Spatial Distribution of Drought Hazard Mapping Based on AHP and GIS in Kampong Speu Province

Chhuonvuoch Koem[1], Korakod Nusit[2], and Sarintip Tantanee[3,*]

ARTICLE INFO

Article history:
Received: 24 February 2021
Revised: 21 June 2021
Accepted: 5 December 2021

Keywords:
Analytical hierarchy process
Cambodia
Drought hazard map
Kampong Speu
Multi-criteria analysis

ABSTRACT

Drought is a meteorological disaster, which frequently affects many regions around the world including Cambodia. The purpose of this research is to identify the spatial distribution of drought hazards by joining criteria that influence drought hazard with the support of the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) in Kampong Speu Province. Multi-criteria investigation is considered for integrating drought hazard mapping that combines all influence parameters to develop detailed information to support drought mitigation plans and strategies. AHP method is applied to calculate eight influence parameters' weight including rainfall, relative humidity, average temperature, maximum temperature, soil types, slope, drainage density, and landuse by using a pairwise comparison matrix. The result shows that Basedth, Samraong Tong, Odongk, and Kong Pisei districts are more prone to drought hazards, which are located in very high hazard zones with 6.87%, 5.47%, 5.34%, and 5.32% of the total area, individually. The results are significant information for decision-makers to plan for further drought mitigation and sustainable development.

1. INTRODUCTION

Drought is one of the greatest critical meteorological disasters that cause enormous influences on the economy, agriculture, natural and water resources, society, and environment [1]-[2]. The incidence and severity of drought have been amplified as a result of climate change combined with human activities around the world [3]-[4]-[5]-[6]-[7]. The drought-related disaster causes a global economic loss of approximately US 6 to 8 billion dollars per year [2]-[8]. The Cambodia National Committee for Disaster Management (NCDM) stated that Cambodia was affected by droughts 1,343 times starting from 1993 to 2013 and affected 2,766,217 victims during the incidences [9]. Moreover, the droughts caused 9% of economic losses in Cambodia [10]. Kampong Speu Province is one of the most drought-affected provinces. In 2002, 2004, 2005, 2006, and 2012, droughts affected 149,175 people, 308,225 people, 681,039 people, 100,592 people, and 1,925 people, respectively [11]. Many hectares of agricultural crop were damaged by droughts [12]. The drought mitigation and preparedness measures are therefore significantly required for minimizing the drought impacts. The previous studies focused on drought monitoring and damage assessment [13]; yet, the drought hazard assessment is insignificantly paid attention to. The spatial distribution and degree of drought hazard comprise a key tool for drought hazard assessment [14]. Consequently, efforts should be made to identify the drought hazard areas along with their degree. Hazard refers to a threatening event, substance, or condition that caused death, injury, and damage to property, livelihood, service, social, economic, and environment [15].

An effective drought hazard mapping accounts for the selection and zoning of all of the influenced factors to the drought hazard [16]. Spatial analysis and satellite information are very important for drought hazard mapping since attribute analysis requires both space and temporal components. The satellite information provides attributes, which are precise, timely, and continuous over a large area. The spatial analysis supports data integration and analysis [17]. Analytical Hierarchy Process (AHP) is a dimension theory using a pairwise comparison that depends on the experts' judgment and previous studies or literature review to obtain the priority scales. Additionally, it is one of the powerful approaches dealing with multi-criteria decision-making [18]-[19]. AHP approach is more effective when combined with GIS [20].

Therefore, this study aims to develop the drought hazard map by incorporating the influenced factors with the help of the AHP approach and GIS techniques. Due to its high

[1]Disaster Management field of study, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand.
[2]Faculty of Engineering, Naresuan University, Phitsanulok, Thailand.
[3]Center of Excellence on Energy Technology and Environment, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand.
*Corresponding author: Sarintip Tantanee; Tel: +66 81 887 8817; Email: sarintipt@nu.ac.th.

drought impacts, therefore, Kampong Speu Province, Cambodia is nominated as the study area of this research. The developed map could benefit the community and national decision-makers, who are involved in disaster management and risk management. Moreover, the map can support the emergency facilities for implementing effective plans or activities before, during, and after disasters [21].

2. MATERIAL AND METHOD

Study Area

Kampong Speu Province, Cambodia, geographically lies between 11.6155° N and 104.3792° E, as shown in Figure 1. It has a total area of 6,966 km^2 with a total population of 872,219 [22]. The province owns seven districts and one municipality with 87 communes. The study area's elevation ranges between 03 and 1,814 m above the mean sea level. Additionally, the average annual rainfall is 1,562 mm with an average temperature of 27.5 °C whereas the average relative humidity is 76.24%. According to the "Center for Excellence in Disaster Management & Humanitarian Assistance" (CFE-DM), the province is one of the most drought-affected provinces in Cambodia since there is a delay of rainfall within the rainy season and no water or too little water within the dry season [10].

