

SCENARIOS OF METEOROLOGICAL DROUGHT IN TIEN RIVER ESTUARY UNDER THE CLIMATE CHANGE CONTEXT USING THE PED INDEX

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Abstract. The article deals with the issues of meteorological drought in the coastal area of the estuary of the Tien river, including Tien Giang and Ben Tre provinces, which have favorable climatic conditions for agricultural development. In the context of climate change, drought often happens, seriously affecting the local economy. In order to estimate the drought level, scientists have come up with many approaches to calculate drought indices for different regions and territories around the world. Based on the natural and socio-economic characteristics of the coastal area of the estuary of the Tien river, it can be seen that the proposed PED meteorological index is suitable for estimating meteorological drought in the study area. Based on emission scenarios 4.5 and 8.5 RCP, this research project establishes a map of meteorological drought scenarios using multivariate regression methods, charting methods, maps, and geographic information systems. The obtained maps show that My Tho City and surrounding areas suffer the highest drought level, in the future, it can reach medium and high levels.

Keywords: Drought Reconnaissance Index, PED, climate change, Tien River Estuary.

1. Introduction

In the context of climate change, drought often happens, seriously affecting the local economy. To estimate the drought level, scientists have come up with many approaches to calculate drought indices for different regions and territories around the world. Drought can be classified into meteorological, agricultural, and hydrological drought. Meteorological drought considers a phenomenon of lacking moisture occurring due to a long period of rainfall less than the average for many years. Thus the meteorological term is entirely mentioned natural conditions.

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In the literature, drought indices vary from simple to complex algorithm, built with different input data, and applied to calculate for different territories. The AAI (Aridity Anomaly Index) meteorological index uses inputs data such as rainfall, temperature, potential evaporation, evapotranspiration) to assess drought phenomenon for India (World Meteorological Organization, 2012). To develop a meteorological drought scenario, the above indices are not suitable, because climate change scenarios only provide data on monthly average temperature and rainfall.

In Meteorological Deciles Index, developed by Australian scientists, rainfall is the input for determining drought index. While the input of the Meteorological Standardized Precipitation Index (SPI), recommended by the World Meteorological Organization (World Meteorological Organization, 2012) is also rainfall [1-3]. However, if rainfall is lonely used to build a meteorological drought scenario, the certainty is not high, because of the increase of temperature in the context of climate change.

Wherefore Meteorological Drought Index such as Reconnaissance Drought Index (RDI) [2, 4, 5], Keetch-Byram Drought Index (KBDI) [6], Weighted Anomaly Standardized Precipitation (WASP) (Lyon, B., 2004), Aridity Index (AI) (Baltas, E., 2007), Crop Moisture Index (CMI) (Palmer, WC, 1968) [7], Hydro-thermal Coefficient of Selyaninov (HTC) using both and temperature and rainfall data will be a appropriate approach to apply in the research topic.

In Southeast Asian countries, the research on meteorological drought also attracts the interest of many scientists, especially CGIAR Research Center in Southeast Asia (2016) conducted a direct observation and evaluation on the intensity and frequency of droughts and saline intrusion in the Mekong Delta.

Thus, it can be seen that there have been many studies in the world working on drought, using indices, or applying remote sensing images to assess the spatial extent of drought. The limitation of these studies is that the drought indices have not been used for appropriate territory, combined with climate change scenarios, remote sensing images to develop meteorological drought scenarios. But, domestic and international studies will be an important scientific principle to develop meteorological drought scenarios for the Tien river estuary in the Mekong Delta.

In Vietnam, there have been also many researches relating to drought, a research project on mapping the frequency of heat and drought in the Northern Delta region [8] and mapping the frequency of heat and drought in the period of 1971 - 2015 for the Northern Delta region. The objective of the study is to establish a drought classification to illustrate and calculate the lack of wastewater in the Ba River basin using three meteorological drought indices (Standardized rainfall index (SPI), Drought Index (J) and PED Index (PED). Doan Quang Tri *et al.* [9] successfully developed a drought map of the Ba River basin. However, this study has not developed a drought scenario.

In recent years, there have been many studies on drought in the context of climate change in the Mekong Delta in general and in Tien Giang and Ben Tre provinces in particular. For instance, the works of Nguyen Dang Tin *et al.* [10, 11] have investigated the current situation and stated the meteorological forecasting process in the Mekong Delta. The study "Establishing drought maps of the Mekong Delta in the context of

climate change" [12] has also produced results of drought maps in the Mekong Delta. Dao Ngoc Hung *et al.* [13, 14] developed a drought scenario in Tien Giang province in the context of climate change. However, the obtained results are still limited, without the reliability assessment of the research results.

