Aggregate-crushing Industry, Health and Environmental Hazards and Control Mechanism in Asia in Last 20 years: A Systematic Literature Review

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1. Abstract

Aggregate-crushing industrial sector plays a crucial role in the construction industry. It produces various desired sizes and shapes of stones depending on the construction of residential or commercial buildings, canals, highways, rail lines, dams, offshore structures, bridges, etc. This operation of stone-crushing results in a significant contribution to environmental and human health by means of 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. Aggregate-crushing machineries lead to environmental degradation by affecting the vegetation and air quality, disrupting local biodiversity. It causes oil contamination. Moreover, High machinery noise during operations like crushing, material handling processes, and heavy-load vehicular movement often exceeds permissible noise limits, leading to noise pollution that affects both human well-being and other health issues in local society and crusher workers. This systematic review elaborates on the findings of different regional research studies that highlight the concern about pollution due to the stone crusher and its effect on human health, the environment, and biodiversity. It also 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. Also, the future research recommendations highlight the critical role of the development of advanced pollution control technologies, the adoption of community-focused strategies, and the alignment of the stone crusher operations with broader sustainable development objectives. Methodologically, PRISMA has been followed to construct this systematic literature review. In this piece, articles from he 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 used for collecting metadata for comparison and analysis. In a nutshell, it has been found 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.

2. Introduction

The stone crushing industry is one of the important sectors of the construction industry [1]. This industry crushes the aggregates out of boulders and sends them for construction. This requires heavy manpower and electric power to be operated along with a better and organized transportation system for shifting mining materials to the industry. These industries are located far from cities, at the outskirt of a small town. Stone crushing industries are known to one of the most pollutant construction industry. The fugitive emissions generated from the stone crushing industry can pose a severe problem for humans and animals, in nearby society, along with threat to aquatic animals, and people dependent on the water bodies nearby[2], [3]. This suspended particulate matter released in the surrounding, later settles on the plant leaves and blocks the stomatal opening, that cause the death of leaves [4]. As well as the dust particles on the leaf surface prevents it from performing photosynthesis due to the disruption in stomatal opening. Which can significantly affect the production of the crops and growth of plants, Leghari *et al*. (2014) found that due to this reason the height, cover, total chlorophyll, and number of leaves content for Vitis vinifera L at the roadside are generally low [5]. Wallenborn et al. (2009) and Seinfeld and Pankow (2003) emphasized the effect of atmospheric particulate matter on environment and human health. They state that exposure to harmful pollutants can significantly impact the economy by affecting human health. Such exposure cases is often seen among the workers, which increase probability of getting ill and possibly premature death [6], [7]. In emerging countries, workers are usually unaware of the harmful effects of prolonged exposure to high pollution levels [8].

This review presents a state-of-the-art review of articles from the last 20 years in the context of Asian countries. In a nutshell, it has been found that the research has been spiked in the last 20 years. The review highlights different type of pollution caused by the stone crushing industry till now. And compare them in the field of different types of pollution and their impact on atmosphere, water bodies and human health. The paper also highlights the comparison of those data against the national limit of different countries and meta data analysis. The review paper indicates the concern related the pollution caused by the stone crushing industry.

3. 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. A total of 296 papers were initially collected from Scopus using relevant keywords. After a rigorous screening and sorting process, this number was reduced to 40 papers, which were further refined to 25 final studies and 4 review studies for inclusion. 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 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 effect.

