Trend analysis of drought indicators in terms of rice yield for drought identification in a Type III climate area in Central Philippines

JOZIL DONNE D. CERNA, MAULYN MURIELLE S. DOMINGUEZ, VINNA YSABELLE U. TUPAS, and ARIS C. LARRODER

Philippine Science High School Western Visayas Campus - Department of Science and Technology (DOST-PSHS WVC), Brgy. Bito-on, Jaro, Iloilo City 5000, Philippines

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Abstract

The most utilized drought indices are the Standard Precipitation Index (SPI) and the Standard Precipitation Evapotranspiration Index (SPEI), which are based on precipitation and temperature data. As tools that utilize a combination of meteorological data, this could provide a means to monitor and forecast drought conditions in relation with agriculture. Thus, this study aims to analyze the trend of SPI and SPEI for drought identification in terms of rice yield in Roxas City, Philippines, which is a Type III Climate area. Annual climate parameters (mean, minimum, and maximum temperature, precipitation, and potential evapotranspiration) were run through the Mann-Kendall test to determine trend significance, and rice yield was tested for correlation to SPI and SPEI. It was found that neither of the drought indices had a specific monotonic trend on a 12-month timescale. Rice yield had a weak negative correlation with SPI ($r = -0.050$) and a weak positive correlation with SPEI ($r = 0.065$), depicting the indices as weak agricultural indicators. However, other studies have found that this correlation is much stronger on a shorter timescale.

Introduction. - Rice was the most commonly consumed food item in the Philippines in 2021, with a roughly 110 million population having a 133 kg per capita rice consumption [1]. This is further supported by the increase in volume of the country's rice output, with 19.07 million metric tons produced in 2018 [2,3]. However, when compared with other Asian countries such as Vietnam, China, Thailand, Indonesia, and India, the Philippines had the second least annual yield [4].

As an agricultural country, continuous monitoring of the current strategies' effectiveness is important. Information about the country's yield-climate relationship can provide a basis for projecting the impact of future climate change [2,5]. The threat climate change brings to the agricultural sector heightens with the foreseen increase in the frequency and severity of extreme weather events such as droughts and floods [6,7].

Climate change and variability are leading factors that affect rice yield, with each 1°C temperature increase leading to a six percent decrease in total rice yield [8,9]. Moreover, water availability below the optimum requirement for the full expression of yield potential leads to drought stress [10].

Ray et al. [11] investigated the relationship between rice yield and annual temperature extremes and found that temperature changes resulted in a -0.02 percent change in rice yield in the Philippines. However, Prabnakorn et al. [12] stated that a shorter time step would better represent crop sensitivity to climate at each growth stage. Among the climatic variables, temperature and precipitation are the two fundamental variables commonly used as indicators for changes in climate [13]. In contrast, Vogel et al. [9] revealed that temperature-related indicators have a stronger predictive capacity for rice yield compared to precipitation-related indicators. The present study addresses this by using annual temperature extremes to investigate the effect of temperature on rice yield.

Researchers often select precipitation-based indices because of their calculation convenience and standardization with respect to available data [14]. They also often base the selection of the drought index on its advantages in other regions. Pei et al. [15], however, suggest that different natural characteristics of different regions may contribute to the poor classification of drought. Furthermore, drought indices in general have a strong connection with agriculture.

In the Philippines, PAGASA (Philippine Atmospheric, Geophysical, and Astronomical Services Administration) only uses the Standard Precipitation Index (SPI) to monitor drought events, which only takes precipitation into account. However, the Standardized Precipitation

Evapotranspiration Index (SPEI), specifically, is more accurate than the SPI in terms of describing drought events because it takes temperature into consideration [12,16]. This study was formed to analyze the trend of two drought indices and correlate each index with the rice yield in a Type III Climate area, as identifying the variations between the drought indices and their characteristics was deemed to require further analysis by Pei et al. [15]. A Type III Climate area is defined by PAGASA [17] as one where the seasons are not very pronounced, with a short dry season lasting only from one to three months, either during the period from December to February or from March to May. It shares similarities with a Type I climate due to its short dry season; however, the season differences in Type I are more pronounced [17]. This study, therefore, has the potential to contribute valuable insights into the application of drought indices in Type III climate areas.

