ESTIMATION OF PARTICULATE MATTER LESS THAN 10 MICRONS VOLUME THROUGH VARIOUS FORMATS OF SPATIAL INTERPOLATION METHODS

***Jumpol ITSARAWISUT*[1]*, *Teerawong LAOSUWAN*[1]**

DOI: 10.21163/GT_ 2022.172.03

ABSTRACT:

The problem on air pollution, especially the problem on smoke caused by accumulation of smoke and dust in the air, is considered as one of important problems in Thailand and this problem is currently more serious increasingly. This study aims to study on relationship between Particulate Matter Less Than 10 Microns (PM_{10}) volume in northern area and physical factors of the area as well as estimate PM_{10} through various formats of Spatial Interpolation Methods and study on appropriateness of each method. The result revealed that mean of 24 hours of PM_{10} volume throughout 5 years from 2017 – 2021 was in the highest level in March with average volume from all weather stations at 101µg/m³ followed by February and April. Month with the lowest PM_{10} volume was July. When analyzing on physical characteristics of areas with high PM_{10} volume, it was found that northern area had landscape of intermontane plateau with small area. Since it was surrounded by mountain ranges, distribution of dust was poor. In addition, since it was located near some neighboring countries, it was affected by dust from wildfire and open burning that was blown from many areas as well as those neighboring countries. When using data on mean of PM_{10} volume from 9 weather stations of Pollution Control Department (PCD) to evaluate PM_{10} volume through various formats of Spatial Interpolation Methods, including Inverse Distance Weight (IDW), Kriging, Spline, and Trend, it was found that IDW was the most suitable method for making map showing distribution of PM_{10} volume, especially from February to April with the highest volume of dust due to the lowest level of difference between estimated value and measured value. For spatial interpolation by using Spline method, it was found to be improper due to the highest level of difference between estimated value and measured value.

Key-words: *Air pollution, PM_{10}, Spatial Interpolation, Geographic Information System*

1. INTRODUCTION

Air pollution is air condition with contamination that may not be seen by naked eyes, for example, dust, natural gas, or pollution emitted from exhaust pipe, etc. It is considered as imminent danger causing huge effects and dangers against our heath. Air pollution is classified as another important problem of Thailand and this problem is currently more serious increasingly (Junpen et al., 2018). There are 2 major causes of air pollution including: human actions, for example, demands on energy for consuming in households, industries, and agriculture as well as air pollution caused by cars, ships, and planes that causes CO_2, NO_2, and hydrocarbons giving bad effects to human's health directly (Canha et al., 2021; Thai et al., 2021). Combustion of these types of fuel also increase the problems on air pollution every year; natural actions, for example, volcanic eruption causing high amount of dust and ash blowing in the air (Perera, 2018; Mperejekumana et al., 2021), wildfire causing smoke that is dangerous for respiratory system, decomposition of humus and carcass that may cause CO_2, CH_4, and NH_3 in case of chemical reaction (Ray et al., 2019; Junpen et al., 2020); and dust caused by broken objects that would be distributed in the air when they are blown by the wind.

[1]*Department of Physics, Faculty of Science, Mahasarakham University, Thailand, *Corresponding author,* *jumpol.i@msu.ac.th*, *teerawong@msu.ac.th*

Although the problem on pollution is unable to be solved but it can be analyzed and monitored continuously in order to control further problems on air pollution (Kim et al., 2014; WHO, 2018).

In each region of Thailand, causes of air pollution are similar and different based on landscape and land utilization (Intarat, 2017; Supasri et al., 2018; Vichit-Vadakan et al., 2011; Suriya et al., 2021). For the problem on haze pollution in the northern part of Thailand, it was found that the major cause was wildfire and open burning in Thailand and neighboring countries. It is a kind of open burning of agricultural wastes for preparing plantation areas for plantation in rainy season, open burning for facilitating puff ball mushrooms and wild sweet leaves collecting, community waste incineration, and firing for warming (Pongkaset et al., 2020). These actions cause the problem on small dust and hazardous gases. This kind of open burning causes the important pollution problem of the northern part of Thailand, i.e., the problem of small dust causing health effects (Choi et al., 2015; Chalvatzaki et al., 2019), especially PM_{10} is a dust with a particulate matter less than 10 microns produced by fuel combustion, open burning, industrial processes, grinding, milling, or powdering of construction. PM_{10} may cause effects against body system when it enters our body, for example, coughing, sneezing, and shortness of breath that are the causes of diseases related to respiratory system.

