International Journal of Agricultural Technology 2020 Vol. 16(3): 655-666
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Drought risk area assessment using GIS in Sa Kaeo Province, Thailand

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Noichaisin, L., Buranaprathepprat, A., Manthachitra, V. and Intarawichian, N. (2020). Drought risk area assessment using GIS in Sa Kaeo Province, Thailand. International Journal of Agricultural Technology 16(3): 655-666.

Abstract Geographic Information System (GIS) model was used to assess drought risk area in Sa Kaeo Province, Thailand. Results indicated that total area of low, moderate, high, and very high drought risk were 103,394 m^2 (1.44%), 3,482,673.76 m^2 (48.40%), 3,406,193.74 m^2 (47.34%) and 203,174.31 m^2 (2.82%), respectively. The historical drought information and field surveys were compared to evaluate the accuracy of model prediction, which was 77.35%. Relationships between studied environmental factors and the drought risk were examined, and the results showed both positive and negative correlations. The factors expressing significant positive correlations with drought risk from high to low were distanced from irrigation area, volume of groundwater, slope, soil drainage, distance from water sources and land use with Pearson correlation coefficients of 0.743, 0.534, 0.510, 0.476 and 0.265, respectively. Meanwhile, the averaged annual rainfall was a negative correlation with drought risk, with Pearson coefficient of -0.853. The results can be used as information for the local administration to help alleviate the effects of continued drought in Sa Kaeo Province.

Keywords: Drought risk, Geographic Information System, Sa Kaeo Province

Introduction

Drought is an important natural type of disaster that causes severe impacts to livelihoods and the environment. The major causes of drought are insufficient amount of rainfall over a prolonged period, lack of water in reservoirs and poor soil properties to hold underground water. The most important phenomenon affecting these factors is climate change (Thai Meteorological Department, 2017). Drought tremendously affects human lives, especially through the quantity and quality of drinking water (Khongsanun,

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2009). In addition, it seriously limits agricultural activities, causing a decrease in agricultural production and further socio-economic losses for the country.

In Thailand, the issue of drought has been managed by government sectors on a year-by-year basis. The Water Crisis Prevention Center (2018) indicated that the drought in Thailand was mainly caused by a dry spell and less frequency of days with rainfall. Long term periods of drought can reduce moisture in soil, causing crop growth and yields to decline. Moreover, it can degrade yields of livestock, forest and fishery products, and the overall economy. Thailand suffered from drought for many consecutive months during the rainy season from 1967 to 1993. Rainfall in the rainy season and annual rainfall in 1979 were both much less than the long-term average, resulting in severe drought and huge losses to Thailand's economy, especially in agriculture, manufacturing and electricity supply (Punprasit, 2006).

Sa Kaeo Province is located in the eastern part of Thailand. Most of its population is engaged in the agricultural sector. Agricultural area in the province covers 3,744.14 km^2 including the following major crop types: paddy field (1,212.34 km^2), cassava (863.21km^2), sugarcane (635.95 km^2) and maize (251.31 km^2). In 2010, Sa Kaeo Province confronted severe drought in 9 districts, 31 sub-districts and 337 villages, with 34.67 km^2 of agricultural area being damaged (Hydro and Agro Informatics Institute, 2017).

The Geographic Information System (GIS) has been widely used for environmental studies (Pijanowski *et al*., 2009; Solaimani *et al*., 2005; Mahiny and Gholamalifard, 2007; Alam *et al*., 2008; Faryadi and Taheri, 2009; Lin and Chen., 2010). For example, Thailand Institute of Science and Technology (1999) assessed the areas at risk of flooding and drought in the central basin of Thailand using GIS. Drought risk is categorized into four levels:- high risk, moderate risk, low risk and no drought areas. The assessment is used for flooding and drought area management. The objective was to identify drought risk area using Geographic Information System (GIS) in Sa Kaeo Province, Thailand.