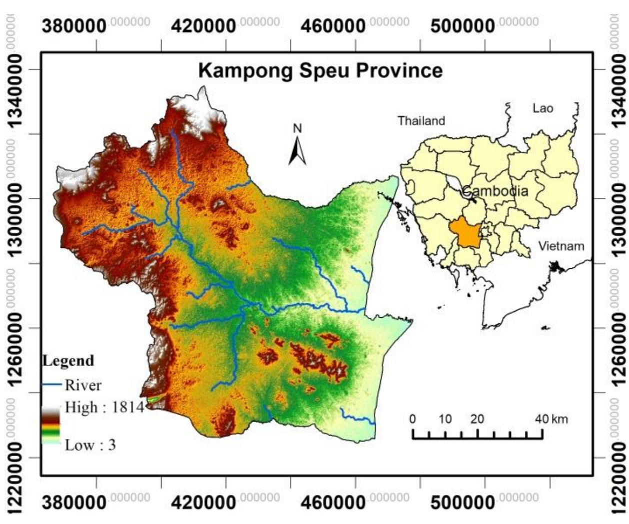


Fig.1. Study area in Kampong Speu Province of Cambodia.

Data Preparation

Various types of data were used for drought hazard mapping in this research. The data and information were collected from various sources to establish the criteria layers using GIS techniques. The satellite information of Tropical Rainfall Measuring Mission (TRMM), NASA POWER, NASA, and USGS was used to obtain rainfall, relative humidity, average temperature, maximum temperature, slope, drainage density, and land use data. Besides, data of administrative boundary and soil types were obtained from Open Development Cambodia (ODC). Table 1 illustrates the data derived from multi-sources and applied for developing a drought hazard map in this study.

Table 1. Types and sources for developing drought hazard map in this research

Data Types	Date	Format	Source	Obtained data
Climate data	2000-2019	NetCDF	TRMM	Rainfall
Climate data	2000-2019	csv	NASA POWER	Relative humidity, average and maximum temperature
Administration	2016	shp	ODC	Study boundary
Soil map	2014	shp	ODC	Soil types
ASTER DEM	2020	Geotiff	NASA	Slope and drainage density
Landsat-8	2019	Geotiff	USGS	Landuse

Method

Reference [19] used climatic factors, soil, landuse, slope, groundwater, and socio-economic factors to develop the drought vulnerability map. This research however focuses on the hazard map. The groundwater data are limited in the study area. The socio-economic factors and groundwater data, therefore, were not used in this research. Furthermore, drainage density was used in the drought assessment [17]. In this research, eight parameters (see in the drought hazard index session) therefore were applied to weigh the drought hazard and its spatial distribution. The drought hazard intensity was grouped into five categories - very low, low, moderate, high, and very high, due to its rating. AHP was applied to obtain each parameter's weight according to their influence on the drought hazard. The conceptual framework of this study was illustrated in Figure 2. It shows that the drought hazard map was developed based on the influences of eight parameters.

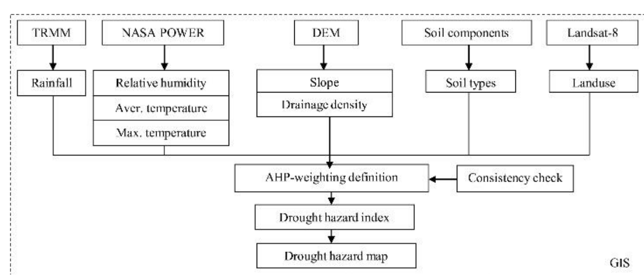


Fig. 2. Conceptual framework of this research.

Drought Hazard Index (DHI)

The drought hazard index consists of rainfall, relative humidity, average temperature, maximum temperature, soil types, slope, drainage density, and landuse. The parameters were manipulated to five influenced hazard levels with a rating score from one to five respectively. The given scores were based on previous studies [18]-[19]-[23]. The pairwise and normalized comparison matrix of 8 x 8 was created to acquire the weight of each parameter. Then the drought hazard index (DHI) was calculated according to Equation 1 [14]-[24]-[25].

$$\text{Hazard} = \sum_{f=1}^{n} W_f \times S_f \quad (1)$$

where, f is the drought hazard parameters, n is the total drought hazard parameters, W_f is the weight of each parameter obtained from the eigenvalue method, and S_f is the parameter's score according to their influence on drought hazard.

Analytical Hierarchy Process (AHP)

AHP is a powerful approach for revealing the problems of multi-criteria analysis [26]-[27]. Each parameter's weight was therefore calculated by using the AHP approach. The pairwise comparison matrix of 8x8 was created to find the importance of one parameter compared to other parameters in the first phase. Then the nine-point fundamental scale was used to measure the significant levels of all drought hazard parameters. The important levels comparable to equal important, moderate important, strong important, demonstrate important, and extreme important were denoted by the intensity of important 1, 3, 5, 7, and 9 respectively in the nine-point fundamental scale. The intermediate level of each significance was given the intensity of important 2, 4, 6, and 8, while the less important parameter is valued from 1/9 to 1 [26]-[28].

