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Article

Evaluating the impact of environmental noise pollution on construction worker productivity in Peshawar, Pakistan: Justifying enforcement of noise regulation policies in the construction sector

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Abstract: Noise pollution in construction sites is a significant concern, impacting worker health, safety, communication, and productivity. The current study aims to assess the paramount consequences of ambient noise pollution on construction activities and workers' productivity in Peshawar, Pakistan. Noise measurements have been recorded at four different construction sites in Peshawar at different times of the day. Statistical analysis and Relative Importance Index (RII) are employed to evaluate the data Risk variables, such as equipment maintenance, noise control, increased workload, material handling challenges, quality control issues, and client satisfaction. The results indicated that noise levels often exceeded permissible limits, particularly in the afternoon, posing significant worker risks. In addition, RII analysis identified communication difficulties, safety hazards, and decreased productivity as significant issues. The results show that noise pollution is directly linked with safety risks, decreased performance, and client dissatisfaction and needs immediate attention by authorities. This paper proposes a strategic policy framework, recommending uniform hand signals and visual communication methods without noise for workers, worker training about safety, and using wearable devices in noisy settings. Communication training for teams and crane operators, proactive quality control, and customer-oriented project schedules are also proposed. These recommendations aim to mitigate the adverse effects of noise pollution, enhance construction industry resilience, and improve overall operational efficiency, worker safety, and client satisfaction in the construction sector of Peshawar, aligning with policy and sustainable development objectives.

Keywords: construction industry; ambient noise pollution; sustainable development; Relative Importance Index (RII); safety hazards; consumer behavior; communication strategies; risk variables; noise regulation enforcement; noise management

1. Introduction

The construction industry, a key driver of urban development, is grappling with a pressing issue—ambient noise pollution. This problem is not just a nuisance, but a significant threat to the well-being and productivity of workers at construction sites in Peshawar, Pakistan (Ahn et al., 2019). With urban growth accelerating and construction projects on the rise, it is imperative to delve into this issue urgently to foster sustainable progress through effective policies. The escalating noise levels at

worksites pose a range of challenges, from safety hazards to communication barriers, all of which hamper worker productivity (Zaman et al., 2022).

Noise pollution at construction sites is not a localized problem, but a global concern that aligns with Sustainable Development Goals (SDGs) and Environmental, Social, and Governance (ESG) principles. ESG, which assesses companies' and industries' responsibility and sustainability, is directly tied to SDGs (Mir et al., 2022; Zaporowska and Szczepański, 2024). Construction activities are a significant contributor to noise pollution, impacting the environment and human health. Recent studies underscore the importance of addressing noise pollution in achieving SDG targets related to health and well-being and sustainable cities and communities. The transition from industrialized practices to sustainable development frameworks, such as ESG, underscores the need for responsible construction practices (Imran et al., 2022; Sarker et al., 2023; Shaikh et al., 2023). Incorporating noise control measures in construction aligns with global climate goals and regional development plans, ensuring sustainable growth and improved quality of life.

However, numerous opinions have mostly centered around prioritizing noise control actions. Currently, the construction industry employs various measures to control noise, such as sound barriers, equipment maintenance, and work schedule adjustments. Some researchers suggest reacting to issues as they emerge, while others advocate proactive steps like investing in quieter equipment and comprehensive training programs (Vandenplas et al., 2018). These diverse views highlight the necessity to explore the most effective strategies for mitigating noise pollution's impact on construction activities.

The primary objective of this study is to bridge the existing research gap by adopting an inclusive approach to assess the relative importance of various factors contributing to noise at worksites (Thompson et al., 2022). To achieve this, we introduce the Relative Importance Index (RII) as an innovative and valuable tool for quantifying and prioritizing these factors. Our research combines quantitative analysis with qualitative insights to generate practical recommendations for Peshawar's construction industry, aiming to enhance productivity and overall project success (Themann and Masterson, 2019). Furthermore, our study aims to comprehensively investigate and analyze the intricate relationship between ambient noise pollution and its effects on different aspects of construction work in Peshawar, Pakistan.

The current research in this field reveals a significant gap in understanding the specific risks and consequences of noise pollution within the industry (Yang et al., 2018), particularly in the context of Peshawar. Previous work has examined the importance of general workplace dangers and safety measures but has yet to deeply probe ambient noise's unique challenges in construction environments. Reviewing key publications underscores the need for a nuanced grasp of how noise pollution impacts productivity at Peshawar's construction sites (Voordt and Jensen, 2023). As urban development shapes Peshawar's landscape, mitigating noise pollution's negative consequences becomes essential for ensuring sustainable and safe construction practices (Sohrabi et al., 2020; Suter, 2007). This research is crucial because it potentially provides evidence-based insights into noise pollution's complex dynamics within the industry. By addressing current gaps, the findings will meaningfully

contribute to academic and real-world implications, potentially revolutionizing the way we approach noise control in construction.

2. Literature review

2.1. Health effects of noise pollution

Noise pollution refers to excessive, unwanted, or disruptive environmental sounds from various sources, such as road and air traffic, construction, loudspeakers, industrial activities, and household appliances (Münzel et al., 2024). Prolonged exposure to excessive noise can have detrimental effects on both physical and mental health, as well as on wildlife and the overall quality of life. Common impacts include permanent hearing loss due to prolonged exposure to loud noise and mental health issues such as stress, anxiety, depression, irritability, and feelings of hopelessness (Münzel et al., 2024; Newbury et al., 2024). Noise pollution can also disrupt sleep patterns, causing insomnia, fatigue, and decreased productivity. It increases the risk of cardiovascular problems by raising blood pressure and heart rate, leading to a higher likelihood of heart attack and stroke.

Noise pollution also causes stress and disorientation, leading to habitat loss and population decline. Furthermore, it can reduce property values, making it difficult to sell or rent real estate, and disrupt workplace productivity by making it hard to concentrate. Cognitive effects are also significant, with noise pollution linked to increased levels of stress hormones, which can interfere with concentration and memory, particularly in children, making it challenging to complete tasks or retain information (Münzel et al., 2024; Newbury et al., 2024; Rahmat et al., 2023). Prolonged exposure can cause auditory problems such as hearing loss and tinnitus (Münzel et al., 2024). Additionally, noise pollution has been linked to non-auditory effects, including increased stress levels, cardiovascular problems, sleep disturbances, and decreased cognitive performance (Münzel et al., 2021; Rahmat et al., 2023). These health issues affect individual workers and contribute to overall productivity losses in construction projects.

2.2. Noise pollution and construction

The construction industry is vital in urban development, contributing significantly to the infrastructure and economy of modern cities. However, this industry also faces substantial challenges, particularly in managing noise pollution, which can adversely affect workers' health, productivity, and overall well-being. Noise pollution in construction arises from various sources, including heavy machinery, power tools, and general site activities. Studies have shown that construction noise levels can exceed acceptable limits, harming workers and the surrounding community (Sadeghi and Vasheghani, 2021; Shaikh et al., 2023). The complexity of construction soundscapes, characterized by intermittent and continuous noise, makes it a significant environmental concern (WHO, 2018).

Noise pollution in construction sites significantly impairs workers' ability to concentrate and communicate effectively, posing serious safety hazards. The inability to hear instructions or warnings can lead to errors and accidents (Mora et al., 2020).

