Millersville University of Pennsylvania

An Analysis of Particulate Matter 2.5 and Public Health in Mae Hong Son, Thailand Throughout the COVID-19 Pandemic and a Review of Air Quality Legislation

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With great thanks,

Keelie

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Abstract

Seasonal crop burnings, practiced in many areas of the world, release large amounts of particulate matter of size 2.5 microns (PM2.5) or under (PM2.5) into the air. Specifically, in areas throughout Southeast Asia, air quality is considered to be hazardous and even toxic during certain times of the year, in part due to these agricultural customs. This study focuses on relationships between seasonal crop burning practices and air quality, for the province of Mae Hong Son, Thailand. Monthly averages of air quality data (February through April) were obtained for Mae Hong Son from the National Resources and Environment Office to assess air quality trends for the area. Furthermore, a literature review was conducted to build an understanding of the effects of particulate pollution on public health, such as respiratory illnesses and mortality rates. Lastly, there was an inquiry into recent global legislation as it relates to air quality and what measures are being put in place to improve the quality specifically in regions such as Mae Hong Son. As an important note, the geographical region of Mae Hong Son was also analyzed in order to defend why this particular area was chosen as the focus of this paper.

1. Introduction

Recent air quality monitoring studies conducted by IQAir, over Southeast Asia, have found an association of moderate, poor, and hazardous air quality indices with seasonal crop burning. (IQAir Staff Writers, 2023). In Thailand, the fifty-seventh most polluted country in the world, crop burning is a major source of air pollution (IQAir Staff Writers, n.d.). In much of Southeast Asia, the burning period lasts from February through April, and these months correspond to the periods of highest air quality indices (IQAir Staff Writers, 2023). During this time, areas such as the Mae Hong Son province experience levels of PM2.5 exceeding 400 $\mu g\ m^{-3}$, which is considered “hazardous” on the AQI scale (IQAir Staff Writers, 2023).

Crop burning practices present environmental and public health concerns, yet these practices are continued as a cost-efficient and less labor-intensive process to clear farming fields for future planting. Although open biomass burning is illegal in farming practices in Thailand, it is still performed because alternative methods of vegetation removal are more expensive (IQAir Staff Writers, 2023). In addition to agricultural burning, rising industry and automobile use have strongly contributed to Thailand’s air pollution load.

To assess the air quality, an air quality index (AQI) chart is used to determine what level of pollutants are deemed safe or hazardous. The AQI is based on the five pollutants--particulates, nitrogen dioxide, carbon monoxide, ground-level ozone, and sulfur dioxide--for which the US National Ambient Air Quality Standards (NAAQS) are set. These standards represent the levels beyond which outdoor air pollution becomes illegal. To calculate the AQI, the percentage of each pollutant of the NAAQS at a particular moment in time is determined. The pollutant with the highest percentage becomes the value of the AQI (*AQI Basics | AirNow.Gov*, n.d.). Typically, an AQI chart is divided into six categories with each category corresponding to a different range of values and the health concerns associated with those values (*AQI Basics | AirNow.Gov*, n.d.).

Although the ranges of each category vary depending on the country's protocol, the categories remain the same: "Good", "Moderate", "Unhealthy for Sensitive Groups", "Unhealthy", "Very Unhealthy", and "Hazardous" (*AQI Basics | AirNow.Gov*, n.d.).

This paper includes air quality data collected before, during, and after the COVID-19 pandemic. Interestingly, there was no change seen in the level of air quality in Mae Hong Son across this period. It was to be expected that during the pandemic that air quality would improve in regions throughout the world due to quarantine periods and stay-at-home orders, but these data do not reflect a decrease in pollutants. Although the data do reveal a potential signal of the COVID-19 pandemic, further research is necessary to determine whether there is a connection between this air quality dataset and the pandemic.

In order to conduct an analysis of the air quality index experienced by the residents of Mae Hong Son, this paper looks to provide an overview of particulate pollution seen in the province due to its geographical location and practice of crop burning. Similarly, from 2020-2023, during the months of February through April, air quality indexes, taken every three hours, were collected to understand the fluctuations in surface PM2.5. This research looks to provide an understanding of how high levels of PM2.5 impact public health, as seen in Mae Hong Son, and further reaches to discuss how current legislation is promoting clean air.

Through this research, we looked for a change in the PM2.5 concentrations within this region during the COVID-19 pandemic, as we anticipated that there may be changes in the biomass burning due to the pandemic. We expected that if such changes existed, they may be motivated by an increased concern about the respiratory health of the Mae Hong Son population. This idea may provide some insight into the decision making behind the biomass burning practices.

2. Background

a. Particulate Matter 2.5 (PM2.5)

PM2.5 is a measurement estimating the concentration of small particles that have diameters less than or equal to 2.5 micrometers (O. US EPA, 2016). With particles of this size, they can be easily inhaled and penetrate deep into the lungs, there, they can potentially enter the blood stream and result in serious illnesses (O. US EPA, 2016). PM2.5 is considered a "fine particle" due to its small size and is commonly composed of sulfate-nitrate-ammonium and organic carbon ("Introduction to Aerosols," n.d.). PM2.5 enters the atmosphere from direct sources such as construction sites, fires, and unpaved roads. Other sources of PM2.5 come from reactions of common pollutants like sulfur oxide and nitrogen oxides emitted from cars, industries, power plants, and fires (O. US EPA, 2016). Due to its size, PM2.5 is transmissible across large areas because of atmospheric convection and aerodynamic size ("Introduction to Aerosols," n.d.). This means PM2.5 can be difficult to study and monitor; however, it is common to look at satellite derived products that are correlated to PM2.5 in order to begin to understand the concentrations experienced in certain parts of the world (*NASA - New Map Offers a Global View of Health-Sapping Air Pollution*, n.d.). Figure 1 highlights the fact that countries in

Northern Africa, the Middle East, and Southeast Asia experience air qualities worse than those in South America and Australia (*NASA - New Map Offers a Global View of Health-Sapping Air Pollution*, n.d.). It is important to note that the World Health Organization's (WHO) standard air quality of PM2.5 is recommended to be below a concentration of 10 μg m^{-3} and gives the consensus on the quality of air surrounding the globe.

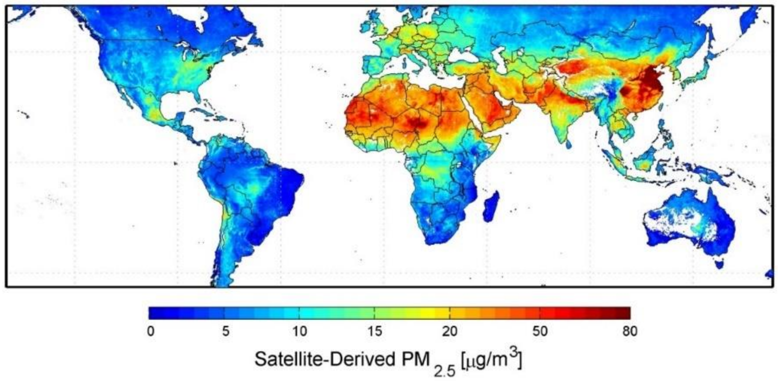

Figure 1 comes from NASA's aerosol optical depth observation and demonstrates the annual mean PM2.5 gathered using satellite observations (*NASA - New Map Offers a Global View of Health-Sapping Air Pollution*, n.d.).

PM2.5 poses great health risks to the public. Notably, PM2.5 can lead to premature death in those with underlying heart or lung disease and can cause severe asthma, irregular heartbeats, decreased lung function, and other respiratory symptoms (O. US EPA, 2016). When understanding how PM2.5 can affect the human respiratory system, it is necessary to highlight both the parts that are targeted and how PM2.5 infiltrates the human body. The human respiratory system is divided into two systems, the upper and lower airway passages (Figure 2). The upper airway passages include the nose and mouth along with the nasal passages from the pharynx to the larynx (Xing et al., 2016). The lower airway passages extend from the vocal cords to the end of every branch of the bronchial tree (Xing et al., 2016).

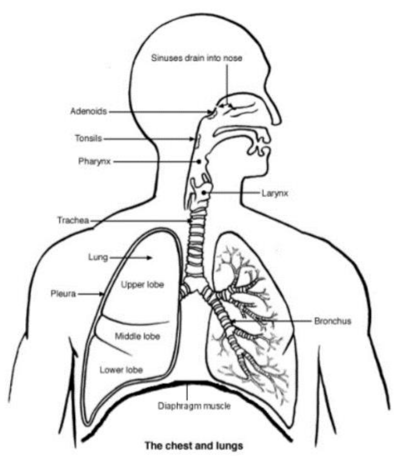

Figure 2 provides a visualization of the upper and lower airways of the respiratory system (Tidy, 2018).

