

Prediction of Future Drought in Thailand under Changing Climate by Using SPI and SPEI Indices

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Abstract. *Climate change is the main cause of the water disasters; directly impacted flood and drought that occur from excess and shortage of water in several areas. Drought risk areas have tendency to suffer from greater severity and higher frequency of disaster in future. Therefore, it is necessary to conduct drought prediction in order to understand water stress conditions in drought hotspots or drought prone areas. Meteorological drought indicators can be calculated from rainfall and temperature. The standardized precipitation index (SPI) and standardized precipitation evaporation index (SPEI) are used in temporal analysis of drought severity. This study aims to predict and compare future droughts under changing climate. The observed climate data from weather stations in Thailand and 10 GCM climate datasets under CMIP5 project were used as inputs. The gamma-gamma transformation method was applied to correct biases of GCM precipitation and temperature data. SPI and SPEI indices were calculated for each weather station to describe drought situation. The number of drought events and their severity were calculated and presented on a drought risk map. The consistency index was used to identify hotspot areas from multiple SPI and SPEI results. These results would raise drought awareness of related government agencies in order to prepare the water plans to cope with water shortage in the drought risk areas.*

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climate change, gamma-gamma transformation, bias correction, standardized precipitation index, standardized precipitation evaporation index

1. Introduction

Meteorological drought is defined as an event that occurs when dry weather patterns dominate an area. Drought conditions can be investigated by using specific indices for assessing drought severity such as Palmer

Drought Index (PDI) [1] and Standardized Precipitation Index (SPI) [2] and Standardized Precipitation Evaporation Index (SPEI) [3]. SPI is a meteorological drought index that is created from precipitation data only. It does not account for evapotranspiration, which limited its ability to capture the effect from temperature variation due to changing climate. On the other hand, the SPEI combines for the possible effects of temperature variability and temperature extremes beyond the context of global warming. [4] Furthermore the SPEI fulfills the requirements of a drought index since its multi-scalar character enables it to be used by different scientific disciplines to detect, monitor and analyze droughts. [5] indicated that drought indices must be statistically robust and easily calculated, and have a clear and comprehensible calculation procedure. Thus, many studies have inscribed the issue of predicted changes in the hydrological cycle with global climate models ([6]; [7]). [6] have shown that a large increase in mean precipitation is expected in the future, especially in Asian monsoon regions, which will reduce drought over the region. [7] have also projected that the precipitation intensity increases due to increased atmospheric water holding capacity. Nevertheless, increases in mean precipitation are tied to increases in surface evaporation rates, which are lower than for atmospheric moisture. This leads to a reduction in the number of wet days and an increase in dry spell length. In order to the changing climate have induced to the drought phenomena, we attempted to address the drought characteristic over Thailand by using both of SPI and SPEI method. The objective of this study is to investigate the change of severity and occurrence of drought situation under changing climate by using multiple bias corrected multi Coupled Model Intercomparison Project (CMIP5) general circulation models (GCMs).

2. Study area

Thailand is located in the tropical area between latitudes 5°37' N to 20°27' N and longitudes 97°22' E to 105°37' E. The total area is 513,115 square kilometers.

The climate of Thailand is under the influence of monsoon winds of seasonal character i.e. southwest monsoon and northeast monsoon. The southwest monsoon which starts in May brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially the windward side of the mountains. Rainfall during this period is also caused by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones which produce a large amount of rainfall. The onset of the southwest monsoon leads to intensive rainfall from mid-May until early October. Rainfall peak is in August or September which some areas are probably flooded. However, dry spells commonly occur for 1 to 2 weeks or more during June to early July due to the northward movement of the ITCZ to southern China. Annual rainfall pattern of the country is about 1,200 - 1,600 mm per year. The study area and observed rain gauge station is shown as Fig.1.

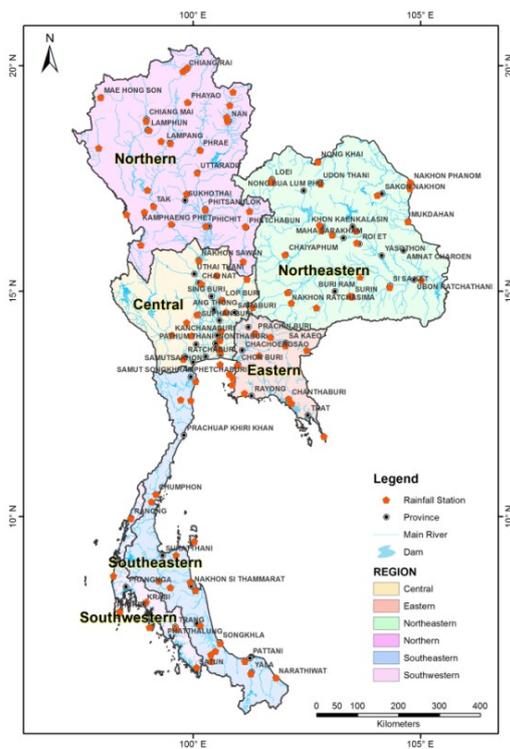


Fig 1.: Study area and rainfall stations [1]

