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Factors Associated with Health Risk Quotient among Communities Exposed to PM2.5 from Stone Crushing Plants in Chonburi Province Thailand

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Research Article

Keywords: PM2.5, Health risk assessment, Hazard quotient, Stone crushing plant, Environmental exposure, Thailand

Posted Date: August 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10160540/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Communities living near stone crushing plants may be exposed to elevated levels of particulate matter ($PM_{2.5}$), increasing potential health risks. This study aimed to identify factors associated with the health risk quotient (HQ) among communities exposed to $PM_{2.5}$ from stone crushing plants in Chonburi Province, Thailand.

Methods

A community-based cross-sectional study was conducted among 368 residents selected using stratified random sampling. $PM_{2.5}$ concentrations were measured at two fixed-site monitoring stations near a stone crushing plant. The average concentration was used to estimate exposure and calculate HQ using the United States Environmental Protection Agency health risk assessment framework. Data were analyzed using Pearson correlation and multiple linear regression analyses.

Results

The mean HQ was 0.996 ± 0.175, and 46.5% of participants had HQ values greater than 1. Pearson correlation analysis identified significant associations between HQ and sex, occupation, distance from the stone crushing plant, primary construction material, household ventilation system, and educational attainment ($p < 0.05$). Multiple linear regression analysis revealed that female sex ($\beta = 0.251$, $p < 0.001$) and a bachelor's degree or higher ($\beta = 0.137$, $p = 0.038$) were significantly associated with higher HQ values.

Conclusions

Nearly half of the participants had HQ values exceeding the acceptable threshold. Female residents and those with higher educational attainment were more likely to have elevated HQ values. These findings support the need for continued air quality monitoring and targeted risk reduction measures in communities surrounding stone crushing plants.

1 Introduction

Air pollution remains one of the most significant environmental health challenges worldwide and continues to contribute substantially to global morbidity and mortality. The World Health Organization (WHO) has identified ambient air pollution as a major public health concern, particularly in rapidly urbanizing and industrializing regions [1, 2]. Among various air pollutants, particulate matter with an

aerodynamic diameter of less than 2.5 micrometers ($PM_{2.5}$) is considered especially hazardous because of its ability to penetrate deeply into the respiratory system and enter the bloodstream [3]. Fine particulate matter has been associated with a wide range of adverse health outcomes, including respiratory diseases, cardiovascular diseases, lung cancer, and premature mortality [4–7]. According to the State of Global Air Report 2024, air pollution remains one of the leading environmental risk factors worldwide, accounting for millions of premature deaths annually [8]. Furthermore, the WHO Air Quality Guidelines recommend maintaining annual $PM_{2.5}$ concentrations at levels substantially lower than those observed in many industrial and urban environments [9].

The health impacts of $PM_{2.5}$ exposure have been extensively documented in both developed and developing countries. Long-term exposure to elevated concentrations of particulate matter has been associated with increased risks of chronic respiratory symptoms, asthma exacerbations, reduced lung function, cardiovascular morbidity, and all-cause mortality [3–7, 10]. Individuals living near industrial emission sources are particularly vulnerable because of their continuous exposure to airborne pollutants. Stone crushing plants are recognized as important sources of particulate emissions generated during blasting, crushing, screening, material handling, and transportation processes [11, 12]. Occupational studies among workers in quarry and stone processing industries have demonstrated significant respiratory health effects associated with dust exposure [11]. In addition, communities residing in surrounding areas may experience prolonged environmental exposure, resulting in elevated health risks despite not being directly involved in industrial activities [12].

In Thailand, $PM_{2.5}$ pollution has become an increasingly important environmental and public health issue. National air quality monitoring reports have shown that $PM_{2.5}$ concentrations frequently exceed recommended standards in several provinces, particularly those characterized by industrial activities and dense transportation networks [13]. Recent health surveillance data from the Ministry of Public Health indicate a substantial burden of respiratory and cardiovascular diseases potentially associated with air pollution exposure [14]. Chonburi Province is one of Thailand's major industrial centers and contains numerous licensed stone crushing and stone processing facilities [15]. Environmental assessments conducted in the province have reported concerns regarding particulate emissions and their potential impacts on nearby communities [16]. Previous studies conducted in Thailand, particularly those undertaken in communities surrounding stone crushing and mineral processing operations in Saraburi Province, have demonstrated elevated health risks among residents exposed to particulate matter, especially during periods of increased particulate concentrations [12, 17].

