(International Print/Online Journal)

SJIF IMPACT FACTOR: 5.565
PUBMED-National Library of Medicine ID-101739732

ISSN (Print): 2209-2870
ISSN (Online): 2209-2862

IJMSCR

International Journal of Medical Science and Current Research (IJMSCR)
Available online at: www.ijmscr.com
Volume 6, Issue 5 , Page No: 293-304
September-October 2023

The Impact of Geographical and Social Factors on the Variations of PM2.5 Concentrations in the Northern and Central Regions of Thailand

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Type of Publication: Original Research Paper
Conflicts of Interest: Nil

Abstract

Fine particulate matter of diameter 2.5 micrometers or smaller (PM2.5) is a potentially hazardous contaminant present in the atmosphere. Despite existing in all regions of Thailand, it is most abundant in the northern and central regions. Therefore, this study aims to compare and contrast the social, topographical, meteorological, and anthropomorphic factors that exist in the central and northern region and determine the degree of influence they exert on PM2.5 concentration. This was accomplished by compiling daily readings (average of 24 hours), throughout five years, from air quality monitoring stations across the two regions, specifically in Chiang Mai and Bangkok. The figures were then averaged, cataloged, and graphed according to the season and year. The findings would later be correlated to geographical factors that may have had an impact, through the process of analyzing relevant studies. Overall, the findings illustrated that Chiang Mai was slightly less polluted than Bangkok during the wet and cold season, but astronomically more polluted in the summer, leading to a higher all-time PM2.5 concentration average of 26.81%. Ultimately, the wet season was the least polluted for both while the summer and winter were the most polluted for Chiang Mai and Bangkok, respectively. In Bangkok, 2017 was the most polluted with each subsequent year decreasing in pollution. For Chiang Mai, 2019 was the most polluted year. The results were influenced by a combination of multiple determinants. Human activities such as biomass burning contributed heavily to Chiang Mai's summer pollution. Thermal inversion is a weather phenomenon responsible for the relatively high levels of PM2.5 present in the winter months. Conversely, the low levels of PM2.5 during the rainy season were largely the consequence of wet deposition caused by precipitation. The mountainous topography of Chiang Mai, as opposed to the low lying plains of Bangkok, causes a trapping effect on the surrounding valleys and creates different microclimates between the windward and leeward sides. Bangkok's proximity to the ocean leads to regular sea breezes which is linked to either an increase or decrease in air pollution, depending on atmospheric variables. Finally, a direct correlation between PM2.5 concentration and year could not be logically established. However, the COVID-19 pandemic and government policies regarding it are believed to have a profound impact on the PM2.5 level of each year.

Keywords: PM2.5, air quality monitoring stations, regions, daily readings

Introduction

Environmental well-being is significantly impacted by air quality, with particulate matter of diameter 2.5 micrometers or smaller (PM2.5) being one of the most prominent contaminants. This microscopic particle holds potential health risks for humans, as extended contact has been associated with various pulmonary and cardiovascular complications (1,2). This concern is particularly pronounced in nations like Thailand. This country is currently undergoing rapid shifts due to urbanization, industrial growth, and agricultural pursuits, all unfolding across a varied geographical backdrop. In this context, comprehending the intricate interplay between geography and PM2.5 levels becomes exceptionally significant. This scholarly article aims to thoroughly examine the interconnections between geographic attributes and fluctuations in PM2.5 concentrations within two focal areas of Thailand: the northern region and the central region. By delving into the geographic elements shaping PM2.5 distribution and their potential effects on air quality management, this investigation strives to provide valuable insights beneficial for decision-makers, scientists, and stakeholders vested in environmental concerns.

Thailand's northern and central regions contrast distinctly in their geographic traits, weather trends, and socio-economic engagements. The northern territory, which includes provinces like Chiang Mai and Chiang Rai, boasts a terrain marked by mountains, valleys, and assorted land utilization practices, spanning from farming to forestry. In contrast, the central region, including the bustling metropolis of Bangkok, features flatter landscapes and a significant concentration of industries. The intricate interplay between terrain, wind patterns, land use, and more creates varying microenvironments that can influence the dispersion and concentration of atmospheric PM2.5 (3,4).

Existing studies have highlighted that elements like temperature inversions, local atmospheric conditions, terrain structure, and patterns of air movement can exert notable influence on the dispersion of PM2.5 concentrations (3,5-7). However, the precise contribution of these factors to the divergent PM2.5 levels in distinct geographical contexts remains an area warranting exploration. This scholarly article aims to bridge this knowledge gap by analyzing empirical data on PM2.5 concentrations in Thailand's northern and central regions, subsequently establishing connections with geographical determinants. Through referencing significant data points in real-world PM2.5 measurements, this study seeks to ascertain the magnitude of impact attributed to these factors and their divergences across the two regions. Utilizing advanced analytical methodologies, this investigation strives to unveil the latent interrelationships between geographical variables and PM2.5, thereby furnishing a comprehensive comprehension of the mechanisms steering air quality disparities spanning these locales.

Ultimately, the outcomes of this research pursuit possess the potential to steer the development of precision-guided interventions and strategies directed at alleviating the unfavorable consequences of PM2.5 contamination. This, in turn, could cultivate a more breathable atmosphere and promote well-being within the communities inhabiting Thailand's northern and central regions.

Methodology

Data Acquisition

The research began by collecting the daily readings, the average throughout 24 hours, from air quality monitoring stations in Bangkok and Chiang Mai through a period of 1826 days, starting from the beginning of 2017 till the end of 2021. In order to obtain values that were more emblematic of the true PM2.5 concentrations in the region, this research consisted of data that was gathered from as many stations as possible.

In total, data from 14 different monitoring stations were collected. However, many monitoring stations were either not functional for long periods of time or not constructed until after 2017, leading to incomplete data. Thus, any monitoring station with more than 180 days worth of missing data would be deemed unfit and eliminated from the study.

