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Research Paper

INVESTIGATION OF SELECTING DROUGHT INDEX FOR AGRICULTURAL DROUGHT REZONING IN GIA LAI PROVINCE

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ARTICLE HISTORY

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ABSTRACT

Based on the data from hydro-meteorological stations, combined with the soil-specific data of Gia Lai province, the study selected the Palmer index to describe the drought. It was suitable with growing season to develop a monthly agricultural rezoning map for Gia Lai province. The study also showed that the number of days over years and the total number of days in the growing season tended to increase from the northern districts to the southern districts of the province and decreased from the eastern districts to the western districts. According to the time distribution from November to April, drought in Gia Lai province tended to increase from November to January, February and gradually decreases to April. According to spatial distribution, drought might decrease from west to east and from north to south. Through this study, it was shown that the areas suffered from agricultural drought were mostly the northwestern districts of the province in January.

Keywords*: Agricultural drought, Agricultural rezoning, Palmer index.*

1. Introduction

Many studies published more than 150 definitions of drought from early 1980s. The definitions reflect regional differences, needs and regulatory issues, but generally, drought is divided into four categories: meteorological, hydrological, agricultural, and socio-economic (Wilhite and Glantz, 1985; Wilhite, 2000). Agricultural drought is the different characteristics of meteorological or hydrological drought affecting agriculture, focusing on the lack of rainfall, the difference between actual evaporation and potential evapotranspiration, lack of water, reduction of underground water level or reservoirs (FAO, 2013; Sabău et al., 2015; Vicente-Serrano et al., 2015; Abhishek and Dodamani, 2018). Agricultural drought often occurs in areas where the soil moisture does not meet the needs of a specific crop in a certain period of time. Agricultural drought may explain the susceptibility of crop changes during different stages of growth during growth period (Allen et al., 1998; Potopová et al., 2015; Anderson et al., 2016; Ma'rufah et al., 2017).

In recent years, Gia Lai province as well as Vietnam has been conducting many practical studies, monitoring and assessments of natural conditions and natural resources in order to im-

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prove living standards, boosting agricultural production, serving the goal of restructuring the provincial agricultural sector. However, the main topics using the meteorology and hydrological resources in the most general method have not had detailed studies and assessments for each locality in the province. In particular, the rezoning of agricultural drought will help minimize the enormous losses caused by this phenomenon every year.

This study focused on selecting the most suitable new drought index to serve the agricultural drought rezoning in Gia Lai province. This is an urgent scientific research, contributing to mitigating natural disasters in order to develop socio-economic development in Gia Lai province in the direction of being sustainable and adapting to the current climate change conditions. These assessments can help regulators as well as manufacturers to actively adjust production plans, in order to increase the system's resilience in drought conditions, and adjust usage rationally groundwater and surface water resources, overcoming the effects that may be caused by drought phenomenon. These issues can be solved to mitigate impacts of natural disasters affected the development of economy and society of Gia Lai province.

2. Methodologies

2.1. Data sources

Meteorological data

Important monitoring data was used to calculate, evaluate, compare and verify data from the model or calculation methods in order to give an accurate assessment of applicability, the practicality of the selected model or calculation method. In the study area, data sources were collected from 7 meteorological stations in Gia Lai province and surrounding areas in Table 1.

Drought data and soil characteristics

The composition of the main soil group in Gia Lai is quite similar including: 1) Yellow red soil (Ferralsols - F): This group of soil has many different types, which are typically soil types: red yellow soil on magma acid (Fa) rock, yellow red soil on clay and metamorphic rocks. (Fs), sepia on magma baze and neutral rocks (Fk); 2) Gray soil (Acrisols - X): the typical soil type for this group of soil is gray soil on magma acid rock (Xa); 3) Alluvial soil (Fluvisols - P): There are 2 typical soil types for this soil group: glay alluvial soil (Pg) and stream alluvial soil (Py); 4) Humus soil (H): There are 2 typical types of soil: red yellow humus soil on magma acid rock (Ha) and yellow red humus soil on clay and metamorphic rocks (Hs).

