used to analyze drought event [11]. SPI has been used to determine drought by the analysis of two drought characteristics i.e., duration and severity [12]. Drought assessment, monitoring, and the prediction had been done using a 6-month timescale SPI [13]. SPI at a 12-month timescale is used to assess the special and temporal characteristics of meteorological drought [14].

The Punpun basin is surrounded by Chotanagpur hill on the southern side and by Sone, Ganga, and Kiul-Harohar-Falgu river system on the other three sides. Rainfall is the only source of contribution to flow in the Punpun River. During the monsoon, the Punpun River contributes a large amount of water to the Ganga, but it remains dry for rest of the year [15]. An increase in dry events and a decrease in both wet and normal events results in frequent drought occurrence with negative SPI values [16]. Different drought indices have been used to characterize and understand the pattern of rainfall change and drought conditions [17]. Prediction of precipitation using statistical downscaling was found to be decreasing [18]. Changes in land use (LU) can have a significant impact on water resources [19]. Drought events can be directly linked to a decrease in vegetation cover [20]. Climate change, combined with climatic variability, has a significant negative impact on water supplies as well as agriculture in countries that depends on agriculture [21]. Losses due to evapotranspiration in Punpun basin was higher during 1980 to 1990 may be results of change in basin characteristic [22]. Climate-induced water deficit is estimated to rise in the future and climate is expected to become drier [23]. PET's increasing trend is a sign of rising temperature, which could be related to the effects of global warming [24]. Drought analysis in the Punpun basin has never been the subject of a serious scientific study. In addition, nothing is known about the features of drought in the basin. Therefore, the objective of this study is to evaluate the drought situation in the Punpun River Basin, India using SPI and SPEI. Further, the temporal characteristics of the drought are also investigated.

2. Materials

2.1. Study Area

The Punpun river basin is located in the south of the Ganga River, between latitudes of 24° 11' to 25° 25' N and longitudes of 84° 9' to 85° 20' E (Figure 1). It is bounded by the Sone River on its west and the Kiul-Harohar-Falgu river system on the east. The Punpun River is mostly a rain-fed river that originates from the Chhotanagpur hills of the Palamu district in Jharkhand. It covers a total of 232 km to join the Ganga River as the right bank tributary near Fatuha, 25 km downstream of Patna. In this study, the Punpun river basin has been selected with a basin area of 8530 km^2. The average annual rainfall in the Punpun river basin during the 1991-2020 years is 960.8 mm. Tributaries of the Punpun River are Batane, Adri, Madar, Kalan, Mohrar, and Dardha, which contribute only during monsoon. During monsoon, when the Punpun river contributes a large amount of water to the Ganga, parts of the basin become flooded, and during the low flow season, it remains dry [15]. Both of these factors have the potential to accentuate water management issues in watershed areas.

2.2. Data Collection

The monthly precipitation (observed) from 1990 to 2010 has been collected from Indian Metrological Department (IMD) Pune for rain-gauge stations Patna, Jahanabad, Goh, Gurua, and Nabinagar. Missing data have been computed by averaging data from the nearby stations. The average rainfall depth on the entire catchment is computed using the Thiessen polygon method. Daily rainfall gridded data of 30 years i.e., from 1991 to 2020 have been obtained from IMD website *(https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html*) [25] over ten grid points of grid size 0.25°×0.25°. Daily maximum Temperature (T_{max}) and minimum temperature (T_{min}) gridded data was also obtained for the duration 1991 to 2015 from the IMD website (*https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html*) [26], and hence, the monthly average and the annual average temperature have been calculated. When a continuous observed data collection is not available, gridded data can be used for hydro-meteorological and climatic studies [27].

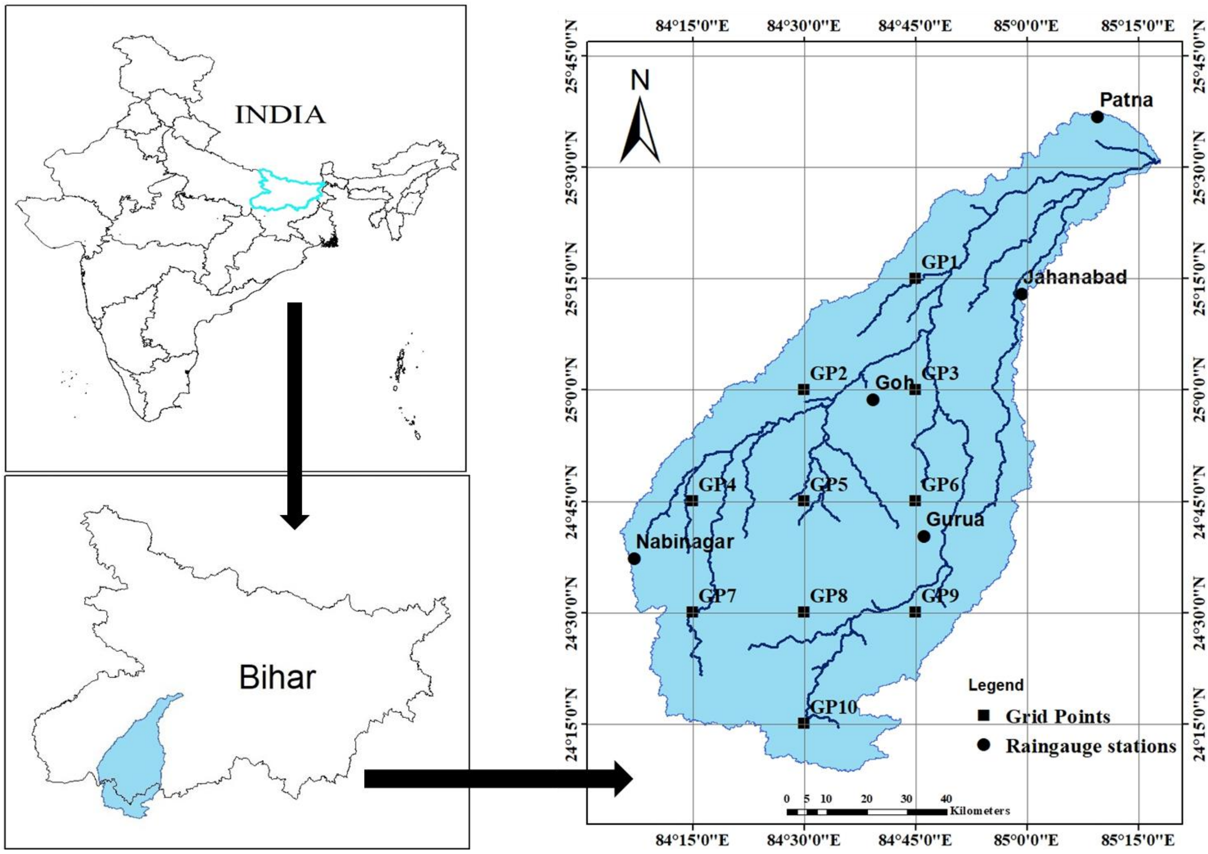


Figure. 1. Location of the Punpun river basin

3. Research Methodology

3.1. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was proposed by Mckee et al., [2] in 1993. It is one of the indices used and recommended by the World Meteorological Organization (WMO) to indicate the amount of precipitation over a specific time period. The SPI is calculated as follows:

Assume x is the amount of precipitation in a particular duration, then probability density function of **Γ** distribution is given by:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}, \, x > 0 \tag{1}$$

where α and β are the parameters of shape and scale.

The gamma function is expressed as:

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1}\, e^{-x} dx \tag{2}$$

The optimal values of α and β is estimated as:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3}$$

$$\beta = \frac{\bar{x}}{\alpha} \tag{4}$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{5}$$

where n denotes the number of different precipitation series.

The following equation can be used to compute the cumulative probability for a given month:

$$G(x) = \int_0^{x} g(x) dx = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} \int_0^{x} x^{\alpha-1} e^{-\frac{x}{\beta}} dx \tag{6}$$

$$SPI = S\frac{t-(c2t+c10+co}{[(d_3t+d_2)t+d_1]t+1.0} \tag{7}$$

$$t = \sqrt{ln\frac{1}{G(x)^2}} \tag{8}$$

where G(x) > 0.5, S = 1 and G(x) ≤ 0.5, S = -1. C_0 = 2.5155, C_1 = 0.8028, C_2 = 0.0203, d_1 = 1.4327, d_2 = 0.1892, d_3 = 0.0013.

3.2. Standardized Precipitation and Evapotranspiration Index (SPEI)

The Standardized Precipitation and Evapotranspiration Index (SPEI) was suggested by Vicente Serrano et al. in 2010 on the basis of the SPI. It quantifies both precipitation and potential evapotranspiration for the analysis of the drought process. Thornthwaite method was followed for calculation of PET which is described as [3]:

$$PET = 16K\left(\frac{10T}{I}\right)^m \tag{9}$$

where, T represents monthly-mean temperature (°C), and heat index (*I*) is computed as the summation of 12 monthly heat index values, obtained from mean monthly temperature using [3]:

$$i = \left(\frac{T}{5}\right)^{1.514} \tag{10}$$

where m is a deduced coefficient which depends on *I* ($m = 6.75\times10^{-7} I^3 - 7.71\times10^{-5} I^2 + 1.79\times10^{-2} I + 0.492$); and K is a coefficient of correction which is dependent on the latitude and month,

$$K = \left(\frac{N}{12}\right)\left(\frac{NDM}{30}\right) \tag{11}$$

where NDM is the total number of days in the given month. The maximum number of sun hours (N), computed as [3]:

$$N = \left(\frac{24}{\pi}\right)\omega_s \tag{12}$$

where (ω_s) the hourly angle of the sun rising, given as:

$$\omega_s = \arccos(-\tan\varphi\tan\delta) \tag{13}$$

where, φ represents the latitude in radians, and δ represents the solar declination in radians computed from:

$$\delta = 0.4093\sin\left(\frac{2\pi J}{365} - 1.405\right) \tag{14}$$

where J is the particular month's average Julian day [3].

The climate–water balance was calculated as follows:

$$D_i = P_i - PET_i \tag{15}$$

where D_i is the i_{th} month moisture deficit (mm), P_i is the i_{th} month precipitation (mm), and PET_i is the i_{th} month potential evapotranspiration (mm)

The value of D_i were aggregated on different time scales:

$$D_n^k = \sum_{i=0}^{k=1}(P_{n-i} - PET_{n-i}),\ n \geq k, \tag{16}$$

where k is the monthly timescale and n is the number of calculations.

In the context of SPEI, a three-parameter probability distribution is utilized and the D series is standardized using a log-logistic distribution f(x) [3]:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1 + \left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \tag{17}$$

where, α, β and γ represent the scale, shape, and origin parameters, respectively.