Consistency Check

The consistency check is normally required for assessing the efficiency of the pairwise comparison matrix. Equation 2 was used to calculate the consistency ratio (CR). The acceptable CR must be lower than 0.1, which is equivalent to 10% [26].

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \quad (2)$$

where, *RI* is the random index, *CR* is the consistency ratio, and *CI* is the consistency index.

RI is provided in T. L. Saaty's study (1980); accordingly, the RI of this research is 1.40 [29]. Moreover, the CI was calculated by Equation 3 [26].

$$\text{CI} = \frac{(\lambda\text{max} - \text{n})}{\text{n} - 1} \quad (3)$$

where, λ_{max} is the eigenvector matrix's largest number, and n is the number of drought hazard parameters.

As a result, the consistency ratio (CR) of this research is 0.06 or 6%, which is less than the acceptable level of 10%, which means that the consistency ratio (CR) of the weighted coefficient is acceptable.

Eight Physical Drought Hazard Parameters

Rainfall: Rainfall is the most significant parameter that influences drought occurrences since its variations could affect the severity of drought [30]. The less number of rainfall incidence usually causes a drastic drought hazard (Table 2). The isohyet map of average annual rainfall from 2000-2019 over Kampong Speu Province has been developed by using Inverse Distance Weight (IDW) interpolation algorithm. The interpolated rainfall ranges from 1,402-1,937 mm are shown in Figure 3.

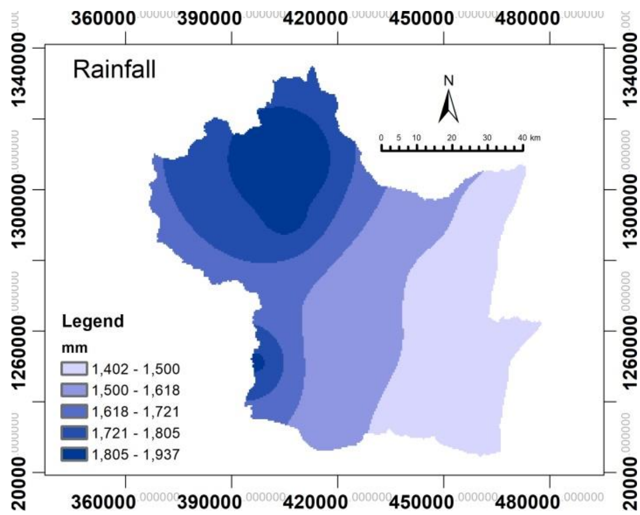


Fig. 3. Isohyet map of average annual rainfall over Kampong Speu Province.

Relative humidity: Humidity is one of the main criteria that affect drought [20]. The low humidity areas are normally prone to drought hazards (Table 2). The iso-humid map of average monthly relative humidity has been created by using the IDW interpolation algorithm. The average monthly relative humidity over the study area ranges from 73-79%. Figure 4 illustrates the iso-humid map of relative humidity over Kampong Speu Province.

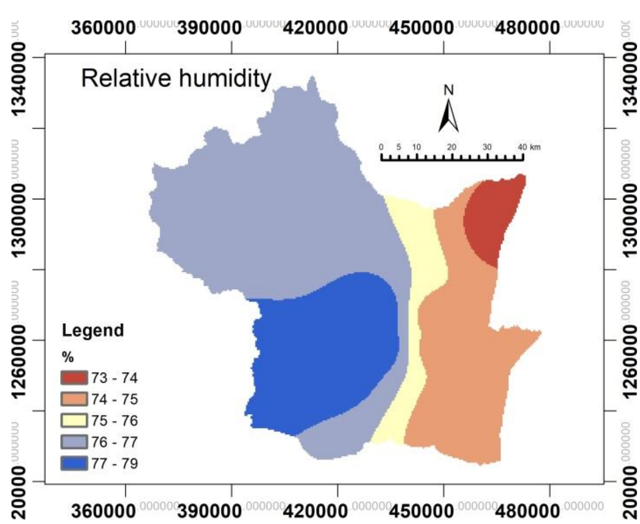


Fig.4. Iso-humid map of average monthly relative humidity over Kampong Speu Province.

Average and maximum temperature: Temperature has significant effects on drought incidence. The warmer temperature increases the evapotranspiration and water demand that put greater stress on the water supply [19].

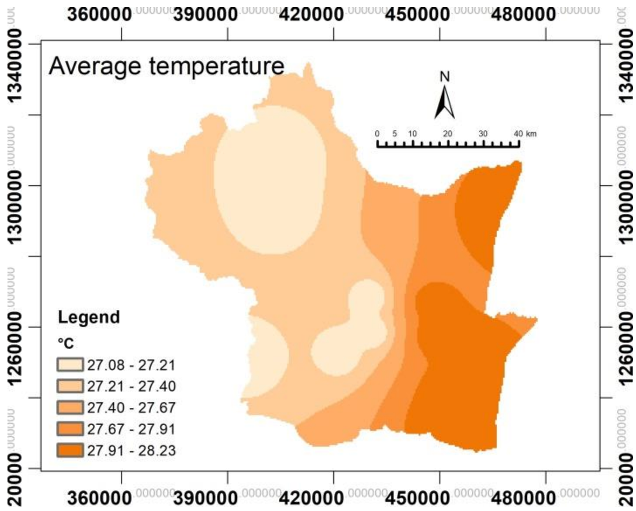


Fig.5. Iso-temperature map of average monthly temperature over Kampong Speu Province.

