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FORECASTING DROUGHT IMPACTS ON AGRICULTURAL LAND USE BY USING GIS AND REMOTE SENSING

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Abstract. The prolonged drought due to climate change has significantly affected the agricultural production of rural communities in the mountainous and plain areas of Vietnam. We use the standardized precipitation index (SPI) combined with Geographical Information Systems (GIS) and Remote Sensing (RS) to simulate and forecast the impacts of drought on agricultural land use in Bac Tra My district, Quang Nam province, in the study. The data were set up for the scenarios RCP 4.5 and RCP 8.5. We also applied the focus group discussion, in-depth interview, and field survey for data cross-checking to ensure highly reliable predictions. We came to four levels of drought: normal, mild, moderate, and severe drought in the 2016–2035 Summer–Autumn crops. Severe drought will occur on a large scale for both scenarios for five types of agricultural land use: paddy, annual crop, perennial, afforestation, and aquacultural land. From the findings, local authorities can consider adapting and mitigating measures to climate change in agricultural land use planning.

Keywords: agricultural land use, drought, forecast, GIS, remote sensing, Bac Tra My

1 Introduction

Drought is a phenomenon caused by climate change [12]. As climate change begins to be felt in various parts of the world, problems with droughts have also become more acute [1, 2, 18]. Numerous studies in recent decades have found that droughts in the world have become more severe because of changes in weather and climate [27]. Drought reduces crop, livestock, and forest production and can result in widespread famine and death. Drought ranks the first among natural hazards in terms of the number of people directly affected and threatens nearly 50% of the most populated areas [3, 10]. Drought substantially threatens smallholder dryland farmers, where rainfed agriculture is generally used for self-subsistence crops in developing countries [14]. The standardized precipitation index (SPI) is a data-driven drought index that has been frequently used [5].

Forecasting droughts and assessing their impacts are complicated missions [4, 23, 7]. Several indices have been developed in recent years to detect the effects of droughts on different systems, depending on the input data [14]. In recent decades, space technologies, such as Geographical Information Systems (GIS) and Remote Sensing (RS), have played a key role in studying different hazards. GIS and RS technology can collect data in a digital form on global and regional scales rapidly and repetitively. They can also be used to monitor the situation before, during, and after an event [19, 24].

Drought studies on a national scale have also been performed in Central Vietnam. Drought indices are a valuable tool for monitoring and assessing different types of drought. The SPI is the most applied index to analyze meteorological drought. It is temporary lower-than-average precipitation resulting in diminished water resources availability and affecting economic activities, human lives, and the environment [6]. This index can be considered one of the most robust and effective drought indices because it can be evaluated on different time scales and allows the analysis of varying drought categories [8]. Furthermore, the SPI is based on precipitation alone and is thus easier to calculate than other complex indices. Therefore, this index is recommended by the World Meteorological Organization for drought studies [28]. It has been used by many researchers in the world and Vietnam [9, 15, 20, 21]. In that context, Bac Tra My is a mountainous district in Quang Nam province with an agricultural farming system that is strongly influenced by climate change, especially drought. For areas with little or no meteorological data or monitoring stations, combining observed data with simulated data from remote sensing is necessary and effective [22]. Bac Tra My district has a large natural area. Still, there is only one hydrological station, so calculating and simulating the drought impacts on the communal level is challenging to ensure accuracy. Therefore, in this study, we use the SPI index to assess drought and apply GIS and RS to simulate and forecast the impacts of drought on agricultural land use in the district. The results will assist stakeholders in decision-making on the formulation and approval of land use planning to adapt to climate change impacts on agriculture development.

2 Study areas

Bac Tra My district locates at 500–1000 metres above sea level. This mountainous region is home to nearly 42.000 people, over 50% of whom are ethnic minority groups. According to the Report