Ultimately, six air quality monitoring stations were selected as representatives of the Northern and Central regions. Two of the stations (35T, 36T) were located in Chiang Mai and the other four (05T, 59T, 61T, 52T) were located in Bangkok.

Data Analysis

To begin the analysis, all the collected information was transferred into a spreadsheet software and organized into two main groups: Bangkok and Chiang Mai.

Next, line graphs illustrating the average quadrimester reading from every individual monitoring station from 2017 to 2021 were created to gain a visual understanding of the cyclical trends present in both regions.

Afterwards, the daily readings from every year from each monitoring station in a given region were grouped into seasons and were all averaged to form a singular value for each season. These values would then be graphed. It should be noted that Thailand's weather tends to be defined by three seasons: the wet season (June to October), the cool season (November to February) and the hot season (March to May).

Similarly, the daily readings from each monitoring station in a given region were grouped into years and were all averaged to obtain the year-round mean for each of the five years. These values would then be summarized into a bar graph for each region.

Data Interpretation

Utilizing these graphical models, a general understanding of the patterns present in PM2.5 distribution through time was achieved. Consequently, there existed some differences and similarities among the values and patterns derived from Chiang Mai and Bangkok monitoring stations. To rationalize and explain this as well as the independent patterns present in both regions, many related papers pertaining to the effects of topography, seasonal patterns, and human behavior on PM2.5 concentration were examined. Many of these factors can be used to explain certain features and trends present in the findings. Moreover, relevant points in the data, such as a period of regression in the PM2.5 readings, were evaluated for any past events it might have coincided with.

Results Summary

The findings were divided into three main sections: overview, seasonal averages, and yearly averages. Firstly, the overview, illustrated by line graphs, serves to display the general trend present in each region as well as the variation in the readings of each monitoring station. Secondly, the other two sections, illustrated by bar charts, have the purpose of displaying any correlation that may exist between PM2.5 levels and the variables of interest, which include the season and year. Values were measured in the standard unit of micrograms per cubic meter (µg/m3) and rounded to the nearest hundredth. Daily readings refer to the 24-hour average.

Details of Air Quality Monitoring Stations

During the research, some monitoring stations had to be excluded due to an overwhelming amount of unavailable PM2.5 readings, leaving six stations to remain. However, even among these six, it is crucial to note that a few entries from the list PM2.5 readings were missing, and therefore not available for analysis or interpretation.

Listed below are the names and locations of the total six air quality monitoring stations that were used to establish the findings. The chosen stations were located in different parts of their respective regions in order to ensure more regionally indicative data.

Bangkok	05T	Hiran Ruchi, Thon Buri district
	52T	Bang Yi Ruea, Thon Buri district
	59T	Phaya Thai, Phaya Thai district
	61T	Phlabphla, Wang Thonglang district
Chiang Mai	35T	Chang Phueak, Mueang Chiang Mai district
	36T	Si Phum, Mueang Chiang Mai district

Overview

The following line graphs display the average PM2.5 readings from each air quality monitoring station across every 4 month period between 2017 and 2021, in Bangkok and Chiang Mai, respectively. Overall, Chiang Mai seemed to be more polluted than Bangkok, as the quadrimester average could soar above 60 µg/m3 while Bangkok's quadrimester average never surpassed 40 µg/m3. Notably, both regions experienced their absolute peak PM2.5 exposures during the first quadrimester, but in different years. For Bangkok, it was 2018, and Chiang Mai, 2019. However, the lowest points in the graphs concurred within the same general timespan, the middle quadrimester of 2020 and 2021. Despite demonstrating a similar fluctuation to one another, the increase and decrease present in Bangkok's graph were less drastic. Lastly, it can be observed that the figures from Bangkok were considerably higher during the final quadrimester of each year than that of Chiang Mai's.

Fig 1.1: Bangkok's Average PM2.5 Readings from Each Monitoring Station for Every Quadrimester (2017-2021)

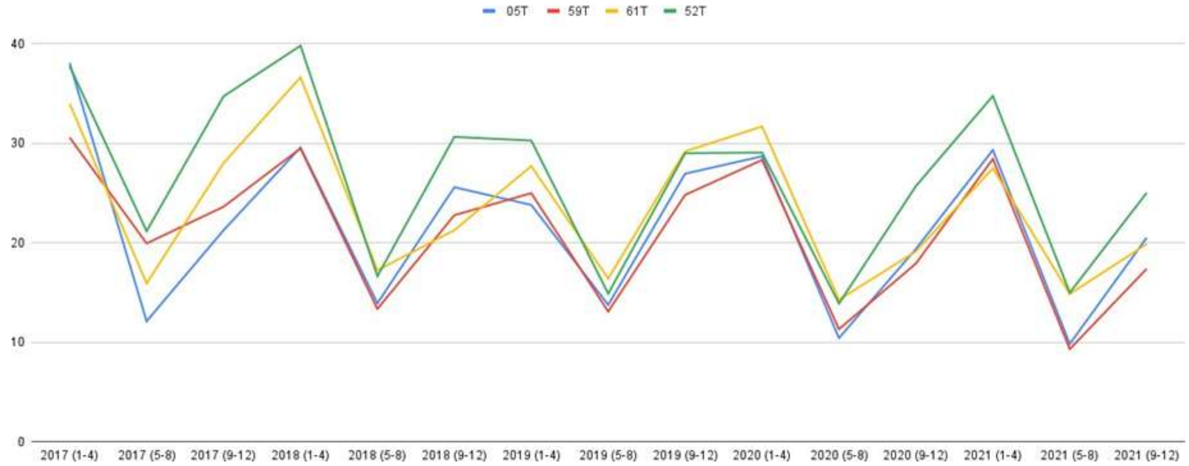
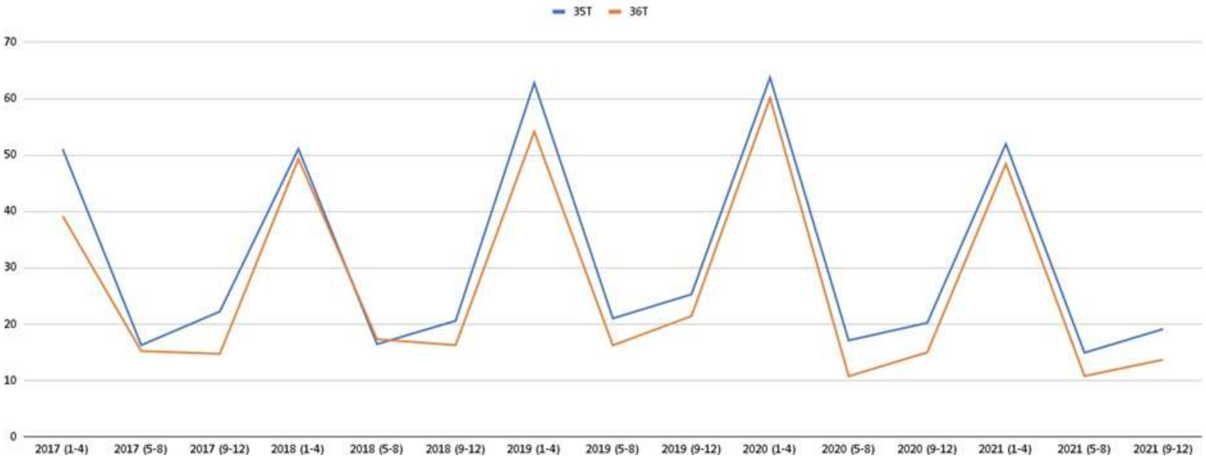


