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Article

Perspective On Air Quality Problems from Particulate Matter to the Health Crisis in Mainland Southeast Asia

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Abstract: Air pollution, notably particulate matter pollution, has arisen as a serious concern in Southeast Asia in recent decades. The combustion of biomass is recognized to have a substantial impact on reducing air pollution in this area. Consequently, its effect on people in this area is significant. In this research, we synthesized several datasets from satellites, global emission, global reanalysis, and Global Burden of Disease (GBD) to give and emphasize the air quality issue forward to the health crisis in mainland Southeast Asia. We found that Individual death rates have increased significantly along with rising biomass-burning emissions in mainland Southeast Asia over the last two decades. Between 2000 and 2019, most countries had a considerable increase in the predicted fatality rates associated with chronic respiratory illnesses. In a handful of countries, death rates have decreased marginally between 2010 and 2019. Several reports highlight the continued prevalence of chronic respiratory diseases that are likely related to poor air quality in Southeast Asia.

Keywords: air quality; Southeast Asia; PM2.5; public health; particulate matter

1. Introduction

The prevalence of fine particulate matter is a significant contributor to the degradation of air quality, a growing concern in numerous regions across the globe. Particulate matter with a diameter of less than 2.5 mm is commonly referred to as fine particulate matter, or PM2.5. The particles possess the ability to penetrate deeply into the lungs and bloodstream owing to their microscopic size, thereby leading to a diverse range of detrimental impacts on human health [1]. The study conducted by Pope et al. [2] in the United States found that prolonged exposure to $PM_{2.5}$ pollution, even at concentrations lower than the current air quality regulations set by the federal government, was associated with an increased risk of mortality due to lung cancer. A recent study conducted by Liu et al. [3] in China has established a correlation between inhaling $PM_{2.5}$ pollution and increased susceptibility to stroke. In addition, Carey et al. [4] found prolonged exposure to $PM_{2.5}$ in the United Kingdom was associated with an increased likelihood of mortality resulting from cardiovascular disease. While Atkinson et al. [5] found that there was a positive correlation between short-term exposure to PM_{10} and an increased probability of hospitalization due to cardiovascular disease in London.

In Southeast Asia, the matter of air pollution caused by biomass burning is a pressing concern for both public health and the environment, with significant consequences, as noted by Amnuaylojaroen et al. [6,7]. Biomass burning refers to the process of combusting organic matter, such as trees and crop residues, for agricultural purposes. In mainland Southeast Asia, burning biomass is a common practice. It is extensively used in rural regions for a variety of functions, including land clearance, cooking, and heating (Amnuaylojaroen et al. [8]. According to Keywood et al. [9], the release of fumes and particulate

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matter from biomass burning can have significant effects on air quality, human health, and ecology. Several studies have shown that biomass combustion is a significant contributor to elevated levels of fine particulate matter ($PM_{2.5}$) in mainland Southeast Asia, resulting in air pollution. Also, PM2.5 concentration in the mainland Southeast Asia tend to be increase in the future [10]. During the dry season, biomass-burning emissions were shown to be responsible for as much as 70% of $PM_{2.5}$ concentrations. Furthermore, scientific investigations have demonstrated that emissions from biomass burning can have major effects on the environment, including climatic changes and ecological deterioration [11]. At the same time, Nhung et al. [12] discovered that inhaling $PM_{2.5}$ from biomass burning relates to increased sensitivity to respiratory and cardiovascular disorders in rural Vietnamese households. According to the study, greater exposure to $PM_{2.5}$ is associated with a 69% and 29% increase in the likelihood of hospitalization for respiratory and cardiovascular disorders, respectively.

Air pollution has detrimental effects on health because it has been identified as a primary cause of death from stroke, heart disease, and respiratory diseases [13]. Certain demographic groups, including children, the elderly, and individuals with pre-existing health conditions, have been found to be particularly vulnerable to the negative effects of $PM_{2.5}$ pollution [7,14,15]. This form of pollution possesses the capability to exacerbate their symptoms and lead to grave health ramifications. Previous studies have underscored the significant impact of $PM_{2.5}$ pollution on the health and welfare of individuals residing in mainland Southeast Asia, as noted by Sun et al. [16]. The conditions encompass an increased vulnerability to cardiovascular and respiratory disorders, cognitive decline, adverse pregnancy outcomes, elevated cancer risk, and mental health complexities. The discoveries mentioned above emphasize the importance of prioritizing the reduction of air pollution as a public health concern in the region. This involves implementing regulations that aim to reduce emissions and improve air quality. Several research studies have been carried out to investigate the impact of fine particulate matter on human health in mainland Southeast Asia. Chankaew et al. [17] conducted a study in Thailand and found that there appears to be a correlation between the occurrence of asthma exacerbations and the high PM2.5 season. According to the findings of Nhung et al. [18] research conducted in Vietnam, there exists a positive association between exposure to PM2.5 and the probability of developing cardiovascular disease.

The investigation pertaining to the issue of air quality and its impact on human health in Southeast Asia is not new. Despite the existence of various studies on the correlation between air quality and its effects on human health in Southeast Asia, no tangible measures have been taken to address this issue in the region. Understanding the fundamental factors that contribute to the issue of air quality and exploring feasible solutions to mitigate its impact on human health and the environment is of utmost importance. The present article aims to provide a perspective on the issue of air quality concerns related to particulate matter over the last decade. Additionally, it seeks to highlight the critical impact of air quality issues on human health in the region. The endeavor at hand is of significant magnitude and will require a considerable amount of time to attain a mutually agreeable outcome for all parties involved, including governmental representatives, regional administrations, indigenous hill-dwelling groups, and the broader populace. From our standpoint, it is imperative to emphasize the necessity of implementing measures aimed at addressing the problem of particulate matter (PM) pollution in mainland Southeast Asia. This entails the execution of strategies targeted at mitigating emissions stemming from biomass combustion and associated origins. Furthermore, it is imperative to augment public knowledge and instruction concerning the health ramifications of air pollution.