Health risk assessment provides an important framework for evaluating the potential health impacts associated with environmental exposure. The Hazard Quotient (HQ) is widely used as an indicator of non-carcinogenic health risk by comparing estimated exposure levels with established reference doses [18]. Exposure assessment approaches incorporating environmental concentrations, inhalation rates, and individual exposure characteristics have been applied extensively in air pollution studies [19, 20]. However, despite growing concerns regarding $PM_{2.5}$ exposure in communities surrounding stone

crushing plants, most previous studies have focused primarily on environmental monitoring and health risk estimation, while limited evidence exists regarding the determinants of health risk quotient (HQ) among affected populations in Thailand. Understanding these determinants is essential for identifying vulnerable groups and developing targeted risk reduction strategies. Therefore, this study aimed to identify factors associated with the health risk quotient (HQ) among communities exposed to $PM_{2.5}$ from stone crushing plants in Chonburi Province, Thailand.

2 Methods

2.1 Study design and study area

A community-based cross-sectional study was conducted among residents living in communities surrounding a stone crushing plant in Chonburi Province, Thailand. The study area was selected because of its proximity to a large-scale stone crushing operation and concerns regarding particulate matter emissions from industrial activities. Data collection was conducted between March and April 2026.

2.2 Study population and sample size

The target population comprised residents aged 18 years and older who had continuously resided within a 5-km radius of the stone crushing plant for at least one year. Individuals who were unable to communicate effectively or provide informed consent were excluded from the study.

The sample size was calculated using Daniel's formula for estimating a population proportion. Based on a population of 17,395 residents [21], a confidence level of 95% (Z = 1.96), an expected proportion of 0.33 [17], and a margin of error of 0.05, the minimum required sample size was 334 participants. To compensate for potential non-response, an additional 10% was added, resulting in a final sample size of 368 participants.

A stratified random sampling technique was used to allocate participants proportionally across villages according to population size. Subsequently, simple random sampling was applied to select eligible participants within each stratum. A total of 368 participants were recruited and included in the analysis.

2.3 $PM_{2.5}$ exposure assessment

Ambient $PM_{2.5}$ concentrations were measured at two fixed-site air monitoring stations located approximately 850 m and 1.0 km from the selected stone crushing plant. Air sampling was conducted continuously for 72 hours between 25 and 27 March 2026. The average $PM_{2.5}$ concentration obtained from both monitoring stations was used as the representative exposure concentration for health risk assessment.

2.4 Health risk assessment

Non-carcinogenic health risk associated with $PM_{2.5}$ exposure was assessed using the Hazard Quotient (HQ) approach recommended by the United States Environmental Protection Agency (US EPA) [18].

The average daily dose (ADD) was calculated using the following equation:

$$\mathrm{ADD} = \frac{(\mathrm{C\ x\ IR\ x\ ET\ x\ EF\ x\ ED})}{(\mathrm{BW\ x\ AT})}$$

1

where C is the $PM_{2.5}$ concentration (mg/m³), IR is the inhalation rate (0.83 m³/hour), ET is the exposure time (24 hours/day), EF is the exposure frequency (365 days/year), ED is the exposure duration (years), BW is body weight (kg), and AT is the averaging time (days).

The Hazard Quotient was calculated as: $\mathrm{HQ} = \frac{\mathrm{ADD}}{\mathrm{RfD}}$ (2)

where the reference dose (RfD) was 0.005 mg/kg/day. HQ values ≤ 1 were considered acceptable, whereas HQ values > 1 indicated a potential non-carcinogenic health risk. HQ was treated as a continuous dependent variable in subsequent statistical analyses.