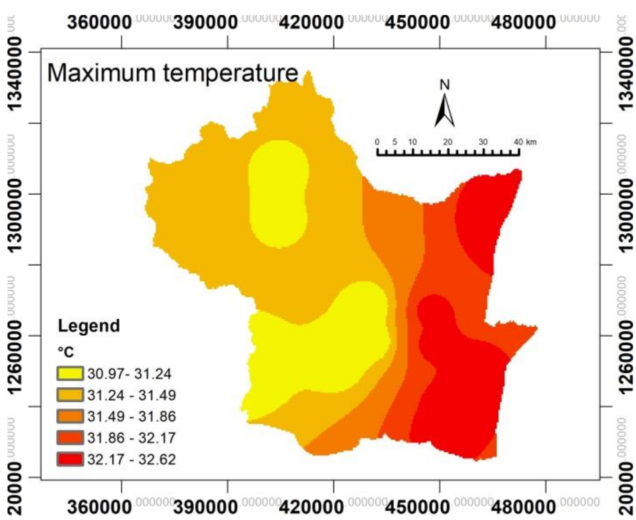


Fig. 6. Iso-temperature map of maximum temperature over Kampong Speu Province.

The IDW interpolation algorithm has created the iso-temperature maps of average and maximum temperature. The interpolation of average temperature ranged from 27-28 °C and maximum temperature ranges from 31-33 °C, as presented in Figures 5 and 6.

Soil types: Types of soil greatly impacts groundwater conducive and moisture-holding [19]. There are eight soil types, which were classified into five classes according to their permeability coefficient as illustrated in Figure 7. Each group of soil has different effect levels on the drought hazard (Table 2).

Drainage density: Drainage density is analyzed by dividing the streamline's length by the areas of the basin. The high drainage density areas are less prone to drought hazards [31]. The hydrological tools were used to derive a drainage density map. Then the drainage density map is divided into five categories by using Jenks Natural Breaks. Figure 9 demonstrated the drainage density, which is ranged from 0.3-4.9 km^{-1}.

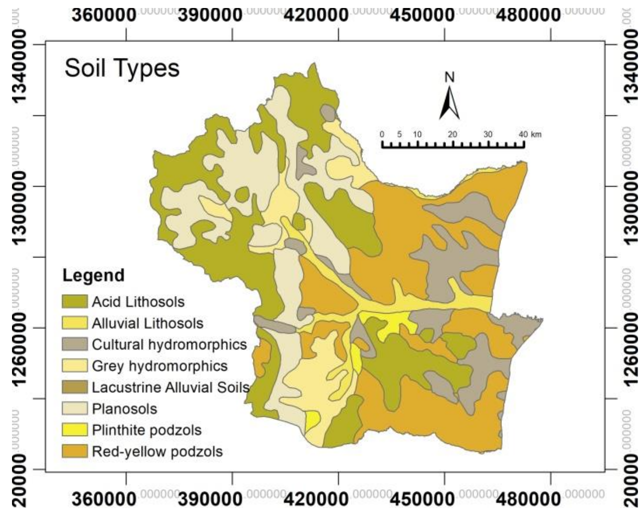


Fig.7. Soil types map over Kampong Speu Province.

Slope: Evapotranspiration rate, soil characteristics, and vegetation are affected by the exposure of slope to wind and sunlight. The slope was used in drought risk assessment [20]. The Digital Elevation Model - DEM was applied to obtain the slope distribution map. Over the study area, the slope ranges from 0-66 degrees, as shown in Figure 8.

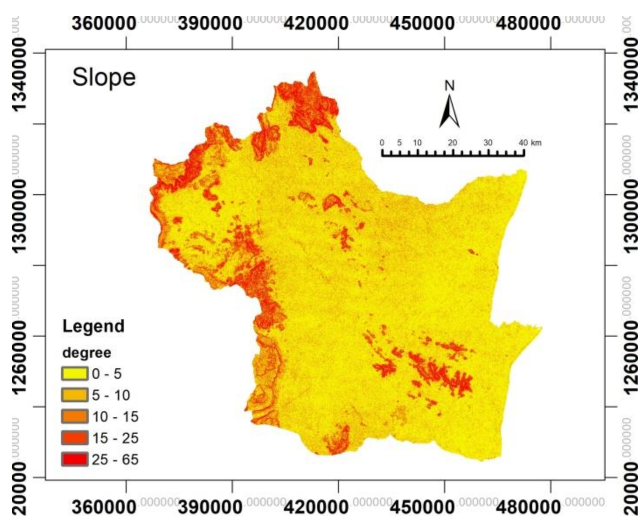


Fig.8. Slope map over Kampong Speu Province.