3. Data

Observed rainfall data from 124 weather stations shown in Fig.1 were obtained from Thai Meteorological Department (TMD). We collected daily rainfall, relative humidity, wind speed, sunshine duration, maximum and minimum temperature in the period 1979 – 2015. For the 10 general circulation models (GCM), precipitation and temperature were downloaded from Lawrence Livermore National Laboratory as shown in Table 1 (<https://pcmdi.llnl.gov/projects/esgf-llnl/>). The concerned time period was divided into 4 periods: present (1979 – 2006), near future (NF: 2018 – 2039), mid future (MF:

2040 - 2069), and far future (FF: 2070 - 2099). Two Representative Concentration Pathways (RCPs) (4.5 and 8.5), developed by IPCC, were selected to project future climate change in Thailand. RCP 4.5 is a scenario of intermediate emissions which stabilizes radiative forcing shortly after year 2100, consistent with a future with relatively ambitious emissions reductions. RCP 8.5 is a scenario of high emissions consistent with a future of no policy changes to reduce emissions which is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time [8].

Modeling group	Model designation	AGCM horizontal/vertical resolution	OGCM horizontal/vertical resolution
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1	T42 L26	1°lon x 1.33° lat L40
Canadian Center for Climate Modelling and Analysis	CanESM2	T63 L35	256 x 192 L40
National Center for Atmospheric Research	CCSM4	1.25lon x 0.9 lat L26	1.1° lonx0.27° – 0.54° lat L60
The Community Earth System Model, version 1– Biogeochemistry	CESM1_BGC	1.25 lon 0.9424 lat	-
Centre National de Recherches Meteorologiques	CNRM-CM5	TL127 L31	1° lon x 1° lat L42
The EC-Earth consortium	EC_EARTH	1.125 lon 1.1215 lat	1 lon x 0.3 –1.0 lat
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University	FGOALS-s2	R42 L26	0.5 –1 lon x 0.5 –1 lat L
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies	MIROC-ESM	T42 L80	256 x 192 L44
Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5	T85 L40	256 x 224 L50
Max Planck Institute for Meteorology	MPI-ESM-LR	T63 L47	GR15 L40

Table 1 Description of GCM climate data used

4. Methodology

4.1 Gamma-gamma transformation

We modified the Gamma-gamma transformation bias correction method proposed by [9],[10]. The daily rainfall data were defined as the independent variables.

The distribution of daily rainfall obtained each month can be approximated by the gamma distribution. The following represent the major steps employed to correct the rainfall data. First, a gamma distribution for observed rainfall data series – $F_{obs}(x_{obs})$ was considered fit. Second, a gamma distribution for GCM rainfall data of the same period was considered fit – $F_{GCM20}(x_{GCM20})$. Third, a gamma distribution for the 21st century GCM rainfall data was considered fit – $F_{GCM21}(x_{GCM21})$. Fourth, the inverse of the GCM rainfall data was taken with observed rainfall data and GCM rainfall data was corrected using (1),

$$X_{GCM20CORR} = F_{obs}^{-1}(F_{GCM20}(X_{GCM20})) \tag{1}$$

; where $X_{GCM20CORR}$ represents the corrected GCM rainfall data in each month during the present period and X_{GCM20} represents the raw rainfall during the present period.

For the future period, the future GCM corrected the rainfall data in each month using (2),

$$X_{GCM21CORR} = X_{GCM21} \frac{F_{obs}^{-1}(F_{GCM21}(X_{GCM21}))}{F_{GCM20}^{-1}(F_{GCM21}(X_{GCM21}))} \tag{2}$$

; where $X_{GCM21CORR}$ is the corrected GCM rainfall data in each month in the future period and X_{GCM21} is the raw rainfall data in each month in future period.

4.2 Standardized precipitation index (SPI)

Standardized precipitation index (SPI) is based on the probability of precipitation for any time scale [11]. SPI is based on the cumulative probability of a rainfall event occurring at a station. The gamma distribution is defined by its frequency or probability density function:

$$G(x) = \int_0^x f(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^\alpha e^{-x/\beta} \tag{3}$$

Since the gamma function is undefined for $x=0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x)$$

; where q is the probability of zero. The cumulative probability $H(x)$ is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI following [12]; we employ the approximate conversion provided by [13] as an alternative.

$$Z = SPI = - \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad 0 < H(x) \leq 0.5$$

$$Z = SPI = + \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad 0.5 < H(x) \leq 1$$

; where

$$t = \sqrt{\ln\left(\frac{1}{H(x)}\right)} \quad 0 < H(x) \leq 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad 0.5 < H(x) \leq 1.0$$

; where $C_0 = 2.515517$, $C_1 = 0.802583$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, and $d_3 = 0.001308$.

[11] used the classification system shown in the SPI value table below (Table 2) to define drought intensities resulting from the SPI.

SPI	Classification
2.0+	extreme wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Table 2 SPI values classification

4.3 Standardized precipitation evapotranspiration index (SPEI)

The SPEI [3] that employed to investigate drought in this study based on Thornthwaite equation (Thornthwaite, 1948) as follows:

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{4}$$

where $W = -2 \ln(P)$ \tag{5}

for $P \leq 0.5$, P being the probability of exceeding a determined D value, $P = 1 - F(x)$. If $P > 0.5$, P is replaced by $1 - P$ and the sign of the resultant SPEI is reversed. The constants are: $C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$. The average value of the SPEI is 0, and the standard deviation is 1. D is the difference between the precipitations (P) and PET for the month i is calculated:

$$D_i = P_i - PET_i \tag{6}$$

; which provides a simple measure of the water surplus or deficit for the analyzed month.

