Future scenarios of temporal distribution drought using RDI_{st} index in the dry season for Tien River mouth, Mekong River Delta

Hung Dao Ngoc[1*] and Phuong Cu Thi[2]
1. Geography Faculty, Hanoi National University of Education, Hanoi 10000, VIETNAM
2. Thuy Loi University, Hanoi, VIETNAM
*daongochung69@gmail.com

Abstract

Tien River estuary is adjacent to the Mekong River Delta, which is the primary food bowl of Vietnam, However, in the current context of climate change, especially during the dry season, the crops yields are already declining and leading to less food supplies. This study introduces the RDIst index and multivariate regression methods for assessing drought in Vietnam. The method developed a regression relationship of RDIst on temperature and rainfall in the local context, and was tested in a tropical estuary climate region in Vietnam, specifically Tien River mouth. Using the RIDst index and multivariate regression method, drought charts were estimated for the baseline period from 1978 to 2017. The method helps to determine the drought variation in spatial terms for the periods 2019-2035 and 2046-2065 under both the medium-low (RCP 4.5) and high (RCP 8.5) emission scenarios.

Results show that the drought level ranges from "none" to "drought" and "extremely serious drought" in future scenarios of climate change. The lowest level of drought takes place along the coastal area of the study region, and the further away is from the sea, the worse the drought level is. This study offers the opportunity to estimate the drought and downscale the drought map from climate change scenarios to local contexts.

Keywords: MRD, drought index, RDIst index, Tien River mouth, climate change scenario, dry season.

Introduction

The study area is adjacent to the Mekong River Delta (MRD) of Vietnam, and this reason accounts for 64.4% of the agricultural land with a population consisting of more than 4 million people[7]. This region annually supplies about 6.3% of the country's rice yield and plays an important role in food security for Vietnam. Drought in the context of climate change, especially during the dry season greatly affects crops yields and reduces the amount of food that people have access to. Therefore, undertaking a study of drought, especially in the current context of climate change, has practical and important outcomes for Tien River estuary. Drought is a meteorological phenomenon with serious destructive impacts on agriculture, the environment and socioeconomic systems[6,9,11,13,23,32,33].

Various drought indices have been devised in the past few decades. Budyko developed a drought index based on the ratio between annual radiation balance and annual rainfall. The World Meteorological Organization (WMO) compiled a list of more than 50 drought indices[35]. Meteorological Index Deciles (DI) were developed by Gibbs and Maher[8] and further refined more recently in the research done by Agwata[2] and Haied et al[10]. The Meteorological Standardized Precipitation Index (SPI) was developed by McKee et al[21] and nearly 20 years later, the Aridity Anomaly Index (AAI) was produced by the India Meteorological Department[34].

Research on this topic has employed input parameters consisting of evapotranspiration, potential evapotranspiration, temperature, wind and solar radiation. The SDI index was developed by Nalbantis and Tsakiris[25] using temperature, precipitation and flow. The Aridity Index (AI) as devised by UNEP[4] was based on the monthly maximum temperature and monthly rainfall and has been applied in many countries. To develop a drought scenario for South Korea, Yu and others[36] applied drought index known as HMM-DI for RCP 4.5 and RCP 8.5 emission scenarios. In 2009, WMO recommended SPI as the main meteorological drought index to monitor and follow drought conditions[34]. The index was used in many studies to assess meteorological drought[1,3,12,18,20,24].

SPI includes only precipitation in the model but has been implemented for many areas in Vietnam; both highland and delta regions[17,19,27,30]. PED index based on monthly average temperature and total monthly rainfall (seasonal or annual) to determine drought was used by Hung et al[15] and further refined by Hung et al.[16] They set out to develop drought scenarios for the Tien River estuary. The Meteorological Drought Index Reconnaissance Drought Index (RDI) uses monthly (seasonal or annual) precipitation and potential evaporation[10,28,29,31,37].

Hung et al[14] used the RDIα index which employed maximum temperature, minimum temperature and rainfall to assess the drought level for climate change scenarios. The research estimated spatial distribution of annual drought index in Tien Giang province.

The above studies have a number of points indicating they are not suitable for this study for the following reasons. First, some studies use drought indices, which require rainfall as input. In the context of climate change, the temperature trend is increasing rapidly over time, so the input also requires temperature. Secondly, other analyses utilised drought indices with inputs including temperature, precipitation, and other factors. It should be noted that the climate change scenario for the study area includes only the temperature and rainfall.

