The Precautionary Behavior Against PM2.5 Exposure

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ABSTRACT

This article presents an integrated theoretical framework combining Protection Motivation Theory (PMT), Precautionary Principles (PP), and Precaution Adoption Process Model (PAPM) to analyze precautionary behavior in response to PM2.5 exposure. The framework examines how various information channels influence decision-making processes, from awareness to action, through cognitive assessments and stages of precaution adoption behaviors. By incorporating a public attention index based on internet searches, the framework links individual-level processes and population-level indicators of concern regarding PM2.5 issues. This integration offers insights for environmental health research and risk communication, informing targeted strategies to promote protective behaviors against air pollution and other environmental threats. The framework suggests that effective interventions should be tailored to different stages of awareness and decision-making, considering various information sources and their impacts. Potential applications include enhancing risk communication strategies, targeting specific demographic groups, and addressing barriers to the adoption of protective behaviors.

Keyword: Environmental health behavior/ PM2.5 exposure/ Precaution Adoption Process Model (PAPM)/ Precautionary Principles (PP)/ Protection Motivation Theory (PMT)

1. INTRODUCTION

In recent years, PM2.5 (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. PM2.5 can remain suspended in the airborne for long periods and penetrate deep into the respiratory system [1]. Long-term exposure to PM2.5, even at low levels leads to premature mortality and other adverse health effects [2-3]. PM2.5 originate from diverse sources, both outdoor and indoor environments, meaning that even areas with seemingly clean air can have high PM2.5 levels due to indoor activities such as burning wood or coal for heating and cooking [4-5].

In 2019, Thailand ranked as the 28th most polluted country among 98 countries, with an annual average PM2.5 concentration of 24.3 micrograms per cubic meter. By 2020, an annual average PM2.5 concentration was recorded at 18.1 micrograms per cubic meter, moving Thailand to 57th place in the rankings. Thailand's PM2.5 level, while improved, remained four times above the WHO's recommended annual air quality guideline value [6].

To reduce the negative effects of PM2.5 exposure, individuals take preventive actions to manage their exposure levels. These range from short-term proactive defensive behaviors (such as using indoor air purifiers or wearing protective masks outdoors) to longer-term passive avoidance strategies (such as avoiding outdoor activities during high PM2.5 periods or relocating to areas with better air quality) [7].

This article presents a pertinent literature on the integration of Protection Motivation Theory (PMT), Precautionary Principles (PP), and Precaution Adoption Process Model (PAPM) to develop a conceptual framework for analyzing precautionary behavior in response to PM2.5 exposure. The framework examines how various information channels influence decision-making processes, from awareness to action through cognitive assessments, stages of precaution adoption behaviors. In addition of incorporating Public Attention Index for PM2.5 (PAI_PM2.5) based on internet searches, the framework links individual-level processes and population-level indicators of concern on PM2.5 issue.

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This integrated framework offers insights for environmental health research, risk communication, and inform targeted strategies to promote protective behaviors against air pollution and other environmental risks. Suggesting that the effective interventions should be tailored to different stages of awareness and decision-making, considering various information sources and their impacts. Policies could focus on enhancing risk communication strategies, targeting specific demographic groups, and addressing barriers to the adoption of protective behaviors.

2. LITERATURE REVIEW

Theories and principles provide comprehensive framework for understanding how individuals perceive and respond to environmental and health risks. Protection Motivation Theory (PMT) explains the cognitive processes behind the threat assessment and coping strategies. Precautionary Principles advocates for preventive action despite to the threat, which can be observed in both proactive defensive and passive avoidance behaviors. Precaution Adoption Process Model (PAPM) outlines the stages individuals go through when deciding to take protective action. Public Attention Index for PM2.5 (PAI_PM2.5) offers a practical measure of public engagement with PM2.5 issues through internet search behavior.

2.1 Protection Motivation Theory (PMT)

The PMT is a psychological framework developed by R. W. Rogers [8]. explores the cognitive processes involved in threat appraisal and coping appraisal, providing insights into how people perceive threats and how threats motivate individuals to adopt protective behaviors. The theory is widely used in health psychology, risk communication, and behavior change interventions.