Fig 1.2: Chiang Mai's Average PM2.5 Readings from Each Monitoring Station for Every Quadrimester (2017-2021)



Seasonal Averages

The graph displays the average daily PM2.5 reading throughout each season from 2017 to 2021. In this research, the five years were divided into three seasons: the summer (March to May), the rainy season (June to October), and the winter (January, February, November, December of the same year).

Fig 2.1: Bangkok's Seasonal Average PM2.5 Readings (2017-2021)

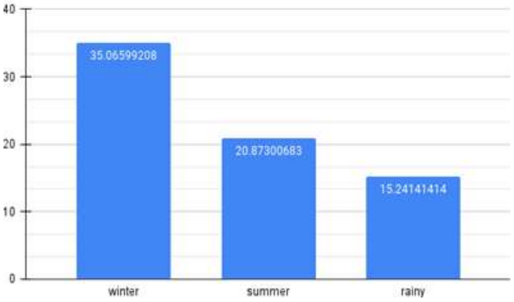
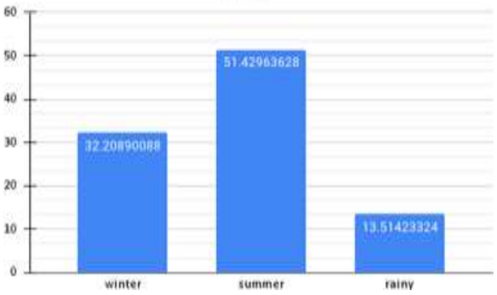


Fig 2.2: Chiang Mai's Seasonal Average PM2.5 Readings (2017-2021)



Chiang Mai and Bangkok possessed similar PM2.5 levels during the wet and cold season. During winter, Bangkok had its highest seasonal average (M = 35.07, SD = 16.09), which was

2.86 µg/m3 above Chiang Mai's average (M = 32.21, SD = 14.81). Interestingly, the rainy season was the least polluted for both Bangkok (M = 15.24, SD = 7.33) and Chiang Mai (M = 13.51, SD = 5.21), but Bangkok was more polluted by a margin of 1.73 µg/m3.

The summer was the only season where a significant disparity could be observed between the two cities. PM2.5 concentration in Chiang Mai during this period was extremely prominent (M = 51.43, SD = 34.56), as evident by the seasonal average being approximately three standard deviations above Bangkok's mean (M = 20.87, SD = 10.07). The relative standard deviation for both regions were also highest during this period.

Yearly Averages


Fig 3.1: Bangkok's Yearly Average PM2.5 Readings

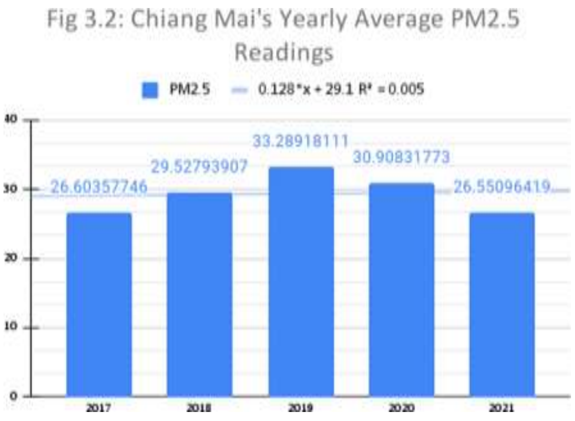


Fig 3.2: Chiang Mai's Yearly Average PM2.5 Readings

From 2017 to 2021, distinct trends pertaining to the average annual PM2.5 concentrations were observed in Bangkok and Chiang Mai. Throughout this period, Bangkok's yearly average tended to slightly decrease from the initial value of 26.44 to 20.91 µg/m3. The projected rate of decrease, as indicated by slope of the trendline, was 1.48 per year. In Bangkok, there seemed to be a negative correlation between year and PM2.5 concentration (r2 = 0.94). Additionally, it should be noted that 2021 was the only year that experienced an increase, albeit an insignificant amount. Conversely, Chiang Mai's yearly average experienced a fluctuating trend that correlated little with the year. From 2017 to 2019, the figure sharply rose from 26.60 to its maximum of

33.29 µg/m3 at a mean rate of 3.34 per year. Afterwards, the figure dipped to its minimum of

26.55 µg/m3 in 2021 at a mean rate of 3.37 per year. Virtually no correlation can be observed between the year and PM2.5 levels in Chiang Mai ($r2 < 0.01$).