Currently, Geographic Information System (GIS) is used to create spatial model from data on map, image, and other kinds of data (Pradabmook & Laosuwan, 2021). GIS can be applied to various fields (Pradabmook & Laosuwan, 2021; Wiatkowska et al., 2021; Jażdżewska et al., 2022) and used as a part of analysis on areas and distribution of air pollution (Eeftens et al., 2016; when surveying to collect field data, there may be some gaps of data when using data to perform mapping. As a result, it is required to estimate value of such gaps by using Spatial Interpolation Methods, for example, topographic mapping, calculation on density of population and weather. Data must be analyzed to use the results of estimation to study on relationship related to other kinds of data (Goovaerts, 1997; Mitmark & Jinsart, 2017; Goutham et al., 2018; Srivastava et al., 2019).

This study was conducted to study on relationship between PM_{10} volume in the northern area of Thailand and physical factors of area, to evaluate PM_{10} volume by using various formats of spatial interpolation methods, and to study on appropriateness of various formats of spatial interpolation methods with evaluation of PM_{10} volume in the northern part of Thailand by using GIS as the operational tool. The obtained results could be useful for managing and controlling air pollution and used as supporting data of further researches on air pollution in other areas.

2. MATERIALS AND METHODS

2.1 Study Area

The northern part of Thailand (**Fig. 1**) has total area of 96,077 km^2 consisted of 9 provinces, i.e., Chiang Rai, Chiang Mai, Nan, Phayao, Phrae, Mae Hong Son, Lampang, Lamphun, and Uttaradit (Wikipedia, 2021). Most landscapes are mountain ranges, mountains, valleys, and intermontane plateau with steeps from the northeastern part that gradually slope to lowlands in the southeastern part and central part before getting higher in the eastern part and the northeastern part in Nan province, i.e., Luang Prabang Range. These plateaus are considered as the sources of various rivers and streams that flow to Mekong River from the north to Chao Phraya River in the south before flowing to Salawin River in the west. For climate, it is classified as tropical zone for some seasons (Department of Mineral Resources, 2021).

Climate of most northern areas is Aw, i.e., tropical wet switched with drought. Average yearly temperature is ranged from 24-27°C with 3 seasons including rainy season (May – October), winter (October–February), and summer (February – May). Province with the lowest temperature is Chiang Rai and province with the highest temperature is Uttaradit. Province with heavy rainfall is Chiang Rai whereas province with the lowest rainfall is Lampang with average rainfall of 1,230 mm/y and 110 rainy days. Zone with low rainfall has average rainfall of 800-1,000 mm/y whereas zone with heavy rainfall has the highest rainfall of 2,000 mm/y.