We has carried out a survey on drought characteristics in all districts throughout the province through the collection of documents and reports of damage caused by natural disasters of the districts in the last 10 years.

Table 1. List of meteorological stations to collect data

No.	Name	Latitude (°)	Longitude (°)	Factor	Time period
1	Kon Tum	14.36	108	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018
2	Dak To	14.65	107.85	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018
3	Pleiku	13.97	108.02	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018
4	An Khe	13.95	108.65	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018
5	Yaly	14.22	107.84	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018
6	Ayunpa	13.4	108.45	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018
7	EaHleo	13.22	108.2	Temperature, precipitation, humidity, wind speed, evaporation and sunny time	1994-2018

In addition, the research also conducted an assessment of the current status of information on soil moisture survey points implemented through the project: “Developing drought maps and the lack of domestic water in the South Central and Highland” (Thuc, 2008). The results showed that the recent information on the status quo has little change compared to the result of the previous soil moisture survey. This research inherited all information about the soil profile characteristics of the previous project.

2.2. Applied Method

There are many methods and indices for calculating drought in the world in general and in Vietnam in particular, but the most used indicators with high accurate, computational and appropriate are the Palmer, SPI and Ped indices.

In the calculation process, the evaluation study determined the period and the drought level from the three indicators mentioned above were then compared with actual survey data. The results shown that the Palmer index includes the Z and PDSI, which was the best optimization for drought simulation and suitable for the growing season of crop. Therefore, this study used the Palmer index to develop an agricultural drought map in Gia Lai province.

2.2.1. Palmer drought index

The Palmer drought index (Palmer, 1965) is one of the first index to explain evaporation and soil moisture conditions, which are widely used for drought analysis and monitoring. The necessary input conditions are weekly or monthly data of precipitation and temperature. PDSI is the water based on moisture balance equation of the upper and lower soil layers. At each time step, additional rainfall and transpiration (ET) is deducted from the calculation area. Based on these calculations, the precipitation value of CAFEC (Climatically Appropriate For Existing Conditions) is determined for each time step. The difference of d (mm/month) between actual rainfall and CAFEC in a given month was shown by starting from the original water supply.

To ensure uniformity between different months and locations, Palmer determined the weighting empirical Kj for each month j of the year. The result of d and Kj is called Z - anomalous index of humidity compared to long-term climate. Palmer used an empirical relationship to turn Z into PDSI - an extreme (or extremely wet) limit index. PDSI is a cumulative index meaning that the value in each month depends on the value in the previous months. The PDSI algorithm contains several experimental constants estimated by Palmer based on data from only two locations. A limitation of the Palmer index is that the calculations are complex, the data must be continuous.

Z - Palmer drought index

Z - Palmer is an anomaly moisture index that meets short-term conditions better than PDSI and is usually calculated for a much shorter period of time to allow the identification of fast-growing drought conditions built by Palmer in the beginning in 1960, the Z - Palmer was usually calculated by month.

Z is calculated using the formula: $Z = Kd$

$$d = P - \hat{P} = P - (\alpha PE + \beta PR + \gamma PRO + \delta PL) \quad (1)$$

The value of d is considered as the moisture standard deviation. Four potential values should also be identified: (1) Input potential evapotranspiration (PE) determined by the Thornthwaite method; (2) Potential recharge of soil moisture (PR) is maximum amount of moisture that can be stored; (3) Potential runoff (PRO) is the difference between rain and PR; (4) Potential loss of soil moisture (PL) is the maximum amount of moisture that can be lost.

Table 2. Drought decentralization according to Z index

Z indicator	Drought level
≥ 3.50	Extremely wet
+2.50 ÷ +3.49	Very wet
+1.00 ÷ +2.49	Moderately wet
-1.24 ÷ +0.99	Normal
-1.25 ÷ -1.99	Moderate Drought
-2.00 ÷ -2.74	Severe Drought
≤-2.75	Extreme Drought

The Z-Palmer index provides a measure of moisture anomalies in an area on both levels: dry and moist. This index is used to compare current periods with known drought periods or can be used to determine the end of periods. Basing on land using data and the water balance method, the Z-Palmer index is quite strong for drought determination.

