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# Noise climate assessment in ceramic industries (Iran) using acoustic indices and its control solutions

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## ABSTRACT

This study aimed at providing a framework for prioritizing workplaces in terms of noise control in the ceramic industry, as exposure to industrial noise has long been recognized as an occupational hazard. A TES-1354 device was used to measure the noise level. The WHC continuous noise index was used to calculate the amount of noise pollution brought on by process equipment. Finally, the industry's workplaces were prioritized for noise control using the noise control prioritization index (NCPI), which considers three factors: the number of individuals exposed, the duration of exposure, and the weighting factor based on the intensity of exposure to noise. The sound pressure level (SPL) values in the studied industry were measured between 69 and 93.70 dB (A). Furthermore, 20.53% of all measured stations were in the high-risk limit (SPL ≥ 85 dB(A)), while 79.47% fell within the safe range (69 ≤SPL<85 dB(A)). For stone crushing workplace, WHC continuous noise index values were found to be near 1, indicating unpleasant working conditions for workers. Additionally, the highest value of NCPI was estimated for the stone crusher workplaces. Our findings indicate that the stone crusher workplace is the priority for noise emission control.

## 1. Introduction

Although industries are vital to a region's economy because they create jobs and revenue, their negative effects on workers' health can lower their standard of living [1-3]. Exposure to harmful factors in the workplace has long been an important issue of industrial health [4-6]. Industrial noise is one of the strongest physical factors that can negatively impact a worker [7,8]. Mass production in industrial settings calls for huge machines and production lines that emit excessive amounts of noise [9,10]. Industrial noise is no longer just background noise in this day and age; for numerous workers, it is an everyday reality that shapes their experiences and long-term health [11-13]. Industrial noise can range from a bothersome

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level to one that can seriously harm the auditory system. Therefore, it becomes crucial to keep noise levels within allowable limits to guarantee safety and boost industrial systems' dependability [14,15]. The International Labor Organization (ILO) reports that occupational diseases claim the lives of 2.3 million workers globally each year [16-18]. The ILO research states that noise pollution in the workplace is just one of several contaminants that might cause occupational illnesses [14,19,20]. Beyond just harming ears, excessive workplace noise also impedes communication, lowers quality of life, and lowers productivity [21,22].

Globally, the production of ceramic is growing at a rate of 300 million m2 annually, and by 2020, it will surpass 10 billion m2. Due to this extraordinary pace of expansion, the number of raw materials needed annually to meet worldwide demand is anticipated to be 230 million tons per year. Iran has a lengthy history regarding its ceramic industry. In 2020, Iran ranked as the sixth producer of ceramics after China, India, Brazil, Vietnam, and Spain, contributing 2.8% of the global production [23,24]. It is one of the world's top producers of ceramics, thanks to the availability of abundant mines that provide raw materials [23]. Despite the ceramic industry's significant contribution to Iran's economic expansion, employee safety and the standard of the work environment have received less attention [25]. Approximately thirty percent of the 10,000 workers in Iran's more than 150 ceramic businesses endure dangerously high levels of noise at work [26]. Experts and decision-makers, as well as workers in the ceramics industry, are concerned about the negative health effects of industrial noise. Ceramic workers have a significant rate of noise-induced hearing loss, according to several studies. Numerous other studies have found a link between blood pressure (hypertension) and noise exposure levels. The majority of ceramic industry machinery during the manufacturing process produces noise as an unintended result of its operation [27]. In the ceramics industry, mechanical operations like cutting, pressing, sifting, crushing stone, and riveting pose a serious risk to worker health [28]. The high decibel levels of these equipment are not limited to the immediate area around the machine operators; they also negatively impact the surrounding weather's acoustic environment and pose a risk to other workers [10]. The noise produced by this equipment was louder than the 85 dB (A) standard [26,29]. The noise could be mostly low- or high-frequency, with unpleasant and jarring temporal noise patterns [30].