Therefore, for a given time scale, the cumulative distribution function was determined as:

$$F(x) = \left[1 + \left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{23}$$

SPEI has been calculated as follows:

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3} \tag{24}$$

Where, $W = \sqrt{-2\ln(P)}$ for P ≤ 0.5 and $W = \sqrt{-2\ln(1-P)}$ for P > 0.5, C_0 = 2.5155, C_1 = 0.8028, C_2 = 0.0203, d_1= 1.4327, d_2 = 0.1892, d_3 = 0.0013.

The sum of all negative SPEI values shows the severity of the drought, while the minimum SPEI value denotes the peak intensity of the drought, and the sum of consecutive months with negative SPEIs represents the drought's duration [28]. Table 1 shows the classification of drought severity based on SPI values. A negative SPI number indicates a dry situation, while a positive value indicates a moist condition. The drought severity classification for SPEI is similar to SPI shown in Table 1.

Table 1. Drought classification based on SPI [2]

Class	SPI
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 to -1.49
Very dry	-1.5 to -1.99
Extremely dry	<-2

The SPI and SPEI are multi-scale drought indices that have been widely used. In this study, 1-, 3-, 6-, 9-, and 12-month timescales SPI and SPEI were computed using the "SPEI" package in R-statistical software [29]. The flowchart of the methodology is presented in figure 2.

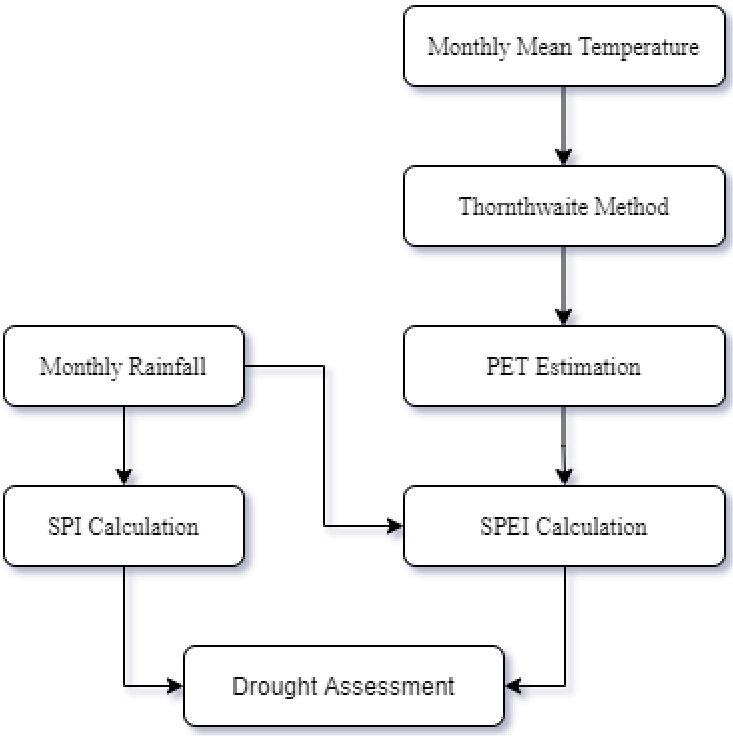


Figure 2. The flowchart of the methodology

4. Results and Discussion

4.1. Annual Rainfall

Monthly rainfall data averaged over the Punpun river basin has been calculated from daily rainfall data obtained from the Indian Meteorological Department (IMD) website over ten grid points of grid size 0.25°×0.25°. Figure 3 shows the correlation between monthly observed rainfall and monthly gridded rainfall data of the Punpun river basin. Since the correlation between observed and gridded data is 0.956, hence gridded data is used in the present study.

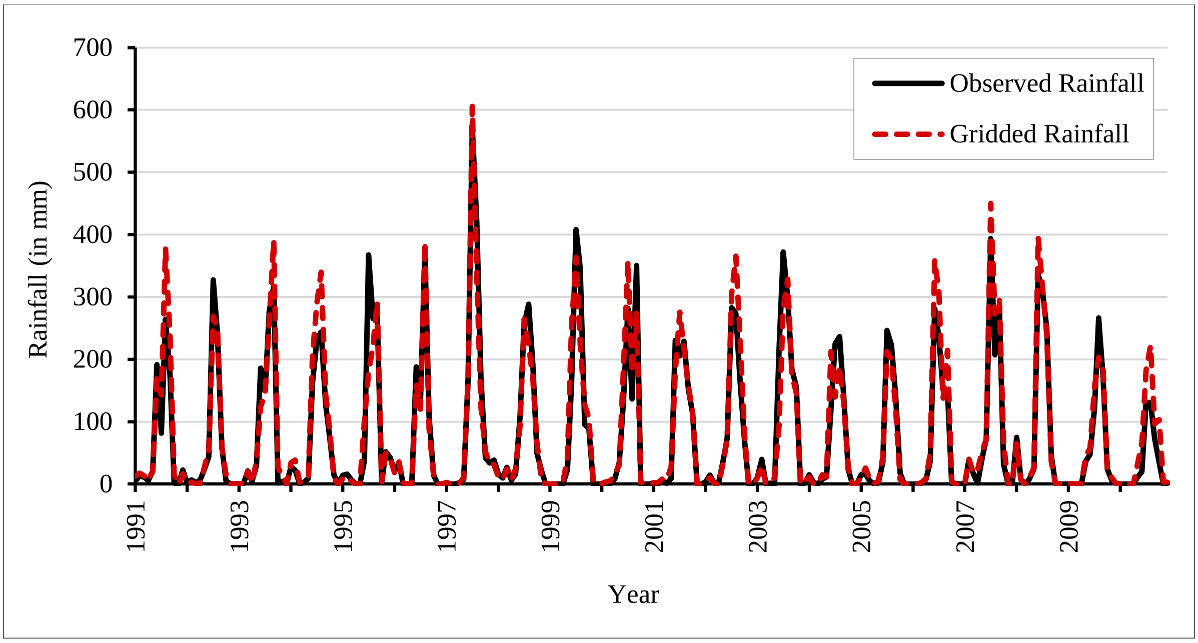


Figure 3. Comparison between observed and gridded rainfall data

4.2. Annual Temperature

Figure 4 shows the annual mean temperature variation averaged over the Punpun river basin. It is observed that the annual mean temperature over the Punpun river basin is increasing during the period from 1991 to 2015. Also, the maximum value of annual mean temperature observed in 2010 was 26.2 °C.

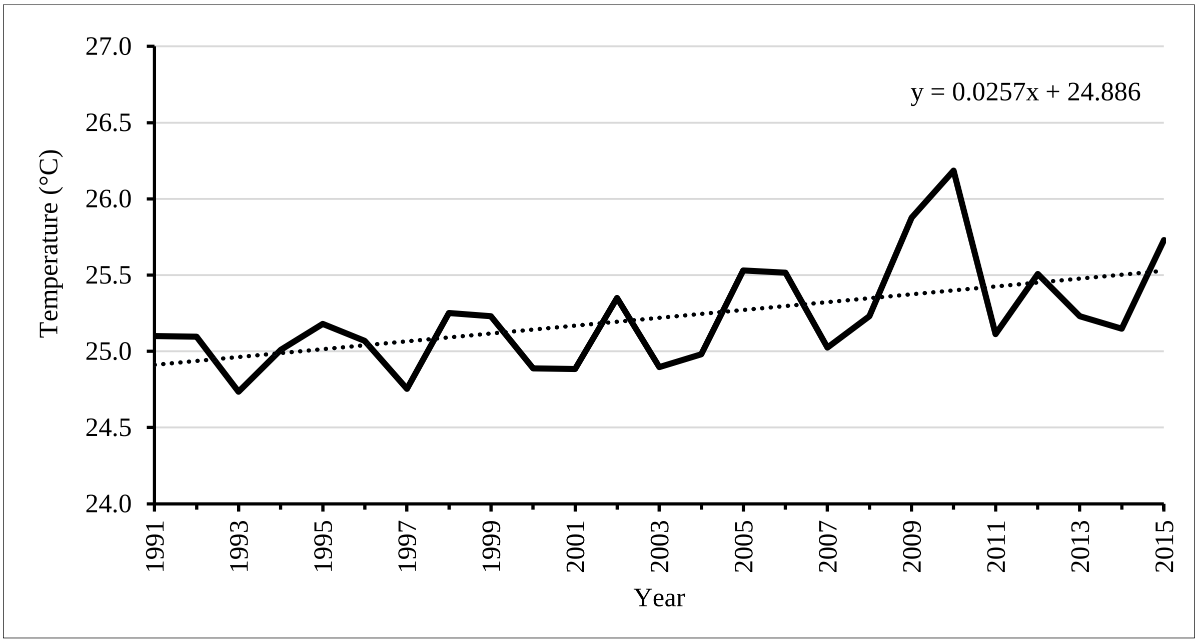


Figure 4. Variation of annual average temperature over the basin (1991-2015)

4.3. Annual Water Deficit

The annual water deficit was computed using climate water balance and is shown in Figure 5. Potential evapotranspiration (PET) was calculated using the Thornthwaite method. The value of annual PET was observed to be greater than annual rainfall from the year 1992 to 2015. Therefore, there was a deficit of water throughout the observed duration. Also, in Figure 5, the variation of annual rainfall and annual PET for the duration 1991 to 2015 is shown.

