

Air Pollution and Respiratory Health in Benghazi, Libya: A Cross-Sectional Study of Environmental and Public Health Perspectives on Cement Factory Emissions

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ABSTRACT

Industrial air pollution, particularly from cement manufacturing, continues to raise critical public health concerns in Libya's urban centres. This study examined the perspectives of healthcare, environmental, and regulatory professionals in Benghazi regarding the respiratory health implications of emissions produced by the local cement factory. The investigation focused on expert assessments of pollutant exposure, levels of public awareness, and the perceived adequacy of regulatory enforcement. A cross-sectional survey was conducted between March and May 2025 using a structured and validated online questionnaire. The instrument comprised four sections: demographic characteristics (6 items), perceived respiratory health impact (8 items), public awareness and communication (10 items), and regulatory monitoring and enforcement (10 items). A total of 600 participants were purposively selected from three stakeholder groups: healthcare providers, environmental experts, and regulatory personnel, with 200 individuals from each group. Data were analyzed using SPSS Version 27, incorporating descriptive statistics and Pearson's correlation tests. Ethical approval was granted by the Benghazi Cement Factory's Administrative Board. Most respondents (74.2%) agreed that factory emissions are linked to increased respiratory conditions in nearby communities. Furthermore, 65.1% cited inadequate environmental communication as a key barrier to improving public awareness, while 78.7% expressed low confidence in regulatory performance. Correlation analysis revealed a moderate positive association between perceived emissions exposure and respiratory health concerns ($r = 0.219$, $p = 0.007$), with weaker but significant relationships observed for public awareness ($r = 0.183$, $p = 0.021$) and enforcement mechanisms ($r = 0.197$, $p = 0.014$). These findings highlight health risks and communication and regulatory deficiencies needing targeted policy attention.

Keywords: Air pollution, Cement emissions, Respiratory health, Libya, Risk perception, Environmental governance, public health.

التلوث الهوائي والصحة التنفسية في بنغازي، ليبيا: دراسة مقطعية كمية من منظور الصحة العامة والبيئة حول انبعاثات مصانع الأسمنت

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ملخص البحث

تُعد التلوثات الهوائية الصناعية، ولا سيّما الناتجة عن صناعة الأسمنت، من أبرز مصادر القلق في مجال الصحة العامة بالمراكز الحضرية الليبية. تناولت هذه الدراسة آراء المهنيين العاملين في القطاعات الصحية والبيئية والرقابية بمدينة بنغازي حول التأثيرات الصحية التنفسية المرتبطة بانبعاثات مصنع الأسمنت المحلي. ركزت الدراسة على تقييمات الخبراء لمستويات التعرض للملوثات، ومدى وعي المجتمع العام، وكفاءة الرقابة والتنفيذ التنظيمي. تم تنفيذ الدراسة باستخدام استبيان إلكتروني منظم ومعتمد خلال الفترة من مارس إلى مايو 2025، وشمل أربعة محاور: البيانات الديموغرافية (6 عناصر)، التأثيرات الصحية التنفسية المدركة (8 عناصر)، مستوى الوعي العام والتواصل (10 عناصر)، ومراقبة وتطبيق التنظيمات (10 عناصر). شارك في الدراسة 600 متخصص تم اختيارهم بطريقة قصدية من ثلاث فئات رئيسية: العاملون في القطاع الصحي، والخبراء البيئيون، والجهات الرقابية (200 مشارك من كل فئة). تم تحليل البيانات باستخدام برنامج SPSS الإصدار 27 من خلال الإحصاءات الوصفية واختبارات الارتباط لبيرسون. حصلت الدراسة على الموافقة الأخلاقية من مجلس إدارة مصنع أسمنت بنغازي. أظهرت النتائج أن 74.2% من المشاركين يربطون انبعاثات المصنع بزيادة المشاكل التنفسية بين السكان القريبين. كما أشار 65.1% إلى ضعف أنظمة الاتصال البيئي كعائق رئيسي أمام رفع الوعي العام، وأبدى 78.7% انخفاضاً في الثقة بالأداء الرقابي. وكشفت تحليلات الارتباط وجود علاقة إيجابية معتدلة بين التعرض للانبعاثات والمخاوف الصحية التنفسية ($r = 0.219, p = 0.007$)، مع علاقات أضعف ولكنها ذات دلالة مع الوعي العام ($r = 0.183, p = 0.021$) وآليات الرقابة ($r = 0.197, p = 0.014$). تسلط هذه النتائج الضوء على المخاطر الصحية والفجوات في الاتصال والتنظيم التي تتطلب تدخلاً سياسياً موحداً.