Industrial noise management is one of the most important measures for protecting the health of workers in the ceramics industry. Measuring noise pressure and noise-related indices are the primary methods used to investigate noise pollution in the ceramics sector. Thus, the first stage in creating programs that can offer primary source control solutions is to examine the indices of noise pollution [31]. Establishing a useful framework for identifying noise sources in ceramic industry workplaces can be facilitated by using these indices to identify safe and harmful limits [32]. In this study, the noise climate in the ceramic industry was investigated using the continuous noise index of WHC. The workplaces were then ranked according to the three parameters of noise exposure level, exposure time, and weighting factor using the noise control prioritization index.

## 2. Literature review

The increased noise levels found in industrial settings have attracted the interest of scientists studying the effects of excessive noise exposure on the auditory system and the potential for noise-induced hearing loss (NIHL) [8,33]. It is important to note that there are various methods for measuring and characterizing non-industrial and industrial noise [34]. Numerous descriptors are available to correlate people's responses to different noise sources. There is widespread usage of statistical descriptors of sound levels, such as sound pressure levels exceeding n% of the measuring period (Ln). The L10, L50, and L90 forms of the Ln statistical descriptors are the most widely used ones. These stand for the sound pressure values that were surpassed, respectively, for 10%, 50%, and 90% of the measurement period. Similarly, the range over which the sound level varies during the measuring period is known as the noise climate (NC) [35]. In reviewing some other papers, a number of popular models for measuring noise exposure are given, claiming that all noise pollution indicators are based on the time integral of squared frequency-weighted sound pressure over a stated time interval.

Some short-period noise indicators have also been developed: LAeq, 1min, and LAeq, 5min. However, they are rarely used. Fernández et al. evaluated six ambient noise indices, including LAeq, 5 min, LAeq, 30 min, and LAeq, 60 min, based on LAeq during brief periods of time. The exposure% and severity% indexes, which are used to summarize the assessment of the environmental noise throughout any selected time frame (including day, evening, and night), were produced by a fuzzy model using these six indicators as inputs [36]. Alayrac et al. conducted a study to determine noise annoyance indices for consistent and ongoing industrial noise sources. They considered the spectrum characteristics of each perceptual category when evaluating different noise annoyance indices [37]. Mardani et al. attempted to assess the quantity of noise generated at the South Pars gas platforms for the first time. In this study, the noise spectrum was 63 Hz~8000 Hz, as indicated by the sound power level (PWL) and sound pressure level (SPL) indices [38]. By employing three indicators of noise pollution level (LNP), acoustic climate (NC), and noise exposure index (NEI), Sahu et al. were able to assess the levels of noise pollution in a non-industrial area of India [39]. Table 1 provides an overview of the metrics that were created to assess noise exposure in publications.

## 3. Methodology

A research approach has been applied to satisfy the study's goals, as illustrated in Fig. 1. The components of this methodology are explained in depth in the following sections.