2.5 Data collection and research instrument

Data were collected through face-to-face interviews using a structured questionnaire administered by the principal investigator and trained research assistants.

The questionnaire consisted of three sections:

1. Demographic characteristics, including sex, age, marital status, education, occupation, and income.
2. Health characteristics, including respiratory symptoms and underlying diseases.
3. Residential and environmental characteristics, including duration of residence, distance from the stone crushing plant, type of residence, primary construction material, household ventilation system, and domestic animal raising around the household.

Content validity was evaluated by three experts in environmental health and occupational health. The questionnaire demonstrated excellent content validity, with an item-objective congruence (IOC) index of 0.95.

A pilot study involving 30 residents from a community with characteristics similar to the study area was conducted prior to the main survey. Reliability testing demonstrated acceptable internal consistency, with a Cronbach's alpha coefficient of 0.856.

2.6 Statistical analysis

Data were analyzed using IBM SPSS Statistics version 26. Descriptive statistics were used to summarize participant characteristics and HQ values. Continuous variables were presented as mean and standard

deviation (SD), whereas categorical variables were presented as frequency and percentage.

Pearson correlation analysis was performed to examine bivariate associations between participant characteristics and HQ. Variables identified from the correlation analysis together with theoretically relevant variables were subsequently entered into a multiple linear regression model using the enter method to identify independent determinants of HQ.

Unstandardized coefficients (B), standardized coefficients (β), 95% confidence intervals (95% CI), and p-values were reported. Multicollinearity was assessed using variance inflation factor (VIF) and tolerance statistics. No evidence of multicollinearity was observed among the independent variables (all VIF values < 2.0 and tolerance values > 0.50). Statistical significance was set at $p < 0.05$.

3 Results

3.1 Characteristics of participants

The characteristics of the participants are presented in Table 1. Of the 368 participants, 54.3% were female and the mean age was 46.02 ± 10.59 years. Approximately half of the participants were married or living together (50.8%). Most participants had completed primary or secondary education (71.5%) and worked in agriculture or labor-related occupations (54.9%). The mean monthly income was 12,350.41 ± 6,971.74 Baht. More than half of the participants reported respiratory symptoms (57.9%), while 25.8% had underlying diseases. The mean duration of residence in the study area was 25.67 ± 11.60 years, and the average distance between participants' residences and the stone crushing plant was 3.46 ± 1.52 km. The mean health risk quotient (HQ) was 0.996 ± 0.175. Overall, 46.5% of participants had HQ values greater than 1, indicating potential non-carcinogenic health risks associated with $PM_{2.5}$ exposure (Table 1).

Table 1
Characteristics of participants (n = 368)

Characteristics	**n (%) / Mean ± SD**
Sex	
Male	168 (45.7)
Female	200 (54.3)
Age (years)	46.02 ± 10.59
Body weight (kg)	64.55 ± 11.45
Marital status	
Single	107 (29.1)
Married/Living together	187 (50.8)
Widowed	52 (14.1)
Divorced/Separated	22 (6.0)
Education level	
Primary school	136 (37.0)
Secondary school	127 (34.5)
Diploma/Vocational certificate	44 (12.0)
Bachelor's degree or higher	61 (16.6)
Occupation	
Agriculture/Labor	202 (54.9)
Self-employed/Business	75 (20.4)
Company employee/Government officer	44 (12.0)
Unemployed/Student	47 (12.8)
Monthly income (Baht)	12,350.41 ± 6,971.74
Respiratory symptoms	
No	155 (42.1)
Yes	213 (57.9)
Underlying disease	

Note: Data are presented as n (%) or mean ± standard deviation (SD). HQ = health risk quotient.

Characteristics	n (%) / Mean ± SD
Sex	
No	273 (74.2)
Yes	95 (25.8)
Duration of residence (years)	25.67 ± 11.60
Distance from stone crushing plant (km)	3.46 ± 1.52
Health Risk Quotient (HQ)	0.996 ± 0.175
HQ ≤ 1	197 (53.5)
HQ > 1	171 (46.5)
Note: Data are presented as n (%) or mean ± standard deviation (SD). HQ = health risk quotient.	