Materials and Methods

Aranyaprathet District, Sa Kaeo Province, Thailand was the studied area which locates in the eastern of Thailand, adjacent to Poi Pet, Cambodia. This province is far from Bangkok about 245 kilometers, with an area of 7,195.44 square kilometers. It is located at latitude 13˙49' 0" N and longitude 102˙4' 0" E (Figure 1).

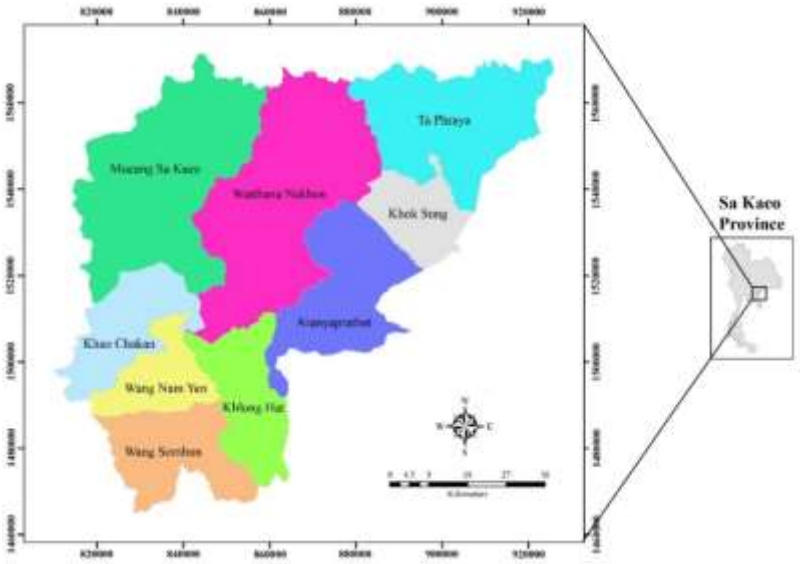

Figure 1. Study area of Sa Kaeo Province, Thailand

Table 1. Secondary data collected from government agencies

Data	Type of information		Data sources	Year
	Point	Polygon		
Meteorological - Average annual rainfall	✓		Meteorological Department of Thailand	Interpolated by GIS Analysis, 2016
Hydrological and Hydrogeological -Volume of groundwater -Distance from water sources -Distance from irrigation area		✓ ✓ ✓	Geo-Informatics and Space Technology Development gency (Public Organization)	2014
Topographical - Soil drainage - Slope		✓ ✓	Geo-Informatics and Space Technology Development Agency (Public Organization)	2014
Land Use Characteristics - Land use		✓	Geo-Informatics and Space Technology Development Agency (Public Organization)	2012

The environmental factors were assessed on the effect of drought risk area in Sa Kaeo Province, to get the primary and secondary data for analysis. The primary data were collected by interviewing ten experts in government sectors related to water resource management. The secondary data were included fundamental data which collected from various agencies, as seen in Table 1.

The relevant environmental factors were considered on the basis of meteorological, hydrological and hydrogeological, topographical and land use data. These factors were weighted and rated by experts and governmental representatives through questionnaires. A forecasting model for drought risk assessment was then applied to GIS. ArcGIS software was used for input, edited, analyzed and represented the spatial data. The conceptual framework is shown in Figure 2.

