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RESEARCH

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Dust Exposure in the Stone Carving Industry and Its Impact on Respiratory Health: An Environmental Risk Assessment

Sutaryono^{1a*}, Rezyana Budi Syahputri^{1b}, Heru Subaris Kasjono^{2c}, Tuti Susilowati^{3d}, Teguh Setyadi^{4e}, Purwanti^{4f}, Sukamsi^{4g}, Dhanik Ernawati^{4h}, Mohamad Samsudin⁵ⁱ, Taufiq Hidayat^{5j}

¹ Health Program Administration, Faculty of Health and Technology, Universitas Muhammadiyah Klaten, Klaten, Central Java, Indonesia

² Politeknik Kesehatan Kementerian Kesehatan, Sleman, Yogyakarta, Indonesia

³ Politeknik Kesehatan Permata Indonesia Yogyakarta, Sleman, Yogyakarta, Indonesia

⁴ Bappeda dan Litbangda Kabupaten Magelang, Magelang Regency, Central Java, Indonesia

⁵ Badan Riset dan Inovasi Nasional (BRIN), Magelang Regency, Central Java, Indonesia

^a Email: sutaryono@umkla.ac.id

^b Email: rezyanabs@umkla.ac.id

^c Email: kherusubaris@gmail.com

^d Email: tutisusilowati2908@gmail.com

^e Email: guhse16@gmail.com

^f Email: purwanti1809@gmail.com

^g Email: kambappedadanlitbangda@gmail.com

^h Email: rayrafasya@gmail.com

ⁱ Email: sam_gaki@yahoo.co.id

^j Email: tyo80@yahoo.co.id

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Abstract

Stone carving in Magelang Regency holds significant potential to enhance community welfare through industrial and tourism development, but it also presents health risks due to PM10 dust exposure exceeding safe limits. This study aims to identify respiratory health risks of stone craftsmen due to dust exposure with the incident of respiratory diseases, using a quantitative approach with observations and primary data collection from 60 respondents. Dust levels were measured using LVDS and HVDS, while the prevalence of Acute Respiratory Infections (ARI) was determined through health examinations. Environmental Health Risk Analysis (ARKL) with the Risk Quotient (RQ) was applied to evaluate long-term exposure. Results showed dust concentrations of 12.941 mg/m³ in Sedayu and 17.647 mg/m³ in Banyudono, both above the threshold, with respiratory disorders more prevalent in Sedayu (53.3%) than in Banyudono (33.3%). RQ values above 1 in both villages indicate significant health risks, highlighting the need for improved PPE use, ventilation, routine air quality checks, and health monitoring to prevent respiratory issues.

Keywords: Stone Carving, Dust, Respiratory Disease, Risk Quotient (RQ).

Corresponding Author:

Sutaryono

Health Program Administration, Faculty of Health and Technology, Universitas Muhammadiyah Klaten, Klaten, Central Java, Indonesia

Email: sutaryono@umkla.ac.id



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1. INTRODUCTION

The development policy direction and priorities of Magelang are aimed at strengthening local potential oriented towards improving community welfare. This policy encourages local potential and fosters regional flagship products to compete nationally, including the development of volcanology and cultural tourism of Mount Merapi, as well as stone carving artisans. The strategy for developing the stone carving craft industry as a tourist destination in Magelang Regency ieconomics a key aspect in leveraging regional potential. In addition to increasing regional revenue, this strategy is expected to expand employment opportunities by creating new jobs and stimulating local economic activities (BPS, 2024; Sutaryono et al., 2024).

Magelang is known as a region with a long history in stone carving. This activity has been ongoing since the era of the ancient Mataram Kingdom, where stone was used to build large temples like Borobudur. Until today, stone carving art continues to evolve and is part of the local wisdom passed down through generations. The stone carving craft in Magelang reflects strong cultural values, with skills passed down from one generation to the next. The distinctive stone carving techniques, aesthetic and spiritual motifs, and the use of local materials are integral to the cultural identity of Magelang's people. Many stone carvings are produced for historical buildings, home decorations, and souvenirs, showing that this craft is a manifestation of local wisdom that continues to be preserved (Istanto & Triyanto, 2019; Kristiutami et al., 2014; Vlad, 2024).

