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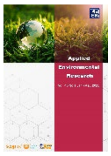

Research Article

Public Attention Index of Air Pollution Exposure from $PM_{2.5}$ in Thailand

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Abstract

Thailand faces a persistent $PM_{2.5}$ challenge, with pollution levels consistently exceeding the World Health Organization’s guidelines. In response, the Thai government has made air pollution a national priority, implementing various policies and city-level plans to reduce exposure. These policies are often temporary and do not fully address root causes, whereas the limited monitoring coverage across Thailand restricts a comprehensive assessment of $PM_{2.5}$ exposure severity. This study addresses the data gap by constructing a public attention index for $PM_{2.5}$, using internet search data from Google Trends, to quantify public awareness and concern regarding $PM_{2.5}$ exposure. This index aims to improve the understanding of $PM_{2.5}$ exposure across Thailand and support more effective air quality management strategies. The findings indicate a statistically significant positive relationship between public attention, $PM_{2.5}$ pollution levels, willingness to pay for $PM_{2.5}$ reduction, and economic and social costs associated with $PM_{2.5}$. The PAI_PM2.5 index serves as a valuable tool for policymakers, offering a data-driven method to align public perceptions with the true severity of pollution issues. The results further indicate that public attention is notably high in severely impacted areas, particularly Bangkok and the northern provinces, yet reveal an awareness gap in regions with significant pollution but low public concern. These findings have important policy implications, highlighting the need for targeted public awareness campaigns and specialized initiatives to improve air quality.

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Introduction

In recent years, $PM_{2.5}$ (fine particulate matter with a diameter of 2.5 micrometers or less) has emerged as a serious environmental and public health concern, particularly in developing countries experiencing rapid population growth. $PM_{2.5}$ has been a long-standing issue in Thailand. This ongoing environmental challenge has no ideal solution to this problem [1].

$PM_{2.5}$ particles originate from both outdoor and indoor sources, indicating that even areas with ostensibly clean outdoor air can exhibit elevated $PM_{2.5}$ levels due to indoor activities, such as burning wood or coal for heating and cooking [2–3]. Additionally, increased $PM_{2.5}$ exposure is attributed to automobile exhaust, industrial emissions, construction activities, and agricultural burning, particularly of off-season rice and sugarcane crops, prior to replanting [1].

$PM_{2.5}$ particles can remain airborne, penetrating deeply into the lungs [1]. Prolonged exposure, even at low levels, is associated with premature mortality and health issues [4–5]. In 2020, Thailand reported a total of 6,883,560 cases of pollution-related illnesses. The northeastern region had the highest number of cases at 2,039,925, followed by the northern region with 1,410,331 cases and the southern region with 1,002,859 cases. Other regions, including the western, greater Bangkok, and central regions, recorded between 530,000 and 580,000 cases. Bangkok had the lowest number of pollution-related illness cases, with a total of 298,396, as shown in Figure 1 [6].

In 2019, Thailand ranked 28th out of 98 countries for pollution, with an annual average $PM_{2.5}$ concentration of 24.3 $\mu g\ m^{-3}$. This concentration increased to 25.7 $\mu g\ m^{-3}$ in 2020, placing Thailand 34^{th} and still four times

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above the World Health Organization (WHO)'s recommended level [5]. Figure 2 shows Thailand's 24-hour average $PM_{2.5}$ levels in 2020, with the northern region highest at 49.9 μg m^{-3} and the southern region lowest at 9.9 μg m^{-3}. The average concentrations in Bangkok and Greater Bangkok were approximately 31 μg m^{-3}, while those in the central and northeastern regions were 16.8 and 18.3 μg m^{-3}, and those in the western and eastern regions were 26.3 and 23.1 μg m^{-3}, respectively [7].

Public attention to $PM_{2.5}$ is increasing throughout Thailand as its impact becomes increasingly apparent. Research by Attavanich [4] revealed that the average annual social cost of $PM_{2.5}$ across 74 provinces in Thailand in 2019 was 2.17 trillion baht per year, equivalent to approximately 11.0% of GDP. By recognizing the severe economic and social costs of $PM_{2.5}$, the Thai government has elevated $PM_{2.5}$ to a national priority, emphasizing the urgent need to address this challenge.

The Thai government has introduced measures to reduce $PM_{2.5}$ pollution, such as restricting diesel engine vehicles to limit black smoke emissions and banning trash burning in public areas. However, these efforts are considered short-term fixes that do not address the root causes, which stem from human-driven activities and face legal and regulatory challenges. Addressing the $PM_{2.5}$ issue requires collaboration among individuals, communities, businesses, industries, policymakers, and government agencies at all levels [3]. In addition to the limited coverage of official airborne monitoring stations, which creates significant data gaps for targeted and effective policymaking, there were only 68 monitoring stations covering 37 of Thailand's 77 provinces in 2020 [7].

Public attention refers to the resources allocated by citizens, special-interest groups, and the media to public issues, shaped by societal priorities and resource distribution. This attention encompasses both qualitative and quantitative dimensions, capturing the depth and scope of focus on a given issue. Public attention involves the active allocation of resources and fluctuates in response to the severity of environmental conditions and the availability of problem-solving resources. Public attention can be measured through surveys, mass media analysis, and internet search data, each offering distinct advantages and limitations.