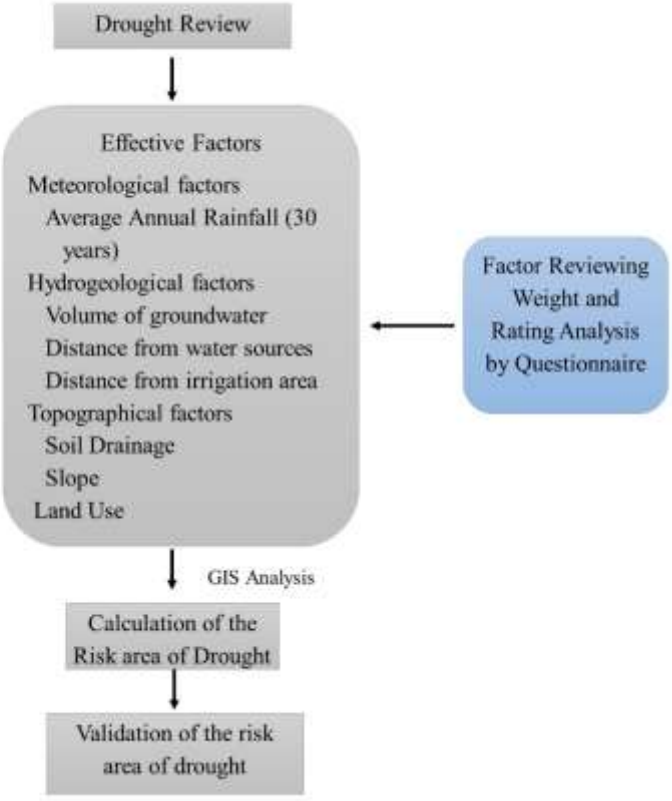

Figure 2. Conceptual framework for assessment of drought risk area

For data import and analysis, at first, geographic data, including average annual rainfall, volume of groundwater, distance from water sources, distance from irrigation area, soil drainage, slope and land use were imported into the GIS program. Each factor was weighed which based on its relative effect on drought, following the expertise evaluation system presented in Chanchaeng (2010). The factors (and weighting score) were averaged annual rainfall (7), volume of groundwater (5), distance from water sources (5.2), distance from irrigation area (5.5), soil drainage (5), slope (4.5) and land use (4.3). Then, the spatial data were overlayed to identify level of drought risk in each area based on the order of affecting factors. A total score at each point was calculated as Weighting Linear Total following Eq. 1 (modified from Dhanarun and Amornsanguansin, 2010):

$$S = W1\,R1 + W2\,R2 + W3\,R3 + ... + Wn\,Rn \quad (1)$$

where S is the score of the risk level of drought, $W1 \ldots n$ is the score of the importance of factors $1 - n$, $R\,1 \ldots n$ is the sub-score of each factor $1 - n$

Drought risk area was assessed which based on the sum of total points and weighting factors. It was used to calculate the mean ($\bar{x}$) and standard deviation (S.D.) and then risk was classified into four levels of severity; 1) very high drought risk (sum of points > $\bar{x}$ + 1 S.D.), 2) high drought risk (sum of points is between $\bar{x}$ and $\bar{x}$ + 1 S.D.), 3) moderate drought risk (sum of points is between $\bar{x}$ and $\bar{x}$ – 1 S.D) and 4) low drought risk (sum of points < $\bar{x}$ – 1 S.D.) The result were then displayed as a spatial map using ArcGIS 10.4 to identify drought risk areas in Sa Kaeo Province. Next, the prediction from the spatial map was verified with historical drought data from the Office of Prevention and Mitigation Sa Kaeo (2016) by using matrix calculation for accuracy assessment.

Results

The factors were weighted and rated by experts and governmental representatives through questionnaires shown in table 2. The factors used for identify drought risk area were consisted of average annual rainfall, volume of groundwater, distance from water sources, distance from irrigation area, soil drainage, slope and land use as shown in Figures 3.

The annual rainfall recored over the past 30 years in most areas in the upper and middle parts of the province was averaged between 1,329.44-1,623.44 mm/year. For the southern part of the province, rainfall was over

1,623.44 mm/year. The averaged annual rainfall between 1,039.90-1,329.44 mm/year was recorded in Pa Rai sub-district, Aranyaprathet district. The volume of groundwater was lower than 5 m^3/h in most areas when compared to other area. The distance from water sources in most areas was less than 1,000 m. The areas within irrigation zones had low drought risk because they received water for consumption from irrigation system. However, the most agricultual area in Sa Kaeo Province are far from irrigation zones causing high drought risk. The factor of soil drainage indicated the the soil properties water drainage in clay soil with fine particles is lower than sandy soil. Water drainage in Sa Kaeo Province is generally low to very low. The degree of slope in the province is lower than 6%. Some areas in the northern part are very steep because of the mountainous terrain where Pang Sida National Park is located. Water rapidly runs off from the soil surface in such high-slope areas. The dominant land use type in the province is agriculture, it may suffer from drought. The forest area is mostly located in the northern part of the province. Drought risk area was assessed by overlaying the studied factors using GIS techniques. The results are shown in Figure 4 and Table 3.