The literature review of former works related to drought and drought scenario shows that several existing issues have not been studied in-depth and have not been thoroughly addressed as follows:

- Studies for other territories are not appropriate for the specific territory.
- Studies in the specific territory have not yet selected the drought index in accordance with its natural characteristics.
- The previous research on the meteorological drought scenario of the Dao Ngoc Hung [14] has just studied in Tien Giang province at an early stage and has not evaluated the confidence of the obtained results.

Therefore, it is necessary to research to select suitable meteorological drought indices according to the natural and socio-economic characteristics of Tien river estuary area. The obtained results will be a prerequisite for sustainable socio-economic development of the coastal areas of the estuary of the Tien river.

2. Content

2.1. Method and data

2.1.1. Method

** Data collection and processing method*

In the process of developing a meteorological scenario in the Tien estuary area, it is very important to collect relevant documents and data. Besides, this study requires a continuous series of data for 40 years of different meteorological stations to ensure the reliability of assessment, which is a principle for establishing the meteorological drought scenario in the study area. The collected documents and data comprise of: Statistics data for the period of 1978 - 2017 such as: temperature and rainfall of 2 meteorological stations My Tho and Ba Tri located in the study area, together with 8 surrounding meteorological stations; Climate change scenario with emissions levels of 8.5 and 4.5; Natural, socio-economic data. After collecting from various sources, data have been processed and standardized to synchronize into a database.

** Estimating meteorological drought by PED index method*

To estimate drought, the Ped's index [7] will be calculated:

$$PED = \frac{\Delta T}{\sigma_T} - \frac{\Delta P}{\sigma_P} \quad (1)$$

where ΔT and ΔP are the difference in air temperature and precipitation related to a specified time. σ_T and σ_P are standard deviations of air temperature and precipitation, respectively. Target thresholds corresponding to climatic conditions are given in Table 1.

Table 1. Classification by PED index

PED	Drought characteristics
<0	Humidity
0 – 0.5	Normal
0.5 – 1	Start drought
1 – 1.5	Slightly drought
1.5 – 2	Medium drought
2 – 2.5	Quite high drought
2.5 – 3	Drought
>3	Severe drought

The power of this drought assessment method is that it is easily calculated using temporal data series of temperature and rainfall. This input will be suitable for developing a meteorological drought scenario in our study area.

** Multivariate regression method*

To develop the meteorological drought scenario of the study area, the authors have built a multivariate regression equation to evaluate the dependence of the drought index on temperature and rainfall. The current drought situation in the period of 1978 - 2017 at the meteorological stations has been calculated and obtained results are applied to solve the equation:

$$Ped = a + b * T + c * P \quad (2)$$

Based on equation (2), we determine the meteorological drought scenario for the study area using climate change and sea-level rise scenario built in 2016 by the Vietnam Ministry of Natural Resources and Environment [15].

** Diagrams, maps, and geographic information systems (GIS) method*

In this study, the authors use charts in one hand to show the differentiation of data, trend lines of temperature, rainfall, and PED index. On the other hand, GIS technology is used to interpolate discontinuous data and then build drought iso-line maps for the study area.

2.1.2. Data used

To conduct this study, the authors used several layers of data including:

The monthly average temperature and rainfall data for the period of 1978 - 2017 are collected from the Meteorological and Hydrological Data Center.

Temperature and rainfall data for the periods of 2016 - 2035, 2046 - 2065 come from the climate change and sea level rise scenarios built in 2016 by Vietnam of the Ministry of Natural Resources and Environment [15].

In terms of space, statistic data are collected from 10 meteorological stations in 2 provinces of Tien Giang, Ben Tre, and its neighbor provinces. Specifically, the data were measured at meteorological stations: Vung Tau, Tan Son Nhat, My Tho, Ben Tre, Ba Tri, Cao Lanh, Cang Long, Soc Trang, Bac Lieu, and Moc Hoa.