Studies have shown that noisy environments can reduce job satisfaction and increase the likelihood of mistakes, leading to project delays and cost overruns (Mohamed, 2021; Rahmat et al., 2023). This underscores the urgent need to address noise pollution in the construction industry for the safety and well-being of workers.

2.3. Regulatory frameworks and mitigations

Numerous regulatory frameworks, such as those set by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA), aim to mitigate noise pollution in construction. These frameworks provide permissible noise exposure limits and guidelines for noise control offering a structured approach to the issue (Obrenovic et al., 2020). Noise-mitigating technologies, such as sound barriers and quieter machinery, and administrative controls, like scheduling noisy activities during less sensitive times, are essential for compliance and worker protection (Nikbakht et al., 2024). These measures reassure us that effective solutions are available to address the issue of noise pollution in construction.

Mitigating noise pollution requires a multi-faceted approach. Engineering controls, such as noise-dampening materials and advanced machinery, can significantly reduce noise levels (Lama et al., 2019). Personal protective equipment (PPE), such as earplugs and earmuffs, is crucial for protecting workers' hearing (Lim et al., 2023). Additionally, training programs that educate workers on the risks of noise and the importance of using protective measures are essential (Vandenplas et al., 2018).

The context of Peshawar, Pakistan, is of particular significance in the study of construction noise pollution. The city's rapid urban growth and increased construction activities have intensified the issue, necessitating the development of effective policies and interventions (Thompson et al., 2022; Zaman et al., 2022). Previous studies have underscored the need for localized research to comprehend the specific impacts and devise tailored solutions (Mir et al., 2023; Voordt and Jensen, 2023; Yang et al., 2018). Despite the extensive research on noise pollution, there remains a dearth of studies focusing on its impact on construction workers' health and productivity in specific urban contexts like Peshawar. Most studies have presented generalized findings without considering local environmental and socio-economic factors (Siddiqua et al., 2022). This study aims to bridge this gap by providing a comprehensive analysis of noise pollution at construction sites in Peshawar, offering evidence-based recommendations for mitigating its adverse effects.

In short, the literature underscores the critical need for comprehensive noise management strategies in the construction industry. The industry can improve working conditions and project outcomes by addressing health and productivity impacts and implementing effective regulatory and technological solutions. Furthermore, recognizing that construction operations are a prime source of noise pollution, national and local political decision-makers worldwide have developed instruments to limit noise levels.

3. Research methodology

The changing times and urban development leave a stamp on the face of the cities through construction sites to establish the architectural landmarks of towns. This

research study pays special attention to construction sites in Peshawar, Pakistan. In contrast, as urban growth has taken its course in the past few years, there have been more and more developmental activities on construction sites. The study area of our research comprised the measurement of environmental sound levels in selected construction sites, including AH Tower, Aafi Towers, Galleria Mall, and Saif Towers. The measurements were conducted over a period of six months, using B & K Type 2250 sound level meters having an accuracy of ± 1 dB. This device was equipped with advanced features for data logging and analysis. Measurements were taken at different times of the day (morning, afternoon, and evening) to capture variations in noise levels during different construction phases. Subsequently, the average value for morning, afternoon, and evening was employed for analysis. Sound level meters were placed around the construction sites to ensure comprehensive data collection. The data collection followed standard procedures outlined by the Environmental Protection Agency (EPA) guidelines.

The survey design was meticulously crafted, ensuring a representative sample size was calculated using the Cochran formula. We considered the population size of both technical staff and workers on construction sites, employing a confidence level of 95% with an error margin of 5% to determine the appropriate sample size. The questionnaires were developed based on a thorough literature review and consultations with experts, covering various aspects such as health impacts, productivity, communication challenges, and overall work environment. This comprehensive approach instills confidence in the research methodology and the validity of the findings.

The research surveys include closed-ended and open-ended questions (Appendix). After collecting questionnaire survey data, replies were analyzed to facilitate respondent analysis, and SPSS statistical analysis and MS Excel were used for respondent analysis. Risk management, a crucial aspect of construction site operations, was also considered in the research process. It assumes the fundamental responsibility for effective activities to prevent problems, care about workers' safety, and improve reliability in general. This was done by identifying potential risks associated with noise pollution at construction sites and proposing mitigation measures.

Relative Importance Index (RII) is used as a measure and evidence of the microcosm of noise pollution and construction site dynamics in the city of Peshawar. The RII was used to prioritize the factors contributing to noise pollution based on their relative importance as perceived by the respondents. For instance, factors such as 'heavy machinery operation' and 'construction material delivery' were given high priority due to their significant contribution to noise pollution. The RII was calculated using the formula:

$$\text{RII} = \frac{\sum W}{A \times N}$$

where W refers to respondents' weightage assigned to each factor, A is the highest possible weight, and N the total number of respondents.

Furthermore, Statistical Analysis (Descriptive Statistics), such as mean, median, standard deviation, and frequency distributions, was used to summarize and analyze the data collected from the questionnaires. These statistical methods were chosen for

their ability to provide a comprehensive overview of the data, including the average response, the most common response, the spread of responses, and the distribution of responses. This analysis helped understand the central tendencies and variations in the responses, providing insights into the key issues related to noise pollution at construction sites. **Figure 1** illustrates the methodology employed in this research study.

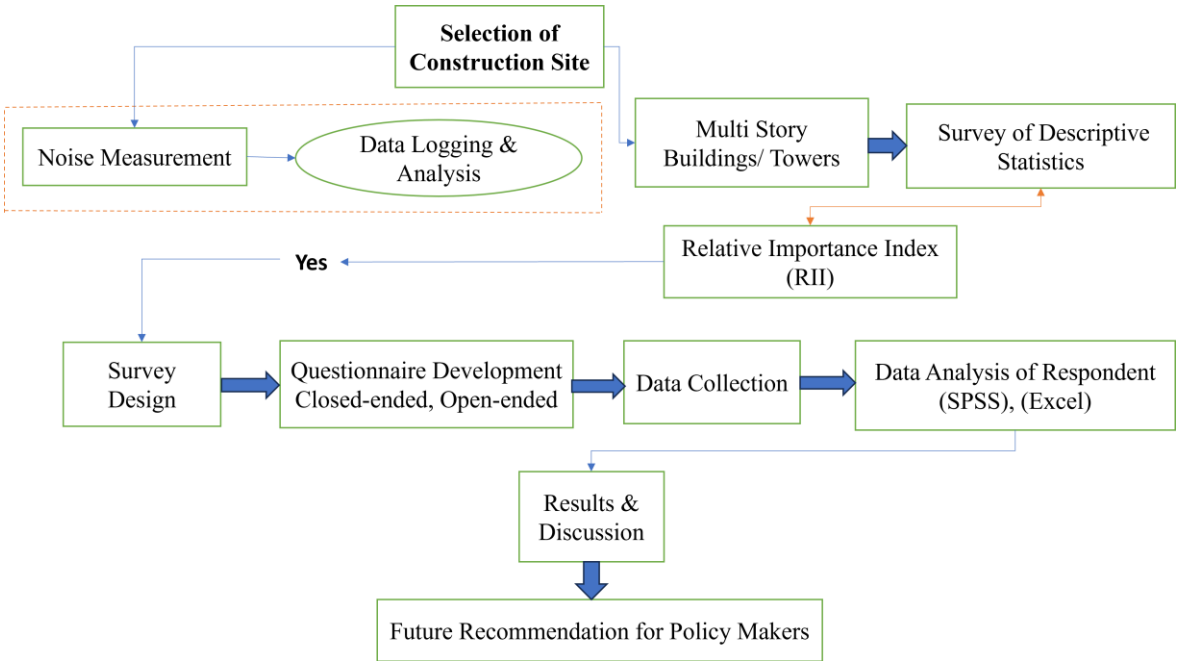


Figure 1. Illustration of the methodology adopted in the study.