SPEI	Classification
2.0+	extreme wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Table 3 SPEI values classification

4.4 Consistency index

In order to assess the level of consistency in severity and occurrence which analyzed from SPI and SPEI by using BC GCM rainfall and temperature, we constructed a consistency index [14-15]. The index is calculated for each grid point as follows.

$$Consistency\ index = \begin{cases} \frac{N_p}{N_p + N_n} (N_p > N_n) \\ -\frac{N_n}{N_p + N_n} (N_p < N_n) \end{cases} \quad (7)$$

Where N_p is the number of BC GCMs that project an increase in SPI or SPEI, and N_n is the number of BC GCMs that projected decrease. Therefore, the sign of the index denotes the direction of changes projected by the majority of the BC GCMs. The goodness of fit tests are used to evaluate the performance of daily BC rainfall data and extreme rainfall indices including Pearson’s correlation (r), root mean square error (RMSE) ([16]; [17]; [18]), mean absolute error (MAE), percent bias (PBIAS) ([19]; [20]), and skill score (SS) ([21]; [22])

5. Results

5.1 Evaluation of monthly BC rainfall

The monthly BC rainfall and temperature data of each GCM was verified using the correlation (r), percent biases (PBIAS), root mean square error (RMSE), mean absolute error (MAE), and skill score (SS) shown in Table 4 and 5.

It can be seen from Table 4 and 5 that the average correlation of monthly BC rainfall data varied from 0.57 to 0.62, RMSE varied from 3.44 to 3.9, MAE varied from 2.24 to 2.51, and SS varied from -0.36 to 0.67. The percent biases (PBIAS) produced a better result which varied from -0.45 to -0.15. In the other hand, average correlation of monthly BC temperature data varied from 0.72 to 0.82, RMSE varied from 1.26 to 1.52, MAE varied from 1.0 to 1.21, and SS varied from 0.37 to 0.88.

GCM	R	PB	RMSE	MAE	Skill score
BCC	0.58	-0.45	3.85	2.47	0.67
CanESM	0.58	-0.15	3.9	2.49	-0.14
CCSM4	0.58	-0.32	3.83	2.45	0.06
CESM1_BGC	0.57	-0.26	3.77	2.45	0.05
CNRM	0.62	-0.19	3.44	2.24	0.13
EC_EARTH	0.58	-0.23	3.88	2.51	-0.36
FGOAL_s2	0.58	-0.19	3.74	2.43	-0.13
MIROC_ESM	0.61	-0.15	3.55	2.33	-0.03
MIROC5	0.58	-0.27	3.9	2.51	-0.17
MPI_ESM_LR	0.61	-0.26	3.62	2.37	-0.08
Max	0.62	-0.15	3.9	2.51	0.67
Min	0.57	-0.45	3.44	2.24	-0.36

Table 4 Performance of bias corrected monthly rainfall

GCM	R	PB	RMSE	MAE	Skill score
BCC	0.78	-1.64	1.28	1.01	0.58
CanESM	0.79	-2.33	1.39	1.10	0.64
CCSM4	0.82	-3.21	1.49	1.21	0.78
CESM1_BGC	0.79	-2.29	1.35	1.07	0.80
CNRM	0.79	-1.77	1.26	1.00	0.79
EC_EARTH	0.79	-2.10	1.34	1.05	0.88
FGOAL_s2	0.72	-2.37	1.52	1.15	0.37
MIROC_ESM	0.78	-2.08	1.37	1.08	0.76
MIROC5	0.80	-1.91	1.28	1.01	0.55
MPI_ESM_LR	0.78	-2.40	1.42	1.11	0.61
Max	0.82	-1.64	1.52	1.21	0.88
Min	0.72	-3.21	1.26	1.00	0.37

Table 5 Performance of bias corrected monthly temperature

The percent biases (PBIAS) produced a better result which varied from -3.21 to -1.64. The evaluation of BC rainfall and temperature data implied that these BC data are able to investigate the changes of future SPI and SPEI

5.2 Existing Drought by SPI and SPEI

From the time series of difference time scale of SPI and SPEI were computed in present period, the severity and occurrence of drought can be identified by using the average SPI and SPEI under -1.0 and number of SPI and SPEI under -1.0 [16] shown as Table 6 and 7. The average severity of all regions by SPI was indicated in moderate dry class which varied from -1.38 to -1.40, while the number of drought events varied 32 to 41 times. The average severity of all regions by SPEI was indicated in moderate dry class which varied from -1.38 to -1.40, while the number of drought events varied 43 to 44 times.