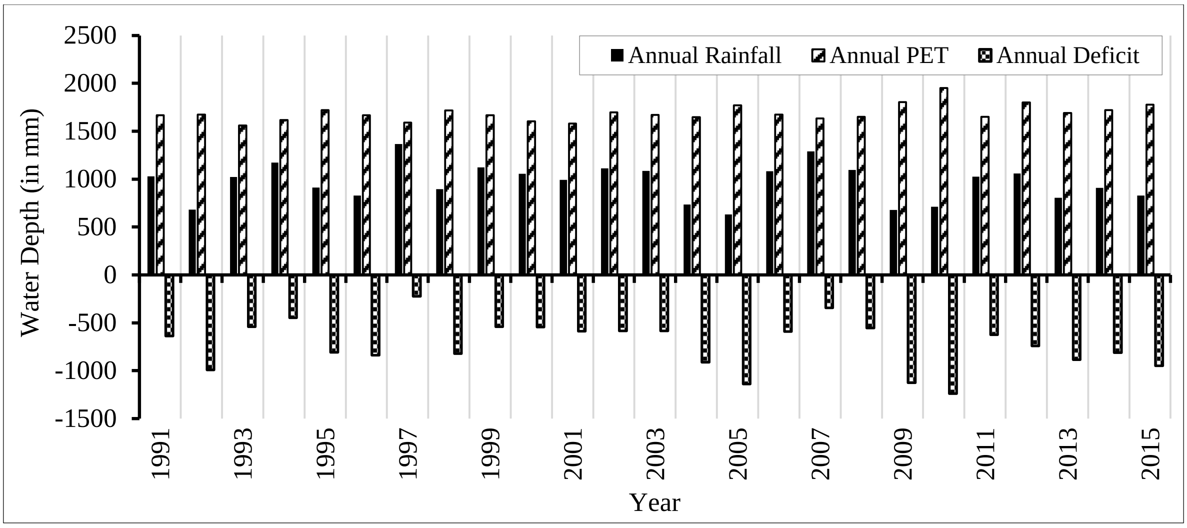
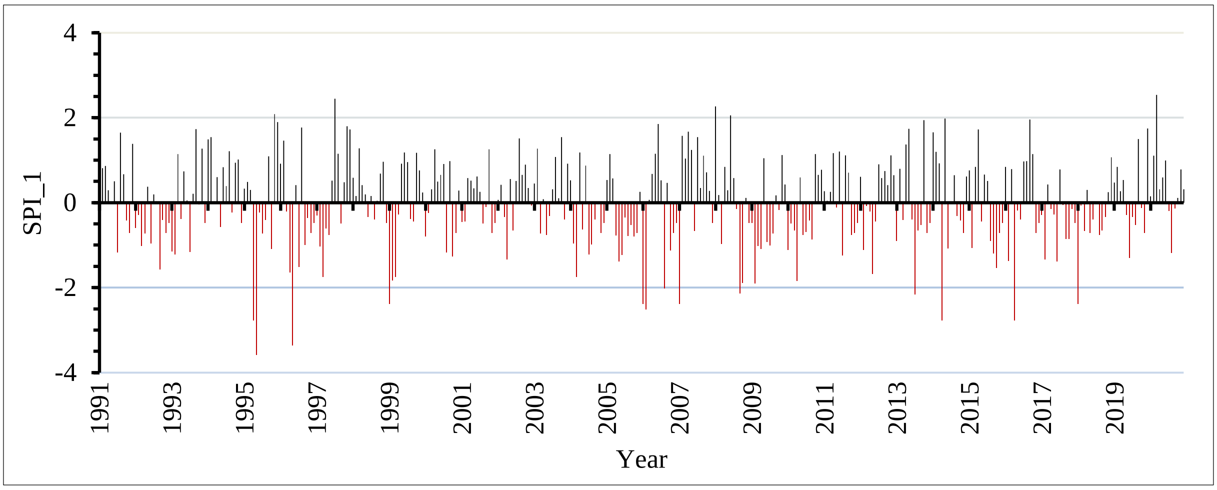


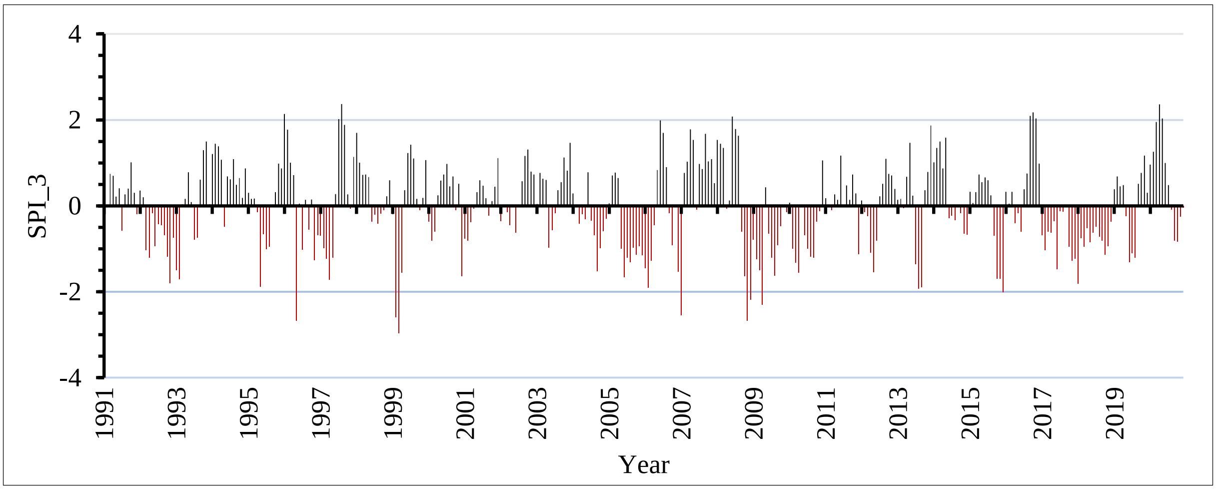
Figure 5. Annual variation of rainfall, PET, and annual water deficit (1991-2015)

4.4. Monthly Variation of SPI

Figure 6 presents the temporal variation of monthly SPI for timescale (1-, 3-, 6-, 9- and 12-month), which have been computed using 30 years (1991 to 2020) rainfall data. The monthly variation of the SPI was visible at various timescales, indicating a distinct change in the dry and wet degrees of each month in the study area, particularly after 2004, when the dry degree of some months expanded considerably. Extreme drought has been observed during the years 1995, 1999, 2006, 2007, 2008, 2013, 2014, 2016, and 2018 having 1-month SPI less than -2.0. Extreme drought occurs in 2008 and 2010 according to 3-, 6- and 9-month SPI with intensity less than -2.0. The maximum duration of drought events occurs from 2017 to 2020 with an intensity of -1.5 in 2018 on a 9-month timescale. For the 12-month timescale, SPI, the maximum duration of drought event occurs during 2017 to 2020 with an intensity of -1.54 in 2020 which shows extreme drought during this duration.



(a)



(b)

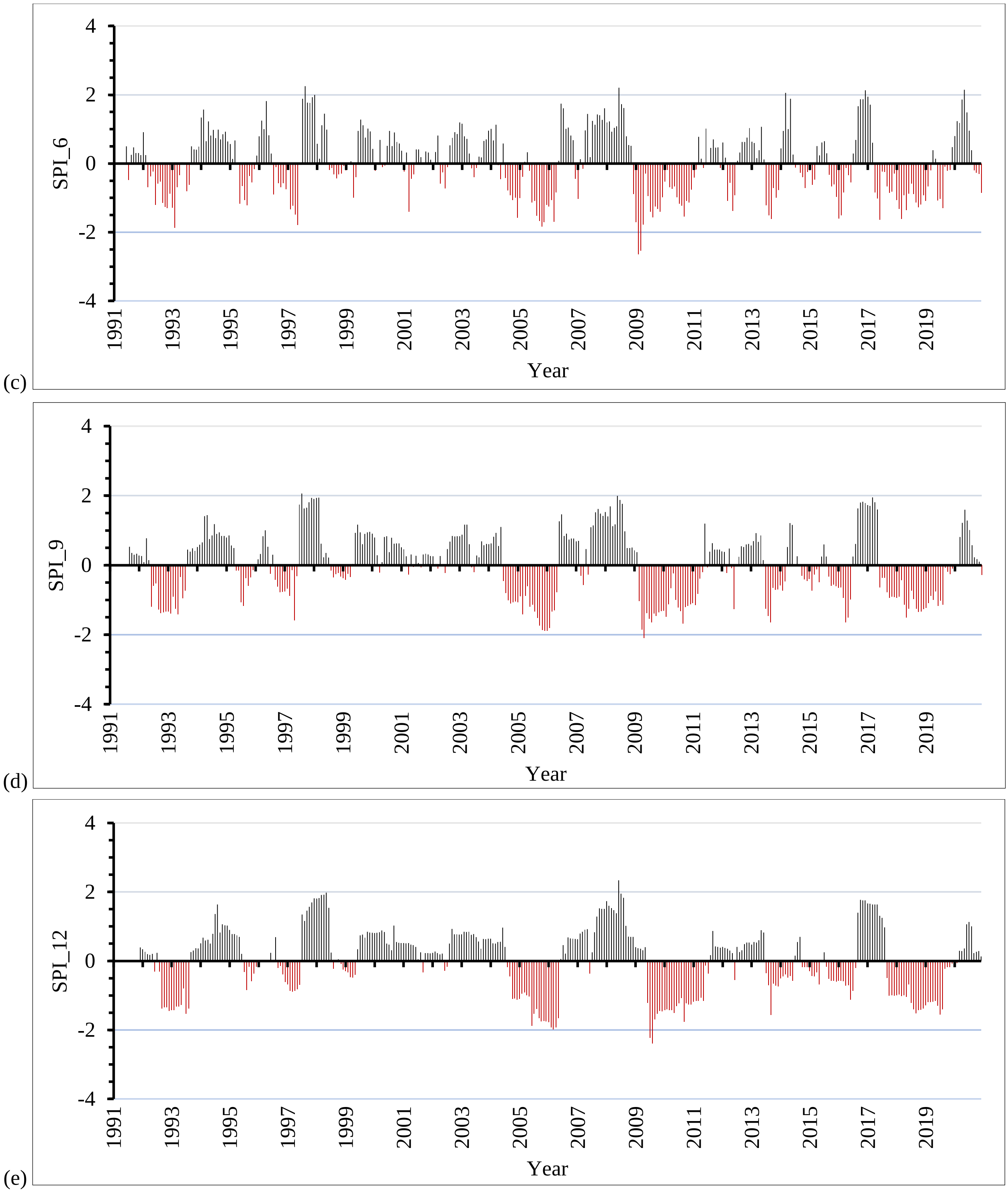
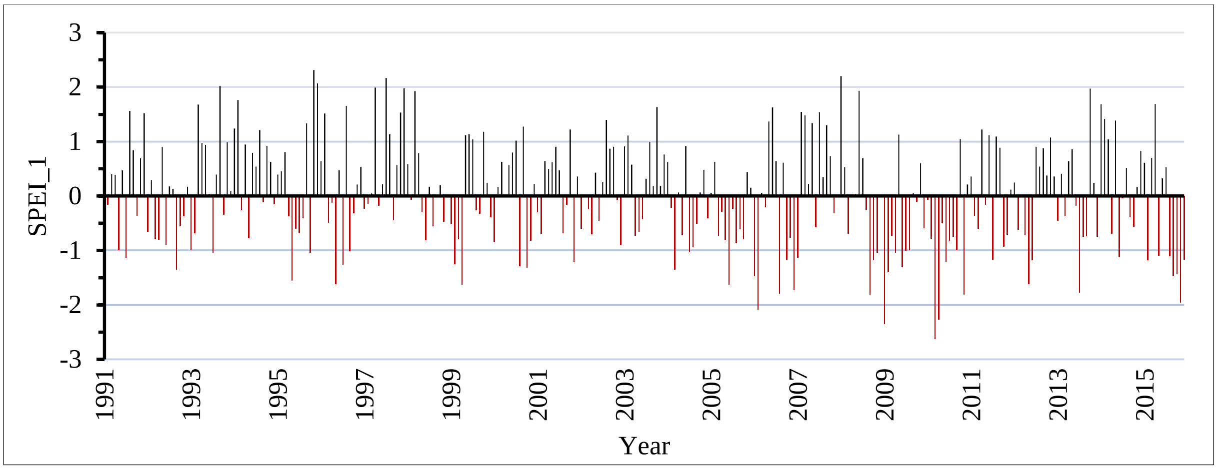
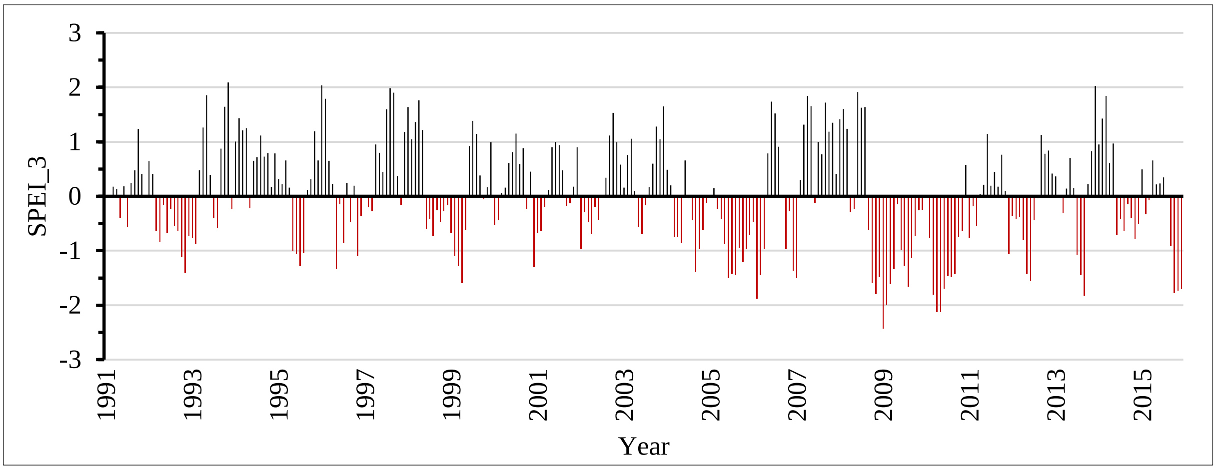