4. Results and discussion

The construction industry, characterized by a collaboration of machinery, tools, and human activity, noise pollution exceeds being a mere annoyance. The revealed challenges for verbal communication, safety hazards, and productivity nuances underscore noise's evident impacts in this unique environment. However, among these intricate social factors, some crucial elements stand out. Our investigation converges with the work done on noise at the workplace, safety issues that are experienced, and the productivity dilemma, completing the broad understanding.

Going beyond theoretical knowledge, the presentation changes into hands-on practical lessons. For each specific consequence, which add to real life dynamics, participators are prompted to enact proactive measures. Having understood the problems of noise pollution, it provided a foundation for the data-based challenges and management strategies. Remediation actions arise which can become a basis for upgraded safety, operation, and results. Despite discovering complexities, this discussion aims to participate in a wider discourse around the adverse effects of construction-related noise pollution.

4.1. Measurement of noise

4.1.1. AH tower, northern bypass, Peshawar

Table 1 illustrates the noise measurements of the AH Tower which is being constructed at different times of the day. The data demonstrates a range in sound pressure levels, the readings being 77.5 dB to 90.8 dB fluctuating in the morning hours. The afternoon levels were also generally lower and an exponential decline in the evenings. The data amalgamated reveals an apparent pattern, which shows that many parts of downtown had noisier levels exceeding allowable levels of noise, during the morning time.

Table 1. AH Tower, noise measurement (dB) during construction.

S.NO	Morning	Afternoon	Evening
1	82.6	75.9	63.2
2	82.5	76.9	64.1
3	80.5	72.9	61
4	90.8	84.2	70.1
5	84.4	77.8	63.2
6	81.4	67.8	53
7	79.7	73.1	62.7
8	80.7	74.1	60.9
9	77.5	70.9	58.1
10	83.4	76.6	65.1
11	80.4	73.8	62

4.1.2. Aafi towers, university town

Table 2 illustrates the noise pollution that showed its peaks at around 6:00 pm and goes on dropping gradually throughout the day at Aafi Towers, University Town, Peshawar. According to the obtained data (**Table 2**), noon and evening are the times that observed noise more than the recommended level. In all these cases, the numbers reveal possible safety hazards for construction workers as they as exposed to excessive levels of noise.

Table 2. Aafi Tower, noise measurement (dB) during construction.

S.NO	Morning	Afternoon	Evening
1	71.8	81.9	68.8
2	84.2	81.5	73
3	82.6	78.5	69.1
4	87.3	73.5	70.2
5	95.5	78.5	67.2
6	91.4	74.8	62.1
7	95.5	73.8	59.2
8	91.4	82.2	61.9
9	92	86.2	58.9

Table 2. (*Continued*).

S.NO	Morning	Afternoon	Evening
10	86.6	84.6	64.2
11	93.2	85.6	66.3

4.1.3. Galleria mall, ring road

Table 3 reveals minimum noise levels in the premises during the morning time, rising throughout the afternoon and evening at Galleria Mall, Ring Road. The frequencies addressed are the noise values that exceeded the legal limits, mostly in the afternoon. This indicates a demand for noise control methods, to permit the security of workers and their compliance with the regulations.

Table 3. Galleria Mall, Ring Road, noise measurement (dB) during construction project.

S.NO	Morning	Afternoon	Evening
1	47.1	77.8	59.3
2	84.8	78.7	56.4
3	82.2	74	55.1
4	92.2	83.4	52.9
5	81.3	84.7	59.9
6	83.6	82	59.4
7	98.8	80.6	62.9
8	104.5	79.9	60.3
9	87.2	83.5	58.8
10	84.9	87.5	58.1
11	93.6	85.3	57.4

4.1.4. Saif towers, university town

Test values of sound level at Saif Towers, University Town (**Table 4**) indicate the same pattern as the others, namely the temperature is low in the morning, and it decreases gradually later in the day. It is shown that the levels of noise at such a time with the whole construction crew were quite high irrespective of the fact that the point can present work problems for the employees. The strategic measures are the most crucial aspects to avoid problems with noise.

Table 4. Saif towers, university town, noise measurement (dB) during construction project.

S.NO	Morning	Afternoon	Evening
1	50.5	75.5	62.9
2	68.6	74.7	68.5
3	81	72.8	62.7
4	63.8	77.3	77.1
5	69	80.8	67.1
6	67.5	81	71.9

Table 4. (*Continued*).

S.NO	Morning	Afternoon	Evening
7	64.2	76	69.2
8	69.2	73.7	63.7
9	63.6	74.5	66.9
10	70.8	82.2	80.5
11	72	85.4	81.8

4.2. Statistical analysis (Descriptive statistics)

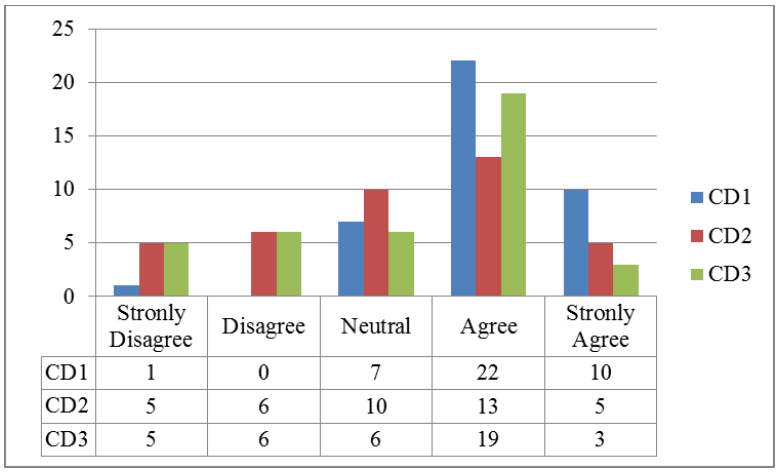
The descriptive statistics help to accumulate a total picture of the perceived quality of noise in construction work areas, ordering to identify the greatest claimed effects (Alzoubi et al., 2022). However, the mean that was obtained during analysis over oxidation indicates a great range of noise pollution's effect on the different phases of construction activities.

Z position from respondents' assessments is the qualitative measure which gives us the possibility of comparing the high, medium, or low level of perception towards all the facts observed throughout the survey. The different mean values of the challenges highlight the unique characteristics of noise pollution associated with the construction site as a whole. Being aware of such disparity brings to the surface the fact that the universal solution of what fits everyone might not be that good for all the problems emerging together due to the presence of ambient noise.

In general, the outcome of the aforementioned studies illustrates the importance of noise pollution, both ambient type and noise pollution on construction activities and the health and safety of workers as well as the completion of projects in Peshawar. This is followed by a qualitative discussion on the above-mentioned results and well as a strategic roadmap that is fit for the perceived challenges having been found in the study. While leveraging a combination of quantitative and qualitative approaches, our goal is fostering a comprehensive approach to the delicate issue of addressing noise pollution in the construction industry.

