ASSESSMENT OF FUTURE DROUGHT HAZARD TO AGRICULTURAL AREA IN MUN RIVER BASIN, THAILAND

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Abstract

The Mun River Basin is one of the river basin in Thailand that is faced drought disaster. It impacts to agriculture area of country which was a huge loss of income. Thus, this research presents an assessment of drought to agricultural area in Mun River Basin under climate change projection from three Reginal Climate Models (RCMs) under two Representative Concentration Pathway (RCP4.5 and 8.5). The future projection is considered into three future period 2020s, 2050s and 2080s. The study used Standardized Precipitation Index (SPI), the distance from surface water resources, and groundwater yield to analyze the future drought hazard with Analytic Hierarchy Process (AHP) for determination the weighting factor. The drought period bases on standing shortage of rainfall for rice, field crops and fruit crops so the SPI were evaluated as SPI1, SPI3, and SPI6, respectively. The future drought hazard maps were showed as four drought levels: very low, low, medium, and high. The results found that SPI1 under RCP4.5 and 8.5 have a trend of drought level as low and medium level in 2020s – 2080s. For SPI3 under both RCP4.5 and 8.5, the drought level has trended to decrease both in 2050s and 2080s by compare with in 2020s, changing form high to medium and low level. For SIP6 under RCP4.5, the drought hazard level has trended to decrease severity under RCP4.5 both in 2050s and 2080s by changed from high to medium. Whereas, the drought hazard level under RCP8.5 was the high hazard level in 2050s and 2080s.

Keywords: *Analytic Hierarchy Process, Climate Change, Drought Hazard, Mun River Basin, SPI*

1. INTRODUCTION

Most of the drought problems are caused by the absence of seasonal rainfall and a little or no rainfall for the long time in river basin. They also include a changing river basin or land use change as a result of community expansion, economic activities, etc. The climate change is one of factors affecting drought disaster [18], [4]. The drought often impacts on the agricultural sector, causing losses in many ways. Many river basins in Thailand are faced with drought disaster almost every year, especially the river basin in the Northeast. The Northeast is an important area of economic crops such as rice, sugarcane, cassava, and corn, etc. These crops have a large production volume in this region worth several hundred thousand million baths. The one of the major river basins in the Northeast is Mun River Basin. In 1997, this river basin suffered severe drought that affected agricultural and caused damage of over 9,300 million baths. In the future, it is predicted that the drought will likely be more severe from climate and land use change. The study of climate change impact on hydrological cycle found that the important factors for streamflow in river basin are temperature and rainfall [13]. Besides, the streamflow changing based on land use change [2], [12]. The Standardized Precipitation Index (SPI) is used to analyze drought hazard from previous study [3], [15]. The study of drought severity using SPI in the lower Nam Phong river basin, which is sub-river in Mun River Basin, indicated that SPI can be used as index for monitoring drought [9], [16]. Moreover, the study of Tingsanchali and Piriyawong [9] used other factors, which are distance from surface water resources and groundwater yield, to study the drought hazard severity. Therefore, the aim of this research is to assess of the future drought hazard in Mun River Basin depend on the rainfall under climate change and land use condition using combination of SPI value, distance from surface water resources, and groundwater yield.

2. STUDY AREA AND DATA COLLECTION

2.1. STUDY AREA

The Mun River Basin is the largest watershed as show in Fig.1. It is located in Northeast Thailand which covers

10 Provinces: Amnat Charoen, Burirum, KhonKaen, Mahasarakham, Nakhon Ratchasima, Roi Et, Sisaket, Surin, Ubon Ratchathaini, and Yasothon. The Mun River Basin, which can be divided as Upper Mun, Middle Mun, and Lower Mun, lies between longitudes 101°30′ – 105°30′ E, and latitudes 14° – 16° N. The river in this basin flows east and converges with the Chi River Basin before reaching its confluence with the Mekong River [6}. The basin area of the Mun River Basin is approximately 71,000 km^2 with 75% of agricultural area. The rainfall pattern this area is influenced by the southeast monsoon so it has rainfall duration in May to September. The annual rainfall is between 800 -1,800 mm. The average monthly temperature ranges between 24°C – 30°C [6].