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2. Air Quality in the Mainland Southeast Asia

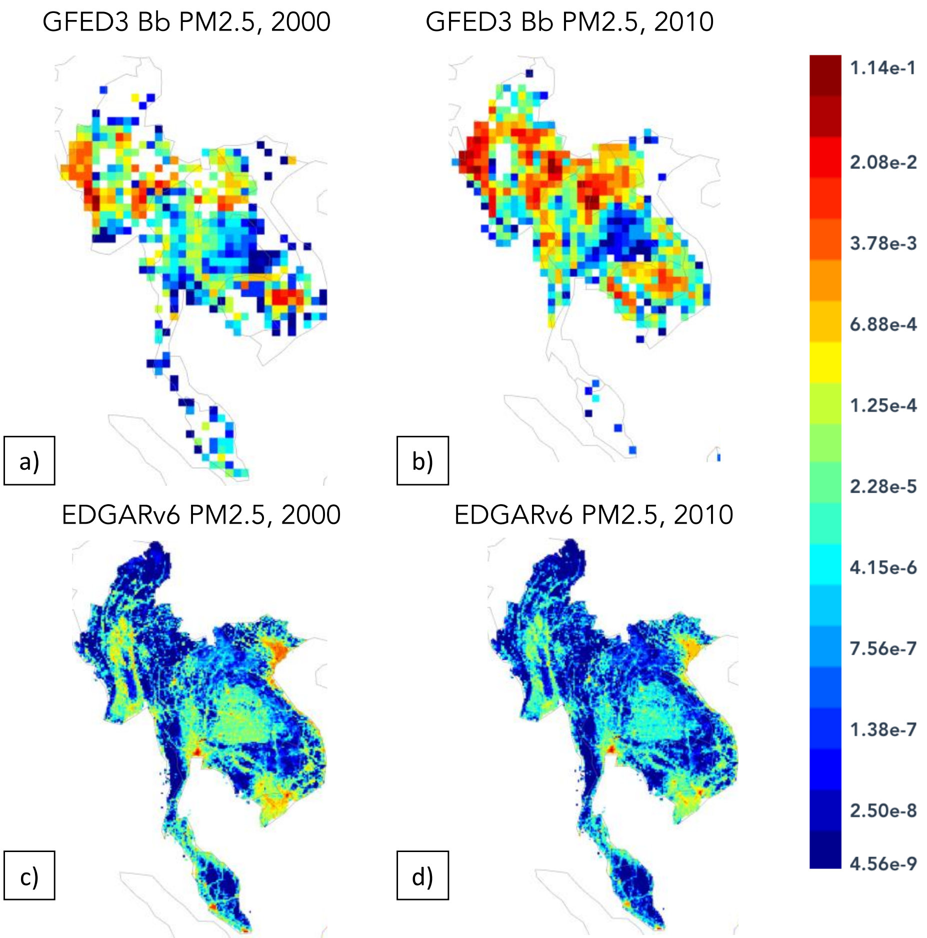

Figure 1. Spatial distribution of PM2.5from biomass burning emission from GFED in a) 2000, and b) 2010, and from anthropogenic emission from EDGARv6 in c) 2000 and d) 2010.

Ramanathan et al. [19] have extensively discussed the topic of air pollution in Southeast Asia, particularly over the continent, for several decades. Similar to air quality concerns in other global regions, the origins of $PM_{2.5}$ in this locality can be generally classified into two categories: anthropogenic sources, which include discharges from industrial activities and transportation, and biomass burning emissions, such as the uncontrolled combustion of agricultural waste and forest fires. Amnuaylojaroen et al. [20] and Duc et al. [21] have reported the observation of pollutant peak periods, particularly with respect to particulate matter, during the dry season, specifically from February to April. According to Amnuaylojaroen et al. [8], emissions from biomass burning, notably those resulting from agricultural and forest fires, have a considerable influence on $PM_{2.5}$ pollution in the region. Particulate matter (PM) released through the process of biomass combustion has a significant impact on the atmosphere, both directly and indirectly, by altering the level of atmospheric radiation [22]. According to Bond et al. [23], biomass burning is a substantial source of fine particulate matter ($PM_{2.5}$) accounting for 41% and 74% of the world's total primary black carbon and organic carbon emissions, respectively [24,25]. The emission data plot of $PM_{2.5}$ is presented in Figure 1, which encompasses both anthropogenic sources from the Emissions Database for Global Atmospheric Research version 6 (EDGARv6) [26] and natural sources from the Global Fire Emissions Database version 3 (GFED3) [27]. The EDGAR and GFED database provide comprehensive information on emissions, including national amounts and grid maps at a resolution of 0.1 and 0.25 degrees for EDGAR and GFED, respectively on a global scale. The data is available for

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various timeframes, ranging from yearly to monthly and even hourly intervals. The data presented illustrates the annual distribution of emissions resulting from biomass burning in mainland Southeast Asia during the years 2000 and 2010. The research findings indicate that there is a significant rise in biomass burning emissions in the mainland Southeast Asia area, in comparison to anthropogenic emissions. Compared to the year 2000, there was a significant rise in biomass burning emissions up to 0.0208 Tg, with a specific focus on the areas of Myanmar, Laos, and the northern part of Thailand.