Consequently, the above drought indices cannot be used to develop drought scenarios based on climate change scenarios. Thirdly, some research calculated the the annual drought indexs, but the annual drought index is not relevant for areas with wet and dry humid climates.

Fourthly and lastly, some analyses formulated regression equations to calculate the drought index for a specific research area, but there are geographical differences within such zones, so many regression equations need to be formulated. This study will apply RDIst in assessing the drought index in the dry season for the estuary area of Tien River. It will highlight climate conditions along the coastal area and suggest modifications in selecting suitable variables. A regression relationship between RDIst and selected climate variables will be developed to estimate RDIst for areas with limited data records and to downscale drought scenarios from climate change scenarios to the local scale.

Material and Methods

Study area: The study area consists of three provinces and these are Tien Giang, Ben Tre and Tra Vinh, which are all located in the Mekong River Delta (MRD). The three provinces in total cover an area of approximately 736.3 thousand hectares[7]. Agricultural production activities in this area depend on natural conditions including high temperature, abundant rainfall, and accreted annually fertile soil. Wet rice is a major crop and it becomes more vulnerable under climate change conditions[26] for the following reasons. Wet rice requires a constantly sufficient amount of water to grow and maintain productivity. Also, the area of these three provinces encapsulates a region with an annual rainfall less than the average annual rainfall of the coastal region in MRD[26].

Data analysis: The study area has a tropical wet and dry climate and the dry season (December-April) is one when only 6-7.5% of the total annual rainfall arrives. This research will select rainfall variable as total rainfall during the dry season in an attempt to assess the drought conditions in the study area. Referring to the increase in temperature, compared to the baseline period, it is expected that the annual temperature in a climate change scenario for the periods 2046-2065 and 2080-2099 will increase by 1.4ºC to 3.4ºC. However, the temperature for the dry season will grow by 1.5ºC-3.5ºC. It is evident that the temperature for the dry season is expected to be higher compared to the annual temperature change.

The present study will select the total rainfall and temperature for the period from December to April as sensitive variables for RDIst analysis, while the locations of these stations are shown in Figure 2.

Empirical equation application: The method involves investigating the long-term climate time series of temperature and rainfall. Temperature and rainfall time series at yearly step in a yearly series were selected and the Reconnaissance Drought Index Standardised (RDIst) is calculated by the following equations[29]:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y} \quad (2)$$

where $y^{(i)}$ is the $\ln(\propto_k^{(i)})$, $\bar{y}$ is its arithmetic mean and $\hat{\sigma}_y$ is its standard deviation:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, i = 1(1)N \quad \text{and j = 1(1)k} \quad (3)$$

where Pij and PETij are the precipitation and potential evapotranspiration of the j-th month of the i-th year, and N is the total number of years covered by the available data. It should be noted that drought conditions are divided into 8 categories according to RDIst values as expressed in Table 1.

