

The Hidden Cost of Urban Pollution: Environmental Exposure, Health Depletion, and Workforce Productivity in Emerging Economies

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Abstract— Urban air pollution represents an emerging challenge for workforce sustainability, yet management research has paid limited attention to how environmental exposure influences human capital productivity, particularly among outdoor workers in rapidly urbanizing emerging economies. Drawing upon the Resource-Based View (RBV), this study examines how pollution exposure affects workers' productive capacity by exploring the relationships among pollution exposure intensity, health-related consequences, behavioral responses, and work productivity impairment. The study adopts a quantitative cross-sectional survey design and collects data from 384 outdoor workers in the Kathmandu Valley, Nepal, including street vendors, construction workers, delivery workers, and traffic police personnel. A structured questionnaire containing 47 measurement items across eight constructs captures workers' exposure experiences, health symptoms, protective behaviors, awareness levels, and productivity outcomes. The study applies Partial Least Squares Structural Equation Modelling (PLS-SEM) through SmartPLS to analyze direct, mediating, and moderating relationships among the research constructs. The findings show that pollution exposure intensity significantly increases work productivity impairment, while pollution-related health symptoms partially explain this relationship. Heat and environmental stress also increase productivity impairment. However, AQI awareness and adaptive preventive behavior do not significantly reduce productivity impairment, highlighting the limitations of individual-level coping responses. The study extends RBV by positioning environmental exposure as a resource-depleting mechanism that influences human capital sustainability and emphasizes the importance of organizational and policy interventions to protect workforce capability.

Keywords— Urban Air Pollution; Human Capital Sustainability; Resource-Based View; Work Productivity Impairment; Outdoor Workers; Environmental Exposure

I. INTRODUCTION

Urbanization has become a defining force reshaping contemporary economic activity, transforming not only the physical configuration of cities but also the nature of work, employment structures, and organizational dependence on human capability[1]. Across emerging economies, accelerated infrastructure development, rising mobility demands, and intensified commercial activities have generated substantial economic opportunities while simultaneously producing new

forms of occupational vulnerability[2]. Air pollution represents one such emerging challenge. Although traditionally examined through environmental and public health perspectives, recent research increasingly recognizes that environmental conditions influence not only population health but also labor productivity, cognitive functioning, and workforce sustainability [3], [4]. The quality of the physical work environment can influence employees' physiological capacity, attention, and ability to sustain productive performance over time. Organizations may continuously invest in technology, innovation, and operational systems; however, these investments ultimately depend on human resources whose productive potential can be weakened when environmental conditions generate persistent physical and cognitive strain[5].

This challenge becomes particularly significant among outdoor workers whose occupational activities require continuous interaction with external environmental conditions[6]. Traffic personnel, construction workers, delivery workers, and street vendors represent essential contributors to urban economic systems, yet their productive capacity is shaped by exposure conditions that organizations often have limited mechanisms to control. Recent evidence demonstrates that workplace exposure assessments provide a more accurate understanding of pollution-related vulnerability than residential exposure alone because occupational environments may generate substantially higher pollutant exposure levels [7]. In rapidly urbanizing regions such as the Kathmandu Valley, increasing vehicle emissions, construction activity, and commercial expansion have intensified air-quality concerns. Although previous studies have extensively documented the health consequences of air pollution, including respiratory illness, cardiovascular risks, and cognitive impairment, comparatively limited attention has been devoted to understanding how environmental exposure influences workforce productivity and organizational outcomes [8], [9].

From a management perspective, this represents an important theoretical omission. Traditional organizational research has primarily emphasized internal resources, including employee knowledge, skills, motivation, and organizational routines, as sources of sustained competitive advantage[10], [11], [12]. The Resource-Based View (RBV)

argues that organizations achieve sustained advantage through resources that are valuable, rare, difficult to imitate, and difficult to substitute [13]. Human capital represents a central strategic resource because employees' knowledge, capabilities, and functional capacity enable organizations to transform resources into performance outcomes. However, existing RBV research has largely focused on how firms acquire, develop, and leverage human resources [14], [15], while giving comparatively limited attention to how external environmental conditions may gradually weaken or deplete those resources.

This limitation becomes increasingly relevant in contexts where employees operate under persistent environmental stress. Although environmental hazards have been widely examined within medical and ecological disciplines [16], [17], management scholarship has rarely conceptualized pollution exposure as a mechanism that can diminish workforce capability. Recent occupational research suggests that prolonged exposure to air pollutants may affect workers through multiple pathways, including increased fatigue, reduced cognitive performance, respiratory burden, and diminished physical capacity [4]. Therefore, pollution exposure should not be interpreted merely as an external environmental inconvenience; rather, it may function as a contextual constraint that influences the preservation and utilization of human resources. Extending RBV in this direction suggests that human capital sustainability depends not only on organizational investments in training, motivation, and development but also on the environmental conditions under which employees perform their work.

The practical implications of this theoretical gap are substantial. Organizations operating in polluted urban environments face a complex managerial challenge: maintaining workforce availability and operational continuity while protecting employees from environmental conditions that may gradually reduce productivity. Recent sustainability research increasingly emphasizes that organizational performance is inseparable from social and environmental conditions affecting [18], [19]. This issue is particularly relevant in the Kathmandu Valley, where outdoor workers perform economically essential activities under continuous exposure conditions. Despite their importance, workplace protection mechanisms, preventive systems, and evidence-based interventions remain insufficiently developed.

This study addresses these theoretical and practical limitations by examining the relationship between urban air pollution exposure and daily productivity among outdoor workers in the Kathmandu Valley. Rather than conceptualizing workers solely as recipients of environmental harm, this research positions them as strategic human resources whose productive capacity is influenced by environmental conditions. Building upon RBV, the study argues that preserving human capital requires attention not only to internal capability development but also to external contextual factors that influence whether those capabilities can be effectively deployed.