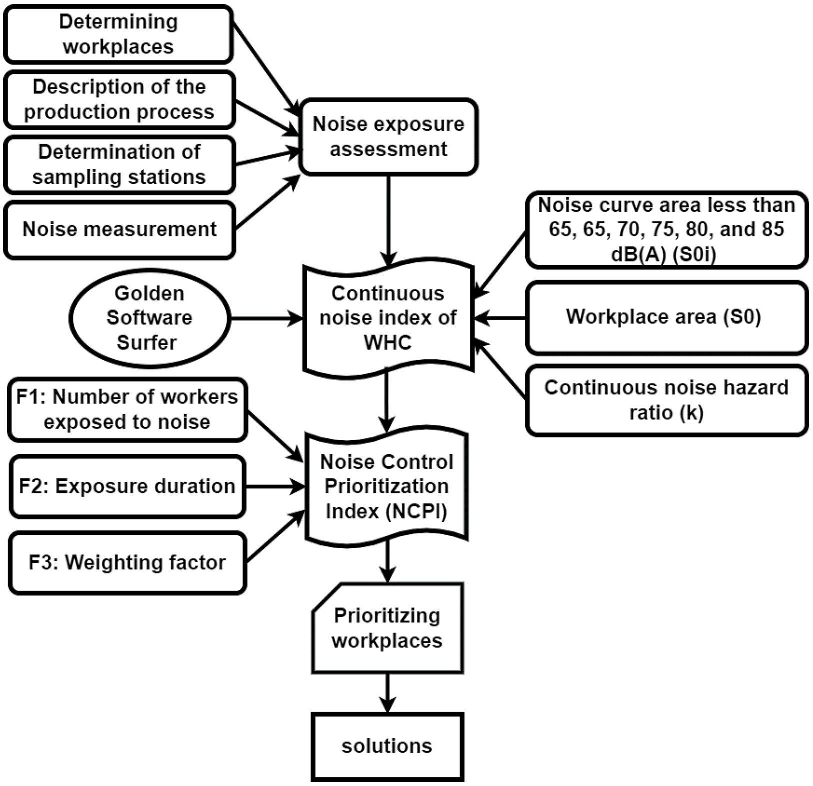

**Fig. 1.** Flowchart of the Research Methodology.

**Table 1.** Metrics to evaluate exposure to noise.

| Metric | Metric application and description of variables | Reference |
|---|---|---|
| $I_{A,1/3oct100\ Hz} = 10\,log(10^{0.1L_{Aeq}} - 10^{0.1L_{A100\ Hz}})$<br>$I_{spec} = (Global\ loudness) - (Specific\ loudness\ in\ Bark\ 2)$ | The analysis included an index that considered the A-weighting, the primary acoustical parameters found, the overall sound pressure level, and the background noise level associated with the appearance of the 100 Hz component. | [37] |
| $L_{NP} = L_{eq} + NC$<br>$NC = L_{10} - L_{90}$<br>$NEI = \frac{I_1}{L_1}$<br>$L_{eq} = 10Log_{10}\left(\frac{1}{T}\sum 10^{(0.1)L_iT_i}\right)$ | A general set of criteria is available to evaluate the degree of noise pollution. The real sound level ($I_1$), the allowable sound level ($L_1$), and the logarithmic average of the discrete-instantaneous noise level for a specific time period ($L_{eq}$, or equivalent continuous noise level) are the variables in these equations. T is the calculation period's duration in hours, and L is the corresponding noise in an hour ($T_i$). The noise levels that surpass 10% and 90% of the entire measurement duration, respectively, are designated as $L_{10}$ and $L_{90}$. These were employed to assess the level of noise pollution ($L_{np}$), noise climate (NC), and noise exposure index (NEI). | [39] |
| $PWL = 10log\left[\frac{W}{W_0}\right]$<br>$SPL = 10\ log\left[\frac{P}{P_0}\right]$<br>$SPL = PWL - 20log\,D - 0.49 - SPL_A$ | Sound pressure and power levels are displayed through metrics. PWL and SPL stand for pressure level (dB) and power level (dB) of sound, respectively. W0 and P0 are reference values, respectively, with W0 = $10^{-12}$ and P0 = $2{\times}10^{-6}$ Pa, respectively. D is the minimum distance (in meters) between the source of pollution and the receptor, and SPLA is the sound pressure level (in decibels) attenuation of noise in the atmosphere. | [38] |
| $D = \left[\frac{C}{T}\right] \times 100$<br>$T(h) = \frac{8760}{2^{(L-79)/3}}$<br>$TWA = 10 \times log_{10}\left(\frac{D}{100}\right) + 79$ | This is how the annual noise exposure and time-weighted average sound level (TWA) are calculated. C is the number of hours per year that the participant reports for the activity; T is the number of hours per year at which the activity is deemed hazardous using our REL over a one-year period; L is the duration of exposure to noise; and D is the exposure dose to noise. | [40] |
| $W_{hi} = \begin{cases} 0 & \text{for } L^*_{EX,8h} < 65\ dB(A) \\ 3.19 \cdot 10^{-9} \cdot 10^{0.1L^*_{EX,8h}} - 1.01 \cdot 10^{-2} & \text{for } 65\ dB(A) \le L^*_{EX,8h} \le 85\ dB(A) \\ 1 & \text{for } L^*_{EX,8h} > 85\ d\,B(A) \end{cases}$<br>$L^*_{EX,8h} = L_{AE} + 10\,log\left(\frac{t_0}{8h}\right) = L_{AE} - 44.6$<br>$L^*_{EX,8h} = L_{Aeq,te} + 10\,log\left(\frac{t_e}{t_0}\right)$<br>$W_{HI} = \frac{S_{hi\,(1)}}{S_c}$ | Impact noise analysis in industries makes use of the $W_{HI}$ indicator. The parameters involved in these formulas are as follows: $t_0$ is the reference time, 1 s; 8 h = 8 × 3600 (s) = 28800 (s); $L_{AE}$ is the A-weighted exposure level for a single event (explosion); and $t_e$ is the exposure period, in seconds. The industry sector in which the $W_{hi}$ = 1 ($m^2$) impulsive noise index hazard in the workplace exists can be identified using simulation research on the industrial acoustic model ($S_{hi(1)}$). The total sector's area (Sc) is $m^2$. | [10] |