3.2 Pearson correlation analysis between participant characteristics and health risk quotient

Pearson correlation analysis was performed to examine the associations between participant characteristics and HQ (Table 2). Significant positive correlations were observed between HQ and sex ($r = 0.296$, $p < 0.001$), occupation ($r = 0.128$, $p = 0.007$), distance from the stone crushing plant ($r = 0.138$, $p = 0.004$), primary construction material ($r = 0.153$, $p = 0.002$), household ventilation system ($r = 0.134$, $p = 0.005$), and bachelor's degree or higher education ($r = 0.230$, $p < 0.001$). In contrast, secondary school education was negatively correlated with HQ ($r = -0.135$, $p = 0.005$). No statistically significant correlations were observed between HQ and income, respiratory symptoms, underlying disease, duration of residence, type of residence, domestic animal raising, marital status, or diploma/vocational certificate education ($p > 0.05$).

Variables identified from the correlation analysis together with theoretically relevant variables were subsequently entered into the multiple linear regression model.

Table 2
Pearson correlation analysis between participant characteristics and health risk quotient (HQ) among communities surrounding stone crushing plants (n = 368)

Variable	r	p-value
Sex	0.296	< 0.001*
Occupation	0.128	0.007*
Income	0.037	0.242
Respiratory symptoms	-0.025	0.314
Underlying disease	0.031	0.279
Duration of residence	0.001	0.489
Distance	0.138	0.004*
Type of residence	-0.060	0.126
Primary construction material	0.153	0.002*
Household ventilation system	0.134	0.005*
Domestic animal raising	-0.002	0.484
Married	-0.046	0.188
Widowed/Divorced	0.041	0.216
Secondary education	-0.135	0.005*
Diploma	-0.086	0.051
Bachelor's degree or higher	0.230	< 0.001*
Note: r = Pearson correlation coefficient. *p < 0.05.		

3.3 Multiple linear regression analysis of factors associated with health risk quotient

The results of the multiple linear regression analysis are presented in Table 3. After adjustment for potential confounding variables, female sex and educational attainment at the bachelor’s degree level or higher remained significantly associated with HQ.

Female participants had significantly higher HQ values than male participants (β = 0.251, p < 0.001). Participants with a bachelor’s degree or higher also had significantly higher HQ values than those with primary school education (β = 0.137, p = 0.038).

No statistically significant associations were found between HQ and occupation, income, respiratory symptoms, underlying disease, duration of residence, distance from the stone crushing plant, type of residence, primary construction material, household ventilation system, domestic animal raising, marital status, secondary school education, or diploma/vocational certificate education ($p > 0.05$).

The final model explained 15.8% of the variance in HQ ($R^2 = 0.158$, Adjusted $R^2 = 0.120$) and was statistically significant overall ($F = 4.130$, $p < 0.001$).

Table 3
Multiple linear regression analysis of factors associated with health risk quotient (HQ) among communities surrounding stone crushing plants (n = 368)

Variables	B	SE	β	t	p-value	95% CI for B
Constant	0.756	0.079	–	9.529	< 0.001	0.600–0.913
Sex	0.088	0.018	0.251	4.751	< 0.001*	0.051–0.124
Occupation	0.001	0.008	0.009	0.169	0.866	-0.015–0.018
Income	-1.12×10^{-6}	0.000	-0.045	-0.771	0.441	0.000–0.000
Respiratory symptoms	-0.004	0.018	-0.010	-0.203	0.839	-0.038–0.031
Underlying disease	-0.009	0.021	-0.023	-0.450	0.653	-0.050–0.031
Duration of residence	0.000	0.001	0.012	0.234	0.815	-0.001–0.002
Distance from stone crushing plant	0.008	0.006	0.071	1.333	0.183	-0.004–0.020
Type of residence	-0.005	0.019	-0.013	-0.247	0.805	-0.043–0.033
Primary construction material	0.033	0.022	0.083	1.481	0.140	-0.011–0.077
Household ventilation system	0.034	0.020	0.095	1.738	0.083	-0.005–0.073
Domestic animal raising	-0.002	0.018	-0.006	-0.106	0.915	-0.038–0.034
Married (ref = Single)	-0.006	0.021	-0.018	-0.295	0.768	-0.047–0.035
Widowed/Divorced (ref = Single)	-0.005	0.028	-0.013	-0.198	0.843	-0.060–0.049