PDSI drought index

Developed by Wayne Palmer in 1965, this index has now become a common index and a background for many other indices. The Palmer index is based on a supply and demand model for soil moisture, using monthly temperature and precipitation information. In addition, the index is dependent on more difficult-to-calibrate factors including evapotranspiration and recharge rate. Palmer tried to overcome these difficulties by developing an approximation algorithm based on precipitation and temperature data.

$$PDSI_i = 0.897PDSI_{i-1} + \frac{1}{3}Z_i \qquad (2)$$

where PDSI of the first month in the series calculated by 1/3Zi and Z is the humidity anomaly index

Table 3. Drought decentralization according to PDSI index

PDSI	Condition
≤ 4.0	Extremely wet
3.0 ÷ 3.99	Very wet
2.0 ÷2.99	Moderately wet
1.0 ÷ 1.99	Slightly wet
0.5 ÷ 0.99	Incipient wet spell
0.49 ÷ -0.49	Near normal
-0.5 ÷ -0.99	Incipient Drought
-1.0 ÷ -1.99	Mild Drought
-2.0 ÷ -2.99	Moderate Drought
-3.0 ÷ -3.99	Severe Drought
≥ -4.0	Extreme Drought

PDSI is the drought index and widely used. PDSI is very effective to evaluate agricultural drought because of its moisture content.

2.2.2. Growth season of crop

A growing season is defined as equal rainfall and potential evapotranspiration in which ETo or PET potential evapotranspiration is calculated by FAO Penman-Monteith method (Allen, 1998).

ET_o is calculated using the formula

$$ETo = \left(\frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)}\right) \quad \text{(mm/day)} \quad (3)$$

where ET_o is reference evapotranspiration (mm/day[1]); Rn is net radiation at crop surface (MJ/m^2/day); G is soil heat flux density (MJ/m^2/day); T is mean daily air temperature at 2m height (°C); u_2 is wind speed at 2m height (m/s); e_s is saturation vapour pressure (kPa); ea is actual vapour pressure (kPa); e_s - e_a saturation vapour pressure deficit (kPa); Δ is slope vapour pressure curve (kPa/°C) and γ is psychrometric constant (kPa/°C).

3. Results and discussions

3.1. Determination of growing season of crop

Based on the characteristics of the growing season, it will give a better overview of the drought occurring in the study area, helping to determine the year of the heaviest drought and the least drought occurrence in the calculation period. Start time and end time as well as length of time of growing season varied from year to year and from region to region. The short growing season leaded to a low soil moisture level in that year and a high possibility of agricultural drought. In contrast to the long growing season, the moisture content was high in the soil, the agricultural drought was rare.

At Pleiku station, the growing season ranges from 154 days to 233 days, the average for many years was 198 days starting from April 25 and ending on November 9. The year of severe drought was in 2015 and 2010, with the growing seasons of 167 and 154 days, respectively. Amplitude was around 25 days. At An Khe station, the growing season ranges from 183 days to 284 days, the average growing season was 266 days starting from April 28 and ending on January 19 of the following year. The year of severe drought was in 2014 and 2015 with 183 and 206 days. Amplitude is around 31 days. At Ayunpa station, the growing season ranged from 157 days to 250 days, with an average of 194 days starting from May 3and ending on December 4. The heaviest drought years were in 2015 and 2012 with 119 and 157 days, respectively. Amplitude is around 45 days. At Yaly station, the growing season ranged from 155 days to 213 days, the average values over many years were 195 days starting from April 21 and ending on November 2. The heaviest drought periods were in 2015 and 2016, with ranges of 155 days and 168 days, respectively. Amplitude was around 19 days.

Thereby it could be seen that the fluctuations in days over years and the total number of days in the growing season tended to increase gradually from the northern districts of the province to the southern districts of the province, and tended to decrease from the eastern districts to the western districts of the province. Spatial distribution of agricultural drought was most likely to occur in the north-western part of Gia Lai province, with a tendency to decrease from north to south and from east to west. The whole province in each region has different drought characteristics. The worst drought year and less frequent drought was uneven throughout the province over the years. Therefore, it is necessary to determine the growing season each year so that the seasons can be changed appropriately to minimize damage caused by drought.