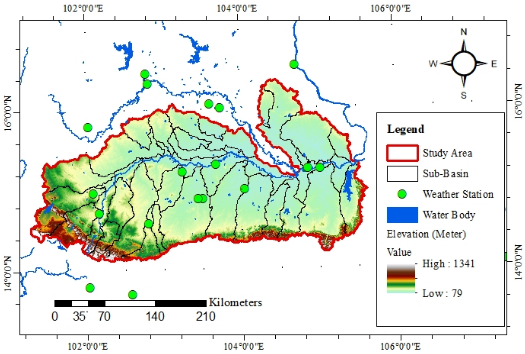


Figure 1 Location of study area in the Mun River Basin

2.2. DATA COLLECTION

The climate data were obtained from observation stations of Thai Meteorological Department (TMD) and Royal Irrigation Department (RID) in the Mun River Basin and nearby. These observated climate data were used as calibration and validation data for methods of bias correction and analysis standardized precipitation index (SPI) [10]. The data of groundwater were used from measuring the groundwater level of Department of Groundwater Resources (DGR). Moreover, the three Regional Climate Changes (RCMs), which are ACCESS, CNRM, and MPI with 0.5° per daily resolution, were projected the future climate change under two Representative Concentration Pathway (RCP4.5 and 8.5).

3. METHODOLOGY

There are three steps for future drought hazard assessment in the Mun River Basin. Firstly, the linear downscaling method was applied for bias correction step to compare and project the future climate. Secondly, this step is an analysis the drought parameters which are SPI, distance from surface water resources, and groundwater yield. SPI was considered from average three future climate (rainfall) projection of the resulted first step. This step determined the drought weighting factors by using Analytic Hierarchy Process (AHP) method [10]. Lastly, it is a simulation the drought hazard levels and prediction the future drought hazard maps under RCP4.5 and 8.5 into three periods: near future (2020s), mid future (2050s), and far future (2080s).

3.1. BIAS COLLECTION

Bias correction is a comparing the RCMs data with the observation data during the historical period. When doing bias correction, the RCMs data should have a consistent value and pattern with the observation data. The daily rainfall data of three RCMs were adjusted data by linear scaling method in this study. Due to this method was used from previous studied [8] – [14] to increase precision of predicted data. Equations (1) and (2) were used for bias correction of historical and simulated rainfall data of RCMs with the observation rainfall data, respectively. The historical and predicted period of this study are 1970 – 2010 and 2011 – 2100, respectively. The standard deviation (SD) and mean values were applied to examine the precision of the dispersion and central tendency of data between RCMs and observation.

$$R'_{his,d} = R_{his,d}\alpha_m \tag{1}$$

$$R'_{sim,d} = R_{sim,d}\alpha_m \tag{2}$$

Where R is the rainfall, "his" and "sim" are the historical and simulated RCMs data, respectively, " $'$ " is the corrected value, α_m is the weighting factor on monthly unit $\alpha_m = \left[\frac{R_{base,d}}{R_{his,d}}\right]/n_d$, n_d is the number days in month, base is the baseline data.

3.2. STANDARDIZED PRECIPITATION INDEX (SPI)

The SPI is the one of simple calculated drought indices and it is often taken as indicator of drought hazard levels with different time scales [8], [14]. The SPI is computed by fitting the rainfall to a suitable distribution and transforming it into standard normal distribution. The SPI is calculated as Eq. (3) which use monthly rainfall data so the daily rainfall was changed as monthly rainfall for 12 months.

$$SPI = \frac{x_i - \bar{x}}{SD} \tag{3}$$

Where $\boldsymbol{x_i}$ is normalized rainfall, $\bar{\boldsymbol{x}}$ is long term mean rainfall, SD is standard deviation.

3.3. DETERMINATION OF DROUGHT WEIGHTING FACTORS

The SPI value, distance from water resources, and groundwater yield are drought factors to delineate drought hazard level in the Mun River Basin. The determination the drought weighting factors were computed by Analytical Hierarchy Process (AHP) method. The distance from surface water resources such as reservoirs or river or irrigation canals was analyzed based on three range levels (near, mid, and far). Groundwater yield were classified into four level depending on aquifer storage level and recovery rate at each location measured from data of groundwater pumping test and previous records. The AHP was separated as four levels drought hazard that are very low, low, medium, and high level. The first step of APH is the rank factors from 1 to 9 levels following relative significant scales. The taking no.1 is equally desirable of the same importance level for a pair of two drought factors. The no.3, 5, 7, and 9 are taken as moderately, strongly, very strongly, and extremely preferred. This study found that SPI value has more effective on agricultural area than the distance from surface water resource and groundwater yield. The next step of AHP is a creating the judgment matrix by using significant scales to weight each factors. The validity of calculation weights of the drought factors with AHP were examined the by using consistency indicators namely: Eigen values, consistency index and consistency ratio. Equations (4) – (6) show the equation of consistency indicators.