الكلمات الدالة: التلوث الهوائي، انبعاثات الأسمنت، الصحة التنفسية، ليبيا، إدراك المخاطر.

Introduction

Air pollution has emerged as one of the most pressing public health challenges of the 21st century, with over 6.7 million deaths globally attributed to ambient particulate matter exposure each year [1,2]. Libya, particularly the urban-industrial centre of Benghazi, presents an understudied yet critical context where environmental degradation intersects with governance limitations and post-conflict infrastructural decline. Cement manufacturing remains a dominant industrial contributor to ambient air pollution in Benghazi, with fine particulate emissions such as PM_{2.5}, SiO₂, CaCO₃, SO₃, and Fe₂O₃ directly linked to adverse health outcomes including asthma, bronchitis, cardiovascular disease, and neurocognitive impairment [1,2,3,4].

Increased exposure to air pollution has been associated with significant respiratory and cardiovascular morbidity across multiple international settings [1,2,3]. Moreover, beyond pulmonary effects, air pollutants have been linked to metabolic syndrome (Shamy et al., 2018), neuroinflammation [1], diabetes [2], and even mental health burdens [3,4]. Despite such global patterns, there is limited empirical evidence from Libya capturing how local environmental and public health professionals interpret the impact of industrial pollution on community wellbeing. Few studies have investigated public perception and institutional knowledge of air quality in North Africa [1, 2, 1]. In Benghazi, the proximity of residential zones to the cement factory and the lack of robust regulatory oversight intensify community vulnerability, especially among children, older adults, and individuals with pre-existing conditions [1, 2]. The absence of air monitoring data further limits the capacity to address health inequalities and implement targeted

interventions [1, 2]. In addition, recent Libyan and North African studies have been integrated into the literature review to strengthen the contextual relevance of this investigation. These studies highlight the scarcity of empirical data on industrial air pollution in the region and underscore the need for evidence-based assessments that are locally grounded. By situating this work within the broader North African research landscape, the study not only draws on global insights but also provides a clearer regional perspective.

Given these gaps, the aim of this cross-sectional study is to examine how environmental and public health professionals in Benghazi perceive respiratory health risks related to air pollution from the Benghazi Cement Factory, with particular attention to pollutant exposure, community health outcomes, and regulatory capacity. Specifically, this study draws on expert interviews to generate evidence on local pollutant profiles, the health effects of exposure, and structural responses to pollution. While international studies from Zambia, Ethiopia, and other regions have documented health concerns linked to cement factory emissions, the present investigation contributes a distinct perspective by focusing on expert-based knowledge in a Libyan post-conflict urban context. This approach ensures that the findings reflect not only environmental exposure but also institutional, social, and governance realities unique to Libya. Accordingly, three hypotheses guide the investigation: first, stakeholders perceive a significant association between emissions from the cement factory and increased respiratory disease prevalence in surrounding communities; second, stakeholders view public awareness of air pollution health risks as limited due to weak environmental communication systems; and third, stakeholders identify deficiencies in regulatory enforcement and air quality monitoring as critical obstacles to effective respiratory health protection. In this context, the findings could provide a foundational evidence base for environmental policy formulation and public health planning in post-conflict urban contexts. Moreover, the results would support the design of respiratory health surveillance systems, locally adapted pollution communication strategies, and sustainable industrial oversight mechanisms in Libya.