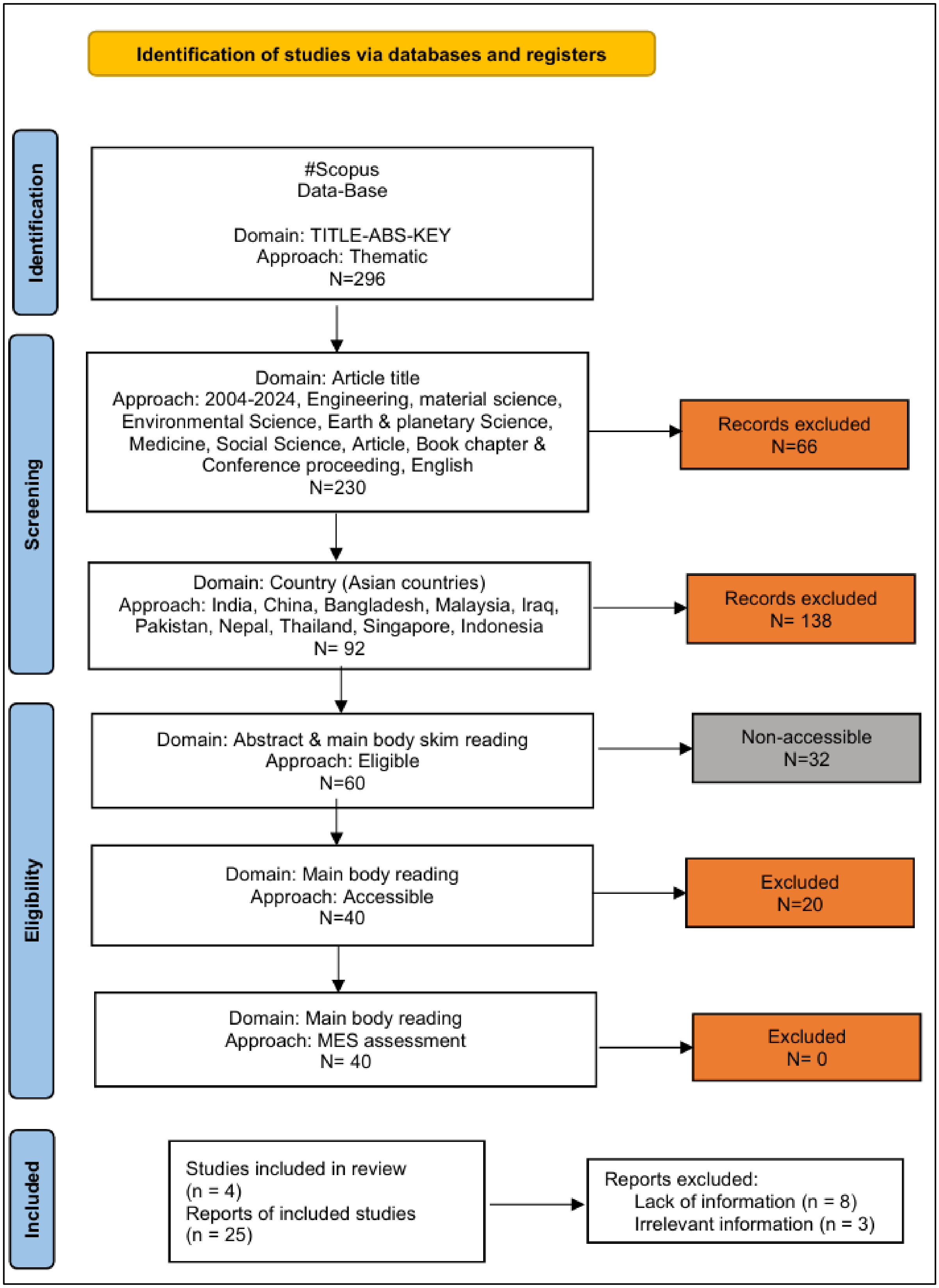

Figure 1: Detailed PRISMA Table

4. Results and discussion

4.1 Bibliometric analysis

The bibliometric analysis has been done under the segment of 'Network Visualisation'. Those index and author keywords have been considered that have occurred at least five times. 3 clusters and total 50 number of keywords have been identified. A total of links (co-occurrences) have been generated. Total link strength has been calculated as 319.00. The keyword that occurs most is. 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 Figure 2. Analyzing 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.

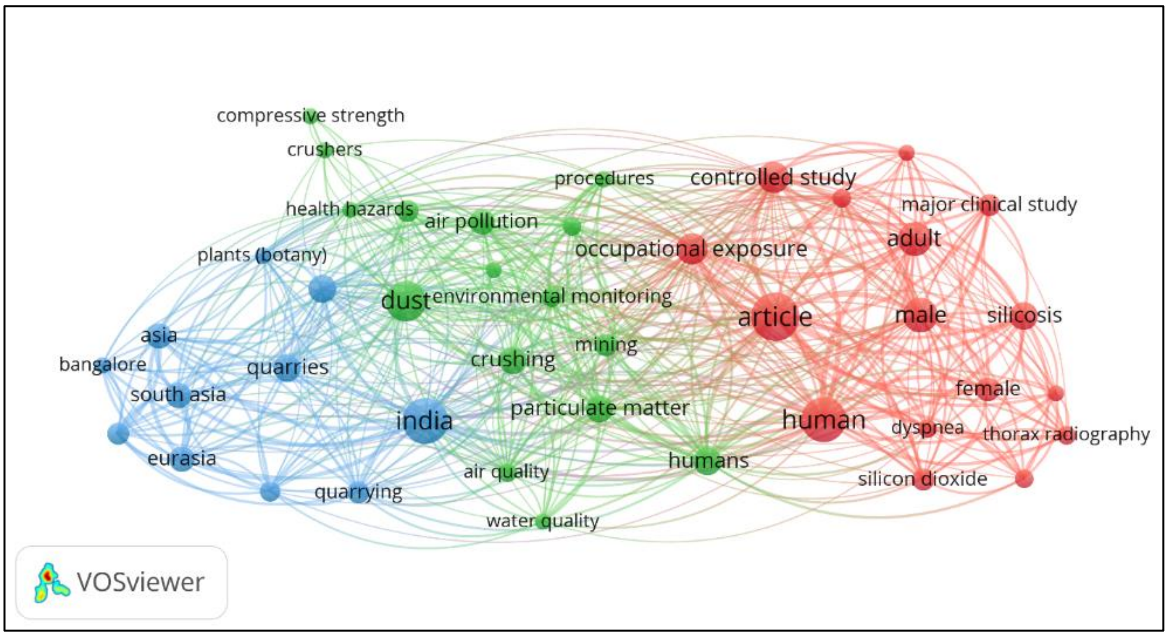

Figure 2: Keyword Co-occurrence Network (Total Link Strength based)