$$\lambda_{max} = \sum\nolimits_{i=1}^{n} \left[\sum\nolimits_{j=1}^{n} a_{ij} W_i \right] \tag{4}$$

$$CR = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

$$CI = \frac{CR}{RI} \tag{6}$$

Where *CI* is the consistency index, *CR* is the consistency ratio, *RI* is the random inconsistency index [1], λ_{max} is the Eigen value, a_{ij} is the judgment matrix data, W_i is the drought parameter weight i, n is the number of factors.

The drought hazard index can be computed by Eq. (7).

$$Hazard\ index = c_1 W_1 + c_2 W_2 + c_3 W_3 \tag{7}$$

Where c_i is the scores, and W_i is the weight (W_1+W_2+W_3=1) [10]. The ranges of score from 1-100% are defined in accordance with the ranges of drought hazard parameter. The values of W_1, W_2, and W_3 are determined according to the relative influence, which are achieved from survey and field data, among the SPI, the distance from surface water resources, and ground water yield (as shown in Table 1).

Table 1 Weighting factors and coefficient of drought hazard factors

No	Parameters	Drought Hazard Level	c_i	W_i
1	SPI	Extremely dry (<-0.75)	1.00	0.63
		Severely dry (-0.51 to -0.75)	0.80	
		Moderately dry (-0.26 to -0.50)	0.60	
		Near normal (-0.01 to -0.25)	0.40	
		Wet (>0)	0.20	
2	Distance of water resources (km)	Very far (>20.01)	1.00	0.26
		Far (10.01 to 20.00)	0.75	
		Medium (5.01 to 10.00)	0.50	
		Near (<5)	0.25	
3	Ground water yield (m^3/hr)	Very high (<2)	1.00	0.11
		High (2 to 10)	0.75	
		Moderate (10 to 20)	0.50	
		Low (>20)	0.25	

4. RESULTS AND DISCUSSIONS

4.1. CLIMATE BIAS CORRECTION AND PROJECTION

The average daily rainfall of three RCMs (ACCESS, CNRM, and MPI) were used to project the future climate under RCP4.5 and 8.5. The baseline data used from Thai Meteorological Department (TMD) in the Mun River Basin and surrounding to compare and adjust daily observed and simulated data by using linear scaling in 1970 – 2010. Table 2 shows the mean and SD which were employed to validate the dispersion and central tendency of the rainfall data between baseline and RCMs [10]. The results indicated that the mean values are quite near the baseline data. But the mean value for some stations are slightly higher than baseline data. Whereas, the SD values of three RCMs are rather lower than baseline values almost all TMD stations.

Table 2 Performance of downscaling method

Sta. ID	Indica-tors	Base-line	ACCESS	CNRM	MPI
381301	Mean	3.15	3.50	3.52	3.35
	SD	10.37	6.90	6.96	6.44
383201	Mean	4.13	4.70	4.75	4.59
	SD	12.14	9.57	11.02	9.11
403201	Mean	2.98	3.39	3.38	3.17
	SD	9.31	7.15	7.53	6.37
405201	Mean	3.68	4.02	4.23	3.97
	SD	11.29	7.20	8.40	8.97
407301	Mean	4.15	5.00	5.16	5.45
	SD	11.89	9.43	10.62	12.54
407501	Mean	4.32	4.94	4.96	4.90
	SD	12.44	8.89	9.62	10.68
431201	Mean	2.78	3.55	3.40	3.32
	SD	8.83	8.67	9.29	8.36
431401	Mean	2.93	3.68	3.48	3.49
	SD	9.10	8.85	9.02	8.75
432201	Mean	3.74	4.37	4.32	4.24
	SD	10.84	8.38	8.35	8.83
432301	Mean	3.89	4.54	4.39	4.36
	SD	11.35	9.74	8.82	9.81
432401	Mean	3.77	4.24	4.17	4.02
	SD	11.38	7.83	7.89	7.30
436401	Mean	3.21	3.95	3.81	3.78
	SD	9.55	8.41	9.55	8.70

The future rainfall were projected by calculating from the average daily rainfall of three corrected RCMs under RCP4.5 and 8.5 for three time periods. The data average method can increase the accuracy of predicted data and decrease the central tendency.