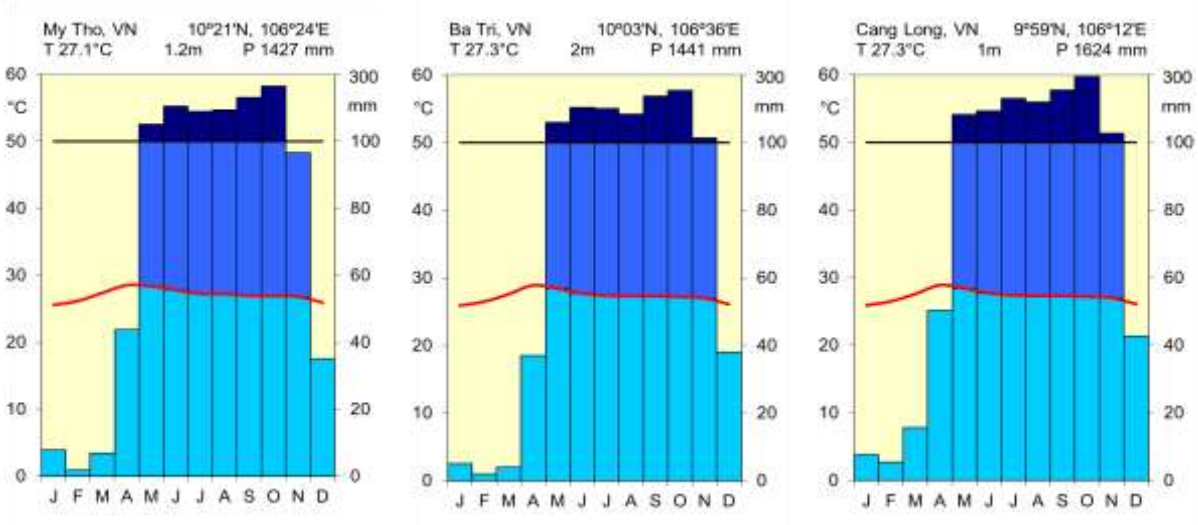


Figure 1: Climate diagram in Ba Tri, My Tho and Cang Long meteostation

Figure 2: Meteostations used in the study

This method can be easily applied using long temporal data series of temperature and rainfall. However, this method is not always available for regions where the data are limited both by space and time. The contribution of this study is to develop and document a regression relationship between RDIst and temperature and rainfall. This relationship can be used for ungauged areas and examines the temporal distribution of the RDIst for climate change scenarios.

Table 1
RDIst classification

RDIst Index	Classification
>=2	extremely wet
1.5 to 1.99	moderately wet
1 to 1.49	moderately wet
0 to 0.99	mildly wet
-0 to -0.99	mild drought
-1 to -1.49	moderate drought
-1.5 to -1.99	severe drought
≤-2	extreme drought

Source [29]

Multivariate regression method: The multivariate regression relationship[5] has been developed for independent variables of temperature and rainfall. It is expressed as follows:

$$RDIst = a + b * T + c * T \quad (1)$$

where P is total rainfall during the dry season and T is total temperature during the dry season.

The relationship has been developed for all stations throughout the study area. Based on these relationships, the spatial distribution of the drought has been downscaled from climate change scenarios to a local study area for two scenarios involving climate change (RCP 4.5 and RCP 8.5). The scenarios were developed by the Vietnam Ministry of Natural Resources and Environment[22].

Results and Discussion

Analyze the drought situation by the RDIst drought index: Empirical equation (2) was applied for temperature and rainfall series covering a period of 38 years as inputs at each station. RDIst for the period 1978-2017 at My Tho Meteostation are shown for Ba Tri meteostation in Figure 4 and at Cang Long Meteostation in Figure 5. To verify the method, a comparison of the calculated RDIst with previous drought analyses was conducted. According to the statistics produced by the Central Hydro-Meteorological Forecast Center over a 40-year period, severe drought occurred in 1983, 1987, 1990, 1992, 1995, 1998, and 2002 and results were completely identical.

Observing figures 3 to 5, we find droughts at meteorological stations at the mouth of the Tien River have the following characteristics: (i) drought levels are only mildly arid; (ii) the ratio of the number of years having drought to the total observation years is half; (iii) drought can last for 3-4 consecutive years and (iv) the amplitude of fluctuation RDIst is about 4.

Regression relationship: Selecting the most appropriate variables is very important in regression analysis. For each station, preliminary climate analysis as mentioned above (Data Analysis) has suggested to use rainfall and temperature during the dry season. While there are many

types of regression analysis, at their core they all examine the influence of one or more independent variables on a dependent variable. This study employed linear multiple regression to identify the influence of the variables T and P on RDIst (the dependent variable). SPSS software helped to analyse the variables for each station. The outcomes obtained are as follows:

- Correlation between P and T is very small; from meteostation My Tho it is 0.098; from meteostation Batri it is 0.011, from meteostation Cang Long it is 0.185. Thus, the selected rainfall and temperature variables are independent: Each variable in the regression relationship represents different factors in the drought phase and must be independent.
- Significance from ANOVA tables is all less than 0.05.
- Significance of Constant, T, P is all less than 0.05.