Threat Appraisal: The cognitive process by which individuals evaluate the level of danger posed by a particular threat, involves with: Perceived severity, refers to individuals' assessment of how serious or severe the consequences of the threat would be if it occurred. Perceived vulnerability, refers to an individuals' belief about their personal likelihood of experiencing the threat.

Coping Appraisal: The cognitive process by which individuals assess their ability to cope with a threat and the effectiveness of the recommended protective action, involves with: Response efficacy, refers to belief that the recommended protective action will be effective in reducing or eliminating the threat. Self-efficacy, refers to individuals' confidence in their ability to perform the recommended protective action. Response costs, refers to perceived costs associated with taking the protective action such as money and time, which are crucial factors to consider.

The theory determines level of protection motivation. A high perceived severity and vulnerability of threat appraisal tends to increase protection motivation, and leading to a higher likelihood to adopting protective behaviors of coping appraisal. Understanding threat appraisal is key for promoting protective behaviors through effective interventions and messaging. Whereas, coping appraisal complements threat appraisal by ensuring individuals capability of addressing perceived threats.

2.2 Precautionary Principles (PP)

The PP defines a new standard of risk management when the existence of risk is subject to some scientific uncertainty. It was introduced at the 1992 Rio Conference in Article 15, stated that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing effective measures to prevent environmental degradation" [9]. The concept of precautionary is strongly linked to the effect of arrival of information over time in sequential models as well as to the situations in which there is ambiguity over probability distributions [10]. Underline the preceding statement, the principle as applied to individuals' behavior can be understood through proactive defensive and passive avoidance behavior, which provide a framework for analyzing how individuals respond to potential risks when faced with the threats.

Proactive Defensive Behavior: This refers to actions that individuals take to actively protect themselves from perceived threats. The purpose is to seek control or mitigate the risks while still

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actively engaging with the risk. This involves investing in protective equipment or technology, making backup plans, actively seeking information and expertise, or engaging in developing skills for effective risk management.

Passive Avoidance Behavior: This refers to avoiding situations or activities perceived threat as potentially risky. The purpose is to reduce the risk by limiting exposure to potential threats. This involves avoiding certain activities or environments, opting out of decisions with uncertain outcomes, or maintaining to the plan even the change presents potential risks.

PP has become a key approach in risk management that has been widely adopted and applied across various fields [9-10]. It often discussed in relation to the policies and environmental contexts, and can also be applied to studying individual behavior. The principle emphasizes the dynamic nature of sequential decision-making with evolving information. Importantly, it's worth noting that individuals employed proactive defensive and passive avoidance behavior at the same time.

2.3 Precaution Adoption Process Model (PAPM)

The PAPM is a stage-based model that describes the process individuals go through when deciding whether to take protective action against a health threat. The model illustrates series of stages aims to explain how individuals come to decisions to take action and how individuals translate the decision into action. Unlike other health behavior models, such as the Health Belief Model, PAPM explicitly includes unawareness and inaction stages and also provides a more detailed description of the process leading up to action [11].

PAPM proposes that individuals' decisions can be categorized into discrete stages. Each stage is characterized by specific patterns of beliefs, behaviors, and informational needs. The specifics of these stages are: Stage 1: Unaware, individuals have no knowledge of the health issue or any related precautionary measures. They are completely unaware of the potential risks or the need for preventive action. Stage 2: Unengaged, individuals have become aware of the health issue but have not yet considered taking action. They recognize the existence of the problem but remain detached from it personally. Stage 3: Undecided, individuals actively consider the advantages of taking precautionary action. They weigh the pros and cons but haven't reached a conclusion. This stage is marked by uncertainty and information-seeking behavior. Stage 4: Decided not to act, some individuals make a conscious decision not to take any precautionary action. This decision is based on their assessment of the situation, which may include perceived low risk, high costs of action, or other personal factors. Stage 5: Decided to act, some individuals have made a firm decision to adopt the precautionary behavior. They have moved past the phase of consideration and are now committed to making a change, although they have not yet begun implementing it. Stage 6: Act, this final stage represents the crucial transition from intention to actual behavior change. In this stage, individuals initiate taking precautionary actions.

The transition through stages is not always linear, individuals can move backward as well as forward or skip stages. Importantly, awareness of the treats doesn't always lead to engagement or action. PAPM addresses the overlooked early stages and the gap between deciding to act and taking action, enabling more targeted interventions and communication strategies in public health efforts.