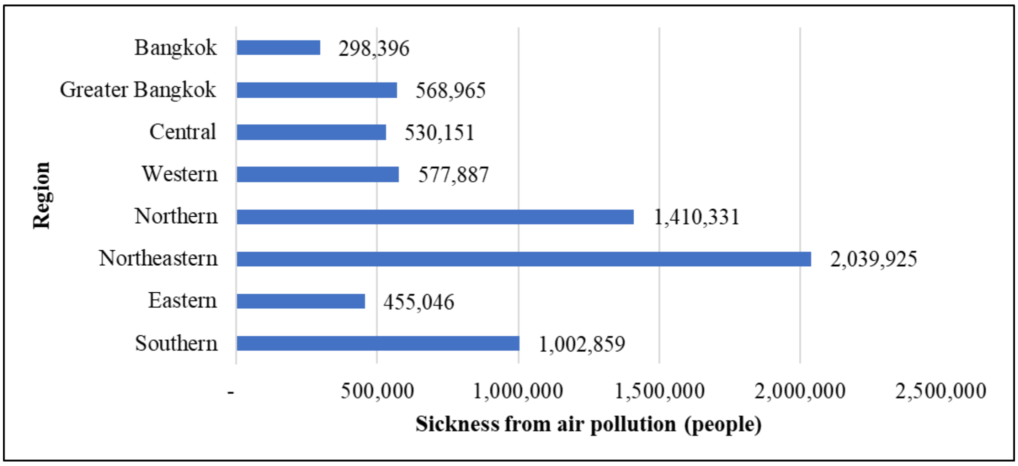

Figure 1 Total number of sickness cases caused by air pollution in Thailand, by region, 2020.

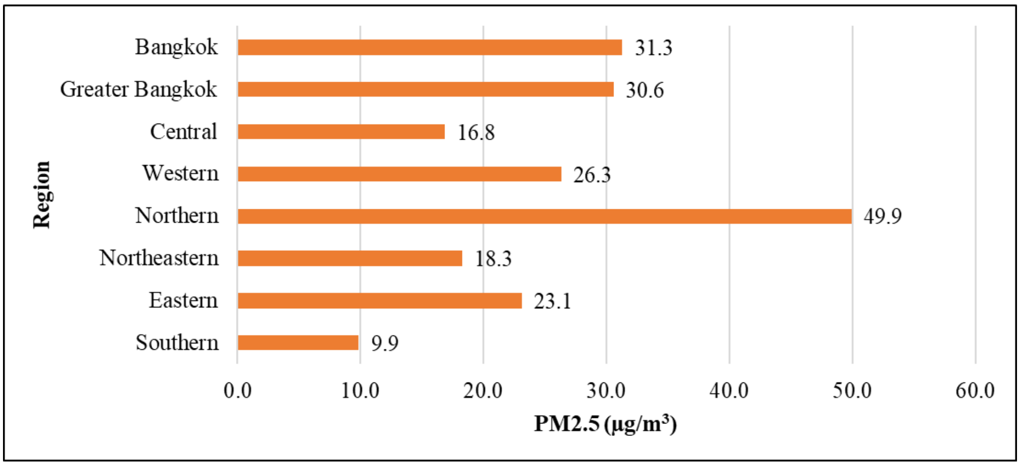

Figure 2 24-hour average $PM_{2.5}$ concentration levels in Thailand, by region, 2020.

The use of internet search data to measure public attention offers real-time, dynamic insights into current interests. This approach captures the interests of diverse groups through routine online behavior, offering a cost-effective and immediate alternative to traditional methods. This approach captures diverse interests through routine online behavior, offering a cost-effective, real-time alternative to traditional methods while eliminating biases from question framing and enabling continuous, unrestricted tracking of public attention [8]. Internet search data are effective tools for tracking actual and real-time public attention [2, 9]. Studies have used internet search data to predict present and near-future unemployment rates [10], measure the effect on company stock prices and volatility [11], examine public attention to spatial and seasonal changes in air pollution exposure [12–13], and construct indicators to measure public attention to environmental pollution issues [14–16].

This study aims to create a public attention index (PAI_PM2.5 index) based on internet search data to quantify the public attention to $PM_{2.5}$ across 77 provinces in Thailand. The PAI_PM2.5 index offers a quantitative measure of public attention regarding $PM_{2.5}$ air pollution and is derived from real-time internet search trends. By evaluating the alignment of the PAI_PM2.5 index with actual $PM_{2.5}$ concentration levels, the willingness to pay for $PM_{2.5}$ reduction and associated economic costs from $PM_{2.5}$ can be determined. This study provides a responsive, data-driven approach to environmental and public health policy making. The findings of this study will be beneficial for policymaking and future research, contributing novel insights to environmental economics research papers, especially in the context of particulate matter.

Materials and methods

1) Public attention

This study presents an empirical model for measuring public attention to $PM_{2.5}$ pollution via internet search data. The model quantifies public awareness of $PM_{2.5}$ pollution through the PAI_PM2.5. The combination of analysis of actual pollution data ($PM_{2.5}$ concentration levels) and public search behavior (PM2.5-related internet search terms) in each province assesses public concern about air quality across different regions. By integrating these two types of data, the model effectively captures the level of public attention and the geographical variations in air quality awareness across provinces. The PAI_PM2.5 index is validated through Pearson correlation analysis, which examines the relationships between the PAI_PM2.5, the $PM_{2.5}$ concentration, the willingness to pay for $PM_{2.5}$ reduction, and the associated economic and social costs of $PM_{2.5}$ exposure [3].