Region	Average SPI under -1.0				Number of SPI under -1.0			
	SPI 1	SPI 3	SPI 6	SPI 12	SPI 1	SPI 3	SPI 6	SPI 12
North	-1.38	-1.39	-1.40	-1.40	30	39	41	41
North East	-1.39	-1.36	-1.35	-1.34	38	41	42	41
Central	-1.40	-1.39	-1.38	-1.38	39	43	43	43
East	-1.38	-1.40	-1.40	-1.41	30	39	41	40
South East	-1.39	-1.43	-1.42	-1.42	35	42	42	41
South West	-1.36	-1.39	-1.41	-1.42	30	39	39	39
All region	-1.38	-1.39	-1.40	-1.40	32	40	41	40

Table 6 Average SPI and Number of SPI under -1.0 in present period

Region	Average SPI under -1.0				Number of SPI under -1.0			
	SPEI 1	SPEI 3	SPEI 6	SPEI 12	SPEI 1	SPEI 3	SPEI 6	SPEI 12
North	-1.40	-1.40	-1.39	-1.38	43	44	44	45
North East	-1.34	-1.33	-1.32	-1.32	41	43	44	42
Central	-1.36	-1.35	-1.35	-1.35	43	45	46	45
East	-1.40	-1.40	-1.41	-1.40	43	45	44	44
South East	-1.40	-1.40	-1.39	-1.39	44	46	45	45
South West	-1.41	-1.40	-1.40	-1.40	43	43	43	42
All region	-1.40	-1.39	-1.39	-1.38	43	44	44	44

Table 7 Average SPEI and Number of SPEI under -1.0 in present period

5.4 Prediction of future drought by SPI and SPEI

The future change of severity and number of drought event by SPI and SPEI calculation under RCP4.5 and RCP8.5 can be predicted as shown in Table 8 and 9. It was found that the future change of severity of drought by SPI tends to vary -1.23% to 2.5% under RCP4.5 and vary -1.41% to 1.93% under RCP8.5, while the future change of occurrence tends to vary 3% to 25% under RCP4.5 and vary 5% to 26% under RCP8.5. The drought events in near future period occurs more frequency than other periods. Fig.2 shows that the change of average SPI6 tends to vary -1.88% to 3.5% under RCP4.5 and vary -0.78 to 4.18 under RCP8.5, while the change of occurrence tends to vary 1% to 27% under 4.5 and vary 2% to 29% under RCP8.5.

Furthermore, it was found that the future change of severity of drought by SPEI tends to vary -3.01% to 1.98% under RCP4.5 and vary -3.68% to 2.03% under RCP8.5, while the future change of occurrence tends to vary 3% to 29% under RCP4.5 and vary 7% to 37% under RCP8.5. The drought events in near future period occurs more frequency than other periods. Fig.2 shows that the change of average SPEI6 tends to vary -3.01% to 1.45% under RCP4.5 and vary -3.68 to 2.03 under RCP8.5, while the change of occurrence tends to vary 6% to 28% under 4.5 and vary 7% to 36% under RCP8.5. North Eastern of Thailand has the highest severity of drought compared with the other regions.

5.6 Consistency index of SPI and SPEI

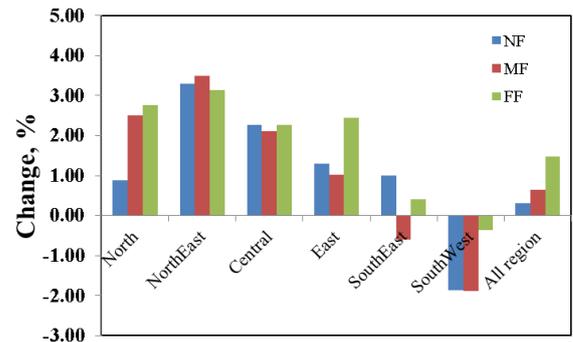
The consistency index of severity and occurrence of drought which calculated from SPI and SPEI can be analyzed as shown in Table 10 and 11. It was found that the consistency of severity by SPI tend to slightly decrease from -0.60 to -0.23 under RCP4.5 and vary -0.69 to 0.16 under RCP8.5, while the consistency of occurrence tends to vary 0.65 to 0.99 under RCP4.5 and vary 0.77 to 0.99 under RCP8.5. In the other hand, the consistency of severity by SPEI tend to vary from -0.75 to 0.27 under RCP4.5 and vary -0.79 to 0.51 under RCP8.5, while the consistency of occurrence tends to vary 0.38 to 1.00 under RCP4.5 and vary 0.59 to 1.00 under RCP8.5.