The study contributes to management research in three ways. First, it extends RBV by introducing environmental exposure as a contextual mechanism through which valuable human resources may be gradually weakened. Second, it advances understanding of the pollution-productivity relationship by examining health-related consequences as an explanatory mechanism linking environmental exposure with reduced work effectiveness. Third, by focusing on outdoor

workers in an emerging economy context, the study expands human capital research beyond traditional organizational boundaries and demonstrates that workforce sustainability is influenced by broader environmental systems. In doing so, this research develops a more contextualized understanding of RBV, emphasizing that valuable human resources must not only be developed and utilized but also protected from environmental conditions that threaten their long-term productive potential.

II. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

A. *Urban Air Pollution Exposure and Work Productivity Impairment*

Air pollution has traditionally been examined through environmental science and public health perspectives, where the dominant emphasis has been placed on exposure-related morbidity, mortality, and ecological consequences. Within this research tradition, polluted environments are primarily conceptualized as external hazards that generate physiological stress among exposed populations. However, recent interdisciplinary research increasingly demonstrates that environmental degradation extends beyond health outcomes and influences economic behavior, labor productivity, and organizational effectiveness. Employees do not perform in isolation from their physical surroundings; rather, their productive capacity is embedded within environmental conditions that may either preserve or gradually diminish their ability to contribute economic value. Empirical studies have demonstrated that exposure to air pollutants can influence worker productivity through multiple pathways, including impaired cognition, fatigue, respiratory stress, and reduced physical functioning [4], [20].

The Resource-Based View (RBV) provides an important theoretical foundation for understanding this relationship. RBV argues that organizations achieve sustained advantage through valuable, rare, inimitable, and non-substitutable resources, with human capital representing one of the most important strategic resources through which organizations create value [13]. Employees' knowledge, skills, experience, and physical capabilities enable organizations to transform resources into productive outcomes. Nevertheless, traditional RBV research has primarily focused on how organizations acquire, develop, and leverage human resources, while paying comparatively limited attention to how external environmental conditions may weaken these resources over time. If employees represent strategic assets, then environmental conditions that systematically reduce their functional capacity represent potential threats to organizational resource sustainability.

Outdoor workers represent a particularly important context for examining this relationship because their occupations require continuous interaction with external environmental conditions. Construction workers, traffic personnel, delivery riders, and street vendors often experience prolonged exposure to pollutants during working hours. Unlike indoor workers who may benefit from controlled workplace environments, outdoor workers have limited ability to avoid exposure while maintaining employment responsibilities. Therefore, pollution exposure intensity may represent a significant contextual factor influencing workforce capability.

Prior research has identified several mechanisms through which pollution exposure may affect productivity. Exposure

to particulate matter, nitrogen dioxide, and other pollutants has been associated with inflammation, respiratory problems, cognitive impairment, and reduced physical [8], [21]. However, the productivity consequences of pollution remain insufficiently examined within management research. Existing studies have predominantly treated pollution as a public health concern rather than as a factor influencing human resource sustainability. Therefore, this study proposes that higher exposure intensity reduces workers' productive capacity.

Hypothesis 1 (H1): Urban air pollution exposure intensity has a significant positive effect on work productivity impairment among outdoor workers.

B. Pollution-Related Health Symptoms as a Mediating Mechanism

Although exposure intensity provides an important explanation for productivity decline, the mechanism through which pollution affects workforce performance requires further examination. Health-related consequences represent a plausible pathway connecting environmental exposure with productivity impairment. Previous research indicates that air pollution exposure can contribute to respiratory symptoms, inflammation, fatigue, and reduced physical functioning, which may subsequently constrain workers' ability to maintain consistent performance levels [8].

From an RBV perspective, health represents an important foundation of human capital effectiveness. Employee capabilities cannot be fully utilized when physiological conditions limit concentration, energy, or physical capacity. Therefore, pollution exposure may gradually deplete human resources by creating health burdens that reduce the effective deployment of employee capabilities.

However, existing literature has rarely examined health symptoms as a mediating mechanism within organizational productivity models. Most environmental studies examine direct health consequences, while management research has paid limited attention to how these consequences translate into workplace outcomes. By introducing health symptoms as an explanatory pathway, this study extends understanding of how environmental conditions influence organizationally relevant outcomes.

Accordingly, this study argues that pollution exposure affects productivity partly because it generates health-related limitations among workers.

Hypothesis 2 (H2): Pollution-related health symptoms mediate the relationship between pollution exposure intensity and work productivity impairment among outdoor workers.

C. Heat and Environmental Stress as Predictors of Productivity Impairment

Outdoor workers are exposed not only to airborne pollutants but also to broader environmental stressors, particularly heat and solar exposure. Environmental stress theory suggests that individuals experience reduced performance when environmental demands exceed their physiological and psychological capacity to adapt. Recent occupational research indicates that heat exposure can increase fatigue, reduce concentration, and negatively influence physical performance, particularly among workers engaged in physically demanding occupations [22], [23].

The relationship between environmental stress and productivity is particularly relevant in urban environments where pollution and heat frequently occur simultaneously. Workers exposed to high temperatures may experience additional physiological strain, which compounds the effects of pollutant exposure. Therefore, focusing exclusively on air pollution may underestimate the broader environmental burden experienced by outdoor workers.

From an RBV perspective, environmental stress represents another mechanism through which workforce resources may become depleted. Physical endurance and cognitive capacity constitute valuable employee capabilities; however, persistent environmental stress may reduce their effective availability.

Therefore, this study proposes:

Hypothesis 3 (H3): Heat and environmental stress has a significant positive effect on work productivity impairment among outdoor workers.