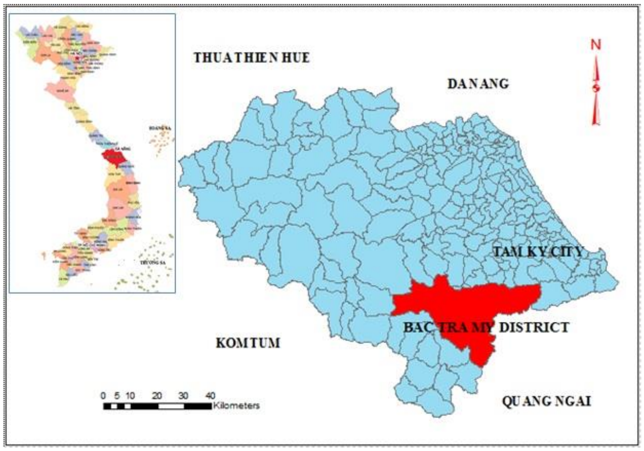

Figure 1. Location of the study area

on Land inventory in 2019, the total natural area of the district is 84,699.38 hectares, and the agricultural land area is 79,410.29 hectares, equivalent to 94.86%. The forest land occupies the most extensive area with 69,552.97 hectares, followed by perennial cropland. The land allocated to rice cultivation, annual crops, and aquaculture accounts for a small proportion. This region has a complex terrain in the upland hills (700–800 metres) with humid tropical monsoon climate. The area is characterized by two distinct seasons: the rainy season (from September to January) and the dry season (from February to August). Although the site is one of the two largest rainfall regions in Quang Nam province, the difference between the maximum and minimum rainfall has been recorded as significant, at 2,400 mm in some places compared with 200 mm in others. High temperatures (25 °C) and humidity (89%) are also recorded. Two to three tropical storms hit the region yearly between September and November. Agricultural activities in such a complex terrain and climate are frequently affected by natural disasters.

3 Materials and methods

3.1 Research materials

The economic and social condition data in the year 2019 were collected from the Department of Statistics and District People's Committee Office; agricultural land area statistic data were gathered from the Natural Resources and Environment Office; the data on agricultural production and effects of drought were collected from the Agriculture and Rural Development Office. The current land use map at a scale of 1/25000 was collected from the Department of Natural Resources and Environment of Quang Nam province; daily rainfall data at Tra My Station from 1978 to 2016 were obtained from the Hydrometeorological Station of Central region. The simulation rainfall data from Tropical Rainfall Measurement Mission (TRMM) remote sensing data used in this study were downloaded from the website http://waterdata.dhigroup.com.

3.2 Data collection methods

Discussion focus group

The research team organized two discussion focus groups (FGD) at the district level, including the participants from the Division of Agriculture and Rural Development, Natural Resources and Environment Office, and the Office of the People's Committee of Bac Tra My district; and four FGDs at the communal level with representatives of Communal People's Committee leaders, cadastral staff, agricultural staff, heads of villages, elders, and experienced farmers. The FGDs provide information on the current drought situation and its impacts on agricultural land use in the study area.

In-depth interviews

Three in-depth interviews were conducted with local representatives of various social and economic groups, especially from the Department of Agriculture and Rural Development of Quang Nam province. These interviews explore various topics concerning climate-related agricultural production, weather extremes, and the drought impacts on agriculture land use. The face-to-face interviews were conducted with a structured guide.

Field survey

This method was applied to study some agricultural land use points and verify the drought impacts on agricultural land use in the study area.

3.3 Drought assessment

The SPI was designed to quantify the precipitation for multiple timescales. These timescales reflect the impact of drought on the availability of the different water resources. The SPI can be calculated from 1 to 72 months. Shorter timescale SPIs, such as 1, 2 or 3 months, can provide early warning of drought and help assess drought severity [17]. The SPI is calculated from formula (1)

$$SPI = \frac{R - \overline{R}}{\sigma} \tag{1}$$

where R is the actual rainfall; $\bar{R}$ is the average rainfall in the study period; σ is the standard deviation.

This study uses the 1-month SPI to calculate the drought level in the Summer–Autumn and Winter–Spring crops. The SPI for all the months within a drought event can be termed the drought's "magnitude": SPI > 0.25: normal drought; –0.49 ≤ SPI ≤ 0.25: mild drought; –0.99 ≤ SPI ≤ –0.5: moderate drought; –1.44 ≤ SPI ≤ –1.00: severe drought; –1.99 ≤ SPI ≤ –1.50: very severe drought; SPI ≤ –2.00: serious drought [25].

3.4 GIS and remote sensing application methods

According to Xihua Yang et al. [29], the Inverse Distance Weighting (IDW) method is considered suitable for interpolating rainfall data series at monitoring and simulation stations . Therefore, the IDW was used to interpolate rainfall values of 26 stations to make a spatial distribution of drought map in the study area.

To forecast the impacts of drought on the agricultural land, we overlapped the estimated drought map of the Summer–Autumn crop under the climate change scenario with five types of land use maps: paddy land, annual cropland, perennial land, forest land, and aquaculture land in Bac Tra My district with the ArcGIS 10.3 software.

The simulation precipitation data were derived from TRMM to enhance the rainfall stations for interpolating drought in the study site. In this study, the spatial distribution of drought was interpolated from the TRMM precipitation data. However, because the rainfall data of TRMM satellite stations can only be exploited from 1997 to 2016, the monthly average rainfall of ground monitoring stations and TRMM satellite stations from 1997 to 2016 were used as input data to perform the simulation. The monthly rainfall to the year 2035 was calculated with the Excel software through the input data sources and the change of forecasting rainfall under two scenarios: RCP 4.5 and RCP 8.5. Among 26 observation stations, only Tra My Station provides actual monitoring data, and the rest 25 stations get simulated rainfall data from the remote sensing data source.