Region	Change of severity, %				Change of occurrence, %			
	SPI 1	SPI 3	SPI 6	SPI 12	SPI 1	SPI 3	SPI 6	SPI 12
RCP4.5 in near future								
North	1.67	0.76	0.87	-0.24	17	24	24	27
North East	0.93	2	3.3	3.51	15	18	17	19
Central	0.95	2.19	2.28	1.91	17	21	20	22
East	1.64	-0.24	1.29	-2.16	20	25	25	33
South East	1.28	-0.74	0.99	-1.01	20	23	27	34
South West	1.97	-0.7	-1.88	-3.53	18	21	25	21
All region	1.61	0.27	0.31	-1.23	18	23	24	25
RCP4.5 in mid future								
North	2.63	2.02	2.51	2.09	4	7	9	8
North East	0.18	1.45	3.5	3.98	0	7	4	5
Central	0.5	0.87	2.1	3.66	2	10	8	8
East	3.68	-0.11	1.02	-0.64	4	9	13	16
South East	3.45	-1.46	-0.59	-0.74	0	10	14	18
South West	2.16	-0.79	-1.88	-2.07	4	2	11	9
All region	2.31	0.41	0.64	0.42	3	6	10	10
RCP4.5 in far future								
North	2.49	2.26	2.76	2.65	7	11	12	9
North East	0.74	2.55	3.14	0.92	0	3	1	2
Central	1.05	2.39	2.26	0.79	1	6	6	4
East	3.37	2.22	2.44	-0.38	8	9	10	10
South East	3.86	0.66	0.41	-0.14	2	11	14	9
South West	2.64	0.71	-0.37	-2.69	4	6	11	12
All region	2.5	1.67	1.48	-0.01	5	8	10	9
RCP8.5 in near future								
North	2.19	0.81	1.06	-0.24	19	25	23	21
North East	-0.04	3.12	2.46	2.57	20	21	22	15
Central	0.52	2.43	1.42	2.24	20	24	25	19
East	1.73	1.16	1.4	0.67	24	24	25	29
South East	1.01	0.4	0.62	-0.27	20	23	29	30
South West	1.52	0.32	-0.28	-1.11	19	23	29	35
All region	1.53	0.96	0.74	0.01	20	24	26	26
RCP8.5 in mid future								
North	1.71	0.75	0.35	-1.89	5	10	6	3
North East	2.09	4.67	4.18	1.84	1	1	2	3
Central	1.3	3.43	2.27	0.36	3	5	7	7
East	2.68	2.37	0.78	-2.62	9	10	12	17
South East	1.87	1.73	1.7	0.61	7	8	11	12
South West	2.08	0.59	-0.78	-1.93	7	6	7	6
All region	1.93	1.48	0.52	-1.41	6	7	8	7
RCP8.5 in far future								
North	1.77	2.05	1.41	0.92	5	8	9	13
North East	1.33	2.3	2.65	1.49	0.2	3	3	-1
Central	1.71	1.65	1.29	0.37	1	6	6	1
East	1.55	0.37	1.42	2.99	8	11	15	11
South East	1.61	-0.44	2.25	3.21	5	11	15	9
South West	1.2	0.22	1.05	2.63	6	7	12	10
All region	1.52	1.01	1.39	1.88	5	8	10	9

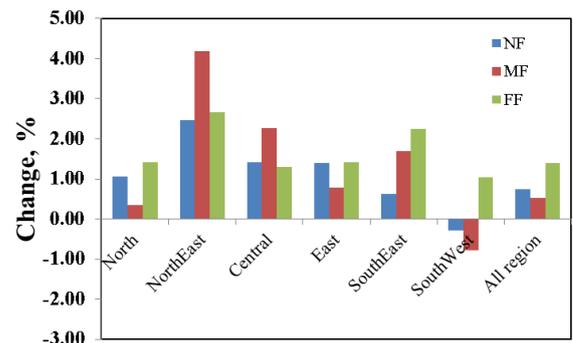
Table 8 Change of severity and occurrence by SPI in future period

Region	Change of severity, %				Change of occurrence, %			
	SPEI 1	SPEI 3	SPEI 6	SPEI 12	SPEI 1	SPEI 3	SPEI 6	SPEI 12
RCP4.5 in near future								
North	0.22	-0.25	0.80	0.48	27	28	25	27
North East	-1.77	-1.07	1.03	1.15	23	21	19	29
Central	-1.37	-0.81	0.50	0.79	24	21	20	26
East	0.04	-0.13	-1.16	-1.70	29	23	25	25
South East	0.38	0.18	0.38	-1.09	29	26	26	26
South West	-0.20	-1.16	-0.59	-0.53	28	27	28	28
All region	-0.20	-0.60	0.01	-0.20	27	26	25	27
RCP4.5 in mid future								
North	-0.32	0.07	0.76	-0.56	14	11	8	3
North East	-1.83	-0.65	1.45	1.74	6	9	6	14
Central	-1.54	-0.47	0.89	1.98	9	8	7	10
East	0.55	-0.06	-1.29	0.31	13	13	15	7
South East	-0.39	0.32	0.16	-0.02	15	14	15	15
South West	-1.02	-0.02	-0.77	-0.61	18	14	17	13
All region	-0.64	-0.05	-0.03	-0.02	14	12	12	9
RCP4.5 in far future								
North	-0.99	-0.20	-0.43	1.62	17	14	16	9
North East	-0.78	-1.45	-0.55	-2.04	9	9	9	15
Central	-0.98	-0.80	-0.88	-1.52	10	8	11	13
East	-0.81	-0.46	-3.01	-1.37	20	12	19	10
South East	-1.47	-1.25	-2.45	-1.92	19	15	21	17
South West	-0.40	-0.85	-1.51	0.33	18	15	19	13
All region	-0.79	-0.64	-1.34	0.02	17	13	17	12
RCP8.5 in near future								
North	-0.10	-0.90	-1.00	1.52	28	28	29	22
North East	-1.34	-0.60	-0.92	0.31	24	23	23	27
Central	-1.70	-0.84	-1.79	-0.83	27	25	26	27
East	-1.13	-1.63	-3.68	-0.28	30	28	33	26
South East	-1.96	-1.62	-2.14	-2.83	32	29	32	37
South West	-1.03	-1.36	-2.95	-2.09	29	29	36	34
All region	-0.92	-1.18	-2.18	-0.55	29	28	31	28
RCP8.5 in mid future								
North	-0.31	0.38	0.73	0.95	17	14	15	13
North East	0.23	1.19	2.03	1.34	13	8	7	15
Central	0.18	0.75	0.93	0.50	13	10	9	14
East	0.73	0.29	-1.55	-0.71	17	16	20	24
South East	0.56	0.14	0.78	0.54	16	18	18	22
South West	0.35	0.80	-0.44	-1.68	19	15	21	26
All region	0.19	0.56	0.11	-0.21	17	14	17	20
RCP8.5 in far future								
North	0.65	-0.09	-0.40	0.28	19	16	17	16
North East	-0.08	1.15	1.60	1.27	15	10	10	16
Central	-0.49	0.33	0.00	1.31	18	12	12	12
East	-0.59	0.01	-2.07	0.44	22	15	21	19
South East	-0.64	-0.72	-1.13	1.77	19	19	24	19
South West	-0.61	0.25	-0.66	0.49	24	19	23	19
All region	-0.19	0.09	-0.64	0.64	21	16	19	17