Magelang has abundant access to andesite stone, one of the best stones for carving. Andesite is found in the slopes of Mount Merapi and Mount Sumbing, part of Magelang's geographical area. The availability of this natural resource means the raw materials for the craft are available in large quantities at relatively low cost. This resource availability is the primary factor supporting the growth of the stone carving craft industry (Sukmarani et al., 2014; Guruh et al., 2024).

The stone carving craft is an important source of income for the region. Besides providing employment for the local population, this industry also contributes to regional income through local taxes and exports. The craft is not only marketed locally but also exported abroad, mainly for building and property decoration purposes. According to the Central Statistics Agency (BPS) of Magelang, the craft industry, including stone carving, contributes up to 12% of regional income through taxes and exports. Apart from being known for Borobudur Temple, Magelang also boasts a tourism attraction related to the stone carving craft. Many tourists are interested in visiting the craft centers to observe the stone carving process firsthand. Villages such as Sedayu and Banyudono have developed into educational tourism destinations where visitors can learn about stone carving and even participate in the carving process. The stone carving craft in Magelang has significant potential to be developed as a thematic tourism destination (BPS, 2024).

Despite bringing many economic and cultural benefits, the stone carving craft activities also have negative impacts on the environment and public health. The stone quarrying and carving processes produce dust that can pollute the air. This dust, especially PM2.5 and PM10, is so small that it can be easily inhaled by the surrounding community, leading to a decrease in air quality (Hamdan et al., 2016; Ilahi et al., 2012). PM10 dust generated from stone carving activities can cause various respiratory diseases, such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). People living and working around the craft locations are at high risk of contracting these diseases due to continuous dust exposure. Long-term exposure to PM10 dust can also increase the risk of lung cancer (Abidin et al., 2021). Found that exposure to PM10 dust exceeding the threshold limit can increase the risk of respiratory diseases by up to 30% compared to unexposed populations. A study on individuals at high risk of aging found a 37.1% decline in lung function. Similarly, reported that among Magelang stone carving workers, 3.3% had chronic bronchitis, 20% showed bronchitis symptoms, and spirometry results indicated 66.6% with mild, 13.3% with moderate, 3.3% with severe

restrictions, and 10% with normal lung function. The results of this study also show that the dust content in the air exceeds the Environmental Quality Standard Value which has exceeded the Environmental Quality Standard Value of dust content in the air is 10 mg/m³, while the measurement results are 12,941-17,647 mg/m³ (Sulistyaningsih, 2020). The effects of particulate matter, silica dust, and nanosilica dust can lead to significant respiratory problems, as their small size allows them to penetrate deep into the lungs, causing inflammation and impaired lung function. Long-term exposure to silica dust can cause diseases such as silicosis, pneumoconiosis, and COPD. The impact of dust on lung function is also evident through spirometry tests, which show a decrease in Forced Vital Capacity (FVC) and Forced Expiratory Volume (FEV1) (Hu et al., 2024; Shekarian et al., 2023). A study reviewed over 400 studies on the impact of coal mining dust, also showed significant deposition of harmful particles in the lungs, leading to chronic lung diseases (Philippova et al., 2022; Abidin et al., 2021).

The stone carving craft activity is an important part of the local economy in Magelang Regency, including in the sub-districts of Muntilan, Dukun, Salam, Sawangan, Mungkid, and Secang, each with its own unique products. The Dukun sub-district, particularly the villages of Sedayu and Banyudono, is a stone quarrying area, such as Keningar and Banaran, and is known as a stone-producing region due to its proximity to Mount Merapi. Many people rely on this craft for their livelihood. However, behind its economic benefits, this activity has serious consequences for the environment and the health of the local community, particularly related to fine particulate dust exposure. According to the concept of sustainable development, it needs to be linked to the triple bottom line approach which includes environmental, economic, and social factors. These three pillars must be met properly so that an industry can develop and survive in the face of competition without causing adverse impacts on the environment. In-depth studies on the environmental impact of this activity, especially air quality and worker health, are still limited. Therefore, it is essential to conduct a study on the environmental health risks of PM₁₀ exposure to the communities working and living near the stone carving sites. This study aims to identify respiratory health risks of stone craftsmen due to dust exposure with the incident of respiratory diseases, so that appropriate mitigation measures can be taken.