D. AQI Awareness and Work Productivity Impairment

While environmental exposure represents a potential threat to workforce capability, workers may possess cognitive resources that enable them to manage environmental risks. AQI awareness represents employees' knowledge regarding pollution levels and potential exposure risks. Theoretically, greater awareness may encourage workers to modify behavior, avoid peak pollution periods, or adopt protective strategies.

Environmental behavior research suggests that awareness can influence risk perception and encourage protective action[24]. However, awareness alone may not always translate into behavioral change, particularly among workers whose occupations require continued exposure. Outdoor workers often have limited autonomy to modify working conditions because avoiding exposure may directly affect income opportunities[25].

This creates an important theoretical tension. On one hand, AQI awareness may represent a valuable informational resource that supports adaptive decision-making. On the other hand, its effectiveness may depend on whether workers possess sufficient control and organizational support to act upon that information. Thus, awareness may be necessary but insufficient to protect productivity.

Accordingly:

Hypothesis 4 (H4): AQI awareness has a significant negative effect on work productivity impairment among outdoor workers.

E. Adaptive Preventive Behaviour and Work Productivity Impairment

Individual preventive behavior represents another potential mechanism through which workers may reduce the productivity consequences of pollution exposure. Preventive behaviors, including mask usage, protective equipment adoption, and exposure avoidance practices, may reduce pollutant intake and mitigate health consequences.

However, the effectiveness of individual adaptation remains debated. While behavioral responses can reduce personal exposure, their effectiveness may be limited when environmental hazards are persistent and occupationally unavoidable[26]. Outdoor workers often operate under conditions where personal protective measures provide only partial protection against continuous exposure[27].

From an RBV perspective, adaptive behavior represents an employee-level capability; however, its effectiveness depends on complementary organizational resources. Without employer support, protective infrastructure, and institutional safety mechanisms, individual actions may have limited ability to preserve workforce productivity.

Therefore:

Hypothesis 5 (H5): Adaptive preventive behavior has a significant negative effect on work productivity impairment among outdoor workers.

III. METHODOLOGY

This study adopted a quantitative research design to examine the relationship between urban air pollution exposure and the daily productivity of outdoor workers in the Kathmandu Valley. Quantitative approaches are appropriate when research seeks to examine relationships among measurable constructs and empirically test theoretically derived relationships using statistical analysis [28]. The research approach was structured around the assumption that environmental exposure operates as a contextual factor influencing workers' health conditions and productive capacity. A cross-sectional survey design was employed because the study aimed to capture existing exposure conditions, behavioral responses, and productivity experiences of outdoor workers during the data collection period rather than examine changes over an extended longitudinal timeframe. Cross-sectional designs are commonly applied in occupational and behavioral research when the objective is to assess associations among variables within a defined population at a particular point in time [29].

The empirical model incorporated multiple constructs representing different dimensions of the pollution–productivity relationship, including perceived air pollution, pollution exposure intensity, heat and environmental stress, pollution-related health symptoms, adaptive and preventive behavior, AQI awareness, nature of work, and work productivity impairment. These constructs enabled the study to move beyond a single exposure–outcome relationship by incorporating environmental, health, behavioral, and occupational dimensions surrounding pollution exposure. The conceptual framework of the study similarly identified urban air pollution as the independent construct, daily productivity as the outcome variable, and occupational characteristics as contextual factors influencing the relationship.

A. Sample and Data Collection

Data were collected from outdoor workers operating across the Kathmandu Valley, encompassing Kathmandu, Lalitpur, and Bhaktapur districts. The sampling frame focused on occupational groups whose daily work activities required prolonged interaction with outdoor environmental conditions. Specifically, the study included street vendors, construction workers, delivery workers, and traffic police personnel because these occupational groups experience repeated exposure to urban environmental conditions as part of their routine work activities. The final sample consisted of 384 respondents, comprising 112 street vendors, 112 construction workers, 88 delivery workers, and 72 traffic police personnel.

Data collection was conducted during the early part of 2026 using a structured questionnaire administered directly to outdoor workers. The questionnaire was designed to capture both environmental exposure experiences and workplace productivity outcomes among individuals whose occupational

responsibilities required regular outdoor engagement. Rather than conceptualizing pollution exposure solely through objective environmental measurements, the study incorporated workers' perceived exposure conditions, exposure intensity, pollution-related health symptoms, adaptive responses, AQI awareness, and productivity-related consequences. This approach enabled the research to examine not only whether pollution exposure was associated with productivity impairment but also the mechanisms through which environmental stressors influenced workforce capability.

The collected questionnaires were subsequently reviewed to ensure data completeness and consistency before statistical analysis. Responses were screened, organized, and prepared for empirical examination. The final dataset represented workers whose occupational characteristics involved substantial interaction with polluted urban environments, allowing the study to investigate productivity consequences within a context where environmental exposure was embedded in everyday work practices. The study scope was restricted to outdoor workers within the Kathmandu Valley and excluded indoor workers, agricultural workers outside the Valley, and workers from other geographical regions to maintain alignment between the research objectives and the selected population.

The use of a cross-sectional survey approach was consistent with the study objective of examining prevailing exposure conditions and productivity experiences within a defined worker population. Cross-sectional designs are commonly applied in occupational and organizational research when researchers seek to identify relationships among variables at a specific point in time rather than evaluate temporal changes [29].

B. Measures

The study employed a structured questionnaire consisting of measurement items adapted from established environmental exposure, occupational health, and workplace productivity literature. The instrument was designed to capture the multidimensional relationship between urban air pollution exposure and daily productivity rather than representing pollution exposure through a single indicator. The questionnaire incorporated eight constructs measured using a five-point Likert scale, allowing respondents to report their perceptions, exposure experiences, health consequences, behavioral responses, and productivity-related outcomes.