Based on the factors described above, the total area with low drought risk was 103,394.19 m^2 (1.44%) in the southern part of the province including parts of Nong Waeng, Nong Muang, Wang Sombun, Wang Mai and Wang Thong sub-districts, Wang Sombun district and the northeast part of the province, in Thap Rat and Kho Khlan sub-districts. The low drought risk in these areas is based on high annual average rainfall and high water-holding capacity of soils as well as high amount of groundwater in the southern part. The total area with moderate risk was 3,482,673.76 m^2 (48.40%), covering some parts of Wang Mai, Wang Thong and Non Mak Kheng sub-districts. High drought risk areas covered 3,406,193.74 m^2 (47.34%) in Sa Kaeo Province. These are located in the northern and northeastern parts of the province, such as in Sae-o, Nong Mak Fai and Thap Rat sub-districts. The total of highly drought risk area was 203,174.31 m^2 (2.82%) in some parts of Pa Rai, Huai Chot, Han Sai and Tha Yeak sub-districts. The accuracy of assessment was performed by comparing with field surveys and the annual report of the Office of Prevention and Mitigation Sa Kaeo are shown in Table 4.

Relationships between the studied environmental factors and the drought risk are both positive and negative correlations (Table 5). The factors of distance from irrigation area, volume of groundwater, slope, soil drainage, distance from water sources and land use were expressed significantly positive correlation of drought risk which Pearson correlation coefficients were 0.743, 0.534, 0.510, 0.476 and 0.265, respectively. Meanwhile, average annual rainfall

had a negative correlation of drought risk, which Pearson coefficient was -0.853.

The results of accuracy checking based on GIS, field surveys and the annual report of the Office for Prevention and Mitigation Sa Kaeo (2016) are shown in Table 4. The accuracy percentage was 77.35%. The field surveys and GIS analysis were shown to be a very high drought risk area due to difficulty to access water sources and irrigation. Mitigation should include water sources and properly developing irrigation systems to be a very high drought risk areas (Figure 5).

Table 2. Primary data summarized from expert interviews

Factors	**Weighting**		**Rating**
		Class	
Average annual rainfall	7	< 1,039.90 mm.	3
		1,039.90 -1329.64 mm.	2
		1329.64 - 1623.44 mm.	2
		> 1623.44 mm.	1
Volume of groundwater	5	< 5 m^3 /hr	3
		5 - 7.5 m^3 /hr	2
		7.5 - 10 m^3 /hr	1
		>10 m^3 /hr	1
Distance from water sources	5.2	> 3,000 m	4
		2,001 - 3,000 m	3
		1,001 - 2,000 m	2
		< 1,000 m	1
Distance from irrigation area	5.5	> 2,000 m.	3
		1,001 - 2,000 m.	3
		0 - 1,000 m.	2
		Within irrigation area	1
Soil drainage	5	Well drained	3
		Moderately well drained	2
		Poorly drained	2
		Very poorly drained	1
Slope	4.5	> 30%	3
		15 - 30%	3
		6 - 15%	2
		< 6%	1
Land Use	4.3	Agricultural land	3
		Urban and built-up land	3
		Forest land	2
		Miscellaneous land	1

Note: The influence of each factor was weighted as 1-7 and rated as 1 - 4; 1 point indicates lowest influence, higher values indicate higher influence.