## 4. Materials and methods

### *4.1. Description of the ceramic manufacturing process*

The term "ceramics" refers to inorganic, non-metallic materials that solidify and take on the required characteristics when heated. Depending on the intended outcome and the type of production (industrial or artisanal), there may be variations in the stages of the ceramic production process. A schematic of this process is shown in Fig. 2. The tools and procedures used in the manufacturing of ceramics are briefly described below.

Raw material procurement: The ceramic production cycle commences with the preparation of raw materials. It is important to prepare the raw materials before they can be processed. The following materials are utilized to make ceramics: clay, feldspar, and quartz/silica sand.

Primary and secondary crushing, grinding, and screening: First-size reduction and homogeneity of raw materials are usually achieved during the quarrying process; however, additional processing is needed to meet the strict technical requirements of ceramic products. Very hard raw materials are crushed into smaller sizes using jaw and cone crushers. Clay particles are often broken up, flattened, and blended with crushing rollers. The raw material is sheared, flattened, and nicked as it passes through pairs of parallel, smooth, hard-steel rollers that are propelled in opposing directions. Two rotors that are fastened to impactors or shoes make up an impact rotor crusher. They rotate, mixing and disintegrating the incoming material continually as they turn in the same direction as one another.

Dry or wet milling (grinding): The production cycle continues with the grinding and atomization phases. The above-discussed comminution procedure usually produces particles that are at least 2 mm in size. The initial coarse sizes must be reduced through grinding and atomization to produce particles with the proper diameter and particle size distribution for the finished product. This grinding could be wet or dry. When the end product does not require extremely high quality and the raw materials are already very uniform in terms of shape and hardness, dry grinding is typically utilized. Wet grinding is suitable for minimizing the particle size of the mixtures used and making them as homogeneous as possible. Hard ceramic spheres tumble within horizontally placed drums in continuous or batch ball mills to achieve even finer grinding. They are made up of revolving rolls that are positioned vertically and work inside an outer ring.

Spray drying: Following wet ball milling, the raw material's aqueous suspension (solids content ~ 60 to 70%) is sprayed under pressure to create small droplets that come into contact with a heated air stream. Highly homogeneous, roughly spherical, hollow granules with a moisture content of 5.5 to 7% are produced when the droplets dry. Because of its excellent flowability, this type of powder makes it easier to accurately load press dies and press very large single ceramics.

Pressing: The granules are shaped using this method, either in granular or powder form, until they acquire a nearly final shape and, most importantly, a consistency that permits them to endure the next processing stages without cracking or deforming. Granules in a predetermined volume are charged into die boxes, and pressure is often supplied from both above and below. Heavy flywheels and cam action drive the pistons. High compaction power, high productivity, uniformity, and ease of adjustment are all possible with modern hydraulic presses. The process of hydraulic pressing is commonly used to shape ceramics.

Frits and glazes, glaze preparation: Applying a crystalline glaze, which can be liquid or powder, or a covering glaze to ceramics either before or between the first and second firing stages is known as glazing. The glazing of ceramics involves the use of glassy raw materials called frits. Frits are crystalline solids melted at high temperatures (1500°C) and quickly cooled to form vitreous compounds that are insoluble in water. Discontinuous drum ball mills are typically used to grind the frit and additives in the glaze manufacturing process. The glaze passes through sieves that vibrate. After that, the parameters of the aqueous suspension are changed.

