Health and Environmental Impacts and Control Measures in the Aggregate-Crushing Industrial Sector of Asia: A 20-Year Systematic Literature Review

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Abstract

This operation of stone crushing results in a significant contribution to environmental and human health issues through air and noise pollution. Crushing of large-sized stones to desired-sized stones (by stone crusher) generates significantly large amounts of fine particulate matter like $PM_{2.5}$ and PM_{10} that directly affect the nearby atmosphere and human health by posing severe respiratory health risks to workers and the nearby communities, like wheezing, asthma, cardiovascular issues, dyspnoea, cough, silicosis, etc. This systematic literature review highlights the mitigation methods, like green buffer zones, enclosure of crushers, suppression systems, and acoustic barriers, by research from all over Asian countries. This review also discusses the corresponding legislative frameworks and standard regulations for emissions and noise levels, in accordance with evaluating the difference between the findings and the prescribed limits. This review paper presents a holistic view of the concept of how stone crushers affect the health and environment and sheds light on innovative solutions. Methodologically, PRISMA has been followed to construct this systematic literature review. In this piece, articles from the last 20 years, contextual to Asian countries, have been reviewed. The countries that have been found under the Asian context are India, China, Bangladesh, Malaysia, Iraq, Pakistan, Nepal, Thailand, Singapore, and Indonesia. After a vigorous review, 296 papers were narrowed down to 40 MES assessments. The Scopus platform was employed for collecting metadata for comparison and analysis. In a nutshell, it has been observed that research related to the awareness of health & environment and mitigation in the last few decades in the Asian context matches the corresponding global footsteps.

Keywords: Stone crusher, Particulate matter, Water contamination, Respiratory health, Environmental pollution, Air pollution, Vegetation damage.

1 Introduction

The stone crushing industry is an important construction industry [1]. It is one of the most polluting ones also. The fugitive emissions generated from the stone crushing industry can pose several severe problems in living beings of different habitats [2, 3]. Suspended particulate matter released in the surrounding environment later settles on the plant leaves, causing problems, even death.[4] Disruption in photosynthesis, due to this, can significantly affect the production of crops and the growth of plants. Leghari et al. (2014) found that due to this reason, the height, cover, total chlorophyll, and number of leaves of Vitis vinifera L (common grape vine) at the roadside were generally low [5]. Wallenborn et al. (2009) and Seinfeld and Pankow (2003) emphasised the effect of atmospheric particulate matter on the environment and human health. They stated that exposure to harmful pollutants was often seen among the workers, which increased the probability of getting ill and possibly premature death [6, 7]. In developing countries, workers are usually unaware of the harmful effects of prolonged exposure to high pollution levels [8].

This article presents a systematic review of articles from the last 20 years, contextual to Asian countries. It has been found that new research has spiked in the last 20 years. The review highlights different types of pollution, along with their effect, on the atmosphere, water bodies, and human health, caused by the stone crushing industry. This article also draws a critical connection between the health and environmental impact.

2 Methodology

This systematic literature review (SLR) was conducted using by PRISMA method, that has been mentioned in fig.1. (("crusher" OR "rock crusher" OR "aggregate crusher" OR "stone crushing" OR "natural crushed aggregate" OR "jaw crusher" OR "hammer crusher" OR "cone crusher" OR "gyratory crusher" OR "stone extraction" OR "stone quarry") AND ("silicosis" OR "COPD" OR "Asthma" OR "Tinnitus" OR "Dermatitis" OR "Cardiovascular Diseases" OR "TB" OR "pollution" OR "Environmental impact" OR "Health Impact" OR "dust pollution" OR "Environmental hazards" OR "Health hazards" OR "silica dust" OR "PM 2.5" OR "PM 10" OR "PM 1" OR "suspended particulate matter" OR "dust emission" OR "fugitive dust " OR "SO2" OR "CO" OR "NOx" OR "noise pollution" OR "noise control" OR "noise barrier")) has been given as the input command under the direction of TITLE-ABS-KEY in the databases, i.e.- Scopus. The focus of this SLR is on papers published in Asian countries or authored by Asian researchers over the past 20 years. By concentrating on the Asian context, this review aims to shed light on the country’s progress in research and development related to the stone crushing industry. The data extracted from these studies are systematically presented through different tables and figures as part of the meta-analysis. Microsoft Excel v21 has been used for the generation of charts and tables. Also, VOSviewer 1.6.20 has been used for creating the bibliometric analysis. Additionally, the preventive measures have been discussed to monitor, control, and reduce the casualties of workers' health deterioration and environmental effects.

