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Evaluating the Association Between Ambient Pollutants and Climate Conditions in Chiangmai, Thailand

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ABSTRACT

The most significant air pollutant is particulate matter of less than 10 microns (PM10), followed by ozone (O_3) during the monitoring period from 2006 to 2022 in Chiangmai. The association between ambient pollutants and climate conditions in Chiangmai was assessed using regression analysis and analysis of variance (ANOVA). The ANOVA analysis indicated that the average temperature was associated significantly with the nitrogen dioxide (NO_2) concentration in the ambient, but the average rainfall volume was associated significantly with most pollutants except only sulfur dioxide (SO_2). From the prediction models, the rise in average temperature affected to increase in the concentrations of PM10 and O_3. Interestingly, the increase in rainfall will be advantageous to compromise the severity of all pollutants. Meanwhile, on hotter days should be careful of the rise of PM10 and O_3 concentrations. Therefore, the vital meteorological variables associated with air pollution are very useful for forecasting the harmful and severity level of each air pollutant.

INTRODUCTION

Chiangmai is the seventh best city in the world for workcation and vacation. Unfortunately, Chiangmai has been facing a serious air pollution crisis for a long time. The severity of the air pollution crisis has increased continuously over the last ten years (Pardthaisonga et al. 2018). The main causes of air pollution consisted of forest fires, and agricultural waste open burning, often known as human-made. It is noteworthy that more than 90% of hot spots (approximately 934 hot spots) occurred in forest areas (both reserved forest and conserved forest) between January and March 2019 (Chiangmai Provincial Smog and Forest Fire Problem Solving Command Center 2019). It impacted a lot of people's well-being, causing health risks, bad environments, economic losses, etc. Thao et al. (2022) conducted research found that the impacts on public health and the economy within the mainland Southeast Asia (MSEA) region. This area encompasses Chiangmai province, which harbors the largest population and is most significantly affected by the particulate matter less than 10 microns (PM10) issue. Interestingly, air pollution can be intensified directly through adverse temperatures and changes in rainfall patterns. The temperature plays a pivotal role in altering the concentration levels of air pollutants in atmospheric physicochemical processes. Temperature influences of the air pollution transported in the horizontal direction by wind and in the vertical direction by turbulent diffusion are determinants of atmospheric stability (Lee et al. 2021). Additionally, temperature significantly impacts the intensity of air pollution in chemical processes, contributing to the formation of secondary air pollutants (Ebi et al. 2021). Rainfall significantly contributes to the reduction of air pollutants through a crucial process known as wet deposition, effectively washing the pollution down from the atmosphere (Pan et al. 2017).

However, there are small studies about Chiangmai air pollution. Nowadays, extreme climate variations occur very rapidly and more frequently due to climate change and global warming. Moreover, Chiangmai has developed dramatically and grown to become an economically powerful city. All resulted in large changes in the land use of Chiangmai (Pardthaisong et al. 2018). The forest area continues to reduce to 69.84% (15,458 km^2) in 2018 as compared with 82.61% (16,609 km^2) in 2008 (Royal Forest Department 2023) resulting from forest fire, deforestation, etc. In addition, the geography of Chiangmai is like a pan basin, which is surrounded by high mountains. Consequently, it risks accumulated air pollution for a longer time easily. Making it difficult to dilute or clean air pollution. The complex topography of Chiangmai significantly influences its meteorology and particulate matter (Solanki et al. 2019). Mountain and valley winds impact particulate matter distribution (Song & Min 2023). Additionally, factors like temperature stratification, mountain boundary layer height, strong and weak synoptic forcing, and thermally induced flows impact how particulate matter spreads across diverse terrain (Giovannini et al. 2020). In summary, the terrain's obstruction can lead to haze accumulation over plains and the lifting of pollution along mountainous regions. These processes contribute to the concentration of particulate matter in specific areas, exacerbating air pollution.

This work aimed to evaluate the association between the four important air pollutants and the climate conditions in Chiangmai, Thailand. The results help to forecast the severity of air pollution. These are beneficial to manage and mitigate air pollution in Chiangmai.

MATERIALS AND METHODS

The selected ambient air quality monitoring station (35T) by the Pollution Control Department (PCD) is located in Chang Phueak, Muang, Chiangmai Province, Thailand. The monthly average value was used to describe the datasets of air pollutants: PM10, ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2)) between 2006 and 2022. Meanwhile, the climate conditions consisted of two variables (average monthly temperature and average monthly rainfall), which were obtained from the Thai Meteorological Department (TMD), Ministry of Digital Economy and Society. The association between ambient pollutants and climate conditions in Chiangmai was assessed using regression analysis and analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Chiangmai Background

The land is surrounded by a lot of mountains. The area feature is like a pan basin (Fig.1). Therefore, when air pollution occurs, it has higher adverse impacts. This is because of easy accumulation and difficult dispersion (Amnuaylojaroen & Kreasuwun 2012). The period between mid-February and late May marks the transition from the Northeast monsoon (which occurs in December-January) to the Southwest