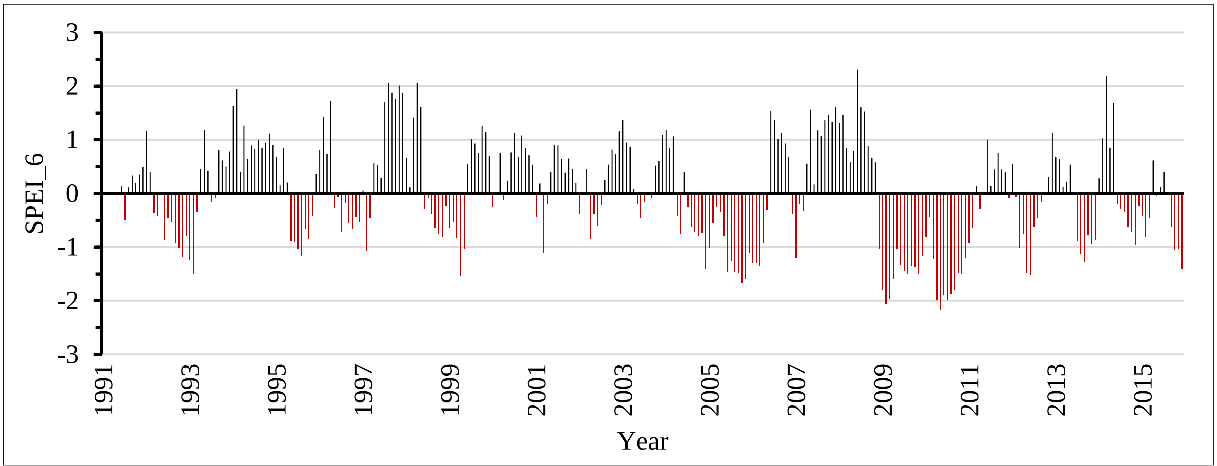
Figure 6. Temporal variation of SPI in the Punpun river basin for (a) 1-month, (b) 3-month, (c) 6-month, (d) 9-month, and (e) 12- month timescale

4.5. Monthly Variation of SPEI

The temporal variation of monthly SPEI for different timescale (1-, 3-, 6-, 9- and 12-month) have been computed using 25 years (1991 to 2015) rainfall and temperature data and is presented in Figure 7. Almost in all timescale, 2009-2010 has SPEI less than -2.0 which suggests that this duration is an extreme drought period. The 1-month SPEI data shows that 2006, 2009, and 2010 has extreme drought with intensity -2.08, -2.35, and -2.62 respectively. Extreme drought occurs in 2009 and 2010 according to 3-and 6-month SPEI with intensity less than -2.0. The 9-month SPEI also shows the extreme drought in the year 2009. There is no extreme drought event observed for the 12-month SPEI but the negative value of the index shows moderate and severe drought. The 2009 to 2010 years are observed as drought periods for almost all-time series calculated. Years 2004 to 2006 has also been observed as drought duration but it is not as severe as 2009 to 2010 duration drought. The intensity and duration of drought have increased after 2004.


SPEI_1
3
2
1
0
-1
-2
-3
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year
(a)


SPEI_3
3
2
1
0
-1
-2
-3
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year
(b)


SPEI_6
3
2
1
0
-1
-2
-3
1991
1993
1995
1997
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2001
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2005
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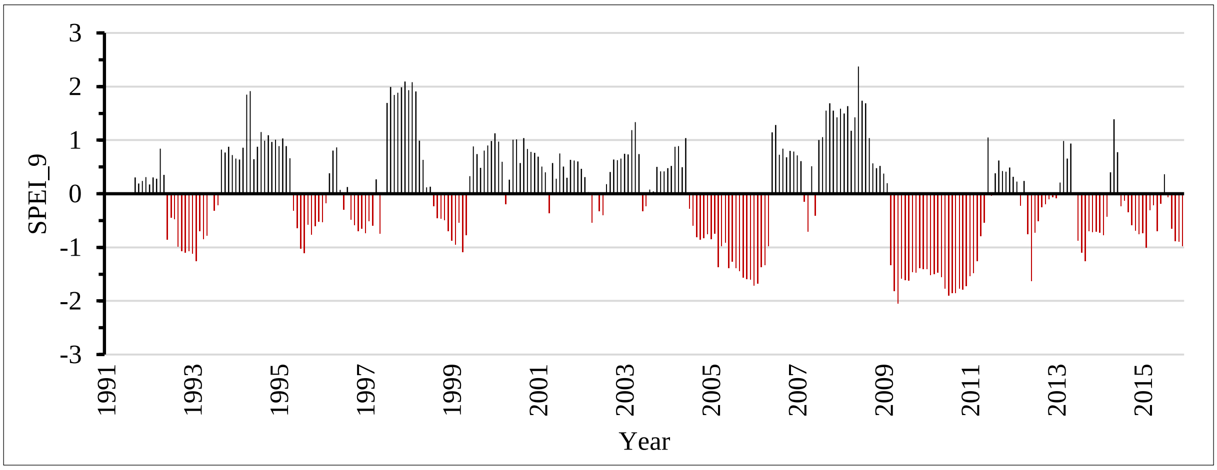
2009
2011
2013
2015
Year
(c)


SPEI_9
3
2
1
0
-1
-2
-3
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year
(d)

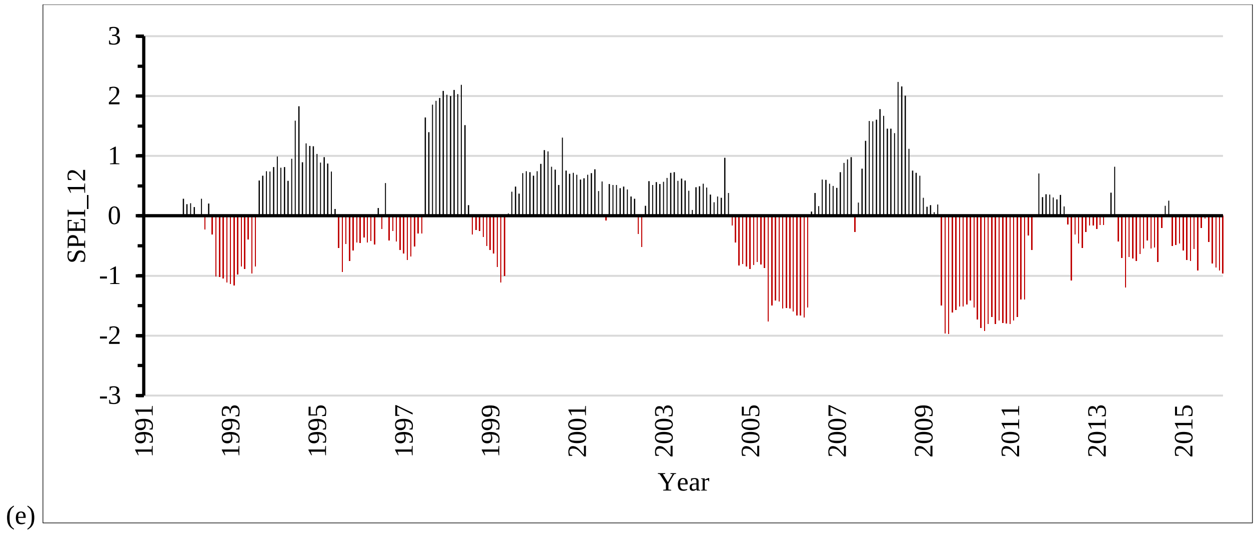


Figure 7. Temporal variation of SPEI in the Punpun river basin for (a) 1-month, (b) 3-month, (c) 6-month, (d) 9-month, and (e) 12- month timescale

4.6. Correlation Analysis of SPI and SPEI

Correlation analysis is a method used to determine the direction and strength of the relationship between the two variables. Since drought indices are based on standardization, Pearson correlation analysis was used for correlation analysis in this study. Table 2 presents the Pearson correlation matrix of drought indices. Correlation coefficient values greater than or equal to 0.8 are chosen as critical values indicating a strong positive relationship.