The future rainfall projection of Ubon Ratchathani meteorological station (407501) in the Mun River Basin was showed in this study as Table 3. The results of future rainfall projection on 2020s (2011 – 2040), 2050s (2041 – 2070), and 2080s (2071 – 2100) under RCP4.5 and 8.5 founded that they did not change for RCP4.5 and increased about 1% for RCP8.5.

Table 3 Annual rainfall rates with different RCPs on 2020s, 2050s and 2080s at Ubon Ratchathani Meteorological Station (407501)

Time	2020s		2050s		2080s	
RCPs	4.5	8.5	4.5	8.5	4.5	8.5
Rainfall	1,732	1,664	1,707	1,741	1,738	1,680

4.2. DROUGHT HAZARD ASSESSMENT

4.2.1. STANDARDIZED PERCIPITATION INDEX (SPI) DETERMINATION

The SPI is considered a drought period base on rainfall shortage. The SPI were evaluated as SPI1, SPI3, and SPI6 for plants shortage rainfall of 1, 3, and 6 month, respectively. The SPI1, SPI3, and SPI6 use to analyze plants shortage rainfall for paddy field (rice), field crop, and fruit crop, respectively. The values of SPI range between -3 to 3 depend on actual rainfall [13]. This study can be classified into four drought levels: mild drought (SPI: -0.01 to -0.25), moderate drought (SPI: -0.26 to -0.50), severe drought (SPI: -0.51 to -0.75), and extreme drought (SPI: <-0.75) as shown in Table 2. The TMD stations were used to compute SPI for three RCMs during 1970 – 2010. Table 4 illustrates the results of SPI1, SPI3, and SPI6 values in 2020s, 2050s, and 2080s under both RCP4.5 and 8.5. The SPI1, SPI3, and SPI6 in 2020s, 2050s, and 2080s have the negative values all TMD stations in the Mun River Basin. The negative value of SPI indicates a drought condition.

Table 4 The SPI1, SPI3 and SPI6 values at TMD stations in 2020s, 2050s and 2080s under RCP4.5 and 8.5