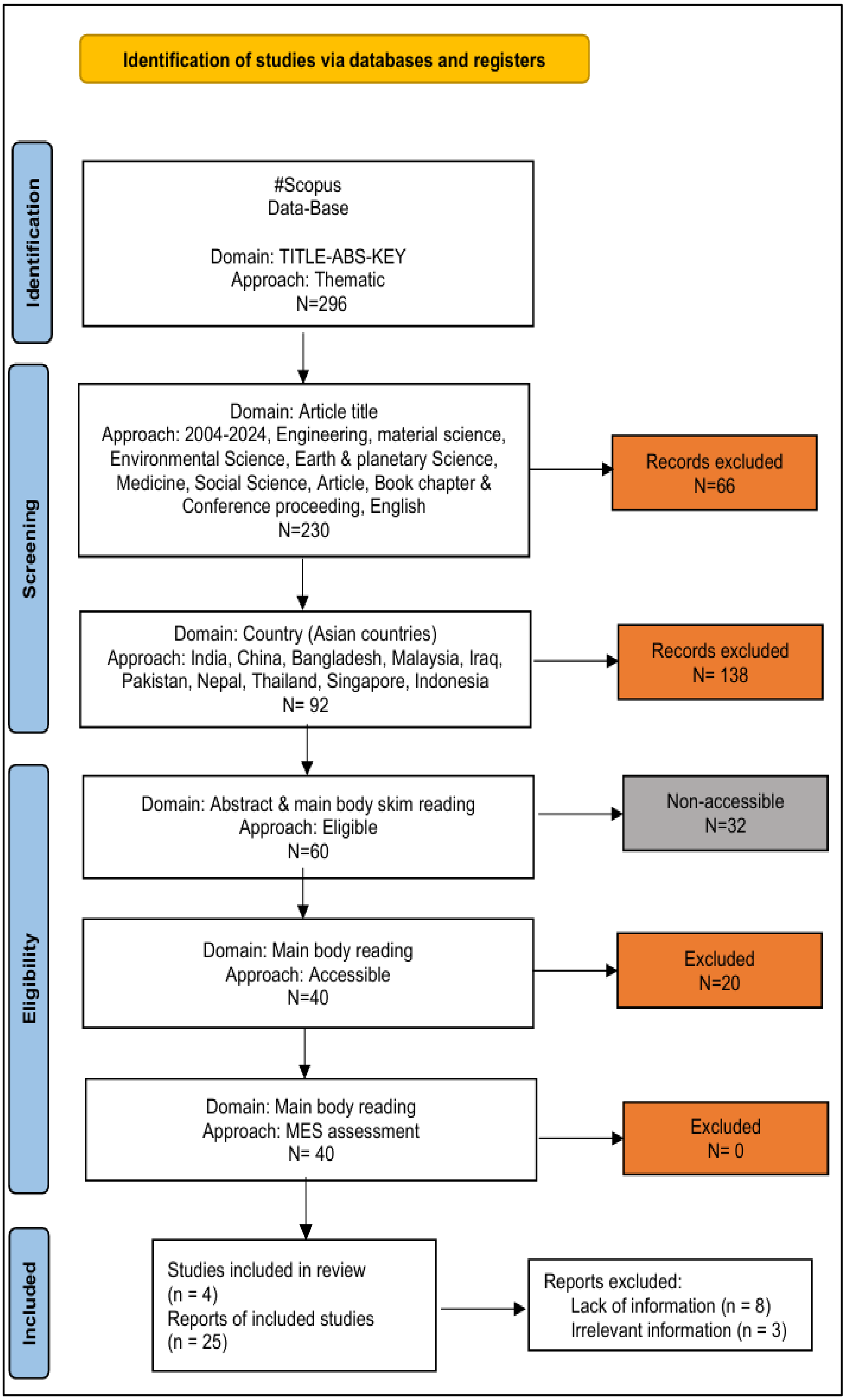

Fig. 1. Detailed Prisma table

3 Results and discussions

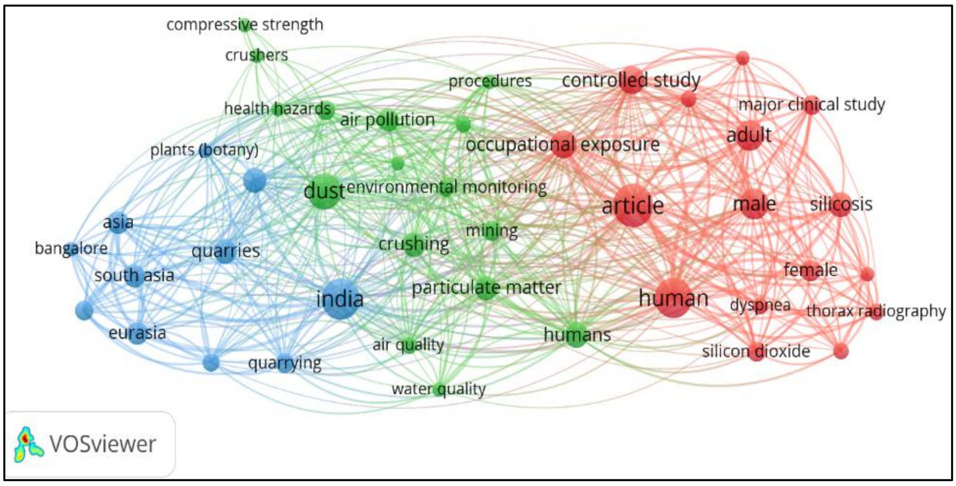

Fig. 2. Keyword Co-occurrence Network (Total Link Strength based)