Once particulate matter has entered the respiratory system, these particles can travel throughout the respiratory system by methods of interception, impaction, sedimentation, and diffusion, and if they are small enough, like PM2.5, the particles can penetrate the blood stream (Xing et al., 2016). Their size has a significant influence on their penetration depth. Upon entering the respiratory system, particulate matter that has a diameter greater than ten micrometers tends to settle in the nasopharyngeal region of the upper airway passages and will predominately impact the nose and throat, leading to coughing, sneezing, running nose, and other cold-like symptoms (Xing et al., 2016). However, particulate matter that has a diameter less than five micrometers and as small as 0.003 micrometers will settle in the tracheobronchial and alveolar regions, found in the lower region of the lungs (Xing et al., 2016). It is the smaller particulate matter that settles deeper into the human body that can influence the heart and lungs.

b. Air Quality Index

When discussing air quality, many studies have shown that mass concentration of a particular pollutant is not the most accurate depiction of whether the pollutant is harmful to human health (Lighty et al., 2000). This calls for other characteristics such as particle number, particle reactivity, and chemical properties to be considered. From epidemiological studies, classifications of air pollutants have been broken down into categories based on the previously mentioned characteristics, but these categories can become confusing and not clear to the general public (Lighty et al., 2000). In order to present a more simplified answer, the air quality index has been globally adapted to explain the air quality of a certain region.

The Air Quality Index (AQI) is a range of values 0 to 500 that assigns the level of air quality to the level of concern for human health (*AirNow.Gov*, n.d.). The AQI consists of six categories assigned to a specific color. These colors represent the hazardous conditions to health associated with the level of air quality. For example, higher values of AQI correspond to a greater health risk (*AirNow.Gov*, n.d.). The AQI uses information from ground-level ozone, particulate pollution (PM10 and PM2.5), carbon monoxide, sulfur dioxide, and nitrogen dioxide levels in order to create each level (*AirNow.Gov*, n.d.). In order to see the relation between AQI values and PM2.5 levels, some charts will include the corresponding PM2.5 levels with the designated AQI. These aerosols are monitored by many government and international organizations in order to determine the air quality safety of many regions of the world. Figure 3 is an example of an AQI chart used in the United States.

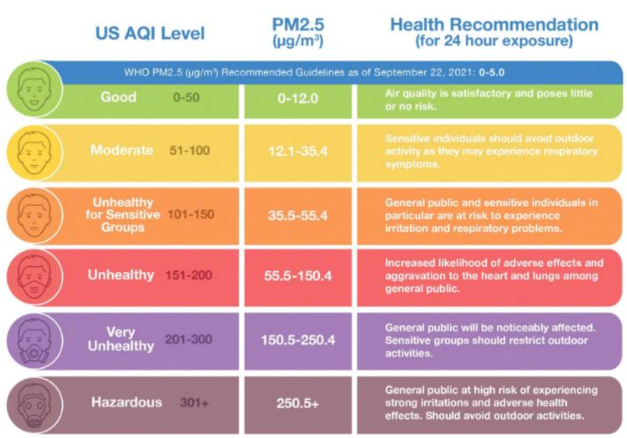

Figure 3 is an example of an AQI used within the US and throughout the world (*First in Air Quality*, n.d.).

Although this chart aligns with air quality regulations in the U.S., it is also used as guidance for the development of AQI charts in other countries (*First in Air Quality*, n.d.). Other countries, such as China, have greater margins between the different categories (Andrews, 2014). For example, and AQI of "good" in China consists of PM2.5 values ranging from 0 to 35 micrograms per cubic meter (Andrews, 2014). With these different metrics, misrepresentations of air quality events can happen. For the context of this paper, the U.S. AQI chart will be referenced since it closely aligns with current WHO standards (*AirNow.Gov*, n.d.).

c. Geographical Region of Mae Hong Son

Knowing what PM2.5 is and how the AQI works, it is necessary to discuss the geographical region of Mae Hong Son. Geographical features such as mountain ranges do have an important effect on the concentration of PM2.5 in a particular area (Berry, 2020). For example, mountain ranges can trap pollutants within the valleys and basins due to temperature inversions, which make it difficult for the pollution to disperse from the area. Mae Hong Son is a province located in the upper north-western region of Thailand (see Figure 4), sharing a border with the Shan State of Myanmar (Kliengchuay et al., 2018). Mae Hong Son is nicknamed to be "The City of Three Mists" due to its dewy winters, smokey summers, and misty rain seasons ("Mae Hong Son," n.d.). The northern region of Thailand is characterized by its numerous mountain ranges (see Figure 4), which act as blockades and allows for air pollution to settle within the valleys (*Mae Hong Son Air*, 2023). The province is densely forested with agriculture being the main source of revenue and pollutants for its residents (Kliengchuay et al., 2018).

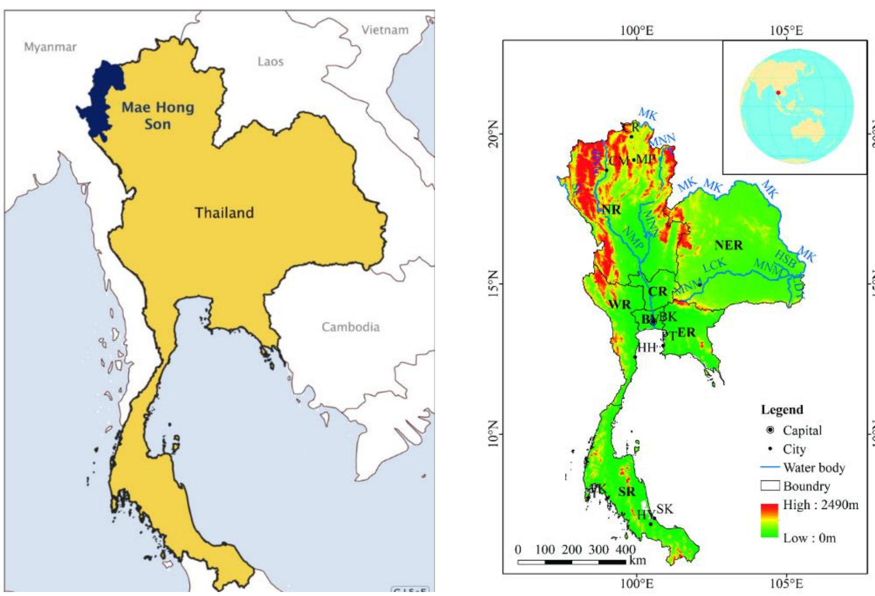

Figure 4: The image on the left is a map of Thailand, with the Mae Hong Son province highlighted in blue ("About Us," n.d.), and the image on the right is a topographic map of Mae Hong Son (Wang et al., 2022).

d. Seasonal Crop Burnings

Being separated from the larger cities of Thailand, such as Bangkok, leaves many residents suffering from poverty, which explains their low cost, yet illegal practice of open field burnings. Farmers in this area cannot afford to hire help to clear fields before the next harvesting season, making it more cost efficient and less laborious to burn the fields (IQAir Staff Writers, 2023). This process at the end of every harvesting season releases large amounts of pollutants into the planetary boundary layer (PBL), accounting for the spike in AQI during these periods. Agriculture in the area consists of pigeon pea stalks, cottons, rice, sugarcane, and maize crops, which regional farmers illegally burn through open burning practices. The burning season is tied to the worst AQI is experienced within the region from February through April (*Mae Hong Son Air*, 2023). Although this method is effective and efficient for clearing the crop fields given the poverty, the lasting effects on health have prompted air quality monitoring throughout the area (*Mae Hong Son Air*, 2023). Unfortunately, until there are better, cheaper alternatives for farmers, the practice of crop burning is expected to continue, worsening the air quality (IQAir Staff Writers, 2023).

3. Methods

To evaluate the quality of the air between 2019-2022, in Mae Hong Son, monthly averages of PM2.5 levels, which were collected by IQAir and Greenpeace, were used. These data identified which months experienced the highest levels of PM2.5. The data collected by these organizations are sourced from over 800,000 governmental air quality stations and low-cost sensors owned by scientists around the world (*Air Quality Reports Explained*, n.d.). In the case of IQAir, the data is accessible through their AirVisual Platform (*Air Quality Reports Explained*, n.d.). The months with the highest levels of PM2.5 were cross compared with the burning season. From this dataset, we identified that the highest levels of PM2.5 occur within the burning season of February through April, which is consistent with the biomass burning season of this region (Figure 5).