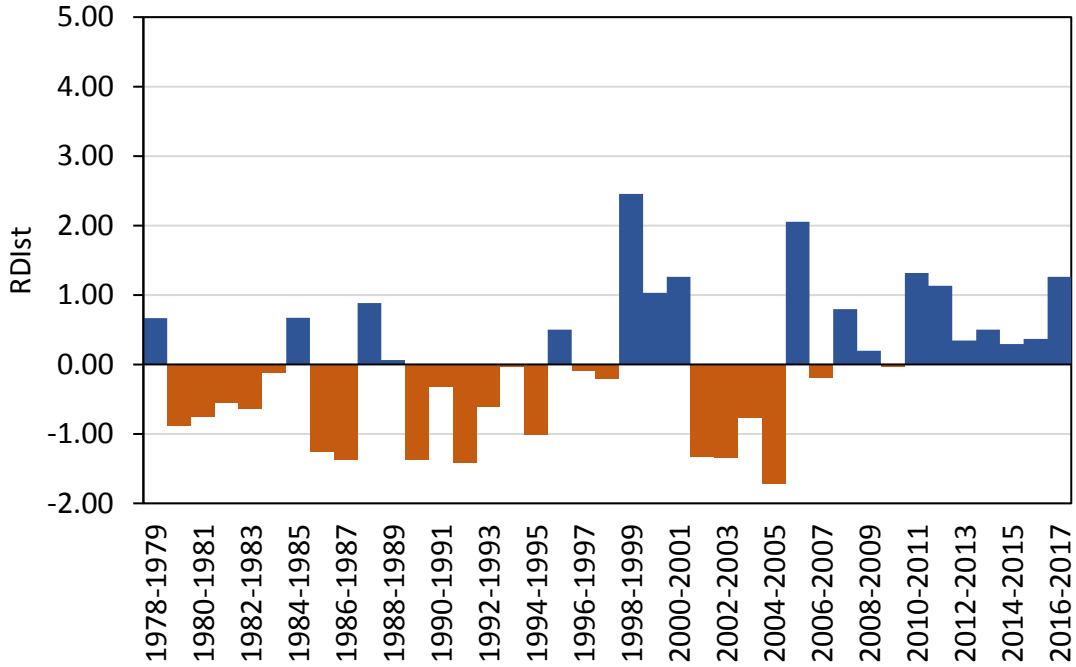


Figure 3: **RDIst at My Tho Meteostation for the dry season from 1978 to 2017**

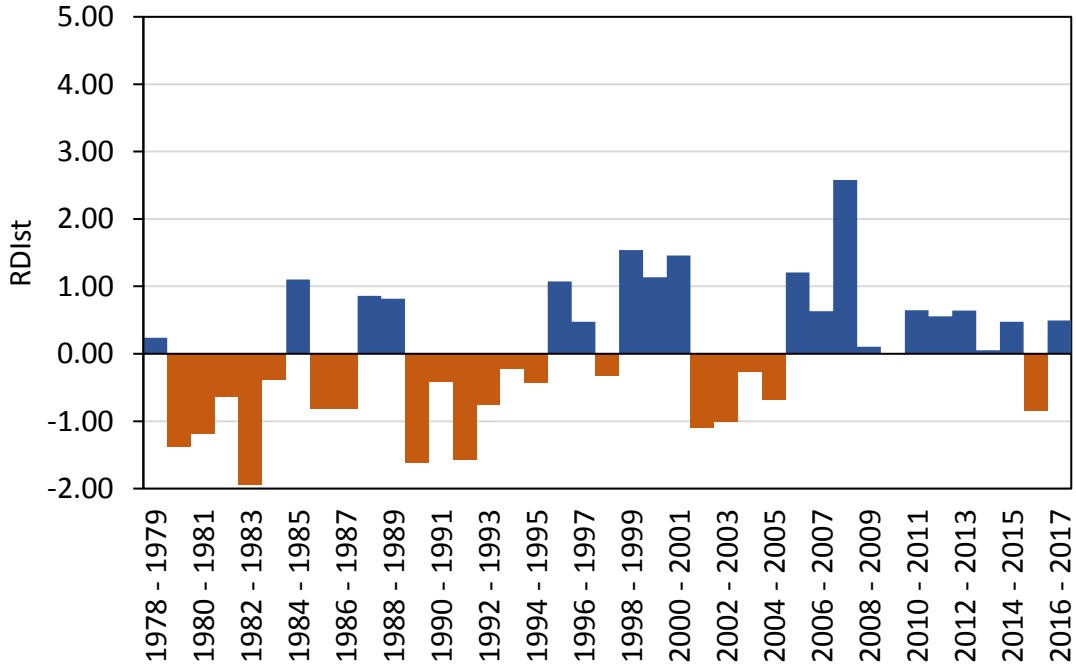


Figure 4: **RDIst at Batri Meteostation for the dry season from 1978 to 2017**

Multivariate regression equation was done for each station. Table 2 shows coefficients of the regression equation and Pearson Correlation (R2). All Pearson Correlation values were more than 0.8 and this confirmed there was a good relationship. Therefore, the regression equations can be accepted. The regression equations were used to estimate drought conditions in the contex of climate change scenarios, i.e. low-medium emission scenario (RCP 4.5) and high emission scenario (RCP 8.5). These were developed by the Ministry of Natural Resources and Environment of Vietnam.