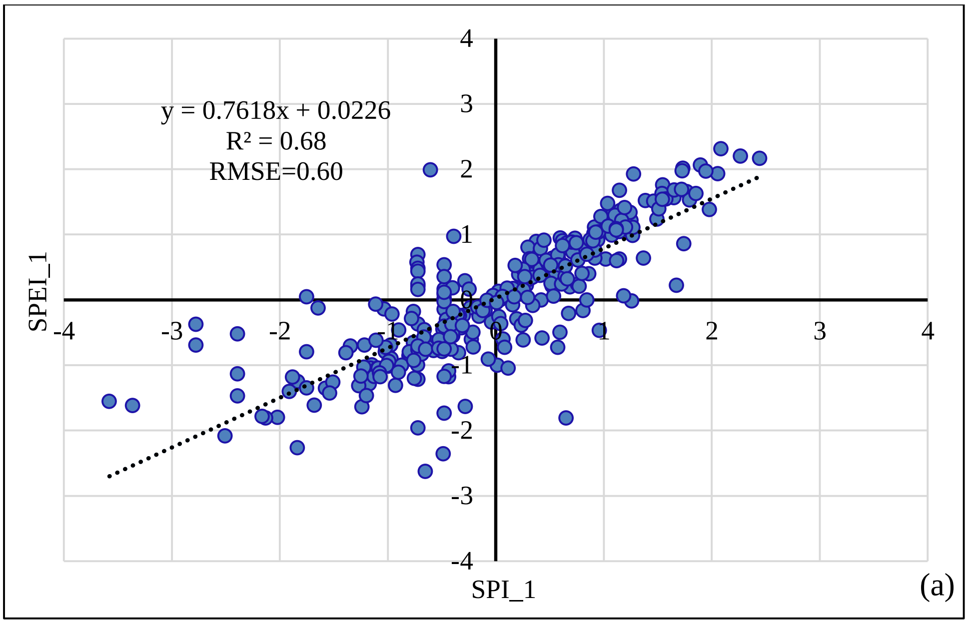
Table 2. Pearson correlation coefficient matrix of SPI and SPEI of different timescale

INDEX	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPEI_1	SPEI_3	SPEI_6	SPEI_9	SPEI_12
SPI_1	1	0.62	0.43	0.29	0.28	**0.82**	0.53	0.40	0.26	0.27
SPI_3		1	0.71	0.53	0.47	0.59	**0.89**	0.67	0.50	0.45
SPI_6			1	**0.80**	0.69	0.45	0.70	**0.92**	0.76	0.66
SPI_9				1	**0.86**	0.32	0.53	0.76	**0.95**	**0.83**
SPI_12					1	0.31	0.50	0.69	**0.85**	**0.96**
SPEI_1						1	0.64	0.50	0.33	0.32
SPEI_3							1	0.77	0.56	0.53
SPEI_6								1	**0.81**	0.72
SPEI_9									1	**0.88**
SPEI_12										1

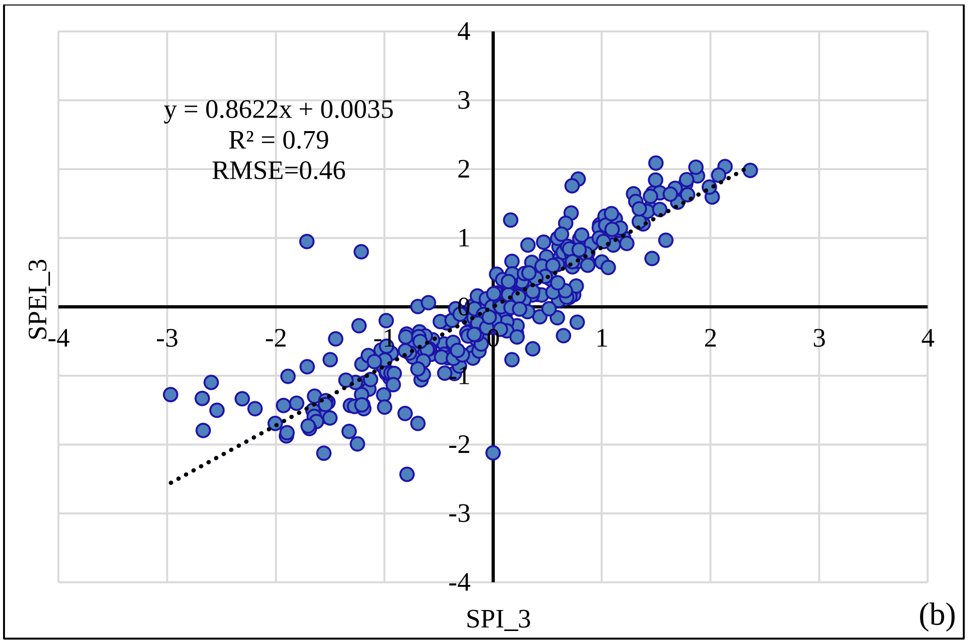
When the correlation matrix is examined, the strongest relationship was observed among the indices in the same timescale. The strongest correlation coefficient (0.96) was observed between SPI_12 and SPEI_12 and the lowest correlation coefficient (0.26) was between SPI_1 and SPEI_9.

4.7. Linear Regression Analysis

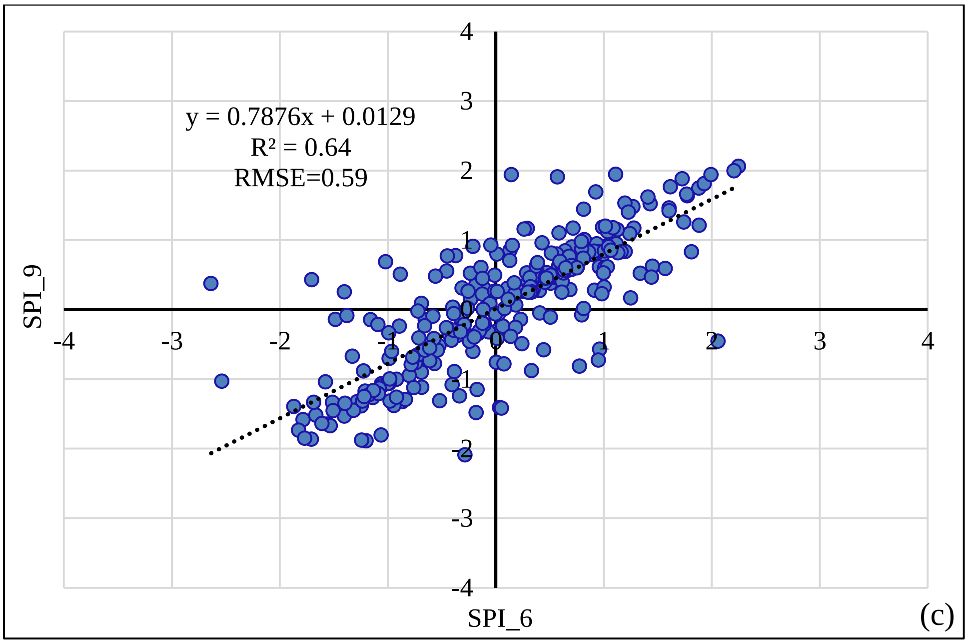
Regression analysis has been used in this study to compare drought indices of different timescale having correlation coefficient value greater than or equal to 0.8. For the comparison of drought indices, scatter diagram (Figure. 8) has been drawn and statistically evaluated by using the coefficient of determination (R^2) and the root mean square error (RMSE).



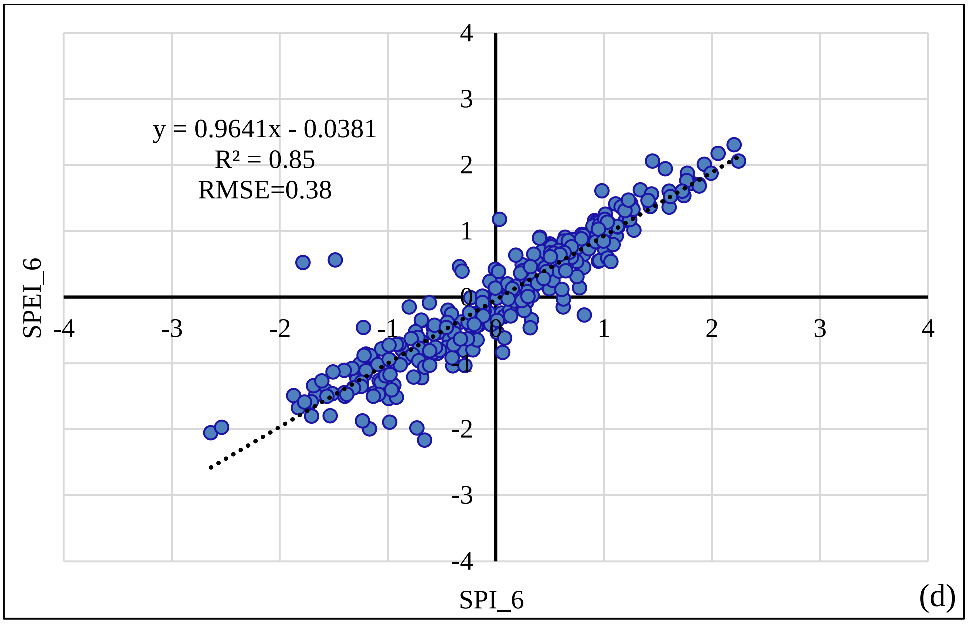
y = 0.7618x + 0.0226
R² = 0.68
RMSE=0.60
SPEI_1
SPI_1
(a)