The study employed bibliometric methods under the segment of 'Network Visualisation'. Those index and author keywords have been considered that have occurred at least five times. 3 clusters and a total 50 number of keywords have been identified. A total of links (co-occurrences of 675) have been generated. Total link strength has been calculated as 1941. Other keywords which have occurred abundantly are human" (26 times), India (27 times), Dust (22 times), male (17 times), occupational exposure & controled study (14 times), adult (16 times), humans (12 times), particulate matter (11 times), air pollution (14 times), atmospheric pollution (14 times), silicosis (14 times) etc. Other than crushing and air pollutants from the air pollution domain, Occupational health (7 times), dyspnea (6 times), and tuberculosis (5 times) have been identified as health issues under the current preconditions. Having a link strength of article 245, occupational exposure & controlled study have co-occurred most of the time. Other significant co-occurrences are eurasia and South Asia (link strength = 86), case report and suspended particulate matter (link strength = 86), controled study and occupation exposure (link strength = 132), dyspnea and forced expiratory volume (link strength = 46), thorax radiography and pollution control (link strength = 52) etc. The keyword co-occurrence network is shown in Fig. 2. Analysing the scientific landscape in the current context, it may not be an exaggeration to state that, in Asian countries, though the research related to pollution by the stone crushing industry is accelerating in present times but the research related to pollution hasn't emerged significantly yet.

3.1 Critical Insight and reflection

The analysis emphasises the health-related terms (like "human", "male", "dyspnea", "tuberculosis") and geographic markers ("India", "South Asia", "Eurasia"), along with the relatively underrepresented terms that are directly linked to environmental mechanisms and mitigation strategies. Such as "mitigation", "green technology adoption" are notably absent. This pattern indicates an emerging and still nascent research landscape, where researchers are describing the consequences rather than mentioning the countermeasures. The most frequent co-occurrence "occupational exposure & controlled study" with the link strength of 245 emphasises that scientific efforts are predominantly clinical or epidemiological, rather than environmental, regulatory, or technical. The formation of a cluster (three clusters, 50 keywords) suggests fragmentation in knowledge. Especially in developing countries, any research domain is generally found to be fragmented in the budding stage, i.e., integration of multidisciplinary collaboration of knowledge is a common lacuna, as there are economic, infrastructural, and policy constraints in these countries.

3.2 Countries involvement

Fig. 3 illustrates the publication count as well as the impact of stone-crushing around various Asian countries. India shows the highest number of publications & involvement, reflecting the significance of research activity and industrial presence. China, Pakistan, and Bangladesh are in the series that indicates the growing environmental concern. Conversely, countries like Nepal, Iraq, and Malaysia have minimal contributions, suggesting underreporting or limited research focus. This disparity highlights the need for broader regional studies and unified scientific attention to pollution-related issues.

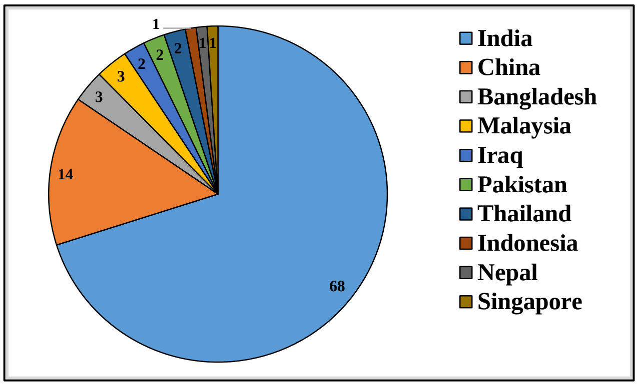

Fig. 3. Publication count from the Asian countries

3.3 Compiled data from existing research on stone-crushing impacts

Table 1. List of Main Criteria and Sub-Criteria for Maintenance Policy Selection

Ref	Location of survey	Noise (dB)					
		Crushing	Quarry	Blast	Drill	Vehicle movement	Road side
[9]	Site 1-10	80.43-97.31	-	-	-	-	-
[10]	India Bharatkoop	102	-	-	-	-	-
	India Banda	99	-	-	-	-	-
	India Kabrai	103	-	-	-	-	-
[12]	India Bettahalsur	>76	79.6	138	109.5	101	90.7
	India Bettahalsur	97.8	74.5	135	111.8	75	76.5
	India Kogilu	93	70.1	139	108.6	82	85
	India Basavanahalli	99.5	72.8	-	-	72	65.2
	India Kallugopanahalli	98.6	75	147	112.9	83.6	75.4
	India Doddabettahalli	96	74.6	148	99	69	65
	India Anjanapura	92	73.8	133	101	70	64

Table 1, it can be observed that the noise pollution of stone crushing industries across Asia is breaching the national standards limits, especially in India, where the level reaches up to 147 dB in Bettahalsur.

3.4 Impact of airborne particulate matter on water bodies in crushing zones

Birbhum district (3 locations): The average of 3 sites in Birbhum, moderate levels of PM10 pollution are recorded, with concentrations reaching up to 112130 µg/m³ at sites, as shown in Table 3.