The Philippines' current water infrastructure has previously been identified as deficient in the National Climate Change Action Plan for 2011–2028 [18]. The findings of this study will improve understanding of the relationship between drought and rice yield, making it important to the country's agricultural research and climate change management plans. While current research and development focus on the creation of new technologies in agriculture, this study's focus is still in line with the recommended management practices for rice production in Asia [19].

The study aimed to determine the relationship between the drought indices SPI and SPEI and rice yield from 2005 to 2020. This is mainly due to the limitations of data availability for the rice yield data; the study was limited to 16 years only, from 2005 to 2020.

Specifically, the study aimed to analyze the trend of SPI and SPEI for drought identification in terms of rice yield in a Type III Climate area from 2005 to 2020 through the following objectives:

(i) compute for the annual mean, minimum, and maximum temperatures of Roxas City from the daily data;

(ii) compute for the annual precipitation of Roxas City from the daily data;

(iii) compute for the annual Potential Evapotranspiration (PET) of Roxas City;

(iv) compute for the annual Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) of Roxas City;

(v) compare the graphs of the annual SPI and SPEI of Roxas City at the given timescale; and

(vi) correlate the annual rice yield with the annual SPI and SPEI classifications of Roxas City.

Methods. - The methodology for this study was adapted from Prabnakorn et al. [12] and Pei et al. [15]. These studies provided the basis for conducting the Pearson Correlation and the Mann-Kendall tests, respectively. Data was requested from identified government agencies (PAGASA and the Capiz Provincial Agriculture Office), and missing data were imputed using multiple imputation. SPI, SPEI, and statistical calculations from the meteorological data were conducted in the R environment version 4.1.2. Their yearly averages were taken using the total annual rice yield data. Pearson's correlation was then employed to identify whether linear relationships existed between the drought indices and rice yield.

Study Area. The study area of Roxas City, Capiz (11°36'00.72"N 122°44'58.74"E) was selected based on the completeness of the available climate and agricultural data. It is within a 25-kilometer radius from its weather station seen in Figure 1. Of the two PAGASA weather stations in Western Visayas, the Roxas City station had the more complete data. Additionally, the study area is a Type III climate area with its dry season that lasts from February to April [17].

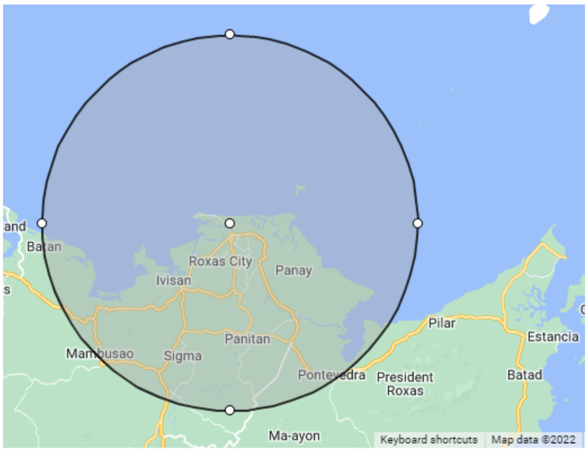

Figure 1. 25-km radial scope of the weather station's climate data

Tabulation and Imputation of Datasets. The raw data were tabulated in Google Sheets; however, there were missing values. In order to identify the data's missingness, the Little's Missing Completely At Random (MCAR) Test was used on the meteorological dataset. After identifying it as Missing Not At Random (MNAR), it was imputed with the random indicator method using the Multivariate Imputation by Chained Equations (MICE) algorithm.