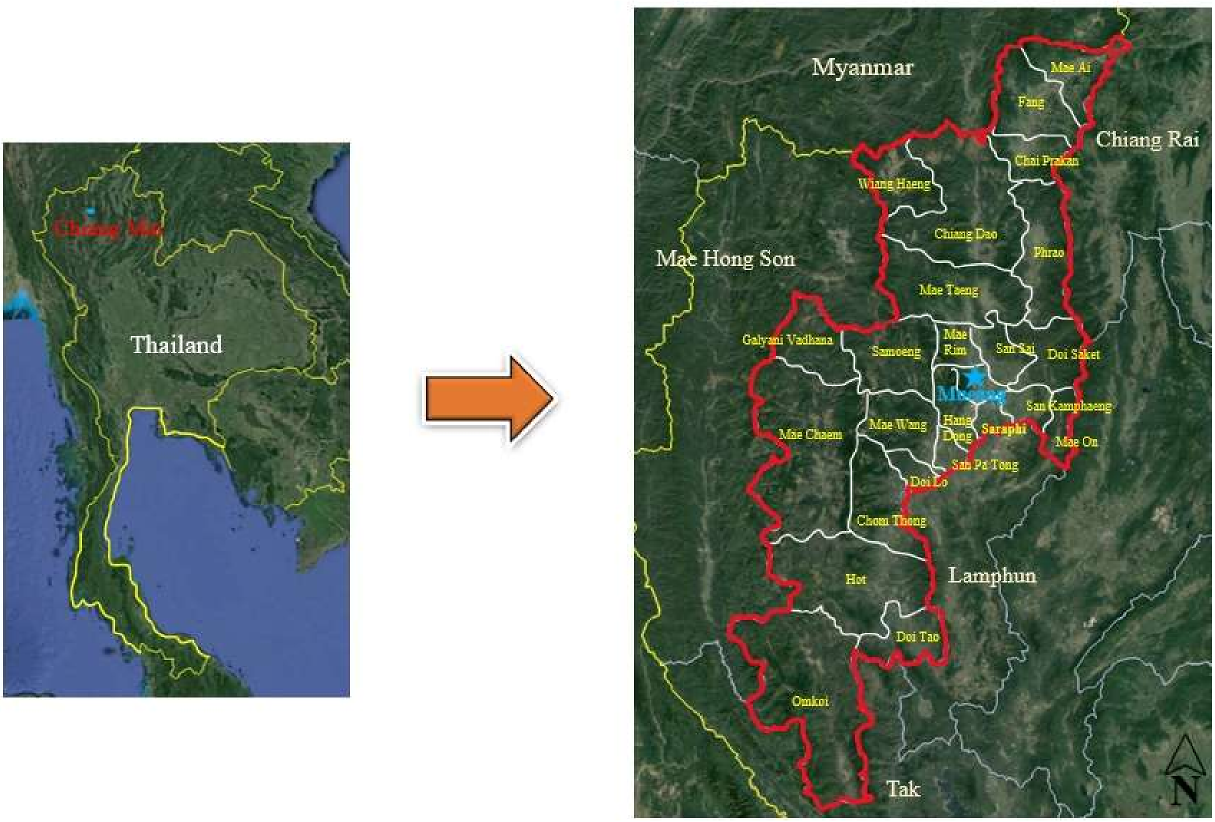

Fig. 1: The topography and ambient air monitoring station location in Chiangmai.

monsoon (commonly observed in July-August). The hottest weather, typically occurring in March-April, coincides with the presence of intense thermal lows in the region. Both meteorology and emissions are interconnected and play pivotal roles in the formation of haze episodes. The Chiangmai land area covers approximately 20,107 km^2. Most land use is forest area within 13,717 km^2 (68%), followed by an agricultural area of 5,005 km^2 (25%), and community and construction of 850 km^2 (4%), respectively (Fig. 2). The main water resources of Chiangmai is Ping River which flows through the center of the province from north to south. Especially, it is an important water resource for air pollution mitigation and safe zone building. For instance, on 21 February 2020, the Chiangmai Provincial Administrative Organization used up to 32 cars to spray water to reduce smog in the commercial zone (Manager Online 2019).

The biggest source of gross provincial products (GPP) per capita is the service section approximately 69.40% (Fig. 3). Importantly, Chiangmai is the central cultural and natural city of upper northern Thailand, which makes the province more attractive to a lot of tourists and investors. It is well known as a UNESCO Creative City of Craft and Folk Art (Yodsurang et al. 2022). The high air pollutant concentration in Chiangmai is affecting tourists because of the need to avert outdoor activities. The tourism income in 2020 (between February and March as the high season) extremely dropped by an average of 65.71% as compared to 2019 (Chiangmai Provincial Office 2020). Importantly, it is related significantly to the supply and demand of workers in the job market.