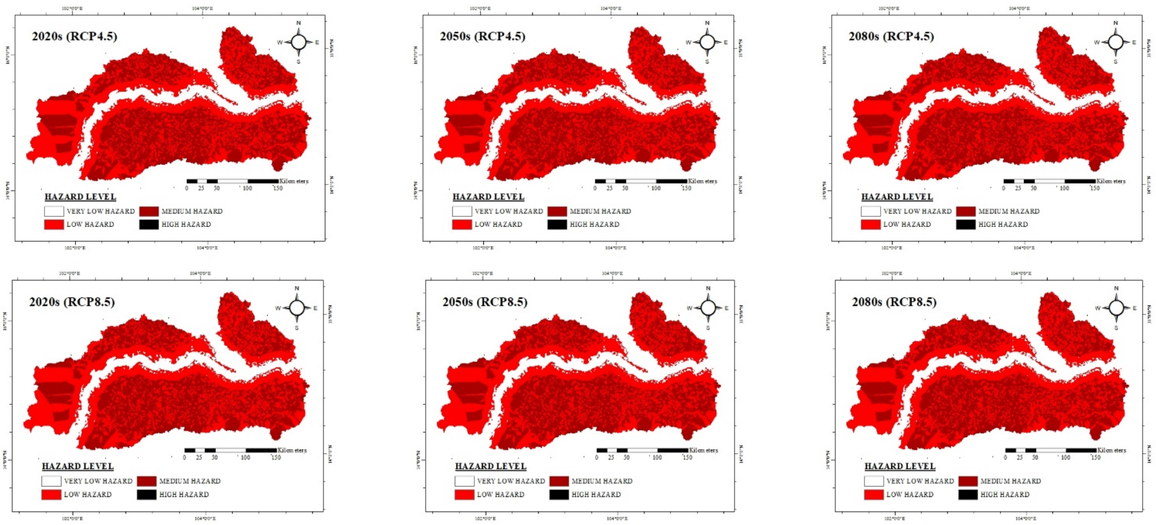
Sta. ID	2020s		2050s		2080s	
RCPs	4.5	8.5	4.5	8.5	4.5	8.5
			SPI1			
381301	-0.18	-0.23	-0.19	-0.17	-0.15	-0.18
383201	-0.20	-0.19	-0.22	-0.17	-0.20	-0.16
403201	-0.17	-0.21	-0.14	-0.13	-0.09	-0.13
405201	-0.19	-0.18	-0.09	-0.12	-0.16	-0.12
405301	-0.22	-0.19	-0.09	-0.07	-0.10	-0.10
407301	-0.16	-0.18	-0.14	-0.09	-0.09	-0.13
407501	-0.14	-0.17	-0.13	-0.09	-0.09	-0.12
409301	-0.21	-0.17	-0.10	-0.10	-0.05	-0.09
431201	-0.19	-0.19	-0.13	-0.11	-0.08	-0.13
431401	-0.20	-0.20	-0.13	-0.12	-0.19	-0.14
432201	-0.19	-0.21	-0.16	-0.13	-0.10	-0.13
432301	-0.21	-0.23	-0.15	-0.13	-0.13	-0.14
432401	-0.17	-0.20	-0.15	-0.13	-0.12	-0.12
436401	-0.21	-0.21	-0.16	-0.13	-0.11	-0.14
			SPI3			
381301	-0.31	-0.38	-0.32	-0.30	-0.24	-0.32
383201	-0.31	-0.37	-0.35	-0.31	-0.31	-0.28
403201	-0.35	-0.42	-0.28	-0.28	-0.21	-0.26
405201	7.65	-0.36	-0.13	-0.25	-0.24	-0.23
405301	-0.30	-0.34	-0.19	-0.16	-0.18	-0.17
407301	-0.29	-0.31	-0.24	-0.19	-0.18	-0.23
407501	-0.28	-0.31	-0.24	-0.20	-0.19	-0.22
409301	-0.27	-0.29	-0.22	-0.19	-0.15	-0.17
431201	-0.39	-0.38	-0.26	-0.24	-0.22	-0.26
431401	-0.39	-0.40	-0.23	-0.27	-0.37	-0.28
432201	-0.33	-0.36	-0.28	-0.24	-0.04	-0.23
432301	-0.36	-0.39	-0.26	-0.24	-0.23	-0.24
432401	-0.33	-0.36	-0.28	-0.26	-0.23	-0.22
436401	-0.39	-0.40	-0.29	-0.27	-0.24	-0.26
			SPI6			
381301	-0.45	-0.49	-0.47	-0.42	-0.34	-0.45
383201	-0.46	-0.53	-0.50	-0.49	-0.49	-0.47
403201	-0.53	-0.57	-0.44	-0.43	-0.40	-0.40
405201	-0.53	-0.53	-0.22	-0.42	-0.36	-0.41
405301	-0.45	-0.48	-0.33	-0.30	-0.33	-0.30
407301	-0.48	-0.49	-0.43	-0.38	-0.36	-0.41
407501	-0.49	-0.51	-0.45	-0.40	-0.39	-0.41
409301	-0.40	-0.41	-0.35	-0.34	-0.29	-0.30
431201	-0.54	-0.52	-0.37	-0.38	-0.38	-0.40
431401	-0.54	-0.56	-0.34	-0.42	-0.51	-0.44
432201	-0.53	-0.53	-0.45	-0.42	-0.38	-0.40
432301	-0.54	-0.55	-0.42	-0.42	-0.42	-0.42
432401	-0.50	-0.53	-0.48	-0.45	-0.41	-0.39
436401	-0.55	-0.54	-0.44	-0.42	-0.41	-0.41