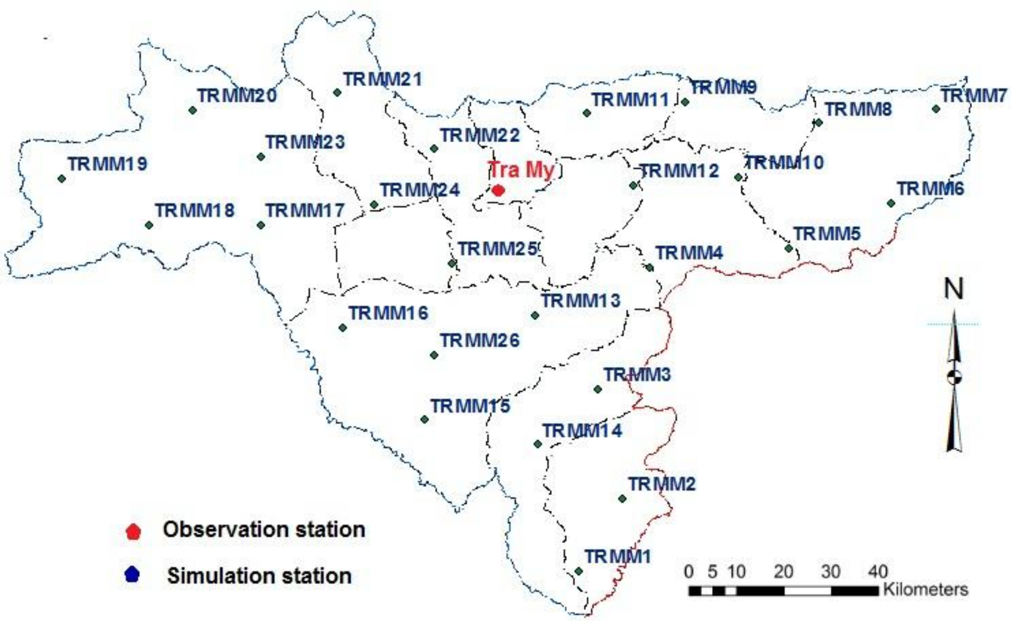

Figure 2. Location map of observation and simulation stations

4 Results and discussions

4.1 Drought forecasting with SPI index according to climate change scenarios of Vietnam

Rainfall forecasting under scenarios RCP 4.5 and RCP 8.5

According to the climate change and sea-level rise scenarios of the Ministry of Natural Resources and Environment announced in 2016, the change of rainfall was simulated under two scenarios: low emission (RCP 4.5) and high emission (RCP 8.5). The rainfall in Quang Nam province in the period 2016–2035 will increase by 18.2% under the RCP 4.5 scenario and decrease approximately by 17.5% under the RCP 8.5 scenario as follows:

– For the RCP 4.5 scenario: Rainfall in seasons tends to increase significantly, but there are differences between seasons. Specifically, according to the RCP 4.5 scenario, from 2016 to 2035, rainfall in winter and spring will increase by 5.9 and 0.2%. It is noteworthy that the autumn rainfall increases up to 28.9%, and the summer rainfall is predicted to decrease by 1.9%.

– For the RCP 8.5 scenario: In 2016–2035, rainfall in the winter months will increase by 6.1%, while the rainfall in the summer and autumn months will increase by 24.4 and 22.7%. Particularly, the rainfall in the spring months will decrease by 7.6%.

From the rainfall observed at Tra My Station and the change of rainfall under the climate change scenario at the RCP 4.5 and RCP 8.5 levels, we simulate the rainfall of the months in the year 2035.

Table 1. Forecasting rainfall by seasons (%) to 2035 according to climate change scenarios RCP 4.5 and RCP 8.5

No.	Average Rainfall	RCP 4.5 scenario	RCP 8.5 scenario
1	Annual	18.2 (13,0÷23,7)	–17.5 (12,2÷22,6)
2	Winter	5.9 (–1,8÷13,4)	6.1 (–4,7÷16,3)
3	Spring	0.2 (–10,4÷10,4)	–7.6 (–15,3÷–0,1)
4	Summer	–1.9 (–11,8÷7,5)	24.4 (3,2÷43,0)
5	Autumn	28.9 (21,1÷36,7)	22.7 (16,2÷29,3)

Source: [16]

Drought forecasting with SPI index under scenarios RCP 4.5 and RCP 8.5

Drought forecasting for Winter–Spring crop

The data analysis shows that the SPI index in the Winter–Spring crop in the year 2035 at the stations in Bac Tra My district under scenarios RCP 4.5 and RCP 8.5 is similar in terms of drought. The SPI index during the Winter–Spring season from January to April at Tra My Station and the 25 simulated stations is displayed as moderate or normal drought. In contrast, the SPI index at Tra My Station in February, which is 0.11 under the RCP 4.5 scenario, is in the threshold of mild drought (–0.49 to 0.25). Meanwhile, the SPI values under the RCP 8.5 scenario present normal precipitation. The SPI indices at all stations are out of the category values (Figure 3).