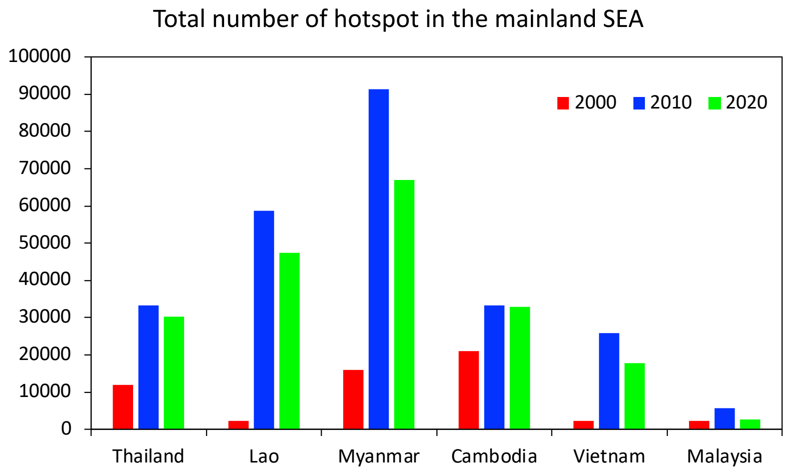

Figure 2. Total number of hotspot of countries in the mainland Southeast Asia in year 2000, 2010 and 2020.

Biomass burning in Southeast Asia is substantially related to fire emissions [28]. In recent decades, there has been a significant rise in biomass burning caused by fires in multiple countries across Southeast Asia [29]. The data from the VIIRS Moderate Imaging Spectroradiometer (MODIS) [30] provides information on the number of fire hotspot locations in various countries, including Thailand, Laos, Myanmar, Cambodia, Vietnam, and Malaysia, for the years 2000, 2010, and 2020 (Figure 2). Based on data obtained in the year 2000, it was observed that Cambodia had the highest number of hotspots, which amounted to 21,077, while Vietnam had the lowest number of hotspots, with a count of 2,293. Over the course of the following two decades, there was significant fluctuation in the number of hotspots detected across different countries. Myanmar witnessed a substantial escalation in the number of hotspots, exhibiting a surge from 15,992 in 2000 to 91,388 in 2010, indicating a remarkable growth of 471%. However, there was a significant decrease in the growth rate of the aforementioned phenomenon in the following decade. As of 2020, the number of hotspots only increased to 66,989. The number of hotspots in Laos underwent a substantial surge, exhibiting a remarkable increase of 2,383% from 2,363 in 2000 to 58,684 in 2010. The region under consideration witnessed a notable slowdown in the growth rate of hotspots during the following decade, akin to Myanmar. This led to a modest rise in the number of hotspots to 47,331 by 2020. During a period of twenty years, Thailand demonstrated a relatively consistent number of hotspots, with a slight decrease from 33,368 in 2010 to 30,234 in 2020. Cambodia and Vietnam underwent a decrease in the number of hotspots over a period of twenty years. Vietnam experienced a significant reduction in the number of hotspots, decreasing from 2,293 in 2000 to 17,821 in 2020. Over the course of three years, Malaysia demonstrated the smallest number of hotspots in comparison to the other five countries. In Southeast Asia, biomass burning is relatively associated with fire emissions [20]. Vadrevu et al. [31] investigated the association between fires and precipitation in Southeast Asian countries, finding that precipitation had a high negative correlation with fire numbers. Furthermore, recent research indicates that the majority of the fires in this region are caused by humans. Forests are set on fire for a variety

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of reasons, including inducing the growth of new grass for grazing, clearing the land for farming, such as cutting and igniting, obtaining minor forest goods such as honey, palatable, and foliage, hunting wild animals, and residue from crops burning in agricultural areas [32–35].