2) Data collection

2.1) $PM_{2.5}$ concentration level

The 24-hour average $PM_{2.5}$ concentration levels, measured in µg m^{-3} from January 1 to December 31, 2020, were collected from airborne monitoring stations located in 56 provinces, which are categorized into seven regions. In total, Thailand has 87 monitoring stations, with 12 in Bangkok, 11 in greater Bangkok, 9 in the Central and Western Regions, 16 in the Northern Region, 11 in the Eastern Region, 7 in the Southern Region, and 5 in the Northeast Region [7]. These data were provided by the Air Quality and Noise Management Bureau, Pollution Control Department (PCD), Ministry of Natural Resources and Environment.

2.2) Internet search terms

The internet search terms "$PM_{2.5}$" and others related to the $PM_{2.5}$ issue were extracted from Google Trends, encompassing all 77 provinces of Thailand, with a monthly average spanning from January 1 to December 31, 2020. The other related terms in both Thai and English represent the most frequently cosearched terms within the same search session as " $PM_{2.5}$" for the specified period, category, and geographical location. The search volume is quantified on a normalized scale ranging from zero to 100. A value of zero indicates that the relative search volume for the selected term is less than 1 percent of the peak popularity observed within the given time period, category, and location. Conversely, a value of 100 denotes the highest search popularity for the selected term.

To ensure that internet search data from Google Trends originate from the province of interest, the study applies provincial-level filtering, restricting search results to specific geographic locations. Additionally, cosearched terms frequently associated with " $PM_{2.5}$" enhance the relevance of selected queries. This approach ensures that Google Trends data accurately capture provincial-level public attention to $PM_{2.5}$ exposure, minimizing the influence of national trends.

2.3) Data Descriptive

The dataset comprises 56 observations, representing $PM_{2.5}$ concentration levels and PM2.5-related internet search intensity across 56 provinces in Thailand. The $PM_{2.5}$ concentration, measured in µg m^{-3}, has a mean of 14.9 µg m^{-3}, ranging from 0.0 to 35.2 µg m^{-3}, reflecting spatial variations in air pollution. Among the PM2.5-related internet search terms, "dust" has the highest average search intensity (63.5%), followed by "pm" (51.0%), "pm 2.5" (36.0%), "pm 2.5" (33.2%), and "2.5 pm" (34.5%), indicating strong public interest in general air pollution topics. Searches for definitions, including "pm" (39.4%) and "pm 2.5" (26.3%), suggest a demand for information on $PM_{2.5}$. Queries related to real-time monitoring, such as "pm 2.5 today" (20.6%) and "level dust today" (15.0%), indicate moderate engagement with current pollution conditions. Less frequently searched terms include regional queries, such as "pm 2.5 Chiang Mai" and "Bangkok pm 2.5" (both 1.8%), searches related to protective measures, such as "mask pm 2.5" (5.3%), and other specific terms, including "dust (in Thai) current pm 2.5" (4.6%) and "Measuring pm 2.5" (3.1%).

3) Data processing

3.1) $PM_{2.5}$ concentration data

The 24-hour average $PM_{2.5}$ concentration levels, which were gathered from 68 airborne monitoring stations, were organized according to the geographic locations of the stations into 37 provincial categories. The data are subsequently grouped into 7 regions on the basis of the classification criteria of the Air Quality and Noise Management Bureau. In provinces where airborne monitoring stations were absent, the $PM_{2.5}$ concentration data were assigned a value of zero.

3.2) Internet search terms

The internet search terms, including "$PM_{2.5}$" and other related terms in both Thai and English, were collected from Google Trends for all 77 provinces in Thailand. The search values that were less than 1 were recorded as zero to standardize the dataset. The collected search terms were then categorized into five groups on the basis of their correlation strength with the $PM_{2.5}$ concentration. The correlation analysis was conducted via bivariate correlation analysis in the STATA program, which employs the Pearson correlation coefficient to estimate the linear association between internet search intensity and $PM_{2.5}$ concentration levels. Statistical significance was assessed via p values, ensuring robustness in identifying meaningful correlations.

4) Public attention index for $PM_{2.5}$ formation

The PAI_PM2.5 is designed to quantify public awareness and concerns about $PM_{2.5}$ issues by using internet search data. The calculation of the PAI_PM2.5 index is defined as Eq. 1.

Dividing $K_{t,i}$ by $G_{t,i}$ removes the upward trend in Google Trends search volumes, which have increased substantially, leading to duplicate data. Additionally, when creating statistical variables from the text corpus, it is essential to account for changes in search terms over time.

Bivariate Pearson correlation analysis was subsequently used to examine the relationships between the PAI_PM2.5 index, the 24-hour average $PM_{2.5}$ concentration ($PM_{2.5}$), the marginal willingness to pay to reduce $PM_{2.5}$ by 1 μg m^{-3} per year (WTP), and the economic and social costs from $PM_{2.5}$ (COST). The bivariate Pearson correlation is defined as follows Eq. 2.

$$\mathrm{PAI\_PM2.5}_{t,i} = \left\{\frac{(K_{t,i}/G_{t,i})}{\max_t (K_{t,i}/G_{t,i})}\right\} \times 100; \qquad ;t = 1, 2, \ldots, f \qquad \text{(Eq. 1)}$$

$$K_{t,i} \in (K_{1,i},\ K_{2,i},\ \ldots, K_{f,i})$$

$$K_{t,i} = \sum_{t=1}^{T} k_{t,i}$$

$$G_{t,i} \in (G_{1,i},\ G_{2,i},\ \ldots, G_{f,i})$$

where $\mathrm{PAI\_PM2.5}_{t,i}$ denotes the public attention index of $PM_{2.5}$ for province i at period t. $K_{t,i}$ denotes the $PM_{2.5}$ internet search volume of group k in province i at period t. $G_{t,i}$ and denotes the total $PM_{2.5}$ internet search volume in province i at period t.