Note: B = unstandardized regression coefficient; SE = standard error; β = standardized regression coefficient; CI = confidence interval. Reference categories were male for sex, single for marital status, and primary school education for educational attainment. Multiple linear regression analysis was performed using the enter method. $R^2 = 0.158$; Adjusted $R^2 = 0.120$; $F = 4.130$; $p < 0.001$. *$p < 0.05$.

Variables	B	SE	β	t	p-value	95% CI for B
Secondary school (ref = Primary school)	-0.033	0.022	-0.089	-1.484	0.139	-0.076–0.011
Diploma/Vocational certificate (ref = Primary school)	-0.033	0.033	-0.061	-1.000	0.318	-0.097–0.032
Bachelor's degree or higher (ref = Primary school)	0.064	0.031	0.137	2.086	0.038*	0.004–0.125

Note: B = unstandardized regression coefficient; SE = standard error; β = standardized regression coefficient; CI = confidence interval. Reference categories were male for sex, single for marital status, and primary school education for educational attainment. Multiple linear regression analysis was performed using the enter method. $R^2 = 0.158$; Adjusted $R^2 = 0.120$; $F = 4.130$; $p < 0.001$. *$p < 0.05$.

4 Discussion

This study investigated factors associated with the health risk quotient (HQ) among communities exposed to $PM_{2.5}$ from stone crushing plants in Chonburi Province, Thailand. The findings indicated that the mean HQ was 0.996 ± 0.175, and nearly half of the participants (46.5%) had HQ values greater than 1.0, suggesting a potential non-carcinogenic health risk from long-term $PM_{2.5}$ exposure. Multiple linear regression analysis identified sex and educational attainment as independent determinants of HQ, whereas occupation, income, respiratory symptoms, underlying disease, duration of residence, distance from the stone crushing plant, residential characteristics, and marital status were not independently associated with HQ.

The present study found that female participants had significantly higher HQ values than males. This finding is consistent with previous studies reporting that women may experience greater susceptibility to particulate matter exposure because of physiological differences, activity patterns, and time spent in residential environments where exposure occurs [3, 22]. Women living in rural and peri-urban communities often spend more time performing household activities and remaining within residential settings, thereby increasing cumulative exposure to ambient particulate matter [22, 23]. Previous epidemiological studies have also demonstrated sex-related differences in vulnerability to adverse health outcomes associated with air pollution exposure [22, 24, 25]. In particular, Chi et al. [25] reported increased susceptibility to $PM_{2.5}$-related cardiovascular effects among postmenopausal women, suggesting that women may be more vulnerable to the adverse health effects of particulate matter exposure.

Educational attainment at the bachelor's degree level or higher was also significantly associated with higher HQ values compared with primary school education. In the present study, individuals with higher

educational attainment may have had different daily mobility patterns, occupational activities, transportation behaviors, or residential exposure characteristics that contributed to increased cumulative $PM_{2.5}$ exposure. Although higher educational attainment is generally associated with improved health literacy and preventive health behaviors, socioeconomic and educational factors may also influence environmental exposure patterns through differences in residential environments, commuting behaviors, and occupational characteristics [24, 25]. Therefore, the positive association observed in this study may reflect differences in environmental exposure circumstances rather than a direct effect of educational attainment itself.