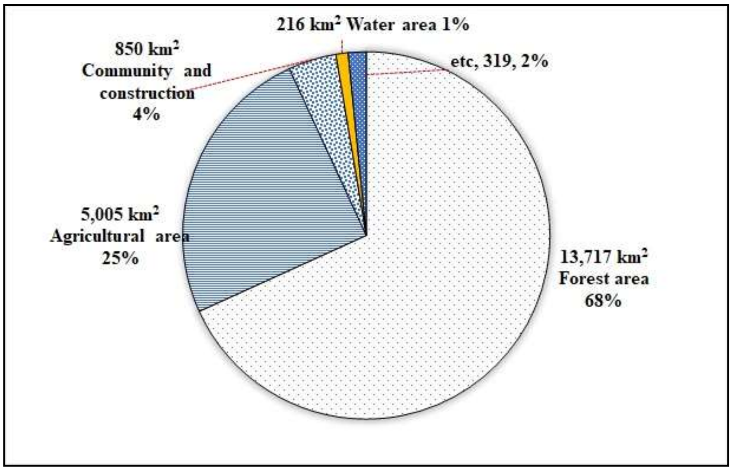

Fig. 2: The proportion of land use (Chiangmai Provincial Office 2020).

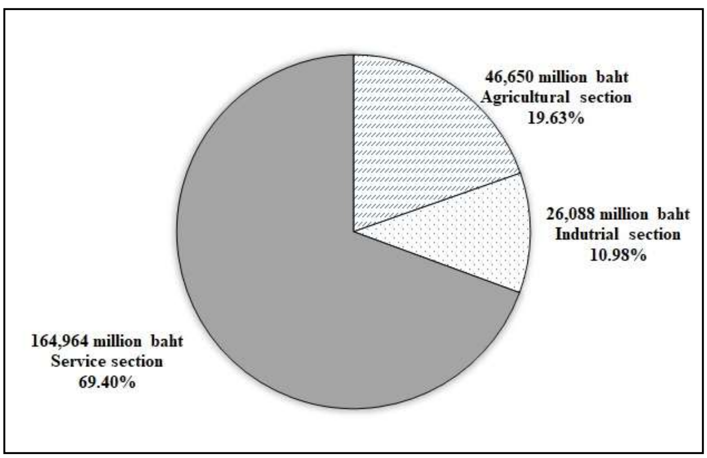

Fig. 3: The proportion of GPP.
(Chiangmai Provincial Office 2020)

Climate Conditions

The average temperature of Chiangmai province in the period 2006 to 2022 is shown in Fig. 4. The average temperature presented high fluctuation during a year. In some years (2010, 2013, 2015) had a large variation, which may be an initial sign of climate change. There was a slight increase in the average temperature over the period. The created linear equation indicates the province's temperature has increased trend by an average of 0.0002°C per month (0.024°C per decade).

Fig. 5 presents the highest volume at 470.6 mm in August 2010. Generally, Thailand's rainy season is from mid-May to mid-October (The Public Relations Department 2023). The monthly rainfall volume was around 106.4 mm in the

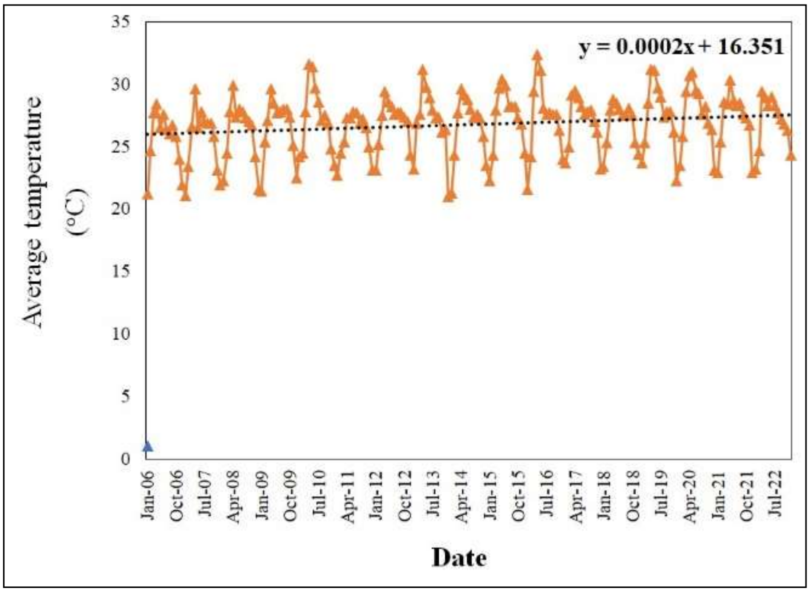

Fig. 4: The average temperature between 2006 and 2022 (The Meteorological Department 2023).