2. RESEARCH METHOD

This research design is observational with a quantitative approach by collecting primary data related to PM₁₀ concentration and respiratory disease examinations. The research sample consists of 30 stone carvers from Sedayu Village and 30 from Banyudono Village, with the inclusion criteria being: stone carvers aged 18 years and above, having worked and lived in the study location for at least three years. Exclusion criteria include participants who are unable to communicate and those who are seriously ill. Control variables included hearing loss, blood pressure, nutritional status and not having a respiratory illness such as asthma CPOD, while smoking and economic status were not controlled. Air quality sampling with PM₁₀ dust parameters using a dustsampler tool at the sampling point location of each village, sampling time is carried out for 24 hours. Measurement of dust content using two 55 mm diameter cellulose filter paper for the Low Volume Dust Sampler (LVDS) tool and two 110 mm diameter cellulose filter paper for the High Volume Dust Sampler (HVDS) tool. Measurement of respiratory disorders through interviews and examinations by a team of doctors including Acute Respiratory Infection (ARI), Pneumonia, Chronic Bronchitis, Chronic Obstructive Pulmonary Disease (COPD), and Pulmonary Tuberculosis (TB) were established based on anamnesis (Bone & Diamond-Fox, 2024; Rogan, 2008). Data analysis was conducted descriptively and supplemented with a risk analysis using the Environmental Health Risk Assessment method (EHRA). The health risk level is expressed as Risk Quotient (RQ), calculated for lifetime

exposure. Ethical clearance approval was issued by the Ethics Committee of Poltekkes Kemenkes Yogyakarta No.DP.04.03/e-KEPK.1/744/2023 on July 31, 2023.

3. RESULTS AND DISCUSSION

The presence of Borobudur Temple in Magelang Regency serves as a powerful magnet attracting people from various parts of the world to visit. This has impacted the lives of the people in Magelang Regency, many of whom have taken up stone carving as a profession, producing products resembling parts of the temple structure. The types of stone crafts produced at the research sites are quite diverse. The term "nithik" has existed since ancient times, starting with simple products like tombstones, which later evolved into kitchen tools such as mortars, pestles, and grinding stones, as well as crafts like lanterns, fountains, gateways, pillars, and eventually art objects and religious items, such as Buddha statues (Istanto, Rohidi, Triyanto 2019).

The research sites in the villages of Sedayu and Banyudono are home to the largest number of stone carving industries compared to other villages in Magelang Regency. The characteristics of the research respondents are shown in Table 1.

Table 1. Respondent Characteristics by Location.

Variable	Research Location			
	Sedayu (n=30)		Banyudono (n=30)	
	n	f (%)	n	f (%)
Age (years)				
< 30	6	46.19	7	53.81
30 – 39	12	52.15	11	47.85
40 – 49	9	75.00	3	25.00
50+	3	25.00	9	75.00
Education Level				
Didn't Complete Elementary School	4	80.12	1	19.88
Elementary School	6	29.99	14	70.01
Junior High School	8	50.00	8	50.00
Senior High School	12	63.19	7	36.81
Professional Lifetime				
< 10	6	27.29	16	72.71
10 – 20	12	66.67	6	33.33
> 20	12	59.97	8	40.03
Income/ Month				
<Regional Minimum Wage	11	40.78	16	59.22
>Regional Minimum Wage	19	57.55	14	42.45

Table 1 shows that the stone craftsmen involved in this study, based on the age of the respondents in both groups, do not differ significantly; however, the proportion of stone craftsmen under the age of 30 is higher in the group from Banyudono Village. In contrast, the proportion of stone craftsmen aged 50 and above is greater in the group from Sedayu Village. The proportion of stone craftsmen with an elementary school education is higher in Banyudono Village (70%) compared to Sedayu Village (29.99%). The proportion of craftsmen with more than 20 years of work experience is higher in Sedayu Village (59.97%), whereas those with less than 10 years of work experience are more prevalent in Banyudono Village (72.71%). Additionally, the proportion of craftsmen earning below the minimum regional wage (UMR) is higher among the stone craftsmen in Banyudono Village (59.22%).

Concentration of PM₁₀ Exposure Risk

The measurement of dust levels utilized two pieces of 55 mm diameter cellulose filter paper for the Low Volume Dust Sampler (LVDS) and two pieces of 110 mm diameter cellulose filter paper for the High Volume Dust Sampler (HVDS). The results of the study indicate that the dust concentration in the air at the stone carving industrial center in Sedayu Village is 12.941 mg/m³, while in Banyudono Village, it is 17.647 mg/m³. These figures exceed the Threshold Limit Value established in the Minister of Manpower Regulation of the Republic of Indonesia Number 5 of 2018 concerning Occupational Safety and Health in the Workplace, which is set at 10 mg/m³.