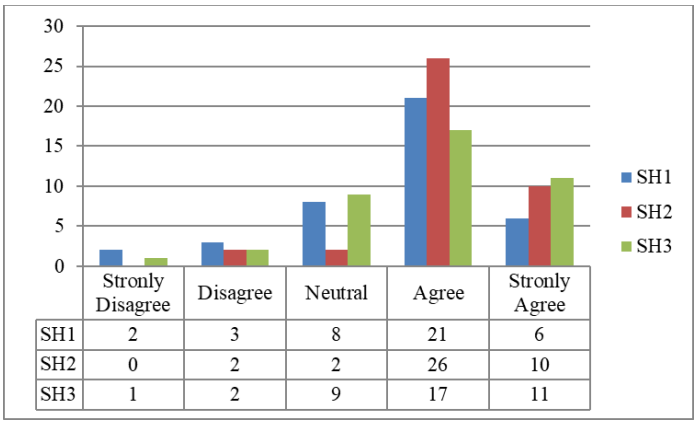
Impacts and difficulties at worksites

Figure 2 shows the reactions to communication which supports the conclusion that communication issues affect construction employees as well. The major number of the results indicated that barriers to verbal communication exist, especially during the construction period in these noisy working zones where effective strategies were considered essential and interesting. In addition, the reactions to communication (**Figure 3**) also show that barriers to verbal communication exist, especially during the construction period in these noisy working zones where effective strategies were considered essential and interesting.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
CD1	1	0	7	22	10
CD2	5	6	10	13	5
CD3	5	6	6	19	3

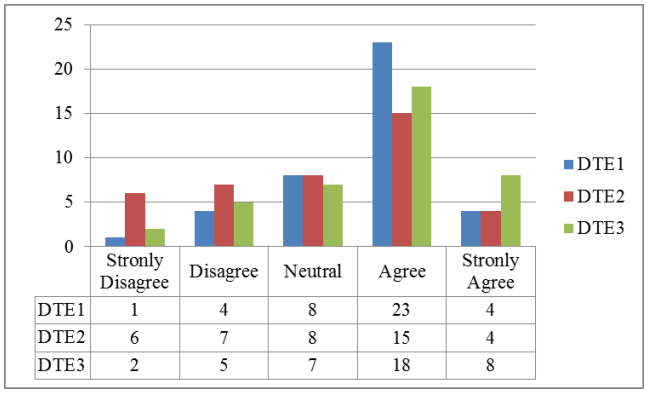
Figure 2. Communication difficulties due to noise at construction sites.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
SH1	2	3	8	21	6
SH2	0	2	2	26	10
SH3	1	2	9	17	11

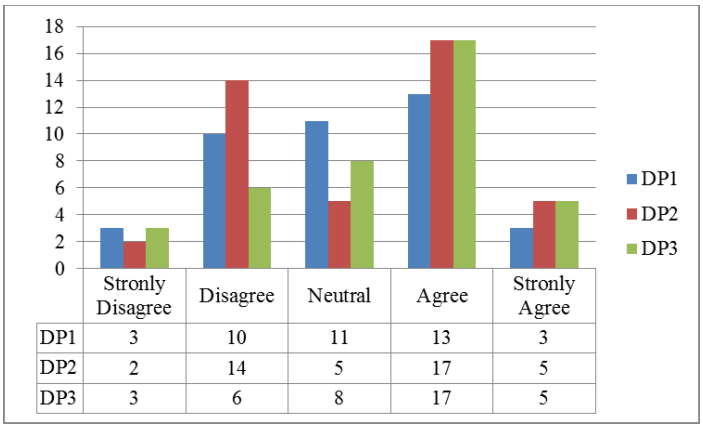
Figure 3. Safety hazards at construction sites.

Workers pointed out that high-level noise disturbances from machines contributed to a significant drop in working efficiency (**Figure 4**). Thus, it suggests the adoption of measures intended for the optimization of progress, multitasking, cutting to size, and calibration in noisy construction environments. On the other hand, noise level suggests change in productivity (**Figure 5**). Subsequently, it caused scheduling delays, increased labor costs, and work interruption and can be presented as a consequence evidencing that noise pollution has major implications on construction projects.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
DTE1	1	4	8	23	4
DTE2	6	7	8	15	4
DTE3	2	5	7	18	8

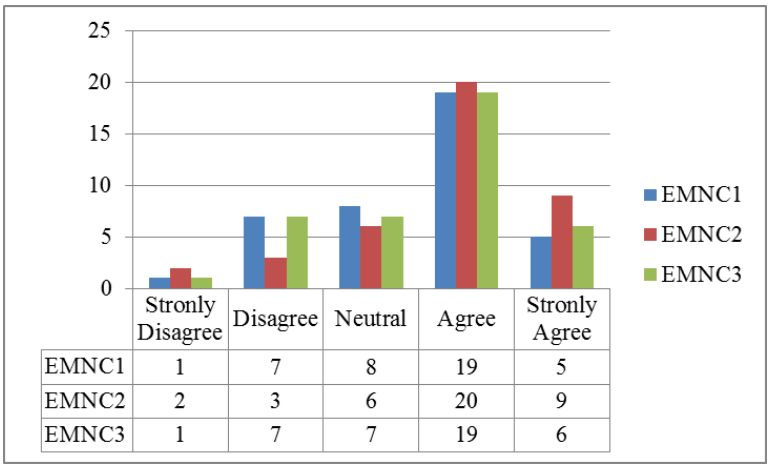
Figure 4. Decreased task efficiency at construction sites.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
DP1	3	10	11	13	3
DP2	2	14	5	17	5
DP3	3	6	8	17	5

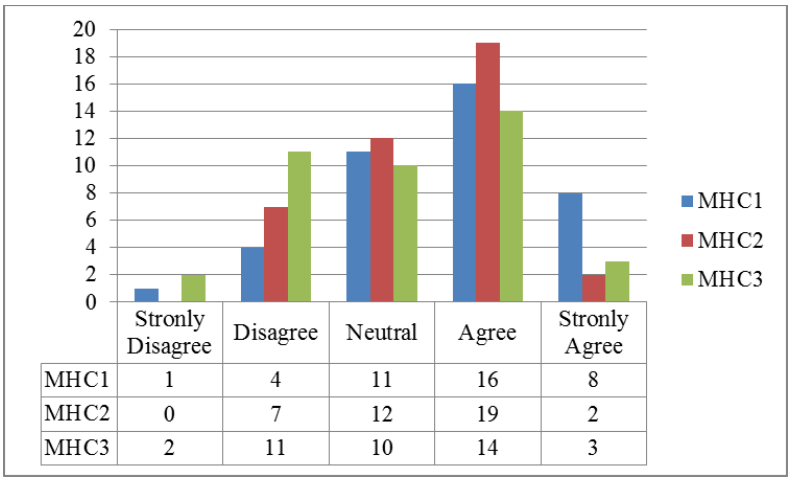
Figure 5. Decreased productivity at construction sites.