4.2 Countries involvement

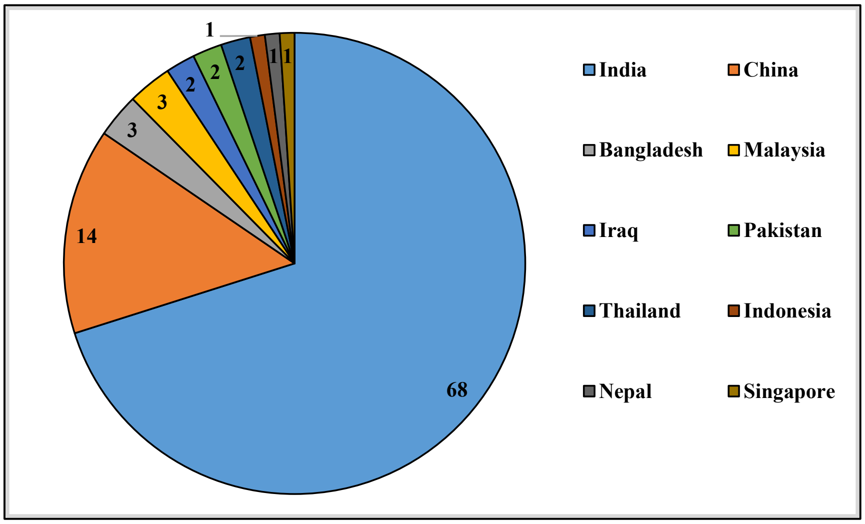

Figure 3: Publication count from the Asian countries.

Figure 3 illustrates the publication count as well 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.

4.3 Compiled Data from Existing Research on Stone-Crushing Impacts

Table 1: Comparison of Noise Pollution Levels at Stone-Crushing Sites Across Asia with National Regulatory

Ref no	Location of survey	Noise level (dB)					
		Crushing	Quarry	Blast	Drill	Vehicle movement	Road side
[9]	Site 1	93.34	-	-	-	-	-
[9]	Site 2	88.34	-	-	-	-	-
[9]	Site 3	96.29	-	-	-	-	-
[9]	Site 4	78.83	-	-	-	-	-
[9]	Site 5	91.73	-	-	-	-	-
[9]	Site 6	80.43	-	-	-	-	-
[9]	Site 7	88.91	-	-	-	-	-
[9]	Site 8	94.48	-	-	-	-	-
[9]	Site 9	93.95	-	-	-	-	-
[9]	Site 10	97.31	-	-	-	-	-
[10]	Bharatkoop	102	-	-	-	-	-
[10]	Banda	99	-	-	-	-	-
[10]	Kabrai	103	-	-	-	-	-
[11]	Dwarka river basin of Eastern India.	> 76	-	-	-	-	-
[12]	Bettahalsur	97.8	79.6	138	109.5	101	90.7

Table 1 (*continued*): Comparison of Noise Pollution Levels at Stone-Crushing Sites Across Asia with National Regulatory

[12]	Bandehosur	93	74.5	135	111.8	75	76.5
[12]	Kogilu	99.5	70.1	139	108.6	82	85
[12]	Basavanahalli	98.6	72.8	-	-	72	65.2
[12]	Kallugopanahalli	95.3	75	147	112.9	83.6	75.4
[12]	Nidagallu	-	-	-	116	76	68.4
[12]	Tamasandra	-	-	-	114	70	68.4
[12]	Kailancha	-	-	156	106.8	65.6	63.8
[12]	Doddabettahalli	96	74.6	148	99	69	65
[12]	Anjanapura	92	73.8	133	101	70	64
[13]	India – Central Pollution Control Board (CPCB)	75	75	75-90	75	75	75
[14]	Nepal – Department of Environment (DoEnv)	~75	75	90	75	70-75	~55
[15]	China – Ministry of Ecology & Environment (MEE)	70-75	75	85-90	75	70-75	60-65
[16]	Bangladesh – Department of Environment (DoE)	75	75	85-90	75	70-75	60
[17]	Iraq – Ministry of Environment	-	75	85-90	75	~75	60
[18]	Malaysia – Department of Environment (DOE)	75	75	85	75	75	65
[19]	Pakistan – Pak Environmental Protection Agency (Pak-EPA)	75	75	85	75	75	65
[20]	Indonesia – Ministry of Environment & Forestry	70-75	75	85	75	75	65
[21]	Thailand – Pollution Control Department (PCD)	70-75	75	85-90	75	75	60-65
[22]	Singapore – National Environment Agency (NEA)	75	75	85	75	70-75	60

From table 1, it can be observed that the noise pollution of stone crushing industries across Asia are breaching the national standards limits, especially in India the level reaches up to 156 dB in Kailancha. The decibel in Kailancha of Ramanagara district in Karnataka, India, is far from the limit set by CPCB. Similarly, violations can be seen in other countries. The table prompts a constant gap between permissible levels and actual readings, indicating poor enforcement.

Table 2: Comparative Analysis of Air Pollutants (SOx, NOx, TSP) at Stone-Crushing Sites Against National Ambient Standards in Asian Countries

Ref no	Location of survey	Site	SO_X (µg/m³)	NO_X (µg/m³)	TSP (µg/m³)
[23]	Quetta, Balochistan, Pakistan.	-	8.03E+08	2.16E+08	-
[24]	Chitrakoot area	A	150	300	-
[24]	Chitrakoot area	B	190	500	-
[24]	Chitrakoot area	C	190	750	-
[24]	Chitrakoot area	D	190	750	-
[24]	Chitrakoot area	E	201	750	-
[25]	Pammal Chennai city	Kavasam	-	-	2470
[25]	Pammal Chennai city	KVS	-	-	823
[25]	Pammal Chennai city	Praveen	-	-	698
[25]	Pammal Chennai city	KTC	-	-	698
[25]	Pammal Chennai city	Vinoth	-	-	442

Table 2 (*continued*): Comparative Analysis of Air Pollutants (SOx, NOx, TSP) at Stone-Crushing Sites Against National Ambient Standards in Asian Countries