4.2.2. WEIGHTING FACTOR DETERMINATION

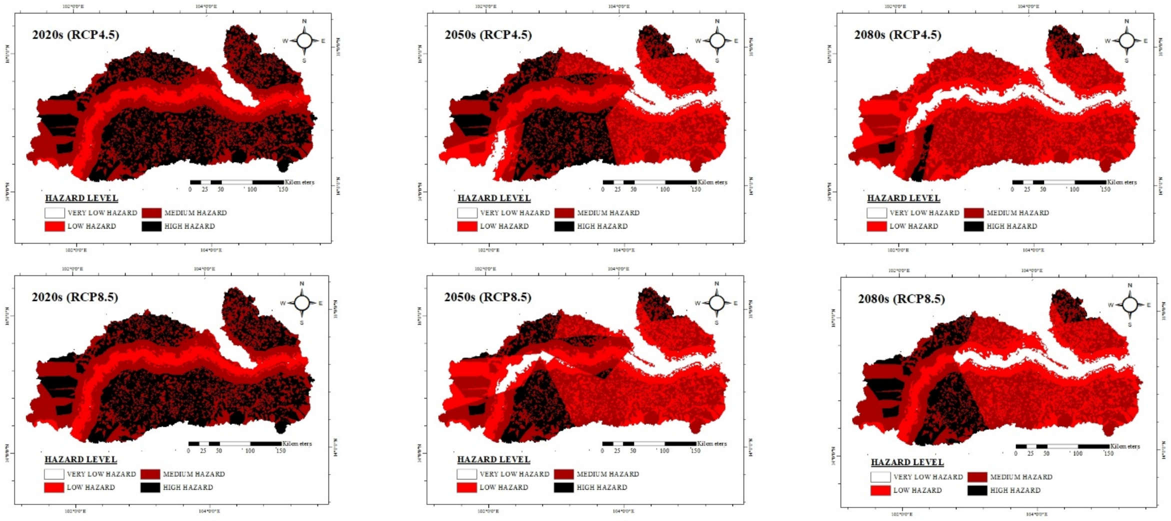
The SPI, distance from surface water resource, and groundwater yield were calculated the weighting factors by using AHP. The weight value was evaluated from relatively according to the ground survey, questionnaire, and meteorological stations data in the Mun River Basin. The result of survey indicated that the SPI has a greater influence on the distance from surface water resources and groundwater yield. Besides, the SPI has the highest effect on rice cultivation during drought duration. The pairwise comparison matrix is created a 3x3 matrix as shown in Table 5. The each element values in row were defined as each drought factors. The values of 1, 3, and 5 were set in first row of element respectively. Moreover, the value of 1 is given to all elements along the diagonal of matrix. In the matrix element of each column below the diagonal element, the reciprocal value of the element above the diagonal element is used to fill in [11], [17]. The pairwise comparison matrix is normalized weight by setting the sum of each column equal 1. The weight of SPI, distance from surface water resources, and groundwater yield are 0.63, 0.26, and 0.11 respectively as shown in Table 6. The consistency parameters such as Eigen value (λ_{max}), consistency index (CI), and consistency ratio were used to verify the weighting factors. The Eigen value should be equal to the number of all drought hazard parameters. The consistency index and ratio should be close to zero. The study found that the Eigen value has equal the number of hazard parameter, which is 3. The consistency index and ratio are about zero.

Table 5 Pairwise Comparison Metrix

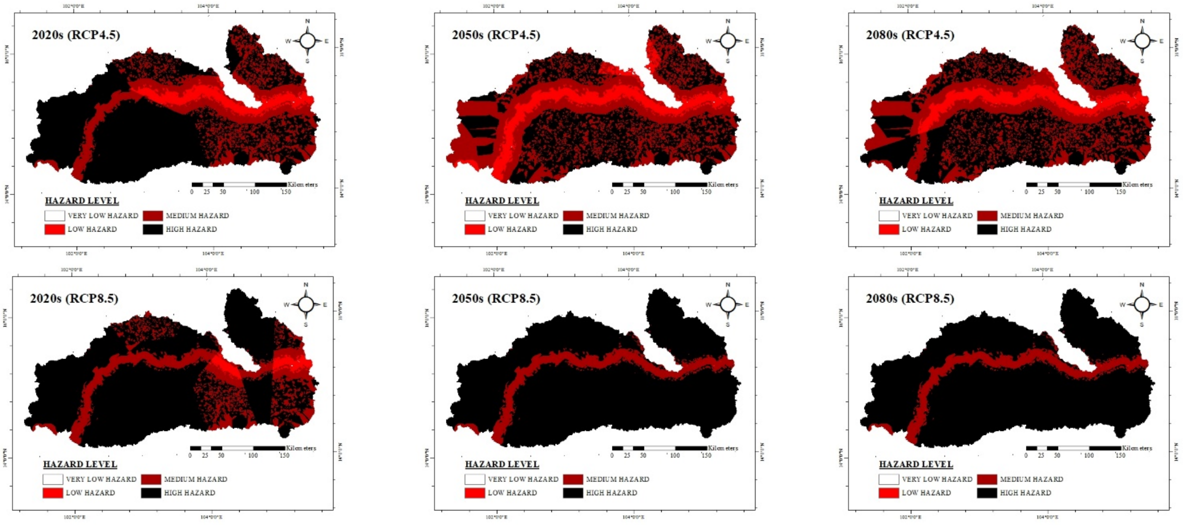
Hazard Factors	SPI Value	Distancefrom water Resource	Groundwater Yield
SPI Value	1	3	5
Diatance from Water Resource	1/3	1	3
Geoundwater Yield	1/5	1/3	1