3.2. Map of agricultural drought rezoning in Gia Lai province

After determining the growing season, it can be seen that drought occurs in Gia Lai province from December to April. Thereby, this study focuses on analyzing and developing drought maps from the set of data calculations from the Palmer index for these months.

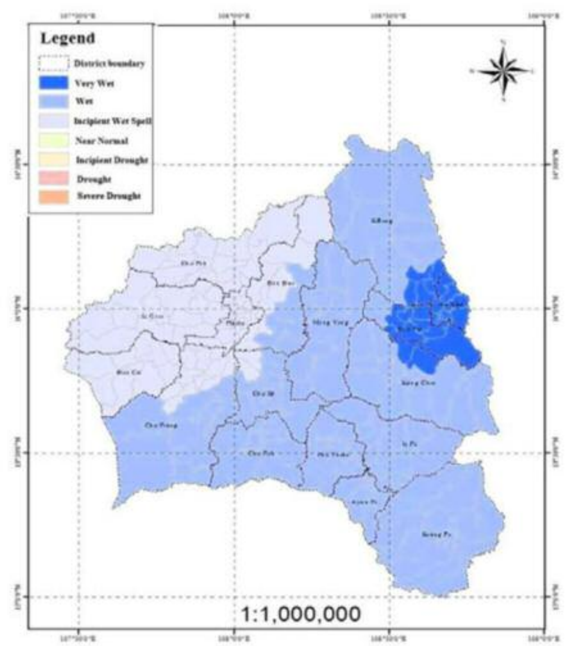

Fig. 1. Map of agricultural drought risk rezoning in Gia Lai province in November

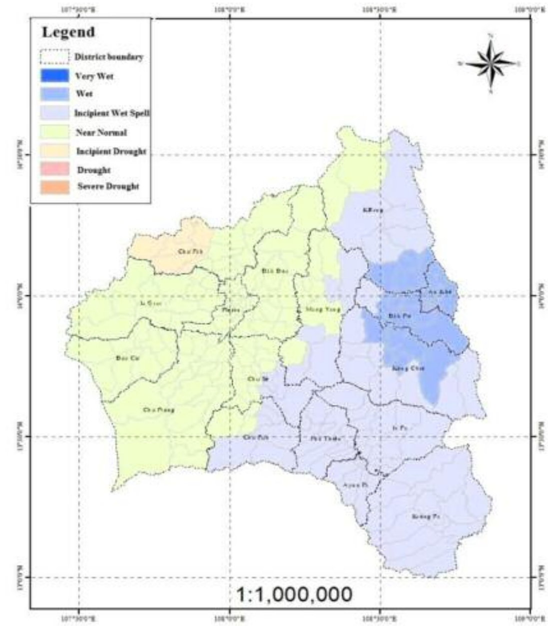

Fig. 2. Map of agricultural drought risk rezoning in Gia Lai province in December