$$r_{xy} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \qquad ; n = 1, 2, 3, \ldots, N \qquad \text{(Eq. 2)}$$

where r_{XY} denotes the Pearson correlation coefficient between X and Y. X_i denotes the value of the $PM_{2.5}$ concentration, the marginal willingness to pay to reduce $PM_{2.5}$ by 1 μg m^{-3} per year, and the economic and social costs from $PM_{2.5}$ for province i, respectively. Y_i denotes the public attention index of $PM_{2.5}$ for province i. $\bar{X}$ denotes the mean of the X values. $\bar{Y}$ denotes the mean of the Y values. n is the number of data pairs. $(X_i-\bar{X})$ denotes deviations of X values from $\bar{X}$. $(Y_i-\bar{Y})$ denotes deviations of Y values from $\bar{Y}$. $\sum(X_i-\bar{X})^2$ denotes the sum of the squared deviations for the X values. $\sum(Y_i-\bar{Y})^2$ denotes the sum of the squared deviations for the Y values.

Table 1 Table of Pearson correlation coefficients for internet search terms and the 24-hour average $PM_{2.5}$ concentration

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
(1) PM2.5	1																									
(2) pm 2.5	.617**	1																								
(3) pm	.656**	.960**	1																							
(4) ฝุ่น	.560**	.923**	.908**	1																						
(5) ฝุ่น pm 2.5	.538**	.935**	.909**	.893**	1																					
(6) ค่า pm	.560**	.715**	.708**	.715**	.708**	1																				
(7) ค่า pm 2.5	.561**	.903**	.889**	.832**	.931**	.712**	1																			
(8) pm 2.5 วัน นี้	.555**	.817**	.783**	.756**	.799**	.645**	.823**	1																		
(9) ค่า ฝุ่น	.592**	.932**	.909**	.893**	.925**	.770**	.917**	.768**	1																	
(10) ค่า ฝุ่น pm	.323**	.479**	.519**	.580**	.564**	.724**	.548**	.526**	.538**	1																
(11) ค่า ฝุ่น pm 2.5	.636**	.868**	.860**	.830**	.852**	.791**	.880**	.747**	.849**	.650**	1															
(12) ฝุ่น pm 2.5 วัน นี้	.505**	.762**	.764**	.746**	.809**	.706**	.849**	.881**	.804**	.645**	.756**	1														
(13) ค่า pm 2.5 วัน นี้	.496**	.791**	.792**	.783**	.814**	.634**	.863**	.776**	.832**	.609**	.796**	.843**	1													
(14) ค่า pm วัน นี้	.517**	.831**	.813**	.780**	.822**	.714**	.870**	.742**	.836**	.608**	.851**	.837**	.858**	1												
(15) pm 2.5 คือ	.187	.229*	.276*	.244*	.321**	.256*	.280*	.128	.244*	.231*	.286*	.182	.314**	.149	1											
(16) pm คือ	.329**	.163	.264*	.202	.256*	.345**	.265*	.163	.241*	.410**	.336**	.350**	.245*	.134	.465**	1										
(17) ค่า ฝุ่น วัน นี้	.540**	.862**	.832**	.853**	.870**	.808**	.863**	.731**	.926**	.608**	.832**	.769**	.818**	.823**	.253*	.285*	1									
(18) ค่า ฝุ่น pm วัน นี้	.252*	.466**	.478**	.519**	.518**	.671**	.538**	.543**	.511**	.890**	.628**	.657**	.633**	.662**	.175	.276*	.601**	1								
(19) หน้ากาก pm 2.5	.494**	.720**	.749**	.741**	.760**	.516**	.724**	.572**	.731**	.443**	.643**	.644**	.707**	.686**	.414**	.290*	.714**	.412**	1							
(20) ค่า ฝุ่น pm 2.5 วัน นี้	.425**	.748**	.762**	.749**	.794**	.729**	.843**	.714**	.788**	.742**	.822**	.831**	.866**	.847**	.346**	.311**	.811**	.764**	.744**	1						
(21) วัด pm 2.5	.221	.393**	.452**	.395**	.403**	.540**	.435**	.432**	.422**	.700**	.492**	.537**	.532**	.553**	.180	.210	.492**	.807**	.352**	.630**	1					
(22) pm 2.5 bangkok	.195	.326**	.405**	.468**	.343**	.368**	.231*	.239*	.319**	.517**	.297**	.304**	.243*	.265*	.146	.296**	.326**	.429**	.393**	.292**	.455**	1				
(23) pm 2.5 เชียงใหม่	.202	.346**	.356**	.290*	.367**	.515**	.470**	.454**	.397**	.659**	.508**	.564**	.588**	.598**	.136	.129	.476**	.800**	.246*	.675**	.829**	-.017	1			
(24) เช็ค pm 2.5	.370**	.500**	.532**	.611**	.550**	.733**	.511**	.476**	.566**	.838**	.606**	.597**	.506**	.558**	.228*	.444**	.609**	.705**	.459**	.644**	.521**	.648**	.382**	1		
(25) pm 2.5 เช็ค	.111	.226*	.320**	.311**	.195	.194	.120	.123	.199	.270*	.153	.161	.131	.154	.098	.154	.193	.248*	.295**	.153	.541**	.863**	-.005	.370**	1	
(26) หน้ากาก กัน pm 2.5	.111	.226*	.320**	.311**	.195	.194	.120	.123	.199	.270*	.153	.161	.131	.154	.098	.154	.193	.248*	.295**	.153	.541**	.863**	-.005	.370**	1.000**	1

Note: **p<0.05, two-tailed ***p<0.01, two-tailed

Results

1) Criteria and selection of PM2.5-related internet search terms

The selected set of internet search terms related to $PM_{2.5}$ was analyzed to assess their correlation with the $PM_{2.5}$ concentration. Pearson correlation coefficients and p values were calculated via bivariate correlation analysis in STATA (Table 1). The results show that 18 terms exhibit a statistically significant positive correlation at the 0.01 level, while 1 term is significant at the 0.05 level, and 6 terms are not statistically significant. Among them, 3 terms demonstrate a high correlation, 12 terms show a moderate correlation, 6 terms have a low correlation, and 4 terms display a very low correlation with 24-hour average $PM_{2.5}$ concentration levels. The strong correlations suggest that the selected internet search terms effectively capture public attention to $PM_{2.5}$ exposure through online search behavior.