[25]	Pammal Chennai city	Geetha	-	-	589
[25]	Pammal Chennai city	Kalaiselvi	-	-	1706
[25]	Pammal Chennai city	Solai	-	-	694
[25]	Pammal Chennai city	Vigneswara	-	-	987
[25]	Pammal Chennai city	Peter	-	-	962
[25]	Pammal Chennai city	Tennish	-	-	342
[26]	Bundelkhand massif & Jhasi	-	4.91	10.66	-
[13]	India – Central Pollution Control Board (CPCB)	-	80	80	100
[14]	Nepal – Department of Environment	-	70	80	120
[15]	China – Ministry of Ecology and Environment (GB3095-2012)	-	150	80	150
[16]	Bangladesh – Department of Environment	-	365	-	150
[17]	Iraq – Ministry of Environment	-	125 aligned with WHO IT-1	Appx 200	150
[18]	Malaysia – Department of Environment (DOE)	-	105	320	150
[19]	Pakistan – Pakistan Environmental Protection Agency (Pak-EPA)	-	120	80	150
[20]	Indonesia – Ministry of Environment and Forestry	-	365	150	150
[21]	Thailand – Pollution Control Department (PCD)	-	300	100	120
[22]	Singapore – National Environment Agency (NEA)	-	125	via PSI index (24-h) — not separately published	50

The critical air pollution mentioned in table 2 indicates the devastating environment around the stone crushing industry. The observation around Chitrakoot area draws a special attention, where the observation around Chitrakoot area draws special attention, where NOx reaches 750 µg/m³ against India's 80 µg/m³ limit. It also indicates that 3 sites of Chitrakoot excided nearly tenfold in national standard and highlighting a severe air quality concern that necessitates urgent regulatory intervention and source-specific mitigation strategies.

Table 3: Comparative Analysis of Water Quality Parameters near Stone-Crushing Sites Against National Environmental Standards in Asian Countries

Ref no	Location of survey	Geological condition	BOD (mg/L)	Turbidity (NTU)	pH	DO (ppm)	TDS (mg/L)	EC (µs/cm)	TS (mg/L)	TSS (mg/L)	COD (mg/L)
[27]	Dwarka river basin along Gopikandar, Pakuria	-	-	-	8.7	3.74	2457	-	-	-	-
[9]	Gowainghat Upazila of Sylhet District	monsoon	2.85	341	7.56	9	47.11	635.34	47.78	0.68	-
		post monsoon	1.8	411.7	7.62	8.33	84.89	598.06	86.01	1.13	-
[28]	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
[13]	India – Central Pollution Control Board (CPCB)	-	>5	-	6.5-8.5	<3	-	-	-	-	-
[14]	Nepal – Department of Environment	-	>5	-	6.5-8.5	<4	-	-	-	-	-
[15]	China – Ministry of Ecology and Environment (GB3095-2012)	-	>6	-	6-9	-	-	-	-	-	<4
[16]	Bangladesh – Department of Environment	-	>5	-	6.5-8.5	<3	-	-	-	-	-
[17]	Iraq – Ministry of Environment	-	>5	-	6.5-8.5	<3	-	-	-	-	-
[18]	Malaysia – Department of Environment (DOE)	-	>7	-	6.5-8.5	<1	-	-	-	-	-
[19]	Pakistan – Pakistan Environmental Protection Agency (Pak-EPA)	-	>6	-	6.5-8.5	<80	-	-	-	-	-
[20]	Indonesia – Ministry of Environment and Forestry	-	>4	-	6-9	<3	-	-	-	-	-

Table 3 (*continued*): Comparative Analysis of Water Quality Parameters near Stone-Crushing Sites Against National Environmental Standards in Asian Countries

[21]	Thailand – Pollution Control Department (PCD)	-	>2	-	6-9	<3	-	-	-	-	-
[22]	Singapore – National Environment Agency (NEA)	-	>5	-	6.5-8.5	<3	-	-	-	-	-

The water quality mentioned in table 3 emphasizes the notable water quality deterioration near stone-crushing sites. Parameters like pH, DO, and turbidity often breach national standards. For instance, Dwarka basin shows low DO (~2.7–3.7 ppm) and high COD (>13,000 mg/L), indicating severe organic pollution. Compared to regulatory limits, most readings signal ecological stress.

4.3.1 Impact of Dust Emissions on Local Water Quality Parameters

Dwarka River basin & Chotanagpur plateau, Gopikandar, Pakuria, India.

The extreme air quality observed in Chotanagpur, as shown in Table 6, with PM10 levels reaching up to 18,900 µg/m³, indicates a hazardous atmosphere for both the environment and the community. This intense air quality, primarily driven by uncontrolled emissions and dust dispersal, is breaching the national regulation limit by the Central Pollution Control Board (CPCB). As a direct consequence, surrounding water bodies are showing alarming signs of degradation, as reflected in Table 3, where biological oxygen demand (BOD) reaches up to 48.2 mg/L, chemical oxygen demand (COD) exceeds 13,000 mg/L, and dissolved oxygen (DO) drops below 4 ppm. These data confirm reflects the massive particulate load in the air is settling into water sources as well as facilitating runoff of toxic materials.

Gowainghat Upazila of Sylhet District, border between Bangladesh and the Indian state of Meghalaya.