Table 2. Comparative Analysis of Water Quality Parameters near Stone-Crushing Sites Against National Environmental Standards in Asian Countries

Ref no.	Location	Geological condition	BOD (mg/L)	Turbidity (NTU)	pH	DO (ppm)	TDS (mg/L)	TS (mg/L)	COD (mg/L)
[17]	Dwarka river basin	River basin	-	-	8.7	3.74	2457	-	-
[9]	Gowainghat	monsoon	2.85	341	7.56	9	47.11	47.78	-
		post monsoon	1.8	411.7	7.62	8.33	84.89	86.01	-
[18]	Dwarka River basin & Chotanagpur plateau fringe	Window_A	45.6	-	8.7	3.74	2457	-	13549.4
		Window_B	48.2	-	8.9	3.18	2369	-	13767.4
		Window_C	29.8	-	8.7	3.14	2415	-	13578.8
		Window_D	41.2	-	8.8	2.72	2289	-	13084.4

Even though the environment there is saturated with dust, the water quality has not yet significantly declined as a result of it. Therefore, before more serious ecological degradation occurs, the area still has the opportunity for proactive intervention through watershed management and preventive dust control.

Table 3. Comparison of Particulate Matter Concentrations (PM_{10}, $PM_{2.5}$, PM_1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

Ref no.	Location of survey	Branch	µg/m³ for PM_{10}	µg/m³ for $PM_{2.5}$	µg/m³ for PM_1	µg/m³ for $PM_{0.5}$	µg/m³ for other sizes
			Crushing/ Dressing/ Drilling (all operations)	Crushing	Crushing	Crushing	Crushing
[21]	Jodhpur	Site 1	4800/ 9300/ 18500	-	-	-	-
[22]	Vietnam Danang	Site 1	4692.46	166.04	12.22+-6.73	5.93+-3.27	-
[17]	India	Site 1	18900	-	-	-	-
[23]	Balasore, Odisha, India	Average of all 5 sites	1053.5	-	-	-	-
[29]	Birbhum district (3 locations)	Average of all 3 sites	112130	-	-	-	-

[9]	Gow ainghat Upazila of Sylhet District	Average of all 10 sites	92.433	52.12 - 523.85	-	-	-
[24]	Ahemdabad	Average of all 3 sites	13943.33	930 - 1340	-	-	3110 - 6330
[16]	Bundelkhand massif & Jhasi of Uttar Pradesh	site 1	254.49	-	-	-	-
[25]	North and Southern Area of Ipoh, Perak	Average of all 33 sites	49.65	26.64	-	-	-
[26]	Trisoolam of Chennai city	Average of all 11 sites	75636	-	-	-	-
[15]	Pammal of Chennai city	Average of all 11 sites	376.72	123.91	-	-	-
[27]	Khurda District of Orissa	Average of all 5 sites	2634	-	-	-	-

Table 4. Comparison of Particulate Matter Concentrations (PM_{10}, $PM_{2.5}$, PM_1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

Ref no.	Location of survey	Sit	SO_X ($\mu g/m^3$)	NO_X ($\mu g/m^3$)	TSP ($\mu g/m^3$)
[13]	Quetta, Balochistan, Pakistan.		8.03×10^8	2.16×10^8	-
[14]	Chitrakoot area	A	150	300	-
		B	190	500	-
		C	190	750	-
		D	190	750	-
		E	201	750	-
[15]	Chennai city	Kavasam	-	-	2470
		KVS	-	-	823
		Praveen	-	-	698
		KTC	-	-	698
		Vinoth	-	-	442
		Geetha	-	-	589
		Kalaiselvi	-	-	1706
		Solai	-	-	694
		Vigneswara	-	-	987
		Peter	-	-	962
		Tennish	-	-	342
[16]	Bundelkhand massif & Jhasi		4.91	10.66	

3.5 Vegetation damage trends across high pm exposure sites

Quetta, Pakistan: Atmospheric emissions near stone crushing sites in Balochistan are extremely high (Table 3: SOx 8.03 x 108 $\mu g/m^3$, NOx 2.16 x 108 $\mu g/m^3$). As a direct consequence, Table 4 reveals that vegetation in the vicinity, including species such as Vitis vinifera (grape vine) and Morus alba (white mulberry), exhibits substantial particulate accumulation on leaf surfaces (up to 8.2 $\mu g/cm^2$). This particulate settlement in leaves results in physiological damage, including stomatal blockage, leaf discolouration, and visible injury symptoms.

Table 5. Assessment of Dust Deposition and Vegetative Damage on Foliage Near Stone-Crushing Sites in Different Seasonal Conditions.

Ref no.	Location of survey	Site	Leaf	BWLS	Dust 8.2 μg/cm²	Leaf damage %	Leaf injured %	Leaf death %
[13]	Balochistan, Pakistan.	-	Vitis vinifera	-	8.2	-	-	-
		-	Morus alba	-	4.6	-	-	-
		-	Prunus armeniaca	-	4.4	-	-	-
[19]	Birbhum district (3 locations)	site 1	-	5.58 (S), 1.72 (R), 4.8 (W)	-	16.5 (S), 6.8 (R), 16.9 (W)	55.2 (S), 46.1 (R), 69.4 (W)	16 (S), 3 (R), 21 (W)
		site 2	-	27.3 (S), 15.8 (R), 38.33 (W)	-	9.11 (S), 4.7 (R), 11.5 (W)	25.7 (S), 24.5 (R), 55.8 (W)	11 (S), 2 (R), 14 (W)
		site 3	-	1 (S), 3 (W)	-	16 (S), 3 (R), 21 (W)	11 (S), 2 (R), 14 (W)	4 (S), 2 (W)
[20]	Lalpahari forest	site 1	Shorea robusta	5.58 (S), 1.72 (R), 4.8 (W)	-	16.5, 6.8, 16.9	55.2, 46.15, 69.3	16, 3, 21
			Madhuca indica	6.86 (S), 3.9 (R), 7.53 (W)	-	18.3 (S), 9.9 (R), 4.7 (W)	41.8 (S), 45.7 (R), 55.2 (W)	23 (S), 5 (R), 19 (W)