(a) Drought hazard maps for paddy field SPI1 under RCP4.5 and 8.5



(b) Drought hazard maps for field crops SPI3 under RCP4.5 and 8.5



(c) Drought hazard maps for fruit crops SPI6 under RCP4.5 and 8.5

Figure 2 Future meterological drought hazard maps of the Mun River Basin for 2020s, 2050s, and 2080s

Table 6 Determination the normalized weights for thematic layer

Hazard Factors	SPI Value	Distance from water Resources	Groundwater Yield	Weight (W_i)
SPI Value	15/23	9/13	5/9	0.63
Diatance from Water Resources	5/23	3/13	3/9	0.26
Geoundwater Yield	3/23	1/13	1/9	0.11
Summation	1.00	1.00	1.00	1.00

4.3. DROUGHT HAZARD LEVEL PREDICTION

The drought hazard indexs were computed to create the drought hazard map in the Mun River basin as shown in Fig. 2. The minimum and maximum drought hazard indices are 34 - 87. Therefore, the drought hazard levels can be separated into four levels by normalized in a range of 0 – 100%, which are very low (0 – 25%), low (25 – 50%), medium (50 – 75%), and high (75 – 100%). Figure 2(a) shows the paddy field of future drought hazard maps with SPI1 under different RCPs in 2020s – 2080s. It indicated that drought hazard levels in 2080s for RCP4.5 and 8.5 were unchanged from 2020s and 2050s. The drought hazard level of SPI1 under RCP4.5 and 8.5 in 2020s – 2080s tends to be mostly low and medium. Figure 2(b) shows the field crop of future drought hazard maps with SPI3 under different RCPs in 2020s – 2080s. They study found that the drought hazard map has trended to decrease severity under RCP4.5 and 8.5 both in 2050s and 2080s by changed from high to medium and low. Figure 2(c) shows of the fruit crops future drought hazard maps with SPI6 under different RCPs in 2020s – 2080s. The result showed that drought hazard level has trended to decrease severity under RCP4.5 both in 2050s and 2080s by changed from high to medium. Whereas, the drought hazard level under RCP8.5 has trended to increase severity as high in 2050s and 2080s. The almost map of SPI6 under RCP8.5 was the high hazard level in 2050s and 2080s. Therefore, the drought under different RCPs (4.5 and 8.5) have more significant in the Mun River Basin in 2020s – 2080s for every crops.

5. CONCLUSIONS

The Mun River Basin future drought hazard was evaluated in 2020s – 2080s under both RCP4.5 and 8.5. The three parameters which are SPI, the distance from surface water resources, and groundwater yield were used to analyze the drought hazard. The future drought hazard map were presented as four levels which are very low, low, medium, and high into three time scales (2020s, 2050s, and 2080s) under RCP4.5 and 8.5. For SPI1 under RCP4.5 and 8.5, the drought hazard level tends to be mostly low and medium in 2020s – 2080s. It did not change each time period. For SPI3 under RCP4.5 and 8.5, the drought level has trended to decrease both in 2050s and 2080s by compare with in 2020s, changing form high to medium and low levels. For SIP6 under RCP4.5, the drought hazard level has trended to decrease severity under RCP4.5 both in 2050s and 2080s by changed from high to medium. Whereas, the drought hazard level under RCP8.5 was the high hazard level in 2050s and 2080s. However, this study is only a projection of the future drought hazard base on rainfall (SPI). If other factors such as evapotranspiration, soil moisture conditions, and change in discharge are taken into account, they may have changed this results. The study results of future drought can help to local people, researchers and policymakers to adapt and change agricultural cycle to reduce potential damage.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Ahmad I., Verma M.K. (2018). Application of Analytic Hierarchy Process in Water Resources Planning: A GIS Based Approach in the Identification of Suitable Site for Water Storage. *Water Recourses Management* 32, 5093-5114.