RDIst estimated for the periods 2016-2035 and 2046-2065: Using temperature, rainfall, and multivariate regression equations, RDIst was estimated for the periods 2016-2035 and 2046-2065, for both medium-low emissions (RCP 4.5) and high emissions (RCP 8.5) scenarios. It should be emphasised that the calculation of RDIst was done by comparing RDIst for the period 1978-2017. The calculated results are shown in figure 6. It emerges that drought has the following characteristics according to the emission scenarios.

Low-medium emission scenario (RCP 4.5): During the dry season 2019-2035, it can be noted that at all meteostations the main levels of drought are only mild. It is only at Cang Long meteostation for the period 2027-2035 that moderate drought is observed. The ratio between the number of years in which there is drought to the total observation years at My Tho meteostation is ¾. At Ba Tri meteostation and Cang Long meteostation the ratio is also ¾. During the dry season for the years 2028 -2031, the climate is wetter (with intensity reaching extremely wet). The remaining years are drier and dry conditions can last for 6 consecutive years. The amplitude of RDIst at My Tho meteostation for the period 2019-2035 is up to 5, and at Ba Tri and Cang Long meteostations for the period 2019-2035 it is up to 6.

During the dry seasons 2046-2065, at all the meteostation the main levels of drought are mild. The ratio between the number of years in which there is drought to the total observation years at My Tho and Cang Long meteostation is nearly 4/5, while at Ba Tri meteostation it is nearly 2/3. At My Tho and Cang Long meteostations dry conditions can last for 9-10 consecutive years. The amplitude of RDIst is upto 4.

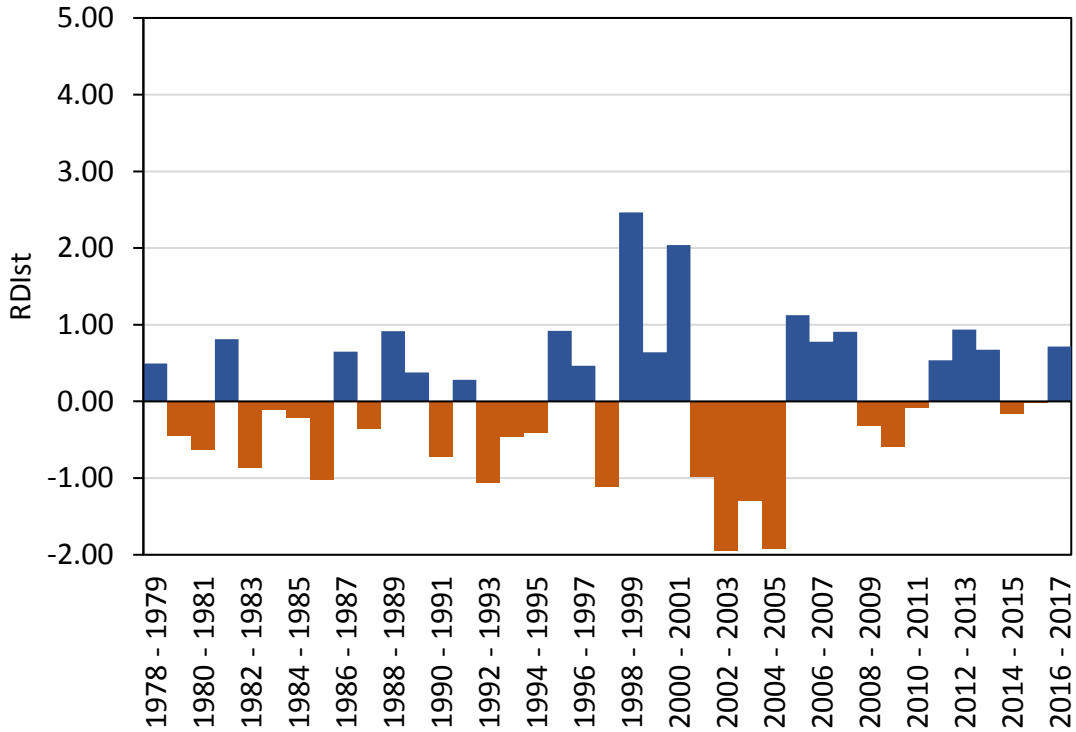


Figure 5: RDIst at Cang Long meteostation for the dry season from 1978 to 2017

Table 2
Multivariate regression coefficients and Pearson Correlation for all stations throughout the study area