Equipment maintenance and noise control were observed to be interlinked as shown in **Figure 6**. The measure of equipment maintenance and noise control stresses the importance of quieter tools and a well-planned maintenance schedule. Workers use hand signals to transmit necessary data in light of noise deficiencies that demand advanced communication facilities. Moreover, material handling issues (**Figure 7**) probably prevent the workers from communicating effectively since the noise may overpower their conversations, hence increasing manual labor. The strategies of good material lifting and non-glitch communication in noisy surroundings are of great need.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
EMNC1	1	7	8	19	5
EMNC2	2	3	6	20	9
EMNC3	1	7	7	19	6

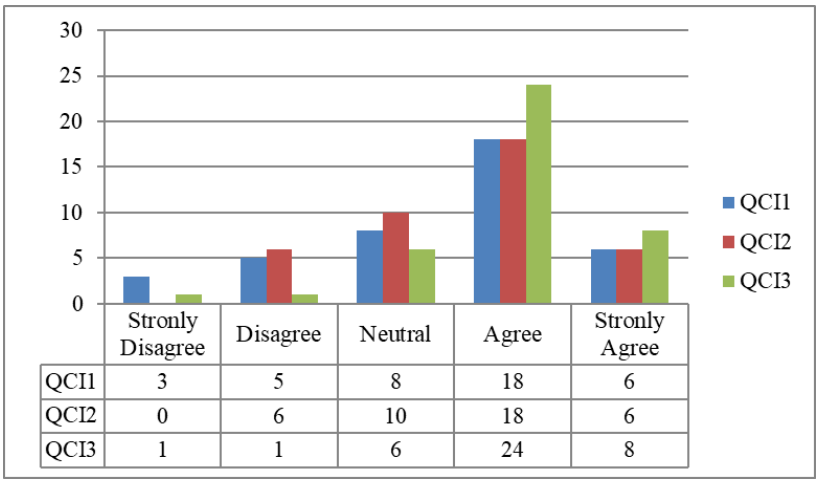
Figure 6. Equipment maintenance and noise control.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
MHC1	1	4	11	16	8
MHC2	0	7	12	19	2
MHC3	2	11	10	14	3

Figure 7. Material handling challenges at construction sites.

Figure 8. emphasizes the quality control problems indicated by the feedback of the survey. Assembly errors, inspection defects, and problems in quality assurance, on the other hand, send the signal of how important it is to develop noise-oriented inspection techniques and underline the essence of proper quality management.



	Stronly Disagree	Disagree	Neutral	Agree	Stronly Agree
QCI1	3	5	8	18	6
QCI2	0	6	10	18	6
QCI3	1	1	6	24	8

Figure 8. Illustration of quality control issues.

4.3. Relative Importance Index (RII)

In this section, the RII analysis (**Figures 9**–**16**) brings a quantitative angle to pollution factors in the noise emission of Peshawar construction sites. This evaluation assigns a relative weight to various aspects. This helps to realistically gauge the importance of each instead of overly emphasizing one over another. Subsequently, the result of this environmental analysis brings numerous critical areas to be addressed due to their significance.

Communication is what one faces mostly, a case of verbal miscommunication that can quickly result in serious turnouts like task coordination and productivity (Sarker et al., 2023). Noise pollution brings in the increased reliance on hand signals, clearly emphasizing the adaptation of site teams, but also putting in the retrospect communication inefficiencies. Dangerous conditions for construction workers may become obvious mainly due to rising levels of noise pollution that can lead to

difficulties in realizing the vision of the situation and active cancellation of the physical signals. It is critical to deme and the overstrain on emergency services due to a poor response makes accidents more prone, so an appropriate system including control of communications is required.

As noted, noise incurs a loss of productive labor thus leading to slowdowns and lesser output. Shortage of task switching is not only a matter of construction workers' productivity but also of a spark for the range of different projects as well. Hence, the results in terms of productivity are seen with longer projects, higher labor costs, and stoppages. Noise and distractions of a similar nature may lead to such results. Considering noise-related issues becomes a priority if it is possible to guarantee on-time finished projects, their completion within or below budget, and employing the best technologies for productivity.

The RII analysis reveals an obvious prioritization of noise control and regular repair and maintenance of equipment in Peshawar's construction sites. Equipping, progressive maintenance scheduling, and the adoption of newer equipment that makes little noise become the most pertinent solutions for the creation of a peaceful working environment. Hence, the noise pollution in construction will enhance the workload and might eventually push construction workers to burnout. Longer hours that prolong after normal working hours may be needed to meet a project deadline, negatively affecting not only personal health but also the total project cost.

The problem of material handling is immense for construction projects which take place in noisy places where even communication with crane operators becomes challenging, posing safety issues and delays. Several possible outcomes like physical workload increase, automatic operation inefficiency, and additional damage to things are the variation of the effect of noise. Consequently, attention becomes directed at the quality control area and the proactive problem-solving, as a reactive measure because resulting from noise in construction workplaces. Instructional mistakes, inspection problems, and impairments of customer satisfaction draw attention to the aspect of the prevention of quality management.

In summary, RII aids in developing the comprehensive framework needed for the assessment and understanding of the multi-faced problems that are associated with noise pollution in construction activities in Peshawar. Several key findings point to the requirement for tailor-made interventions to introduce communication barriers, accidents potential, productivity cancellations, and a whole lot of them to ensure a seamless construction project.

4.3.1. Verbal communication challenges and coordination

The articulated impeachment of sound pollution on verbal interaction within construction areas discloses a main problem, that is locked to job arrangement and output success. The fact that teams have to resort to hand signaling during times when noise levels are heavily elevated, acts as both a showcase of the adaptive powers of construction crews and simultaneously tends to accentuate inefficiencies of the barrier that comes from the communication gap (Shaikh et al., 2023).

The extreme event clearly shows that noise is a factor that obstructs the smooth sending and receiving of messages. This disruption (**Figure 9**), not only causes interruptions but also leads to loss in quality, including breakdowns in communication,

operational issues, and deviations from safety rules (Sarker et al., 2023). The negative impact on non-verbal communication can have a domino effect on task planning and illustrates the complex nature of noise pollution on the construction site.

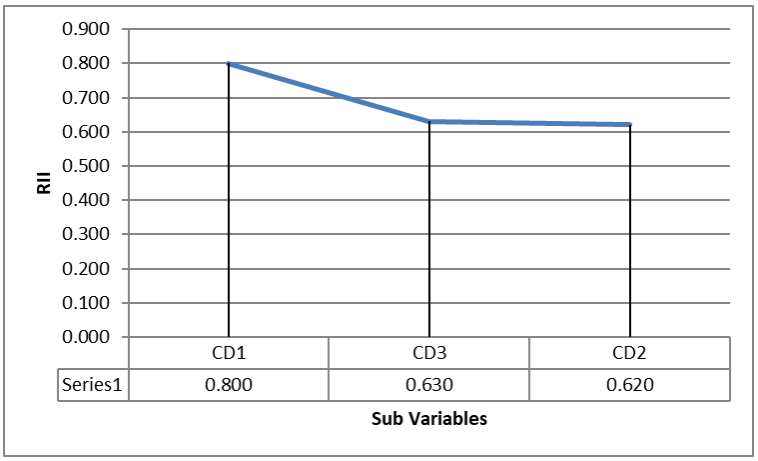


Figure 9. RII for communication difficulties at construction sites.