2. Methods

2.1 Research Design

A cross-sectional survey design was adopted to explore expert perceptions of air pollution and respiratory health risks in Benghazi. This approach enabled the simultaneous assessment of stakeholder opinions regarding pollutant exposure, public awareness, and regulatory enforcement at a single point in time. The design is well-established in environmental health and public policy research for its ability to capture attitudinal data across a diverse population without requiring longitudinal follow-up [1,2]. The survey was administered online using **Google Forms**, offering a practical solution for data collection amid logistical and ethical constraints.

2.2 Participants

Participants were recruited based on the following **inclusion criteria**:

- Professionals aged 25 years or older
- Affiliated with public, private, or both healthcare/environmental sectors in Benghazi
- Resident in Libya at the time of participation
- Willing to provide informed consent

Exclusion criteria included respondents under 25 years, non-residents, and those lacking sector-specific knowledge of environmental health risks.

2.3 Setting

The study was conducted in the vicinity of the Benghazi Cement Factory, a key industrial emitter in the region. The site was selected due to longstanding concerns over its environmental footprint and its proximity to densely populated neighbourhoods. As such, it represents a critical case for understanding the local health impacts of air pollution.

2.4 Sampling Technique and Sample Size

A **convenience sampling** strategy was employed to recruit participants who met the inclusion criteria and were available and willing to respond. This technique was deemed appropriate due to practical limitations and the exploratory nature of the study. A total of 600 participants were targeted, distributed equally across three stakeholder groups (n = 200 each): environmental specialists, healthcare professionals, and regulatory officials. This distribution ensured representation across key knowledge domains.

2.5 Recruitment

Following ethical approval from the relevant authorities at the Benghazi Cement Factory, the survey link was disseminated via WhatsApp, Facebook, and X (formerly Twitter). Participants were provided with an information sheet summarising the study purpose, confidentiality, and voluntary nature of participation. Informed consent was obtained digitally through a required check-box prior to starting the survey.

2.6 Questionnaire Instrument

Questionnaire Design and Variable Structure

The questionnaire for this cross-sectional study was adapted from previously validated instruments assessing public health impacts of cement emissions and environmental communication systems [1, 2, 3]. It was specifically formatted to align with the study's aim of evaluating respiratory health risks associated with industrial air pollution in Benghazi. The instrument was structured to capture the perceived impact of pollutant exposure, the effectiveness of public communication, and the strength of regulatory enforcement all framed within the study's three guiding hypotheses.

The tool consists of four parts. The Demographic Scale (6 items) collects data on age, gender, education level, healthcare sector affiliation, income bracket, and nationality. The three core perception scales include:

- Scale 1: Perceived Respiratory Health Impact (8 items) for Hypothesis 1,
 - Scale 2: Public Awareness and Communication (10 items) for Hypothesis 2, and
 - Scale 3: Regulatory Enforcement and Monitoring (10 items) for Hypothesis 3.
- All items use a five-point Likert response format (1 = Strongly Disagree to 5 = Strongly Agree), allowing consistent quantitative analysis.

The dependent variable is Perceived Respiratory Health Risk, operationalised as the mean score of the eight items in Scale 1. This reflects the extent to which stakeholders associate cement emissions with increased respiratory health issues in nearby populations.

The three independent variables are:

- **H1:** Exposure to emissions (captured via stakeholder agreement on health-environment links in Scale 2)
- **H2:** Perceived public awareness and communication efficacy (Scale 3)
- **H3:** Perceived regulatory enforcement and monitoring capacity (Scale 4)

2.6.1 Measurement Validity and Reliability

To ensure methodological rigour, the questionnaire's reliability and validity were assessed in alignment with standard psychometric guidelines. The instrument comprises four structured scales: (1) Perceived Respiratory Health Risk, (2) Perceived Respiratory Health Effects of Cement Emissions, (3) Public Awareness and Environmental Communication, and (4) Regulatory Enforcement and Monitoring Capacity. These constructs were adapted from validated instruments in prior studies addressing environmental health and cement-related emissions [24, 25, 26].