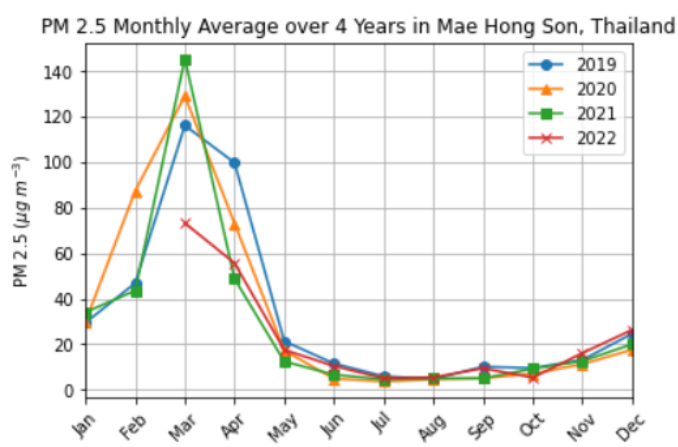

Figure 5 is a graph plotting the monthly averages of PM2.5 collected in Mae Hong Son, Thailand over the years of 2019 through 2022.

A second dataset was collected to study the spatiotemporal variations of PM2.5 at finer timescales. Using surface PM2.5 data collected at the National Resources and Environment Office in Mae Hong Son, Thailand, measurements from every three hours and occurring daily from February through April were compiled. This dataset spanned from 2020 to 2023 and was accessed through the Air Quality Explorer service (https://aqatmekong-servir.adpc.net/). Air Quality Explorer is a platform used by many governments and organizations in the lower

Mekong countries such as the Pollution Control Department (PCD), Geo-Informatics & Space Technology Development Agency (GISTDA), the Royal Forest Department/Department of National Parks, Wildlife and Plant Conservation, Rajamangala University of Technology Lanna, and the Northern Center for Solving Haze Problem and Forest Fire Control (*Air Quality Explorer*, n.d.). The Air Quality Explorer also allows a comparison of these surface values against various products derived from the National Aeronautics and Space Administration's (NASA) satellites and forecasting systems. For example, the Air Quality Explorer highlights products from the AQUA and TERRA satellites (*Air Quality Explorer*, n.d.). These polar-orbiting satellites host instruments such as the Visible Imaging Radiometer Suite (VIIRS), the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Air Quality Forecasts bias (*Air Quality Explorer*, n.d.). Together, the Air Quality Explorer synthesizes these datasets to provide a visual of historic and real-time observations of air quality and fires to support air quality forecast measures and aiding policymakers in developing air quality legislation (*Air Quality Explorer*, n.d.).

Gathered from satellite images, the severity of the air quality experienced during these months can be understood through the retrieval of aerosol optical depth (AOD). AOD is an estimate of the extinction of a light beam due to particles in the atmosphere blocking or scattering light (US Department of Commerce, n.d.). Taken from NASA's Earth Observing System Data and Information System (EOSDIS), AOD over the Mae Hong Son province at the beginning and ending of each month, February through April, was collected to sample the high levels of air pollutants, including PM2.5, being experienced over the region. The images were collected from the first day of the month with exceptions to February 2020 and March 2022 due to gaps in the satellite data. The color scheme represents the attenuation of light due to aerosols and has a logarithmic scale between 0-5. A higher AOD is seen through the richer colors, with the dark red colors indicating less than 1% of photons will reach the surface (*EOSDIS Worldview*, n.d.). This product is derived through a retrieval using MODIS observations between 0.4 to 14.5 micrometers (visible to thermal infrared) to generate values of AOD at a wavelength of 0.55 micrometers. This radiometric quantity is correlated with the concentration of PM2. (*Aqua Summary*, 2024).

The purpose of this data collection is to characterize the vast differences in air quality experienced monthly, daily, and every three hours as these open burnings continue to happen throughout the COVID-19 pandemic. As a whole, this data analysis and connection to public health aims to assess if clean air legislation is changing the narrative for residents of Mae Hong Son and, more broadly, the region of Southeast Asia.

4. Trends in Surface PM2.5 Concentrations

By analyzing the monthly averages from 2019-2022 (Figure 5), PM2.5 concentrations during the biomass burning season are still elevated with the months of February, March, and April experience some of the highest recorded levels of PM2.5 over the entire course of the year, so it becomes necessary to understand what levels of PM2.5 are being experienced during these months on a daily occurrence.

Looking at data collected by Air Quality Explore from the National Resources and Environment Office in Mae Hong Son, the dataset of PM2.5 used in this paper was collected every three hours daily throughout the months of February through April. The timescale corresponds to Indochina Time (ICT), which is seven hours ahead of Coordinated Universal Time (UTC). Furthermore, there were several times throughout the dataset that a PM2.5 level reading was missing. These times will create occasional discontinuities in the graphs.

In the year 2020, despite the COVID-19 pandemic intensifying, the month of March had the greatest number of instances of PM2.5 levels exceeding the “Hazardous” AQI (Figure 6). The end of February and beginning of April also recorded several “Hazardous” AQI. Over the course of the three months, 8:00 ICT proved to be the peak of PM2.5 levels for the day with a few days occurring at 5:00 ICT and 11:00 ICT. The lower levels of PM2.5 occurred consistently around 17:00 ICT with a few exceptions.

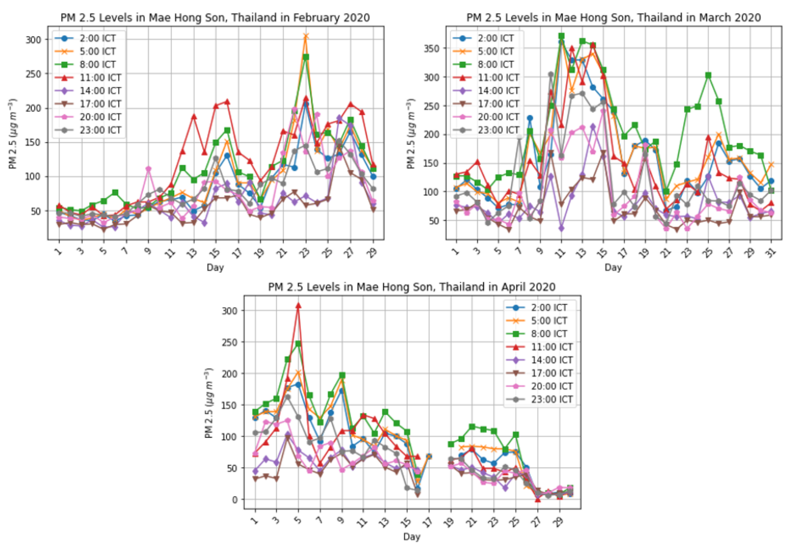

Figure 6 is a collection of graphs depicting the months February (top left), March (top right), and April (bottom center) from the year 2020 and their corresponding daily measurements (*Air Quality Explorer*, n.d.).

In 2021, similar PM2.5 trends occurred when compared to 2020 (Figure 7). March continued to have the greatest number of PM2.5 instances exceeding the “Hazardous” AQI with dangerous levels reaching about 400 AQI, but the times of peak levels of PM2.5 fluctuated monthly and daily. From the latter half of February through the middle of March and resuming at the beginning of April, 8:00 ICT, 11:00 ICT, and 14:00 ICT proved to be the times with the highest PM2.5 levels. In the other periods, the times were rather equivalent or closely different with the level of PM2.5.

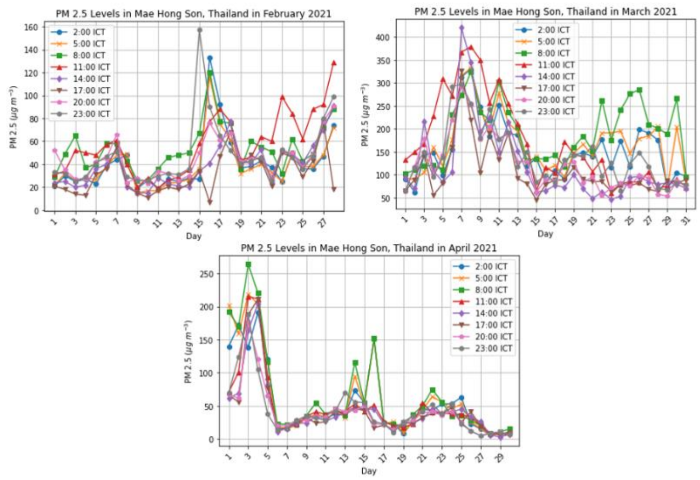

Figure 7 is similar to Figure 6 but for the year 2021 (*Air Quality Explorer*, n.d.).