2.4 Public Attention Index for PM2.5 (PAI_PM2.5)

The PAI_PM2.5 index is a proxy measure designed to quantifying public attention to PM2.5 issues through online search behaviors, which reflects public's threat appraisal and information-seeking in response to perceived PM2.5 risks. Individuals' expressions of concern toward the risk from PM2.5 exposure could be detected by online search to locate the resolutions to the problem (internet search behavior) such as reading media news online or searching for relevant information about PM2.5 issue. The index estimates public attention to PM2.5 issues in Thailand by analyzing internet search data across 77 provinces. The methodology involves collecting monthly search data, selecting terms most correlated with actual PM2.5 levels, and calculating the index using a formula that normalizes search

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volumes. The resulting index is then validated against actual PM2.5 levels, economic and social costs, and willingness to pay for pollution reduction. This method provides a comprehensive understanding of public reactions to air quality changes, enabling policymakers to assess perceptions and develop effective interventions for environmental health.

3. METHODOLOGY

3.1 Conceptual Framework

Figure 1 is the conceptual framework presents an integrated conceptual framework of the Precaution Adoption Process Model (PAPM), Protection Motivation Theory (PMT), Precautionary Principles (PP), and Public Attention Index to PM2.5 Exposure (PAI_PM2.5). This integration demonstrates how external factors (exposure levels and information availability) and internal processes (threat perception and coping strategies) work together to move individuals through stages of awareness and action regarding to PM2.5 exposure. It shows both the cognitive progression through the PAPM stages, and the factors influencing this progression in the determinants section.

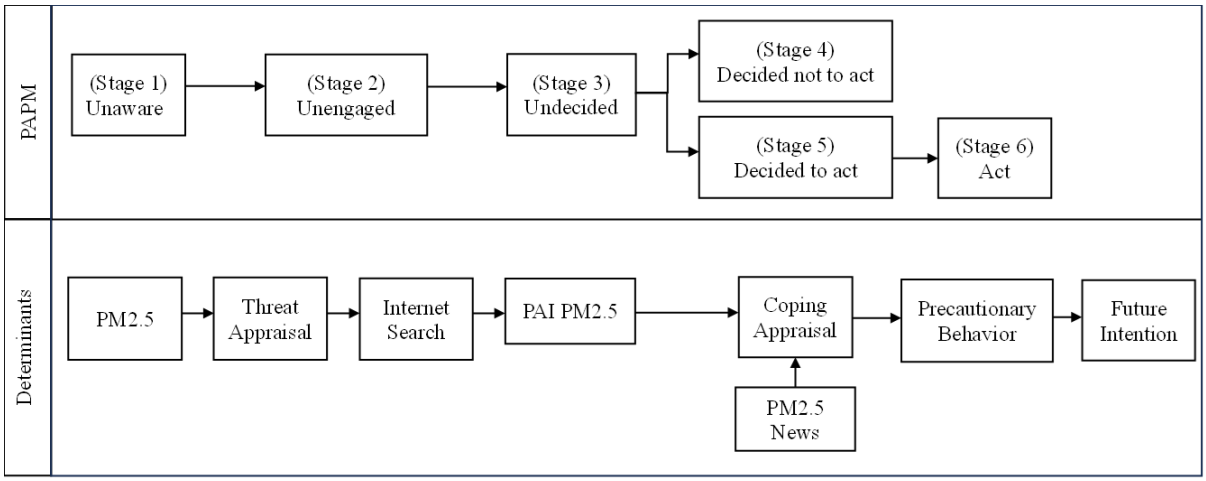

Figure 1. Conceptual Framework

The PAPM section outlines stages from “Unaware” to “Act” which illustrating the progression of awareness toward decision-making. The determinant section outlines the specific determinants related to PM2.5 exposure that influence progression through the PAPM stages, starting with the severity of PM2.5, leading through threat appraisal, internet search, and public attention index for PM2.5 exposure, to coping appraisal, precautionary behavior, and future intention.

The framework highlights the crucial roles of internet searches, news and information on the issue of PM2.5 exposure in shaping public attention, and subsequent decision-making stages. It demonstrates the effects of information sources on precautionary behaviors. Table 1 and Table 2 provide detailed information on how each component in the framework is defined and measured.