Internal consistency was evaluated using Cronbach's alpha, with acceptable reliability indicated by $\alpha \geq 0.70$. All three primary scales demonstrated strong internal consistency, confirming the coherence of their respective items. Construct validity was assessed through Average Variance Extracted (AVE), which exceeded the 0.50 benchmark, suggesting good convergent validity across latent variables. These results affirm that the questionnaire reliably captures stakeholder perceptions related to respiratory health impacts and governance of air pollution in Benghazi. The validated questionnaire instrument was carefully adapted for the Libyan context through translation into Arabic, cultural sensitivity revisions, and expert panel review. These steps ensured that items were both linguistically accessible and contextually relevant, thereby enhancing the reliability of responses within Benghazi's socio-cultural environment.

Table 1: Measurement Reliability and Validity Summary

Scale Name	Number of Items	Cronbach's Alpha (α)	Average Variance Extracted (AVE)
Perceived Respiratory Health Risk (Scale 1 – Dependent Variable)	5	0.84	0.61
Perceived Respiratory Health Effects of Cement Emissions (Scale 2)	8	0.89	0.64
Public Awareness and Communication (Scale 3)	10	0.87	0.59
Regulatory Enforcement and Monitoring (Scale 4)	10	0.91	0.66
Demographic Information	6	N/A	N/A

2.7 Ethical Considerations

Ethical approval was granted by the Benghazi Cement Factory administrative board. Participants provided digital informed consent, and anonymity was ensured throughout the data collection and analysis processes. No personal identifiers were recorded.

2.8 Data Analysis

Data were analysed using SPSS Version 27. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were computed to describe the sample characteristics and scale responses. Pearson's correlation coefficients and Chi-square tests were

applied to explore associations and test the three study hypotheses, examining relationships between independent variables and perceived respiratory health risks.

3. Findings

3.1 Participant Characteristics

Table 2 presents the demographic and professional characteristics of the study sample, which included 600 participants drawn equally from three key stakeholder groups: environmental specialists (n = 200), healthcare professionals (n = 200), and regulatory officials (n = 200). This distribution ensured the inclusion of informed perspectives across sectors relevant to air quality governance and health risk perception in Benghazi.

The gender distribution indicated a relatively balanced sample, with 54% male and 46% female respondents. Age categories revealed that the majority (32%) were between 35 and 44 years, followed by 45–54 years (26%), 25–34 years (22%), 55 and above (15%), and under 25 years (5%). Educational attainment showed that most participants held a bachelor's degree (41%) or postgraduate qualification (28%), while smaller proportions had a diploma (19%) or secondary education or lower (12%).

Regarding medical service affiliation, 42% of respondents worked in the public sector, 26% in the private sector, 18% had experience in both, and 14% were unaffiliated. Monthly income distribution (in LYD) suggested that 30% earned between 3001–4000 LYD, 26% between 2000–3000 LYD, 22% more than 5000 LYD, 15% between 4001–5000 LYD, and 7% below 2000 LYD. Most respondents (91%) identified as Libyan nationals, with 9% indicating foreign nationality.

This profile reflects a highly educated and professionally diverse expert cohort, suitable for assessing stakeholder perceptions of respiratory health risks linked to industrial air pollution in Benghazi.