[2] Al-Safi H.I.J., Sarukkalige P.R. (2018). Evaluation of the impacts of future hydrological changes on the sustainable water resources management of the Richmond River catchment. *Journal of Water and Climate Change* 9, 137-155.

[3] Guenang G.M., Kamga, F.M. (2014). Computation of the Standardized Precipitation Index (SPI) and its use to assess drought occurrences in Cameroon over recent decades. *Journal of Applied Meteorology and Climatology* 53, 2310-2324.

[4] Janes T., McGrath F., Macadam I., Jones R. (2019). High-Resolution Climate Projections for South Asia to Inform Climate Impacts and Adaptation Studies in the Ganges-Brahmaputra-Meghna and Mahanadi Deltas. *Sci. Total Environ.* 650, 1499–1520.

[5] Lee S.Y., Hamlet A.F., Grossman E.E. (2016). Climate change impacts of Climate Change on Regulated Streamflow, Hydrologic Extremes, Hydropower Production, and Sediment Discharge in the Skagit River Basin. *Northwest Science* 90, 23-43.

[6] Manee D., Tachikawa Y., Yorozu K. (2015). Analysis of Hydrologic Variable Changes Related to Large Scale Reservoir Operation in Thailand. *Journal of Japan Society of Civil Engineers*, Ser. B1 (Hydraulic Engineering), 71.

[7] McKee T.B., Doesken N.J., Kleist J. (1993). The relationship of drought frequency and duration to time scales. *Paper presented at the Proceedings of the 8th Conference on Applied Climatology*.

[8] Nyunt C.T., Kawahara Y. (2017). Assessment of Reservoir Inflow and Operating Rule under Climate change. *Journal of Japan Society of Civil Engineers*, Ser.B1 (Hydraulic Engineering), 73.

[9] Pandhumas T., Kuntiyawichai K., Jothityangkoon C., Suryadi F.X. (2020). Assessment of climate change impacts on drought severity using SPI and SDI over the Lower Nam Phong River Basin, Thailand. *Engineering and Applied Science Research* 47, 326-338.

[10] Promping, T., Tingsanchali, T. (2020). Meteorological Drought Hazard Assessment under Future Climate Change Projection for Agriculture Area in Songkhram River Basin, Thailand. *2020 International Conference and Utility Exhibition on Energy, Environment and Climate Change (ICUE)*, 1–2.

[11] Saaty R.W. (1987). *The analytical hierarchy process – what it is and how it is use*. Mathmatical Modelling, 9(3-5), 161 – 176.

[12] Salis H.H.C.D., Costa A.M.D., Vianna J.H.M., Schuler M.Z., Nunne A., Fernandes L.F.S., Pacheco F.A.L. (2019). Hydrologic modeling for sustainable water resources management in urbanized karst areas. *International Journal Environmental Research Public Health* 16, 2542.

[13] Shrestha S. (2014). Climate Change Impact on Reservoir Inflows of Ubolratana Dam in Thailand. *Climate Change impacts and Adaptation in Water Resources and Water Use Sectors*, 25-41.

[14] Svoboda M., Fuch, B., Integrated Drought Management Programme (IDMP). (2016). *Handbook of Drought Indicators and Indices.* Drought Mitigation Center Faculty Publications, 117.

[15] Tingsanchali T., Piriyawong T. (2018). Drought risk assessment of irrigation project areas in river basin. *Engineering Journal*, Chulalongkorn University 22, 279-287.

[16] Toda O., Tanji H., Somura H., Higuchi K., Yoshida K. (2004). Evaluation of tributaries contribution in the Mekong River Basins during rainy and dry season. *In: Proceedings of the 2nd Asia Pacific Association of Hydrology and Water Resources Conference*, 239–248.

[17] Vaidya O.S., Kumer S. (2006). Analytic hierarchy process: An Overview of application. *European Journal of Operational Research* 169(1), 1-29.

[18] Wei W., Yan Z., Jones P.D. (2020). A Decision-Tree Approach to Seasonal Prediction of Extreme Precipitation in Eastern China. *Int. J. Climatol* 40, 255-272.