At Sylhet, moderate levels of PM10 pollution are recorded, with concentrations reaching up to 431 µg/m³ at site 8, as shown in Table 6. As a direct consequence, the adjacent water bodies largely conform to acceptable environmental standards, as indicated in Table 3, where biological oxygen demand (BOD) remains below 3 mg/L and dissolved oxygen (DO) ranges between 8-9 ppm. Due to the high contrast of industrialised and severely polluted zones, the overall water quality shows notable resilience despite the presence of some suspended solids and seasonal turbidity. 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 4: 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	Leaf area damage %			Leaf Injured %			leaf death %		
				Summer	Rain	Winter		Summer	Rain	Winter	Summer	Rain	Winter	Summer	Rain	Winter
[23]	bypass in the Quetta, Balochistan, Pakistan.	-	Vitis vinifera	-	-	-	8.2	-	-	-	-	-	-	-	-	-
[23]	bypass in the Quetta, Balochistan, Pakistan.	-	Morus alba	-	-	-	4.6	-	-	-	-	-	-	-	-	-
[23]	bypass in the Quetta, Balochistan, Pakistan.	-	Prunus armeniaca	-	-	-	4.4	-	-	-	-	-	-	-	-	-
[38]	Birbhum district (3 location)	site 1	-	5.58	1.72	4.8	-	16.5	6.8	16.9	55.2	46.1	69.4	16	3	21
		site 2	-	27.3	15.8	38.33	-	9.11	4.7	11.5	25.7	24.5	55.8	11	2	14
		site 3	-	1	0	3	-	16	3	21	11	2	14	4	0	2
[39]	Lalpahari forest	site 1	Shorea robusta	5.58	1.72	4.8	-	16.5	6.8	16.9	55.2	46.15	69.3	16	3	21
			Madhuca indica	6.86	3.9	7.53	-	18.3	9.9	4.7	41.8	45.7	55.2	23	5	19
		site 2	Shorea robusta	27.3	15.8	38.33	-	9.1	4.68	11.5	25.7	24.5	55.8	11	2	14
			Madhuca indica	13.6	8.74	36.54	-	10.1	4.8	11.9	17.3	20.7	22.2	7	2	22
		site 3	Shorea robusta	1	0	3	-	5	3.3	6.2	29.6	28.8	37.5	4	0	2
			Madhuca indica	0	0	4	-	5.4	3.7	9.13	13.6	21.4	15.9	3	1	3

Table 5: Prevalence of Respiratory and Occupational Health Symptoms Among Workers in Stone-Crushing Zones Across South Asia

<table>
<tr><th>Ref no</th><th>Location of survey</th><th>Cough-ness</th><th>Shortness of breath</th><th>Wheeze</th><th>Tightness in chest</th><th>Dyspnoea</th><th>Silicosis</th><th>Tuberculosis</th><th>Asthma</th><th>Allergy</th><th>Headache</th><th>Tiredness</th><th>Breathlessness & Eye/ skin irritation</th></tr>
<tr><td>[40]</td><td>Lalmonirhat</td><td>28.33</td><td>4.58</td><td>2.29</td><td>1.68</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td></td></tr>
<tr><td>[29]</td><td>Jodhpur</td><td>7.5</td><td>-</td><td>3.8</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td></td></tr>
<tr><td>[23]</td><td>Quetta, Balochistan, Pakistan. (Site 1)</td><td>80</td><td colspan="7">78.33</td><td>73.33</td><td>75</td><td>96.66</td><td></td></tr>
<tr><td>[23]</td><td>Quetta, Balochistan, Pakistan. (Site 2)</td><td>76.36</td><td colspan="7">75.54</td><td>65.45</td><td>58.1</td><td>89.09</td><td></td></tr>
<tr><td>[23]</td><td>Quetta, Balochistan, Pakistan. (Site 3)</td><td>77.35</td><td colspan="7">83.02</td><td>71.69</td><td>79.24</td><td>88.68</td><td></td></tr>
<tr><td>[23]</td><td>Quetta, Balochistan, Pakistan. (Site 4)</td><td>70</td><td colspan="7">94</td><td>74</td><td>88</td><td>96.66</td><td></td></tr>
<tr><td>[23]</td><td>Quetta, Balochistan, Pakistan. (Site 5)</td><td>88.09</td><td colspan="7">80.95</td><td>76.2</td><td>80.95</td><td>90.47</td><td></td></tr>
<tr><td>[24]</td><td>Chitrakoot area</td><td>57</td><td colspan="7">71.1</td><td>74.3</td><td>68.6</td><td>60.6</td><td></td></tr>
<tr><td>[10]</td><td>Bharatkoop</td><td>30</td><td colspan="7">46</td><td>52</td><td colspan="2">28</td><td>52</td></tr>
<tr><td>[10]</td><td>Kabrai</td><td>40</td><td colspan="7">52</td><td>62</td><td colspan="2">36</td><td>64</td></tr>
<tr><td>[10]</td><td>Banda</td><td>20</td><td colspan="7">36</td><td>40</td><td colspan="2">20</td><td>36</td></tr>
<tr><td>[26]</td><td>Bundelkhand massif & Jhasi</td><td>65</td><td>-</td><td>51</td><td colspan="5">79</td><td></td><td>58</td><td>-</td><td>72</td></tr>
<tr><td>[41]</td><td>Lalitpur, Nepal</td><td>27</td><td>21</td><td>24</td><td></td><td></td><td></td><td></td><td>6</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 6: Comparison of Particulate Matter Concentrations (PM10, PM2.5, PM1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