The internet search terms are categorized into five groups on the basis of their correlation coefficients (Table 2). Group 1 includes terms that are statistically significant and positively correlated at the 0.01 level, with a high correlation (0.60 ≤ r < 0.79) with the $PM_{2.5}$ concentration. Group 2 consists of terms that are significant at the 0.01 and 0.05 levels, showing high to moderate correlations (0.40 ≤ r < 0.79) with the $PM_{2.5}$ level. Groups 3 and 4 follow the same criteria as Groups 1 and 2, respectively, but exclude "$PM_{2.5}$" search terms. Group 5 includes all terms that are statistically significant and positively correlated at the 0.01 and 0.05 levels. These correlation-based groupings form the basis for five alternative classifications used in calculating the PAI_PM2.5 index.

2) Bivariate Pearson correlation analysis

The correlation analysis indicates a statistically significant positive relationship between the PAI_PM2.5 index and the $PM_{2.5}$, COST, and WTP. For $PM_{2.5}$, high correlations are found in Group 1 (r = 0.660) and Group 5 (r = 0.624), with moderate to low correlations in the other groups. All COST calculations show moderate correlations, ranging from r = 0.336 to r = 0.571. For WTP, moderate correlations appear in Group 3 (r = 0.536) and Case 4 (r = 0.559), whereas the other groups show low correlations. The significance of these correlation coefficients between the PAI_PM2.5 index and the variables $PM_{2.5}$, COST, and WTP suggests that the PAI_PM2.5 index effectively reflects public concern regarding $PM_{2.5}$ issues, as influenced by levels of $PM_{2.5}$ exposure, economic and social costs, and willingness to pay for $PM_{2.5}$ reduction (Table 3).

Table 2 Classification of PM2.5-related internet search terms by the degree of correlation and statistical significance

Group	Terms	Sig.	Correlation	Internet search term
1	All	0.001	High	pm, ค่าฝุ่น pm 2.5 (level dust pm 2.5), pm 2.5
2	All	0.01 and 0.05	High and Moderate	ค่าฝุ่น (level dust), ค่า pm 2.5 (level pm 2.5), ฝุ่น (dust), ค่า pm (level pm), pm 2.5 วันนี้ (pm 2.5 today), ค่าฝุ่นวันนี้ (level dust today), ฝุ่น pm 2.5 (dust pm 2.5), ค่า pm วันนี้ (level pm today), ฝุ่น pm 2.5 วันนี้ (dust pm 2.5 today), ค่า pm 2.5 วันนี้ (level pm 2.5 today), หน้ากาก pm 2.5 (mask pm 2.5), ค่าฝุ่น pm 2.5 วันนี้
3	PM2.5	0.01	High	ค่าฝุ่น pm 2.5, pm 2.5
4	PM2.5	0.01 and 0.05	High and Moderate	ค่า pm 2.5, pm 2.5 วันนี้, ฝุ่น pm 2.5, ฝุ่น pm 2.5 วัน นี้, ค่า pm 2.5 วัน นี้, หน้ากาก pm 2.5, ค่า ฝุ่น pm 2.5 วันนี้
5	All	All	All	All Search terms are selected

Note: Terms = Criteria of internet search terms. Sig. = significance level of the Pearson correlation. Correlation = Correlation strength. Search term = Internet search terms for the $PM_{2.5}$ topic from Google Trends. The English translations of the internet search terms are in parentheses.

Table 3 Table of Pearson correlations for the public attention index for the $PM_{2.5}$ concentration, $PM_{2.5}$ concentration, economic and social costs from $PM_{2.5}$, and marginal willingness to reduce the $PM_{2.5}$ concentration by 1 μg m^{-3} per year

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) $PM_{2.5}$ level	1							
(2) COST	.259*	1						
(3) WTP	.207	.978**	1					
(4) Group 1	.660**	.404**	.357**	1				
(5) Group 2	.542**	.336**	.277*	.759**	1			
(6) Group 3	.359**	.571**	.536**	.493**	.523**	1		
(7) Group 4	.286*	.554**	.559**	.444**	.512**	.848**	1	
(8) Group 5	.624**	.356**	.275*	.823**	.888**	.524**	.467**	1

Note: (1) $PM_{2.5}$ level = 24-hour average PM2.5 concentration. (2) COST = economics and social cost for $PM_{2.5}$. (3) WTP = marginal willingness to pay to reduce $PM_{2.5}$ by 1 μg m^{-3}. (4) to (8) = The PAI_PM2.5 index criteria classify internet search terms related to $PM_{2.5}$ on the basis of correlation strength and statistical significance in Table 2.