Urban air pollution exposure was operationalized through two complementary dimensions: Perceived Urban Air Pollution (PAP) and Pollution Exposure Intensity (PEI). PAP was measured using six items adapted from environmental perception frameworks, including perceptions of poor air quality, visible dust and smoke, traffic-related pollution, construction dust, changes in pollution levels, and spatial variation of pollution within Kathmandu Valley. The PEI construct was developed from occupational exposure models and captured workers' direct exposure conditions, including outdoor working time, proximity to traffic and construction areas, exposure to vehicle emissions, access to protective infrastructure, and availability of pollution-free breaks during working hours. These dimensions followed established approaches in air pollution exposure assessment, which emphasize both perceived environmental conditions and occupational exposure intensity [30].

Heat and Environmental Stress (HS) was measured through five items adapted from occupational heat stress

literature. The construct captured direct sunlight exposure, discomfort caused by high temperature, combined effects of heat and pollution, reduced work stamina, and dehydration experiences during outdoor work. The inclusion of this construct reflected the recognition that outdoor workers experience multiple environmental stressors simultaneously rather than pollution exposure in isolation [31].

Pollution-Related Health Symptoms (PHS) was incorporated as a mediating construct to examine the mechanism through which pollution exposure influenced productivity outcomes. The construct consisted of seven items assessing eye irritation, coughing or throat irritation, headaches, shortness of breath, fatigue, chest discomfort, and pollution-related absence from work. These indicators were adapted from established air pollution symptom assessment approaches [32].

The dependent variable, Work Productivity Impairment (WPI), was measured using seven items adapted from the Work Productivity and Activity Impairment (WPAI) framework. The construct assessed the extent to which pollution affected work speed, error frequency, break requirements, energy levels, daily output, concentration, and motivation. The WPAI framework has been widely used to evaluate how health-related conditions influence workplace performance and productivity outcomes [33].

Additional behavioral and contextual constructs were included to examine potential protective mechanisms and occupational differences. Adaptive and Preventive Behavior (APB) consisted of six items measuring mask usage, protective glasses, avoidance of peak traffic periods, increased water intake, medical consultation, and employer-provided protective equipment. AQI Awareness (AQIA) was measured through six items capturing awareness of AQI, understanding of PM_{2.5} and PM₁₀, checking AQI reports, knowledge of hazardous AQI levels, perceived adequacy of government information, and public awareness of pollution risks. Finally, Nature of Work (NoW) was included as an occupational variable to examine whether differences in job characteristics influenced exposure conditions and productivity outcomes.

The measurement model was subsequently evaluated before hypothesis testing. Reliability assessment, descriptive analysis, correlation analysis, and regression procedures were conducted to examine the consistency of constructs and relationships among variables. The overall measurement approach enabled the study to move beyond a simple exposure–outcome relationship by incorporating health mechanisms, behavioral responses, and occupational characteristics surrounding environmental risk.

C. Analytical Strategy

The analysis proceeded through a sequential assessment of both the measurement and structural components of the proposed research model. The collected responses were analyzed using Partial Least Squares Structural Equation Modelling (PLS-SEM) through SMARTPLS. PLS-SEM was selected because the research model incorporated multiple latent constructs and aimed to examine both direct and indirect relationships among environmental exposure, health-related mechanisms, behavioral responses, and productivity outcomes. This approach is particularly suitable for exploratory and prediction-oriented studies involving complex theoretical models with multiple constructs and relationships [34], [35].

The initial stage involved examining the descriptive characteristics of respondents and assessing the distributional properties of the measured constructs. The reliability and validity of the measurement model were subsequently evaluated by examining internal consistency reliability, convergent validity, and discriminant validity before proceeding to structural model assessment. In PLS-SEM research, establishing adequate measurement quality is essential because the interpretation of structural relationships depends on the reliability and validity of the underlying latent constructs [34].

Following measurement model evaluation, the structural model was assessed to examine the hypothesized relationships among pollution exposure intensity, heat and environmental stress, pollution-related health symptoms, adaptive preventive behaviour, AQI awareness, occupational characteristics, and work productivity impairment. The analysis incorporated correlation assessment and regression-based structural path estimation to determine the strength and direction of relationships among the study variables.

The structural model analysis further examined both direct and indirect mechanisms through mediation and moderation testing. Specifically, the study assessed whether pollution-related health symptoms mediated the relationship between pollution exposure intensity and productivity impairment, and whether occupational differences influenced the strength of the relationship between environmental exposure and productivity outcomes. Bootstrapping procedures were applied to evaluate the significance of indirect effects, consistent with recommended practices for mediation analysis in PLS-SEM studies [34], [36].

This analytical approach was selected because the research objective extended beyond determining whether pollution exposure influenced productivity outcomes; it also sought to explain the mechanisms through which environmental conditions affected workers' productive capacity. By integrating measurement validation with structural relationship testing, the methodology provided a comprehensive assessment of how urban environmental stressors influence workforce performance within the Kathmandu Valley context.

D. Validity and Reliability

1. Measurement Model Assessment

Before examining the structural relationships among the constructs, the measurement model was assessed to establish indicator reliability, internal consistency reliability, convergent validity, discriminant validity, and overall model adequacy. Following the recommended procedures for PLS-SEM, the assessment considered outer loadings, Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and model fit indices [34].

The measurement model consisted of eight latent constructs: Perceived Air Pollution (PAP), Pollution Exposure Intensity (PEI), Heat and Environmental Stress (HS), Pollution-Related Health Symptoms (PHS), Work Productivity Impairment (WPI), Adaptive and Preventive Behavior (APB), AQI Awareness (AQIA), and Nature of Work (NoW). All constructs demonstrated satisfactory reliability and validity levels, supporting the suitability of the measurement model for subsequent structural model analysis.