Drought forecasting for Summer–Autumn crop

The calculated results show that the SPI drought index in the Summer–Autumn crop under scenarios RCP 4.5 and RCP 8.5 is smaller than in the Winter–Spring crop. The specific data of SPI in June and July are at the threshold of severe drought (–1.44 to –1.0). Whereas, most of the SPI

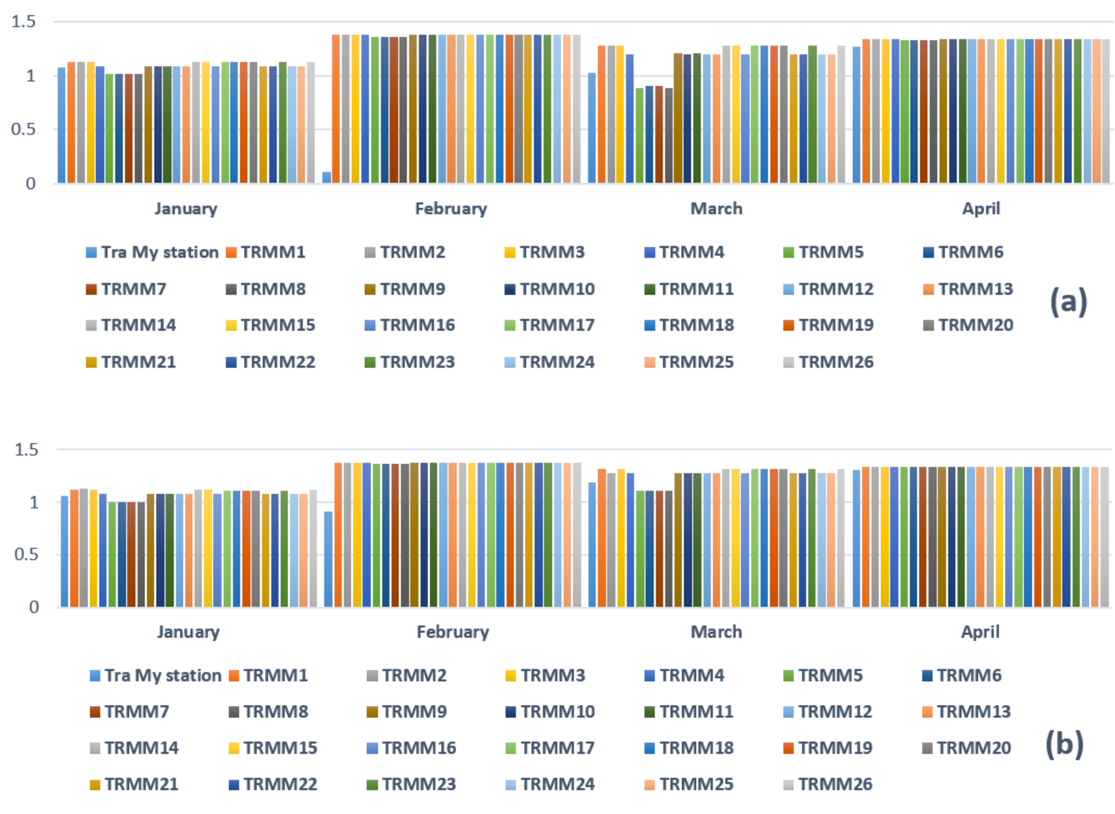

Figure 3. Forecasted SPI values of Winter–Spring crop in year 2035 for Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

values in August correspond to moderate drought (–0.99 to –0.5). For some stations, the SPI values conform to a range of mild drought (–0.49 to 0.25). By contrast, most of the SPI values show a normal or mild drought in May (Figure 4).

4.3 Predicting the drought effects on agricultural land use

The SPI results reveal that severe drought is predicted to appear in the Summer–Autumn crop, but it almost does not occur in the Winter–Spring crop. Therefore, we only analyze the data of the predicted drought in the Summer–Autumn crop.

Forecasting drought for Summer–Autumn crop in year 2035 according to climate change scenarios

The interpolation results of SPI value in the Summer–Autumn crop under scenarios RCP 4.5 and RCP 8.5 are shown in Figure 5 and Table 2.