3) Public attention index for $PM_{2.5}$ analysis

In 2020, the 24-hour average $PM_{2.5}$ concentration across Thailand varied significantly (Table 4). Regionally, Bangkok has the highest level of public interest in $PM_{2.5}$ issues, reflected in its maximum attention index (100). Following Bangkok, the northern region showed substantial concern (67), with the greater Bangkok scoring a PAI_PM2.5 of 62, followed by the central region (48), western region (38), and southern region (31).

At the provincial level, eight out of the top ten provinces with the highest attention to $PM_{2.5}$ are located in the northern region, where the $PM_{2.5}$ concentration levels frequently exceed the WHO's guidelines [2]. The WHO's Interim Target 3 (IT-3) recommends that annual $PM_{2.5}$ concentrations should not exceed 15 µg m^{-3}, whereas 24-hour averages should remain below 35 µg m^{-3}.

Table 4 Twenty-four-hour average $PM_{2.5}$ concentration levels and the public attention index for $PM_{2.5}$ by region and province, 2020

Region/Province	24-h $PM_{2.5}$	PAI_PM2.5	Region/Province	24-h $PM_{2.5}$	PAI_PM2.5
Bangkok	**23.17**	**100**	**Northeastern**	**25.71**	**33**
Greater Bangkok	**22.08**	**62**	Khon Kaen	29.09	47
Nonthaburi	20.29	77	Nakhon Ratchasima	27.01	40
Samut Prakan	22.87	63	Chaiyaphum	N/A	38
Pathum Thani	22.10	63	Loei	22.85	37
Nakhon Pathom	20.22	58	Maha Sarakham	N/A	37
Samut Sakhon	24.93	51	Nakhon Phanom	N/A	35
Northern	**29.96**	**67**	Nong Khai	25.67	33
Chiang Mai	30.91	98	Ubon Ratchathani	23.93	33
Phrae	30.93	93	Udon Thani	N/A	33
Phayao	32.17	89	Roi Et	N/A	31
Nan	28.74	83	Sakon Nakhon	N/A	30
Lampang	27.55	82	Yasothon	N/A	29
Tak	27.99	76	Kalasin	N/A	28
Chiang Rai	36.23	75	Buri Ram	N/A	28
Lamphun	27.37	70	Surin	N/A	28
Kamphaeng Phet	N/A	64	Si Sa Ket	N/A	26
Mae Hong Son	32.30	61	Bueng Kan	N/A	-
Uttaradit	N/A	56	Nong Bua Lam Phu	N/A	-
Phitsanulok	N/A	56	Mukdahan	N/A	-
Sukhothai	N/A	50	Amnat Charoen	N/A	-
Nakhon Sawan	25.35	44	**Western**	**22.96**	**38**
Phetchabun	N/A	40	Ratchaburi	22.96	42
Phichit	N/A	36	Phetchaburi	N/A	36
Uthai Thani	N/A	0	Prachuap Khiri Khan	N/A	36
Central	**23.02**	**48**	**Southern**	**14.07**	**31**
Ayutthaya	23.10	53	Phuket	14.51	41
Saraburi	28.79	50	Songkhla	19.38	38
Kanchanaburi	26.45	49	Narathiwat	14.46	36
Ang Thong	N/A	48	Surat Thani	14.53	34
Suphan Buri	N/A	47	Yala	11.53	34
Chai Nat	N/A	45	Krabi	N/A	33
Lopburi	N/A	43	Pattani	N/A	31
Samut Songkhram	13.75	-	Trang	N/A	29
Sing Buri	N/A	-	Nakhon Si Thammarat	N/A	28
Eastern	**19.77**	**47**	Phang-nga	N/A	28
Rayong	18.29	56	Phatthalung	N/A	24
Chon Buri	18.87	51	Chumphon	N/A	23
Prachin Buri	24.83	48	Satun	10.01	19
Chachoengsao	18.90	48	Ranong	N/A	-
Sa Kaeo	17.94	45			
Trat	N/A	43			
Nakhon Nayok	N/A	43			
Chanthaburi	N/A	41			

Note: N/A = No 24-hour average of $PM_{2.5}$ concentration levels available due to the absence of air monitoring stations in this province. 24-h $PM_{2.5}$ = 24-hour average of $PM_{2.5}$ concentration levels in µg m^{-3}. PAI_PM2.5 = Public attention index for $PM_{2.5}$.

The top ten provinces with the highest PAI_PM2.5 indices, listed in descending order, are Bangkok (100), Chiang Mai (98), Phrae (93), Phayao (89), Nan (83), Lampang (82), Nonthaburi (77), Tak (76), Chiang Rai (75), and Lamphun (70). Notably, there are 33 provinces with a PAI_PM2.5 index but no available airborne monitoring stations. The presence of the PAI_PM2.5 index in these provinces indicates that alerts from $PM_{2.5}$ exposure can increase people's attention to the risk of air pollution, in addition to the measured levels of airborne pollutants.

$PM_{2.5}$ concentration levels can be represented by color-coded zones indicating different air quality levels. These classifications are based on the PCD's guidelines, which categorize $PM_{2.5}$ into five color codes, with blue for very good air quality, green for good air quality, yellow for moderate air quality, orange for unhealthy air quality for sensitive groups, and red for very unhealthy air quality, as shown in Table 5 [14].

Table 5 $PM_{2.5}$ color coding system for air quality assessment in Thailand

Color code	24-h $PM_{2.5}$	Air quality
Blue	0.0 - 15.0	Very Good
Green	15.1 - 25.0	Good
Yellow	25.1 - 37.5	Moderate
Orange	37.6 - 75.0	Unhealthy for sensitive group
Red	75.1 and over	Very unhealthy

Note: 24-h $PM_{2.5}$ = 24-hour average $PM_{2.5}$ concentration level in μg m^{-3}.