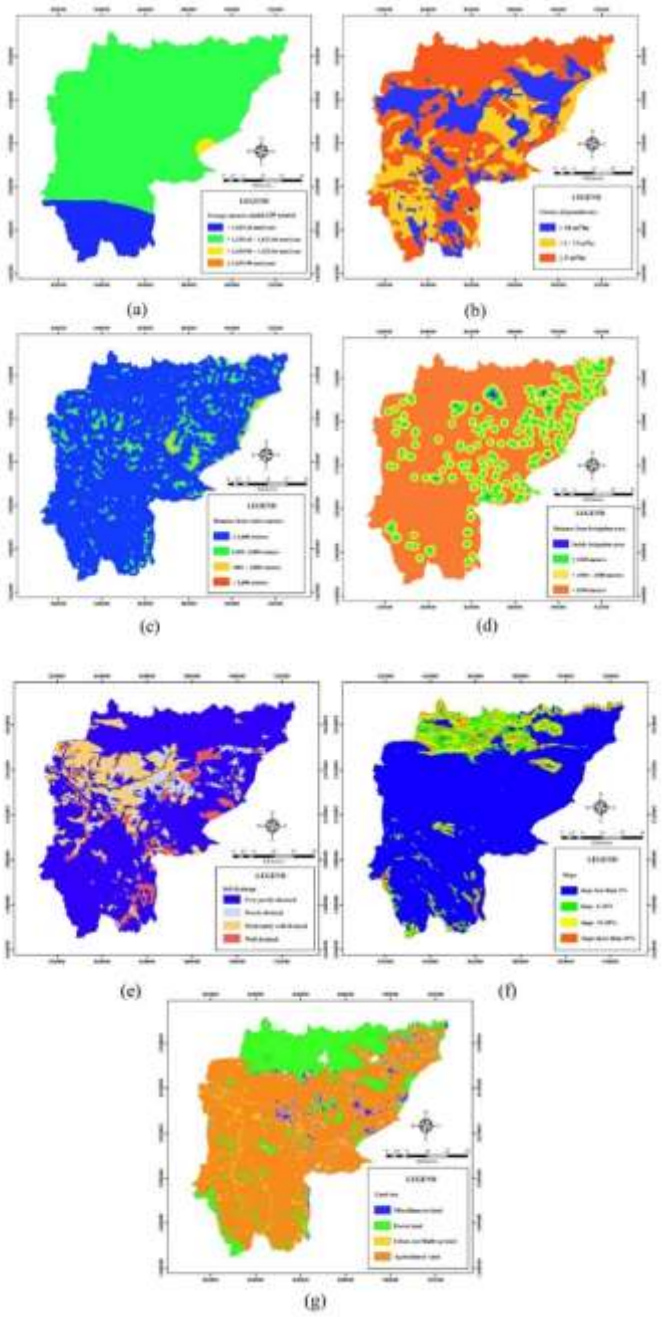

Figure 3. Spatial maps of average annual rainfall (a), volume of groundwater (b), distance from water sources (c), distance from irrigation sources (d), soil drainage (e), slope (f) and land use (g)

Table 3. Drought risk area in Sa Kaeo Province based on GIS analysis

Level	Percentage	Area (m^2)
Low	1.44	103,394.19
Moderate	48.40	3,482,673.76
High	47.34	3,406,193.74
Very high	2.82	203,174.31
Total	100.00	7,195,436.00