In 2022, PM2.5 levels remained rather consistent throughout the day with only slight variations and a few outliers (Figure 8). An important note about the 2022 data is that the PM2.5 levels were significantly lower for the month of March and April when compared to 2020 and 2021. February's levels decreased from 2020 but were similar to 2021 except instead of the peak being early in the month it was at the end.

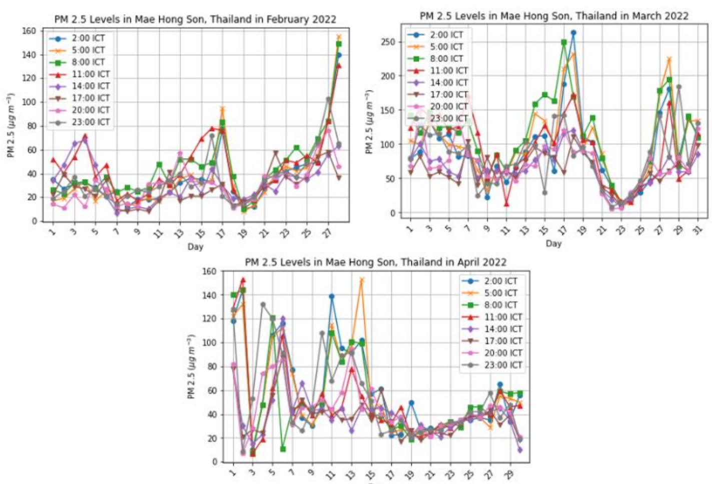

Figure 8 is similar to Figure 7 but for 2022 (*Air Quality Explorer*, n.d.).

In 2023, the months of February and April showed similar patterns experienced over the previous three years (Figure 9). Notably, March's peak of PM2.5 levels was achieved on the second to last day of the month at 11:00 ICT with an AQI of 599. An AQI of this value is considered toxic and beyond hazardous.

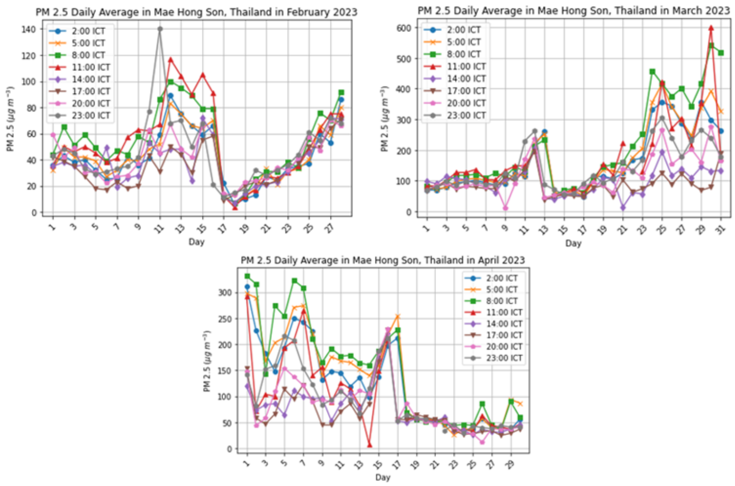

Figure 9 is similar to Figure 8 but for 2023 (*Air Quality Explorer*, n.d.).

After understanding the levels of PM2.5 being experienced over this four year period, at a single site, we wished to understand the spatial variations of pollution. By looking at the NASA AOD, we assessed how widespread the poor air quality was throughout the region. Through the progression of months, beginning in February and going through April, the widespread impact of biomass burning on air quality is clearly evident.

Looking at the satellite images from 2020 (Figure 10), the beginning of February showed an optically thin layer of aerosols covering the Mae Hong Son province with the AOD ranging between 0.165-0.170. When looking at the end of February, the range of AOD increased to 0.535-0.540. This progression demonstrates the onslaught of burnings that the buildup of air pollutants over the region. Looking at March, the AOD consistently ranges between 0.700-1.130 from the beginning to the end of the month, insinuating the severity of air quality being experienced at the surface. In April, the beginning of the month is like March, but by the end of April, the AOD is at 0, indicating the monsoonal shift to the rainy season.

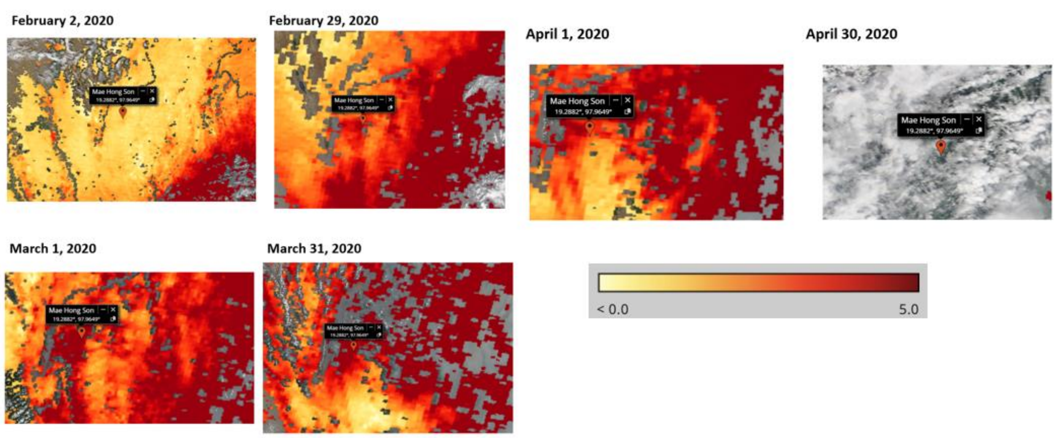

Figure 10 consists of the satellite images of February (top), March (middle), and April (bottom) from the year 2020 (*EOSDIS Worldview*, n.d.).

In the following year (2021), the satellite retrievals depict similarly high levels of AOD that are widespread to those gathered in 2020 (Figure 11). February begins with the AOD ranging between 0.180-0.185 throughout the region, but by the end of the month, this has increased to values between 0.700-1.130. The beginning of March experiences slightly lesser values of AOD ranging between 0.515-0.520, but as the month progresses and moves into April, the values remain consistent between 0.700-1.130 before reaching 0 at the end of April.

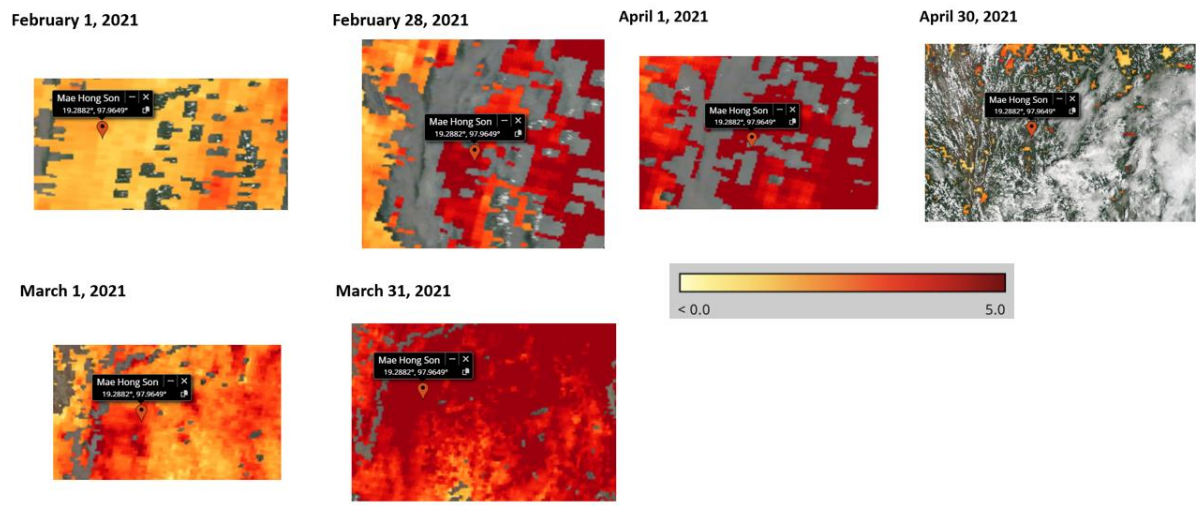

Figure 11 is similar to Figure 10 but for 2021 (*EOSDIS Worldview*, n.d.).