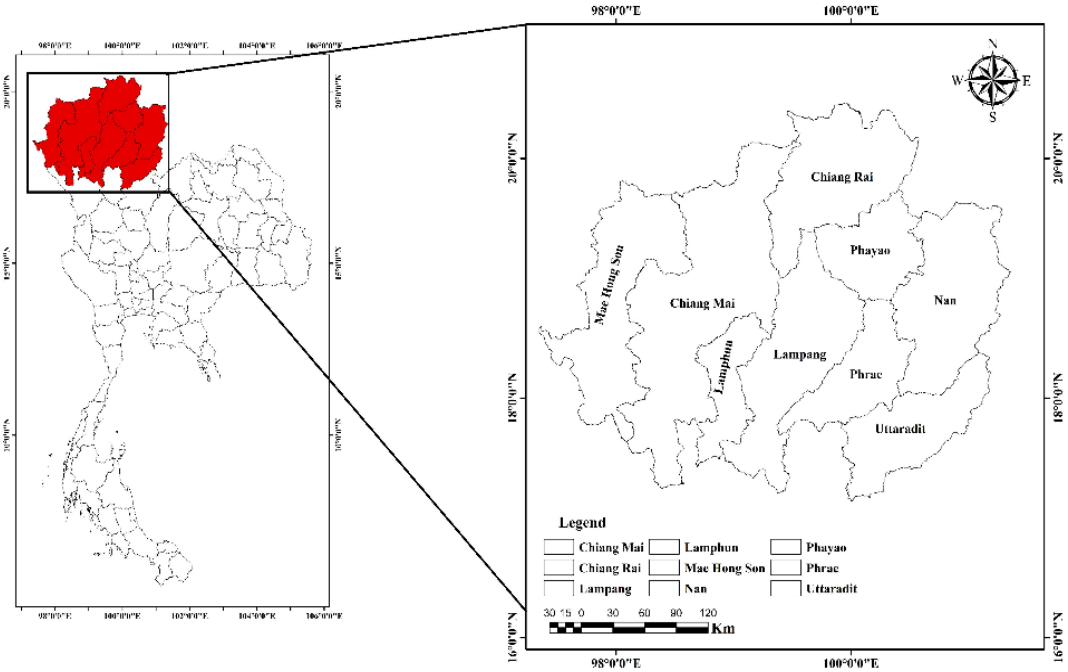


Fig. 1. The northern part of Thailand.

2.2 Collection and Preparation of Data on GIS

This research was conducted to study on methodology and operational guidelines from documents and researches related to distribution of dust and air pollution in Thailand and other countries. Subsequently, data were collected from various sources in order to evaluate PM_{10} volume in the northern part by using Spatial Interpolation Methods consisted of the following data:

(1) Data on PM_{10} volume in the northern part (Source: Pollution Control Department);

(2) Data on location of weather stations (Source: Pollution Control Department);

(3) Data on boundary of the northern part and administrative boundaries of provinces in the northern part (Source: Royal Thai Survey Department); and

(4) Data on height of areas in the northern part (Source: Royal Thai Survey Department)

2.3 Research Tools

(1) High quality computer for data processing;

(2) GIS software package, in this study, ArcMap 10.2 was used as the base software; and

(3) Data on dust volume from Air4Thai website (http://air4thai.pcd.go.th/webV3/#/Home)

2.4 Procedures of Data Analysis

The Materials and Methods should be described with sufficient details to allow others to replicate and build on the published results. Please note that the publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

(**1**) Collect data on PM_{10} volume from weather stations of Pollution Control Department, data on location of weather stations, and data on boundary of the northern part and administrative boundaries of provinces in the northern part for inputting into GIS system.

(**2**) Analysis on relationship between PM_{10} volume and physical characteristics of area in the northern part consisted of locations, distance from neighboring countries, months with dust distribution, and landscapes in the manner of intermontane plateau with differences on sizes of plateaus and height, etc.

(**3**) Spatial Interpolation Methods was analyzed by using data obtained from measurement of PM_{10} volume from 9 weather stations of Pollution Control Department during 2017 – 2021 through 4 Spatial Interpolation Methods including IDW, Kriging, Spline, and Trend. Subsequently, PM_{10} volume was mapped and Table on Conclusion of Differences of Monthly PM_{10} Volume Data during 2017-2021 was made. There were 9 weather stations used in analysis through spatial interpolation including:

1) Ministry of Natural Resources and Environment in Chiang Rai (No.1), located between the latitude of 19.910 and the longitude of 99.823;

2) Public Health Office in Mae Sai District, Chiang Rai (No.2), located between the latitude of 20.427and the longitude of 99.883;

3) Chiang Mai City Hall in Muang District, Chiang Mai (No.3), located between the latitude of 18.925 and the longitude of 98.651;

4) Yupparaj Wittaqyalai School in Muang District, Chiang Mai (No.4), located between the latitude of 18.791 and the longitude of 98.978;

5) Nan Municipality Office in Nan District, Nan (No.5), located between the latitude of 18.784 and the longitude of 100.779;

6) Phayao Learning Park in Muang District, Phayao (No.6), located between the latitude of 19.168 and the longitude of 99.896;

7) Phrae Weather Station in Muang District, Phrae (No.7), located between the latitude of 18.128 and the longitude of 100.162;

8) Ministry of Natural Resources and Environment in Mae Hong Son (No.8), located between the latitude of 19.304 and the longitude of 97.971; and

9) Sobprad Sub-District Health Promoting Hospital in Mae Moe District, Lampang (No.9), located between the latitude of 18.250 and the longitude of 99.763.

(**4**) Differences and appropriateness of each Spatial Interpolation Methods were analyzed in order to obtain appropriate methods for mapping the map showing distribution of PM_{10} volume in the northern part.

3. RESULTS AND DISCUSSION

3.1. Result of Evaluation of PM_{10} Volume and Relationship with Physical Factors of Area

The result of evaluation of PM_{10} volume and relationship with physical factors of area from mean of 24 hours of PM_{10} volume throughout 5 years from 2017 – 2021 obtained from 9 weather stations was shown in **Table 1**.