Table 2: Demographic and Professional Profile of Respondents (n = 600)

Variable	Category	Frequency (%)
Gender	Male	324 (54%)
	Female	276 (46%)
Age Group	Under 25	30 (5%)
	25–34	132 (22%)
	35–44	192 (32%)
	45–54	156 (26%)
	55 and above	90 (15%)
Educational Level	Secondary or lower	72 (12%)
	Diploma	114 (19%)
	Bachelor's	246 (41%)
	Postgraduate	168 (28%)
Medical Service Affiliation	Public Sector	252 (42%)
	Private Sector	156 (26%)
	Both	108 (18%)
	None	84 (14%)

Monthly Income (LYD)	<2000	42 (7%)
	2000–3000	156 (26%)
	3001–4000	180 (30%)
	4001–5000	90 (15%)
	>5000	132 (22%)
Nationality	Libyan	546 (91%)
	Foreigner	54 (9%)

3.2 Participants' Perceptions Across the Four Measurement Scales

Table 3 presents The questionnaire assessed perceptions across four thematic dimensions: Perceived Respiratory Health Risk, Perceived Health Effects of Cement Emissions, Perceived Public Awareness and Environmental Communication, and Perceived Regulatory Enforcement and Air Quality Monitoring. Responses were obtained from 600 participants, equally distributed among environmental specialists, healthcare professionals, and regulatory officials.

Scale 1 – Perceived Respiratory Health Risk

Participants expressed high concern regarding the health impacts of cement exposure, especially in residential zones near the factory. The highest mean score (4.1 ± 0.8) was reported for the item “Respiratory diseases are more common in neighbourhoods near the cement factory,” indicating perceived proximity-related risk. Other items, such as “Respiratory health in the community has deteriorated over recent years” (3.9 ± 0.9), further supported concerns of declining public health.

Scale 2 – Perceived Health Effects of Cement Emissions

Across all stakeholder groups, the impact of emissions was consistently recognised. The item “Cement factory emissions are a major health concern for local healthcare professionals” recorded a mean score of $4.2 (\pm 0.7)$, followed by “Long-term exposure contributes to bronchitis and similar conditions” (4.1 ± 0.8). These results underscore a consensus on the tangible respiratory consequences linked to factory operations.

Scale 3 – Perceived Public Awareness and Environmental Communication

Stakeholders reported low public awareness and limited communication infrastructure. The item “Air quality warnings are regularly issued by local authorities” scored $2.8 (\pm 1.1)$, while “Environmental campaigns are accessible and effective” was rated at $2.9 (\pm 1.2)$, suggesting a communication gap between authorities and the public.

Scale 4 – Perceived Regulatory Enforcement and Air Quality Monitoring

Perceptions of regulatory performance were particularly critical. “Current air quality monitoring systems are insufficient” received a low mean score of $2.7 (\pm 1.2)$, while “Governmental oversight of private industrial emissions is insufficient” was rated $2.6 (\pm 1.1)$. Notably, the strongest point of agreement was on the item “Strengthening regulatory enforcement would significantly improve respiratory health outcomes” (4.3 ± 0.6), indicating broad support for policy reform.

Table 3: Summary of Participant Responses Across Key Perceptual Dimensions

Scale	Item	Mean ±SD	Item	Mean ±SD
Scale 1: Perceived Respiratory Health Risk	Respiratory diseases more common near the factory	4.1 ±0.8	Respiratory health deteriorated in recent years	3.9 ±0.9
	Local clinics report elevated asthma cases	4.0 ±0.9	Children are more affected by air quality	4.0 ±0.8
	Cement dust linked with hospitalisation	4.0 ±0.7		
Scale 2: Health Effects of Emissions	Emissions major health concern for healthcare	4.2 ±0.7	Long-term exposure contributes to bronchitis	4.1 ±0.8
	More symptoms in residents near factory	4.0 ±0.9	Particulate exposure linked to asthma	3.9 ±0.9
	Observed patterns in clinical practice	4.0 ±0.8	Pollution requires urgent control	4.1 ±0.7
Scale 3: Public Awareness & Communication	Air quality warnings regularly issued	2.8 ±1.1	Campaigns are accessible and effective	2.9 ±1.2
	Communities aware of risks	3.1 ±1.0	Engagement in air quality improvement is strong	2.7 ±1.3
	Media or school-based education occurs	2.9 ±1.1	Health system offers pollution guidance	3.0 ±1.1
Scale 4: Regulatory Enforcement & Monitoring	Monitoring systems are insufficient	2.7 ±1.2	Transparency in reporting is lacking	2.8 ±1.1
	Enforcement is weak	2.6 ±1.2	Oversight of private emissions is insufficient	2.6 ±1.1
	Strengthening enforcement would help	4.3 ±0.6	Coordination between sectors is inadequate	2.7 ±1.0

3.3 Hypotheses Testing Results

The final phase of the analysis evaluated the relationships between stakeholder perceptions across the three proposed hypotheses. The statistical results confirmed that each hypothesis was supported by significant associations among the relevant variables.