Drying: It takes the hottest and driest air to remove the final few percent of water from the ceramic body. Gas burners and hot air recovered from kiln cooling zones are currently the main sources of heat for drying ceramics. The drying properties of ceramic raw materials vary, but for the most part, they benefit from a warming-up period at high humidity with little to no moisture loss, followed by the major drying stage, where the workplaces come into contact with hotter and drier air.

Firing: The fire step of the production cycle comes after the drying phase, which is necessary to help the object shed any remaining moisture and plasticity so that it may be fixed in its final shape. Special furnaces are used for firing, which can continue for many hours and involves temperatures between 800 and 2000°C. The procedure might alternatively consist of two steps, and the final product will have less volume. The end outcome is determined only by the firing temperature. Any moisture that remains after clay-based ceramics are burned in a kiln is driven off at temperatures between 100 and 200°C. The typical starting point for vitrification and the creation of new crystalline compounds and glassy phases is around 900°C, which ends around 1050°C (for many brick clays) or 1100°C (for more refractory fireclays).

### *4.2. Cutting, squaring, and packing*

Cutting is a finishing process applied when a ceramic's final shape with precise dimensions is successfully created. Cutting techniques, such as wire electrical discharge machining, laser beam machining, abrasive water jet machining, and hybrid machining, have also been applied to cut ceramics. Therefore, in order to achieve the appropriate proportions and finishes for ceramics, cutting processes need to be not only extremely effective but also carefully selected to preserve the integrity of the ceramics.

Squaring is a process for standardizing the edges of ceramics, which are adjusted using a squaring machine line. One of the functions of the machine is to smooth and trim the edges so that they are even, straight, and match the ceramic's proportions. It's not just squaring the edges of ceramic surfaces; it's also smoothing them to remove imperfections and anomalies. The extreme accuracy with which dry squaring machines are made guarantees that every ceramic fulfills the particular dimensional and quality requirements.

Packaging is a process to protect manufactured ceramics. Ceramics are packed effectively and safely using a variety of instruments and supplies. Bubble wrap provides impact protection and cushioning. Strapping tools are used to apply strapping bands around larger ceramic items or pallets for stability during transportation. Utility knives, or scissors, are used for cutting packaging materials to size or open boxes. Box cutters are specifically designed to cut cardboard boxes safely and efficiently.

### *4.3. Study population and noise source*

This cross-sectional analytical study was conducted in the ceramics sector in Yazd, a province in central Iran. The informed consent provided by each participant or the subject's legal guardian to undertake this research was confirmed by this study. The statistical population for this study consisted of all workers in the production sector. Administrative offices and other workplaces that were not directly associated with sources of noise pollution were excluded from the monitoring scope. Two hundred and one part-time workers who worked two or three shifts were among the individuals affected by noise pollution. Each employee completed a single shift in 7.5 hours. The study examined the following workplaces: two stone crusher workplaces (SC1 and SC2), two press dryer workplaces (PD1 and PD2), two spray ball milling workplaces (SBM1 and SBMS2), one glazing workplace (G), two glazing line workplaces (GL1 and GL2), two furnace workplaces (F1 and F2), and two packaging and squaring workplaces (PS1 and PS2).

The workforce breakdown for each workplace was as follows: One glazing unit employed eleven people; two glazing line workplaces employed forty-six; two spray-ball milling workplaces employed twenty-one; two press-dryer workplaces employed twenty-six; two stone crusher workplaces employed twelve; two furnace workplaces employed twenty-eight; and two packaging and squaring line workplaces employed forty-six. The primary sources of noise pollution in these work environments were stirrers, screens, jaw and hammer crushers, and sieves. Noise from the equipment was produced all the time in every workplace. The waveform of the released noise was nonperiodic. Broadband noise was the main source of energy distribution. Although the exact distance between each worker and the noise source varied, it was generally thought to be 0.5 m.