Discussion

The purpose of this study is to determine the existence and extent of the effects that geographical factors have on PM2.5 distribution in the Northern and Central regions. In order to accomplish this goal, this section of the research investigated if and how the seasonal and annual trends presented in the results summary correlate to geographical determinants or past events described in other relevant studies.

Agricultural Biomass Burning

According to ChooChuay et al. (2022), it is commonly agreed upon that the main contributor to The northern region's high level of PM2.5 appears to be the routine biomass burning that occurs there. In Chiang Mai and other rural areas of Thailand, open burning is frequently used to clear agricultural fields after harvesting crops. Farmers burn leftover crop residues, such as rice straw and corn stalks, as a method of preparing fields for the next planting season. This practice typically occurs over the dry season (March to mid-April), which coincides with the summer (March to May) (8). This fact supports the findings from the previous section and offers an explanation as to why and how PM2.5 concentrations during Chiang Mai's hot season were uniquely excessive compared to that of Bangkok's.

In Chiang Mai, the practice of seasonal open burning is notably more widespread compared to Bangkok (9). This distinction offers an avenue for shedding light on the contrasting average summer measurements in these two cities (see Figures 2.1 and 2.2).

The act of burning biomass results in the direct release of a considerable volume of PM2.5 into the atmosphere. Biomass, including agricultural remnants and forest detritus, is often subjected to incomplete combustion due to unregulated burning conditions. This generates fine particles that readily suspend in the air, augmenting the levels of PM2.5 (10-12).

Moreover, this practice culminates in heightened concentrations of PM2.5, especially in close proximity to the burning sites. These pollutants can remain aloft and get carried by local wind patterns. Consequently, PM2.5 and associated pollutants stemming from open burning can be transported over extended distances by regional wind movements. This mechanism facilitates the dispersal of PM2.5 to regions beyond the immediate vicinity of the burn locations, thereby contributing to the broader escalation in PM2.5 levels across the region (8,13).

Temperature Inversion

Thermal inversion refers to a meteorological condition where a layer of warm air traps cooler air near the ground's surface (14). This reversal of the normal atmospheric temperature gradient restricts vertical mixing of air pollutants and results in the accumulation of pollutants near the ground. Thermal inversion is primarily a winter phenomenon (15). Bangkok’s urban environment is particularly susceptible to this phenomenon, as it produces more atmospheric pollutants and has higher thermal masses than rural areas, resulting in more frequent inversions with higher concentrations of pollutants (16). This supports the relationship displayed in Figure 2.1, offering an explanation as to why Bangkok’s PM2.5 levels are highest during the winter.

Exacerbating the effects of thermal inversion is Bangkok's geographical setting of a low elevation area that is surrounded by hills. These factors allow thermal inversion to occur more frequently and intensely by allowing cold air to sink in and limiting the dispersion of pollutants (17). Taking into account the preceding information, one could speculate that thermal inversion may be more prominent in Bangkok than in Chiang Mai. If this is the case, it would shed light on why the average winter PM2.5 reading was higher in Bangkok than Chiang Mai (see Figure 2.1 and 2.2), although more extensive research is required to validate this claim.

Precipitation and Wet Deposition

During the wet season of both Chiang Mai and Bangkok, the PM2.5 readings were noticeably lower than that of other seasons. According to Duhanyan and Roustan, rainfall is recognized as one of the main natural processes to improve air quality. Through further analysis of related papers, it is found that rainfall typically reduces particulate matter in the atmosphere mainly via wet deposition which is separated into two main mechanisms (18):

Below-cloud Scavenging (BCS): In air quality modeling, BCS refers to the physical processes leading to the removal of pollutants, gasses, and particulate matter from the atmosphere by precipitating hydrometeors (raindrops, snowflakes, hailstones) (18). This is achieved by hydrometeors irreversibly collecting ambient pollutants in their path as they precipitate. The extent at which BCS occurs is dependent on multiple variables such as rain intensity, hydrometeor size, and collection efficiency (19).

In-cloud Scavenging (ICS): ICS occurs when aerosols act as cloud condensation nuclei and form cloud droplets or ice crystals which then grow and fall as precipitation or when aerosols collide with existing cloud droplets (19,20). In-cloud scavenging is particularly effective for removing smaller particles and aerosols from the atmosphere, including those in the PM2.5 size range (21). However, its effectiveness can vary based on local atmospheric conditions and the characteristics of the pollutants and particles present in the air (22).

Mountainous Terrain and Elevation

The topology of Bangkok and Chiang Mai differ largely due to the presence of mountains and high elevation in the northern region. Compared to the flat plains of Bangkok, Chiang Mai’s obstructive topography has an adverse effect on PM2.5 dispersion (23).

Valleys enclosed by mountain ranges are predisposed to experiencing episodes of stagnant air, particularly evident during instances of temperature inversions (24). In such scenarios, pollutants, encompassing

PM2.5, encounter hindered vertical mixing and subsequently accumulate in proximity to the earth's surface (14,15). Consequently, elevated concentrations of pollutants, including PM2.5, emerge within these valley areas (25).

On the windward side (upwind side), mountains operate as formidable barriers to the transit of air masses (26). As prevailing winds confront these geological features, their trajectory is compelled upwards, triggering the ascent of air and subsequent cooling of the atmosphere.

This process can lead to the entrapment and concentration of pollutants, including PM2.5, within valleys or on the windward side (17,27).

On the contrary, the leeward side (downwind side) of mountain ranges witnesses the descent of air that had earlier been compelled to ascend and cool on the windward side (27) .This downward airflow generates a downslope movement. This movement facilitates the dissemination of pollutants and PM2.5 away from the mountainous region. However, it also presents the possibility of these pollutants being transported and deposited in lower altitudes or valleys located on the leeward side (28,26).