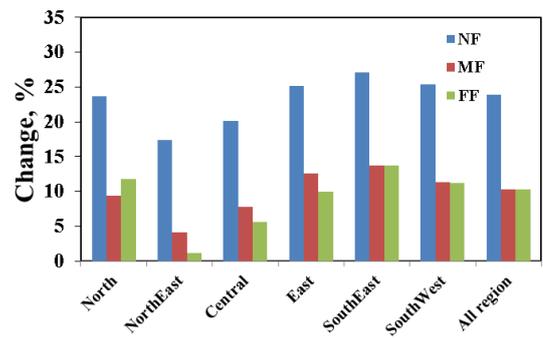
Table 9 Change of severity and occurrence by SPEI in future period



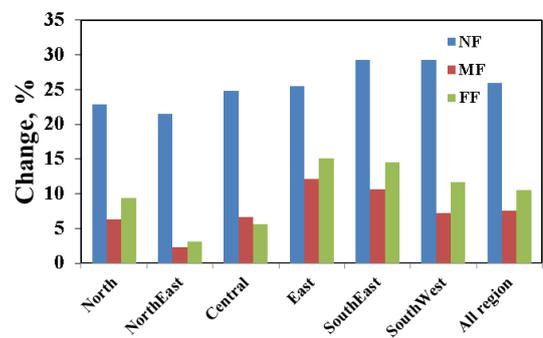
(a) SPI6 under RCP4.5



(b) SPI6 under RCP8.5

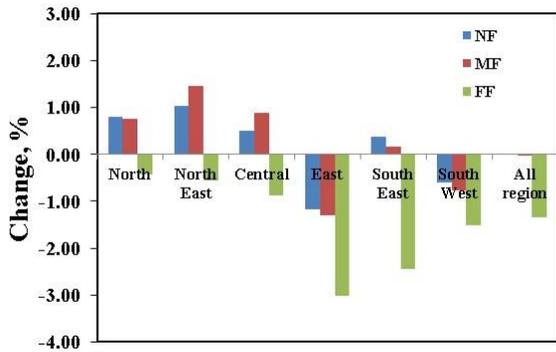


(c) Number of SPI6 under -1.0 under RCP4.5

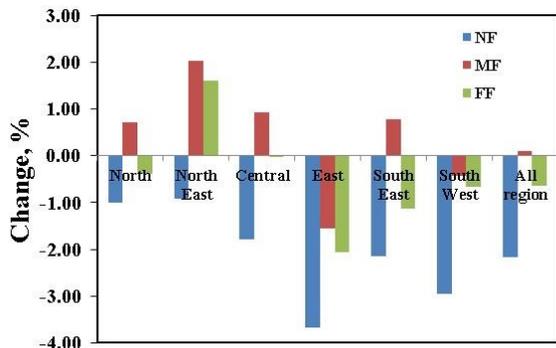


(d) Number of SPI6 under -1.0 under RCP8.5

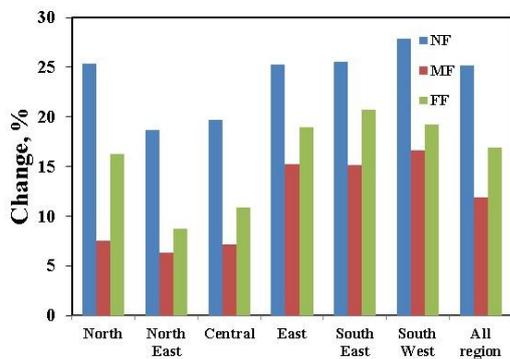
Fig. 2 : Change of drought severity by SPI6 under RCP4.5 and RCP8.5