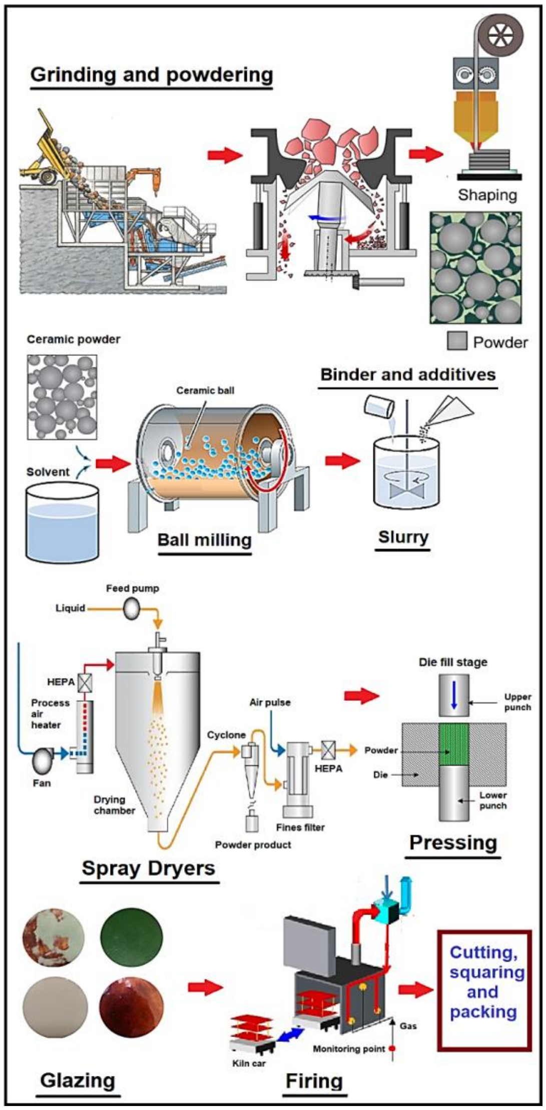

**Fig. 2.** Schematic of the ceramic production process.

### *4.4. Noise measurements*

A preliminary sampling was taken before researching to ascertain how many noise samples were needed. In this way, default values of the parameters were obtained to determine the adequacy of sampling. Then, it was confirmed that the sample size satisfied the requirements for statistical significance in terms of sample adequacy. The computation of a confidence interval and margin of error, which were founded on accepted statistical practices, was required to assess sample adequacy. Consequently, the sufficiency of the sampling process was assessed using Eq. 1:

$$n = \frac{Z_{\alpha/2}^{2} \times S^{2}}{d^{2}} \qquad (1)$$

where n is the required sample size and Z is the Z-score corresponding to the desired confidence level. For 95%, the critical value was considered 1.96, S is the standard deviation (that was obtained from a preliminary study conducted by the researchers and was 2), and d is the accuracy of the estimate (given a sample error of less than 4%). By using these computations and strictly adhering to the rules of statistical sampling, it was ensured that the sample size was sufficient to derive reliable conclusions from the data [10].

The measuring devices and calibration requirements were chosen in compliance with Section III, Chapter 5 of the Occupational Technical Manual (OTM) and the Occupational Safety and Health Administration (OSHA) [31]. The frequency-weighing network's TES-52A noise level meter was used to evaluate the level of noise pollution. This device is capable of averaging four consecutive readings and recording or displaying the average number. The device was set up to measure sound levels and display the noise level in dB (A) using an A-weighting network. In addition, the dimensions of the site layout and the locations of the equipment and production machines were measured using a distometer. The ISO 9612: 2009-based station method was used to gauge the level of noise in the workplaces [41,42]. These stations were put in strategic areas to maximize study accuracy after first ensuring adequate distribution throughout the area. A 5 m x 5 m grid of cells was built up to build the stations using this strategy. Then, according to where the equipment was placed, some inaccessible spots in the cell grid were eliminated. Every measurement was taken in the center of each grid cell [43]. Overall, it was found that there were 62, 154, 76, 47, 97, 65, and 79 samples on the stone crusher, spray ball milling, press dryer, glazing, glazing line, furnace, packaging and squaring workplaces, respectively. In this investigation, a total of 580 samples were used to quantify SPL. In accordance with ISO and manufacturer standards, instrument calibration was carried out for every set, both prior to and following testing [42]. In this way, the TES-52A was calibrated using the TES-1356 calibrator and adjusted using the rule of 3 dB (A) to the allowed limit of 85 dB (A) in Iran. At a 94 dB (A) sound pressure level and 1000 Hz frequency, the calibration was completed [44].