Table 2 illustrates the stages of the PAPM in relation to public awareness and response to PM2.5 pollution threats. The table integrates key concepts from PMT, including threat and coping appraisal, while also considering internet search behavior and precautionary actions. Each of the six stages is clearly defined and associated with specific determinants, providing a comprehensive view of how people progress in their understanding and response to PM2.5 exposure risks.

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Table 1. The Notation and Definition of Variables in Conceptual Framework

Notation	Definition
PM2.5	The 24-hour average of PM2.5 concentration levels in micrograms per cubic meter. This reflects the actual severity of PM2.5.
Threat Appraisal	A combination of perceptions of the severity of potential harm (perceived severity) and the likelihood of experiencing that harm (perceived vulnerability), towards a perceived severity of the risk from PM2.5 exposure. This derived from PMT.
Internet Search	Internet search term on the issue of PM2.5, the secondary data collected across 77 provinces of Thailand, provided by Google Trends. This reflects the information-seeking behavior related to PM2.5.
PAI_PM2.5	Public attention index for PM2.5 exposure. This reflects the attention on the issue of PM2.5.
Coping Appraisal	An assessment of precautionary action according to the concept of PMT involves assessing the effectiveness of potential protective actions (response efficacy) and ability to successfully implement these actions (self-efficacy).
PM2.5 News	News and information on the issue of PM2.5 which can be categorized according to the source (formal and informal) and types (on-line and off-line).
Precautionary Behavior	An action on how people respond to the threat of PM2.5 exposure. This encompasses proactive defensive and passive avoidance behavior.
Future Intention	An individual's planned future behavior or decisions in response to PM2.5 exposure risks. This reflects how individuals' awareness, perceptions, and chosen precautionary behaviors impact their decision-making regarding future actions related to PM2.5 exposure.

Table 2. Description of Conceptual Framework

PAPM Stages	Determinant	Definition
Stage 1: Unaware	- PM2.5	In this initial stage, individuals have no knowledge or awareness about the harmful effects of PM2.5 exposure or how to protect themselves from it. The only relevant factor here is the actual PM2.5 level which is defined as the 24-hour average of PM2.5 concentration levels in micrograms per cubic meter. At this point, despite being exposed to PM2.5, individuals have not formed any opinions about it due to the lack of awareness.
Stage 2: Unengaged	- Threat Appraisal - Internet Search	As individuals move into this stage, they develop some knowledge and awareness about the harmful effects of PM2.5 and potential protective measures, but not yet become actively engaged with the issue. Because, an individual may believe that the issue is irrelevant to them. After perceiving the risk from PM2.5 exposure (called Threat Appraisals in PMT), individuals express of concern toward the risk from PM2.5 that could be detected by online search to locate the resolutions to the problem (called Internet Search Behavior) such as reading media news online or searching for relevant information about PM2.5 exposure. The Public Attention Index for PM2.5 (PAI_PM2.5) is formed at this stage, reflecting the level of public attention to the PM2.5 issue as measured by internet search behavior.
Stage 3: Undecided	- PM2.5 News - PAI_PM2.5	Individuals have knowledge and awareness about harmful and protective measures but are uncertain about taking action due to limited knowledge. Therefore, individuals in this stage actively seeking information which influenced by public attention for PM2.5 (PAI_PM2.5) and news on the issue of PM2.5 (PM2.5 News).
Decision making (Stage 4 and 5)	- Coping Appraisal - Precautionary Behavior	Once individuals perceive harmful and engages with the problem of PM2.5, they will decide whether or not to act in such precautionary activities based on their preference to cope with the PM2.5 risk. This decision-making process, known as Coping Appraisals in PMT.
Stage 4: Decided not to act		Individuals being aware and engaged, some decide not to take protective action against PM2.5 exposure. This could be due to low perceived threat, low response efficacy, or low self-efficacy. The decision in this stage is influenced by their assessment of coping strategies
Stage 5: Decided to act		Individuals being aware and engaged, some decide to take preventive action against PM2.5 exposure, which based on adopted precautionary preference. This decision is influenced by their evaluation of effective coping strategies.