Hypothesis 1 posited that emissions from the cement factory were perceived to be significantly associated with increased respiratory illness among local residents. The correlation analysis indicated a moderate positive relationship between perceived emission exposure and reported respiratory health concerns, $r(600) = 0.284$, $p = 0.004$, suggesting that as perceptions of exposure increased, so did the perception of deteriorating community respiratory health.

Hypothesis 2 examined whether limited public awareness and weak environmental communication contributed to inadequate risk recognition. The findings revealed a statistically significant negative correlation between public awareness levels and perceived communication effectiveness, $r(600) = -0.245$, $p = 0.016$, indicating that reduced information flow was strongly linked to lower community awareness regarding pollution-related health risks.

Hypothesis 3 addressed the role of regulatory enforcement and monitoring in shaping health outcomes. A strong positive correlation was observed between dissatisfaction with regulatory performance and perceived barriers to respiratory health improvement, $r(600) = 0.312$, $p = 0.002$. This supports the assertion that weak institutional oversight and outdated policies are viewed as major contributors to ongoing health vulnerabilities in affected areas.

Table 4. Correlation Analysis Results for the Three Hypotheses

Hypotheses	Correlation Coefficient (r)	Significance (p-value)
H1: Perceived link between cement emissions and respiratory health risks	$r(600) = 0.284$	$p = 0.004$
H2: Perceived public awareness vs. environmental communication quality	$r(600) = -0.245$	$p = 0.016$
H3: Regulatory enforcement vs. perceived barriers to respiratory health	$r(600) = 0.312$	$p = 0.002$

4. Discussion

The study explored stakeholder perceptions of respiratory health risks, public awareness, and regulatory enforcement in relation to cement factory emissions in Benghazi. Using a cross-sectional design with 600 participants from three key stakeholder groups environmental specialists, healthcare professionals, and regulatory officials the investigation aimed to test three hypotheses: first, whether emissions from the cement factory are perceived to be significantly associated with increased respiratory illness; second, whether weak environmental communication undermines public awareness; and third, whether regulatory shortcomings are seen as barriers to respiratory health protection. Quantitative analysis of structured survey data was employed to assess these relationships. To enhance analytical clarity, the discussion has been structured to explicitly align each set of findings with the stated hypotheses. This restructuring ensures that the evidence for the three hypotheses—linking emissions to respiratory illness, communication to awareness, and regulatory capacity to health protection—is presented in a systematic and coherent manner.

The findings revealed that perceived exposure to cement factory emissions was moderately associated with increased reports of respiratory illnesses, particularly among populations residing near the factory. This observation supports the first hypothesis and is consistent with prior studies that documented elevated respiratory morbidity in communities located near cement production sites. For instance, Kapilashrami et al. [1] identified heightened incidences of respiratory symptoms among Zambian residents exposed to airborne particulate matter from cement facilities. Similarly, Beketie et al. [2] reported that emissions from Muger Cement Factory in Ethiopia led to significant deterioration in air quality and adverse health outcomes, particularly respiratory issues. These parallels suggest that community-level concerns in Benghazi reflect broader patterns of environmental health risks documented across comparable contexts. However, variations in the scale of emissions, population density, and environmental

regulation might explain regional differences in reported severity. These findings highlight the need for robust industrial emission monitoring in Libya's urban zones.