ref no	Location of survey	branch	µg/m³ For PM10	µg/m³ For PM2.5	µg/m³ For PM1	µg/m³ For PM0.5	µg/m³ For other size
			Crushing/ Dressing/ Drilling (all operations)	Crushing	Crushing	Crushing	Crushing
[29]	Jodhpur	-	4800/ 9300/ 18500	-	-	-	-
[30]	Vietnam Danang	-	4692.46	166.04	12.22+- 6.73	5.93+- 3.27	-
[27]	India (Gopikandar, Pakuria, Kathikund, Shikaripara, Nalhati, Rampurhat, Md. Bazar)	-	18900	-	-	-	-
[31]	Balasore, orissa, India	Ganesh	1182.79	-	-	-	-
		Uma	1072.62	-	-	-	-
		Sai	1001.23	-	-	-	-
		Laxmi	955.45	-	-	-	-
		Jagannath	1055.37	-	-	-	-
[31]	Birbhum district (3 location)	Site 1	184630	-	-	-	-
		Site 2	120520	-	-	-	-
		Site 3	31240	-	-	-	-
[9]	Gow ainghat Upazila of Sylhet District	Site 1	154.23	328.02	-	-	-
		Site 2	8.25	52.12	-	-	-
		Site 3	32.54	78.21	-	-	-
		Site 4	19.23	94.61	-	-	-
		Site 5	45.14	92.15	-	-	-
		Site 6	39.01	143.51	-	-	-
		Site 7	84.21	304.15	-	-	-
		Site 8	431.32	287.13	-	-	-
		Site 9	43.19	287.21	-	-	-
		Site 10	67.21	523.85	-	-	-
[32]	Ahemdabad	Site 1	10340	1340	-	-	3110
		Site 2	19490	1640	-	-	7400
		Site 3	12000	930	-	-	6330
[26]	Bundelkhand massif & Jhasi of Uttar Pradesh	-	254.49	-	-	-	-

Table 6 (*continued*): Comparison of Particulate Matter Concentrations (PM10, PM2.5, PM1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

[33]	North and Southern Area of Ipoh, Perak	Kilang Simen Khantan	231.7	146.3	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Khantan	81.8	39.3	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Desa Tanjung Murni	24.9	19.5	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Chepor	21.9	7.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Changkat Kinding	15	6.1	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Meru	22.7	16.3	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Keledang	93.4	45.7	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Ringan Bercham	51.9	31.7	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Sri Tanjung	12	8.4	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kilang Simen Tasek	213.7	121.3	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Becham Jaya	29.8	15.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kampung Lata	17	9.7	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Ipoh Selatan	34.5	27.5	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kampung Kepayang	20.1	13.1	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kampung Dato Ahmad	20.1	14.7	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Jelapang	31	20.1	-	-	-

Table 6 (*continued*): Comparison of Particulate Matter Concentrations (PM10, PM2.5, PM1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

[33]	North and Southern Area of Ipoh, Perak	Pusat Bandar Ipoh	37.7	25.9	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Silibin	41.5	19.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Jelapang 2	40.1	21.6	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Masjid Negeri	29.8	13	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Flora Tropika	26.6	11.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Desa Indah	29.8	17.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Camay	34.2	14.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perusahaan Mengelembu	50.1	23.5	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Mengelembu	46.1	25.8	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Bukit Merah	22.9	11.2	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Pengkalan Jaya	45.8	24.3	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Taman Sri Palma	27.4	13.9	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Industri Ringan Kinta Jaya	53.1	16.9	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Indstri Pemecahan Batu	56.3	36.3	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Bandar Pulai Jaya	34.2	18.3	-	-	-

Table 6 (*continued*): Comparison of Particulate Matter Concentrations (PM10, PM2.5, PM1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

[33]	North and Southern Area of Ipoh, Perak	Kilang Simen Pinji	139.9	37.1	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Lahat	27.9	17.2	-	-	-
[33]	North and Southern Area of Ipoh, Perak	Kawasan Perindustrian Pengkalan	23.2	13.3	-	-	-
[34]	Trisoolam of Chennai city	Subramanian	101000	-	-	-	-
		Gnanaselvam	87000	-	-	-	-
		Praveena	78000	-	-	-	-
		Sri Ganesh	74000	-	-	-	-
		Vignreshwara	97000	-	-	-	-
		Janakriman	63000	-	-	-	-
		Vijayaram	93000	-	-	-	-
		Dwaraga	90000	-	-	-	-
		Ashok crusher	42000	-	-	-	-
		Swaminathan	50000	-	-	-	-
		Kamatchi	57000	-	-	-	-
[25]	Pammal of Chennai city	Kavasam	1200	388	-	-	-
		KVS	315	85	-	-	-
		Praveen	265	106	-	-	-
		KTC	265	78	-	-	-
		Kalaiselvi	1025	213	-	-	-
		Solai	110	73	-	-	-
		Vigneswara	445	117	-	-	-
		Peter	179	138	-	-	-
		Tennish	90	41	-	-	-
		Vinoth	94	61	-	-	-
		Geetha	156	63	-	-	-
[35]	Khurda District of Orissa	34319	2200	-	-	-	-
		34229	1400	-	-	-	-
		34211	7200	-	-	-	-
		34224	670	-	-	-	-
		34231	1700	-	-	-	-
[13]	India – Central Pollution Control Board (CPCB)	-	100	60	-	-	-

Table 6 (*continued*): Comparison of Particulate Matter Concentrations (PM10, PM2.5, PM1) at Stone-Crushing Sites with Ambient Air Quality Standards across Asian Countries