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PAPM Stages	Determinant	Definition
Stage 6: Acting	- Future Intention	In this final stage, where decisions turn into actions, and these actions shape future intentions regarding PM2.5 exposure response. Individuals have taken preventive action to protect themselves against PM2.5 exposure. Their behavior influences future intentions regarding PM2.5 exposure.

3.2 Econometric Model

Logit regression is a statistical method used for examining the relationship between a binary dependent variable and a set of independent predictor variables that can be continuous or categorical [12]. Let there be N observations and k characteristics (exogeneous variables) on each observation, $(n = 1 \ldots . N)$. The dichotomous qualitative response model is defined as:

$$y_n^* = X_n\beta + u_n \qquad ; (n = 1, \ldots, N) \qquad (1)$$
$$y_n = \begin{bmatrix} 1 \; if \; y_n^* \geq 0 \\ 1 \; if \; y_n^* < 0 \end{bmatrix}$$

Where; β denotes the $k \times 1$ vector of unknown coefficients. u_n denotes the error term. X_n denotes the $1 \times k$ vector of exogenous variables. y_n^* denotes the unobservable dependent variable. The observable dependent indicator variable y_n takes the value 1 with probability p_n and the value 0 with probability $1 - p_n$. Due to the assumption on error term is $i.i.d$ of logit regression. Thus, the logistically distributed p_n is given by:

$$p_n = \frac{1}{1 + \exp(-X_n\beta)} \qquad (2)$$

3.3 Empirical Model

For the empirical analyses, this study employs the Logit regression to analyze precautionary behavior in response to PM2.5 exposure, with an emphasis on how various information channels influence these behaviors. The model is defined as:

$$BEHAVIOR_n^k = \beta_1 PAIPM25_n + \beta_2 PM25_n + \beta_3 NEWS\_SOURCE_n^k \qquad ; (n = 1, \ldots, N) \qquad (3)$$
$$+ \beta_4 NEWS\_TYPES_n^k + \beta_5 DEMOGRAPHIC_n$$
$$+ \beta_6 CONTROL_n + u_n$$
$$BEHAVIOR_n^k = \begin{bmatrix} 1 & if & BEHAVIOR_n^k \geq 0 \\ 0 & if & BEHAVIOR_n^k < 0 \end{bmatrix}$$

Where; $BEHAVIOR_n^k$ denotes types k of precautionary behavior against PM2.5 exposure of individual n, consists of proactive defensive and passive avoidance behavior which is dummy variable equal to 1 if individuals n adopts proactive defensive behavior and 0 if individuals n adopts passive avoidance behavior. PAI_PM25_n denotes public attention index for PM2.5 issue of individual n. The value is presented in a range of 0 to 100. $PM25_n$ denotes the 24-hour average of PM2.5 concentration levels in micrograms per cubic meter of the province that individual n is inhabited. $NEWS\_SOURCE_n^k$ denotes PM2.5 news from source k that individuals n perceive, consist of formal source (such as government departments and agency, news agency, and media broadcasting) and informal source (such as friends and relatives, community leader, influencer, and youtuber) which is dummy variable equal to 1 if individuals n perceive PM2.5 news from formal source and 0 if individuals n perceive PM2.5 news from informal source. $NEWS\_TYPE_n^k$ denotes types k of PM2.5 news that individuals n perceive,

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consists of on-line and off-line media which is dummy variable equal to 1 if individuals n perceive PM2.5 news from on-line media, and 0 if individuals n perceive PM2.5 news from off-line media.

$DEMOGRAPHIC_n^k$ denotes group of variables that represents demographic characteristic of individual n, consists of $MALE_n^D$ is gender of individual n which is dummy variable equal to 1 if individual n is male, and 0 if individual n is female; AGE_n is age of individual n; $SICKNESS_n^D$ is health condition of sickness caused by PM2.5 exposure consists of chronic obstructive pulmonary disease, ischemic heart diseases, inflammatory eye disease, eczema and atopic dermatitis, other-related disease groups, and lung cancer which is considered as a long-term effect of individual n which is dummy variable equal to 1 if individual n is being sick caused by PM2.5 exposure, and 0 if otherwise; $MARRIED_n^D$ is marital status of individual n which is dummy variable equal to 1 if individual n is currently married, and 0 if otherwise. $EDUCATION_n^D$ is highest education attainment level of individual n in group of no educational attainment, primary school, secondary school, high school, undergraduate, and graduate. $OCCUPATION_n^D$ is occupation type of individual n in group of students, public servant, full-time employee, self-employed, farmer, part-time employee, retired, and unemployed.