From **Table 1**, it was found that mean of 24 hours of average PM_{10} volume throughout 5 years from 2017– 2021 was in the highest level in March with average volume from all weather stations at 101 µg/m³ followed by April and February with volume of 73 and 66 µg/m³, respectively. The lowest volume was in July with average volume from all weather stations at 19 µg/m³ that was similar to June with average volume of 20 µg/m³. When considering on mean of each weather station, it was found that Chiang Mai City Hall in Chiang Mai had the highest mean, i.e., 47 µg/m³ followed by Public Health Office in Mae Sai District, Chiang Rai, and Phrae Weather Station with mean of 43 and 42 µg/m³, respectively. From analyzing on physical characteristics of areas with high volume of small dust, it was found that they were intermontane plateaus with small areas and pressure of cooler air mass in upper atmosphere causing poor distribution of dust. In addition, with landscape surrounded by mountain ranges and neighboring countries like Myanmar and Laos, this area had to encounter with dust problem from wildfire and wind from various sources as well as those from neighboring countries blew open burning that.

Table 1.

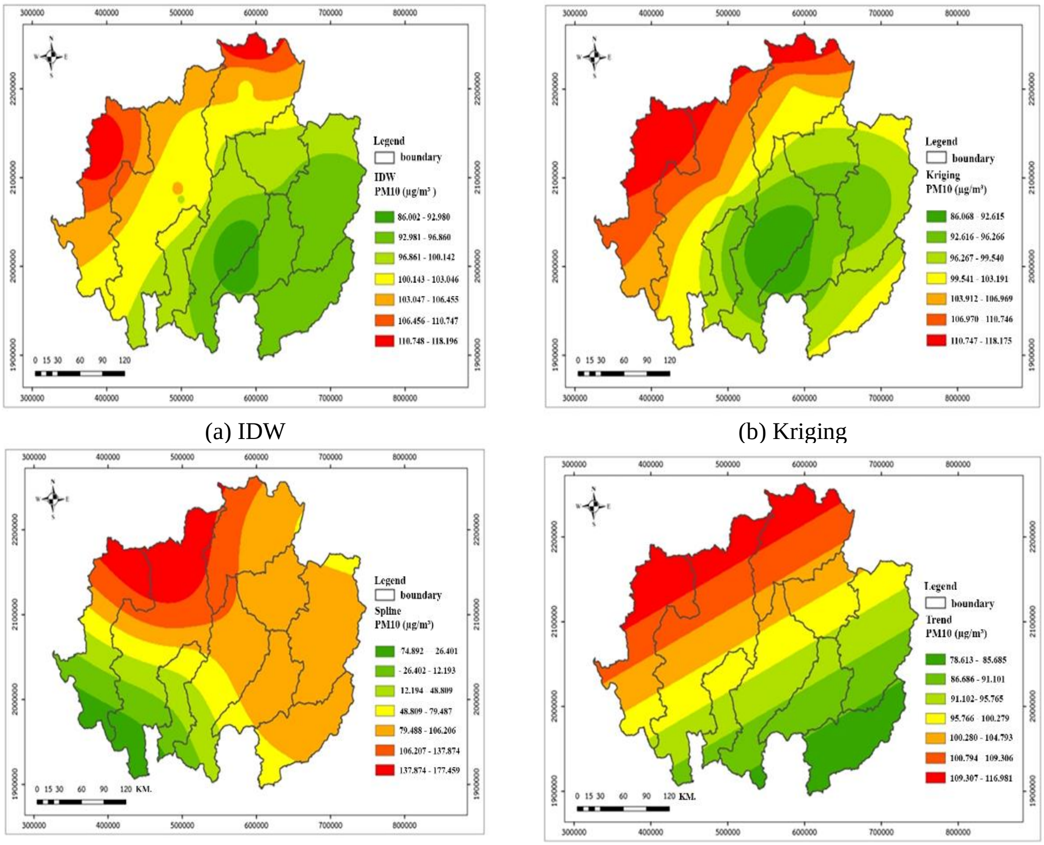
Mean of 24 hours of PM_{10} volume throughout 5 years from 2017 – 2021 (μg/m³).