Landuse: Landuse is one of the factors that severely influence the drought hazard [19]. Each landuse type has different impact levels on the drought (Table 2). The supervised image classification was applied to obtain the landuse map. The land is used by built-up, agricultural forest, water, and bare soil (Figure 10).

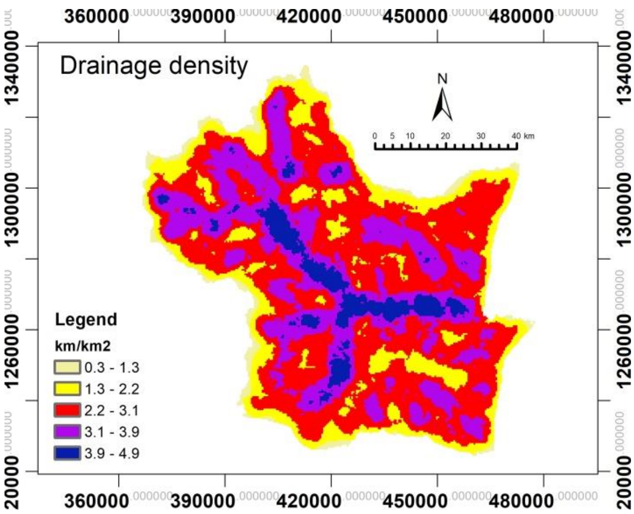


Fig. 9. Drainage density map over Kampong Speu Province.

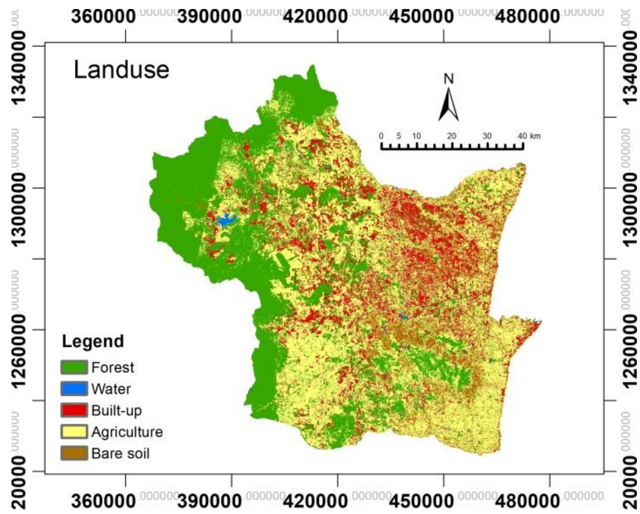


Fig.10. Landuse map over Kampong Speu Province.

Table 2. Parameter' classes based on their weighted values

Parameter	Class	Area (km^2)	Rating	Weight
Annual rainfall (mm)	1,402-1,500	2,062	5	0.33
	1,500-1,618	1,763	4	
	1,618-1,721	1,129	3	
	1,721-1,805	1,262	2	
	1,805-1,937	750	1	
Average monthly relative humidity (%)	73-74	279	5	0.09
	74-75	1,459	4	
	75-76	502	3	
	76-77	3,272	2	
	77-79	1,454	1	
Average monthly temperature (°C)	27.91-28.23	1,378	5	0.17
	27.67-27.91	706	4	
	27.40-27.67	758	3	
	27.21-27.40	2,541	2	
	27.08-27.21	1,583	1	
Maximum monthly temperature (°C)	32.17-32.62	1,165	5	0.07
	31.86-32.17	835	4	
	31.49-31.86	717	3	
	31.24-31.49	2,848	2	
	30.97-31.24	1,402	1	
Soil types	Acid lithosols	1,831	5	0.03
	Alluvial lithosols	341	5	
	Lacustrine alluvial	1	5	
	Plinthite podzols	108	4	
	Red-yellow podzols	1,929	3	
	Cultural hydromorphics	870	2	
	Grey hydromorphics	590	2	
	Planosols	1,297	1	
Slope (degree)	26.0-65.6	228	5	0.02
	16.2-26.0	479	4	
	9.0-16.2	540	3	
	4.4-9.0	2,185	2	
	0-4.4	3,535	1	
Drainage density (km^{-1})	0.3-1.7	252	5	0.24
	1.7-2.4	1,260	4	
	2.4-2.9	3,220	3	
	2.9-3.6	1,780	2	
	3.6-4.9	454	1	
Landuse	Agriculture	2,937	5	0.04
	Built-up	1,132	4	
	Forest	2,565	3	
	Bare soil	310	2	
	Water	22	1	

3. RESULTS AND DISCUSSION

The spatial distribution of the drought hazard map was established with the AHP approach combined with GIS techniques. Tables 3 and 4 show the drought hazard parameters' (8 x 8) pairwise and normalized pairwise comparison matrix. The rainfall parameter has the highest weight with a value of 0.33 following by drainage density 0.24, average temperature 0.17, relative humidity 0.09, and maximum temperature of 0.07. The landuse, soil types, and slope have the lowest weights compared to the other parameters with the weight of 0.04, 0.03, and 0.02, respectively, as illustrated in Table 4.