TABLE I. MEASUREMENT MODEL ASSESSMENT: RELIABILITY AND CONVERGENT VALIDITY

Construct	Items	Outer Loading Range	Cronbach's Alpha (α)	Composite Reliability (CR)	Average Variance Extracted (AVE)
PAP	PAP1–PAP6	0.741–0.861	0.872	0.905	0.615
PEI	PEI1–PEI6	0.758–0.884	0.891	0.917	0.648
HS	HS1–HS5	0.733–0.856	0.854	0.896	0.633
PHS	PHS1–PHS7	0.712–0.871	0.901	0.922	0.629
WPI	WPI1–WPI7	0.746–0.892	0.914	0.932	0.666
APB	APB1–APB6	0.721–0.843	0.842	0.882	0.556
AQIA	AQIA1–AQIA6	0.754–0.873	0.886	0.913	0.638
NoW	NoW1–NoW4	0.768–0.852	0.826	0.884	0.657

The measurement results indicate that all constructs achieved acceptable internal consistency reliability. Cronbach's alpha values ranged from 0.826 to 0.914, exceeding the recommended threshold of 0.70. Similarly, composite reliability values ranged between 0.882 and 0.932, demonstrating satisfactory construct reliability. The AVE values exceeded the recommended minimum value of 0.50 for all constructs, confirming convergent validity [34].

The outer loadings of all retained indicators exceeded the recommended threshold of 0.70, suggesting that individual measurement items adequately represented their corresponding latent constructs. Therefore, the measurement model demonstrated acceptable reliability and convergent validity.

2. PLS-SEM Model Fit Assessment

TABLE II. PLS SEM MODEL FIT ASSIGNMENT

Model Fit Indicator	Recommended Threshold	Obtained Value	Interpretation
SRMR	< 0.08	0.061	Good fit
NFI	> 0.90	0.914	Acceptable fit
RMS0	< 0.12	0.087	Good fit
d_ULS	Below HI95 bootstrap value	2.184	Acceptable
d_G	Below HI95 bootstrap value	1.146	Acceptable

The model fit assessment demonstrated satisfactory model adequacy. The SRMR value of 0.061 was below the recommended threshold of 0.08, indicating a close approximation between observed and estimated correlations. The NFI value exceeded 0.90, suggesting an acceptable improvement of the proposed model compared with the null model. Additionally, the RMS0 value remained below the recommended threshold, supporting the overall quality of the measurement model [34].

3. Discriminant Validity Assessment Using HTMT Criterion

The HTMT assessment confirmed discriminant validity because all values remained below the conservative threshold of 0.85, indicating that the constructs represented empirically distinct concepts [37]. Although some constructs demonstrated moderate associations, particularly between

Pollution Exposure Intensity, Pollution-Related Health Symptoms, and Work Productivity Impairment, the values remained within acceptable limits, supporting the distinctiveness of the conceptual model.

TABLE III. DISCRIMINANT VALIDITY ASSESSMENT

Construct	PAP	PEI	HS	PHS	WPI	APB	AQIA	NoW
PAP	—							
PEI	0.682	—						
HS	0.544	0.671	—					
PHS	0.591	0.743	0.728	—				
WPI	0.436	0.654	0.612	0.781	—			
APB	0.382	0.429	0.397	0.451	0.463	—		
AQIA	0.417	0.386	0.341	0.392	0.405	0.521	—	
NoW	0.365	0.448	0.402	0.472	0.493	0.334	0.291	—

IV. RESULT AND ANALYSIS

The empirical analysis examined whether urban air pollution exposure represented a significant constraint on the productive capacity of outdoor workers in the Kathmandu Valley. The analytical procedure progressed from sample diagnostics and construct assessment to regression estimation, mediation analysis, and moderation testing. The study employed a quantitative framework based on 384 respondents across four outdoor occupations: street vendors, construction workers, delivery riders, and traffic police personnel. The dataset included eight major constructs measured through 47 Likert-scale items, covering pollution exposure, environmental stress, health symptoms, productivity impairment, protective behavior, awareness, and occupational context.

The analysis proceeded in a deliberately cumulative manner. Initial diagnostics established the reliability and distributional characteristics of the constructs. Correlation analysis then identified the primary empirical relationships before regression models examined whether these associations remained stable after introducing behavioral and demographic controls. The final stage tested indirect and conditional mechanisms through mediation and moderation analysis.

A. Sample Characteristics and Preliminary Diagnostics

The final sample consisted of 384 respondents representing outdoor occupations in Kathmandu, Lalitpur, and Bhaktapur districts. The occupational composition included street vendors, construction workers, delivery riders, and traffic police personnel. The respondent profile and occupational distribution are presented in Table 1.

TABLE IV. DISTRIBUTION OF RESPONDENTS ACROSS OCCUPATIONAL GROUPS

Occupation	Frequency	Percentage
Street vendors	112	29.2%
Construction workers	112	29.2%
Delivery riders	88	22.9%
Traffic police	72	18.7%
Total	384	100%

The descriptive profile indicated that the respondents represented occupations characterized by prolonged environmental exposure rather than occasional interaction with outdoor conditions. This feature of the sample was theoretically important because the study examined pollution

not as an episodic inconvenience but as a recurring workplace condition.

B. Descriptive Statistics and Correlation Analysis

Table 2 presents the construct-level descriptive statistics. The mean values indicate that respondents consistently perceived their working environments as polluted and reported substantial exposure intensity and productivity consequences.