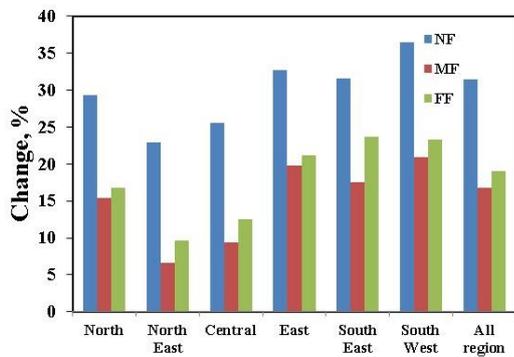
(a) SPEI6 under RCP4.5



(b) SPEI6 under RCP8.5



(c) Number of SPEI6 under -1.0 under RCP4.5



(d) Number of SPEI6 under -1.0 under RCP8.5

Region	Consistency of severity, %				Consistency of occurrence, %			
	SPI1	SPI3	SPI6	SPI12	SPI1	SPI3	SPI6	SPI12
RCP4.5 in near future								
North	0.07	-0.22	0.02	-0.41	0.85	0.95	0.91	0.87
NorthEast	0.01	0.30	0.27	0.44	0.82	0.87	0.84	0.83
Central	0.11	0.36	0.27	0.10	0.83	0.90	0.88	0.86
East	0.51	-0.27	0.33	-0.61	0.89	0.89	0.93	0.94
SouthEast	0.32	-0.45	0.33	-0.41	0.97	0.93	0.97	0.97
SouthWest	0.00	-0.54	-0.41	-0.71	0.87	0.90	0.93	0.80
All region	0.13	-0.26	-0.01	-0.44	0.87	0.92	0.92	0.86
RCP4.5 in mid future								
North	0.51	0.05	0.04	-0.04	0.45	0.42	0.22	
NorthEast	-0.31	0.30	0.56	0.35	-0.37	0.65	0.53	0.49
Central	0.01	0.14	0.41	0.48	-0.08	0.68	0.66	0.45
East	0.61	-0.54	-0.34	-0.57	0.01	0.56	0.80	0.76
SouthEast	0.59	-0.62	-0.25	-0.40	-0.28	0.83	0.86	0.86
SouthWest	0.45	-0.56	-0.51	-0.55	0.42	0.32	0.69	0.31
All region	0.42	-0.25	-0.14	-0.22	0.08	0.49	0.62	0.41
RCP4.5 in far future								
North	0.48	0.34	0.25	-0.26	0.24	0.78	0.62	0.61
NorthEast	-0.02	0.37	0.22	-0.37	-0.24	0.09	0.11	0.43
Central	0.03	0.29	0.18	-0.04	-0.08	0.55	0.54	0.37
East	0.72	0.53	0.37	-0.47	0.55	0.78	0.67	0.54
SouthEast	0.76	-0.09	0.00	-0.45	0.07	0.84	0.87	0.53
SouthWest	0.49	-0.08	-0.15	-0.57	0.22	0.59	0.59	0.44
All region	0.46	0.20	0.11	-0.38	0.20	0.67	0.61	0.50
RCP8.5 in near future								
North	0.63	-0.08	0.06	-0.56	0.89	0.95	0.85	0.83
NorthEast	-0.15	0.65	0.13	0.31	0.87	0.96	0.97	0.82
Central	0.08	0.53	0.07	0.21	0.87	0.98	0.98	0.86
East	0.72	-0.06	0.28	-0.31	0.96	0.94	0.93	0.89
SouthEast	0.68	-0.24	0.07	0.05	0.98	0.98	0.99	0.96
SouthWest	0.46	-0.28	-0.30	-0.52	0.90	0.95	0.96	0.89
All	0.49	-0.05	-0.02	-0.34	0.91	0.96	0.93	0.87
RCP8.5 in mid future								
North	0.28	-0.26	-0.08	-0.68	0.59	0.77	0.51	-0.06
NorthEast	0.44	0.68	0.50	-0.09	-0.07	0.34	0.46	0.64
Central	0.26	0.58	0.14	-0.22	0.05	0.64	0.71	0.67
East	0.70	0.26	0.22	-0.69	0.66	0.88	0.81	0.82
SouthEast	0.62	0.31	0.64	-0.11	0.69	0.86	0.87	0.76
SouthWest	0.21	-0.31	-0.17	-0.50	0.62	0.65	0.45	0.15
All	0.34	-0.03	0.03	-0.50	0.53	0.72	0.58	0.30
RCP8.5 in far future								
North	-0.20	-0.04	-0.08	-0.58	0.51	0.61	0.62	0.64
NorthEast	0.13	0.24	0.20	-0.30	-0.27	0.14	0.53	0.07
Central	0.17	-0.01	-0.12	-0.22	-0.11	0.48	0.62	0.17
East	0.14	-0.46	-0.35	-0.49	0.69	0.74	0.81	0.64
SouthEast	0.34	-0.53	0.18	-0.35	0.49	0.80	0.90	0.49
SouthWest	0.12	-0.59	-0.43	-0.40	0.34	0.70	0.73	0.33
All region	0.05	-0.30	-0.21	-0.44	0.37	0.64	0.70	0.45