Figure 4. Forecasted SPI values of Summer–Autumn crop in year 2035 for Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

The results show that the Summer–Autumn crop of the year 2035 in Bac Tra My district under scenarios RCP4.5 and RCP 8.5 faces normal, mild, moderate, and severe drought. Among these, severe drought accounts for 91.76 and 90.24% under RCP 4.5 and RCP 8.5. Under the RCP 8.5 scenario, the severe drought affects agricultural land less than under the RCP 4.5 scenario in 10 communes. By 2035, the non-drought area will have been approximately 10% more under the RCP 8.5 scenario than under the RCP 4.5 scenario. Tra Giang and Tra Son communes and Tra My town are expected to be unaffected by drought. Conversely, the mild and moderate drought under RCP 8.5 is expected to be higher than under the RCP 4.5 scenario. The forecasted results show that Tra Bui and Tra Giac are the two communes affected by severe drought with a large proportion.

Table 2. Statistics on affected area in Summer–Autumn crop by drought in year 2035 under the RCP 4.5 and RCP 8.5 scenarios in Bac Tra My district

Drought level	RCP 4.5 scenario		RCP 8.5 scenario	
	Area (ha)	**Percentage (%)**	**Area (ha)**	**Percentage (%)**
Normal	551.18	0.65	625.87	0.74
Mild	1740.97	2.06	1907.92	2.26
Moderate	4659.28	5.52	5695.23	6.75
Severe	77391.46	91.76	76113.88	90.24
Total	**84342.91**	**100.00**	**84342.91**	**100.00**

Source: Own data processing results, 2020

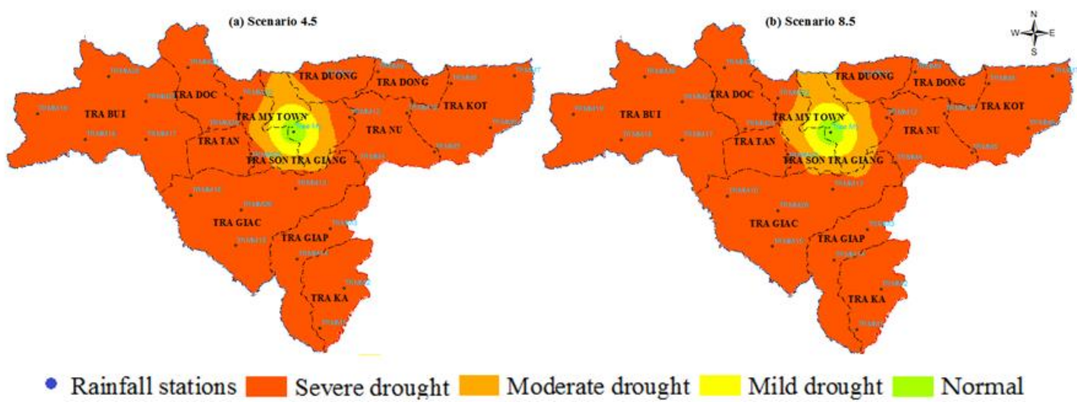

Figure 5. Predicted drought map of Summer–Autumn crop in year 2035 in Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

Effects of drought on agricultural land use in Summer–Autumn crop in 2035

We assume that the agricultural land area in 2035 will not change compared with the state in 2016. The results of simulating drought risk for Summer–Autumn agricultural land in Bac Tra My district in 2035 under scenarios RCP 4.5 and RCP 8.5 are shown in Figures 6–10.

Paddy land

Table 3 shows that the paddy area in 13 communes will be affected by severe drought in the Summer–Autumn crop. Meanwhile, only three communes will not be affected by drought, accounting for 3.68 and 4.01%, under the RCP 4.5 and RCP 8.5 scenarios. For the range of mild drought, there is only a slight difference (0.32%) between the RCP 8.5 scenario and the RCP 4.5 scenario. Paddy land of Tra My town, Tra Duong, Tra Giang, and Tra Son communes is forecasted to be affected at a moderate level of 7.87% (RCP 4.5) and 8.20% (RCP 8.5). The most severely

Table 3. Paddy land affected by drought in Summer–Autumn crop in year 2035

Drought level	RCP 4.5 scenario		RCP 8.5 scenario	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Normal	56.45	3.68	61.45	4.01
Mild	151.92	9.91	156.92	10.23
Moderate	120.74	7.87	125.74	8.20
Severe	1204.34	78.54	1189.34	77.56
Total	**1533.47**	**100.00**	**1533.47**	**100.00**