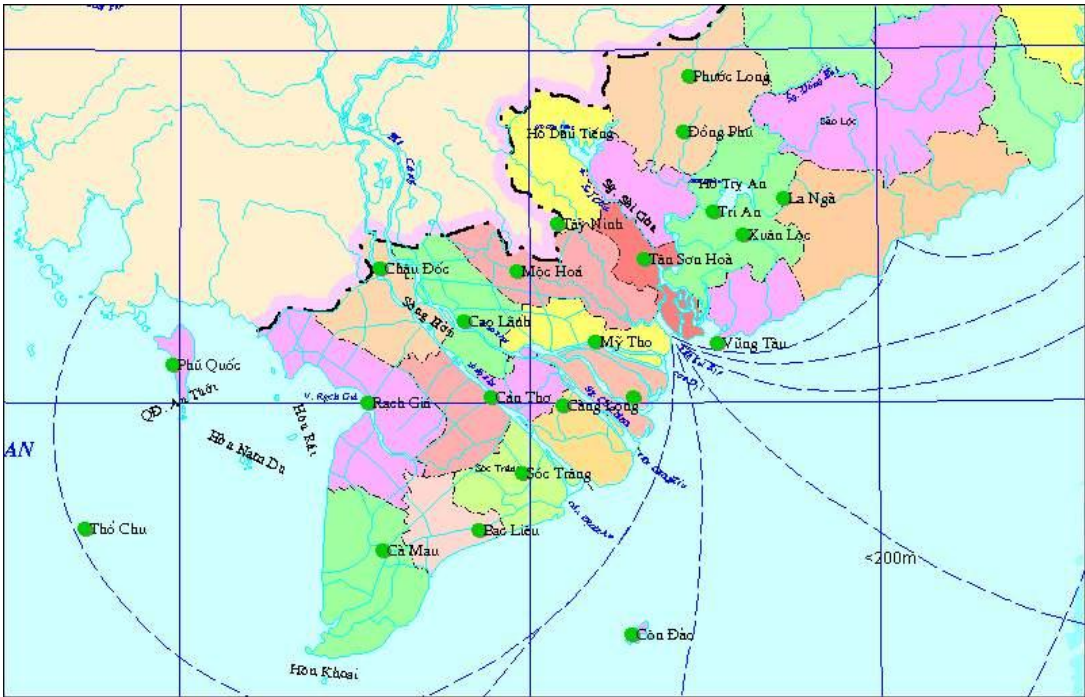


Figure 1. Location of meteorological station network (green dots) [16]

2.2. Research results

Based on the PED drought index, using annual temperature and rainfall at 10 meteorological stations in the study area, the meteorological drought index results in the period of 1978 - 2017 were deduced. According to of the Meteorological and Hydrological Data Center, for the past 40 years, in the South, there have been severe drought occurring in 1983, 1986, 1988, 1996, 1998, and, especially, several phenomena in recent time.

Figure 2 presents the result caculated for Ba Tri meteorological station (Ben Tre), the PED index for 10 research stations has been estimated in a similar approach.

These annual average temperature, rainfall data in the period 1986 - 2005 are considered as a baseline for adjusting the model and then deducing the value of temperature and rainfall in the periods of 2016 - 2035 and 2046 - 2065 (Table 2).

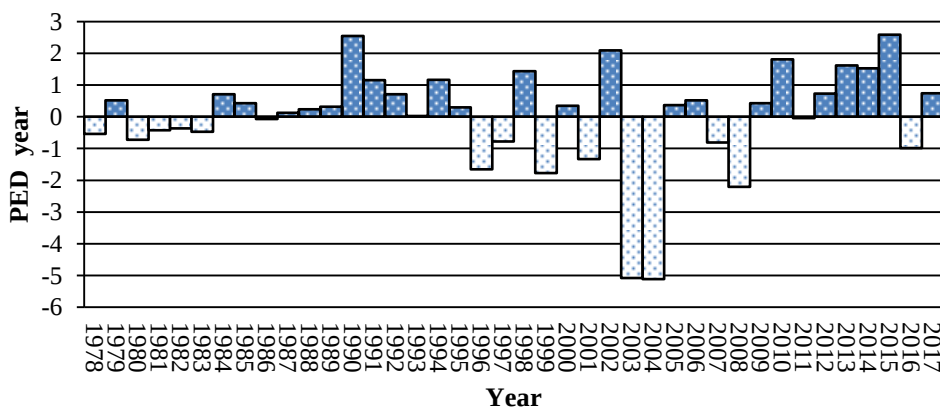


Figure 2. PED index by year at Ba Tri meteorological station (Ben Tre) in the period of 1978 - 2017