3.6 Impact of airborne particulate matter on respiratory health in crushing zones.

According to the data shown in Table 6 relatively low but non-negligible respiratory health issues among stone quarry workers in Jodhpur, with symptoms such as cough (7.5%) and wheezing (3.8%), and fewer multiple symptom combinations like wheeze & dyspnoea is about 3.5%, dyspnoea & silicosis 3.5%, coughness & wheeze 1.6%, coughness & dyspnoea 1%, upto 6% having dyspnoea, wheeze, coughness, and silicosis. However, as shown in Table 3, dust concentrations in key operational areas are alarmingly high, particularly during dressing (9,300 μg/m³) and drilling (18,500 μg/m³). This discrepancy may indicate underreporting, delayed symptom manifestation, or limited health surveillance. Nonetheless, the data confirm that workers operate in a highly hazardous environment, and the intensity of airborne particulates presents a serious long-term risk, warranting immediate occupational health interventions and sustained monitoring.

Bundelkhand massif & Jhansi, Uttar Pradesh, India: Table 8 records dramatically higher respiratory ailment rates among workers: cough (65%), wheeze (51%), and overall problems like tightness in chest, dyspnoea, silicosis, tuberculosis, asthma reached upto (79%), with additional symptoms like headache (58%) and breathlessness/eye & skin irritation (72%). Table 3 data support the point of elevated particulate concentrations up to 254.49 μg/m³ for PM_{10}.

Table 6. Prevalence of Respiratory and Occupational Health Symptoms Among Workers in Stone-Crushing Zones Across South Asia.

<table>
<tr><th>Location of survey</th><th>Bangladesh - Burimari Land Port area of Patgram upazila in Lalmonirhat</th><th>India – Jodhpur</th><th>North-western, Quetta, Baloc-histan, Pakistan. (Site 1-5)</th><th>India – Chitra-koot area</th><th>India – Bhara-tkoop</th><th>India - Kabrai</th><th>India - Banda</th><th>India - massif & Jhasi of Uttar Pradesh</th><th>Lalitpur, Nepal</th></tr>
<tr><td>Coughness</td><td>28.33</td><td>7.5</td><td>70-88.09</td><td>57</td><td>30</td><td>40</td><td>20</td><td>65</td><td>27</td></tr>
<tr><td>Shortness of breath</td><td>4.58</td><td></td><td rowspan="8">78.33</td><td rowspan="8">71.1</td><td rowspan="8">46</td><td rowspan="8">52</td><td rowspan="8">36</td><td>-</td><td>21</td></tr>
<tr><td>Wheeze</td><td>2.29</td><td>3.8</td><td>51</td><td>24</td></tr>
<tr><td>Tightness in chest</td><td>1.68</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Dyspnoea</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Silicosis</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Tuberculosis</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Asthama</td><td>-</td><td>-</td><td>-</td><td>6</td></tr>
<tr><td>Allergy</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Allergy</td><td>-</td><td>-</td><td>73.33</td><td>74.3</td><td>52</td><td>62</td><td>40</td><td>-</td><td>-</td></tr>
<tr><td>Headache</td><td>-</td><td>-</td><td>75</td><td>68.6</td><td rowspan="2">28</td><td rowspan="2">36</td><td rowspan="2">20</td><td>58</td><td>-</td></tr>
<tr><td>Tiredness</td><td>-</td><td>-</td><td></td><td></td><td>-</td><td>-</td></tr>
<tr><td>Breathlessness & Eye/ skin irritation</td><td>-</td><td>-</td><td>-</td><td>-</td><td>52</td><td>64</td><td>36</td><td>-</td><td>-</td></tr>
<tr><td>Ref no.</td><td>[40]</td><td>[21]</td><td>[13]</td><td>[14]</td><td>[10]</td><td>[10]</td><td>[10]</td><td>[16]</td><td>[41]</td></tr>
</table>

The prevalence of severe symptoms matches the known high dust levels in this area, affirming a direct connection between excessive particulate exposure and acute as well as chronic respiratory health deterioration among workers here. This site stands out for both heavy pollution and pronounced health impacts

Chitrakoot, Bundelkhand, Uttar Pradesh: The air quality data in Table 4 indicate the chronic exposure to harmful gaseous pollutants in the Chitrakoot region. In site E, it was observed that sulfur oxides SOx and nitrogen oxides NOx content reach up to 201 µg/m³ and 750 µg/m³, respectively, well beyond typical ambient thresholds. As a direct consequence, Table 6 reports widespread respiratory health issues among quarry workers: 57% suffer from cough, 71% experience shortness of breath, and nearly 75% report persistent breathlessness or irritation. This strong correlation between elevated dust emissions and the prevalence of respiratory symptoms points to a significant occupational health burden. The Chitrakoot area highlights the urgent necessity of workers' health surveillance.

Nonetheless, the data confirm that workers operate in a highly hazardous environment, and the intensity of airborne particulates presents a serious long-term risk, warranting immediate occupational health interventions and sustained monitoring.