For the satellite images taken in 2022, the patterns of the AOD remain consistent with the previous two years, but the values of AOD were reduced (Figure 12). The AOD experienced in February is less than that experienced in the previous years. The beginning of the month experienced values between 0.070-0.075, and the end of the month experienced values between 0.410-0.415. The end of March 2022 has sparse regions of AOD values between 1.560-1.990, but the majority of the region is clear. The beginning and end of April are both sparse with areas of AOD ranging between 0.655-0.660.

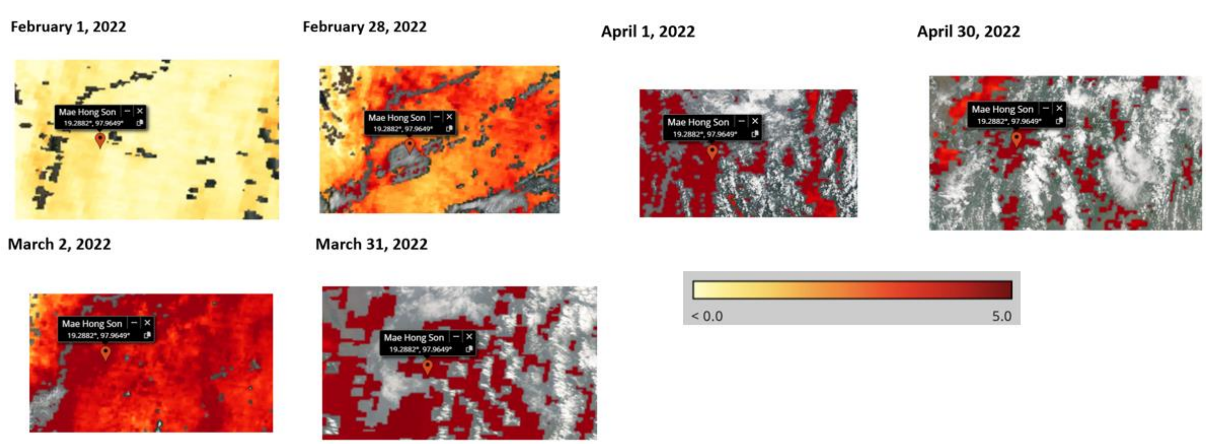

Figure 12 is similar to Figure 11 but for 2022 (*EOSDIS Worldview*, n.d.).

As for the year 2023, the AOD remained consistent with the pattern seen in 2022. The beginning of February had values ranging between 0.410-0.415. From the end of February until the beginning of April, the AOD ranged between 1.560-1.990, consistently over the region. At the end of April, the values slightly decreased to 0.700-1.130 (Figure 13).

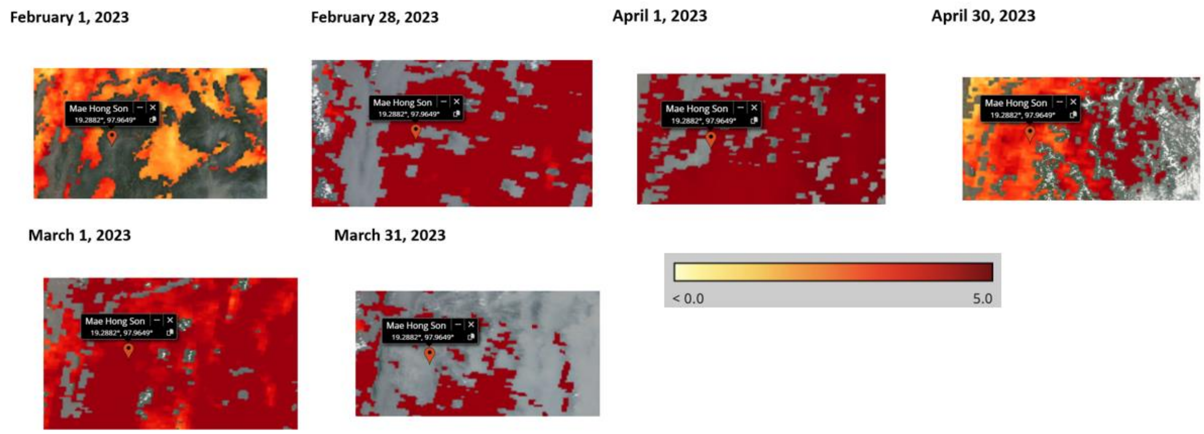

Figure 13 is similar to Figure 12 but for 2023 (*EOSDIS Worldview*, n.d.).

For the purpose of this paper, a statistical test was omitted from the data analysis due to the relationship between AOD data and how PM2.5 is derived from AOD data. This study of PM2.5 over Mae Hong Son intends to show a relationship between periods of dense AOD and high levels of PM2.5 readings, but it does not look to establish a statistical relationship between the two occurrences. As explored through several literature sources, periods of dense AOD do commonly correspond to periods of high PM2.5 levels, but it is important to understand that the limitations of MODIS's spatial and temporal scales do make this conclusion difficult; however, many studies have been able to look past these insufficiencies and still produce results that demonstrate a connection between the two. Yang et al., 2019 notes that this relationship between PM2.5 and AOD has been on the decline since 2014 with necessary upgrades needing to be made on MODIS. This insufficiency seen through "older" technology is something that can be fixed through the implementation of newer, more updated technology. This is further emphasized in other studies done by Zheng et al., 2017 and Zhang & Kondragunta, 2021. For the context of this paper, having both the satellite images of AOD and the surface measurements of PM2.5, the limitations of MODIS are outside the scope of the paper and, thus, are ignored in this context, but in the event of future research, improvements need to be made to the instrument in order to improve the correlation between AOD and PM2.5 back to the state it was at before 2014.

5. Discussion

The analysis of PM2.5 levels taken in Mae Hong Son demonstrates the severity of air quality experienced during February through March of each year as illegal crop burnings release large amounts of air pollutants into the air. In supporting the data, the satellite images, showing large values of AOD, further support the buildup of PM2.5 over the region. The colors of the satellite images also correspond nicely with the AQI chart colors, providing a full visual of the air quality being experienced by those in Mae Hong Son. Similarly, understanding how exceedingly high the levels of PM2.5 reach in the area, this only begins to question how human health is impacted on a daily basis and brings about the ideas of what living conditions are like.

In order to fully understand what the data represents and how it can be interpreted, a basic data description was conducted to highlight some key features of the data. For the year 2020, the lowest PM2.5 level was observed on April 27 at 11:00 ICT with a value of 1 µg m^{-3}, which is the lowest recorded value of all four years, which could demonstrate a signal from the COVID-19 pandemic, but further analysis would be required. The highest value was on March 14 at 8:00 ICT with a value of 355 µg m^{-3}. The lowest value is safely within a "Good" AQI, but the highest value exceeds the "Hazardous" PM2.5 level on the AQI chart by over 100 µg m^{-3}. February 23, March 14, and April 5 were the days each month with the greatest average of PM2.5. Figure 14 displays the data for February, March, and April.

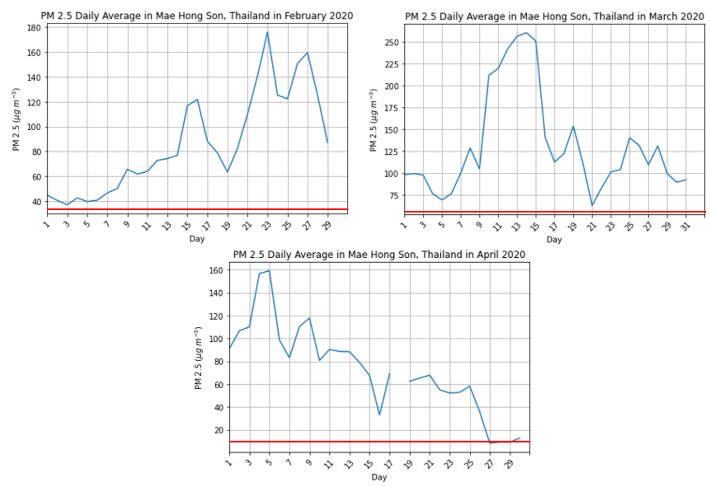

Figure 14 is a collection of graphs depicting the months February (top left), March (top right), and April (bottom center) from the year 2020 and their corresponding daily averages of surface atmosphere PM2.5 levels (*Air Quality Explorer*, n.d.). The red line indicates the WHO's standard air quality for PM2.5 concentration of 10 µg m^{-3}.