Hence, the intricate terrain of mountains yields microclimates, wherein localized weather conditions diverge substantially between opposing sides of a mountain range. These microclimates foster diverse modes of PM2.5 dispersion and aggregation (27).

Even though mountains can lead to higher pollution within a certain vicinity, findings have shown that PM2.5 tends to decrease with increased altitude (29,30). Elevated locations may experience diminished PM2.5 levels due to reduced emissions and enhanced pollutant dispersion mechanisms (31). Conversely, lower elevations might encounter heightened concentrations due to local sources of pollution and constricted dispersion capabilities (23).

Proximity to the Sea and Sea Breeze

Proximity to the ocean is a significant factor that differentiates the topology of Bangkok and Chiang Mai. Resulting from the sea during the day, the coastal breeze is thought to have a positive effect on PM 2.5 dispersion. However, this may not always be the case, since the mechanisms and variables by which sea breeze occurs is nuanced (32).

Coastal breezes are a localized wind phenomenon influenced by variations in temperature between the adjacent land and sea. In daylight hours, the land undergoes more rapid heating than the nearby water, leading to the formation of a pressure gradient (Masselink & Pattiaratchi, 1998). This gradient prompts the movement of cooler air from the sea toward the land. As this maritime air advances inland, it can profoundly affect the dissemination of aerial pollutants, encompassing PM2.5 (23).

One of the most noteworthy consequences of coastal breezes on PM2.5 concentrations is their potential to scatter and dilute pollutants that accrue above urban regions. The cleaner sea air contributes to decreasing the overall volume of PM2.5 particles, culminating in an advancement of air quality and a decrease in health hazards among city residents (23). This affirmative influence becomes especially marked amid spells of elevated pollution, as coastal breezes furnish a natural mechanism for the elimination of pollutants (24).

Although coastal breezes can be advantageous in mitigating PM2.5 pollution, their impacts hinge upon numerous variables. Wind velocity, orientation, and atmospheric steadiness all wield a pivotal role in determining the efficacy of pollutant dispersal (32-34). In particular, the speed at which the sea breeze develops can be crucial in influencing dispersion. On the days where the sea breeze developed in a few minutes, the onset concentration of pollutants seemed to increase, while it appeared to decrease during gentle sea breeze episodes. (33). Fixed atmospheric conditions, for instance, can impede the full potential of coastal breezes, allowing pollutants to linger close to the ground (35). Furthermore, the timing of coastal breeze initiation is of significance; pollutants generated later in the day might not encounter the same degree of dispersion as those that are present during the initial inception of the coastal breeze (24,33,36).

In fact, some studies suggest that sea breeze circulation, particularly in mountainous environments, may exacerbate surface level air pollution (28,37). As summarized by Lu and Turco (1994), sea breezes induced by land–sea thermal contrast, as well as upslope winds induced along mountain flanks, both create vertical transport that can lead to the formation of elevated pollution layers

(26). Through undercutting the mixed layer and lofting pollutants into the stable layer, the sea breeze circulation creates pollution layers.

The COVID-19 Lockdown

The PM2.5 concentrations recorded in both the northern and central regions of Thailand experienced a notable decrease from the previous years during 2020 onwards (see Figures 3.1 and 3.2). The reduction in air pollution due to COVID-19 is a potential contributor to this relationship, as human activities, transportation, and industrial processes underwent significant changes due to the pandemic-related measures (38,39).

The implementation of lockdowns and travel restrictions had an immediate outcome: a notable decrease in the movement of vehicles and industrial operations (39,40). This drop in vehicular presence on roads and scaled-down industrial pursuits resulted in decreased emission of pollutants, encompassing precursors to PM2.5 like nitrogen oxides (NOx) and volatile organic compounds (VOCs) (41,42). As a result, a transient enhancement in air quality unfolded, coupled with a reduction in PM2.5 concentrations across diverse regions of Thailand, including urban centers such as Bangkok (43,44).

Various sectors, notably those tied to manufacturing and construction, underwent periods of deceleration or temporary cessation during the pandemic (38). This contraction in industrial activities contributed to a decrease in the release of pollutants, which in turn exerted a favorable influence on the quality of the air (45).

Concurrently, a dip in the demand for energy was evident. This decline in energy consumption led to diminished emissions stemming from sources like power plants and other energy-related installations, thus contributing to the enhancement of air quality. (46,47)

Amidst the decline in several sources of PM2.5 throughout the pandemic, Thailand's practice of agricultural burning persisted, though at a reduced rate (48). The limitations resulting from the pandemic might have potentially induced altered agricultural practices or a shift in timing, impacting the extent of crop burning. Contingent on local circumstances, this shift could have influenced the levels of PM2.5 in specific regions (49,50). As a result, periods of astronomically high periods of PM2.5 concentrations during the dry season in the latter years, recorded by monitoring stations, were more sparse and less intense.

Conclusion

This study aimed to correlate topographical, meteorological, and social factors to the variance in the actual PM2.5 measurements within the northern and central regions of Thailand as well as comparing and contrasting the extent and nature of these relationships. Previously, few studies have been conducted, using real PM2.5 readings as evidence, into the geographical factors that may influence these regions. Thus, this research assisted in filling this gap in knowledge by introducing real-world PM2.5 and analyzing it in accordance with the seasons and and year. The findings revealed that the summer was the only season in which Chiang Mai showed a considerable lead in PM2.5, with its other seasons falling very slightly behind that of Bangkok. The determining factor during the summer was most likely the prevalent biomass burning period in the northern region, but for the other seasons, Bangkok showed a slight lead due to the high ambient PM2.5 levels resulting from the industries and traffic in the megacity. In analyzing the topographical layout of Bangkok and Chiang mai, it was concluded that the flat, coastal area of Bangkok has better ventilation through sea breeze than Chiang mai's mountainous terrain, which serves as a barricade and, at times, a means of pollutant dispersion to peripheral areas. According to the findings, the wet season displayed the lowest average PM2.5 levels for both regions due in large part to a weather phenomenon whereby pollutants, including PM2.5, gets collected and washed away within the precipitating hydrometeors. Another weather phenomenon that impacted PM2.5 levels in both regions was temperature or thermal inversion, although the extent of this impact remained ambiguous, as it could not be concluded whether thermal inversion had had more of an effect in Chiang mai or Bangkok. However, thermal inversion is believed to have a profound impact on rising PM2.5 levels during the winter months.