4.3.2. Safety hazards and emergency response

The research establishes a major relationship between construction noise hazards and security issues. It is worth noting that the losses are very grave in reduced situational awareness and decreased alarm audibility. As a result, the workers become very vulnerable to accidents. This increased risk draws attention to the fact that one must consider contingency planning strategies for disaster protocols and disaster communication management (Obrenovic et al., 2020). Time is of the essence in meeting this challenge, with concerted safety measures being the only way to prevent the increasing disturbance through sound (**Figure 10**).

Furthermore, crises and related noise disruptions reveal a unique intervention demand. It urges the stakeholders in security establishments to improve the safety frameworks that have all-inclusive coordinated emergency response systems and raised alarm audibility (Sadeghi and Vasheghani, 2021). This multi-faceted approach is a critical tool in controlling the risk and also again reminds us of the importance of noise control for a secure workplace.

The safety issue requiring revisiting existing construction safety protocols is identified in the study. Resolving intrinsic noise in pollution can be achieved by performing a holistic review of emergency preparedness, situational awareness, and communication infrastructure (Aluko et al., 2022). These kinds of activities can't continue without being evidenced while designing resilient noise environments.

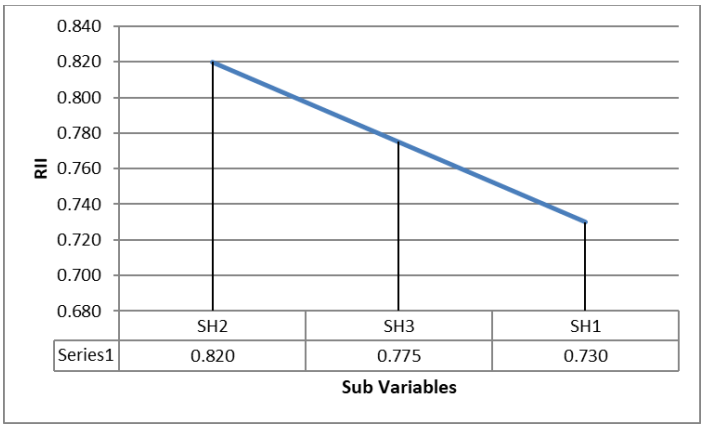


Figure 10. RII for safety hazards at construction sites.

4.3.3. Task efficiency and productivity

In construction firms, it is evident that the adverse effects of noise pollution on work efficiency and productivity are undeniable. The paper exposes a plot wherein the interruptions caused by noise create a potential hindrance to the course of a task.

The character multitasking, which is the idea of productivity in a noisy environment, meets its limit in the ambient noise. These figures depict a scene of variable noise levels that make it difficult to allocate tasks professionally. This attitude, beyond hindering individuals' effectiveness, also leads to the overall project being delayed (Sarker et al., 2023; Vandenplas et al., 2018).

Annual equipment calibration, which is a process that demands precision, emerges to be the next casualty in construction sites' acoustic battlefield (Ahn et al., 2013). This research demonstrates issues associated with noise pollution which may lead to additional difficulties in getting the right calibration. The operational efficiency of the task is lowered, the safety standards that are required are compromised, and potentially bad quality happens in all the projects that are done.

The financial implications of projects being over time clocks are very significant. Extended cycles incur major expenses resulting both from the increased labor and the surging ones to the budgets. As a result, well-designed mitigation strategies become a necessity, which provides a dual advantage of a more efficient work process and outstanding results. Moreover, **Figures 11** and **12**, show how noise pollution affects task effectiveness and productivity. These visuals play a highly significant role in bringing out the tangible results of noise on the main operational areas of Peshawar's construction sites (Shaikh et al., 2023).

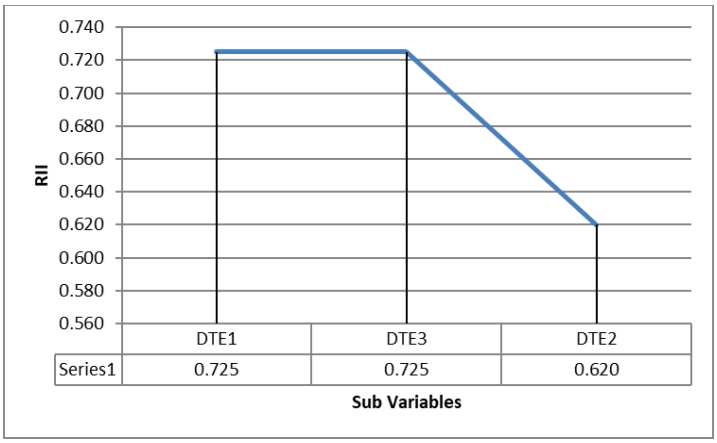


Figure 11. RII for decreased task efficiency.

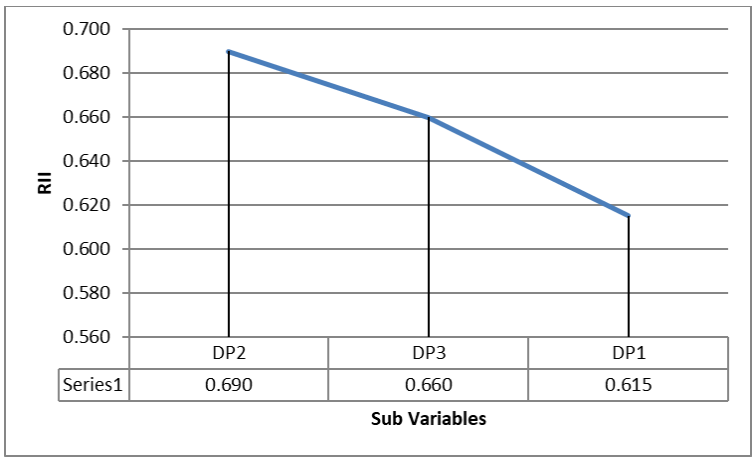


Figure 12. RII for decreased productivity.

4.3.4. Equipment maintenance, noise control, and material handling

The finding from the Relative Importance Index (RII) for equipment maintenance and noise control (**Figure 13**) is important to realize the assessment of the contribution of the two elements made to the reduction of noise pollution in Peshawar.

The noise mitigation and the rigorous maintenance approach of the industry are indications of its active role in dealing with ambient noise problems (Shaikh et al., 2023). The fact that quieter machines combined with well-planned and scheduled maintenance programs aim to provide a highly productive environment is a strategic move, not just an observation (Mir et al., 2023).

Besides the lower noise levels, noise-free equipment gives evidence of positive employee well-being. The rather tailored relationship of control, and maintenance shows the industry's ability to strive to agree with set regulations and also meet its intended productivity goals (Ahn et al., 2013; Vandenplas et al., 2018).

The importance of strategic noise reduction practices and structured handle procedures is substantially boosted with the inclusion of material handling struggles (**Figure 14**). The fine-tuned interworking of noise and material elements requires an all-embracing solution. It requires not only using quieter fleets but also planning shipping processes that are both streamlined and accommodate high levels of efficiency under loud conditions.

Succeeding in solving the noise issue multiplicity, the combination of control, maintenance, and handling becomes the most efficient and complete method (Shaikh et al., 2023; Yang et al., 2018). It will be more than the noise cutting, but the orderly management of processes, safety, and the entire operation. In the complexity of the construction sector, the ecological factors interlink together, bringing out the need to calibrate integrated strategies that shall deal with noise disturbing the ambient peace of Peshawar.