Conduct of SPI and SPEI Analysis. The SPI expresses the amount of precipitation over time, while the SPEI calculates the difference between the cumulative precipitation and potential evapotranspiration. The code for the SPI and SPEI analyses was adapted from Beguería and Vicente-Serrano [20]. Potential evapotranspiration (PET) was calculated using the Thornthwaite [21] equation, which is ideal when only temperature and precipitation data are available. Other equations, such as those of Hargreaves [22], also utilize temperature and precipitation; however, they returned a value of infinity when tested with the data, which was not considered significant.

$$PET = 1.6b\left(\frac{10T_m}{I}\right)^a$$

Where:

b is the total monthly daylight hours divided by 360

T_m is the monthly mean temperature

I is the annual heat index

a is the empirical constant; cubic function of I

Data Analysis. The resulting values from the SPI and SPEI calculations match a specific SPI and SPEI category that determines drought conditions in an area. This assessment for SPI and SPEI was adapted from Prabnakorn et al. [12] and the Standardized Precipitation Index User Guide of the World Meteorological Organization, respectively. The values from 2005 to 2020 were then graphed to analyze the variations.

Table 1. Dry and wet conditions corresponding to the seven SPI and SPEI categories.

Value	SPI Category	SPEI Category
≧ 2.00	Extremely wet (EW)	Extreme wet (EW)
1.50 to 1.99	Very wet (VW)	Severe wet (SW)
1.49 to 1.00	Moderately wet (MW)	Moderate wet (MW)
0.99 to -0.99	Near normal (NN)	Normal (N)
-1.00 to -1.49	Moderately dry (MD)	Moderate drought (MD)
-1.50 to -1.99	Severely dry (SD)	Severe drought (SD)
≦ 2.00	Extremely dry (ED)	Extreme drought (ED)

Conduct of the Mann-Kendall Test. To analyze the monotonic trend of the temperature, precipitation, PET, SPEI, and SPI data, the Mann-Kendall Test was conducted using the *MannKendall* function in R Software. The null hypothesis for this test is that no monotonic trend exists, while the alternative hypothesis is that a trend exists.

Conduct of Pearson Correlation. The SPI and SPEI values acquired from the SPI and SPEI analyses, along with the annual rice yield of the study area, were utilized to implement the Pearson Correlation Test using the *cor.test* function in R Software.

Results and Discussion. - The trend analysis done through Mann-Kendall showed that temperature and potential evapotranspiration (PET) are both increasing, while precipitation showed no monotonic trend. A significance level of 95%, or a p-value of 0.05, was presumed. The table below summarizes the results of the Mann-Kendall test.

Table 2. Outputs of the Mann-kendall test with the climate data.

Dataset	Kendall's tau	2-sided p-value
Mean Temperature	0.205	2.5392e-05
Minimum Temperature	0.314	2.22e-16
Maximum Temperature	0.143	0.0032147
Precipitation	-0.00517	0.91591
PET	0.148	0.0023863
SPI	-0.00846	0.86266
SPEI	-0.0404	0.40647

Based on the values found in Table 2, the minimum temperature and mean temperature were the variables that exhibited the two most significant increasing trends. Their positive tau values indicated an increasing trend, with the strength of it increasing as it got closer to 1. Maximum temperature and potential evapotranspiration also displayed a significant increasing trend. Precipitation was the only single climate variable that displayed no monotonic trend from 2005 to 2020. The SPI and SPEI values of Roxas City were also run through the Mann-Kendall Test in RStudio to assess whether a monotonic upward or downward trend exists in their generated graph of values. The results imply that no significant upward or downward trend exists among the annual SPI and SPEI values of Roxas City from 2005 to 2020.

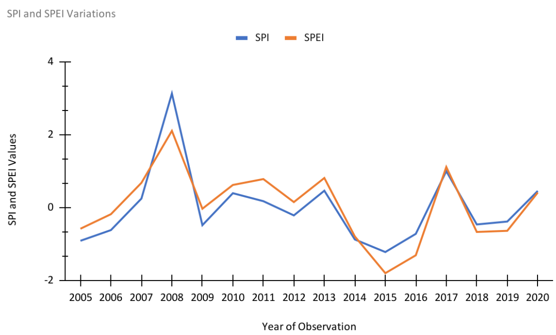

Figure 2. Combined graph of the annual SPI and SPEI values of Roxas City from 2005 to 2020.