Respiratory Health Examination

The results of the health examination of respondents of chisel stone craftsmen based on anamnesis and physical examination by a doctor are shown in table 2, indicating that the proportion of stone craftsmen suffering from Acute Respiratory Infections (ARI) in Sedayu Village (61.56%) is higher compared to Banyudono Village (38.44%). This indicates that the incidence of respiratory disorders is more prevalent among the group of stone craftsmen working in the stone carving industrial center (relocation) or in Sedayu Village compared to the group of stone craftsmen working in residential areas (non-relocation) in Banyudono Village.

Table 2. Diagnosis of Respiratory Health Disorders

Diagnosis of Respiratory Health Disorders	Research Location			
	Sedayu (n=30)		Banyudono (n=30)	
	n	f (%)	n	f (%)
No Abnormalities	14	42.42	19	57.58
Acute Respiratory Infections	16	61.56	10	38.44
Chronic Bronchitis	0	0	1	100

Environmental Health Risk Analysis

The estimation of the magnitude of impact is conducted by calculating the health risks arising from hazardous sources using the environmental health risk analysis method. In this case, the health risk pertains to respiratory disorders, which can be calculated using the following formula (Abidin et al., 2021).

$$RQ = \frac{I}{RfC}$$

Where:

RQ = Health impact risk level (non-carcinogenic)

I = Intake or inhalation of risk agents

RfC = Reference value for inhalation exposure risk agents

The intake or inhalation of risk agents can be calculated using the following formula:

$$I = \frac{C \times R \times t_E \times f_e \times D_t}{W_b \times t_{avg}}$$

Where:

I = Concentration of risk agents entering the human body per day for a specific body weight (mg/kg × day)

C = Concentration of risk agents in ambient air (mg/m³)

- R = Inhalation rate / volume of air inhaled per hour (m^3/hour) (Default value: $0.83 \text{ m}^3/\text{hour}$)
- t_E = Duration or number of hours of exposure per day (hours/day) (default value for residential exposure: 24 hours/day, for vendors: 8 hours/day calculated from average selling time)
- f_E = Duration or number of days of exposure per year (default value for residential: 350 days/year, for vendors: 300 days/year assuming 6 working days per week)
- D_t = Duration or number of years of exposure
- W_b = Population group body weight (default value for Indonesian adults: 55 kg)
- t_{avg} = Average time period for non-carcinogenic health effects (30 years or 10,950 days)

The calculation of health risks as a derivative impact of declining air quality based on its parameters can be seen in the following table.

Table 3. Calculation of Health Risks.

Parameter (PM_{20})	C (mg/m^3)	Intake	RfC	RQ
Sedayu	12.941	0.04994	0.014	3.567
Banyudono	17.647	0.06810	0.014	4.864

Rfc : Reference value for inhalation exposure risk agents

RQ : Health impact risk level (non-carcinogenic)

Based on the health risk calculations in Table 3, it is evident that there are health risks in the area, particularly respiratory diseases (Acute Respiratory Infections, ARI), with a risk quotient (RQ) greater than 1 in both Sedayu and Banyudono Villages. The calculation of the Average Risk Level (EHRA) indicating an RQ value above 1 suggests that the community and workers around the craft area are at high health risk due to PM_{10} dust exposure. An EHRA value greater than 1 indicates that the intensity of exposure and prolonged working duration increase the likelihood of health issues, particularly affecting the respiratory system and other disorders.

The study results show that the respondents suffering from ARI in Sedayu Village (61.56%) and Banyudono Village (38.44%) indicate a strong correlation between PM_{10} exposure and the health conditions of the craftsmen. PM_{10} (Particulate Matter 10) consists of air particles with a diameter of less than 10 micrometers, which are small enough to enter the human respiratory tract and reach the lower lungs, causing various respiratory disorders such as Acute Respiratory Infections (ARI), bronchitis, chronic obstructive pulmonary disease (COPD), and decreased lung function (Fasola et al., 2020; Firmanto, 2018; Yan et al., 2022). The excessive concentration of dust in the air resulting from stone carving production processes, along with the accumulation of solid waste in the form of stone debris disposed of in the environment, coupled with some craftsmen's reluctance to use personal protective equipment (PPE) while working, has had detrimental effects on the health of stone craftsmen.