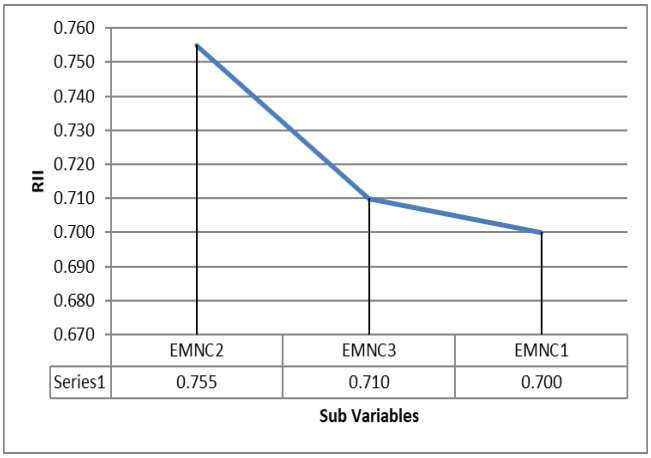


Figure 13. RII for equipment maintenance and noise control.

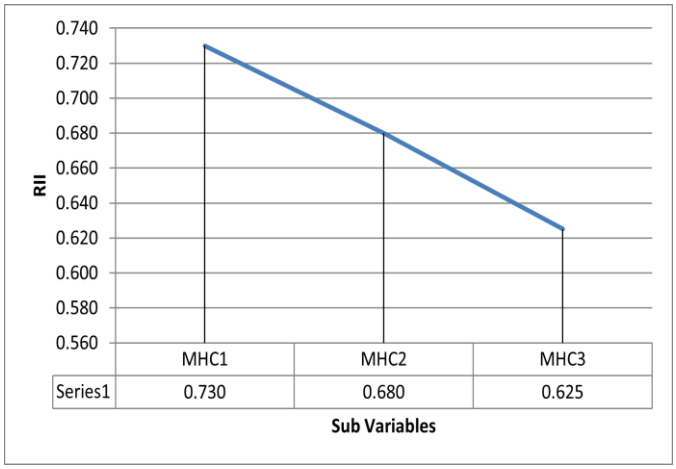


Figure 14. RII for material handling challenges.

4.3.5. Quality control and client satisfaction

Construction's sophisticated design contributes to this effect, as noise becomes a determining factor for quality control and customer service (Aluko and Amidu, 2005). The study unfolds a narrative where noise assaults are across the assembly stages and in the inspection procedures which truly is of worries that there might be possible mistakes and other problems to guarantee quality (**Figures 15** and **16**).

Through such an approach, proactive problem-solving plays a leading role, being very vital to maintaining the project's integrity. To control every aspect of the outcome and be sure that the final products are of the best quality, it becomes a necessity to address control issues in the initial stages. Research recommends a proactive approach not only to dealing with problems here and now but to be proactive in mitigating any

potential quality problems that are or will be affected by noise pollution (Sarker et al., 2023; Yang et al., 2018).

The other rippling effect of noise disturbances on customer satisfaction is that it just somehow reaches its shores. Disruptions are not only a cause of time delay but also soaks in the light of timely completion which is one of the major factors considered in the success of construction ventures (Eboli and Mazzulla, 2021; Vardaxis et al., 2018). The study shows the symbiotic relationship of quality management with the communication channels and the customers feedback as well in general. Being involved in customer satisfaction and noise issues harmonize with each other. Meeting the deadline corresponds to fulfilling the client expectations, preventing them from being irritated by late timelines or rough communication. In addition, this intricate relationship of the struggle between control and satisfaction, the message comes to be centered on the fact that noise—beyond its proximity to the actual construction progress—becomes quite pivotal in the formation of the general narrative of the project success and the overall satisfaction of the stakeholders (Shaikh et al., 2023).

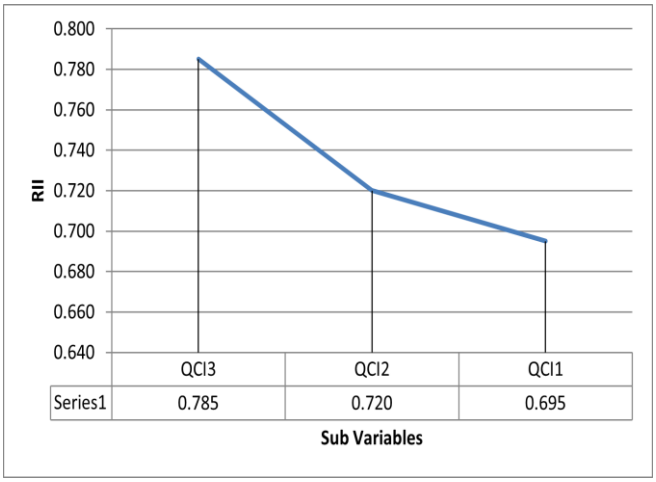


Figure 15. RII for quality control issues.

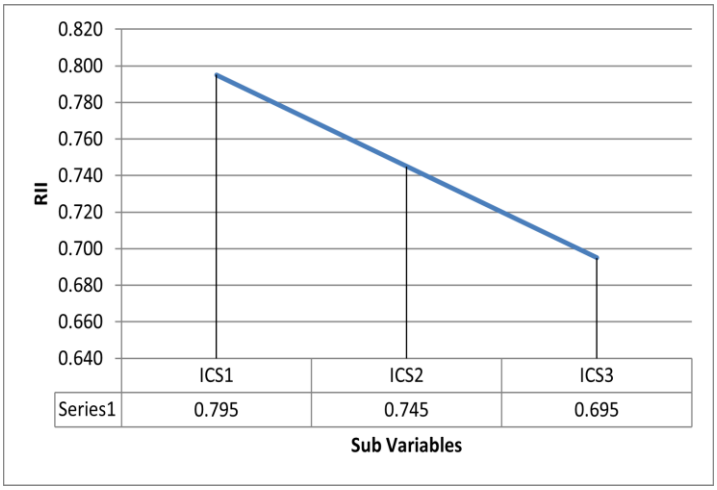


Figure 16. RII for impact on client satisfaction.

4.3.6. Overall risk variables

The holistic RII relative importance index rating for the risk variable accounts for noise pollution's multifaceted and complex influence on construction sites. Such iteration of impacts as noise, extensively over the board, dwarfs and in many cases surpasses isolated concerns.

Among various safety hazards that the RII exemplifies, it is not only statistics; they are real and practical risks for workers' wellness. Protection of human lives with the associated noise requires the establishment of preventive measures and fire control system (Rani and Laws, 2018; Xu et al., 2023). Alongside worker safety, consumer dissatisfaction is also an aspect to consider (Rahmat et al., 2023). The RII provides a very valid reason why satisfaction is affected by the noise-related delays in the project. Timely job accomplishment both logistics and image as well as customer satisfaction preservation.

The combined implications suggest the relevance of proactiveness. This is not just an academic exercise but our moral obligation. The overall welfare needs an integrated solution including responsible strategies, efficient communications, and careful measures. Operational efficiency and noise have difficulties on the horizon to overcome each other (Ahn et al., 2013). The RII serves as a diagnostic tool, showing intervention points where the workflow should be smoothed, schedules should be maintained and resources should be optimally allocated.