Weather stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
No.1	34.00	57.20	102.8	80.80	45.20	20.00	17.80	25.00	21.20	22.00	26.8	35.8	40.71
No.2	34.60	55.80	118.20	87.60	46.60	26.80	19.20	16.00	22.00	23.00	29.20	37.80	43.06
No.3	44.80	72.20	105.20	85.20	47.60	23.60	26.80	28.40	29.20	31.40	35.60	44.00	47.83
No.4	45.00	69.20	98.60	78.40	44.20	29.80	31.80	30.80	30.00	32.20	36.60	43.40	47.5
No.5	37.20	59.60	94.00	74.80	41.00	17.80	20.20	20.80	24.60	27.20	29.80	36.60	40.30
No.6	40.00	66.20	98.00	54.80	26.00	10.20	10.20	10.20	12.00	19.00	21.60	31.40	32.45
No.7	48.80	78.00	96.00	66.00	38.20	20.20	19.00	17.80	22.00	27.60	34.40	45.20	42.76
No.8	37.40	68.40	114.20	70.10	38.40	17.20	17.80	16.80	16.60	25.00	27.80	38.40	40.67
No.9	42.20	69.60	86.00	59.40	38.20	16.80	17.00	15.00	16.20	18.40	20.20	34.20	36.1
Mean	40.44	66.24	101.44	73.01	40.60	20.26	19.97	20.42	21.53	25.08	29.11	38.53	41.26

March was considered as the period with no main monsoon that was flown to Thailand, i.e., northeast monsoon and southwest monsoon. Consequently, general climate was swelter and drought. As a result, there was no factor to reduce and distribute density of dust. Therefore, based on data analyzed in this research, it was found that PM_{10} volume was in the highest level in March.

3.2. Result of Evaluation of PM_{10} Volume through Spatial Interpolation Methods

Data on mean throughout 5 years from 2017 – 2021 obtained from 9 weather stations were analyzed by 4 Spatial Interpolation Methods including IDW, Kriging, Spline, and Trend. The result was shown in **Fig. 2** and **Table 2**.



(a) IDW (b) Kriging

(c) Spline (d) Trend

Fig. 2. Spatial Interpolation Methods (a) IDW, (b) Kriging, (c) Spline and (d) Trend.

The result of spatial interpolation of average PM_{10} volume throughout 5 years from 2017 – 2021 obtained from 9 weather stations revealed that the highest PM_{10} volume was in March followed by February and April. Similarly, actual measurement revealed that the lowest PM_{10} volume was in July and September. This was different from mean obtained from actual measure that revealed that the lowest volume was in August.

Table 2.

PM_{10} volume from Spatial Interpolation Methods (μg/m³).

Month	IDW	Kriging	Spline	Trend	Mean
January	40	40	41	39	40
February	65	66	67	66	66
March	101	100	102	100	101
April	72	72	75	73	73
May	39	39	42	40	40
June	19	19	22	20	20
July	18	18	20	19	19
August	19	19	22	20	20
September	21	21	19	23	21
October	25	25	25	25	25
November	29	29	29	29	29
December	38	38	38	38	38

3.3. Differences between Spatial Interpolation Methods and Actual Measurement

Data on PM_{10} volume obtained from analysis through 4 methods from 9 weather stations were compared with data obtained from actual measurement. In this research, it was found that each weather station yielded different value of data. In March with the highest PM_{10} volume, it could represent difference of each method as shown in **Table 3**.

Table 3.

Differences between Spatial Interpolation Methods and Actual Measurement.

Weather stations	PM_{10} from Station	Spatial Interpolation Methods							
		IDW		Kriging		Spline		Trend	
		Spatial Interpolation	(+/-)	Spatial Interpolation	(+/-)	Spatial Interpolation	(+/-)	Spatial Interpolation	(+/-)
No.1	102	110	-8	110	-8	110	-8	115	-13
No.2	118	125	-7	125	-7	125	-7	124	-6
No.3	105	115	-10	115	-10	115	-10	110	-5
No.4	98	96	-2	96	-2	96	-2	96	-2
No.5	94	95	-1	95	-1	95	-1	95	-1
No.6	98	100	-2	100	-2	100	-2	105	-7
No.7	96	97	-1	97	-1	97	-1	97	-1
No.8	114	117	-3	117	-3	117	-3	116	-1
No.9	86	90	-4	90	-4	90	-4	88	-2
Total difference			**38**		**38**		**38**		**25**

From **Table 3**, it was found that when analyzing data on PM_{10} volume obtained from 9 weather stations of Pollution Control Department in the northern part during 2017 – 2021 in March through 4 Spatial Interpolation Methods including IDW, Kriging, Spline, and Trend, it was found that Trend yielded the lowest differences, i.e., 25, whereas IDW, Kriging, and Spline yielded the highest differences, i.e.,38. Spatial interpolation of each method yielded different value as follows:

Spatial Interpolation Methods through IDW method had the lowest differences at Chiang Mai City Hall in Chiang Mai whereas the highest differences were found at Nan Municipality Office in Nan and Phrae Weather Station in Phrae.