Trạm khí tượng	Equations			r^2
	a	b	c	
My Tho	1.5553	-0.0843	0.0104	0.88
Ben Tre	0.4054	-0.0437	0.0077	0.80
Tra Vinh	8.6569	-0.3615	0.0093	0.84

High emission scenario (RCP 8.5): During the dry season 2019-2035, it is noted that at all the meteostations the main levels of drought are only mild. Only at Cang Long meteostation for the period 2027-2035 is drought observed to be moderate. The ratio between the number of years in which there is drought to the total observation years is ¾. During the dry season for the years 2028 -2031 it is wetter (with intensity sometimes reaching extremely wet).

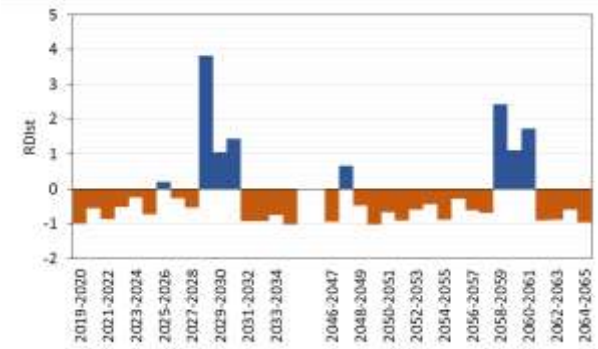
The remaining years are drier and dry conditions can last for 6 consecutive years. The amplitude of RDIst at My Tho meteostation for the period 2019-2035 is up to 3, and at Ba Tri and Cang Long meteostations for the period 2019-2035 is up from 4 to 6.

During the dry season 2046-2065, all meteostations record the levels of drought as being mild. The ratio between the number of years in which there is drought to the total observation years at My Tho and Cang Long meteostation is nearly 4/5, while at Ba Tri meteostation it is nearly 2/3.

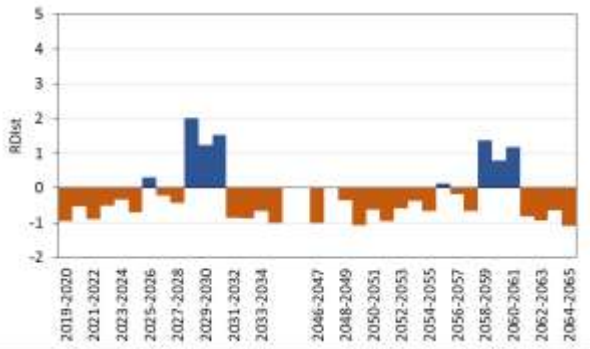
RDIst for *Low-medium emission scenario (RCP 4.5)*

RDIst for *High emission scenario (RCP 8.5)*

(a)

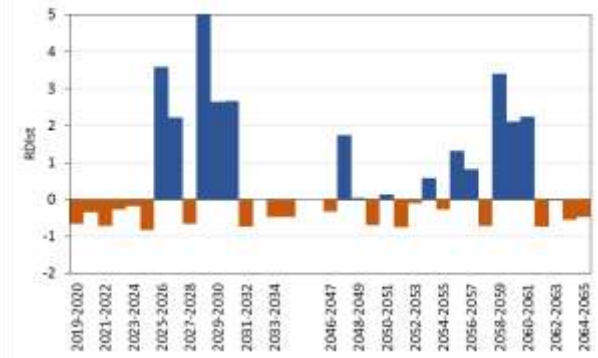


(b)