[14]	Nepal – Department of Environment		120	40	-	-	-
[15]	China – Ministry of Ecology and Environment (GB3095-2012)		150	75	-	-	-
[16]	Bangladesh – Department of Environment		150	65	-	-	-
[17]	Iraq – Ministry of Environment		150	35	-	-	-
[18]	Malaysia – Department of Environment (DOE)		150	35	-	-	-
[19]	Pakistan – Pakistan Environmental Protection Agency (Pak-EPA)		150	35	-	-	-
[20]	Indonesia – Ministry of Environment and Forestry		150		-	-	-
[21]	Thailand – Pollution Control Department (PCD)		120	50	-	-	-
[22]	Singapore – National Environment Agency (NEA)		50	25	-	-	-

4.3.2 Impact of Airborne Particulate Matter on Respiratory Health in Crushing Zones

Jodhpur, India

According to the data shown in table 5 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 6, dust concentrations in key operational areas are alarmingly high, particularly during dressing (9,300 µg/m³) and drilling (18,500 µg/m³), significantly breaching the national limit set by CPCB. 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 5 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 6 data support the point of elevated particulate concentrations up to 254.49 $\mu g/m^3$ for PM10. 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 2 indicate the chronic exposure of harmful gaseous pollutants in the Chitrakoot region. In site E it was observed that sulfur oxides SO_x and nitrogen oxides NO_x content reach up to 201 $\mu g/m^3$ and 750 $\mu g/m^3$, respectively, well beyond typical ambient thresholds. As a direct consequence, Table 5 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.

4.3.3 Vegetation Damage Trends Across High PM Exposure Sites

Quetta, Pakistan

Atmospheric emissions near stone crushing sites in Balochistan are extremely high (Table 2: SOx 803,000,000$\mu g/m^3$, NOx 216,000,000$\mu g/m^3$), crossing the limit of the Pakistan Environmental Protection Agency. The site poses a threat to living organisms around that area. As a direct consequence, table 4 reveals that vegetation in the vicinity, including species such as Vitis vinifera and Morus alba, 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 discoloration, and visible injury symptoms. The combined effects of exacerbating gaseous emissions and dust deposition create a hostile microclimate for greenery around it, contributing to long-term risks to vegetation health, productivity, and ecological stability.

Birbhum district (Lalpahari forest), India

Airborne dust concentration around the stone quarrying zones of Lalpahari forest indicates a threat to the environment. The PM10 concentration spiked up to 184,630 $\mu g/m^3$, crossing the barrier of the national limit as detailed in table 6. This is reflected in severe vegetative impacts, as documented in Table 4, which details the damage to plant life surrounding the crusher. Especially on species such as Shorea robusta and Madhuca indica, the dust deposition on the leaf surface is up to 6.86 $\mu g/cm^2$. This particulate overload has led to over 55% leaf area injury and leaf mortality rates exceeding 20%. The obstruction of stomatal pores, disruption of photosynthetic processes, and ongoing foliar degradation collectively threaten plant vitality and the overall stability of the forest ecosystem.

4.4 Systemic Gaps and Regulatory Deficiencies in Pollution Control

The data presented in tables 2 and 6 highlight the severity of dust emissions and pollution levels across Asia. This effectively influences the health condition of workers, vegetation, and waterbodies around it, which is supported by the data in tables 3, 4, and 5. These data from the systematic literature review indicates that there is a clear lack of regulatory enforcement, as environmental parameters such as noise levels (exceeding 100 dB), PM10 concentrations (reaching up to 184,630 $\mu g/m^3$), and NOx emissions (up to 750 $\mu g/m^3$) far surpass permissible limits without consequence. Dust emission control measures are largely absent, leading to ecological stress such as 69.4% leaf death and severe water pollution with DO as low as 2.7 ppm. Despite that, pollution supported by table 6 worker safety is critically neglected, with no consistent use of PPE or periodic health checkups, despite health issues like coughing and dyspnoea affecting over 80% of workers with no consistent use of PPE or periodic health checkups despite health issues like coughing and dyspnoea affecting over 80% of workers. Furthermore, there is a lack of integration between environmental, health, and ecological management, and significant data gaps persist in certain regions. These findings emphasize the urgent need for unified, technology-driven, and health-centred regulatory frameworks.