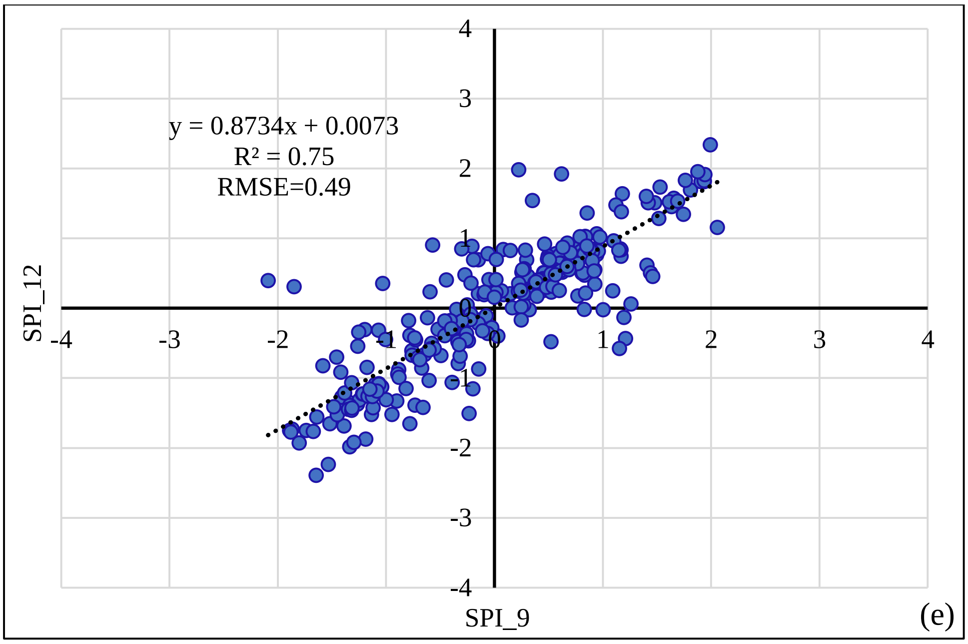


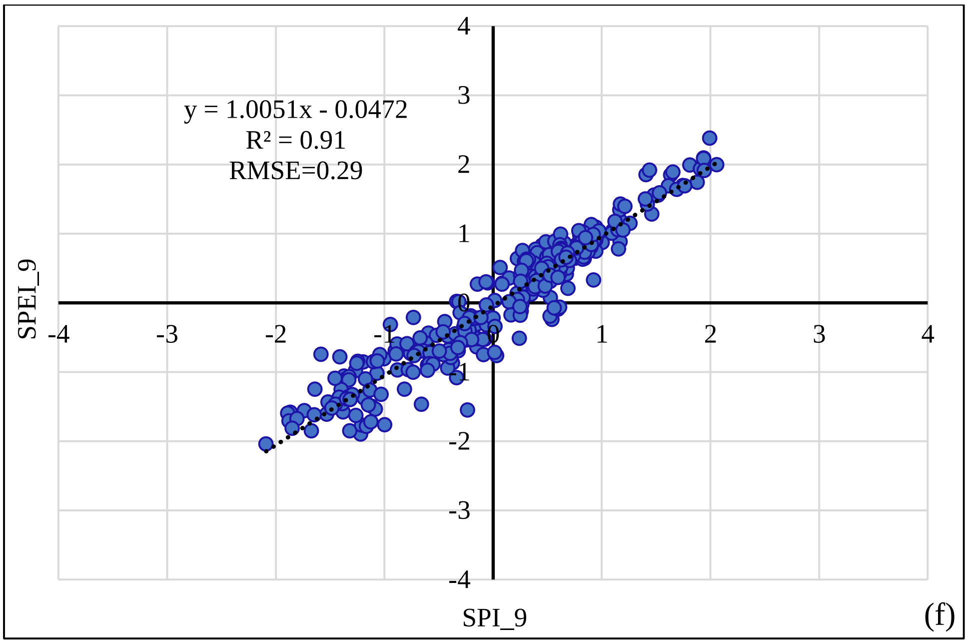
y = 0.8622x + 0.0035
R² = 0.79
RMSE=0.46
SPEI_3
SPI_3
(b)

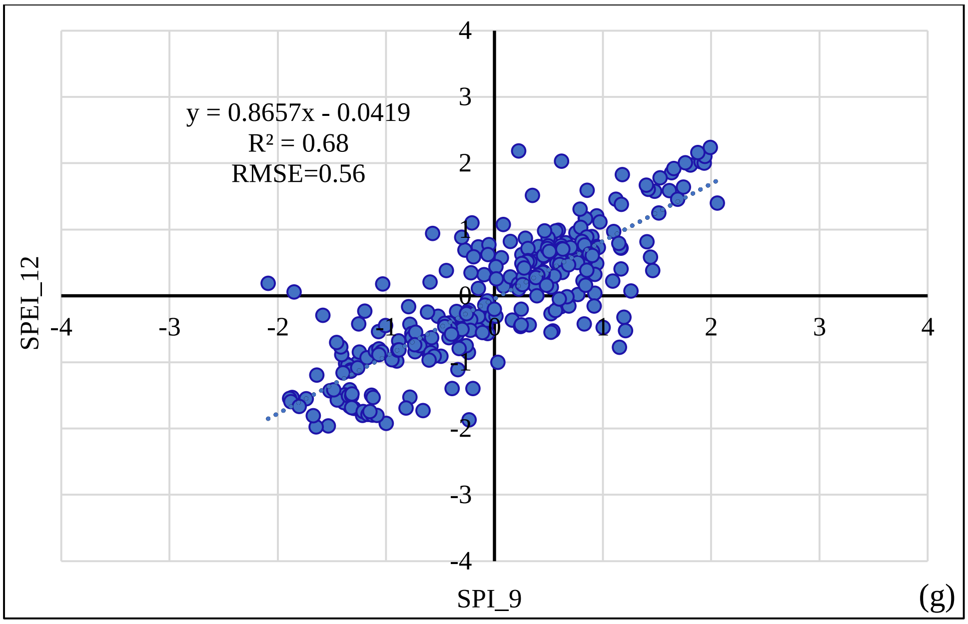


y = 0.7876x + 0.0129
R² = 0.64
RMSE=0.59
SPI_9
SPI_6
(c)

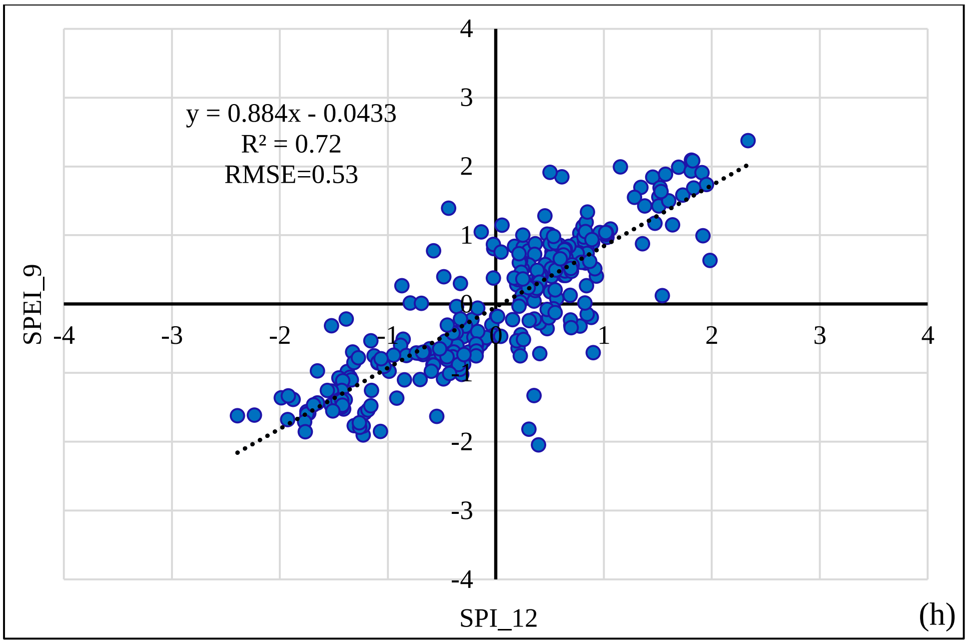

y = 0.9641x - 0.0381
R² = 0.85
RMSE=0.38
SPEI_6
SPI_6
(d)


y = 0.8734x + 0.0073
R² = 0.75
RMSE=0.49
SPI_12
SPI_9
(e)

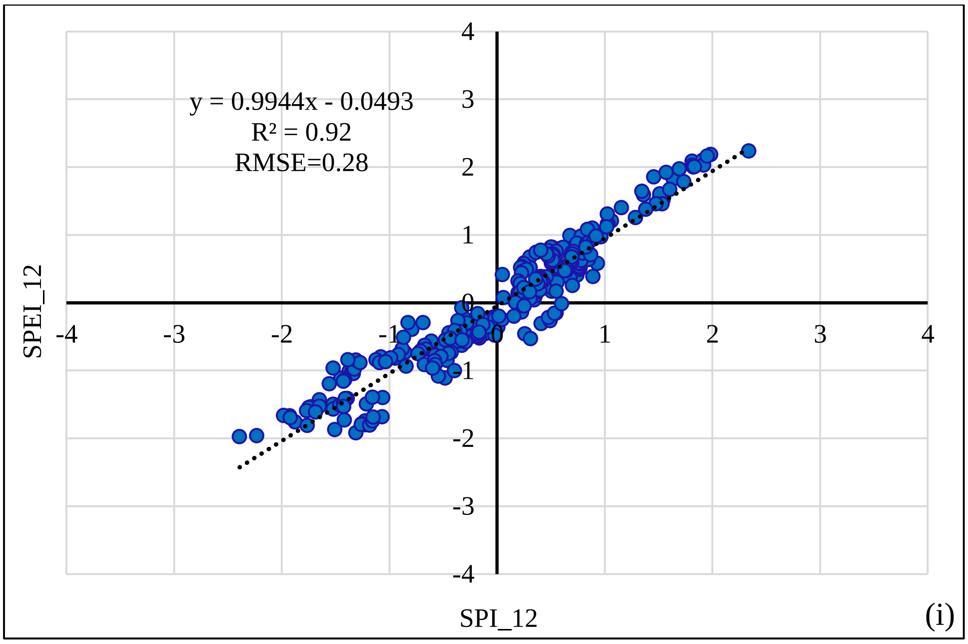

y = 1.0051x - 0.0472
R² = 0.91
RMSE=0.29
SPEI_9
SPI_9
(f)



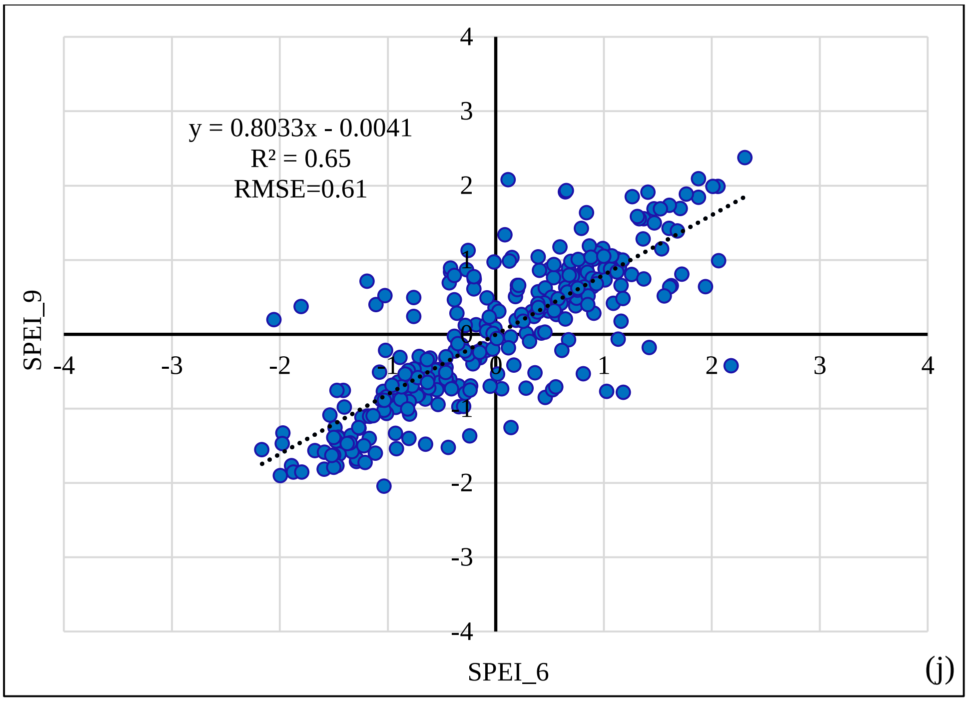
y = 0.8657x - 0.0419
R² = 0.68
RMSE=0.56
SPEI_12
SPI_9
(g)



y = 0.884x - 0.0433
R² = 0.72
RMSE=0.53
SPEI_9
SPI_12
(h)



y = 0.9944x - 0.0493
R² = 0.92
RMSE=0.28
SPEI_12
SPI_12
(i)