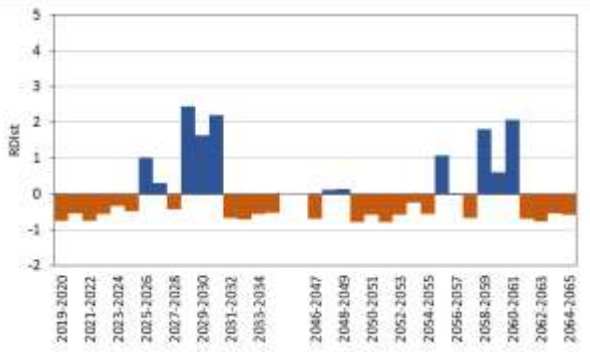


RDIst at My Tho Meteostation for the dry season

(c)

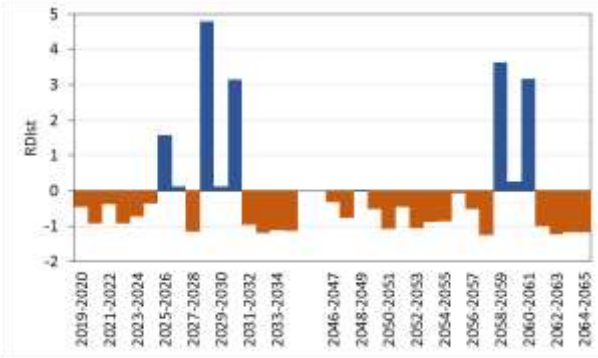


(d)

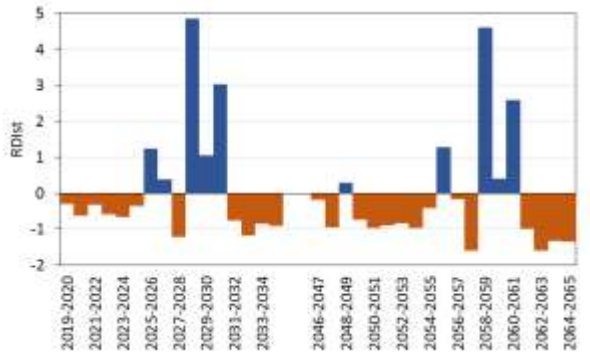


RDIst at Ba Tri Meteostation for the dry season

(e)



(f)



RDIst at Cang Long Meteostation for the dry season

Figure 6: RDIst for the periods 2019-2035 and 2046-2065, referring to the dry season in the Tien River estuary area

At My Tho meteostation, dry conditions can last for 9 consecutive years. At Ba Tri and Cang Long meteostations, dry conditions can last for 6 consecutive years. The amplitude of RDIst is from 2 to 6.

Conclusion

Tien River estuary area has a tropical wet and dry climate characterised by heavy rainy season and prolonged dry season. The drought conditions are currently being significantly affected by climate change. Through the analysis of RDIst index, the following can be concluded. The calculated RDIst index is consistent with the droughts reported by Vietnam's Ministry of Natural Resources and Environment. A regression relationship between RDIst and temperature and rainfall has been found in the study area in local contexts. This made it possible to downscale RDIst from the climate change scenarios to gauges and mapping the drought conditions throughout the study area.

According to the calculated results, we established the following. First, the number of years of drought in the periods 1978–2017, 2019–2035 and 2046–2065 are ½, ¾, 4/5 respectively. Secondly, the number of continuous years of drought gradually rose during the periods 1978–2017, 2019–2035, 2046–2065, from 4–5 years to 5–6 and 6–10 years respectively. Thirdly, the amplitude of fluctuations in the term indicator under drought scenarios is about 4–6, which is higher than the real period of about 4–6. Fourthly, the difference in the level of drought and the number of years of drought between the RCP 4.5 and RCP 8.5 scenarios is small.

However, in wet years there is a big difference. For the wet years, the humidity level according to the RCP 4.5 scenario is much larger than the RCP 8.5 scenario. Consequently, the amplitude of the RDIst fluctuations in the RCP 4.5 scenario is greater than RCp 8.5. Fifthly and finally, at the 3 weather stations in the study area, the drought intensity along the coastal areas is the lowest, but is higher further inland in study area. Drought was also higher at the Cang Long Meteostation in the southwest of the study area.

Recommendations

The development of drought scenarios as they will emerge in the future using the meteorological drought index RDIst has significant implications for sustainable socio-economic development in the study area. This drought scenario provides a good reference for devising policies on the use and management of water resources, especially in planning drought-resistant and salt-tolerant crops in agricultural production.

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