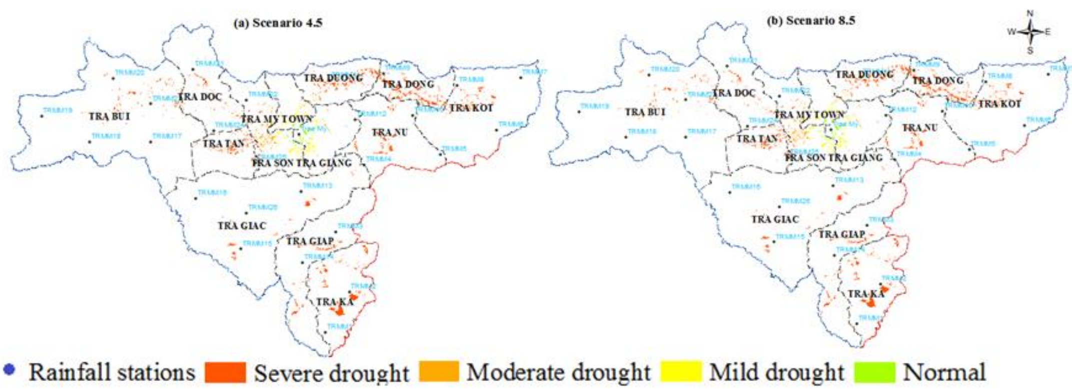

Figure 6. Predicted drought map affecting Summer–Autumn paddy land in Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

affected areas are concentrated in Tra Ka, Tra Dong, Tra Duong, Tra Tan, and Tra Nu communes, ranging from 100 to 200 ha.

Annual cropland

The data in Table 4 show that the annual cropland area in 11 communes will mainly be affected by the severe drought threshold under both RCP 4.5 and RCP 8.5 scenarios. The percentage of the affected area under the RCP 4.5 scenario is higher than under the RCP 8.5 scenario at 91.47 and 90.3%. Conversely, the area affected by mild drought under the RCP 8.5 scenario is higher than under the RCP 4.5 scenario at 3.28 and 2.89%. Besides, the annual cropland of Tra Giang and Tra Son communes and Tra My town is forecasted not to be affected by drought, accounting for 3.21% under the RCP 4.5 and 3.60% under the RCP 8.5 scenario. Five communes are projected to be affected by moderate drought at 2.43% under the RCP 4.5 scenario and 2.82% under the RCP 8.5 scenario. Whereas, the annual crops affected by severe drought are forecasted to concentrate in Tra Kot, Tra Ka, Tra Dong, and Tra Bui communes, ranging from 100 to 300 hectares.

Table 4. Annual cropland affected by drought in Summer–Autumn crop in year 2035

Drought level	RCP 4.5 scenario		RCP 8.5 scenario	
	Area (ha)	Percentage (%)	Percentage (%)	Area (ha)
Normal	41.15	3.21	46.15	3.60
Mild	37.03	2.89	42.03	3.28
Moderate	31.18	2.43	36.18	2.82
Severe	1172.78	91.47	1157.78	90.30
Total	**1282.14**	**100.00**	**1282.14**	**100.00**

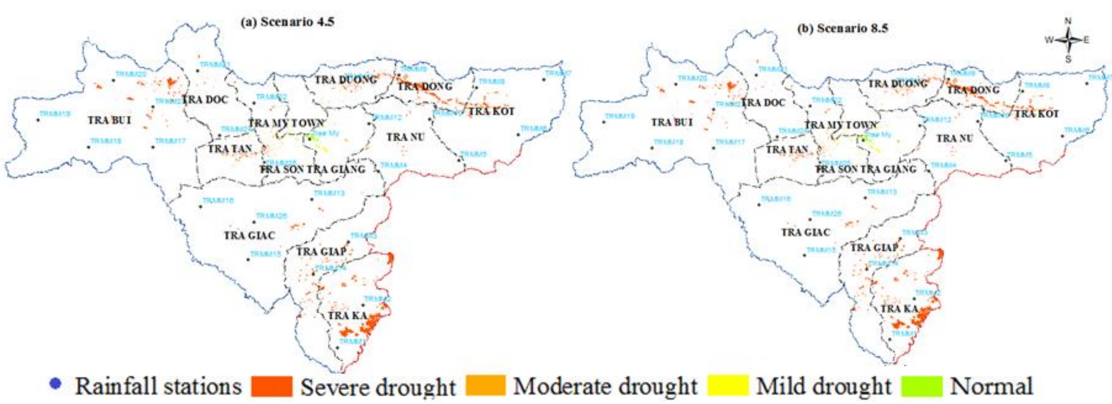

Figure 7. Predicted drought map affecting of Summer–Autumn annual crop in Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

Perennial land

Table 5 shows that the Summer–Autumn perennial crop in 12 communes is mainly affected by severe drought, accounting for 96.08% of the district's area under the RCP 4.5 scenario and 95.83% under the RCP 8.5 scenario. Only three communes will have perennial cropland in the threshold of no drought or mild drought. The proportion of these thresholds under the RCP 4.5 scenario is lower than under the RCP 8.5 scenario. Besides, perennial cropland in six communes is forecasted to have been affected by moderate drought, accounting for 2.36 (RCP 4.5) and 2.44% (RCP 8.5). The perennial land affected by severe drought is concentrated mainly in Tra Giac, Tra Giap, Tra Ka, Tra Nu, and Tra Bui communes and varies from 800 to more than 1000 ha. Tra Giac commune has the most affected perennial crop area.