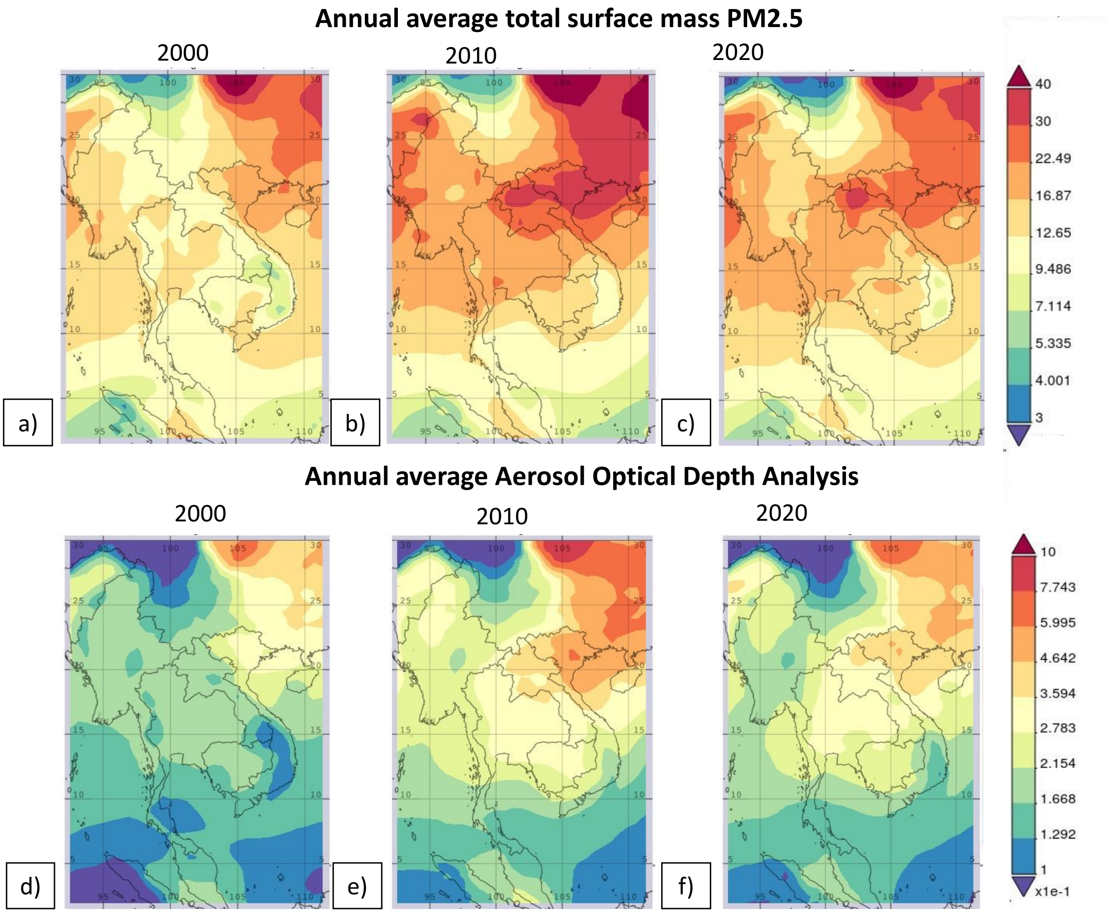

Figure 3. Spatial distribution of surface mass $PM_{2.5}$ in a) 2000, b) 2010, and c) 2020, and aerosol optical depth in d) 2000, e) 2010 and f) 2020 in the mainland Southeast Asia.

The spatial distribution of surface mass $PM_{2.5}$ and aerosol optical depth in mainland Southeast Asia for the years 2000, 2010, and 2020, as obtained from MERRA [36], is depicted in Figure 3. According to the MERRA reanalysis data, heightened levels of $PM_{2.5}$, ranging from 16 to 22 μg/m^3, were detected in the year 2000 in a number of countries, such as Thailand, Myanmar, and Lao. The years 2010 and 2020 witnessed a significant rise in $PM_{2.5}$ levels, which ranged from 22 to 40 μg/m^3. A marginal reduction in the $PM_{2.5}$ concentration was observed in several regions of Myanmar, Thailand, and Laos during the year 2020. The spatial distribution of Aerosol Optical Depth (AOD) showed a similarity to the distribution of $PM_{2.5}$ concentration, as illustrated in Figure 4d–f. The incidence of AOD demonstrated an increasing pattern in various countries, such as Myanmar, Lao, and Thailand, between 2010 and 2020, as opposed to the year 2000. The heightened levels of $PM_{2.5}$ concentration in this locality can be ascribed to the increase in hotspot and biomass-burning emissions. The distribution of air quality, especially during dry season is dominated by Asian Winter Monsoon [20]. From November to March, the Asian Winter Monsoon circulates air from the Asian continent to the oceanic. In March, the winds reached the northern region of Thailand via two primary paths. The primary channel is distinguished by winds traveling from eastern Asia into Laos and the northern part of Thailand, while the additional channel is distinguished by winds moving from Myanmar and enter the northern part of Thailand from the northwest. These circulation patterns transport and distribute trace gases and aerosols released by biomass burning in this region [20].

3. Health Effect of Poor Air Quality

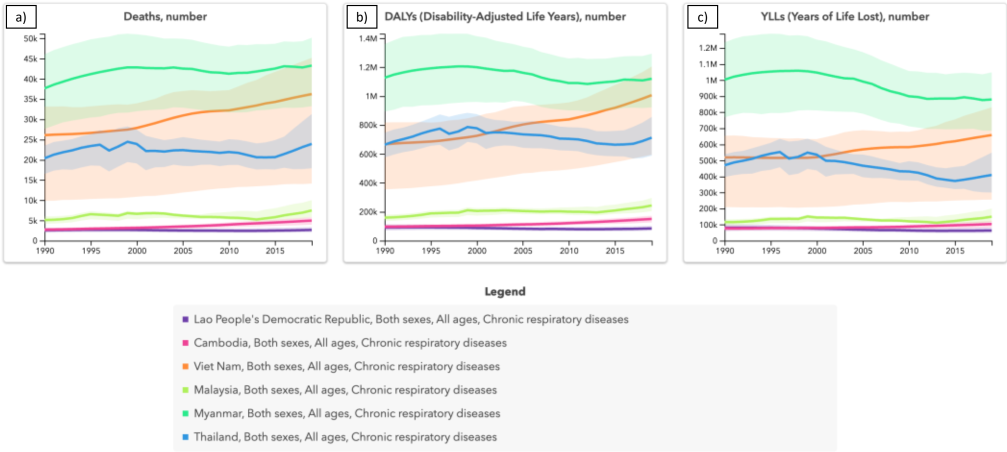

Figure 4. Number of a) death b) disability adjusted life years, and c) years of life lost in the mainland Southeat Asia from chronic respiratory disease during 1990–2019.