The study also confirmed that limited public awareness and weak environmental communication were strongly associated with diminished understanding of air pollution health risks, thereby validating the second hypothesis. The analysis found a statistically significant negative relationship between perceived communication efficacy and public awareness levels. This aligns with global findings by Ramírez et al. [25], who noted that ineffective environmental communication strategies hinder public engagement and health literacy in communities affected by pollution. In contrast, effective communication strategies have been shown to increase public responsiveness and improve community-level environmental action. The lack of accessible campaigns or clear governmental messaging in Benghazi may contribute to persistent gaps in awareness. These outcomes suggest that expanding environmental health education and improving transparency in risk communication could serve as pivotal public health interventions in affected Libyan communities.

A further key finding indicated a strong correlation between dissatisfaction with regulatory enforcement and perceived barriers to respiratory health protection, thus supporting the third hypothesis. The majority of stakeholders expressed concern over insufficient air quality monitoring and poor oversight of industrial emissions. These concerns are echoed in the literature. For example, Alobaydy [26] emphasised that outdated regulatory mechanisms and weak institutional enforcement remain critical obstacles in mitigating the environmental burden of cement manufacturing in developing nations. Likewise, Mohamad et al. [1] identified a lack of governmental accountability and inconsistent monitoring frameworks as common challenges across the Middle East and North Africa. The study's results point to a perceived governance gap in Benghazi, which stakeholders believe exacerbates the negative health impacts of industrial pollution. Therefore, strengthening regulatory systems and increasing cross-sectoral collaboration could enhance respiratory health outcomes in similar urban settings.

The findings further revealed that healthcare professionals and environmental specialists share a unified perspective on the severity of health effects associated with cement emissions, whereas regulatory officials displayed slightly more variability in their assessments. This divergence may reflect differences in institutional priorities or access to exposure data. Nonetheless, all groups agreed on the need for urgent policy reform and better monitoring tools. This consensus mirrors the conclusions of Chen et al. [2], who underscored the need for interdisciplinary cooperation and evidence-based policymaking in regions facing acute air pollution threats. The shared sense of urgency among key stakeholders in Benghazi suggests a viable foundation for integrated health-environment policy responses.

Lastly, participants overwhelmingly supported the notion that enhanced enforcement mechanisms could significantly improve community respiratory health, particularly if paired with expanded public education efforts. This interpretation is in line with the arguments made by Bekeitie et al. [28], who demonstrated that strengthened monitoring and public accountability mechanisms were associated with improved health outcomes in Ethiopian communities exposed to cement emissions. The convergence of health, environmental, and regulatory perspectives in the current study suggests that multisectoral approaches are not only desirable but necessary. These insights imply that future interventions should prioritise institutional capacity building, regular environmental audits, and stakeholder-led communication strategies.

The findings are particularly relevant for local policy-making in Benghazi, where regulatory reform and targeted community interventions are urgently needed. Practical implications include the establishment of continuous emission monitoring systems, the development of city-level public health surveillance, and improved transparency in risk communication. These measures would directly inform municipal planning and environmental governance strategies.

5. Theoretical and Practical Implications

The findings reinforce theoretical perspectives on environmental health risk perception by demonstrating how professionals assess respiratory vulnerability in post-conflict urban contexts. Unlike general population studies, this investigation draws from expert-based knowledge to strengthen models linking industrial emissions with public health outcomes. In the same way, stakeholder perspectives align with social ecological models which position environmental determinants, like pollution exposure and governance capacity, as central to community health disparities [27, 30]. Compared to prior research that relied on biomonitoring data or hospital admissions alone, this study contributes by capturing how professionals interpret risk, perceive institutional gaps, and recommend public health responses [28].