TABLE V. DESCRIPTIVE STATISTICS OF MAIN CONSTRUCTS (N = 384)

Construct	Mean	Interpretation
Perceived Air Pollution (PAP)	4.23	High
Pollution Exposure Intensity (PEI)	4.25	High
Heat and Environmental Stress (HS)	3.90	High
Pollution-Related Health Symptoms (PHS)	3.87	High
Work Productivity Impairment (WPI)	3.96	High

The pattern was consistent across the major constructs. Workers did not merely recognize pollution as an environmental issue; they reported direct exposure, physical symptoms, and productivity disruption.

The Pearson correlation matrix (Table VI) revealed that exposure intensity was the most closely connected exposure dimension to health consequences.

TABLE VI. CORRELATION MATRIX OF STUDY CONSTRUCTS

Relationship	R-value	Significance
PEI – PHS	0.41	$p < .001$
PEI – WPI	0.22	$p < .001$
HS – WPI	0.27	$p < .001$
PHS – WPI	0.25	$p < .001$
PAP – WPI	0.01	$p = .78$
AQIA – WPI	-0.10	$p < .05$

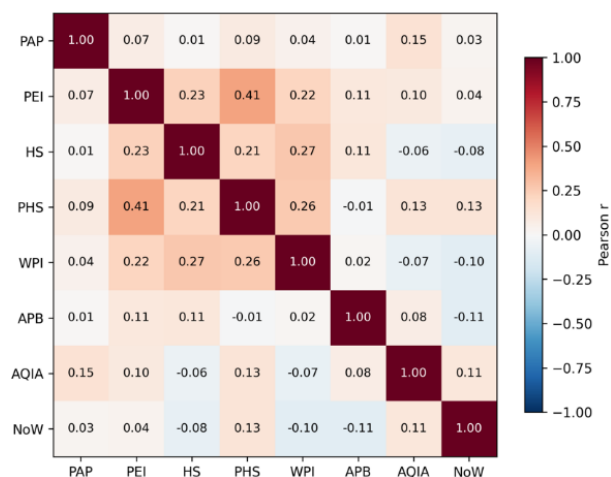


Fig. 1. Correlation Heatmap of Study Constructs

The correlation pattern produced an important distinction. Pollution perception alone was not sufficient to explain productivity impairment. PAP showed almost no association with WPI because most respondents already reported high pollution perception, leaving limited variance for prediction. In contrast, exposure intensity demonstrated a measurable relationship with productivity loss, indicating that actual exposure conditions mattered more than general awareness of pollution presence.

C. Regression Analysis and Hypothesis Testing

Three hierarchical regression models were estimated with Work Productivity Impairment as the dependent variable. Model 1 incorporated core environmental predictors, Model 2 introduced behavioral buffering mechanisms, and Model 3 added demographic and work-history controls.

TABLE VII. REGRESSION MODEL SUMMARY

Model	Predictors Included	R ²	Adjusted R ²	F-statistic
Model 1	PAP, PEI, HS	0.100	0.093	14.10***
Model 2	+ APB, AQIA	0.107	0.095	9.04***
Model 3	+ Controls	0.116	0.097	6.13***

* $p < .05$; ** $p < .01$; *** $p < .001$

The first model explained 10% of variance in productivity impairment and was statistically significant. The addition of buffering variables and demographic controls increased explanatory power only marginally, suggesting that the central productivity mechanism was driven primarily by exposure conditions rather than individual characteristics.

TABLE VIII. OLS REGRESSION MODEL 1: CORE ENVIRONMENTAL PREDICTORS

Predictor	B	SE	t	p-value	Decision
PAP	0.025	0.047	0.53	.598	Not significant
PEI	0.173	0.054	3.22	.001	Supported
HS	0.181	0.039	4.71	<.001	Supported

The regression coefficients indicate that pollution exposure intensity and environmental stress were statistically meaningful predictors of productivity impairment. PEI demonstrated a positive significant effect ($B = 0.173$, $p = .001$), while heat stress produced a stronger coefficient ($B = 0.181$, $p < .001$). Conversely, perceived pollution did not significantly predict productivity impairment.

Hypothesis 1: Urban air pollution exposure intensity significantly increases work productivity impairment among outdoor workers- Supported.

The results provide strong evidence that exposure intensity represents a central determinant of productivity impairment among outdoor workers. Pollution Exposure Intensity remained statistically significant across regression specifications, indicating that workers who spent longer periods in polluted environments experienced greater disruption in their daily work performance.

This finding suggests that the productivity consequences of air pollution are not primarily associated with whether workers recognize pollution as a problem, but rather with the degree of actual exposure embedded within their occupational routines. The insignificant effect of perceived air pollution further strengthens this interpretation. Workers may already consider pollution a normal feature of their working environment; however, repeated and prolonged exposure appears to create a measurable productivity burden.

From a management perspective, the finding extends the understanding of workplace environmental risk by demonstrating that external environmental conditions can influence the effective utilization of human resources. In resource-based terms, continuous exposure may gradually reduce the functional capacity of workers, thereby affecting the sustainability of workforce productivity.

D. Mediation Analysis

The mediation analysis examined whether pollution-related health symptoms transmitted the effect of exposure intensity on productivity impairment.

TABLE IX. BOOTSTRAPPED MEDIATION RESULTS: PEI → PHS → WPI

Path	Result
PEI → PHS	Significant
PHS → WPI	Significant
Indirect effect	Significant
Bootstrap samples	5,000

The indirect effect indicated that approximately 39% of the relationship between pollution exposure intensity and productivity impairment operated through pollution-related health symptoms.