Table 10 Consistency of severity and occurrence by SPI in future period

Fig. 3: Change of drought severity by SPEI6 under RCP4.5 and RCP8.5

Region	Consistency of severity, %				Consistency of occurrence, %			
	SPI1	SPI3	SPI6	SPI12	SPI1	SPI3	SPI6	SPI12
RCP4.5 in near future								
North	-0.07	-0.44	-0.24	-0.19	0.99	0.99	0.88	0.88
NorthEast	-0.61	-0.56	0.11	-0.02	0.93	0.93	0.90	0.89
Central	-0.54	-0.43	0.15	0.02	0.97	0.94	0.92	0.89
East	-0.34	-0.40	-0.56	-0.55	1.00	0.96	0.93	0.88
SouthEast	-0.37	-0.37	0.02	-0.44	1.00	1.00	0.96	0.85
SouthWest	-0.44	-0.64	-0.54	-0.41	1.00	0.97	0.96	0.92
All region	-0.33	-0.50	-0.30	-0.29	0.99	0.97	0.93	0.89
RCP4.5 in mid future								
North	-0.35	-0.14	0.05	-0.54	0.89	0.86	0.46	0.38
NorthEast	-0.59	-0.57	0.14	0.23	0.48	0.78	0.69	0.73
Central	-0.60	-0.45	0.07	0.27	0.64	0.74	0.72	0.64
East	-0.25	-0.22	-0.48	-0.32	0.85	0.85	0.83	0.65
SouthEast	-0.52	-0.48	-0.21	-0.33	0.88	0.87	0.87	0.88
SouthWest	-0.66	-0.40	-0.43	-0.56	0.95	0.84	0.85	0.73
All region	-0.49	-0.31	-0.19	-0.37	0.86	0.84	0.71	0.61
RCP4.5 in far future								
North	-0.52	-0.45	-0.43	-0.40	0.94	0.90	0.89	0.77
NorthEast	-0.45	-0.67	-0.38	-0.48	0.52	0.75	0.74	0.69
Central	-0.40	-0.37	-0.31	-0.32	0.72	0.68	0.75	0.59
East	-0.57	-0.58	-0.75	-0.55	0.96	0.89	0.91	0.77
SouthEast	-0.72	-0.66	-0.75	-0.52	0.96	0.89	0.94	0.85
SouthWest	-0.53	-0.57	-0.69	-0.65	0.95	0.87	0.89	0.75
All region	-0.53	-0.52	-0.57	-0.51	0.90	0.86	0.87	0.75
RCP8.5 in near future								
North	-0.30	-0.59	-0.60	-0.34	0.99	0.99	0.96	0.92
NorthEast	-0.66	-0.57	-0.35	0.28	0.92	0.98	0.94	0.89
Central	-0.69	-0.53	-0.59	-0.14	0.98	0.98	0.96	0.90
East	-0.49	-0.71	-0.75	-0.24	0.99	1.00	0.99	0.85
SouthEast	-0.79	-0.72	-0.67	-0.71	0.98	1.00	1.00	0.96
SouthWest	-0.65	-0.70	-0.67	-0.63	1.00	0.99	0.99	0.93
All region	-0.54	-0.64	-0.64	-0.40	0.99	0.99	0.98	0.92
RCP8.5 in mid future								
North	-0.40	-0.30	-0.37	-0.32	0.92	0.89	0.80	0.77
NorthEast	-0.18	0.02	0.02	-0.19	0.77	0.79	0.73	0.59
Central	-0.33	-0.06	-0.08	-0.08	0.80	0.84	0.76	0.65
East	-0.40	-0.32	-0.35	-0.40	0.90	0.94	0.89	0.91
SouthEast	-0.51	-0.32	0.32	-0.15	0.90	0.95	0.92	0.83
SouthWest	-0.30	0.00	-0.58	-0.64	0.96	0.88	0.89	0.86
All region	-0.36	-0.16	-0.34	-0.39	0.91	0.89	0.84	0.80
RCP8.5 in far future								
North	-0.02	-0.19	-0.44	-0.13	0.96	0.88	0.80	0.78
NorthEast	-0.46	0.28	0.51	0.27	0.91	0.83	0.79	0.67
Central	-0.37	0.14	-0.13	0.28	0.95	0.88	0.81	0.64
East	-0.55	-0.29	-0.63	0.21	0.99	0.90	0.87	0.82
SouthEast	-0.51	-0.54	-0.39	0.36	1.00	0.98	0.95	0.70
SouthWest	-0.48	-0.02	-0.42	0.09	1.00	0.90	0.85	0.77
All region	-0.34	-0.11	-0.38	0.09	0.98	0.89	0.84	0.75

Table 11 Consistency of severity and occurrence by SPEI in future period

6. Conclusions

From the existing severity that analyzed by SPI and SPEI performed the moderate drought varied from -1.38 to -1.40, while the drought occurrences by SPEI (43 to 44 times) have more frequency than SPI (32 to 41 times).

For the future change of severity of drought by SPI slightly change from -1.41% to 2.5% under RCP4.5 and RCP8.5, while the future change of occurrence tends to increase 3% to 26% under RCP4.5 and RCP8.5. The future change of severity by SPEI tends to vary -3.68% to 2.03% under RCP4.5 and RCP8.5, while the future change of occurrence tends to increase 3% to 37% under RCP4.5 and RCP8.5. The drought events in near future period occurs more frequency than other periods. From the results, it shows that severity by SPI of North-Eastern tend to slightly increase, while the occurrence of South Eastern, Eastern, and South Western tend to increase.

The consistency index of severity by SPI performed high value than severity of drought by SPEI under RCP4.5, while the consistency index of severity by SPEI performed high value than severity of drought by SPI under RCP8.5. Moreover, the consistency of occurrence by SPEI performed high value than occurrence by SPI.

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