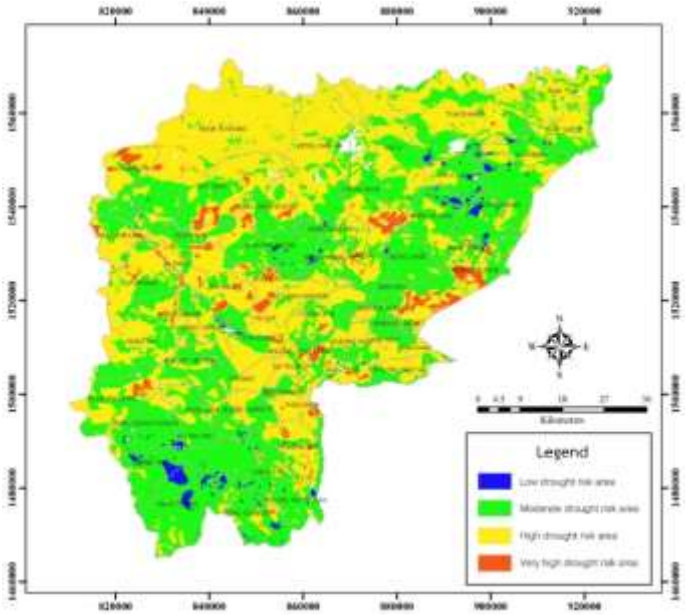

Figure 4. Drought risk area in Sa Kaeo Province from GIS analysis

Table 4. The accuracy assessment of drought risk area

Drought risk	Result				
	Very High	High	Moderate	Low	Summary
Very High	7	1	1	0	9
High	0	14	2	1	17
Moderate	0	3	13	1	17
Low	0	0	3	7	10
Total	7	18	19	9	53

Table 5. Multiple correlation coefficients between environmental factors and drought risk area

Factor	Pearson correlation coeffient
Average annual rainfall	-0.853*
Volume of groundwater	0.534*
Distance from water sources	0.467*
Distance from irrigation area	0.743*
Soil drainage	0.476*
Slope	0.510*
Land use	0.265*

* statistical significance level at P = 0.05

Figure 5. A very high drought risk area and an irrigation system

Discussion

The results indicated that most area of 95.74% in Sa Kaeo Province were facing moderate and high level of drought risk. The most important factor affecting drought in the province is the annual rainfall which is the source of water for agriculture and consumption (Srisurat, 2000). In addition, the risk may be intensified as a result from rising average temperatures caused by urbanization and climate change. Soytong *et al*. (2018) monitored urban heat islands in the eastern region of Thailand and found an increasing trend of average temperature due to urbanization. The highest average temperatures in Rayong, Chon Buri, Trat and Sa Kaeo provinces were 31.36 ^{o}C, 30.48 ^{o}C, 28.51 ^{o}C and 28.30 ^{o}C, respectively in 2011. The values in all provinces increased to 33.18 ^{o}C, 32.82 ^{o}C and 32.14 ^{o}C for Chon Buri, Sa Kaeo and Prachinburi provinces, respectively in 2017. The data indicate that Sa Kaeo Province has an enormous increasing trend of average temperature of about 4.5 ^{o}C for just 6 years. This rate however may include many influencing factors such as short-term variations, global climate change, measurement accuracy and error.

Na-U-Dom *et al.* (2020) studied on drought assessment in Sa Kaeo Province during dry season and found slightly and moderately drought normally occurred but severe and extremely drought occurred during dry season from late 2001 to early 2002. This study suggests the importance of short-term or year-to-year climate variation. The drought is also related to regional climate phenomena such as El Nino. The influence of El Nino as reported by Noichaisin *et al*. (2019) is able to increase the problem of water shortage in Sa Kaeo Province. It was found that total area with moderate and low water shortage decreased while the area with high and very high water shortage increased as compared to normal years during El Nino periods.

The average rainfall in Sa Kaeo province each year is between 1,329.44-1,623.44 mm, close to the average rainfall in Thailand which is approximately 1,572.5 mm (Thai Meteorological Department, 2019) Some areas are not arid because of little rain but lack of irrigation systems in order to provide water for uses during the dry season. Increasing water storages and irrigation canals to increase the chances of arid areas to access water resources becomes crucial. A good and effective irrigation system insures water supply in irrigated agriculture and helps to reduce drought (Dolores and Jose, 2019). The research finding suggested that Sa Kaeo Province should manage and extend irrigation systems to cover from the high risk to the low risk areas to reduce the drought that may be intensified in the future.

Acknowledgments

The authors would like to thanks the Geo-Informatics and Space Technology Development Agency (Public Organization) and The Meteorological Department of Thailand for providing secondary data for this research.

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(Received: 10 August 2019, accepted: 1 April 2020)