Table 3. Pairwise comparison matrix

	Rainfall	Relative humidity	Average temperature	Max. temperature	Slope	Soil types	Landuse	Drainage density
Rainfall	1.00	5.00	2.00	7.00	9.00	7.00	7.00	3.00
Relative humidity	0.20	1.00	0.33	3.00	5.00	3.00	3.00	0.33
Aver. temperature	0.50	3.00	1.00	4.00	7.00	5.00	5.00	0.33
Max. temperature	0.14	0.33	0.25	1.00	5.00	3.00	3.00	0.33
Slope	0.13	0.20	0.14	0.20	1.00	0.50	0.50	0.11
Soil types	0.17	0.33	0.20	0.33	2.00	1.00	0.50	0.11
Landuse	0.17	0.33	0.20	0.33	2.00	2.00	1.00	0.11
Drainage density	0.33	3.00	3.00	3.00	9.00	9.00	9.00	1.00
Total	2.63	13.20	7.13	18.87	40.00	30.50	29.00	5.33

Table 4. Normalized pairwise comparison matrix

	Rainfall	Relative humidity	Average temperature	Max. temperature	Slope	Soil types	Landuse	Drainage density	Weight
Rainfall	0.38	0.38	0.28	0.37	0.23	0.23	0.24	0.56	0.33
Relative humidity	0.08	0.08	0.05	0.16	0.13	0.10	0.10	0.06	0.09
Aver. temperature	0.19	0.23	0.14	0.21	0.18	0.16	0.17	0.06	0.17
Max. temperature	0.05	0.03	0.04	0.05	0.13	0.10	0.10	0.06	0.07
Slope	0.05	0.02	0.02	0.01	0.03	0.02	0.02	0.02	0.02
Soil types	0.06	0.03	0.03	0.02	0.05	0.03	0.02	0.02	0.03
Landuse	0.06	0.03	0.03	0.02	0.05	0.07	0.03	0.02	0.04
Drainage density	0.13	0.23	0.42	0.16	0.23	0.30	0.31	0.19	0.24

Equation 1 was used to create the final drought hazard map of Kampong Speu Province with the additional results of hazard values acquired from statistical analysis (Figure 11). The results indicate that 26.30% of the total areas fall in moderate drought hazard categories. The 24.36% and 20.88% of Kampong Speu Province are located in very high and low drought hazard levels. Moreover, 14.64% of the total areas are found in high drought hazards, and another 13.82% of the total areas are located in the very low drought hazard categories.

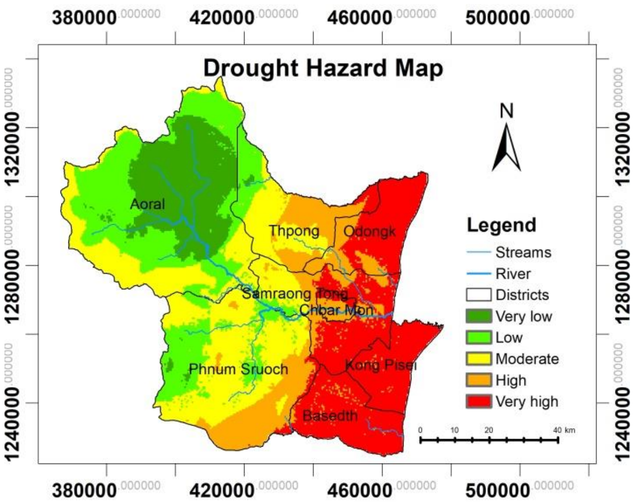
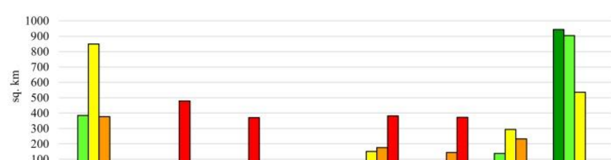


Fig.11. Spatial distribution of drought hazard map over Kampong Speu Province.

The results also show that some districts in Kampong Speu are prone to very high drought hazards. These districts are Basedth (6.87% of the total areas), Samraong Tong (5.47% of the total areas), Odongk (5.34% of the total areas), and Kong Pisei districts (5.32% of the total areas). Moreover, the very low and low drought hazard areas are located in Aoral district with 13.55% and 12.97% of the total areas, respectively. Figure 12 presents a bar chart of the drought hazard areas in all districts of Kampong Speu Province.