Spatial Interpolation Methods through Kriging method had the lowest differences at Chiang Mai City Hall in Chiang Mai whereas the highest differences were found at Nan Municipality Office in Nan and Phrae Weather Station in Phrae.

Spatial Interpolation Methods through Spline method had the lowest differences at Chiang Mai City Hall in Chiang Mai whereas the highest differences were found at Nan Municipality Office in Nan and Phrae Weather Station in Phrae.

Spatial Interpolation Methods through Trend method had the lowest differences at Nan Municipality Office in Nan District, Nan, Phrae Weather Station in Muang District, Phrae, and Ministry of Natural Resources and Environment in Mae Hong Son.

3.4. Result of Analysis on Monthly Differences of Spatial Interpolation Methods

The result of analysis on monthly differences of 4 Spatial Interpolation Methods based on mean of data of 12 months during 2017–2021 was shown in **Table 4**.

Table 4.

Analysis on Monthly Differences of Spatial Interpolation Methods.

Month	IDW	Kriging	Spline	Trend	PM_{10} from Station	Least different	Most different
January	40	40	41	39	40	Trend	Spline
February	65	66	67	66	66	IDW	Spline
March	101	100	102	100	101	Kriging/Trend	Spline
April	72	72	75	73	73	IDW/ Kriging	Spline
May	39	39	42	40	40	IDW/ Kriging	Spline
June	19	19	22	20	20	IDW/ Kriging	Spline
July	18	18	20	19	19	IDW/ Kriging	Spline
August	19	19	22	20	20	IDW/ Kriging	Spline
September	21	21	19	23	21	Spline	Trend
October	25	25	25	25	25	all method	without
November	29	29	29	29	29	all method	without
December	38	38	38	38	38	all method	without

From **Table 4**, it was found that when considering on appropriateness of 4 Spatial Interpolation Methods from 12 months during 2017–2021 including IDW, Kriging, Spline, Trend, spatial interpolation through IDW and Kriging was the appropriate method for mapping the map showing distribution of PM_{10} volume due to the lowest differences between spatial interpolation and actual measurement of 10 months from 12 months followed by Trend and Spline of 5 months and 12 months.

3.5 Result of Analysis on Seasonal Differences of Spatial Interpolation Methods

Differences of PM_{10} volume obtained from 4 Spatial Interpolation Methods including IDW, Kriging, Spline, and Trend obtained from actual measurement of 12 months were analyzed in each season with differences of climate during 2017–2021. In this research, it was found that IDW, Kriging, and Trend were the most appropriate methods for analyzing in drought, during January, February, March, and April, with high PM_{10} volume because it yielded the lowest differences. The method that was improper was Spline because differences were in the highest level in this duration. For rainy season from May to July, August, September, and October, with low PM_{10} volume, the result revealed that Kriging was the most appropriate method for spatial interpolation during this period of time because it yielded the lowest differences. Improper method was Spline because it yielded the highest differences during this period of time. For inter in November and December with higher PM_{10} volume, the result revealed that IDW, Kriging, Spline, and Trend were the most appropriate methods for spatial interpolation because it yielded the lowest differences.

4. CONCLUSIONS

For relationship between PM_{10} volume in the northern part and physical factors of area found from mean of 5 years from 2017–2021, it was found that PM_{10} was in high level in summer from the end of February to March and April due to lower level of high pressure caused by northeast monsoon. Consequently, temperature was higher causing swelter weather and drought that was generally cause of wildfire in various areas of the northern part. In addition, weeds were also burnt in summer for facilitating collection of forest products and preparing plantation areas for agriculture in rainy season. Consequently, PM_{10} was highly increased in summer. In addition, the northern part also had landscape in the manner of intermontane plateaus with small areas surrounded by mountain ranges and neighboring countries therefore lower atmosphere was compressed by cooler air mass than upper atmosphere causing poor dust distribution. Mean of 24 hours of average PM_{10} volume throughout 5 years from 2017-2021 was in the highest level in March with average volume from all weather stations at 101 µg/m³ followed by April and February with volume of 73 and 66 µg/m³, respectively. The lowest PM_{10} volume was found in August with average volume from all weather stations at 19 µg/m³. Moreover, when analyzing on data on average PM_{10} volume through 4 Spatial Interpolation Methods including IDW, Kriging, Spline, and Trend for finding appropriateness, it was also found that IDW was the most appropriate method for mapping the map showing distribution of PM_{10} volume because differences of value obtained from Spatial Interpolation Methods and actual measurement were in the lowest level, i.e., 10 months, whereas Spline was improper due to the highest differences of value obtained from Spatial Interpolation Methods analysis and actual measurement, i.e., 7 months from 12 months.