For 2021, the lowest PM2.5 level was observed on February 16 at 17:00 ICT with a value of 7 µg m^{-3}, and the highest value was on March 7 at 14:00 ICT with a value of 420 µg m^{-3}. The lowest value is safely within a "Good" AQI, but the highest value exceeds "Hazardous" AQI even more so than the highest value of 2020. February 16 and 28, March 7, and April 3 were the days each month with the greatest average of PM2.5. Figure 15 displays the data for February, March, and April.

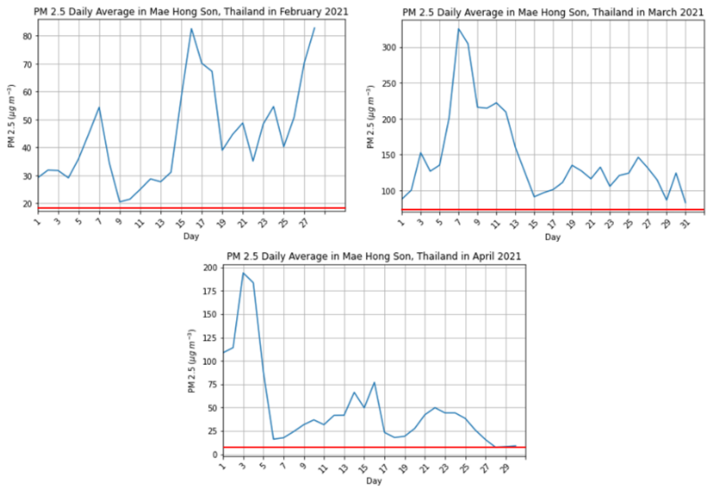

Figure 15 is similar to Figure 14 but for 2021. (*Air Quality Explorer*, n.d.).

For 2022, the lowest PM2.5 level was observed on March 22 at 20:00 ICT with a value of 5 $\mu g\ m^{-3}$, and the highest value was on March 18 at 2:00 ICT with a value of 263 $\mu g\ m^{-3}$. The lowest value is safely within a "Good" AQI, but the highest value slightly exceeds a "Hazardous" AQI. February 28, March 18, and April 1 were the days each month with the greatest average of PM2.5. Figure 16 displays the data for February, March, and April.

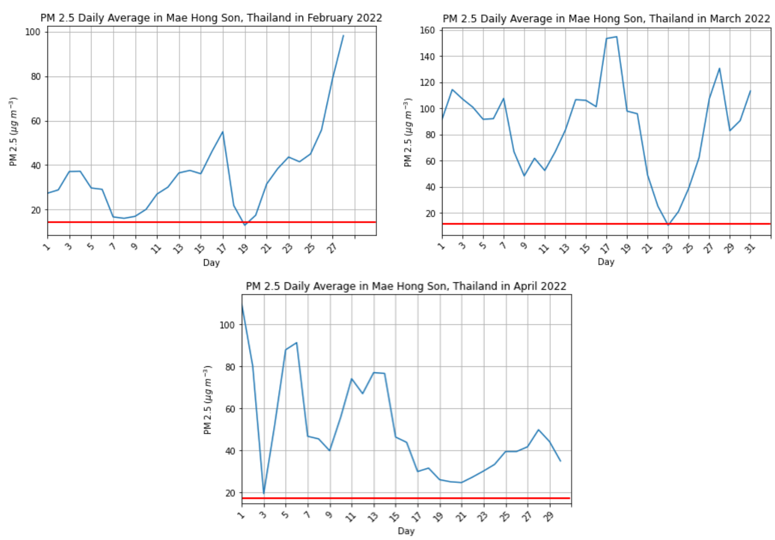

Figure 16 is similar to Figure 15 but for 2022 (*Air Quality Explorer*, n.d.).

For 2023, the lowest PM2.5 level was observed on February 18 at 11:00 ICT with a value of 4 $\mu g\ m^{-3}$, and the highest value was on March 30 at 11:00 ICT with a value of 599 $\mu g\ m^{-3}$ with the highest recording from all four years. The lowest value is safely within a "Good" AQI, but the highest value almost doubles the threshold for a "Hazardous" AQI. February 12, March 30, and April 1 were the days each month with the greatest average of PM2.5. Figure 17 displays the data for February, March, and April.

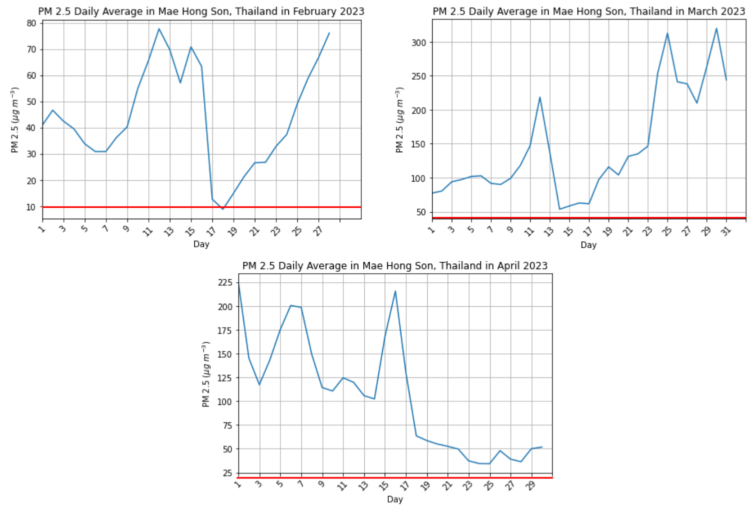

Figure 17 is similar to Figure 16 but for 2023 (*Air Quality Explorer*, n.d.).

This analysis serves to provide a connection between the AQI categories and the levels of PM2.5 experienced in Mae Hong Son, Thailand over the months February through April for the years 2020-2023. Furthermore, being able to associate the quantitative amount of PM2.5 to the qualitative description as presented in the AQI generates an ability to understand what is being discussed on days of poor air quality and allows for the public to assess the potential threat to their health.

Within the context of current events occurring during this period, this dataset contains air quality data from before, during, and after the COVID-19 pandemic, yet there does not seem to be much of a difference during the years of no global pandemic and during the year of quarantine and stay-at-home orders. Many have concluded that during the time the deadliest public health crisis was not COVID-19 but rather the air quality being experienced (Faulder, 2021). It was further expressed that comparing the health threats presented by COVID-19 compared to air pollution was like comparing apples to oranges, and this has allowed the level of air pollution to be deemed as a chronic problem throughout the region (Faulder, 2021). Reasons such as sacrifice for urban development, growing energy production, and the transition from an under-developed country to a developing country serve to explain why there is a lack of adequate clean air policies and why the threat to public health is overlooked (Faulder, 2021). Others have said that the air quality problem in Thailand, and Southeast Asia as a whole, is the "status quo," and adding COVID-19 to the mix created a "COVID + Air Pollution cocktail" that presented itself as an emergent issue that was ignored (Lawrence, 2020). Lawrence, 2020 further explains that "transboundary threats," defined as "invisible enemies" (i.e. air pollution), did not stop during the global lockdown, and because of this, deaths as a result from COVID-19 mixed with exposure to air pollution accounted for a 15% increase in the global COVID-19 death rate when exposed to PM2.5 (Lawrence, 2020). Although this statistic is not broken down further to highlight the deaths seen in Thailand, this does propose the hypothesis that if a person has contracted COVID-19 after being exposed to polluted air, then their chances of survival are decreased (Lawrence, 2020). Even after experiencing a global pandemic and not seeing significant any changes to air pollution, within this dataset, in Mae Hong Son demonstrates that lack of focus or attention required to reduce PM2.5 levels or improve air quality.