$CONTROL_n^k$ denotes group of control variables of individual n that consists of $LN(INCOME\_R)_n$ is log total income of individual n; $LN(INCOME\_HH)_n$ is log total income of individual n's household; $CORES(ELDERLY)_n^D$ is coresident status of individual n and elderly aged 60 and over which is dummy variable equal to 1 if individual n live with elderly aged 60 years and over, and 0 if otherwise; $CORES(CHILDREN)_n^D$ is coresident status of individual i and children aged below 12 years in the same house which is dummy variable equal to 1 if individual n live with children aged below 12 years, and 0 if otherwise; $CORES(SICKNESS)_n^D$ is coresident status of individual n with a patient suffering from an illness caused by PM2.5 exposure, consists of chronic obstructive pulmonary disease, ischemic heart diseases, inflammatory eye disease, eczema and atopic dermatitis, other-related disease groups, and lung cancer which is considered as a long-term effect, which is dummy variable equal to 1 if individual n live with respiratory patient, and 0 if otherwise. u_n denotes the error term.

4. DISCUSSION

The analyzing of human cognition and behaviors are inadequate under the explanation by a single theory, necessitating multiple perspectives for comprehensive understanding more efficiently. This article presents an integrated framework of Protection Motivation Theory (PMT), Precautionary Principles (PP), and Precaution Adoption Process Model (PAPM) that provides a comprehensive view of how various information channels influence individuals' perceptions, motivations, and adoption of precautionary action throughout the decision-making process. PAPM explains the transition process of how individuals adopt precautionary behavior, from being unaware of a risk (PM2.5 exposure) to taking or not taking the precautionary action. While PMT explains how individuals assess PM2.5 threats and protective measures based on perceived severity, vulnerability, and coping ability in determining their adoption of precautionary behaviors.

Contributions of the integrated framework in combining cognitive processes of the risk from Protection Motivation Theory (PMT) which offering insights into why some take action against PM2.5 risks while others do not, the response against the risk from Precautionary Principles (PP), and behavior change stages from Precaution Adoption Process Model (PAPM). Firstly, this reveals how differences in information types and sources impact behavior across different awareness and decision-making stages, which helps identify critical points for more targeted and effective public health communication to promote health protective policies related to the risk from environmental, especially from PM2.5 exposure and potentially other environmental health-related behavior. Second, it enables a more dynamic analysis of behavior change, examining how factors such as risk perception and efficacy beliefs evolve over time and influence progression through the Precaution Adoption Process Model (PAPM) stages. Third, this framework also corporate contextual factors, demographic characteristics, to illustrating their potential impact on both cognitive processes and stage progression. Last, the integration bridges individual-level cognitive processes (Protection Motivation Theory: PMT) with

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population-level indicators (Public Attention Index for PM2.5: PAI_PM2.5), offering a more comprehensive view of public response to the risk from PM2.5 exposure. The integration offers insights for environmental health research and risk communication, informing targeted strategies to promote protective behaviors against air pollution and other environmental threats. The framework suggests that effective interventions should be tailored to different stages of awareness and decision-making, considering various information sources and their impacts. Potential applications include enhancing risk communication strategies, targeting specific demographic groups, and addressing barriers to the adoption of protective behaviors.

5. CONCLUSION

This article presents an innovative integrated theoretical framework combining Protection Motivation Theory (PMT), Precautionary Principles (PP), and Precaution Adoption Process Model (PAPM) to comprehensively understand precautionary behavior against PM2.5 exposure. This integration offers key contributions to environmental health behavior research, including comprehensive behavioral analysis, insights into information impact across awareness stages, dynamic behavior change analysis, incorporation of demographic influences, and bridging individual and population-level indicators.

The framework enhances the understanding of how individuals respond to environmental health risks, particularly PM2.5 exposure, from initial awareness to taking preventive action. This offers a foundation for future research in environmental health, potentially informing more effective public health interventions and design and implementation of policy.

Conflict of Interest

The authors declare that there is no conflict of interest.

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