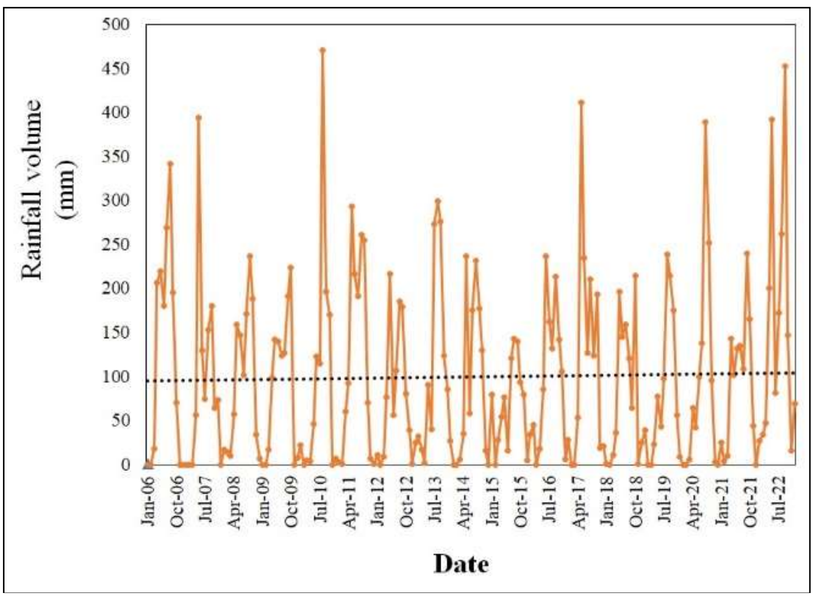

Fig. 5: The rainfall volume between 2006 and 2022 (The Meteorological Department 2023).

monitoring period. On average, there was 1,276.8 mm a year, as compared with Thailand's average rainfall volume of 1,622.9 mm between 1991 and 2020 (Office of Natural Resources and Environmental Policy and Planning 2023). This indicated that Chiangmai a low rainfall area resulted in negative impacts on air pollution control. Moreover, rainfall is so difficult to precipitate lately due to climate change, El Nino, etc. For example, in 2019 (El Nino) had particulate matter less than 2.5 microns (PM2.5) much higher than in 2017 (La Nina) (Kraisitnitikul et al. 2024). The governor is very aware of this obstacle. Therefore, the Department of Royal Rainmaking and Agricultural Aviation is assigned to making artificial rainfall in Chiangmai.

Ambient Air Quality Monitoring

The trends in the concentrations of PM10 exceeded or were close to the 24-hour National Ambient Air Quality Standards (NAAQS) (less than 120 μg/m^3) between 2012 and 2022 (Fig. 6). Especially, March had the highest PM10 concentration during the summer season, which is the biomass open-burning period (February to April) after harvesting (Kawichai et al. 2022). There was an increase in the number of hospital outpatient department visitors

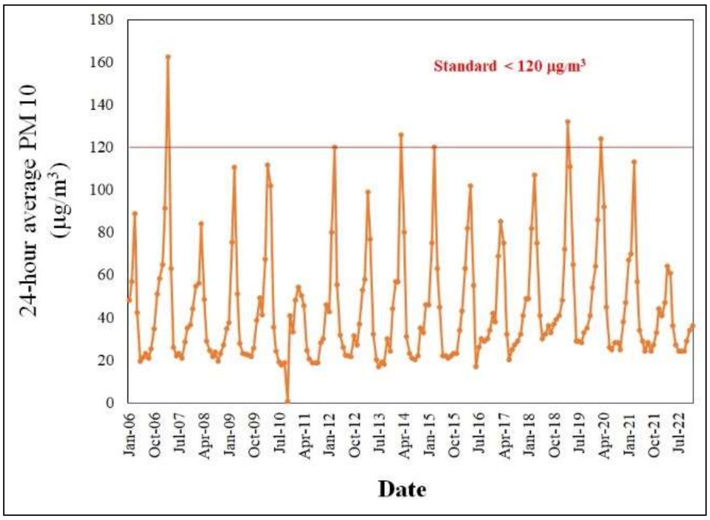

Fig. 6: The 24-hour average PM10 concentration (Pollution Control Department 2023).

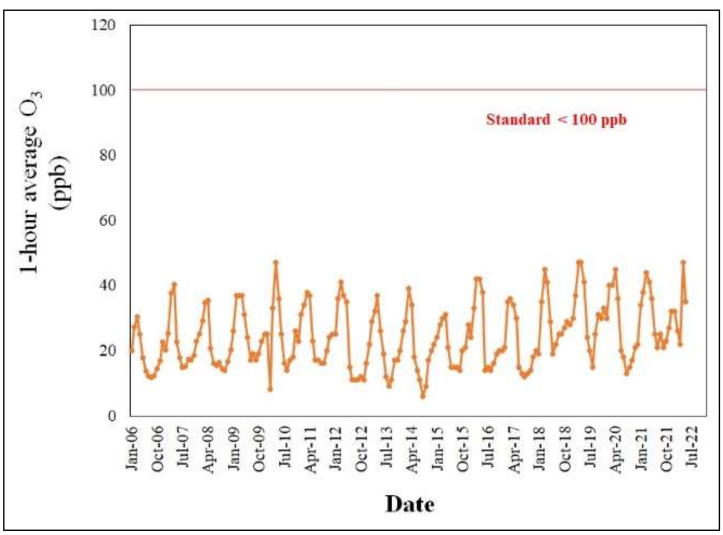

Fig. 7: The 1-hour average O_3 concentration (Pollution Control Department 2023).