6. Implications

Having an overview of the quality of air experienced in Mae Hong Son, Thailand, this allows for a deeper understanding of how these high levels of PM2.5 affect human health. This section looks to analyze public health concerns, discuss the consequences of poor health care and the mortality rates associated with poor air quality, and how this applies to the larger region of Southeast Asia. The connection between the quantitative data and public applicability draws an important relationship between air quality and public health.

a. Public Health Concerns

As previously discussed, PM2.5 is related to many health concerns and can aggravate underlying conditions. PM2.5 is dangerous in the sense that it is small enough to penetrate deep into the lungs and can potentially enter the bloodstream under certain conditions. The severity of public health concerns should be separated into two categories: effects due to short-term exposure and effects due to long-term exposure. The differences exhibited by these two circumstances define the risk posed to human health.

Short-term air pollutant exposure is defined as experiencing high AQI on a certain day or series of days but not prolonged exposure (*Health Impacts of PM2.5*, 2020). A common health effect associated with short-term exposure is the irritation of the nose, eyes, ears, and throat (*Health Impacts of PM2.5*, 2020). Short-term exposure can lead to more severe health risks such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD) (*Health Impacts of PM2.5*, 2020). Although short-term exposure rarely leads to severe health effects, unless a person is experiencing underlying health conditions or is young or elderly, these effects still present public health concerns in areas such as Mae Hong Son, Thailand due to the lack of available medical care, so in this case, even short-term exposure can lead to unexpectedly severe side effects as time progresses and proper medical treatment is not received.

Long-term pollutant exposure is defined as experiencing high AQI levels for the entirety of a person's existence (i.e. their lifetime, approximated at 70 years) and is linked to many severe and fatal health conditions (R. 05 US EPA, 2023). As shown in Figure 18, illnesses such as respiratory diseases, lung infections, lung cancer, chronic heart disease, diabetes, and other health problems are only a few examples of the impacts PM2.5 can have on human health (*Health Impacts of PM2.5*, 2020). Statistics from 2019 and account for the global percentage of people who were exposed to dangerous air pollution levels, diagnosed with a health condition as a result, and were unable to recover from the illness. In context with Figure 18, air pollution was defined to consist of PM2.5, ozone, and household air pollutants (*Health Impacts of PM2.5*, 2020). Globally, PM2.5 is responsible for inducing chronic health conditions that ultimately lead to fatalities.

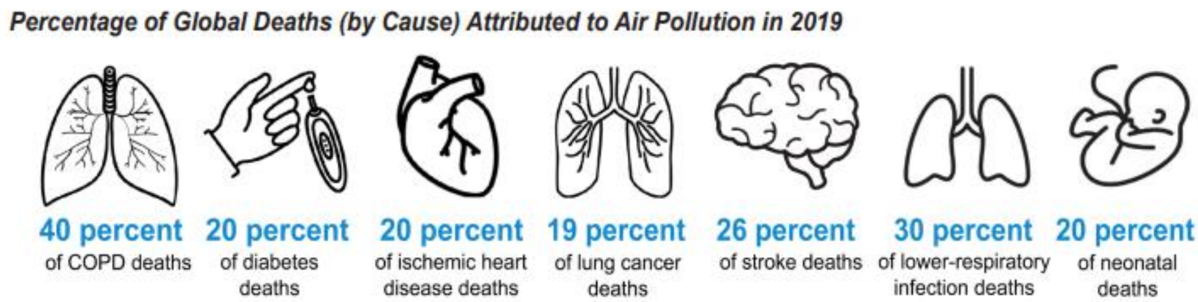

Figure 18 is a diagram depicting the percentage of deaths caused by air pollution induced chronic health conditions (*Health Impacts of PM2.5*, 2020).

Even though these illnesses are strongly linked to PM2.5, the metabolisms and antibodies of some people are strong enough to make a full recovery; however, this requires expert medical treatment, but it does not mean that PM2.5 has not posed a threat to health. Commonly, exposure to high levels of PM2.5 and other air pollutants will shorten a person's life expectancy, cause reproductive consequences, and impose neurological effects (*Health Impacts of PM2.5*, 2020). Exposure, especially long-term, to PM2.5 should not be taken lightly, and if symptoms progress, medical treatment is advised.

The health effects and risks of PM2.5 pose a great burden to society through its impacts on lifespan and the number of years lived with associated illnesses and the mortality rates, mostly occurring with long-term exposure (*Health Impacts of PM2.5*, 2020). Public concern fuels anxiety and nerves associated with what happens after being exposed to high levels of PM2.5 consistently, especially for infants, children, and the elderly. These concerns should drive citizens to fight for change and for the right of clean air, but instead, there is a steadfast nature to embrace the negative outcomes and live with the global burden that is unhealthy air quality.

b. Mortality Rates

In developing countries, the health effects of PM2.5 cannot always be treated due to the lack of sufficient health care. With this, mortality rates are high in areas suffering from poor air quality, especially in children, elderly populations, and those with underlying health conditions. Looking specifically at deaths in Thailand (see Figure 19), over the past thirty years, the Thai people have been exposed to unhealthy levels of PM2.5, resulting in large amounts of deaths annually. In Figure 19, the number of deaths is given per 100,000 people and has experienced a strong decline from the earlier half of this three-decade period. Although the annual deaths have decreased, there is still an alarmingly high number of deaths as a result of PM2.5. This sharp decrease beginning after 1998 is noted, but further research is needed in order to determine the cause of this sharp decline in deaths.

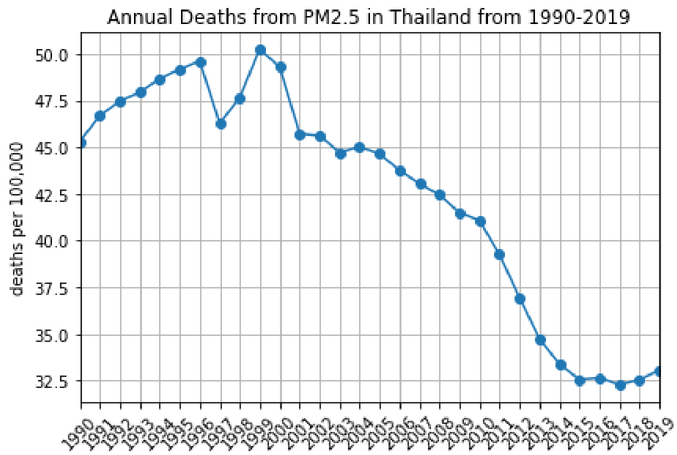

Figure 19 is a graph depicting the annual deaths from PM2.5 in Thailand from 1990 to 2019 (Berry, 2020).

In 2021, there were approximately 29,000 deaths due to the PM2.5 concentration across Thailand overshooting WHO's AQG (*Air Pollution Responsible*, 2022). The northern provinces of Thailand were six times the National Air Quality Standard and served as the location where most deaths occurred (*Air Pollution Responsible*, 2022). Although this is not the highest the mortality rate has been, if PM2.5 levels are not lowered, the life expectancy of Thai citizens will continue to decrease, and PM2.5 will continue to account for a significant portion of deaths each year.

Understanding the associated health risks with PM2.5 and the morbidity of these particles, concern is raised for the young and elderly. Specifically looking at the Mae Hong Son province, the remoteness of its mountain villages makes it difficult to receive adequate health care, and the burning seasons pollute the surface atmosphere to levels deemed as toxic by the WHO, but this does not stop the illegal burning practices.

c. Long-Term Effects for Southeast Asia

If no progress is made at improving air quality throughout Southeast Asia, environmental, health, and sustainability problems will continue to worsen (Abdul Jabbar et al., 2022). Southern Asia experiences the worst air quality worldwide due to unsustainable industrial practices, illegal burning practices, and hazardous economic and environmental practices (Abdul Jabbar et al., 2022). There is an urgent need to address the ongoing air quality crisis throughout Southeast Asia, and many have begun to devise plans of action to tackle the ongoing issue. Suggestions such as expanding air quality monitoring to rural areas, reducing industrial and agricultural waste, and optimizing the resources of private sectors to advocate across local, regional, and national jurisdictions are only a few means of improving air quality (*Urgent Action Needed*, 2022). Tackling the air quality problems in Southeast Asia is a complex, unilateral, multi-staged action requiring the unification of citizens, government, and scientists in order to improve air quality and promote more sustainable agricultural, industrial, and cultural practices.