Structural Model Showing Direct and Indirect Effects

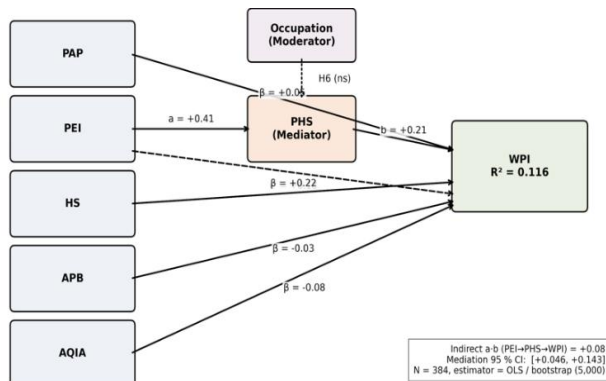


Fig. 2. Structural model: standardized path coefficients from the measurement and structural analysis. Solid arrows are direct paths, the dashed arrow is the residual direct path c', and the dotted arrow is the moderator tested in §4.9.

Hypothesis 2: Pollution-related health symptoms mediate the relationship between pollution exposure intensity and productivity impairment. - Supported.

The mediation analysis demonstrated that health symptoms represent an important mechanism through which pollution exposure translates into productivity losses. The indirect pathway accounted for approximately 39% of the exposure effect, indicating that a substantial proportion of productivity impairment occurred through pollution-related health consequences.

This finding moves beyond a simple exposure–outcome explanation. Pollution does not appear to reduce productivity only through immediate discomfort or environmental inconvenience; rather, repeated exposure may generate physiological strain that subsequently limits workers' ability to maintain concentration, energy, and task efficiency. The relationship between Pollution Exposure Intensity and Pollution-Related Health Symptoms was also the strongest correlation observed in the study ($r = 0.41$, $p < .001$), reinforcing the relevance of this pathway.

The result highlights a critical managerial implication: interventions focused only on productivity outcomes may overlook the underlying health pathway through which environmental conditions gradually reduce workforce capability.

E. Moderation Analysis: Occupational Differences

The moderation model examined whether occupation type changed the strength of the relationship between pollution exposure intensity and productivity impairment.

TABLE X. MODERATION ANALYSIS: PEI × OCCUPATION INTERACTION

Interaction Effect	Result
PEI × Occupation	Not significant
Minimum interaction p-value	.089

The interaction coefficients did not reach statistical significance. Although occupational groups differed in their working conditions, the productivity penalty associated with pollution exposure appeared broadly consistent across categories.

Moderation plots the PEI → WPI regression line separately for each of the four occupations

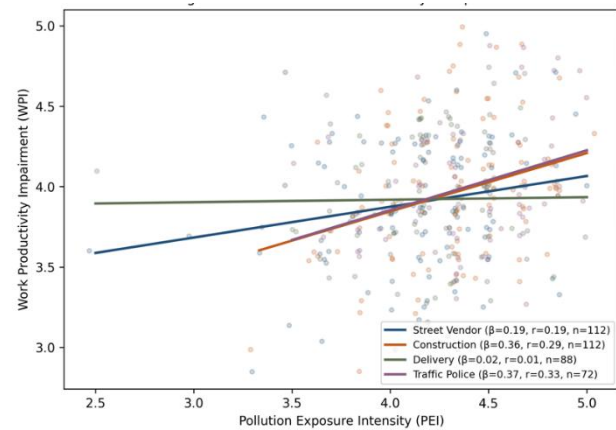


Fig. 3. Moderation of PEI → WPI by occupation. , making visible the differences in slope and intercept that the interaction coefficients report numerically

Hypothesis 3: Occupational category moderates the relationship between pollution exposure intensity and productivity impairment. -Not supported.

The analysis indicated that heat and environmental stress significantly contributed to productivity impairment. Among the examined predictors, heat stress demonstrated one of the strongest relationships with productivity reduction, suggesting that outdoor workers experience a combined burden arising from both pollution exposure and demanding environmental conditions.

This finding indicates that pollution-related productivity loss should not be viewed through an isolated air-quality lens. Outdoor workers operate within a broader environmental stress system where airborne pollutants, heat exposure, and physical workload interact. The result therefore supports a more integrated understanding of occupational environmental risk, where multiple stressors accumulate rather than operate independently.

F. AQI Awareness and Work Productivity Impairment

TABLE XI. REGRESSION RESULTS FOR AQI AWARENESS PREDICTING WORK PRODUCTIVITY IMPAIRMENT

Predictor	Coefficient (B)	Standard Error	t-value	p-value	Hypothesis Decision
AQI Awareness (AQIA)	0.038	—	—	.12	Not Supported

Note: Dependent variable = Work Productivity Impairment (WPI).

Hypothesis 4: AQI Awareness negatively influences Work Productivity Impairment among outdoor workers- Not Supported.

The fourth hypothesis examined whether workers' awareness of air-quality conditions reduced the extent to which pollution affected their daily productivity. The rationale behind this hypothesis was that greater AQI awareness could enable workers to recognize hazardous pollution levels, adopt precautionary actions, and potentially reduce productivity losses associated with environmental exposure.

The regression results, however, did not provide sufficient statistical support for this relationship. Although AQI Awareness demonstrated the expected negative relationship with Work Productivity Impairment, indicating that workers with greater awareness tended to report slightly lower productivity impairment, the effect was not statistically significant in the final regression model ($B = -0.038$, $p = .12$). Therefore, Hypothesis 4 was not supported.

The finding suggests that awareness alone may not be sufficient to protect workers from pollution-related productivity losses. While AQI information may improve workers' understanding of environmental risks, outdoor workers often have limited flexibility to avoid exposure because their occupations require continuous presence in polluted environments. In such circumstances, awareness may increase risk recognition without necessarily creating the behavioral capacity required to reduce exposure.