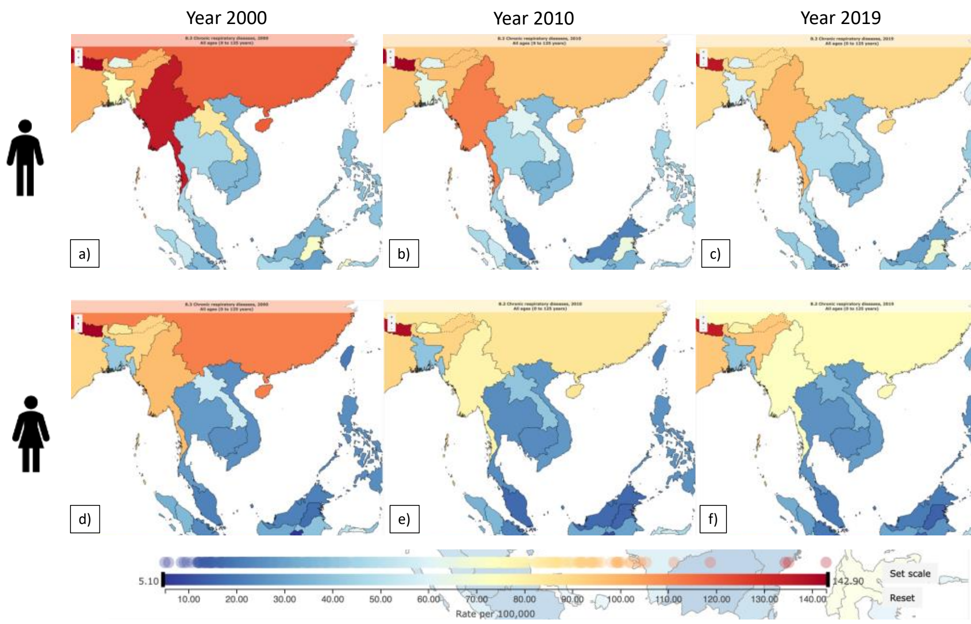

Figure 5. Death from chronic respiratory disease in Southeast Asia for male in a) 2000, b) 2010, and c) 2019, and for female in d) 2000, e) 2010 and f) 2019.

The deteriorating air quality in Southeast Asia over the past few decades has had a direct impact on the health of individuals residing in this region [6]. According to the Global Burden of Disease Study (GBD) 2019 [37], chronic respiratory diseases were responsible for a significant number of deaths in mainland Southeast Asia between 1990 and 2019, as illustrated in Figure 4. The present study provides an assessment of mortality rates linked to chronic respiratory illnesses, such as chronic obstructive pulmonary disease, asthma, and other respiratory diseases, in mainland Southeast Asia spanning the period from 1990 to 2019. According to the data, there was an increase in the number of

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deaths attributed to chronic respiratory diseases in Cambodia from 12,756 in 1990 to 14,413 in 2019. Likewise, it can be observed that in Laos, there has been a rise in the mortality rate from 2,096 in 1990 to 3,179 in 2019. The mortality rate in Malaysia has exhibited an upward trend, with a rise from 6,565 in 1990 to 7,754 in 2019. The mortality rate in Myanmar has exhibited an upward trend, with fatalities rising from 38,962 in 1990 to 59,782 in 2019. The mortality rate in the Philippines has shown an upward trend, with a rise from 35,858 in 1990 to 51,186 in 2019. Between 1990 and 2019, there was an increase in the number of deaths in Thailand from 29,630 to 36,750, and in Vietnam, the number of deaths rose from 36,698 to 48,568 during the same period. The report by GBD found that Cambodia incurred 238,290 disability-adjusted life years (DALYs) in 1990, which increased to 306,245 DALYs in 2019. In 1990, Laos, Malaysia, and Myanmar incurred 29,232, 139,703, and 947,801 disability-adjusted life years (DALYs), respectively. In 2019, these countries experienced an increase in DALYs, with Laos, Malaysia, and Myanmar reporting 46,364, 182,303, and 1,448,635 DALYs, respectively. In 1990, the quantity of disability-adjusted life years (DALYs) recorded in Thailand was 676,741, which subsequently rose to 794,748 by 2019. The incidence of disability-adjusted life years (DALYs) in Vietnam exhibited an increase from 1,117,224 in 1990 to 1,658,316 in 2019. Within the designated temporal scope, a significant number of years of life lost (YLLs) in mainland Southeast Asia were attributed to chronic respiratory diseases, including but not limited to chronic obstructive pulmonary disease and asthma, among other respiratory ailments. In 1990, Cambodia documented approximately 80,051 years of life lost (YLLs), an amount that rose to 101,328 YLLs in 2019. The YLLs in Laos were 10,271 in 1990 and increased to 15,156 in 2019. The YLLs in Malaysia were 42,112 in 1990 and increased to 51,715 in 2019. The number of years of life lost (YLLs) in Myanmar experienced an increase from 318,056 in 1990 to 492,813 in 2019. In 1990, Thailand experienced 272,644 years of life lost (YLLs), which subsequently rose to 328,846 in 2019. Likewise, it can be observed that in Vietnam, the years of life lost (YLLs) amounted to 323,631 in 1990 and exhibited an increase to 455,831 by 2019. Within the designated temporal parameters, chronic respiratory ailments exerted a substantial influence on the overall health of the populace residing in mainland Southeast Asia, leading to a noteworthy quantity of fatalities as well as a significant burden of disability-adjusted life years (DALYs) and years of life lost (YLLs). This highlights the necessity for continuous endeavors to alleviate air pollution and other hazardous elements linked with these ailments in the locality.