because of respiratory disease in the period of January-March from 209,413 visitors in 2006 to 237,348 visitors in 2007. This period had the highest record of PM10 level (Bank of Thailand 2007). Additionally, it was confirmed that the increase in PM10 concentration was related to asthma and chronic obstructive pulmonary disease in Chiangmai. This appearance of emergency exacerbations was after around one week (Pothirat et al. 2016). Because the PM10 can be inhaled into and deposited in the respiratory tract system and lungs. Moreover, Jeensoon et al. (2018) found that fine particle matter has a high effect on visibility at low altitudes in Chiangmai.

Meanwhile, other pollutants (O_3, SO_2, NO_2) spread far from their standards very much. O_3 likes to lift in January of every year, which is the last period of the winter season (Fig. 7). This is starting to warm up and give more sunlight. Accordingly, O_3 formation is more accelerated in warm and sunny weather (EPA 2023). As well known that O_3 is a secondary pollutant that occurs through photochemical reactions linking to other pollutants (nitrogen oxides and volatile organic compounds). Considering the threshold O_3 concentration of 50 ppb is harmful to human health with long-term exposure. Anxiously, the air pollution crisis will drive it close to the threshold of toxic concentration recently (UK Air Pollution Information System 2023). In Thailand, a small group of people know that O_3 is an air toxicant on the ground level. For example, the misunderstanding of some tourist attractions presented the slogan "visiting to inhale O_3 pollution for longevity" (Bavonkiti 2012). This resulted in less concern and awareness about O_3.

Normally, SO_2 and NO_2 are used to be the cause of acid rain. Their concentrations are very low with a small spreading variation (Fig. 8 and Fig. 9). Mostly, this resulted from biomass burning in the forest, emitting lower NO_2 and SO_2 than in rice fields (Acharya et al. 2018). The study by Brassard et al. 2014 indicated that SO_2 and NO_2 were released from agricultural waste burning significantly higher than forest biomass burning in Quebec, Canada. Typically, SO_2 was produced from oil and coal burning but NO_2 was generated from fossil fuels such as gasoline (Brassard et al. 2014). Accordingly, their emissions depend on the fuel's nitrogen and sulfur content (South Carolina Department of Health and Environmental Control 2023).

Interestingly, all pollutants are likely to rise to the highest concentration at the same interval between February and April. Therefore, this interval is a critical time, which needs a special monitor for air pollution as well as an effective early warning and controlling system.

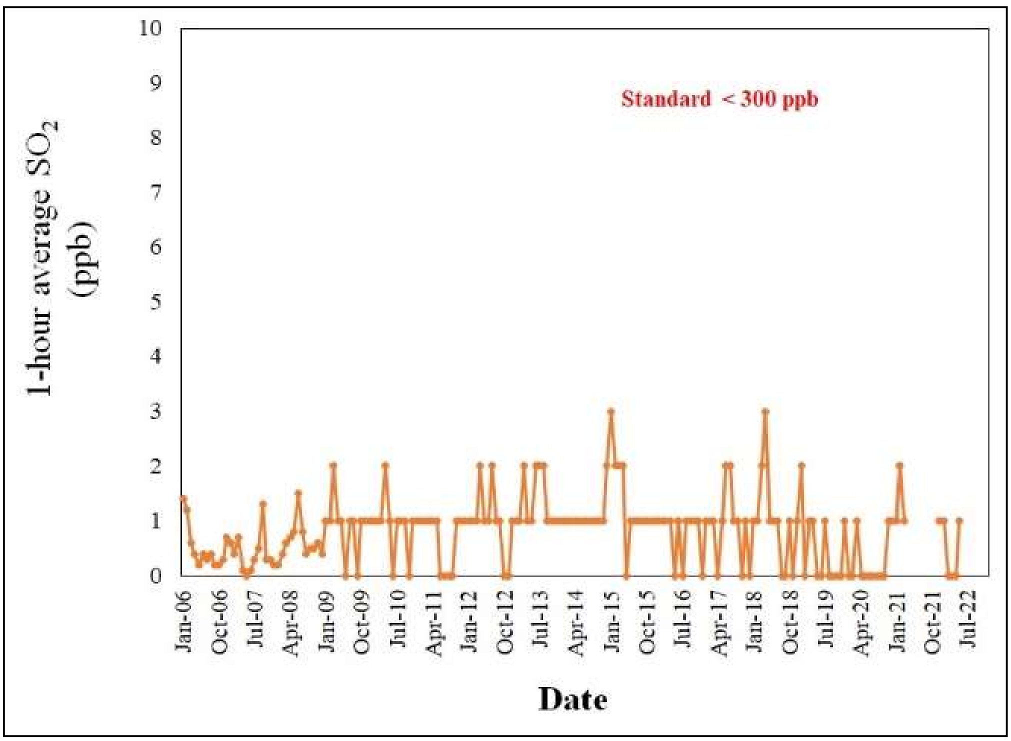

Fig. 8: The 1-hour average SO_2 concentration (Pollution Control Department 2023).