	Phnum Srouch	Basedth	Kong Pisei	Chbar Mon	Samraong Tong	Odongk	Thpong	Aoral
Very low	11.83	0.00	0.00	0.00	0.00	0.00	7.09	943.96
Low	385.26	0.00	0.00	0.00	27.59	0.00	137.95	903.76
Moderate	848.18	0.00	0.00	0.00	150.76	3.75	293.04	536.22
High	376.79	28.78	6.51	54.78	175.98	144.06	232.94	0.20
Very high	28.18	478.68	370.69	26.02	381.33	372.26	39.41	0.00

Fig.12. Areas of drought hazard in each district

According to CFE-DM, Kampong Speu Province was affected by droughts, particularly during El Niño in 2015-2016, which caused a severe impact on society [10]. The northeast, east, and southeast parts of Kampong Speu are mostly covered by built-up and agriculture. These areas as well receive less rainfall and high temperature; therefore, these areas fell in the very high drought hazard regions. The result reveals that Chbar Mon municipality is situated in the high drought hazard regions; however, the historical data [32] demonstrates that Chbar Mon municipality was unaffected by droughts. It could be due to the facilities existing there better than others do. Reference [33] mentioned that the high vulnerability of drought in Cambodia depends on the high poverty level and huge reliance on the agriculture level. The lack of food security, power supply, irrigation facilities, and low productivities add more vulnerability to drought. Moreover, the level of drought hazard spatial distribution compare to the drought historical data loss is a bit different although the areas prone to drought in both AHP and historical data are found in the same districts. This might be biased due to the weighted values of each parameter [34], which could have huge effects on the developed hazard map. Additionally, the satellite-based climatological data might be inaccurate [35] as the ground observed data were not used. Furthermore, the bias could be related to the parameters selected since the socio-economic factors were not taken into account in this research. The drought hazard study is just one component of the drought risk assessment. The further study, therefore, should take into account the drought risk assessment by using the AHP approach, which as well as associated with the experts' opinions rather than focusing on literature review only. Besides, the use of observed climatological data should be considered.

4. CONCLUSION

The study established a multi-criteria drought hazard map, which integrates eight influence parameters on drought hazard including rainfall, relative humidity, average temperature, maximum temperature, soil types, slope, drainage density, and landuse by using the AHP method combined with GIS techniques. This research only focused on the physical parameters and remote sensing data. The result revealed that Kampong Speu Province is located in moderate drought hazard 26.30% and followed by very high hazards 24.36%, low hazard 20.88%, high hazard 14.64%, and very low hazard 13.82% of the total areas. Moreover, Basedth, Samraong Tong, Odongk, and Kong Pisei districts have a very high hazard to drought whereas Aoral district is found located mostly in the very low and low hazard to drought. The ground truth data was not used to compare with the drought hazard map since it was not available. The current study could support decision-makers in developing potential preventive measures in drought mitigation and planning under the perspective of climate change Besides, further study in this area could make use of the existing approaches presented in the research. Additionally, a Community-Based Early Warning System (CBEWS) is very significant for predicting and forecasting drought hazards, consequently mitigating the impact of drought, and reducing damages.

ACKNOWLEDGMENT

C. K. would like to express sincere gratitude to Her Royal Highness Princess Sirindhorn for funding the scholarship. The authors appreciate the Faculty of Engineering, Naresuan University for supporting the research.

REFERENCES

[1] Dumitraşcu, M., Mocanu, I., Mitrică, B., Dragotă, C., Grigorescu, I., and Dumitrică, C. 2018. The assessment of socio-economic vulnerability to drought in Southern Romania (Oltenia Plain). *International Journal of Disaster Risk Reduction*, 27: 142-154.

[2] Pei, W., Fu, Q., Liu, D., Li, T., Cheng, K., and Cui, S. 2019. A Novel Method for Agricultural Drought Risk Assessment. *Water Resources Management*, 33(6):2033-2047.

[3] Jiao, W., Tian, C., Chang, Q., Novick, K. A., and Wang, L. 2019. A new multi-sensor integrated index for drought monitoring. *Agricultural and Forest Meteorology*, 268:74-85.

[4] Li, F., Li, H., Lu, W., Zhang, G., and Kim, J.-C. 2019. Meteorological Drought Monitoring in Northeastern China Using Multiple Indices. *Water*, 11(1):72.

[5] Wang, Y., Yang, J., Chang, J., and Zhang, R. 2019. Assessing the drought mitigation ability of the reservoir in the downstream of the Yellow River. *Sci Total Environ*, 646, 1327-1335.

[6] Mohsenipour, M., Shahid, S., Chung, E.-s., and Wang, X.-j. 2018. Changing Pattern of Droughts during Cropping Seasons of Bangladesh. *Water Resources Management*, 32(5):1555-1568.

[7] Rahman, M. R., and Lateh, H. 2016. Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data. *Environmental Earth Sciences*, 75(12).

[8] Zhang, Q., Sun, P., Li, J., Xiao, M., and Singh, V. P. 2014. Assessment of drought vulnerability of the Tarim River basin, Xinjiang, China. *Theoretical and Applied Climatology*, 121(1-2):337-347.

[9] NCDM. 2013. National Action Plan for Disaster Risk Reduction (NAP-DRR) 2014-2018. Phnom Penh: The Royal Government of Cambodia.

[10] CFE-DM. 2017. Cambodia Disaster Management Handbook. Phnom Penh: Center for Excellence in Disaster Management & Humanitarian Assistance.