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3.7 Prevention and countermeasure.

Wearing N95 masks significantly protects stone crushing industry workers by filtering out over 95% of harmful airborne dust, including respirable crystalline silica and ultra-fine particles generated during crushing, blasting, or grinding activities supported by Figure 4. This reduces inhalation of toxic particles, lowers the risk of lung diseases, and enhances overall respiratory health and workplace safety [28].

Roadside shelterbelts and greenbelts significantly reduce environmental pollution in urban settings. They filter out dust, soot, and total suspended particles from the air, improving ambient air quality. These vegetative barriers also act as natural sound absorbers, lowering traffic-induced noise and enhancing comfort for workers, as shown in Figure 2. Additionally, shelterbelts boost urban biodiversity by providing habitats for birds and insects, regulate microclimates, and prevent soil erosion. Their effectiveness depends on the density and structural arrangement of the planted vegetation, with denser crowns offering greater pollution removal benefits [29].

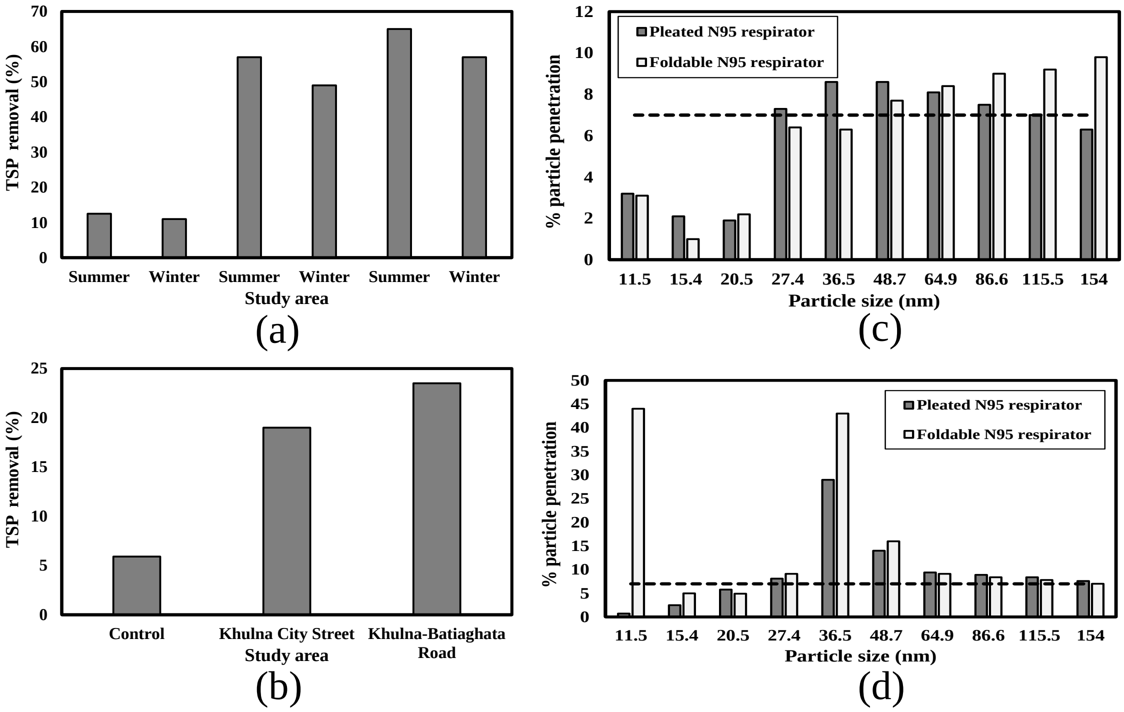

Fig 4: (a) Average removal efficiency of total suspended particles (TSP) from air by roadside shelterbelts along two major streets in Khulna City, Bangladesh, during summer and winter (mean ± SD). (b) Average reduction in traffic-induced noise by the same greenbelts (mean ± SD), (Md. N. Islam et al. 2012). Penetration percentages of nanoparticles (11.5–154.0nm) through pleated and foldable N95 respirators during (c) soil moving by bulldozers and (d) concrete blasting and grinding at a construction site.

4. Discussions

Policy vacuums on mitigation despite evident health risks
Throughout the review article, the co-occurrence of keywords such as “silicosis,” “dyspnoea,” “tuberculosis,” and “occupational exposure” indicates the concern about chronic

respiratory health issues faced by workers in the stone crushing industry. The absence of keywords such as “regulation,” “compliance,” “pollution control technology,” or “workplace standards” clearly shows a policy vacuum in current academic discourse.

Occupational health standards and enforcement

i. Set respiratory PPE as mandatory for all workers with appropriate training.
ii. An active real-time dust monitoring system must be in place at crushing sites through IoT-based systems
iii. Conduct mandatory medical checkups and health surveillance for early silicosis, TB detection.
iv. Initialise dust suppression systems strictly (e.g., water sprays, enclosed conveyors).
v. Modernise the crushing technologies to the low-emission ones, with incentives such as green tax credits.
vi. Promote isolated zoning that restricts the crushing units away from densely populated areas or ecologically sensitive areas.