The mortality count arising from chronic respiratory ailments, namely chronic obstructive pulmonary disease, asthma, and other respiratory diseases, in Southeast Asia was found to display gender-based variations, as per the results of the Global Burden of Disease Study (GBD) 2000 [37] (Figure 5). The displayed fatality count for males and females within the specified region during the year 2000 was ascertained. In the context of Cambodia, the number of male deaths was recorded as 1,661 while the number of female deaths was documented as 1,530. In contrast, Laos reported significantly lower numbers, with 229 deaths among males and 199 among females. The recorded deaths in Malaysia were 3,217 among males and 2,457 among females. Based on the data, there were 13,487 reported deaths among males and 10,586 reported deaths among females in Myanmar. The recorded number of deaths in Thailand was 13,051 for males and 9,638 for females. The mortality rate for males in Vietnam was 16,262, while for females it was 13,491. According to available data, the number of fatalities in Cambodia in 2010 was approximately 2,405 for males and 2,208 for females. In the country of Laos, the recorded count of male fatalities was 300, while the count of female fatalities was 259. The nation of Malaysia documented 4,486 male deaths and 3,318 female deaths. According to available data, the number of male fatalities in Myanmar was documented as 20,222, whereas the number of female fatalities was recorded as 16,093. The number of recorded deaths for males in Thailand was 15,384, whereas for females it was 11,348. The number of fatalities documented in Vietnam was 21,477 for males and 17,624 for females. The evaluation of mortality rates for males and females in the region during the year 2019 is presently underway.

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According to the mortality statistics of Cambodia, there were 4,327 documented deaths among males and 3,958 documented deaths among females. In Laos, the number of recorded deaths among males was 448, while the number of recorded deaths among females was 387. The recorded deaths in Malaysia were 6,491 for males and 4,851 for females. From the currently available data, the mortality rate in Myanmar reveals that there were 30,569 deaths among males and 24,429 deaths among females. The recorded deaths in the Philippines were 33,448 among males and 27,390 among females. The recorded number of deaths among males in Thailand was 23,284, whereas the recorded number of deaths among females was 16,903. The recorded deaths in Vietnam were 34,286 among males and 28,175 among females. In the study by Baptista et al. [38], PM2.5 is strongly positively linked with chronic respiratory illness mortality, implying that increased particulate matter exposure increases mortality. Many Asian countries have experienced increased air pollution from both industry and motor vehicle emissions in the recent decade [39]. Pollution is also caused by crop waste burning and bushfires in different Asian countries [40,41]. Furthermore, there was a rise in the incidence of asthma exposure to air pollution in the group of studies conducted on Asian populations investigated in the US-based Health Effects Institute (HEI) report [42], with a risk score of >1 and 2, enhancing a possibility for air contaminants in driving up the incidence of asthma [39].

4. Air Quality Mitigation in Southeast Asia

The evidence suggests that air pollution is a matter that extends beyond the confines of a particular locality [43]. The absence of a defined boundary for air necessitates the resolution of air pollution issues through either collaborative effort among regions or the establishment of worldwide environmental regulations, which are currently non-existent [44]. There exists a pressing demand for novel transnational environmental legislation aimed at regulating the nations responsible for the emission of pollutants and preventing further degradation. It is possible for conscientious community members to address cross-border air pollution concerns collaboratively and amicably. Comprehending the significance of transboundary air pollution is a crucial aspect as the outcomes emanating from diverse geographical origins furnish valuable insights for policymaking [45]. Understanding both local pollution and transboundary air pollution is crucial for contribution apportionment. Overlooking or underestimating either type of pollution can be avoided by considering both. Simultaneously, Southeast Asia exhibits a dearth of data from various nations within the vicinity, whereas a significant portion of the sedimentary archives that are accessible are inadequately resolved and insufficiently dated or lack any chronological information [46]. In the immediate future, it is imperative for Southeast Asian nations to contemplate enhanced collection and surveillance of pollution data. This can be achieved by augmenting the number of ground-based air quality observation stations, organizing regional field campaigns to differentiate air pollution in Southeast Asia, and instituting routine country-level Environmental Impact Assessments (EIAs) [45,46]. Comprehending the impact of regional pollution holds significance in the context of cross-border air pollution concerns. The acquisition of data pertaining to pollution in the vicinity has the capacity to furnish an impartial comprehension of the extent of pollution in areas that receive it. Furthermore, Luong [47] proposed a number of strategies to address the aforementioned concerns. These include the reduction of open burning of agricultural and municipal waste, the exploration of alternative options for the burning of agricultural waste, the enhancement of supervisory capacity for open biomass burning and associated air pollution, and the promotion of regional cooperation to combat open biomass burning and associated air pollution. Addressing this challenge necessitates that governments in the area undertake enduring financial and political obligations towards pollution monitoring and research and exhibit a willingness to exchange information and react efficiently to indications of chronically inadequate air quality. The provision of such information holds significant potential for environmental managers and policymakers operating at local, national, and regional levels.

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5. Conclusions

The issue of air pollution, specifically caused by particulate matter, has emerged as a significant concern across the Southeast Asian region in recent decades. The burning of biomass is known to have a significant impact on mitigating the issue of air pollution in this particular area. The impact on individuals in this geographical area is substantial. The mortality rates of individuals over the past two decades have exhibited a noteworthy increase. Between 2000 and 2019, a significant rise in the estimated mortality rates linked to chronic respiratory diseases has been detected across the majority of nations. From 2010 to 2019, a number of countries exhibited a marginal reduction in their mortality rates. The aforementioned findings underscore the persistent prevalence of chronic respiratory that are likely related to air quality problem ailments in Southeast Asia and underscore the necessity of efficacious public health interventions aimed at mitigating the underlying risk factors that precipitate these fatalities.