The values of temperature and precipitation were compared with the climatological normals for Roxas City from 1991 to 2020 from Figures 3 to 6. The average values of mean, minimum, and maximum temperature from 2005 to 2020 all exceeded their respective climatological normals. This indicates a warming trend within this timespan. Figure 7 shows the annual potential evapotranspiration trend, while Figure 8 shows the annual time series of rice yield.

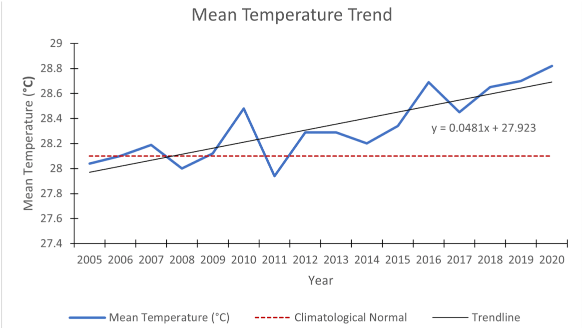

Figure 3. Graph of the annual mean temperature trend in Roxas City from 2005 to 2020.

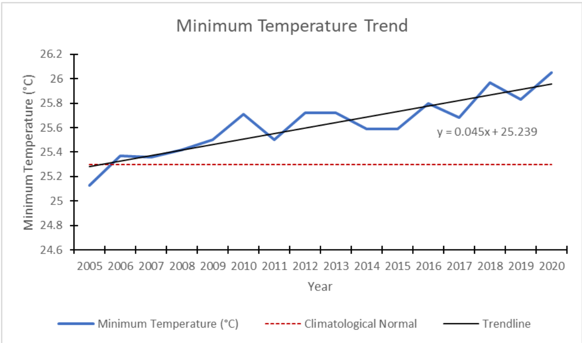

Figure 4. Graph of the annual minimum temperature trend in Roxas City from 2005 to 2020.

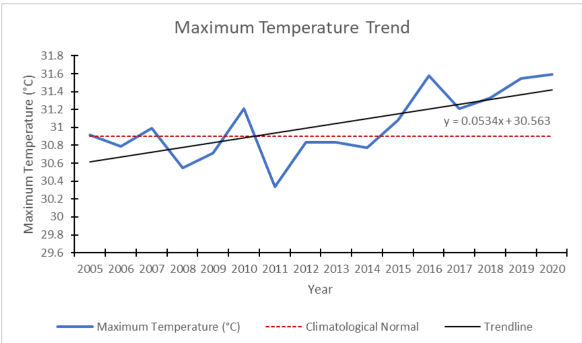

Figure 5. Graph of the annual maximum temperature trend in Roxas City from 2005 to 2020.

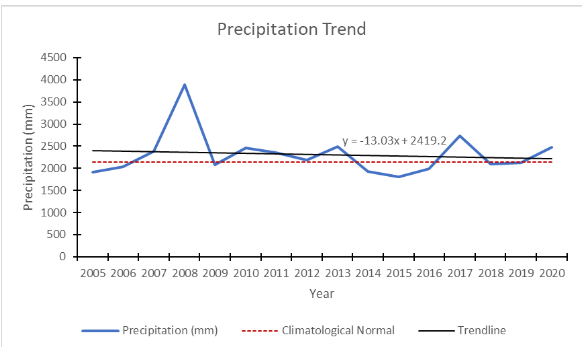

Figure 6. Graph of the annual precipitation trend in Roxas City from 2005 to 2020.

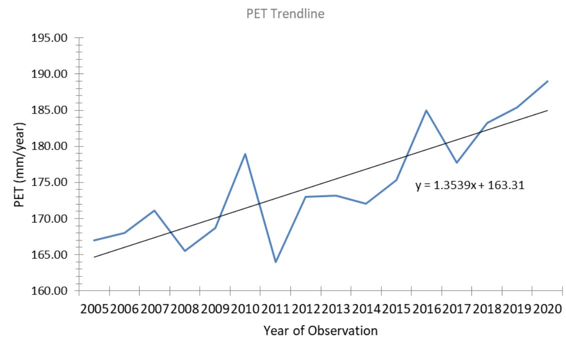

Figure 7. Graph of the annual potential evapotranspiration trend in Roxas City from 2005 to 2020.