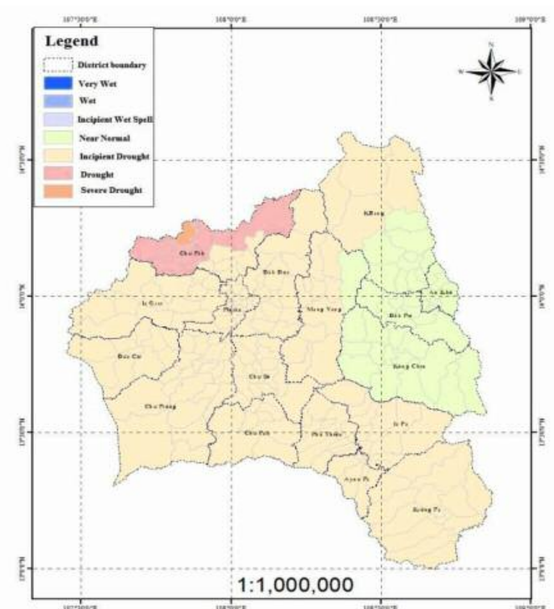

Fig. 3. Map of agricultural drought risk rezoning in Gia Lai province in January

Based on the agricultural drought-specific zoning of Gia Lai province, it could be seen that there is almost no risk of drought happening throughout the province (November, December). The moisture content in soil is from wet to very wet in November (Fig. 1). In December, there was a gradual decline and the area of Chu Pah district happened drought (Fig. 2). According to space, soil moisture content decreases from East to West and from South to North of the province. Drought has begun to occur in the northwest region of the province.

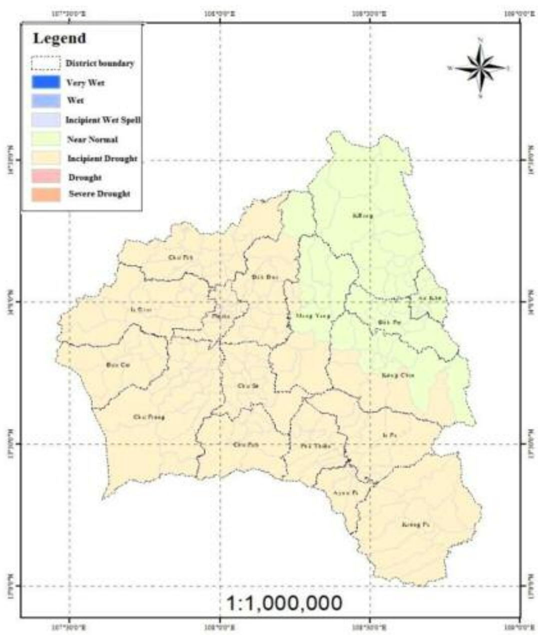

Fig. 4. Map of agricultural drought risk rezoning in Gia Lai province in February

In January, drought began to occur in most of Gia Lai province, except An Khe, Dak Po and Krong Chro districts, the northern part of Kbang district, and the northeastern part of Mang Yang district. Severe drought occurred in Chu Pah district, a district located in the Northwest of Gia Lai province (Fig. 3). In February, drought was reduced in Chu Pah district. Districts like Mang Yang and Kbang have terminated (Figs. 3-4). In terms of spatial distribution, severe drought occurred in the northwestern region of the province. Drought gradually decreases from north to south and from east to west.

Labedzki and Kanecka-Geszke (2009) studied standardized evapotranspiration as an agricultural drought index based on 40 meteorological stations located in various agro-climatic regions of Poland. A great spatial differentiation of the frequency of droughts depending on drought category and soils were determined (Labedzki and Kanecka-Geszke, 2009; Labedzki and Bak, 2014). Drought index can be used to implement an early warning system for drought and to operate adrought monitoring service. Water supply is calculated by the cumulatively effective precipitation with the application of the weight to the precipitation. Water demand was derived from the actual evapotranspiration, which was calculated applying a crop-coefficient to the reference evapotranspiration (Kim et al., 2014; Sun et al., 2012).