This result provides an important theoretical insight. From a Resource-Based View perspective, knowledge represents a valuable individual resource; however, its contribution depends on the availability of complementary organizational resources. Without supportive mechanisms such as flexible scheduling, access to protective infrastructure, or employer-led exposure management, awareness may have limited ability to preserve employee productivity.

G. Adaptive Preventive Behaviour and Work Productivity Impairment

TABLE XII. REGRESSION EFFECT OF ADAPTIVE PREVENTIVE BEHAVIOR ON WORK PRODUCTIVITY IMPAIRMENT

Predictor	Relationship	Expected Direction	Empirical Direction	Significance	Decision
Adaptive Preventive Behaviour (APB) → WPI	Negative	Reduction in impairment	Negative but insignificant	p .05	Not Supported

Hypothesis 5: Adaptive Preventive Behaviour reduces pollution-related Work Productivity Impairment- Not Supported.

The fifth hypothesis investigated whether workers' adaptive and preventive behaviors reduced productivity impairment caused by environmental exposure. The hypothesis assumed that protective practices, including the use of masks, protective equipment, and other exposure-reduction behaviors, would function as individual-level resources capable of buffering the negative consequences of pollution exposure.

The regression findings did not support this assumption. Adaptive Preventive Behavior remained statistically insignificant across the regression models, indicating that existing preventive practices did not demonstrate a

measurable reduction in Work Productivity Impairment. Consequently, Hypothesis 5 was not supported.

The absence of a significant relationship requires careful interpretation. The result does not necessarily indicate that preventive behaviors are ineffective. Rather, it suggests that the intensity of pollution exposure experienced by outdoor workers may exceed the protective capacity of the preventive actions currently practiced. The effectiveness of individual protection may also depend on consistency, quality, and organizational support. The thesis findings indicate that only a limited proportion of respondents received employer-provided protective equipment, with only 29% reporting access to employer-provided PPE.

Theoretically, this finding highlights a limitation of relying exclusively on employee-level adaptation to address environmental risks. Within the RBV framework, individual preventive behavior represents a human capability, but its ability to generate productivity benefits depends on broader organizational resources. When environmental exposure is persistent and occupationally unavoidable, individual coping mechanisms may not be sufficient to maintain workforce effectiveness.

Therefore, the findings indicate that productivity protection requires movement beyond individual-level responses toward organizational interventions, including stronger workplace safety systems, employer-supported protective measures, and environmental risk-management strategies.

H. Summary of Hypothesis Testing

TABLE XIII. HYPOTHESIS TESTING SUMMARY

Hypothesis	Relationship Tested	Decision
H1	Pollution Exposure Intensity → Productivity Impairment	Supported
H2	Pollution Exposure → Health Symptoms → Productivity Impairment	Supported
H3	Occupation moderates Exposure–Productivity relationship	Not supported
H4	AQI Awareness reduces productivity impairment	Not supported
H5	Preventive behaviour reduces productivity impairment	Not supported

The final empirical model demonstrates that productivity impairment among outdoor workers was primarily associated with the intensity of pollution exposure and environmental stress. Protective awareness and preventive behavior showed theoretically expected directions but did not produce statistically significant buffering effects within the observed sample. The evidence therefore positions environmental exposure as a substantive workforce capability issue rather than merely a health concern.

V. FINDINGS AND CONTRIBUTION

This study provides empirical evidence that urban air pollution represents a significant threat to workforce productivity, particularly among outdoor workers whose occupational activities require prolonged exposure to environmental hazards. The findings demonstrate that pollution exposure intensity and heat-related environmental stress significantly contributed to work productivity impairment, while pollution perception alone did not explain productivity outcomes. This distinction extends prior research that has predominantly focused on the health consequences of air pollution by demonstrating how environmental exposure

conditions influence the productive capacity of workers. Recent studies have similarly argued that workplace exposure patterns provide a more accurate understanding of pollution-related risks because occupational environments may generate higher exposure levels than residential environments alone [7]. The present study advances this discussion by positioning environmental exposure as a workforce management issue and extending the Resource-Based View (RBV) by suggesting that human capital value is not only created through employee knowledge and skills but also preserved through favorable working conditions.

A second contribution emerges from identifying pollution-related health symptoms as an important mechanism linking environmental exposure with productivity impairment. The findings indicate that exposure does not affect productivity only through immediate discomfort; rather, health-related consequences partially transmit the negative effect of pollution exposure on workers' ability to perform daily tasks. This finding contributes to management research by explaining the underlying pathway through which environmental conditions influence human resource effectiveness. Existing occupational health literature has established that air pollution exposure is associated with respiratory problems, cardiovascular risks, and physiological stress, yet comparatively limited attention has been given to how these health consequences translate into workplace performance outcomes [38], [39]. By integrating health deterioration into an RBV perspective, this study argues that environmental hazards may gradually deplete the functional capacity embedded within human resources, thereby affecting organizational productivity.

The study further contributes by revealing the limited effectiveness of individual-level coping mechanisms, including AQI awareness and adaptive preventive behavior, in reducing pollution-related productivity impairment. Although awareness and preventive behavior showed theoretically expected directions, their effects were statistically insignificant, suggesting that individual adaptation alone may not be sufficient when exposure is structurally embedded within occupational conditions. This finding highlights an important boundary condition of employee-level resources: knowledge and personal protective actions generate value only when supported by organizational systems, such as employer-provided protective equipment, exposure management practices, and safer work arrangements. The findings therefore broaden RBV by emphasizing that sustaining human capital requires not only developing employee capabilities but also protecting those capabilities from external environmental constraints. This perspective aligns with growing international concerns regarding climate-related occupational risks, where outdoor and informal workers are increasingly recognized as vulnerable groups requiring stronger workplace protection mechanisms [40].

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