Given the study findings indicating that PM_{10} levels exceed the threshold limit and the associated risk of increased prevalence of respiratory diseases, several mitigation measures are needed to reduce health risks for craftsmen and the community around the stone carving industrial center. Recommended mitigation measures include the consistent use of personal protective equipment (PPE). The study findings on the use of PPE among respondents are presented in Table 4.

Table 4. Personal Protective Equipment Usage.

Variable	Category	Research Location			
		Sedayu (n=30)		Banyudono (n=30)	
		n	f (%)	n	f (%)
PPE Availability	Available	21	56.77	16	43.23
	Unavailable	9	39.11	14	60.89
PPE Usage at Work	Yes, always	5	33.27	10	66.73
	Yes, rarely	6	50.00	6	50.00
	No	19	57.55	14	42.45
PPE Type	Earmuff	1	100.00	0	0.00
	Earplug	14	79.27	4	20.73
	Headset	1	100.00	0	0.00
	Cotton/cloth	13	33.21	26	66.79
Mask Availability	Yes	29	50.89	28	49.11
	No	1	33.00	2	67.00
Mask Usage	Yes, always	17	54.84	14	45.16
	Yes, rarely	9	40.93	13	59.07
	No	4	57.08	3	42.92
Mask Type	Surgical/medical mask	3	49.05	3	50.95
	Multi-layer cloth mask	10	82.93	2	17.07
	Single-layer cloth mask	17	40.20	25	59.80

Many craftsmen show little concern for the use of personal protective equipment (PPE) while working. In both Banyudono and Sedayu Villages, many still do not use PPE during work. In Sedayu, 57.55 percent of craftsmen do not use PPE, a higher proportion compared to Banyudono, which is 42.45 percent. Regarding the type of PPE, most of them only use cotton or cloth to reduce noise while working. The proportion of stone craftsmen who do not wear masks while working is also higher in Sedayu (57.08%), while those who rarely use masks while working are more prevalent in Banyudono (42.92%). The type of mask used is mostly a single-layer cloth mask, with a higher proportion in Banyudono (59.80%) compared to Sedayu (40.20%).

Information from respondents during interviews, the obstacles experienced in the use of PPE due to lack of awareness of the importance of using PPE with a variety of reasons, including that they feel there are no health problems while being stone carving craftsmen, other informants said the impact of dust was used to “kulinan”, using PPE felt uncomfortable.

The necessary follow-up includes increasing health education about the correct and proper use of PPE, selecting PPE that is comfortable and ergonomic for workers/stone craftsmen to ensure sustained use. Wearing masks can reduce PM10 exposure by up to 95%, thereby reducing the risk of respiratory diseases caused by exposure to fine particles (Smith et al., 2016). Another effort that can be made is ensuring good ventilation systems in industrial environments, as this can reduce fine particle exposure and improve air quality, ultimately lowering the incidence of respiratory diseases (Felgueiras et al., 2023; Jung et al., 2023). Regular monitoring of air quality is a crucial step in environmental health risk management, particularly in industrial areas that generate hazardous particles like PM10 (Kampa & Castanas, 2008; Manisalidis et al., 2020). Additionally, periodic health checks, including lung function examinations (Kashyap et al., 2023; Los et al., 2019). Ongoing education and training on occupational safety are also essential in improving workers' compliance with PPE use and adopting safer work practices, ultimately reducing the incidence of respiratory and other diseases (Yeon & Shin, 2020).

4. CONCLUSION

The results showed that dust levels in the environment of the stone carving industry centers in Sedayu Village amounted to 12.941 mg/m³ and in Banyudono amounted to 17.647 mg/m³, this figure has exceeded the Threshold Value that has been set, which is 10 mg/m³. Based on the Environmental Health Risk Assessment (EHRA) method, it is known that the RQ>1 value indicates that PM10 dust exposure has a high risk impact on the respiratory health (ARI) of the community and workers around the stone carving craft area. Future research can focus on smaller dust exposure with PM 2.5 and survival analysis is needed to determine the length of time the severity of respiratory disease occurs. Mitigation efforts that need to be suggested are increasing awareness of the use of PPE through counseling from related agencies and the provision of PPE infrastructure and substitution of chisel stone machine tools that do not produce much dust.

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