4.5 Prevention and countermeasures

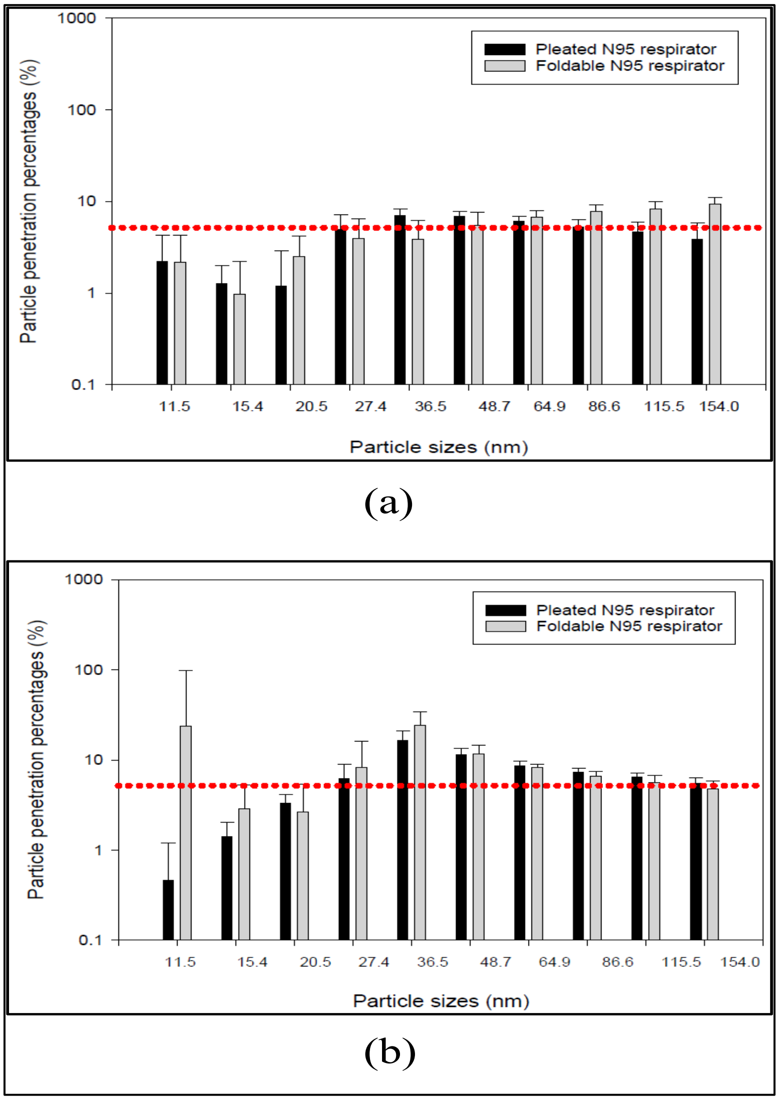

Figure 4: Penetration percentages of nanoparticles (11.5–154.0nm) through pleated and foldable N95 respirators during (a) soil moving by bulldozers and (b) concrete blasting and grinding at a construction site. The dotted red line marks the 5% penetration threshold, representing the efficacy cutoff for N95 respirators. Error bars indicate standard deviations (A. Adhikari *et al. 2018*).

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 fig. 1. This reduces inhalation of toxic particles, lowers the risk of lung diseases, and enhances overall respiratory health and workplace safety [36].

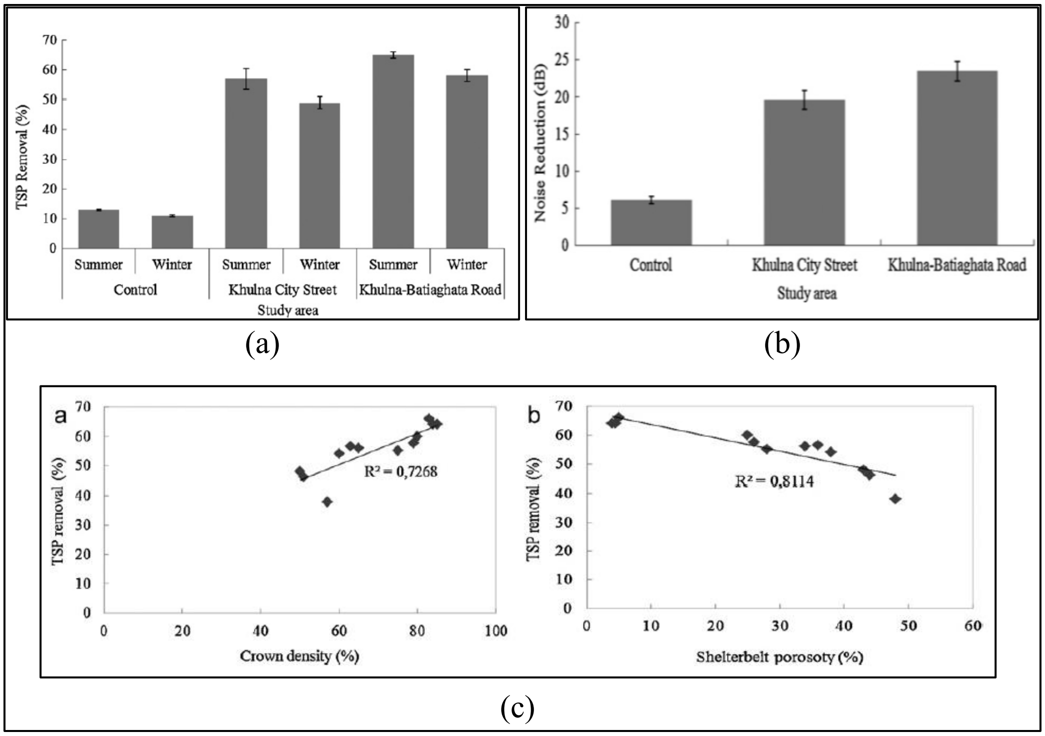

Figure 5: (a) Average removal efficiency of total suspended particles (TSP) from air by roadside shelterbelts along two major streets in Khulna City, Bangladesh, during summer and winter (mean ± SD). (b) Average reduction in traffic-induced noise by the same greenbelts (mean ± SD). (c) Regression analysis showing the relationship between TSP removal percentage, crown density, and shelterbelt porosity (Md. N. Islam *et al. 2012*).

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 fig. 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 [37] .

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 µg/m³ and SOx to 8.03E+08 µg/m³, far from the national standard limit. Particulate matter, especially PM10, reaches hazardous levels—up to 184,630 µg/m³—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 of national regulations and standards of emission and exposure, there is a lack of constant monitoring, 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 prioritized. 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.

CRediT authorship contribution statement

Sourav Ghosh: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Munshi Izaz Refaz: Writing – original draft, Writing – review & editing, Supervision, Software, Methodology. Mainak Maiti: Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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