[11] NCDM. 2019. Disaster Loss Databases: Temporal Behaviour. Retrieved from http://camdi.ncdm.gov.kh/DesInventar/profiletab.jsp

[12] MAFF. 2013. Plan of Action For Disaster Risk Reduction in Agriculture in Kampong Speu Province 2014-2018. Phnom Penh: Ministry of Agriculture, Forestry, and Fisheries.

[13] Chhinh, N., and Millington, A. 2015. Drought Monitoring for Rice Production in Cambodia. *Climate*, 3(4); 792-811.

[14] Skilodimou, H. D., Bathrellos, G. D., Chousianitis, K., Youssef, A. M., and Pradhan, B. 2019. Multi-hazard assessment modeling via multi-criteria analysis and GIS: a case study. *Environmental Earth Sciences*, 78(2).

[15] Corps, M. 2010. Establishing Community Based Early Warning System: Practitioner's Handbook.

[16] Belal, A.-A., El-Ramady, H. R., Mohamed, E. S., and Saleh, A. M. 2012. Drought risk assessment using remote sensing and GIS techniques. *Arabian Journal of Geosciences*, 7(1): 35-53.

[17] Hoque, M. A., Tasfia, S., Ahmed, N., and Pradhan, B. 2019. Assessing Spatial Flood Vulnerability at Kalapara Upazila in Bangladesh Using an Analytic Hierarchy Process. Sensors (Basel), 19(6).

[18] Jain, V. K., Pandey, R. P., and Jain, M. K. 2014. Spatio-temporal assessment of vulnerability to drought. *Natural Hazards*, 76(1):443-469.

[19] Palchaudhuri, M., and Biswas, S. 2016. Application of AHP with GIS in drought risk assessment for Puruliya district, India. *Natural Hazards*, 84(3):1905-1920.

[20] Hoque, M. A., Pradhan, B., and Ahmed, N. 2020. Assessing drought vulnerability using geospatial techniques in northwestern part of Bangladesh. *Sci Total Environ*, 705.

[21] Elkhrachy, I. 2015. Flash Flood Hazard Mapping Using Satellite Images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). *The Egyptian Journal of Remote Sensing and Space Science*, 18(2): 261-278.

[22] NIS-MoP. 2019. General Population Census of Cambodia 2019. Phnom Penh, Cambodia: National Institute of Statistics, Ministry of Planning.

[23] Pandey, S., Pandey, A. C., Nathawat, M. S., Kumar, M., & Mahanti, N. C. 2012. Drought hazard assessment using geoinformatics over parts of Chotanagpur plateau region, Jharkhand, India. *Natural Hazards*, 63(2):279-303.

[24] Abu El-Magd, S. A., Amer, R. A., and Embaby, A. 2020. Multi-criteria decision-making for the analysis of flash floods: A case study of Awlad Toq-Sherq, Southeast Sohag, Egypt. *Journal of African Earth Sciences*, 162, 103709.

[25] Mohamed, S. A. 2019. Application of satellite image processing and GIS-Spatial modelling for mapping urban areas prone to flash floods in Qena governorate, Egypt. *Journal of African Earth Sciences*, 158.

[26] Saaty, T. L. 1990. How to make a decision: The Analytic Hierarchy Process. *European Journal of Operational Research*, 48(1):9-26.

[27] Saaty, T. L., and Vargas, L. G. 2012. Models, Methods, Concepts & Applications of the Analytic Hierarchy Process (2nd ed. Vol. 175). New York, USA: Springer.

[28] Saaty, T. L. 2008. Decision making with the analytic hierarchy process. Int. J. Services Sciences, 1(1): 83-98.

[29] Saaty, T. L. 1980. The analytical hierarchy process: planning, priority setting, resource allocation. Pittsburg: RWS publication.

[30] Zhai, L., and Feng, Q. 2008. Spatial and temporal pattern of precipitation and drought in Gansu Province, Northwest China. *Natural Hazards*, 49(1):1-24.

[31] Jose, S. K., Jayakumar, M., and N, S. 2016. Drought Vulnerability Detection and Mapping in Attapadi, A Part of Southern Western Ghats, India - Using Geoinformation Science and Technology. *International Journal of Science and Research (IJSR)*, 5(11):1430-1434.

[32] CamDi. 2020. Cambodia disaster damage & loss information system. National Committee for Disaster Management (NCDM) http://camdi.ncdm.gov.kh/DesInventar/profiletab.jsp?countrycode=kh2&continue=y

[33] Nguyen, H., Prabhakar, S. V. R. K., and Shaw, R. 2009. Adaptive drought risk reduction in Cambodia: Reality, perceptions and strategies. *Environmental Hazards*, 8(4):245-262.

[34] Seejata, K., Yodying, A., Wongthadam, T., Mahavik, N., and Tantanee, S. 2018. Assessment of flood hazard areas using Analytical Hierarchy Process over the Lower Yom Basin, Sukhothai Province. *Procedia Engineering*, 2012, 340-347.

[35] Bhart, V., and Singh, C. 2015. Evaluation of error in TRMM 3B42V7 precipitation estimates over the Himalayan region. *Journal of Geophysical Research: Atmospheres*, 120, 12,458-412,473.