Solving the multivariate regression system, with the dependent variable as the PED drought index and independent variable as the annual average temperature and rainfall, the dependency equation of PED, the annual temperature and rainfall is established as follows:

$$Ped = -35.81 + 1.529 * T - 0.00343 * P \quad (3)$$

Predictor	Coef	SE Coef	T	P
Constant	-35.81	0.1048	28.05	0.000
Temperature	1.529142	0.003783	-28.85	0.000
Precipitation	-0.00242997	0.00000606	95.73	0.000
S = 0.00745721		R-Sq = 99.7%	R-Sq (adj) = 99.7%	
PRESS = 0.00282801			R-Sq(pred) = 99.60%	

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.70751	0.35376	6361.38	0.000
Residual Error	38	0.00195	0.00006		
Total	40	0.70946			
Source	DF	Seq SS			
Temperature	1	0.19792			
Precipitation	1	0.50959			

Unusual Observations

Obs	Temp	RDI	Fit	SE Fit	Residual	St Resid
1	26.1	1.06009	1.04315	0.00309	0.01694	2.50R
25	27.4	0.44361	0.41816	0.00389	0.02544	4.00RX

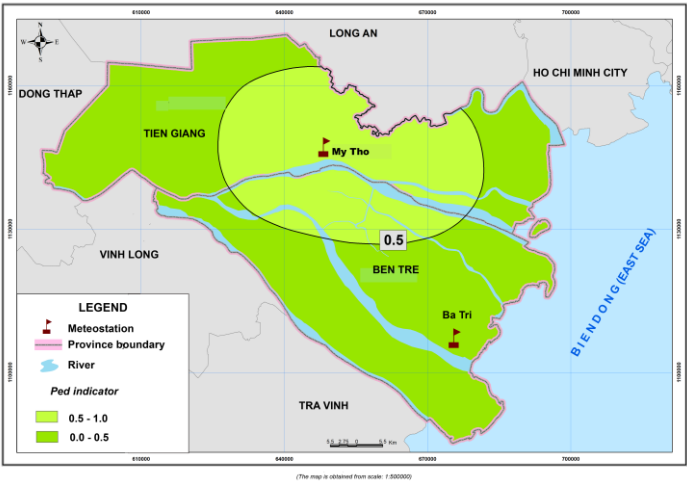
with the correlation coefficient $R^2 = 99.7\%$, the calculated results are highly reliable, and the multivariate regression system is accepted.

Based on the data series of the meteorological stations, we calculate the value of annual average temperature and rainfall in the baseline period of 1996 - 2015.

Table 2. PED scenario according to the climate change scenario of Tien estuary area

Province /City	RCP4.5 Scenario			RCP8.5 Scenario		
	1996 - 2015	2016 - 2035	2046 - 2065	1996 - 2015	2016 - 2035	2046 - 2065
Ho Chi Minh	X	-0.25349	0.825646	0.071514	0.071514	1.55173
Ba Ria Vung Tau	X	-0.62805	0.43341	-0.28307	-0.28307	1.106672
Long An	X	-0.34953	0.293388	-0.24946	-0.24946	1.273978
Vinh Long	X	-0.08542	0.845618	0.000248	0.000248	1.480464
My Tho	0.769509	0.769509	1.673612	1.12419	1.12419	2.394118
Ba Tri	-0.31733	-0.04175	0.966896	0.229313	0.229313	1.583633
Can Long	-0.2513	0.089603	0.894723	0.21488	0.21488	1.719994
Can Tho	0.104816	0.104816	0.997001	0.399483	0.399483	1.505461
Soc Trang	-1.22558	-1.22558	-0.12166	-1.03906	-1.03906	0.167172

From the aforementioned data, ArcGIS software is used to interpolate the values to build a PED index scenario map for the periods of 1996-2015, 2016 - 2035, and 2046 - 2065. The results are shown in Figure 3.



a) 1996 - 2015 period

Figure 3. Current state and PED scenario according to climate change scenario in the Tien River etsy area