Afforestation land

The data in Table 6 shows that the area of afforestation land in all 13 communes in the district will mainly be affected at the threshold of severe drought, accounting for 92.07% under the RCP 4.5 scenario, and this portion is lower under the RCP 8.5 scenario (89.91%). At other drought

Table 5. Perennial cropland affected by drought in Summer–Autumn crop in year 2035

Drought level	RCP 4.5 scenario		RCP 8.5 scenario	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Normal	15.24	0.25	20.24	0.34
Mild	79.46	1.32	84.46	1.40
Moderate	142.40	2.36	147.40	2.44
Severe	5803.91	96.08	5788.91	95.83
Total	**6041.01**	**100.00**	**6041.01**	**100.00**

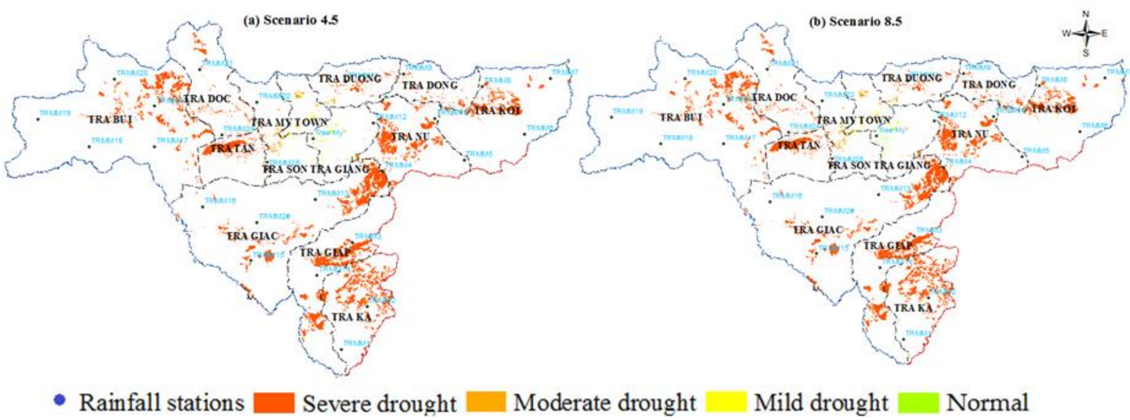

Figure 8. Predicted drought map affecting of Summer–Autumn perennial crop in Bac Tra My district: (a) Scenario 4.5; (b) Scenario 8.5

thresholds, the affected forest-land area under the RCP 8.5 scenario is higher than under the RCP 4.5 scenario. As for mild drought, the affected area accounts for 1.64% under the RCP 4.5 scenario and 2.36% under the RCP 8.5 scenario. Only three communes are unaffected by drought, accounting for 0.39% under the RCP 4.5 scenario and 1.11% under the RCP 8.5 scenario. Six communes are forecasted to face moderate drought (5.89%) under the RCP 4.5 scenario and 6.61% under the RCP 8.5 scenario. The most affected area by severe drought is Tra Kot, Tra Giac, and Tra Bui communes, ranging from 8,000 to more than 14,000 hectares. Tra Bui commune has the largest affected afforestation area.

Aquaculture land

The data in Table 7 and Figure 8 show that the aquaculture land of 11 communes will be affected by severe drought (69.34 and 53.42%) under the RCP 4.5 and RCP 8.5 scenarios. Meanwhile, the aquaculture areas affected by moderate drought under the RCP 8.5 scenario will be expected nearly twice larger than under the RCP 4.5 scenario in Tra My Town, Tra Giang, and Tra Son communes. Tra Kot, Tra Giap, Tra Duong, and Tra Ka communes are forecasted to have

Table 6. Afforestation land affected by drought in Summer–Autumn crop in year 2035

Drought level	RCP 4.5 scenario		RCP 8.5 scenario	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Normal	271.75	0.39	771.75	1.11
Mild	1136.73	1.64	1636.73	2.36
Moderate	4080.11	5.89	4580.11	6.61
Severe	63758.68	92.07	62258.68	89.91
Total	**69247.27**	**100.00**	**69247.27**	**100.00**