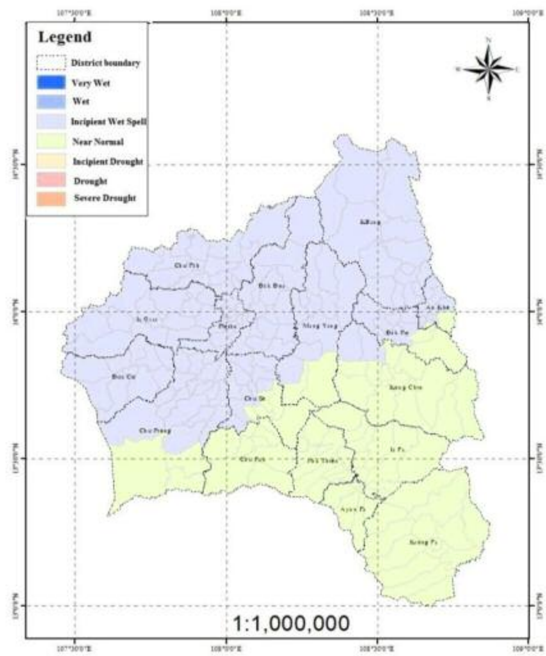

Fig. 5. Map of agricultural drought risk rezoning in Gia Lai province in March

From March to April the entire Gia Lai province has almost terminated drought season. Most of the areas were wet enough for the next growing season (Figs. 5-6). Therefore, the map of drought risk distribution in Gia Lai province, it showed that drought tended to increase from November to January, and decreasefrom February to April. Spacially, drought could decrease from west to east and from north to south. Thereby the most likely area for drought occurrence was in the northwestern region of the province.

A study conducted by Kamruzzaman et al. (2019) to assess the spatiotemporal characteristics of agricultural droughts inBangladesh during 1981-2015 using the Effective Drought Index (EDI). The study identified that thecharacteristics (severity and duration) of drought were also analyzed in terms of the spatiotempo-ralevolution of the frequency of drought events. They found that the western and central regions ofthe country are comparatively more vulnera-ble to drought. Moreover, the southwestern re-gion was more prone to extreme drought, whereas the central region is more prone to se-vere droughts (Kamruzzaman et al., 2019). How-ever, agricultural drought is often characterized by current water demand-supply conditions, without considering the rarity of drought event in the historical period. Agricultural drought caused by soil water deficit exerts great influ-ence on ecosystems and growth of crops. Accu-rate monitoring and detection of spatio-temporal characteristics of agricultural drought are mean-ingful for food security. In order to overcome the limitations of using crop water deficit indicator or dryness anomaly indicator only, an integrated evapotranspiration deficit index combining water deficit and dryness probability was pro-posed (Zhao et al., 2017).

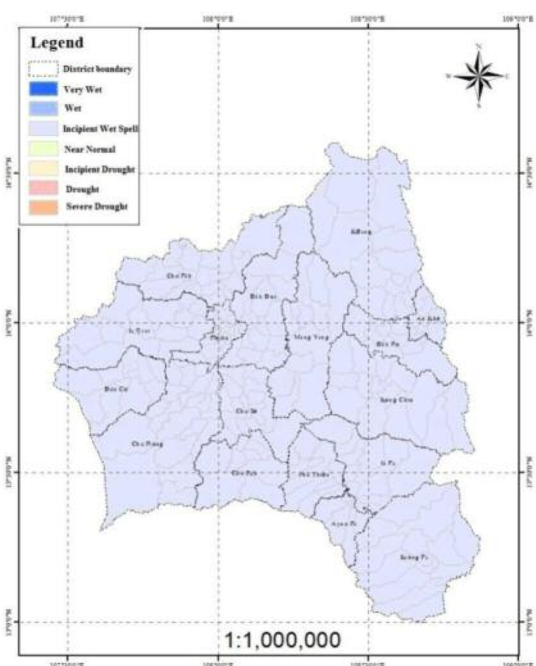

Fig. 6. Map of agricultural drought risk rezon-ing in Gia Lai province in April

4. Conclusion

This study has important implications for as-sessing drought and particularly agricultural drought that can occur in Gia Lai province, which is subject to many impacts and changes under current conditions. The fluctuations in days over years and the total number of days in the growing season tended to increase gradually from the northern districts to the southern dis-tricts of the province, and tended to decrease from the eastern districts to the western districts of the province.

The agricultural drought rezoning is new re-sults for the province in the Central Highlands in this study. A detailed district-level drought maps for the months in Gia Lai province, has been de-veloped, reflecting spatial-specific densities for each month; drought tended to increase from No-vember to January, and decrease from February to April. Basing on space, drought could de-crease from west to east and from north to south. Thereby, the drought area happens in the districts of the northwest region of the province. The re-search results can contribute as a scientific back-ground for the locality to refer to the agricultural development orientations. Orientations in agri-culture need to study carefully the mechanism of weather and the impacts of natural disasters, es-pecially the drought in agriculture.

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