7. Legislation Review

Policy development in the developing world has focused on activities within urban areas over the past two decades. For areas like Mae Hong Son, where agricultural practices are of more concern, there is a lack of governmental control for illegal open crop burning. An analysis of global and Thai legislation begins to build the picture of where air quality policy is now and where it will be going in the future. Although, there are many legislative pieces that discuss air quality and climate change, such as the Paris Agreement on climate change, there are simply too many to discuss individually, so this section will highlight a few key policies and their relation to air quality.

a. Global Policies

The 2019 Climate Action Summit hosted between the United Nations (UN), the World Health Organization (WHO), and the United Nations Environment Programme (UN Environment) was held on July 23, 2019 and called "…on national and subnational governments to commit to achieving air quality that is safe for citizens, and to align climate change and air pollution policies by 2030" ("United Nations Announces 2019," 2019). This initiative looked to implement policies for air quality and climate change governed by the WHO Ambient Air Quality Guideline (AQG) values and sustainability policies for the transport of emissions, defining vulnerable groups of people to provide financial and medical support, and track international progress through the Breathelife Action Platform ("United Nations Announces 2019," 2019). The goal of the Climate Action Summit was for social and political participants to commit to a healthier and safer future in terms of health and wellbeing; furthermore, the "call to improve air quality is part of a wider movement to harness social and political drivers to improve people's health, reduce inequities, promote social justice and maximize opportunities of decent work for all, while protecting the climate for future generations" ("United Nations Announces 2019," 2019). The Climate Action Summit called upon world leaders to reassess what is considered to be a healthy air quality and relied on factual support from greenhouse gas emissions, number of premature deaths resulting from air pollution, and highlighting mitigation efforts seen through national budgeting for cleaner air and health benefits ("United Nations Announces 2019," 2019). This discussion serves as the basis for future collaboration amongst international partners for the desperate need for cleaner air.

Specifically discussing PM2.5, from its initial standard set in 2005, WHO updated its AQG for PM2.5 due to the large impact air pollution is having on public health across the globe. This new standard came alongside many others set for the major contributors to air pollution. With this updated information, mean concentrations of PM2.5 are not to exceed 5 $\mu g\ m^{-3}$, which is half of the old standard of 10 $\mu g\ m^{-3}$ (Hoffmann et al., 2021). This change is the result of intensive air quality research that has occurred over the past two decades and strongly concluded that health effects of air pollution are serious and effect not only the respiratory system but all bodily organs (Hoffmann et al., 2021).

In order to hold accountability of nations, the first Global Assessment of Air Pollution Legislation (GAAPL) was conducted in September of 2021 to present air quality legislation of 194 countries and the European Union in accordance with the new AQG (*Regulating Air Quality*, 2021). The goal of this report is to emphasize the quality of governance required to uphold air quality standards in order to meet public health goals through developing legislation that "…integrates accountability, enforceability, transparency, and public participation" (*Regulating*

Air Quality, 2021). The greatest challenge uncovered by the GAAPL is the lack of legislation that provides a clear framework and systematic air quality monitoring, which prompted the development of the Sustainable Development Goals included in the GAAPL report (*Regulating Air Quality*, 2021).

These few examples of air quality legislation demonstrate that changes are occurring on the international and national level in order to improve air quality across the globe. There is significant work being done by the WHO along with the UN to understand the science being reported and implementing these findings into legislation in order to reduce the number of illnesses and deaths caused by poor air quality. As science progresses, more legislative reforms will continue to be reviewed, but the changes being seen at the international level are forcing nations to reevaluate their stance and contributions to lowering levels of key pollutants like PM2.5. Building this relation between air quality research, public health, and policy is one contribution to providing developed and underdeveloped areas with cleaner air, yet changes will not be significant without international collaboration and participation.

b. Thai Air Quality Policies

Legislative changes are also being implemented at the national level in Thailand. In 2019, the Royal Thai Government proposed the "Addressing the pollution problem (particulate matter) 2019-2024" national action plan, which sought for local authorities to address sources of air pollution such as open field burnings and factories (Kummetha, 2022). This document is considered a modern piece of legislation for the Thai government, but it lacks clear ways to implement methods for reducing air pollution. Furthermore, there is a demand, being fronted by humanitarian and international agencies, for Thailand to acquire a more powerful law regarding air quality and other humanitarian issues along with a new law enforcement body to uphold these policies (Kummetha, 2022). Although Thailand is making progress towards producing successful legislative pieces, the cultural differences between the urban and rural areas makes it difficult for law enforcement to uphold the policies. In the case of Mae Hong Son, which is comprised of mostly rural, mountain villages, it will not receive the same level of enforcement and doctrine necessary to improve air quality, especially when compared to city areas such as Bangkok. This is just one example of the challenges Thailand will face as new air quality legislation is drafted. Other challenges such as the lack of scientific advancement, in terms of air quality monitoring, and financial concerns also impede the process.

Thailand abides by the National Ambient Air Quality Standards, which are in alignment with the AQG set by WHO, but the majority of their environmental legislation is broad and does not specifically address one issue (Hoffmann et al., 2021). There is also a lack of education regarding air quality, how to prevent large levels of pollutants from entering the air, and the effects poor air quality has on health (Kummetha, 2022). However, non-profit organizations like Greenpeace and voluntary partnerships like Climate and Clean Air Coalition do provide information on air quality and educate citizens to understand the effects of poor air quality in order to drive a need for change. A common stance that many take is that clean air is a human right, and by understanding how to implement clean air practices, these organizations hope to achieve change in many developing and underdeveloped countries (*Air Pollution Responsible*, 2022). Yet, this change has not been effectively seen throughout the region.

The Thai government's insufficient attention towards cleaner air quality is consequential for not only the country but also for Southeast Asia. Air pollutants, and particularly PM2.5, can travel great distances, making this more than a Thai problem (Kummetha, 2022). A greater focus needs to be directed towards managing the sources of PM2.5 such as the field burnings, by enforcing the illegalness of their practice. Through this, Thailand and its citizens will begin to create a future of cleaner air and, eventually, reduce the number of illnesses and deaths from poor air quality.

8. Conclusion

Air quality has a significant impact on human health. Understanding the connection between high levels of PM2.5 and health risks presents an interesting argument for the safe practice of crop burning. By studying the Mae Hong Son province of Thailand, with its elevated PM2.5 levels in the months of February through April, it becomes clear that the illegal crop burnings are contributing large amounts of PM2.5 into the surface atmosphere. The AQI levels experienced in this region pose great concern for public health. Knowing the effects PM2.5 can have on health demonstrates the severity of the situation. Although PM2.5 commonly can cause cold symptoms, without receiving medical treatment, PM2.5 can cause long-term health problems and even death. The location of Mae Hong Son makes this study interesting due to its northern border being comprised of the Shan Hills high-mountain range, which contributes to the buildup of PM2.5.

After looking at PM2.5 yearly, monthly, and every three-hour daily recordings, the levels of PM2.5 exceed the recommended standards, set by organizations such as WHO, IQAir, and Greenpeace. Upon further analysis, some recordings almost double the hazardous level of PM2.5. Satellite images provide a great visual for understanding how PM2.5 blankets the surface atmosphere, making the air toxic and unbreathable. Furthermore, a simple data exploration reveals the daily averages of PM2.5 experienced and highlights other key details in the dataset.

Looking past what the data explains quantitatively, an analysis for what these PM2.5 levels mean for public health was assessed. Explaining the common symptoms and diseases associated with PM2.5 presents a range of severe consequences for short-term and long-term exposure to PM2.5. Similarly, mortality rates from Thailand were looked at to provide a figure to the number of deaths per year due to PM2.5.

Lastly, international and Thai legislation was reviewed to see what is being done about poor air quality. As international legislation has continued to evolve and heighten restrictions on burning practices, agriculture, industry, and economics in order to reduce air pollution, the Thai government has remained rather unresponsive to the issues. Instead of enforcing legislation, Thai laws do not provide a clear regulatory standard for air quality, and instead, these documents remain unclear what Thailand's stance on air quality is, their efforts to improve air quality, and what should be done about illegal crop burnings.

All in all, this paper provides insight to how air quality and public health are related in Mae Hong Son, Thailand. There is a lot that needs to be done regarding air quality and levels of PM2.5 at this location and Southeast Asia as a whole. By developing an understanding for the severity of health impacts PM2.5 can cause, the hope that others will realize their rights to clean air and advocate against practices that harm the environment and release toxic levels of pollutants into the atmosphere. In addition to the recommendation for advocating for clean air, this paper presents a unique perspective by conducting a literature review of air quality legislation and calls for the public to become aware of their country's laws and regulations regarding air quality. Sympathetically, there needs to be greater response and mitigation efforts given the amount of PM2.5 released into the atmosphere and a broadened awareness for the quality of air that is being experienced across the globe.

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