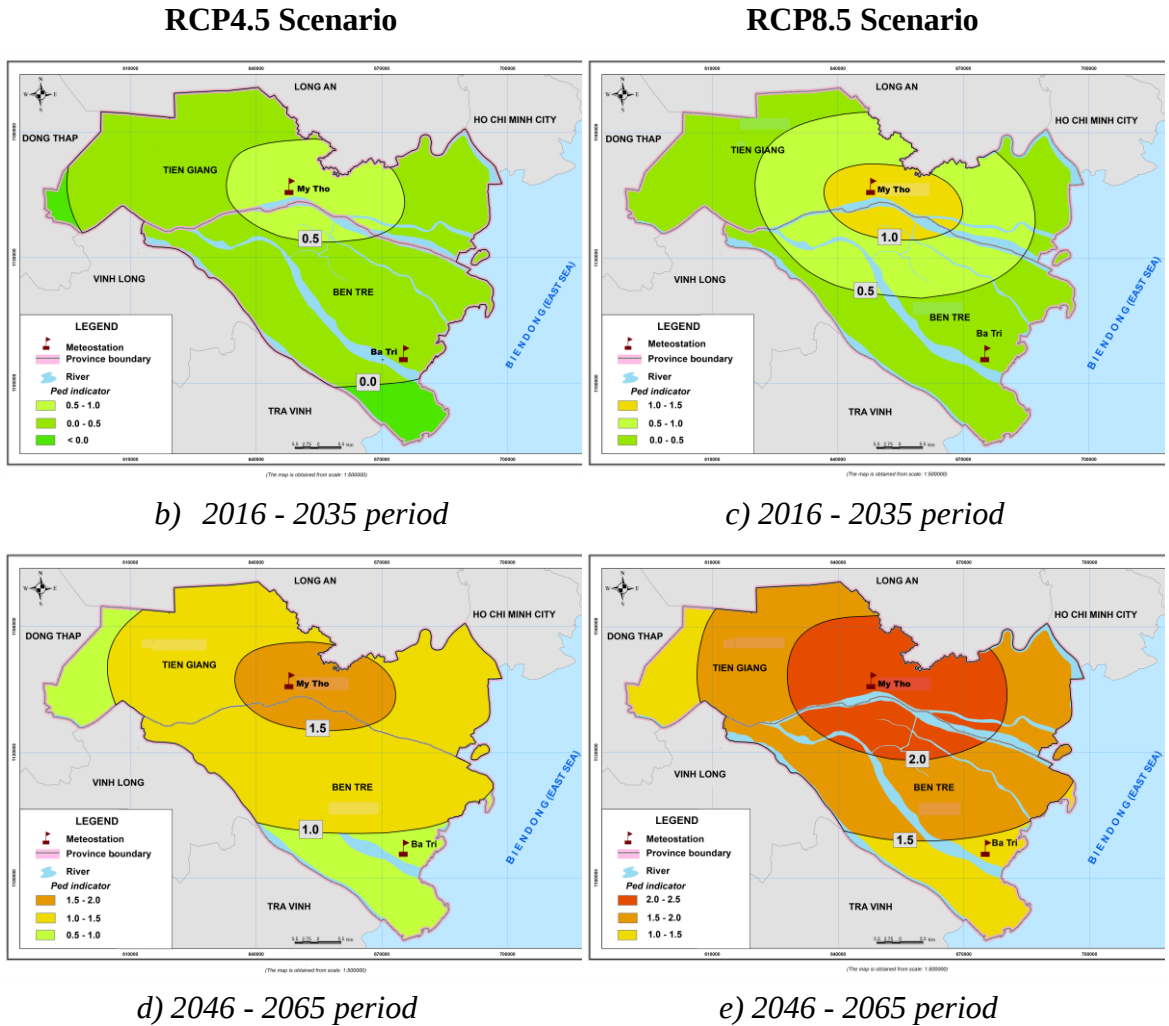


Figure 3. Current state and PED scenario according to climate change scenario in the Tien River estuary area

3. Conclusions

Tien River estuary area has a tropical monsoon climate, characterized by a rainy season and a dry season, deeply affected by climate change. Through the analysis of PED drought index, the authors recognized that the drought situation in the study area is the following:

- Over time, from 1996 to 2005 (20 years), on an annual average, the entire study area was not affected by drought. However, whether under the medium-low emission scenario or the high emission scenario, drought level will increase over time from slight to a high level.

- By space, the study area is drier than the surrounding area, especially the strongest level at My Tho meteorological station (Tien Giang) and its surrounding areas. Here, by the period of 2046-2045, the forecasted drought level will reach a slight level under RCP 4.5 emission scenario or high drought level under RCP 8.5 emission scenario.

- Based on the results of climate change scenarios, the development of a drought scenario for the future using the meteorological drought indexes has practical significance. This drought scenario is a valuable document in management and decision-making. It provides an orientation for sustainable socio-economic development in this area, especially in the replacement of drought-resistant and salt-tolerant species in agricultural production.

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