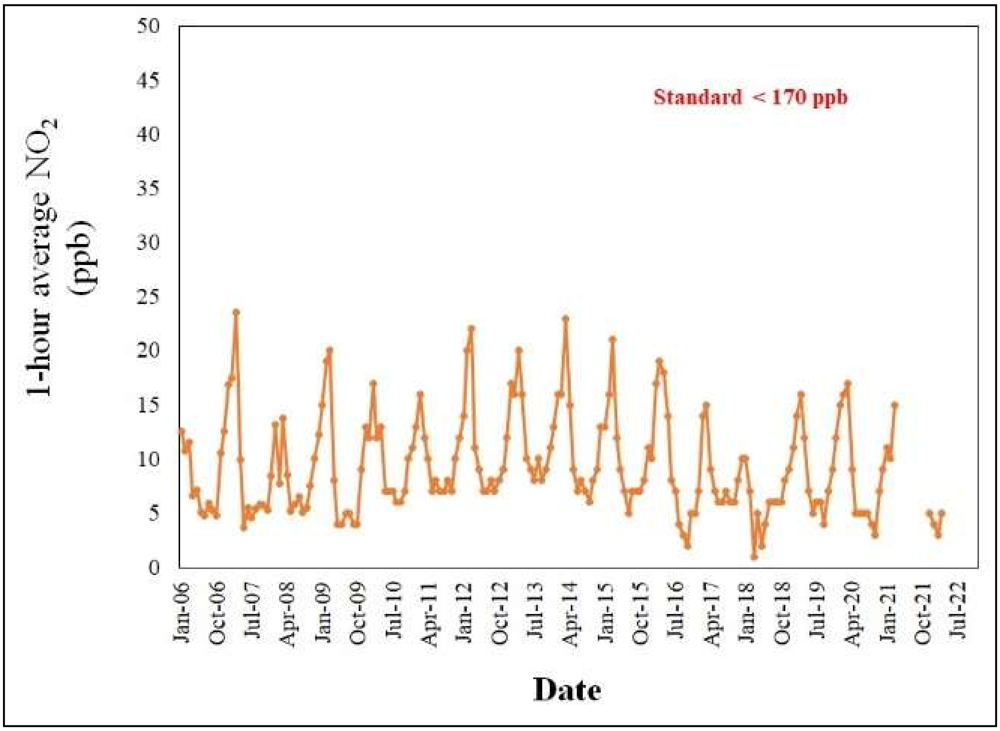

Fig. 9: The 1-hour average NO_2 concentration (Pollution Control Department 2023).

Table 1: The regression of analysis and ANOVA results.

Independent variable	Dependent variable	F-value	P-value	R^2	Predictive model
Average temperature	PM10	0.055	0.814	0.000	PM10 = 39.241 + 0.188 (Temp)
	O_3	5.400	0.021	0.027	O_3 = 6.890 + 0.652 (Temp)
	SO_2	0.645	0.423	0.003	SO_2 = 1.206 – 0.0015 (Temp)
	NO_2	10.943	0.001	0.056	NO_2 = 21.128 – 0.443 (Temp)
Average rainfall	PM10	73.873	0.000	0.282	PM10 = 56.991 – 0.138 (Rainfall)
	O_3	37.865	0.000	0.173	O_3 = 27.834 – 0.04 (Rainfall)
	SO_2	4.112	0.044	0.023	SO_2 = 0.899 – 0.001 (Rainfall)
	NO_2	66.376	0.000	0.280	NO_2 = 11.363 – 0.024 (Rainfall)

Remark: A P-value less than 0.001 is statistically highly significant.

ANOVA Results

According to the ANOVA results in Table 1. The average temperature associated with only NO_2 by P-value is less than 0.001. Because NO_2 is photochemical smog, its degradation is related directly to the presence of sunlight and relatively high temperature (Han et al. 2011) as shown in Equation 1.

$$NO_2 \xrightarrow[\text{Sunlight } (h\nu)]{} NO + O^* \qquad ...(1)$$

On the other hand, the rainfall volume is associated significantly with the most pollutants (PM10, O_3, NO_2), except only SO_2.

Noteworthy, the increase in average temperature resulted in the decrease of SO_2 and NO_2 concentrations. The higher average temperature may accelerate the degradation of SO_2 and NO_2 converting to other intermediates (NASA 1997). Conversely, this encourages the occurrences of PM10 and O_3. Similarly, the concentrations of O_3 were found to rise with the increases in temperature during heatwaves in Birmingham, UK (Kalisa et al. 2018). Differently, the PM10 concentration tends to be higher during wintertime with small rainfall and low temperature in Hanoi, Vietnam (Dung et al 2019). This is because the PM10 emission sources are different from Chiangmai, which most PM10 from biomass and forest fires in summer.