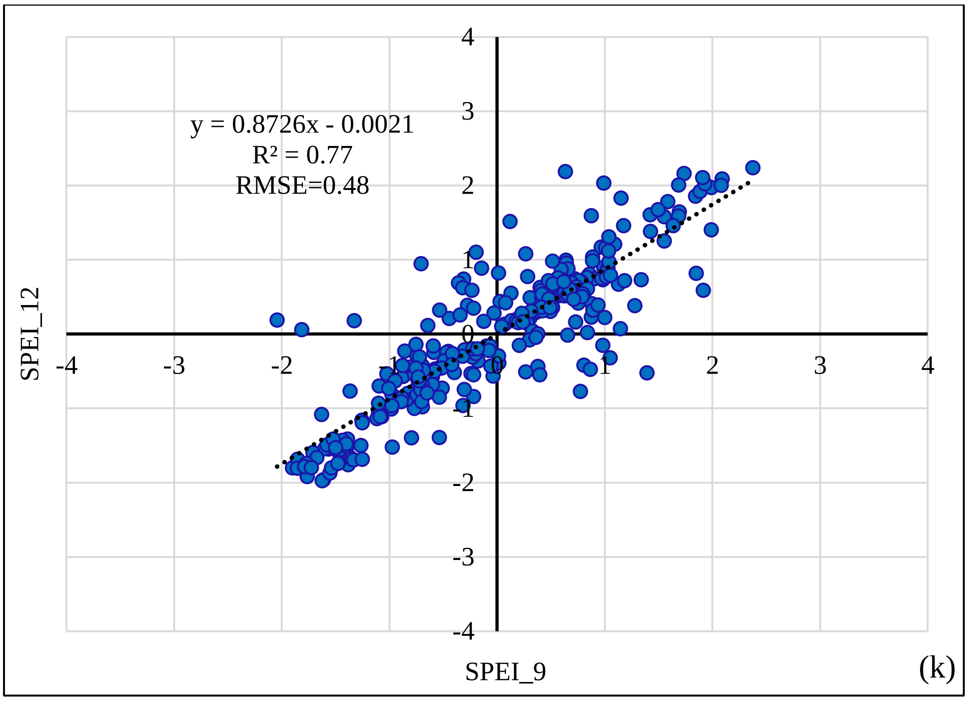


Figure 8. Scatter diagrams of drought indices: (a) SPI_1 AND SPEI_1, (b) SPI_3 and SPEI_3, (c) SPI_6 and SPI_9, (d) SPI_6 and SPEI_6, (e) SPI_9 and SPI_12, (f) SPI_9 and SPEI_9, (g) SPI_9 and SPEI_12, (h) SPI_12 and SPEI_9, (i) SPI_12 and SPEI_12, (j) SPEI_6 and SPEI_9, (k) SPEI_9 and SPEI_12.

When the diagrams are examined, strongest fit has been shown by values of SPI_12 and SPEI_12 (Figure 8. i). Also, the results of statistical indicators shows that the value of SPI gives close result with SPEI in the same timescale. Greatest value of R^2 is 0.92 and lowest value RMSE is 0.28 for SPI_12 and SPEI_12 scatter diagram, which indicated that the indices give close results.

4.8. Comparison of SPI_12 and SPEI_12

It has been seen that there is good relationship between SPI and SPEI. Table 2 suggest, there is strong correlation between SPI_12 and SPEI_12. Both the indices have correlation coefficient of 0.96 and shows similar pattern of drought occurrence. These index values have been compared for the duration 1991 to 2015 and presented in Figure 9. Both the drought indices suggest drought event occur during 2004-2005 and 2009 and 2010.

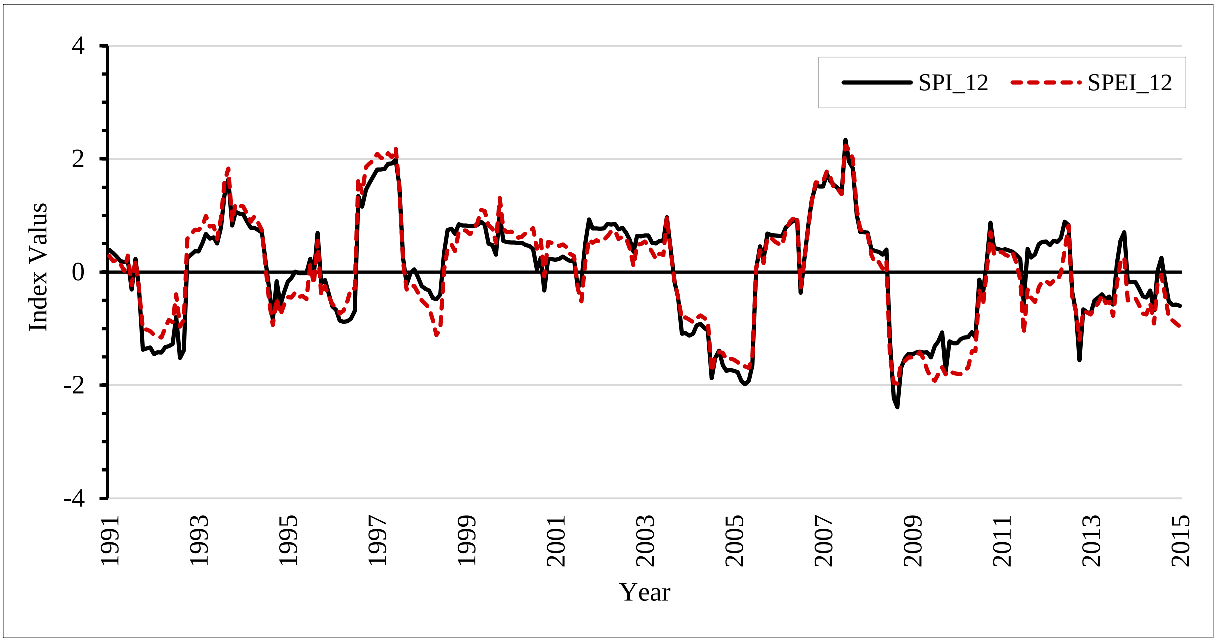


Figure 9. Comparison plot between SPI and SPEI

4.9. Variation of SPEI_12 with Temperature

Figure 10 displays the variation of SPEI_12 with temperature. It is observed that when the temperature is rising, index value decreases. Negative index value shows significant drought. It is also observed that in 2010, when the annual mean temperature is maximum the value of SPEI is minimum in the observed duration. This shows that temperature is one of the critical variables along with rainfall in the analysis of drought.

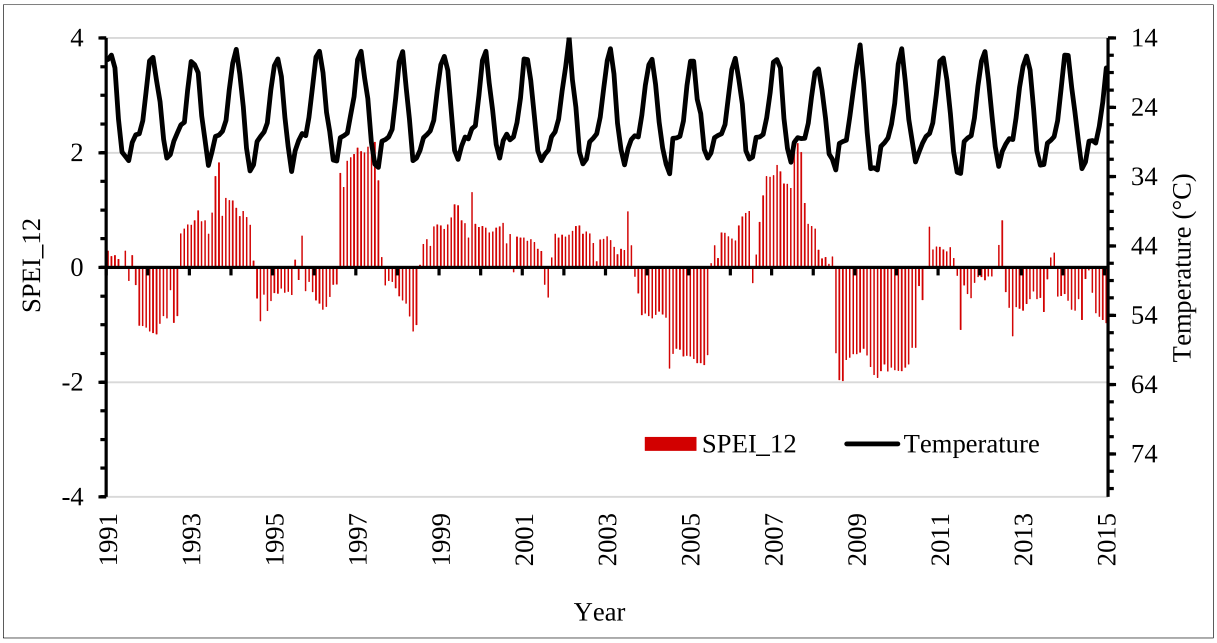


Figure 10. Variation of SPEI_12 with Temperature (1991 -2015)

4.10. Analysis of Seasonal Drought

In this study, winter (December to February), pre-monsoon (March to May), monsoon (June to September), and post-monsoon (October to November) are considered as the four seasons [30]. Figures 11 and 12 show the seasonal variation of SPI_12 and SPEI_12 in the Punpun river basin. Values of both the indices shows negative trend in all the seasons for 12-months timescale. This implies that the probability of drought occurrence is increasing. Both SPI and SPEI show only moderate and severe drought during monsoon and post-monsoon season and the occasional bout of the extreme drought event.