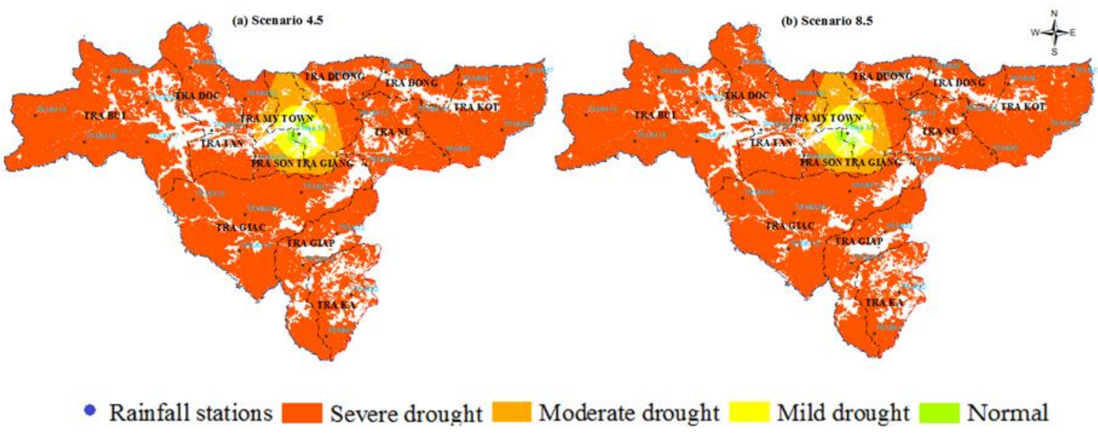

Figure 9. Predicted drought map affecting of Summer–Autumn planted forest in Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

Table 7. Aquaculture land affected by drought in Summer–Autumn crop in year 2035

Drought level	RCP 4.5 scenario		RCP 8.5 scenario	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Normal	1.59	5.62	3.09	10.92
Mild	4.40	15.56	5.90	20.86
Moderate	2.68	9.49	4.18	14.80
Severe	19.60	69.34	15.10	53.42
Total	**28.27**	**100.00**	**28.27**	**100.00**

Source: Own data processing results, 2020

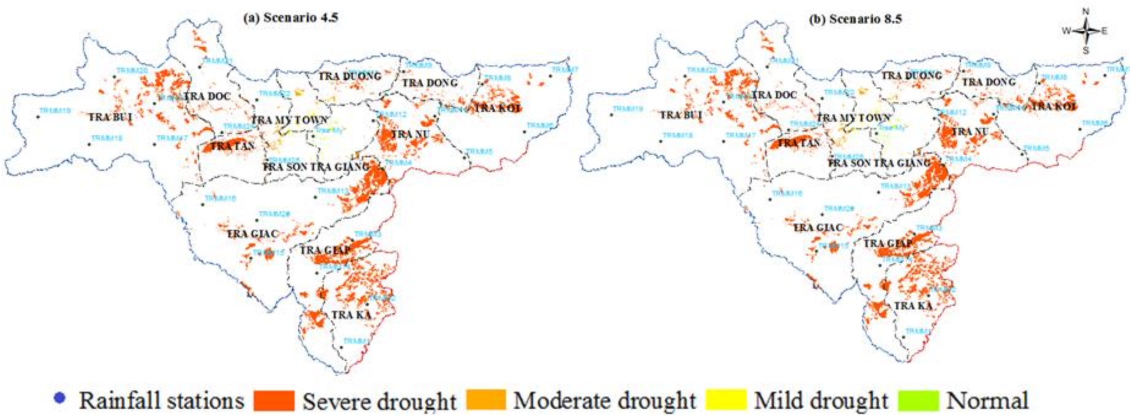

Figure 10. Predicted drought map affecting of Summer–Autumn aquaculture land in Bac Tra My district: (a) Scenario RCP 4.5; (b) Scenario RCP 8.5

moderately affected aquaculture areas occupying 9.49% (RCP 4.5) and 14.80% (RCP 8.5). It is forecasted that the area of aquaculture land affected by the most severe drought will be concentrated in Tra Tan and Tra Giap communes.

4 Conclusion

The research combined the analysis of the simulation precipitation data from the Tropical Rainfall Measurement Mission to enhance the data collected from the rainfall stations in Bac Tra My district in 2016–2035 to interpolate of drought under draught scenarios RCP 4.5 and RCP 8.5. Normal, mild, moderate, and severe drought for the Summer–Autumn crop in the year 2035 is expected in the site. Severe drought will occur on a large scale under both scenarios. However, the RCP 8.5 scenario shows a smaller agricultural area affected by severe drought than the RCP 4.5 scenario. Tra Giang and Tra Son communes and Tra My town are expected to be unaffected by drought, but Tra Bui and Tra Giac communes will be substantially affected by severe drought. The results can help the local authorities of Quang Nam province and Bac Tra My district take measures to adapt and mitigate the impact of climate change on agricultural land use to minimize risk for vulnerable groups.

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