Meanwhile, the rainfall increase affected to reduction of all pollutants. Same as the particulate matter less than 2.5 microns (PM2.5) is less in the rainy season because rain has a wet deposition effect on PM2.5 in Chiangmai and no open burning which constitutes a significant source of emissions in this period (Anusasanana et al. 2022). At 896 monitoring stations in China between 2014 and 2019, Liu et al. (2020) found that the concentrations of all air pollutants (PM2.5, PM10, SO_2, carbon monoxide (CO), NO_2, and O_3) were positively associated with ambient pressure, but significantly negatively associated with wind speed, rainfall, and relative humidity.

Lastly, the Thai government can use these results for artificial rainmaking and planning to mitigate the air pollution crisis in Chiangmai. Haleem et al. (2023) stated that artificial rain is a promising defense method for air pollution management. However, field measurements are necessary to further evaluate the cost-effectiveness of the method, including the other benefits or challenges. Moreover, the predictive models are very useful for forecasting the harmful and severity level of each air pollutant according to the average temperature and rainfall volume.

CONCLUSION

The rainfall volume can significantly reduce all air pollutants in the ambient, especially PM10 in Chiangmai. Therefore, we should help to increase the rainfall volume. Admittedly, the increasing average temperature may reflect to rise of PM10 and O_3. Climate change monitoring by using the average temperature is vital for preparing and preventing the harmful effects of both pollutants. Finally, further research should study more meteorological variables associated with air pollution such as relative humidity, wind speed, solar radiation, etc.

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REFERENCES

Acharya, P., Sreekesh, S., Kulshrestha, U. and Gupta, G., 2018. Characterisation of emission from open-field burning of crop residue during harvesting period in north-west India. *Environmental Monitoring and Assessment*, 190: 1-19.

Anusasananan, P., Morasum, D., Suwanarat, S. and Thangprasert, N., 2022. Correlation between PM2.5 and meteorological variables in Chiang Mai, Thailand. *Journal of Physics: Conference Series*, 2145(2022): 1-9.

Bank of Thailand, 2007. The smog situation on the upper northern of Thailand. Retrieved February 22, 2023, from: https://www.tei.or.th/thaicityclimate/public/document-36.pdf

Bavonkiti, S., 2012. To inhale pure ozone or not? For what. *Thammasat Medical Journal*, 12(1): 198-200.

Brassard, P., Palacios, J.H., Godbout, S., Bussieres, D., Lagace, R., Larouche, J.P. and Pellettier, F., 2014. Comparison of the gaseous and particulate matter emissions from the combustion of agricultural and forest biomasses. *Bioresource Technology*, 155(March 2014): 300-306.

Chiangmai Provincial Office, 2020. Report on the results of driving Thailand together. Retrieved March 8, 2023, from: https://www.chiangmai.go.th/thaitogether/assets/pdf/3_3.pdf

Chiangmai Provincial Office, 2020. Summary of Chiangmai province 2020. Retrieved February 27, 2023, from http://chiangmai.go.th/managing/public/D8/8D17Jan2022133138.pdf

Chiangmai Provincial Smog and Forest Fire Problem Solving Command Center, 2019. Report on work to solve smog and forest fire problems in Chiang Mai Province. Retrieved January 20, 2023, from https://chiangmai.mnre.go.th/

Duan, Y., Duan, L., Wang, J. and Anthony, E.J., 2019. Observation on simultaneously low CO, NOx and SO_2 emission during Oxy-coal combustion in a pressurized fluidized bed. *Fuel*, 242: 374-381.

Dung, N.A., Son, D.H., Hanh, N.T.D. and Tri, D.Q., 2019. Effect of meteorological factors on PM10 concentration in Hanoi, Vietnam. *Journal of Geoscience and Environment Protection*, 7(11): 138-150.

Ebi, K.L., Vanos, J., Baldwin, J.W., Bell, J.E., Hondula, D.M., Errett, N.A., Hayes, K., Reid, C.E., Saha, S., Spector, J. and Berry, P., 2021. Extreme weather and climate change: Population health and health system implications. *Annual Review of Public Health*, 42(1): 293-315.

EPA, 2023. Trends in ozone adjusted for weather conditions. Retrieved February 2, 2023, from https://www.epa.gov/air-trends/trends-ozone-adjusted-weather-conditions

Giovannini, L., Ferrero, E., Karl, T., Rotach, M.W., Staquet, C., Castelli, S.T. and Zardi, D., 2020. Atmospheric pollutant dispersion over complex terrain: Challenges and needs for improving air quality measurements and modeling. *Atmosphere*, 11(6): 1-32.

Haleem, N., Kumar, P., Uguz, S., Jamal, Y., McMaine, J. and Yang, X., 2023. Viability of artificial rain for air pollution control: insights from natural rains and roadside sprinkling. *Atmosphere*, 14(1714): 1-18.