ACKNOWLEDGMENTS

This research project was financially supported by Mahasarakham University

REFERENCES

Adamkiewicz, Ł., Maciejewska, K., Skotak, K., Krzyzanowski, M., Badyda, A., Juda-Rezler, K., & Dąbrowiecki, P. (2021). Health-Based Approach to Determine Alert and Information Thresholds for Particulate Matter Air Pollution. *Sustainability*, 13(3), 1345.

Canha, N., Diapouli, E., & Almeida, S.M. (2021). Integrated Human Exposure to Air Pollution. *Int. J. Environ. Res. Public Health*, *18*(5), 2233.

Chalvatzaki, E., Chatoutsidou, S.E., Lehtomäki, H., Almeida, S.M., Eleftheriadis, K., Hänninen, O., & Lazaridis, M. (2019). Characterization of Human Health Risks from Particulate Air Pollution in Selected European Cities. *Atmosphere*, 10(2), 96.

Choi, H., Melly, S., & Spengler, J. (2015). Intraurban and Longitudinal Variability of Classical Pollutants in Kraków, Poland, 2000–2010. *Int. J. Environ. Res. Public Health*, 12(5), 4967–4991.

Eeftens, M., Meier, R., Schindler, C., Aguilera, I., Phuleria, H., Ineichen, A., & Künzli, N. (2016). Development of land use regression models for nitrogen dioxide, ultrafine particles, lung deposited surface area, and four other markers of particulate matter pollution in the Swiss SAPALDIA regions. Environ. Health, 15(1), 53.

Department of Mineral Resources. (2021). Thailand Geopark. Available online: https://en.wikipedia.org/wiki/Northern_Thailand (Accessed on 15 October 2021).

Goovaerts, P. (1997). Kriging vs stochastic simulation for risk analysis in soil contamination. In Geo-ENVI—Geostatistics for Environmental Applications; Soares, A., Gomez-Hernandez, J., Froidevaux, R., Eds., Kluwer Academic Publishers: Dordrecht, The Netherlands, 247–258.

Goutham, P.M., Jayalakshmi, S., & Samundeeswari, R. (2018). A Study on Comparison of Interpolation Techniques for Air Pollution Modelling. *Indian J.Sci.Res.*, 17(2), pp 58–63.

Intarat, T. (2011). Geoinformatics Application on Air Quality Assessment: A Case Study in Chon Buri Province. *Burapha Science Journal*, 16(1), 32–40.

Jażdżewska, I.A., Lechowski, Ł., & Babuca, D. (2022). GIS-Based Approach for the Analysis of Geographical Education Paths. *ISPRS Int. J. Geo-Inf.*, *11*(1), 41.

Junpen, A., Pansuk, J., Kamnoet, O., Cheewaphongphan, P., & Garivait, S. (2018). Emission of Air Pollutants from Rice Residue Open Burning in Thailand. *Atmosphere*, 9(11), 449.

Junpen, A., Roemmontri, J., Boonman, A., Cheewaphongphan, P., Thao, P.T.B., & Garivait, S. (2020). Spatial and Temporal Distribution of Biomass Open Burning Emissions in the Greater Mekong Subregion. *Climate*, 8(8), 90.

Kim, H.H., Lee, G.W., Yang, J.Y., Jeon, J.M., Lee, W.S., Lim, J.Y., Lee, H.S., Gwak, Y.K., Shin, D.C., & Lim, Y.W. (2014). Indoor Exposure and Health Risk of Polycyclic Aromatic Hydrocarbons (PAHs) via Public Facilities PM2.5, Korea (II). *Asian J. Atmos. Environ.*, 8(1), 35–47.