Despite this, it is crucial to accept the fact that analyzing multiple variables across two vastly different cities provides an incomplete representation of the relationships they have with each other and with PM2.5 due to the lack of control variables. Since no single variable could be precisely attributed as the definitive cause behind a particular feature of the graphs, there is doubt casted on the extent in which each variable could affect PM2.5. Thus, future studies should focus on studying a wider range of cities so that the findings are more concrete and indicative of the truth. Nevertheless, the findings of this research is detrimental in paving the groundwork for future studies by providing an increased understanding between geopolitical determinants and real-world PM2.5 levels in the northern and central regions of Thailand. It is my sincere hope that the results of this study will be helpful for government officials, Thai citizens, or any other researcher in developing prevention or intervention methods regarding the pollution in these regions in order to foster a healthier environment for the humans living here

References

1. Pun VC, Kazemiparkouhi F, Manjourides J, Suh HH. Long-term PM2.5 exposure and respiratory, cancer, and cardiovascular mortality in older US adults. Am J Epidemiol [Internet]. 2017 [cited 2023 Sep 5];186(8):961–9. Available from: https://academic.oup.com/aje/article/186/8/961/3852285
2. Xing Y-F, Xu Y-H, Shi M-H, Lian Y-X. The impact of PM2.5 on the human respiratory system. Journal of Thoracic Disease [Internet]. 2016 [cited 2023 Sep 5];8(1):E69. Available from: http://dx.doi.org/10.3978/j.issn.2072-1439.2016.01.19
3. Lin G, Fu J, Jiang D, Hu W, Dong D, Huang Y, et al. Spatio-temporal variation of PM2.5 concentrations and their relationship with geographic and socioeconomic factors in China. Int J Environ Res Public Health [Internet]. 2013 [cited 2023 Sep 5];11(1):173–86. Available from: https://www.mdpi.com/1660-4601/11/1/173
4. Sirithian D, Thanatrakolsri P. Relationships between meteorological and particulate matter concentrations (PM2.5 and PM10) during the haze period in urban and rural areas, northern Thailand. Air Soil Water Res [Internet]. 2022;15:117862212211172. Available from: http://dx.doi.org/10.1177/11786221221117264
5. Gramsch E, Cáceres D, Oyola P, Reyes F, Vásquez Y, Rubio MA, et al. Influence of surface and subsidence thermal inversion on PM2.5 and black carbon concentration. Atmos Environ (1994) [Internet]. 2014;98:290–8. Available fromh90 0m pn http://dx.doi.org/10.1016/j.atmosenv.2014.08.066
6. Yang X, Zhang T, Zhang Y, Chen H, Sang S. Global burden of COPD attributable to ambient PM2.5 in 204 countries and territories, 1990 to 2019: A systematic analysis for the Global Burden of Disease Study 2019. Sci Total Environ [Internet]. 2021;796(148819):148819. Available from: http://dx.doi.org/10.1016/j.scitotenv.2021.148819
7. Collaud Coen M, Andrews E, Aliaga D, Andrade M, Angelov H, Bukowiecki N, et al. Identification of topographic features influencing aerosol observations at high altitude stations. Atmos Chem Phys [Internet]. 2018 [cited 2023 Sep 5];18(16):12289–313. Available from: https://acp.copernicus.org/articles/18/12289/2018/
8. Chuesaard T, Chetiyanukornkul T, Kameda T, Hayakawa K, Toriba A. Influence of biomass burning on the levels of atmospheric polycyclic aromatic hydrocarbons and their Nitro derivatives in Chiang Mai, Thailand. Aerosol Air Qual Res [Internet]. 2014;14(4):1247–57. Available from: http://dx.doi.org/10.4209/aaqr.2013.05.0161
9. Kayee J, Sompongchaiyakul P, Sanwlani N, Bureekul S, Wang X, Das R. Metal concentrations and source apportionment of PM2.5 in Chiang Rai and Bangkok, Thailand during a biomass burning season. ACS Earth Space Chem [Internet]. 2020;4(7):1213–26. Available from: http://dx.doi.org/10.1021/acsearthspacechem.0c00140
10. Arunrat N, Pumijumnong N, Sereenonchai S. Air-pollutant emissions from agricultural burning in Mae chaem basin, Chiang Mai province, Thailand. Atmosphere (Basel) [Internet]. 2018;9(4):145. Available from: http://dx.doi.org/10.3390/atmos9040145