Han, S., 2011. Analysis of the relationship between O_3, NO and NO_2 in Tianjin, China. *Aerosol and Air Quality Research*, 11(2): 128-139.

Jeensorn, T., Apichartwiwat, P. and Jinsart, W., 2018. PM10 and PM2.5 from haze smog and visibility effect in Chiang Mai province Thailand. *Applied Environmental Research*, 40(3): 1-10.

Kalisa, E., Fadlallah, S., Amani, M., Nahayo, L. and Habiyaremye, G., 2018. Temperature and air pollution relationship during heat waves in Birmingham, UK. *Sustainable Cities and Society*, 43: 111-120.

Kawichai, S., Prapamontol, T., Cao, F., Song, W. and Zhang, Y., 2022. Source identification of PM2.5 during a smoke haze period in Chiang Mai, Thailand, using stable carbon and nitrogen isotopes. *Atmosphere*, 13(7): 1-12.

Kraisitnitikul, P., Thepnuan, D., Chansuebsri, S., Yabueng, N., Wirinya, W., Saksakulkrai, S., Shi, Z. and Chantara, S., 2024. Contrasting compositions of PM2.5 in Northern Thailand during La Niña (2017) and El Niño (2019) years. *Journal of Environmental Sciences*, 135: 585-599.

Lee, S., Lee, S.J., Kang, J.H. and Jang, E.S., 2021. Spatial and temporal variations in atmospheric ventilation index coupled with particulate matter concentration in South Korea. *Sustainability*, 13(16): 1-13.

Liu, Y., Zhou, Y. and Lu, J., 2020. Exploring the relationship between air pollution and meteorological conditions in China under environmental governance. *Scientific Reports*, 10(14518): 1-11.

Manager online, 2019. Increasing mobilize vehicles to spray water all over Chiang Mai for moisture increasing to reduce smog and dust. Retrieved February 25, 2023, from https://mgronline.com/local/detail/9620000018351

NASA, 1997. Chemical kinetics and photochemical data for use in stratospheric modeling. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

Office of Natural Resources and Environmental Policy and Planning, 2023. Report on average rainfall volume indicator (2556-2565). Retrieved February 26, 2023, from http://env_data.onep.go.th/reports/subject/view/167

Pan, Y.P., Zhu, X.Y., Tian, S.L., Wang, L.L., Zhang, G.Z. and Zhou, Y.B., 2017. Wet deposition and scavenging ratio of air pollutants during an extreme rainstorm in the North China Plain. *Atmospheric and Oceanic Science Letters*, 10(5): 348-353.

Pardthaisonga, L., Sin-ampol, P., Suwanprasit, C. and Charoenpanyanet, A., 2018. Haze pollution in Chiang Mai, Thailand: A road to resilience. *Procedia Engineering*, 212: 85-92.

Pollution Control Department, 2023. Ministry of Natural Resources and Environment. Retrieved February 22, 2023, from http://air4thai.pcd.go.th/webV2/download.php

Pothirat, C., 2016. Effects of seasonal smog on asthma and COPD exacerbations requiring emergency visits in Chiang Mai, Thailand. *Asian Pacific Journal of Allergy and Immunology*, 34(4): 1-6.

Royal Forest Department, 2023. Forest area by type and province between 2008 and 2018. Retrieved February 2, 2023, from https://forestinfo.forest.go.th/Content.aspx?id=80

Solanki, R., Macatangay, R., Sakulsupich, V., Sonkaew, T. and Mahapatra, P.S., 2019. Mixing layer height retrievals from mini MPL measurements in the Chiang Mai valley: Implications for particulate matter pollution. *Frontiers in Earth Science*, 7(308): 1-12.

Song, Y. and Min, S., 2023. Impacts of complex terrain features on local wind field and PM2.5 concentration. *Atmosphere*, 14(5): 1-14.

South Carolina Department of Health and Environmental Control, 2023. Retrieved January 5, 2023, from https://scdhec.gov/sites/default/files/Library/CR-008071.pdf

Thai Meteorological Department, 2023. The average temperature and rainfall volume 2006 - 2022. Retrieved February 23, 2023, from https://www.tmd.go.th/service/tmdData

Thao, N.N.L., Pimonsree, S., Prueksakorn, K., Thao, P.T.B. and Vongruang, P., 2022. Public health and economic impact assessment of PM2.5 from open biomass burning over countries in mainland Southeast Asia during the smog episode. *Atmospheric Pollution Research*, 13(6): 101418.

The Public Relations Department, 2023. The seasons of Thailand. Retrieved February 2, 2023, from https://thailand.go.th/issue-focus-detail/009_142

UK Air Pollution Information System, 2023. Retrieved February 22, 2023, from https://www.apis.ac.uk/overview/pollutants/overview_o3.htm

Yodsurang, P., Kiatthanawat, A., Sanoamuang, P., Kraseain, A. and Pinijvarasin, 2022. Community-based tourism and heritage consumption in Thailand: An upside-down classification based on heritage consumption. *Cogent Social Sciences*, 8(1): 1-20.

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