In essence, the result of this analysis provides a guideline to industry stakeholders. Proactivity follows the pace, whether implementing noise-free motorways, providing education, or thinking about novel means of communication. This unified approach aims to align the sector with sustainable development goals, prioritizing occupational health, operational efficiency, and productivity through comprehensive policy measures.

5. Conclusions

In conclusion, a complex and multidimensional relationship exists between surrounding noise and its dispersed effects on construction sites. We narrow down our analysis of high-risk determinants from communication issues to safety hazards and productivity constraints, which illustrates the complex character of the noise pollution challenges in the construction industry. The construction sector in Peshawar faces significant challenges from noise pollution, affecting human health and the environment. Despite statutory and policy provisions designed to regulate noise pollution globally and locally, effective implementation remains a pressing issue. While these regulations are ambitious and well-intentioned, there is an urgent need to ensure thorough and consistent enforcement to meet their intended goals, protecting workers and the surrounding community.

The analysis of noise measurements at four construction sites reveals consistent patterns of noise levels fluctuating throughout the day, often exceeding allowable limits in the afternoon and posing risks to workers' health and safety. Descriptive statistics and RII further emphasize the critical role of noise control measures and equipment maintenance in mitigating the adverse effects of noise pollution. In addition, communication challenges due to noise interference are evident, leading to

inefficiencies and safety risks. Safety hazards, such as reduced situational awareness and alarm audibility, underscore the need for enhanced emergency response protocols and crisis management strategies.

The decline in task efficiency and productivity is a significant concern, with noise disruptions impeding multitasking and task allocation. Equipment maintenance and noise control emerge as pivotal factors in fostering a productive and safe working environment, in conjunction with strategies to tackle material handling challenges and ensure quality control. Furthermore, the impact of noise pollution extends beyond operational issues to impact client satisfaction and overall project success. Timely completion and effective communication play crucial roles in meeting client expectations and maintaining stakeholder satisfaction. Therefore, it is imperative to develop and implement enhanced emergency response protocols and crisis management strategies to address the challenges posed by noise pollution.

In short, this study emphasizes the importance of proactive interventions and integrated solutions to address the complex challenges of noise pollution in the construction industry. By prioritizing occupational health, safety, and operational efficiency, stakeholders can work towards sustainable development goals and ensure the well-being of workers and the success of construction projects in Peshawar.

Integrating mitigation in the way we do business is inevitable in the face of these hurdles. This research functions as a wake-up call for inter-stakeholder collaboration towards evidence-based solutions for a safer, more efficient, and client-pleasing city. Embracing insights and fostering proactive management enables overcoming current issues and laying the foundations for sustainable, successful futures.

6. Future recommendations

Based on the findings of this study, the following recommendations are proposed for policymakers to effectively address and mitigate noise pollution and its impacts on workers at construction sites:

- Ensure that existing noise regulations are up-to-date with current research findings and international standards and subsequent implementation at construction sites.
- Regular monitoring and reporting of noise levels at construction sites are required.
- Require construction companies to submit periodic noise measurement reports to relevant authorities.
- Provide incentives for construction companies to adopt and invest in noise control, technologies, such as noise barriers, silencers, and advanced machinery with lower noise emissions.
- Offer tax benefits for installing noise control equipment to reduce the financial burden on construction companies.
- Mandate the provision of high-quality personal protective equipment (PPE), such as earplugs and noise-mitigating headphones, for workers exposed to high noise levels.
- Ensure periodic health assessments for construction workers to monitor and address any adverse health effects from noise exposure.

- Promote training programs for construction managers and workers on noise management practices and the importance of noise reduction.
- Conduct public awareness campaigns to educate the community about the impacts of construction noise.
- Ensure noise control measures are integrated with broader sustainability goals, including the SDGs and ESG principles.
- Encourage sustainable construction practices that minimize environmental impacts, including noise pollution, and enhance overall project sustainability.
- Formulate long-term strategies for noise reduction in urban planning and construction, considering future urbanization trends and infrastructure development.
- Regularly evaluate and update noise control policies to reflect changing construction practices, technological advancements, and emerging research findings.

By implementing these recommendations, policymakers can significantly reduce noise pollution at construction sites, improve worker health and safety, and contribute to the overall sustainability of construction activities.

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Appendix

Questionnaire of the Research

Research Topic

Synergistic Consequences of Environmental Noise pollution on worker productivity and activities at construction sites in Peshawar

Statement of Instruction

Dear Participants,

I appreciate your participation in this research study which aims to investigate the synergistic consequences of environmental noise pollution on worker productively and activities at construction sites in Peshawar. As an MS student of Construction Engineering and Management, this study is a vital part of our ongoing efforts to understand and address the challenges faced by construction workers in Peshawar due to environmental noise pollution.

This questionnaire is designed to gather valuable insights directly from construction workers like you. Your input will play a vital role in helping us understand the specific challenges faced by workers in Peshawar's construction industry due to noise pollution. Your experiences. opinions. and suggestions will contribute to the development of effective strategies to enhance worker productivity, safety, and overall well-being on construction sites.

Please take a few minutes to complete the following questionnaire thoughtfully and to the best of your knowledge. Your honest and accurate responses are highly valuable to us. Please indicate your level of agreement with the following statements:

Likert Scale: I: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree.

Variable l: Communication Difficulties		
1)	Verbal miscommunication affects task coordination and productivity	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Limited use of radios due to noise hinders effective communication	
3)	Increased reliance on hand Signals is necessary for communication due to noise	
Variable 2: Safety Hazard		
1)	Reduced audibility of alarms poses a risk to safety	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Decreased situational awareness due to noise can lead to accidents	
3)	Ineffective emergency response is a concern in noisy condition	
Variable 3: Decreased Task Efficiency		
1)	Slower work pace is observed due to noise-related distractions	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Equipment calibration delays occur because of noise disruptions.	
3)	Limited multitasking is a challenge in noisy environments.	
Variable 4: Decreased Productivity		
1)	Work stoppages happen because workers wait for quieter periods.	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Extended project timelines are a result of noise- related delays.	
3)	Higher labor costs are incurred due to reduced productivity.	
Variable 5: Equipment Maintenance and Noise Control		
1)	Maintenance scheduling effectively minimizes noise disruptions.	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Investment in quieter equipment is a priority to reduce noise.	
3)	Timing on noise reduction is provided to workers.	
Variable 6: Increased Workload		
1)	Extended work hours are necessary to meet project deadlines.	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Overtime costs have increased due to the impact of noise.	
3)	Burnout risk among workers has risen due to increased workload.	

Variable 7: Material Handling Challenges		
1)	Communication with crane operators is challenging due to high noise levels.	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Material damage occurs more frequently in noisy work environments.	
3)	Increased Manual Labor is required for ma1erial handling due to noise.	
Variable 8: Quality Control Issues		
1)	Inspection difficulty is a concern when assessing quality in noisy conditions.	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Errors in assembly arc more likely to occur in noisy work environments.	
3)	Reactive problem solving is needed to address quality control issues arising from noise	
Variable 9: Impact on Client Satisfaction		
1)	Project delays nega1ively affect client satisfaction	1) Strongly Disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly Agree
2)	Quality concerns due to noise can impact the client's perception of the project.	
3)	Communication challenges with clients due to noise can affect their satisfaction.	