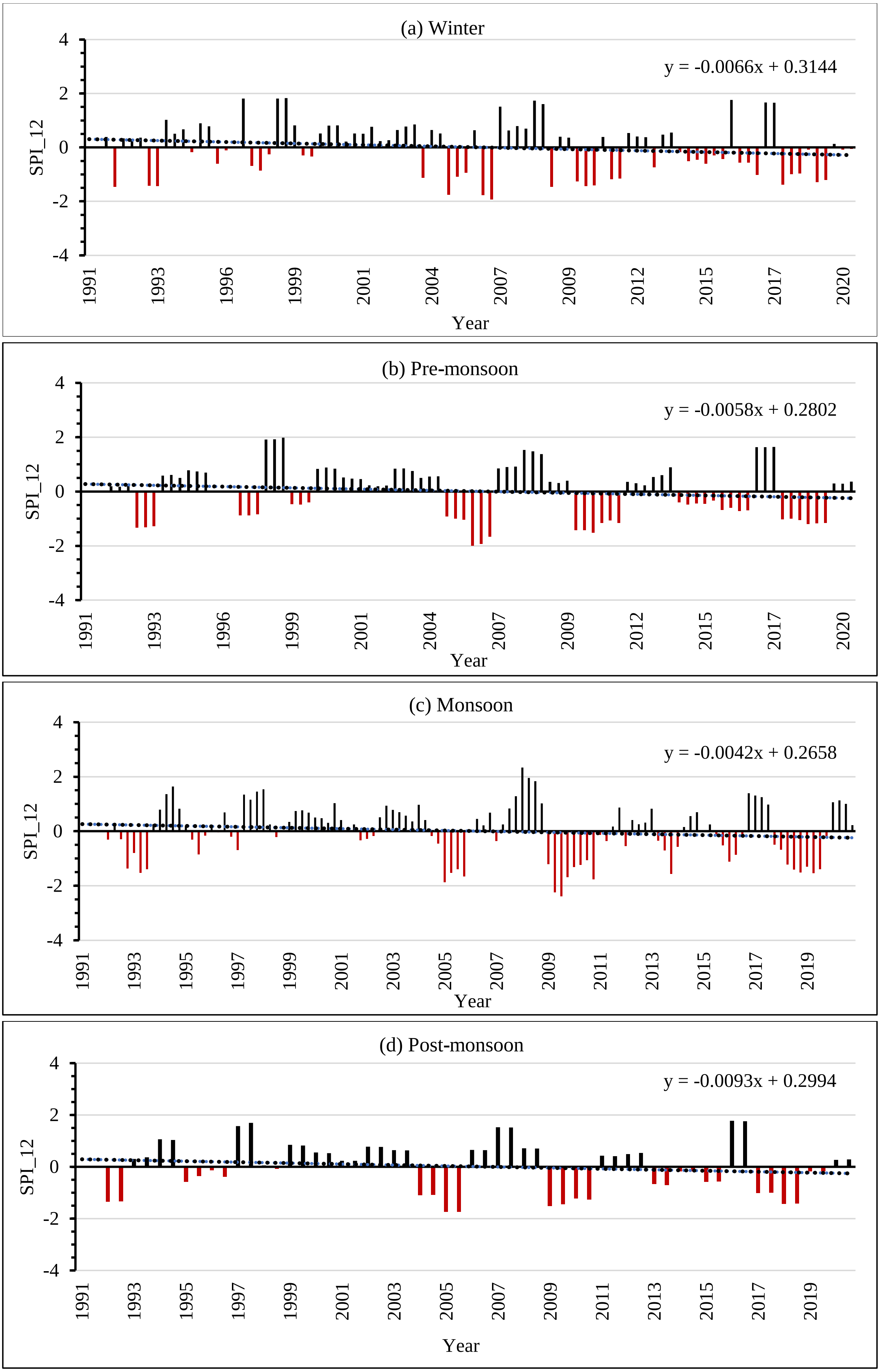


Figure 11. Seasonal Variation of SPI_12 in Punpun river basin (a) Winter, (b) Pre- monsoon, (c) Monsoon, and (d) Post-monsoon

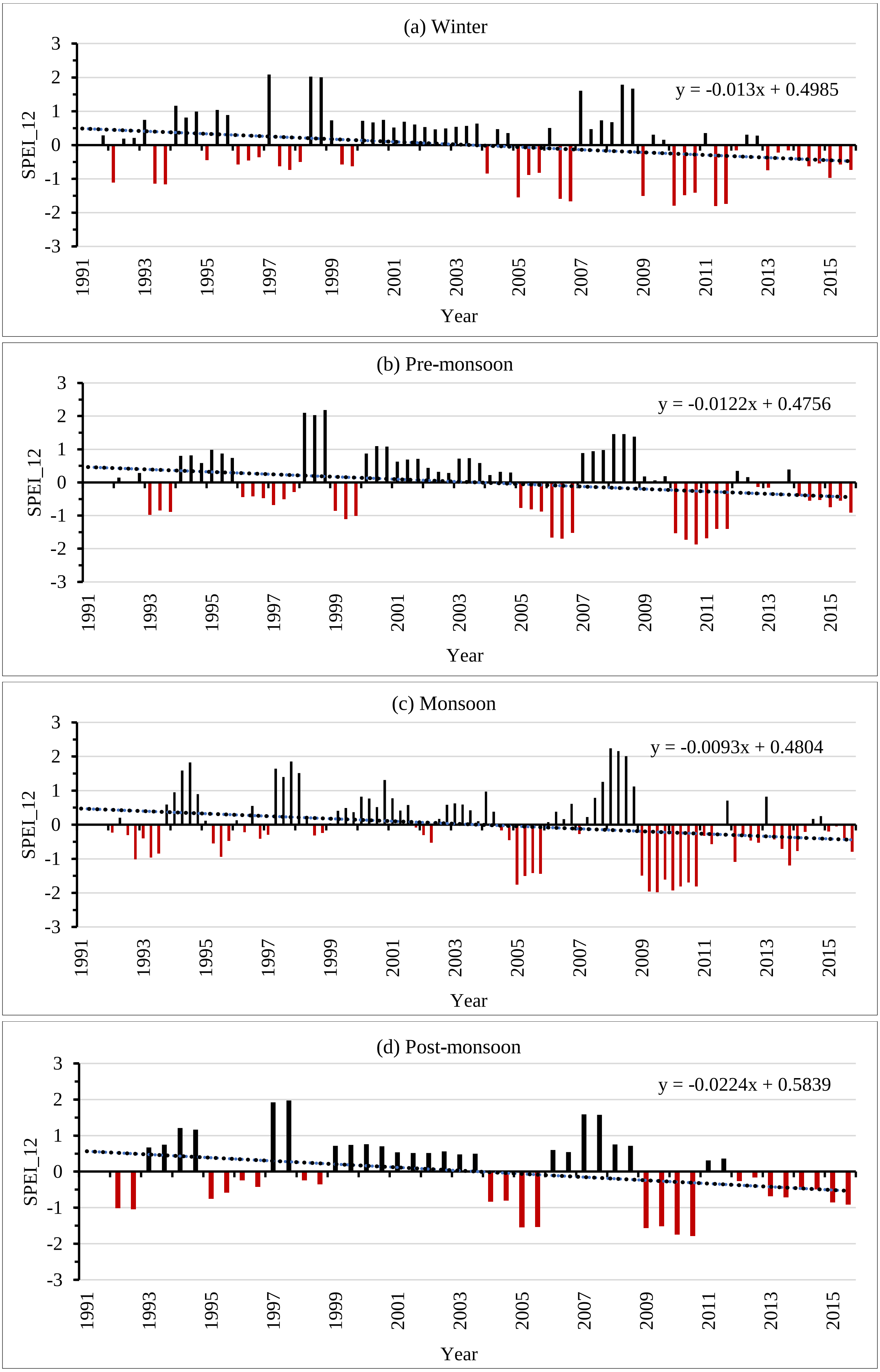


Figure 12. Seasonal variation of SPEI_12 in Punpun river basin (a) Winter, (b) Pre- monsoon, (c) Monsoon, and (d) Post-monsoon

4.11. Performance of Drought Indices with Respect to Historic Drought

According to International Food Policy Research Institute (IFPRI discussion paper 013898, December 2014), Bihar was not the only state affected by drought in 2009, it was one of the worst droughts India has seen in more than 100 years. All the districts of the study area were facing shortage of water and declared drought affected area by the state government. Drought led recession in agricultural economy has been reported by 66th round of consumption survey by National Sample Survey Office (NSSO). It is also evident from the Figure 12, that drought has occurred during 2004-2005 and 2009-2010. Both the drought indices, (i.e., SPI and SPEI) is indicating occurrence of drought on all timescale in the present study.

Meteorological drought becomes critical if it persists for longer duration. In this study 1-, 3-, 6-, 9-, and 12-month scale indices has been used for drought analysis. Shorter timescale indices talk about the meteorological condition where as higher timescale can be used for the water availability for the crops having crop period more than 3-4 months. If drought situation continues for longer period, it will affect the agricultural economy and consequently socio-economic drought will occur. Gridded data has been used for the analysis in this paper, since available observed data was not uniformly available in the study area. Policies maker may use the results of this study to counter water scarcity related issues in future and better measures can be adopted for reducing the effects of drought.

5. Conclusion

In any river basin, drought assessment using a suitable drought index is vital for effective water resources management. In this study, the drought situation has been evaluated using two globally accepted drought indices namely SPI and SPEI at different timescales. The performance of both indices at different timescale has been examined with an aim of identifying a suitable drought index for the Punpun river basin. Based on the results of this study, it can be concluded that the Water deficit is constantly increasing over the study duration, as a result of decreasing rainfall and increasing PET trend in the basin. Both the drought indices indicated drought conditions from 2008 to 2010 for all timescale used in the study. The correlation matrix of 1-, 3-, 6-, 9-, and 12-month scale indices of SPI and SPEI indicates that both the indices show a strong relationship for the same timescale. Also, there was the highest correlation coefficient R^2 is 0.92 and the lowest value of RMSE is 0.28. The observation of SPI and SPEI indicated drought period during 2009 to 2010 for almost all timescale. The period 2004 to 2006 has also been observed as drought period but it is not as severe as 2009 to 2010 duration drought. The intensity and duration of drought have also increased after 2004. A negative trend of both the indices have been observed in all seasons on all timescale. The 12-month scale indices perform better in detecting historic drought. The dependency of SPEI on temperature is also clearly observed in this study. Hence, SPEI at a 12-month scale is recommended for drought monitoring in the study area. This analysis may be used for effective planning and water management practices.

6. Declarations

6.1. Author Contributions

Conceptualization, S.S.O and T.R.; methodology, S.S.O., T.R. and V.S.; software, S.S.O and T.R.; formal analysis, S.S.O; writing—original draft preparation, S.S.O; writing—review and editing, V.S. and T.R. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Data available in a publicly accessible repository that does not issue DOIs: Publicly available datasets were analyzed in this study. This data can be found here: *https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html*.

6.3. Funding

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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