4) Percentage ranking of $PM_{2.5}$ concentration levels and the public attention index for $PM_{2.5}$

In 2020, $PM_{2.5}$ concentrations in Thailand were observed across blue, green, and yellow zones. This study subsequently performed a comparative analysis of the percentage rankings of the PAI_PM2.5 index and actual $PM_{2.5}$ concentration levels. The percentage ranking was used to standardize the PAI_PM2.5 and 24-hour average $PM_{2.5}$ concentration level on the same scale, enabling direct comparison of the two metrics.

Figure 3 shows the regional percentage rankings of the 24-hour average $PM_{2.5}$ concentration and public attention index (PAI_PM2.5) in 2020. The three maps categorize regions where public attention exceeds pollution levels (A), falls below pollution levels (B), or aligns with pollution levels (C).

In the blue zone, which represents very good air quality, eight provinces have $PM_{2.5}$ concentration percentage rankings that exceed their PAI_PM2.5 index percentage rankings. This indicates that the actual air quality in these eight provinces is better than what public attention would reflect, as public attention levels remain relatively low despite good air quality conditions.

There are 20 provinces in the green zone with good air quality. Among these provinces, 12 (60.0%) have $PM_{2.5}$ level percentage rankings that are higher than their PAI_PM2.5 index percentage rankings, suggesting that the air quality may be worse than the level reflected by the level of public attention. In contrast, the remaining 8 provinces (40.0%) have PAI_PM2.5 levels that exceed the $PM_{2.5}$ level, indicating that public concern about air quality is greater than the actual pollution level in these cases.

For the provinces in the yellow zone, where the air quality is moderate, there are 26 provinces. Among these provinces, 17 (65.4%) have $PM_{2.5}$ levels that are higher than PAI_PM2.5, indicating that pollution levels are high, but public attention is lower than might be expected. Conversely, 9 provinces (34.6%) in this category receive more public attention than $PM_{2.5}$ concentration levels do, suggesting a proactive concern among residents about air quality in these areas.

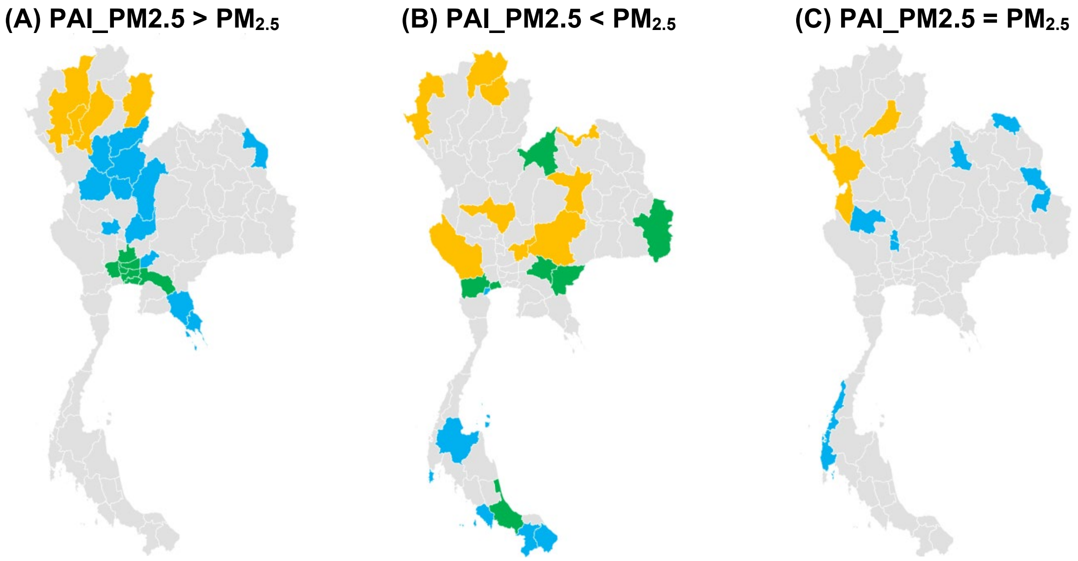

Figure 3 Comparative percentage rankings of 24-hour average $PM_{2.5}$ concentrations and the public attention index across regions, 2020.

Figure 4 indicates that public attention to $PM_{2.5}$ pollution generally corresponds with pollution severity, particularly in highly affected regions such as Bangkok, Greater Bangkok, and northern Thailand. However, some mismatches suggest variations in risk perception or information access. In the analysis of regional patterns, Bangkok (PM2.5: 76%, PAI_PM2.5: 96%) and greater Bangkok (PM2.5: 83%, PAI_PM2.5: 90%) had the highest percentage rankings of both $PM_{2.5}$ levels and the PAI_PM2.5 index, reflecting poor air quality alongside a strong level of public attention. The central region presents mixed results, with some provinces reporting higher $PM_{2.5}$ ranks (such as 72% in Khon Kaen) and others indicating elevated PAI_PM2.5 indices (such as 58% in Ubon Ratchathani), highlighting the varied relationship between air quality and public awareness.

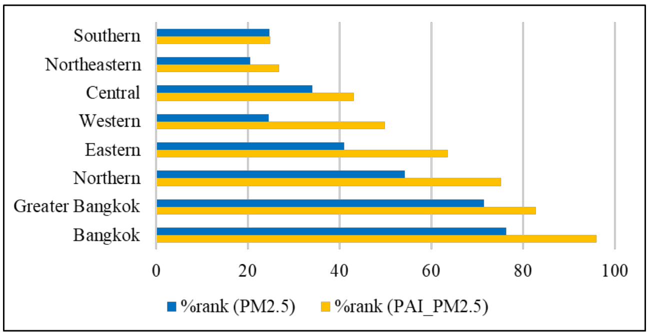

Figure 4 Percentage rankings of 24-hour average $PM_{2.5}$ concentrations and public attention index across regions, 2020.