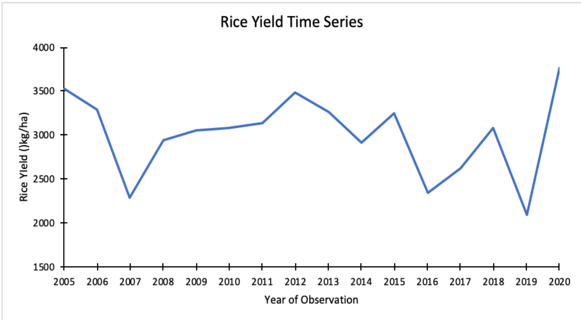

Figure 8. Graph of the annual rice yield trend in Roxas City from 2005 to 2020.

The Pearson correlation coefficient conducted between annual yield and SPI resulted in an r-value of -0.04972216 or -0.050, and the Pearson correlation coefficient between annual yield and SPEI is 0.06546188 or 0.065.

Pearson correlation coefficient values range from -1 to 1. If interpreted, Zvizdojevic and Vukotic [24] describe the major cut-offs as:

-1 - a perfectly negative association between two variables

0 - no association between two variables

1 - a perfectly positive association between two variables

Furthermore, a positive Pearson correlation coefficient reflects that the two variables are directly proportional, while a negative Pearson correlation coefficient reflects that the two variables are inversely proportional. However, given the low correlation values, this would imply that the association between the drought indices and rice yield has no significant linear relationship or is nonlinear.

Some scientific evidence points towards temperature as the climate variable that holds significant influence over rice yield [25]. The results of the current study, however, show that despite the significantly warming mean, minimum, and maximum annual temperatures, rice yield trends still remain without a constant pattern. Interestingly, the study's precipitation trend was also neither significantly increasing or decreasing.. As SPI and SPEI showed no significant upward or downward trend during the study period either, annual temperature and precipitation data alone may not be enough in characterizing rice yield trends.

Identifying and comprehending the risks that climate change poses to vulnerable sectors such as agriculture is critical for authorities to implement timely mitigation efforts. The weak correlations between rice yield and drought magnitudes for Roxas City suggest that drought magnitudes as measured by SPI and SPEI may not be a significant indicator of rice yield in some areas. Although the current impact is low, the influence on rice yield may be more serious in the future if temperatures continuously rise to a level that negatively targets specific growth stages of rice.

Limitations. In understanding the results of the correlation between the rice yield and the drought indices, factors such as irrigation and hybrid rice varieties were not considered in this study; the rice data utilized both rainfed and irrigated agricultural practices, which may have an effect on the rice yield data. These external factors that contribute to the growth stages of rice were not defined in this study, which looked at rice yield alone.

Conclusion. - The two drought indices have weak relationships with annual rice yield in Roxas City, Capiz. Annual SPI displayed a weak negative relationship, and annual SPEI displayed a weak positive relationship. Furthermore, both SPI and SPEI may not be strong predictors for rice yield.

Recommendations. - The applicability of SPI and SPEI may vary depending on the area's climate type [15], thus it would be ideal to look into other climate types as well. Other drought-sensitive crops may have higher linearity with the aforementioned drought indices. Conducting studies with the 30-year standard reference period would be more ideal to compare to climatological normals, and specifically for the rice yield data, it is recommended that the data be detrended in consideration of crop damage reports and other humanitarian influences in the analysis. Seasonal variations would be better observed on higher temporal resolutions (i.e. quarterly average) and may be given better analysis through the implementation of an autocorrelation analysis. Lastly, future analyses may want to consider the type of relationship between drought indices and rice yield aside from the linear level.

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