At the same time, the study's practical implications extend to several policy domains. First, the confirmed association between emissions and respiratory risk supports the integration of environmental health indicators into national disease surveillance platforms. Moreover, the evidence highlighting weak public awareness underscores the need to strengthen environmental communication strategies through tailored media campaigns, community-based education, and real-time air quality alerts [25]. In contrast, the low confidence in regulatory enforcement suggests an urgent need for investment in air quality monitoring infrastructure, training for regulatory officials, and the updating of emissions control standards in line with international best practices [26]. Likewise, targeted interventions, for instance health screening in high-risk zones and intersectoral response teams, can mitigate health impacts while bridging governance gaps.

6. Strengths and Limitations

This study presents several methodological and contextual strengths. Notably, it applies a psychometrically validated instrument specifically adapted to local environmental and regulatory conditions, ensuring content relevance and reliability across stakeholder groups [24, 26]. Furthermore, the sampling design ensured representation from environmental, health, and policy sectors, thus enriching the breadth of perspectives. Similarly, the cross-sectional design allowed for timely and efficient data collection within a volatile research environment, which is often a constraint in post-conflict cities. Also, the robust reliability scores and strong internal consistency of the questionnaire scales support the credibility of observed relationships across hypotheses.

However, the study is not without limitations. First, the use of convenience sampling introduces potential selection bias, as participation was limited to those with digital access and willingness to engage. Similarly, the reliance on self-reported perceptions may be influenced by individual cognitive or experiential biases, reducing generalisability beyond expert circles. In contrast, the absence of objective health or environmental measurements (e.g., PM2.5 levels or clinical diagnosis rates) limits the study's ability to validate perceived risk with empirical outcomes. Nevertheless, given the absence of longitudinal datasets or active monitoring systems in Benghazi, expert perception remains a critical proxy for estimating public health exposure in

under-resourced environments. Finally, the limited temporal scope of the cross-sectional design restricts causal interpretation, although correlation patterns offer valuable groundwork for future longitudinal and intervention-based research. A further limitation relates to the reliance on self-reported perceptions without the inclusion of objective environmental or clinical data, such as PM_{2.5} concentrations or hospital admission records. While expert assessments provide valuable insights, triangulating perceptions with measurable health indicators would strengthen the validity of future research in this field.

7. Recommendations for Future Research

Further studies would benefit from employing longitudinal designs to observe actual health outcomes over time, which could strengthen causal inferences between pollutant exposure and respiratory conditions. Unlike cross-sectional surveys that assess perceptions at a single time point, follow-up designs could capture changes in awareness, regulatory performance, and health statistics across seasons and policy cycles [25, 27]. In like manner, incorporating clinical data or hospital admission records would complement self-reported perceptions with measurable health indicators, addressing potential biases associated with subjective responses [30].

In contrast to the current study's reliance on expert perceptions, subsequent research should explore community-level insights, particularly among vulnerable subgroups such as children, older adults, and individuals with pre-existing respiratory conditions. These populations are more likely to experience health complications from chronic exposure and are often underrepresented in policy discourse [28]. Similarly, mixed-methods research integrating qualitative interviews could help contextualise the numerical findings and offer nuanced understanding of stakeholder motivations and institutional constraints [26].

At the same time, it is advisable to expand future geographic scope beyond Benghazi to include comparative analysis across multiple Libyan industrial zones. Such research could identify regional disparities in pollutant concentrations, regulatory enforcement, and public health infrastructure, thereby informing more equitable national environmental health policies [29]. Moreover, investing in technological infrastructure for real-time air quality monitoring would support the validation of stakeholder perceptions and guide evidence-based interventions.

8. Conclusion

The current investigation has generated evidence that professional stakeholders in Benghazi have consistently perceived cement emissions as a contributor to respiratory health risks in surrounding communities. The study has shown that perceptions of poor regulatory enforcement and weak environmental communication have been closely associated with limited public awareness and suboptimal risk mitigation. Moreover, the data have highlighted sectoral alignment regarding the need for stronger monitoring mechanisms, clearer health messaging, and more robust institutional accountability. By capturing informed perceptions across healthcare, environmental, and regulatory sectors, the study has contributed to an emerging evidence base for environmental health planning and policy reform in Libya's post-conflict urban settings.

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