Levei, L., Hoaghia, M.A., Roman, M., Marmureanu, L., Moisa, C., Levei, E.A., Ozunu, A., & Cadar, O. (2020). Temporal Trend of PM_{10} and Associated Human Health Risk over the Past Decade in Cluj-Napoca City, Romania. *Appl. Sci.*, 10(15), 5331.

Mitmark, B., & Jinsart, W. (2017). A GIS Model for PM_{10} Exposure from Biomass Burning in the North of Thailand. *Applied Environmental Research*, 39(2), 77–87.

Mperejekumana, P., Li, H., Wu, R., Lu, J., Tursunov, O., Elshareef, H., Gaballah, M.S., Nepo, N.J., Zhou, Y., & Dong, R. (2021). Determinants of Household Energy Choice for Cooking in Northern Sudan: A Multinomial Logit Estimation. *Int. J. Environ. Res. Public Health*, 18(21), 11480.

Peng, Y., Li, W., Luo, X., & Li, H. (2019). A geographically and temporally weighted regression model for spatial downscaling of MODIS land surface temperatures over urban heterogeneous regions. *IEEE Trans. Geosci. Remote Sens.*, 57(7), pp. 5012–5027.

Perera, F. (2018). Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. *Int. J. Environ. Res. Public Health*, Vol. 15(1), 16.

Pongkaset, A., Supapwanich, C., & Sonbut, J. (2020). Meteorological Factors related to PM10 and Health Risk Assessment for Resident Exposed to PM10 in Yala City, Yala Province. *The Public Health Journal of Burapha University*, 15(2), 39–49.

Pradabmook, P., & Laosuwan, T. (2021). The Integration of Geo-informatics Technology with Universal Soil Loss Equation to Analyze Areas Prone to Soil Erosion in Nan Province. *ARPN Journal of Engineering and Applied Sciences*, 16(8), 823–830.

Pradabmook, P., & Laosuwan, T. (2021). Estimation of PM 10 using Spatial Interpolation Techniques. *International Journal on Technical and Physical Problems of Engineering,* 13(4), 33–39.

Ray, R.L., Ibironke, A., Kommalapati, R., & Fares, A. (2019). Quantifying the Impacts of Land-Use and Climate on Carbon Fluxes Using Satellite Data across Texas, U.S. *Remote Sensing*, 11(17), 1733.

Srivastava, P.K., Pandey, P.C., Petropoulos, G.P., Kourgialas, N.N., Pandey, V., & Singh, U. (2019). GIS and Remote Sensing Aided Information for Soil Moisture Estimation: A Comparative Study of Interpolation Techniques. *Resources*, 8(2), 70.

Supasri, T., Intra, P., Jomjunyong, S., & Sampattagul, S., (2018). Evaluation of Particulate Matter Concentration by Using a Wireless Sensor System for Continuous Monitoring of Particulate Air Pollution in Northern of Thailand. *Journal of Information Technology Research*, 1(2), pp 65–78.

Suriya, W., Chunpang, P., & Laosuwan, T. (2021). Patterns of relationship between PM10 from air monitoring quality station and AOT data from MODIS sensor onboard of Terra satellite. Scientific Review Engineering and Environmental Sciences, 30(2), 236–249.

Thai, T., Bernatik, A., &Kučera, P. (2021). Air Pollution Associated with Total Suspended Particulate and Particulate Matter in Cement Grinding Plant in Vietnam. *Atmosphere*, 12(12), 1707.

Vichit-Vadakan, N., & Vajanapoom, N. (2011). Health impact from air pollution in Thailand: current and future challenges. *Environ Health Perspect*, 119(5), A197–A198, 2011.

WHO. (2018). First WHO Global Conference on Air Pollution and Health, Geneva, Switzerland, 30 October–1 November 2018; WHO: Geneva, Switzerland.

Wiatkowska, B., Słodczyk, J., & Stokowska, A. (2021). Spatial-Temporal Land Use and Land Cover Changes in Urban Areas Using Remote Sensing Images and GIS Analysis: The Case Study of Opole, Poland. *Geosciences*, 11(8), 312.

Wikipedia. (2021). Northern Thailand. Available online: https://en.wikipedia.org/wiki/Northern_Thailand (Accessed on 15 November 2021).

Zhong, S., Yu, Z., & Zhu, W. (2019). Study of the Effects of Air Pollutants on Human Health Based on Baidu Indices of Disease Symptoms and Air Quality Monitoring Data in Beijing, China. *Int. J. Environ. Res. Public Health*, 16(6), 1014.