11. ChooChuay C, Pongpiachan S, Tipmanee D, Deelaman W, Iadtem N, Suttinun O, et al. Effects of agricultural waste burning on PM2.5-bound polycyclic aromatic hydrocarbons, carbonaceous compositions, and water-soluble ionic species in the ambient air of Chiang-Mai, Thailand. Polycycl Aromat Compd [Internet]. 2022;42(3):749–70. Available from: http://dx.doi.org/10.1080/10406638.2020.1750436
12. Hays MD, Fine PM, Geron CD, Kleeman MJ, Gullett BK. Open burning of agricultural biomass: Physical and chemical properties of particle-phase emissions. Atmos Environ (1994) [Internet]. 2005;39(36):6747–64. Available from: http://dx.doi.org/10.1016/j.atmosenv.2005.07.072
13. Khamkaew C, the Environmental Science Program, Faculty of Science, Chiang Mai university, Chiang Mai, 50200, Thailand, Chantara S, Wiriya W, the Environmental Chemistry Research Laboratory (ECRL), Chemistry Department and the Environmental Science Program, Faculty of Science, Chiang Mai university, Chiang Mai, 50200, Thailand, the Environmental Chemistry Research Laboratory (ECRL), Chemistry Department and the Environmental Science Program, Faculty of Science, Chiang Mai university, Chiang Mai, 50200, Thailand. Atmospheric PM2.5 and its elemental composition from near source and receptor sites during open burning season in Chiang Mai, Thailand. Int J Environ Sci Dev [Internet]. 2016;7(6):436–40. Available from: Atmospheric_PM2.5_and_Its_Elemental_Comp20210801-9969-67kc8i.pdf
14. Mignot J, Lazar A, Lacarra M. On the formation of barrier layers and associated vertical temperature inversions: A focus on the northwestern tropical Atlantic: BLS IN NORTHWESTERN TROPICAL ATLANTIC. J Geophys Res [Internet]. 2012;117(C2). Available from: http://dx.doi.org/10.1029/2011jc007435
15. Hamamoto H, Yamano M, Kamioka S, Nishijima J, Monyrath V, Goto S, et al. Estimation of the past ground surface temperature change from borehole temperature data in the Bangkok area. In: From Headwaters to the Ocean: Hydrological Changes and Watershed Management - Proc of the International Conference on Hydrological Changes and Management from Headwaters to the Ocean, HYDROCHAN 2008. 2009. p. 535–9.
16. Rendón AM, Salazar JF, Palacio CA, Wirth V, Brötz B. Effects of urbanization on the temperature inversion breakup in a Mountain Valley with implications for air quality. J Appl Meteorol Climatol [Internet]. 2014;53(4):840–58. Available from: http://dx.doi.org/10.1175/jamc-d-13-0165.1
17. Zhang Y, Zhao T, Shu Z, Liang D, Fu W, Zhu Y. Attenuation of mountain-valley circulations on PM2.5 pollution over the western Sichuan basin, southwest China. Atmos Pollut Res [Internet]. 2023;14(7):101796. Available from: http://dx.doi.org/10.1016/j.apr.2023.101796
18. Duhanyan N, Roustan Y. Below-cloud scavenging by rain of atmospheric gases and particulates. Atmos Environ (1994) [Internet]. 2011;45(39):7201–17. Available from: http://dx.doi.org/10.1016/j.atmosenv.2011.09.002
19. Laakso L. Ultrafine particle scavenging coefficients calculated from 6 years field measurements. Atmos Environ (1994) [Internet]. 2003;37(25):3605–13. Available from: http://dx.doi.org/10.1016/s1352-2310(03)00326-1
20. Jones AC, Hill A, Hemmings J, Lemaitre P, Quérel A, Ryder CL, et al. Below-cloud scavenging of aerosol by rain: a review of numerical modelling approaches and sensitivity simulations with mineral dust in the Met Office's Unified Model. Atmos Chem Phys [Internet]. 2022;22(17):11381–407. Available from: http://dx.doi.org/10.5194/acp-22-11381-2022
21. Yang Y, Lin Q, Fu Y, Lian X, Jiang F, Peng L, et al. Stage-resolved in-cloud scavenging of submicron and BC-containing particles: A case study. Atmos Environ (1994) [Internet]. 2021;244(117883):117883. Available from: http://dx.doi.org/10.1016/j.atmosenv.2020.117883

22. Dingle AN, Lee Y. An analysis of in-cloud scavenging. J Appl Meteorol [Internet]. 1973;12(8):1295–302. Available from: http://dx.doi.org/10.1175/1520-0450(1973)012<1295:aaoics>2.0.co;2
23. Zhang K, Zhao C, Fan H, Yang Y, Sun Y. Toward understanding the differences of PM2.5 characteristics among five China urban cities. Asia Pac J Atmos Sci [Internet]. 2020;56(4):493–502. Available from: http://dx.doi.org/10.1007/s13143-019-00125-w
24. Bei N, Zhao L, Wu J, Li X, Feng T, Li G. Impacts of sea-land and mountain-valley circulations on the air pollution in Beijing-Tianjin-Hebei (BTH): A case study. Environ Pollut [Internet]. 2018;234:429–38. Available from: http://dx.doi.org/10.1016/j.envpol.2017.11.066
25. Silcox GD, Kelly KE, Crosman ET, Whiteman CD, Allen BL. Wintertime PM2.5 concentrations during persistent, multi-day cold-air pools in a mountain valley. Atmos Environ (1994) [Internet]. 2011; Available from: http://dx.doi.org/10.1016/j.atmosenv.2011.10.041
26. Lu R, Turco RP. Air pollutant transport in a coastal environment. Part I: Two-dimensional simulations of Sea-Breeze and mountain effects. J Atmos Sci [Internet]. 1994;51(15):2285–308. Available from: http://dx.doi.org/10.1175/1520-0469(1994)051<2285:aptiac>2.0.co;2
27. Zhang Z, Yang S, Jiang X, Qiao X, Xiang Y, Zhang D. DC flashover dynamic model of post insulator under non-uniform pollution between windward and leeward sides. Energies [Internet]. 2019;12(12):2345. Available from: http://dx.doi.org/10.3390/en12122345
28. Grossi P, Thunis P, Martilli A, Clappier A. Effect of Sea Breeze on air pollution in the greater Athens area. Part II: Analysis of different emission scenarios. J Appl Meteorol [Internet]. 2000;39(4):563–75. Available from: http://dx.doi.org/10.1175/1520-0450(2000)039<0563:eosboa>2.0.co;2
29. Hu W, Zhao T, Bai Y, Shen L, Sun X, Gu Y. Contribution of regional PM2.5 transport to air pollution enhanced by sub-basin topography: A modeling case over Central China. Atmosphere (Basel) [Internet]. 2020;11(11):1258. Available from: http://dx.doi.org/10.3390/atmos11111258
30. Ha H. Geographic variation in mentally unhealthy days: Air pollution and altitude perspectives. High Alt Med Biol [Internet]. 2017;18(3):258–66. Available from: http://dx.doi.org/10.1089/ham.2016.0137
31. Brakema EA, Tabyshova A, Kasteleyn MJ, Molendijk E, van der Kleij RMJJ, van Boven JFM, et al. High COPD prevalence at high altitude: does household air pollution play a role? Eur Respir J [Internet]. 2019;53(2):1801193. Available from: http://dx.doi.org/10.1183/13993003.01193-2018
32. Miller STK, Keim BD, Talbot RW, Mao H. Sea breeze: Structure, forecasting, and impacts: SEA BREEZE. Rev Geophys [Internet]. 2003;41(3). Available from: http://dx.doi.org/10.1029/2003rg000124
33. Di Bernardino A, Iannarelli AM, Casadio S, Mevi G, Campanelli M, Casasanta G, et al. On the effect of sea breeze regime on aerosols and gases properties in the urban area of Rome, Italy. Urban Clim [Internet]. 2021;37(100842):100842. Available from: http://dx.doi.org/10.1016/j.uclim.2021.100842
34. Simpson JE. A comparison between laboratory and atmospheric density currents. Q J R Meteorol Soc [Internet]. 1969;95(406):758–65. Available from: http://dx.doi.org/10.1002/qj.49709540609
35. Kristensen L, Jensen NO, Petersen EL. Lateral dispersion of pollutants in a very stable atmosphere—the effect of meandering. Atmos Environ [Internet]. 1981;15(5):837–44. Available from: http://dx.doi.org/10.1016/0004-6981(81)90288-2
36. Masselink G. The effect of sea breeze on beach morphology, surf zone hydrodynamics and sediment resuspension. Mar Geol [Internet]. 1998;146(1–4):115–35. Available from: http://dx.doi.org/10.1016/s0025-3227(97)00121-7
37. Clappier A, Martilli A, Grossi P, Thunis P, Pasi F, Krueger BC, et al. Effect of Sea Breeze on air pollution in the greater Athens area. Part I: Numerical simulations and field observations. J Appl Meteorol [Internet]. 2000;39(4):546–62.