Policy instruments and legal reform

i. Make stringent rules regarding Environmental Impact Assessment (EIA) requirements for the Industry.
ii. Apply pollution taxes or emissions-based penalties for units with non-compliance.
iii. Encourage public-private partnerships in developing pollution-controlling technology.

Research & capacity building

i. Fund interdisciplinary research that focuses on technical mitigation and policy modelling.
ii. Monitor and compare mitigation progress in the region where the crusher is located.
iii. Introduce training programmes for local administrators to implement pollution control norms.

5. Conclusion

The SLR establishes a clear link between the operations of stone crushing industries and their impact on the environment and health consequences across Asian countries.

Noise levels at crushing sites of every Asian country regularly breach their national permissible limit, ranging from 75 – 90 dB, indicating a lack of noise control measures. Air pollution is alarmingly high, with NOx concentrations rising to 750 $\mu g/m^3$ and SOx to 8.03E+08 $\mu g/m^3$. Particulate matter, especially PM10, reaches hazardous levels—up to 184,630 $\mu g/m^3$—contributing to respiratory conditions such as coughing, wheezing, and dyspnoea observed in over 80% of workers. The particulate matter present in the atmosphere not only affects human health but also affects the surrounding vegetation, causing damage such as up to 69.4% leaf death, and contaminates nearby water bodies by reducing dissolved oxygen to critically low levels (as low as 2.7 ppm).

These findings demonstrate the failure in environmental governance, occupational safety, and regulatory enforcement across the studied regions. Despite national regulations and standards of emission and exposure, there is a lack of constant monitoring, and the use of protective equipment and effective mitigation technologies perpetuates both human and ecological harm.

To address these challenges, there is an urgent need for a comprehensive, multi-sectoral response. This must include real-time environmental monitoring using IoT-based sensors, strict implementation of dust and noise suppression systems, mandatory personal protective equipment (PPE) usage, and regular health checkups for workers. Governments must enforce environmental regulations through inspections, penalties, and mandatory compliance reporting. In parallel, rehabilitation of damaged ecosystems and afforestation around stone-crushing zones should be prioritised. Ultimately, aligning stone-crushing operations with sustainable development goals is critical not only to protect environmental integrity but also to safeguard public health and ensure social equity for vulnerable worker populations.

References

1. M. Evertsson, “Cone Crusher Performance,” 2015, doi: 10.13140/RG.2.1.2212.7526...

2. S. Ravindran, “Stone crushers and dust problem,” Middle East J Sci Res, vol. 14, no. 12, pp. 1734–1740, 2013, doi: 10.5829/idosi.mejsr.2013.14.12.31.

3. A. Goel, S. Rathi, and M. Agrawal, “Toxicity potential of particles caused by particle-bound polycyclic aromatic hydrocarbons (PPAHs) at two roadside locations and relationship with traffic,” Environmental Science and Pollution Research, vol. 25, no. 30, pp. 30633–30646, Oct. 2018, doi: 10.1007/s11356-018-3043-6.

4. LaDou, J. (2003). International occupational health. International journal of hygiene and environmental health, 206(4-5), 303-313.

5. K. L. Saadullah, A. Z. Mudassir, M. S. Atta, F. Muhammed, R. S. Gulam, and A. Waris, “Effect of road side dust pollution on the growth and total chlorophyll contents in Vitis vinifera L. (grape),” Afr J Biotechnol, vol. 13, no. 11, pp. 1237–1242, Mar. 2014, doi: 10.5897/ajb12.2652.

6. J. H. Seinfeld and J. F. Pankow, “Organic Atmospheric Particulate Material,” Annu Rev Phys Chem, vol. 54, pp. 121–140, 2003, doi: 10.1146/annurev.physchem.54.011002.103756.

7. J. G. Wallenborn, M. J. Schladweiler, J. H. Richards, and U. P. Kodavanti, “Differential pulmonary and cardiac effects of pulmonary exposure to a panel of particulate matter-associated metals,” Toxicol Appl Pharmacol, vol. 241, no. 1, pp. 71–80, Nov. 2009, doi: 10.1016/j.taap.2009.08.003.

8. Fatusi, A., & Erhabor, G. (1996). Occupational health status of sawmill workers in Nigeria. Journal of the Royal Society of Health, 116(4), 232-236..

9. Z. Ahmed, R. Alam, S. A. Akter, and A. Kadir, “Environmental sustainability assessment due to stone quarrying and crushing activities in Jaflong, Sylhet,” Environ Monit Assess, vol. 192, no. 12, Dec. 2020, doi: 10.1007/s10661-020-08754-9.

10. Pal, S., & Mandal, I. (2021). Impacts of stone mining and crushing on environmental health in Dwarka river basin. Geocarto International, 36(4), 392-420.

11. S. Pal and I. Mandal, “Noise vulnerability of stone mining and crushing in Dwarka river basin of Eastern India,” Environ Dev Sustain, vol. 23, no. 9, pp. 13667–13688, Sep. 2021, doi: 10.1007/s10668-021-01233-2

12. Naik, D. P., Malini, U., & Somashekar, K. (2007). Noise pollution in stone quarrying industry-a case study in Bangalore district, Karnataka, India. Jr Ind Poll Cont, 23, 43-8.