The average HQ observed in this study was close to the threshold value of one, indicating that a substantial proportion of residents may be exposed to $PM_{2.5}$ at levels that could contribute to adverse health effects. This finding is consistent with previous studies conducted in communities located near stone crushing, quarrying, and mineral processing operations, where elevated particulate matter concentrations were associated with increased respiratory symptoms and higher health risk estimates [11, 12, 17, 26]. Stone crushing activities generate airborne particulate matter through blasting, crushing, screening, transportation, and material handling processes, all of which contribute to environmental emissions affecting nearby communities [11, 12]. Previous studies have reported that residents living near quarrying and stone processing facilities may experience prolonged exposure to particulate matter and consequently elevated health risks [12, 17].

Interestingly, distance from the stone crushing plant was significantly correlated with HQ in the Pearson correlation analysis but did not remain significant in the multiple linear regression model. This finding suggests that the relationship between distance and HQ may be influenced by other environmental and individual-level factors included in the regression model. Similar observations have been reported in environmental exposure studies, which found that particulate matter exposure is affected not only by distance from the emission source but also by meteorological conditions, terrain characteristics, housing structures, ventilation characteristics, and individual activity patterns [19, 20, 23, 27]. Consequently, residential distance alone may not adequately reflect individual exposure levels in communities located near industrial emission sources.

This study has several strengths. First, it applied a quantitative health risk assessment approach using the hazard quotient framework recommended by the United States Environmental Protection Agency, providing an objective estimate of non-carcinogenic health risk associated with $PM_{2.5}$ exposure [18]. Second, the study included a relatively large community-based sample and incorporated multiple demographic, environmental, and residential variables into the analysis. Furthermore, the use of multiple linear regression analysis allowed adjustment for potential confounding factors and facilitated identification of independent determinants of HQ.

However, several limitations should be acknowledged. $PM_{2.5}$ concentrations were obtained from fixed-site monitoring stations and may not fully represent individual exposure variability. In addition, the cross-sectional design limits causal inference between participant characteristics and HQ. Future studies

should incorporate personal exposure monitoring, spatial exposure modeling, and longitudinal study designs to better evaluate exposure-response relationships and improve the accuracy of individual risk estimation [19, 23].

5 Conclusion

The findings of this study suggest that female residents and individuals with higher educational attainment may experience higher $PM_{2.5}$-related health risks in communities surrounding stone crushing plants. Nearly half of the participants had HQ values exceeding the acceptable threshold, indicating potential non-carcinogenic health risks associated with long-term $PM_{2.5}$ exposure. These findings highlight the importance of identifying vulnerable populations and strengthening environmental health protection measures in communities located near stone crushing plants.

Environmental and public health agencies should strengthen continuous air quality monitoring and implement effective dust-control measures in areas surrounding stone crushing operations. Community-based risk communication programs should be developed to increase awareness of $PM_{2.5}$ exposure and promote preventive behaviors among residents. Future studies should employ longitudinal study designs and personal exposure monitoring to improve exposure assessment accuracy and further investigate environmental, behavioral, and occupational determinants of health risk associated with particulate matter exposure.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Human Research Ethics Committee of Mahasarakham University (Approval No. 081–012/2569). All procedures involving human participants were performed in accordance with the ethical standards of the Human Research Ethics Committee of Mahasarakham University and the Declaration of Helsinki and its later amendments or comparable ethical standards. Written informed consent was obtained from all participants prior to participation in the study.

Clinical trial number

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Funding

This research was financially supported by Mahasarakham University, Thailand.

Author Contribution

JM: Conceptualization, study design, data collection, statistical analysis, interpretation of findings, and manuscript drafting.TB: Study design, interpretation of findings, and critical revision of the manuscript.WT: Study design, interpretation of findings, and critical revision of the manuscript.JW: Study supervision, academic guidance, critical manuscript review, and final approval of the manuscript.All authors read and approved the final manuscript.

Acknowledgement

The authors would like to express their sincere gratitude to the village health volunteers and local administrative officers in Huai Kapi Subdistrict, Chonburi Province, for their assistance with participant recruitment and data collection. The authors also gratefully acknowledge all participants and research assistants for their valuable cooperation and support throughout the study.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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