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References

1. Chen, R.; Hu, B.; Liu, Y.; Xu, J.; Yang, G.; Xu, D.; Chen, C. Beyond PM2. 5: The role of ultrafine particles on adverse health effects of air pollution. Biochimica et Biophysica Acta (BBA)-General Subjects **2016**, *1860*, 2844–2855.
2. Pope III, C.A.; Lefler, J.S.; Ezzati, M.; Higbee, J.D.; Marshall, J.D.; Kim, S.-Y.; Bechle, M.; Gilliat, K.S.; Vernon, S.E.; Robinson, A.L. Mortality risk and fine particulate air pollution in a large, representative cohort of US adults. Environmental Health Perspectives **2019**, *127*, 077007.
3. Liu C, Chan KH, Lv J, Lam H, Newell K, Meng X, Liu Y, Chen R, Kartsonaki, C., Wright, N., Du, H. Long-Term Exposure to Ambient Fine Particulate Matter and Incidence of Major Cardiovascular Diseases: A Prospective Study of 0.5 Million Adults in China. Environmental Science & Technology. 2022 Aug 31;56(18):13200-11.
4. Carey, I.M.; Anderson, H.R.; Atkinson, R.W.; Beevers, S.D.; Cook, D.G.; Strachan, D.P.; Dajnak, D.; Gulliver, J.; Kelly, F.J. Are noise and air pollution related to the incidence of dementia? A cohort study in London, England. BMJ open **2018**, *8*, e022404.
5. Atkinson, R.W.; Carey, I.M.; Kent, A.J.; van Staa, T.P.; Anderson, H.R.; Cook, D.G. Long-term exposure to outdoor air pollution and incidence of cardiovascular diseases. Epidemiology 2013, 44-53.
6. Amnuaylojaroen, T.; Parasin, N.; Limsakul, A. Health risk assessment of exposure near-future PM2. 5 in Northern Thailand. Air Quality, Atmosphere & Health **2022**, *15*, 1963–1979.
7. Amnuaylojaroen, T.; Parasin, N. Future Health Risk Assessment of Exposure to PM2. 5 in Different Age Groups of Children in Northern Thailand. Toxics **2023**, *11*, 291.
8. Amnuaylojaroen, T.; Macatangay, R.C.; Khodmanee, S. Modeling the effect of VOCs from biomass burning emissions on ozone pollution in upper Southeast Asia. Heliyon **2019**, *5*, e02661.
9. Keywood, M.; Kanakidou, M.; Stohl, A.; Dentener, F.; Grassi, G.; Meyer, C.; Torseth, K.; Edwards, D.; Thompson, A.M.; Lohmann, U. Fire in the air: Biomass burning impacts in a changing climate. Critical Reviews in Environmental Science and Technology **2013**, *43*, 40–83.
10. Amnuaylojaroen, T.; Surapipith, V.; Macatangay, RC. Projection of the near-future PM2. 5 in Northern Peninsular Southeast Asia under RCP8. 5. Atmosphere. 2022 11, 13(2), 305.
11. Crutzen, P.J.; Andreae, M.O. Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. Science **1990**, *250*, 1669–1678.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 28 April 2023 doi:10.20944/preprints202304.1186.v1