Available from: http://dx.doi.org/10.1175/1520-0450(2000)039<0546:eosboa>2.0.co;2

38. Gupta V, Santosh KC, Arora R, Ciano T, Kalid KS, Mohan S. Socioeconomic impact due to COVID-19: An empirical assessment. Inf Process Manag [Internet]. 2022;59(2):102810. Available from: http://dx.doi.org/10.1016/j.ipm.2021.102810
39. Researchgate.net. [cited 2023 Sep 5]. Available from: https://www.researchgate.net/profile/Shohini-Roy/publication/343222400_ECONOMIC_IMPACT_OF_COVID-19_PANDEMIC/links/5fa1e11e92851c14bc036d68/ECONOMIC -IMPACT-OF-COVID-19-PANDEMIC.pdf
40. Zhang J, Hayashi Y, Frank LD. COVID-19 and transport: Findings from a world-wide expert survey. Transp Policy (Oxf) [Internet]. 2021;103:68–85. Available from: http://dx.doi.org/10.1016/j.tranpol.2021.01.011
41. Liu Z, Ciais P, Deng Z, Lei R, Davis SJ, Feng S, et al. Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nat Commun [Internet]. 2020;11(1). Available from: http://dx.doi.org/10.1038/s41467-020-18922-7
42. Rodríguez-Urrego D, Rodríguez-Urrego L. Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. Environ Pollut [Internet]. 2020;266(115042):115042. Available from: http://dx.doi.org/10.1016/j.envpol.2020.115042
43. Stratoulias D, Nuthammachot N. Air quality development during the COVID-19 pandemic over a medium-sized urban area in Thailand. Sci Total Environ [Internet]. 2020;746(141320):141320. Available from: http://dx.doi.org/10.1016/j.scitotenv.2020.141320
44. Wetchayont P. Investigation on the impacts of COVID-19 lockdown and influencing factors on air quality in Greater Bangkok, Thailand. Adv Meteorol [Internet]. 2021;2021:1–11. Available from: http://dx.doi.org/10.1155/2021/6697707
45. Chauhan A, Singh RP. Decline in PM2.5 concentrations over major cities around the world associated with COVID-19. Environ Res [Internet]. 2020;187(109634):109634. Available from: http://dx.doi.org/10.1016/j.envres.2020.109634
46. Abu-Rayash A, Dincer I. Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic. Energy Res Soc Sci [Internet]. 2020;68(101682):101682. Available from: http://dx.doi.org/10.1016/j.erss.2020.101682
47. Krarti M, Aldubyan M. Review analysis of COVID-19 impact on electricity demand for residential buildings. Renew Sustain Energy Rev [Internet]. 2021;143(110888):110888. Available from: https://www.sciencedirect.com/science/article/pii/S1364032121001829
48. Wetchayont P, Hayasaka T, Khatri P. Air quality improvement during COVID-19 lockdown in Bangkok metropolitan, Thailand: Effect of the long-range transport of air pollutants. Aerosol Air Qual Res [Internet]. 2021;21(7):200662. Available from: http://dx.doi.org/10.4209/aaqr.200662
49. Sonbawne SM, Devara PCS, Bhoyar PD. Multisite characterization of concurrent black carbon and biomass burning around COVID-19 lockdown period. Urban Clim [Internet]. 2021;39(100929):100929. Available from: http://dx.doi.org/10.1016/j.uclim.2021.100929
50. Kganyago M, Shikwambana L. Did COVID-19 lockdown restrictions have an impact on biomass burning emissions in sub-Saharan Africa? Aerosol Air Qual Res [Internet]. 2021;21(4):200470. Available from: http://dx.doi.org/10.4209/aaqr.2020.07.0470.