In the eastern region, both the $PM_{2.5}$ levels and the PAI_PM2.5 index percentage rankings are generally lower than those in the northern and central regions. For example, many eastern provinces have values of approximately 60%, indicating better air quality along with a correspondingly lower level of public attention.

The western region, despite limited data, reveals a mix of moderate and high rankings for both measures, suggesting variable air quality and public attention. The southern region stands out with consistently low percentage rankings for both the $PM_{2.5}$ levels and the PAI_PM2.5 index, with values generally less than 30%, indicating relatively good air quality but also a lower level of public attention.

There is regional variation in air quality across Thailand. The northern and northeastern regions typically experience higher $PM_{2.5}$ levels (often exceeding 70%), indicating poorer air quality, whereas the southern region records lower $PM_{2.5}$ levels, indicating better air quality. Moreover, public attention gaps are evident, especially in the northeastern region, where the PAI_PM2.5 indices do not consistently align with actual air quality conditions. In Bangkok, for example, the percentage rank of the PAI_PM2.5 index is notably higher than that of the $PM_{2.5}$ level, suggesting a heightened level of public concern about air quality even though pollution levels are relatively lower than those in other regions.

Discussions

This study's findings align with those of previous studies that used internet search data to assess environmental risk awareness and public concern. Jiang et al. [15] reported that search trends reliably indicate air pollution levels, whereas Nazar and Plata-Nazar [12] reported that pollution increases correspond with heightened public search activity. Ryu and Min [9] confirmed that air quality perception can be quantified through search terms, and Xu et al. [13] reported that online attention mediates pollution-related behavior. Yang et al. [16] noted sociocultural influences on public concern. Misra and Takeuchi [2] and Attavanich [4] examined the economic and societal effects of pollution, whereas Newig and Hesselmann [8] modeled public attention dynamics.

Public awareness of $PM_{2.5}$ pollution generally aligns with pollution severity, particularly in Bangkok, Greater Bangkok, and northern Thailand. Protection motivation theory [17] suggests that higher perceived threats drive increased information seeking, yet regional variations persist. Some northeastern provinces display an attention gap where $PM_{2.5}$ levels exceed public attention, suggesting disparities in risk perception and information access [16].

Some regions attract little public attention despite high levels of pollution and are influenced by socio-economic factors, media coverage, and perceived risk. Figure 1 and Figure 2 (Introduction) illustrate this disparity, showing that while some areas with high $PM_{2.5}$ exposure also report high illness rates, public concern does not always reflect these trends. In 2020, Thailand recorded 6,883,560 cases of pollution-related illnesses, with the northeastern region (2,039,925 cases) and northern region (1,410,331 cases) experiencing the highest burden and Bangkok having the lowest (298,396 cases) [6]. The northern region also recorded the highest 24-hour average $PM_{2.5}$ concentration (49.9 $\mu g\ m^{-3}$), whereas the southern region had the lowest (9.9 $\mu g\ m^{-3}$) [7]. Higher pollution levels [6] correspond to greater illness rates [7], and public awareness remains inconsistent.

Several methodological constraints should be considered. Google Trends data may be biased by internet access and regional disparities. Additionally, search behavior may not always align with pollution exposure. The limited air quality monitoring of only 56 of the 77 provinces creates data gaps. External factors, including media coverage and seasonal pollution, may distort search trends, leading to time lags between pollution levels and public attention.

Conclusions

This study developed the PAI_PM2.5 index to measure public attention to $PM_{2.5}$ pollution in Thailand via internet search data from Google Trends. The PAI_PM2.5 index indicates public concern by capturing the PM2.5-related search frequency, reflecting the perceived severity of pollution and how public attention aligns with actual pollution levels. Bivariate Pearson correlation analysis confirmed a positive association between the PAI_PM2.5 index, the 24-hour average $PM_{2.5}$ concentration, economic and social costs, and the marginal willingness to pay for $PM_{2.5}$ reduction, demonstrating that internet search data serve as a reliable proxy for public attention.

The findings indicate a gap between $PM_{2.5}$ levels and public attention toward $PM_{2.5}$, suggesting that low attention may limit protective measures against pollution-related health risks. Over 78% of the provinces in Thailand experience critically high $PM_{2.5}$ levels, whereas public concern, as measured by the PAI_PM2.5 index, remains disproportionately low in several regions. This discrepancy between pollution severity and public awareness is particularly evident in Ubon Ratchathani (PM2.5: 70%, PAI_PM2.5: 58%) and Khon Kaen (PM2.5: 72%, PAI_PM2.5: 54%), where severe air pollution persists while public awareness remains low. Targeted awareness campaigns and policy interventions are necessary to bridge the gap between public perceptions and the true severity of air pollution. To increase awareness and promote proactive pollution mitigation efforts, policy makers should improve real-time air quality updates, broaden public education efforts, and launch targeted local outreach programs.

Despite the contributions of this study, several limitations persist. Biases in internet search data, limited air quality monitoring coverage, and external influences such as media attention and seasonal pollution spikes may affect the accuracy of the results. Nevertheless, this study contributes to the broader field of environmental economics and public policy by demonstrating how internet search behavior serves as a dynamic tool for monitoring public awareness of environmental issues.

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