13. S. K. Leghari, M. A. Zaidi, M. F. Siddiqui, A. M. Sarangzai, S. U. R. Sheikh, and Arsalan, “Dust exposure risk from stone crushing to workers and locally grown plant species in Quetta,

Pakistan," Environ Monit Assess, vol. 191, no. 12, Dec. 2019, doi: 10.1007/s10661-019-7825-1

14. Chaurasia, S., Singh, R., & Pathak, V. (2009). Environmental Study of Stone Crusher. Cough, 35(20), 15-57.

15. R. Sivacoumar, ; R Jayabalou, ; S Swarnalatha, and K. Balakrishnan, "Particulate Matter from Stone Crushing Industry: Size Distribution and Health Effects", doi: 10.1061/ASCE0733-93722006132:3405

16. S. Ganesh and M. M. Singh, "Impact Of Stone Crusher On Ambient Air Quality And Human Health Jhansi Region In Bundelkhand U.P," INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH, vol. 8, p. 8, 2019, [Online]. Available: www.ijstr.org

17. I. Mandal and S. Pal, "COVID-19 pandemic persuaded lockdown effects on environment over stone quarrying and crushing areas," Science of the Total Environment, vol. 732, Aug. 2020, doi: 10.1016/j.scitotenv.2020.139281

18. S. Pal and I. Mandal, "Impacts of stone mining and crushing on environmental health in Dwarka river basin," Geocarto Int, vol. 36, no. 4, pp. 392–420, 2021, doi: 10.1080/10106049.2019.1597390

19. D. C. Saha and P. K. Padhy, "Effect of particulate pollution on rate of transpiration in Shorea robusta at Lalpahari forest," Trees - Structure and Function, vol. 26, no. 4, pp. 1215–1223, Aug. 2012, doi: 10.1007/s00468-012-0697-4

20. D. C. Saha and P. K. Padhy, "Effects of stone crushing industry on Shorea robusta and Madhuca indica foliage in Lalpahari forest," Atmos Pollut Res, vol. 2, no. 4, pp. 463–476, 2011, doi: 10.5094/APR.2011.053

21. S. K. Singh, G. R. Chowdhary, and G. Purohit, "Assessment of Impact of High Particulate Concentration on Peak Expiratory Flow Rate of Lungs of Sand Stone Quarry Workers," 2006. [Online]. Available: www.ijerph.org

22. T. T. K. Pham, S. H. Le, T. Nguyen, R. Balasubramanian, and P. T. M. Tran, "Characteristics of airborne particles in stone quarrying areas: Human exposure assessment and mitigation," Environ Res, vol. 245, Mar. 2024, doi: 10.1016/j.envres.2023.118087

23. R. Bihari Panda, "Dust pollution in stone crusher units in and around balasore, Orissa, India," 2012. [Online]. Available: https://www.researchgate.net/publication/295435764

24. Semple, S., Green, D. A., McAlpine, G., Cowie, H., & Seaton, A. (2008). Exposure to particulate matter on an Indian stone-crushing site. Occupational and environmental medicine, 65(5), 300-305.

25. M. I. M. Ismail, M. H. Ibrahim, T. A. Ladan, C. Muryani, and P. Wijayanti, "Looking at the relationship of PM10 suspended particle concentration from daily observations and annual observations of the Ipoh Meteorological Department, Perak," in IOP Conference Series: Earth and Environmental Science, Institute of Physics, 2024. doi: 10.1088/1755-1315/1314/1/012106.

26. R. Sivacoumar, S. Mohan Raj, S. J. Chinnadurai, and R. Jayabalou, “Modeling of fugitive dust emission and control measures in stone crushing industry,” Journal of Environmental Monitoring, vol. 11, no. 5, pp. 987–997, 2009, doi: 10.1039/b818362g

27. P. Gottesfeld, M. Nicas, J. W. Kephart, K. Balakrishnan, and R. Rinehart, “Reduction of respirable silica following the introduction of water spray applications in Indian stone crusher mills,” Int J Occup Environ Health, vol. 14, no. 2, pp. 94–103, 2008, doi: 10.1179/oeh.2008.14.2.94.

28. A. Adhikari, A. Mitra, A. Rashidi, I. Ekpo, J. Schwartz, and J. Doehling, “Field evaluation of N95 filtering facepiece respirators on construction jobsites for protection against airborne ultrafine particles,” Int J Environ Res Public Health, vol. 15, no. 9, Sep. 2018, doi: 10.3390/ijerph15091958.

29. M. N. Islam, K. S. Rahman, M. M. Bahar, M. A. Habib, K. Ando, and N. Hattori, “Pollution attenuation by roadside greenbelt in and around urban areas,” Urban For Urban Green, vol. 11, no. 4, pp. 460–464, 2012, doi: 10.1016/j.ufug.2012.06.004.

30. E. Kabir, A. Islam, and M. Taufikuzzaman, “An investigation into respiratory health problems of workers at stone crushing industries in Bangladesh,” J Health Res, vol. 32, no. 2, pp. 172–178, Apr. 2018, doi: 10.1108/JHR-01-2018-017.

31. K. Karki, A. Chaurel, A. K. Neupane, K. Parajuli, and R. Ghimire, “Risk perception among residents living near industries in Godawari Municipality of Lalitpur, Nepal,” Environ Anal Health Toxicol, vol. 38, no. 4, Dec. 2023, doi: 10.5620/eaht.2023029.