12. Nhung NT, Schindler C, Chau NQ, Hanh PT, Dien TM, Thanh NT, Künzli, N. Exposure to air pollution and risk of hospitalization for cardiovascular diseases amongst Vietnamese adults: Case-crossover study. Science of The Total Environment. 2020 Feb 10;703:134637.
13. Lelieveld, J.; Klingmüller, K.; Pozzer, A.; Pöschl, U.; Fnais, M.; Daiber, A.; Münzel, T. Cardiovascular disease burden from ambient air pollution in Europe reassessed using novel hazard ratio functions. European heart journal **2019**, *40*, 1590–1596.
14. Feng, C.; Li, J.; Sun, W.; Zhang, Y.; Wang, Q. Impact of ambient fine particulate matter (PM2. 5) exposure on the risk of influenza-like-illness: A time-series analysis in Beijing, China. Environmental Health **2016**, *15*, 1–12.
15. Parasin, N.; Amnuaylojaroen, T.; Saokaew, S. Exposure to PM10, PM2. 5, and NO2 and gross motor function in children: A systematic review and meta-analysis. European Journal of Pediatrics. 2023, 9,1-10.
16. Sun, X.; Zhang, R.; Wang, G. Spatial-temporal evolution of health impact and economic loss upon exposure to PM2. 5 in China. International Journal of Environmental Research and Public Health **2022**, *19*, 1922.
17. Chankaew K, Sinitkul R, Manuyakorn W, Roekworachai K, Kamalaporn, H. Spatial estimation of PM2. 5 exposure and its association with asthma exacerbation: A prospective study in Thai children. Annals of Global Health. 2022;88(1).
18. Nhung, N.T.T.; Amini, H.; Schindler, C.; Joss, M.K.; Dien, T.M.; Probst-Hensch, N.; Perez, L.; Künzli, N. Short-term association between ambient air pollution and pneumonia in children: A systematic review and meta-analysis of time-series and case-crossover studies. Environmental Pollution **2017**, *230*, 1000–1008.
19. Ramanathan, V.; Feng, Y. Air pollution, greenhouse gases and climate change: Global and regional perspectives. Atmospheric environment **2009**, *43*, 37–50.
20. Amnuaylojaroen, T.; Inkom, J.; Janta, R.; Surapipith, V. Long range transport of southeast asian pm2. 5 pollutions to northern Thailand during high biomass burning episodes. Sustainability **2020**, *12*, 10049.
21. Duc, H.N.; Bang, H.Q.; Quan, N.H.; Quang, N.X. Impact of biomass burnings in Southeast Asia on air quality and pollutant transport during the end of the 2019 dry season. Environmental Monitoring and Assessment **2021**, *193*, 565.
22. Pani, SK.; Wang, SH.; Lin, NH.; Chantara, S.; Te, LC.; Thepnuan, D. Black carbon over an urban atmosphere in northern peninsular Southeast Asia: Characteristics, source apportionment, and associated health risks. Environ. Poll. 2020,259. https://doi.org/10.1016/J.ENVPOL.2019.113871.
23. Bond, TC.; Streets, DG.; Yarber, KF.; Nelson, SM.; Woo, JH.; Klimont, Z. A technology-based global inventory of black and organic carbon emissions from combustion. Journal of Geophysical Research: Atmospheres, 2004, 109(D14), 43. https://doi.org/10.1029/2003jd003697.
24. Fu, J.S., Hsu, N.C., Gao, Y., Huang, K., Li, C., Lin, N.H., & Tsay, S.C. (2012). Evaluating the influences of biomass burning during 2006 BASE-ASIA: A regional chemical transport modeling. Atmospheric Chemistry and Physics, 12(9), 3837–3855. https://doi.org/10.5194/acp-12-3837-2012.
25. Li, G.; Bei, N.; Cao, J.; Huang, R.; Wu, J.; Feng, T. et al. A possible pathway for rapid growth of sulfate during haze days in China. Atmospheric Chemistry and Physics, 2017, 17(5), 3301–3316. https://doi.org/10.5194/acp-17-3301-2017.
26. Crippa, M. et al. Fossil CO2 and GHG emissions of all world countries. Publication Office of the European Union: Luxemburg. 2019.
27. Giglio, L.; Randerson, JT.; Van Der Werf, GR. Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4). Journal of Geophysical Research: Biogeosciences. 2013, 118(1), 317–328.
28. Lee, HH.; Iraqui, O.; Gu, Y.; Yim, SH.; Chulakadabba, A.; Tonks, AY.; Yang, Z.; Wang, C. Impacts of air pollutants from fire and non-fire emissions on the regional air quality in Southeast Asia. Atmospheric Chemistry and Physics. 2018, ,18(9),6141-56.
29. Khodmanee, S.; Amnuaylojaroen, T. Impact of biomass burning on ozone, carbon monoxide, and nitrogen dioxide in Northern Thailand. Frontiers in Environmental Science. 2021,8(9), 641877.
30. Giglio, L.; Schroeder, W.; Justice, CO. The collection 6 MODIS active fire detection algorithm and fire products. Remote Sens. Environ. 178, 31–41 (2016).Vadrevu, KP.; Lasko, K.; Giglio, L.; Schroeder, W.; Biswas, S.; Justice, C. Trends in vegetation fires in south and southeast Asian countries. Scientific reports, 2019, 9(1), 1-13.
31. Padoch, C.; Pinedo-Vasquez, M. Saving slash-and-burn to save biodiversity. Biotropica 42, 550–552 (2010).
32. Ramakrishnan, P.S. Shifting agriculture and sustainable development: An interdisciplinary study from north-eastern India. (Parthenon Publishing Group, 1992).
33. Van Vliet, MT. et al. Vulnerability of US and European electricity supply to climate change. Nat. Clim. Change, **2012**, *2*, 676.
34. Sanchez, PA.; Bandy, DE. Alternatives to slash and burn: A pragmatic approach to mitigate tropical deforestation. An. Acad. Bras. Ciênc., **1992**, *64*, 7–34.
35. GMAO (2015) MERRA-2 tavgU_2d_lnd_Nx: 2d, diurnal, time-aver- aged, single-level, assimilation, aerosol Diagnostics V5.12.4. Greenbelt, MD: Goddard Earth Sciences Data and Information Services Center (GES DISC). https://doi.org/10.5067/KPUMV XFEQLA1.
36. Vaduganathan, M.; Mensah, GA.; Turco, JV.; Fuster, V.; Roth, GA. The Global Burden of Cardiovascular Diseases and Risk: A Compass for Future Health. Journal of the American College of Cardiology. 2022,20, 80(25),2361-71.
37. Baptista, EA.; Dey, S.; Pal, S. Chronic respiratory disease mortality and its associated factors in selected Asian countries: Evidence from panel error correction model. BMC Public Health, **2021**, *21*, 1–11.
38. Chung KF, Zhang, J., Zhong, N. Outdoor air pollution and respiratory health in Asia. Respirology. 2011, 16(7), 1023–1026.
39. Dennekamp, M., Abramson MJ. The effects of bushfire smoke on respiratory health. Respirology. 2011, 16(2), 198-209.

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40. Vijayakumar, K.; et al. Effects of agriculture crop residue burning on aerosol properties and long-range transport over northern India: A study using satellite data and model simulations. Atmos Res. 2016,178,155-63.
41. Health Effects Institute. International Scientific Oversight Committee. Outdoor Air Pollution and Health in the Developing Countries of Asia: A Comprehensive Review. HEI, Boston, MA, 2010.
42. Organization, W.H. Air quality guidelines: Global update 2005: Particulate matter, ozone, nitrogen dioxide, and sulfur dioxide; World Health Organization: 2006.
43. Soejachmoen, M.H. Tackling southeast asia's air pollution. Global Asia **2019**, *14*, 40–46.
44. Scott, J.; Holder, J. Law and new environmental governance in the European Union. Law and new governance in the EU and the US 2006, 211-242.
45. Chen, Q.; Taylor, D. Transboundary atmospheric pollution in Southeast Asia: Current methods, limitations and future developments. Critical Reviews in Environmental Science and Technology **2018**, *48*, 997–1029.
46. Luong, N.D., 2022. Actions needed to reduce open biomass burning and associated PM2.5 pollution in Southeast Asia countries, POLICY BRIEF, Asia-Pacific Network for Global Change Research (https://www.apn-gcr.org/wp-content/uploads/2022/02/Policy-brief-APN-project-CRRP2019-11MY-Nguyen_Published-version_updated.pdf, accessed on 24 April 2023).