### *4.5. Continuous noise index of $W_{HC}$*

The WHC continuous noise index was one metric used to evaluate the degree of noise pollution created by the process equipment. Kosała & Stępień [10] applied the index WHC, and the resulting equation is as follows:

$$W_{HC} = \frac{\sum_{i}^{j} k_{65-85dB} \cdot S_{0i}}{S_0} \tag{2}$$

where S0 is the assessed workplace area (m2), S0i is the workplace area with noise contours smaller than 65, 65, 70, 75, 80, and 85 dB (A) (i = 1.... ,6 with curves <65, 65 ...., 85 dB (A)), (m2), κ is the ratio of hazards from continuous noise, defined by Eqs. 2 and 3:

$$\kappa = \frac{10^{0.1\,(L_{Aeq}-65)}}{10^{0.1(85-65)}} \tag{3}$$

$$L_{Aeq} = L_{Aeq.Te} + 10 \times \log\left(\frac{T_e}{T_0}\right) \tag{4}$$

where LAeq is the equivalent A-weighted noise pressure level (dB (A)), LAeq.Te is the actual A-weighted noise pressure level over the entire work shift (dB), Te is the actual working time during the entire work shift (h), and T0 = 8 hours [45]. Finding the LAeq's spatial distribution in each workplace is essential to computing WHC. IDW mapping was used to determine the spatial distribution of LAeqs with noise contours smaller than 65, 65, 70, 75, 80, and 85 dB (A). The WHC index values ranged from 0 to 1, where 0 denoted a favorable acoustic environment (where the effects of continuous noise are negligible), and 1 denoted the detrimental effects of continuous noise.

### *4.6. Noise mapping*

Noise mapping is a modern way to provide a graphical representation of the noise level distribution in workplaces [45]. The current study used a global positioning system (GPS) device to determine the exact coordinates of each site where data on noise levels was collected [46]. Next, an Excel file (.XLS) containing the noise values measured at each station's coordinates was created. The noise contour distribution and mapping were done using Golden Software Surfer, version 27.1.229 [47,48]. Subsequently, the IDW method was used to interpolate the LAeqs with noise contours smaller than 65, 65, 70, 75, 80, and 85 dB (A).

### 4.7. Noise Control Prioritization Index (NCPI)

The NCPI was used to rank workplaces in order of importance for reducing noise pollution and worker exposure to noise. In addition to the noise exposure values, other considerations in the conceptualization of this index included the number of workers exposed to noise in each workplace, the duration of workers' exposure, and the weighting factor corresponding to the noise pressure level. Eq. 4 expresses this process mathematically:

$$NCPI = \frac{\sum_{i=1}^{n} w_i \times p_i \times t_i}{\sum PT} \tag{5}$$

where wi is the weighting factor corresponding to the noise pressure level, pi is the number of workers exposed to noise for each area within the desired range of noise pressure levels, parameter ti is the noise exposure time (h), P is the total number of workers on all workplaces, and T is the total exposure time (h). Based on the lowest and maximum noise observed in each workplace, a weighting factor was supplied for the construction of this equation (Table 2). A workplace weight factor was distributed according to the dose ratio and adherence to the 3 dB (A) criterion, which saw an exponential increase in weight with rising noise pressure. The denominator of the equation was the total number of workers plus their exposure time at each workplace in order to normalize the NCPI data.

### *4.8. Statistical analyses*

Descriptive statistics were computed for the data: minimum, maximum, mean, standard deviation, and coefficient of variation. The significance of variations in the mean noise between workplaces with a standard value of 85 dB (A) was evaluated using a one-sample t-test. Duncan's post hoc test and one-way ANOVA were utilized to assess the significance of variations in the noise level amongst workplaces. The data's normality was evaluated using the one-sample Kolmogorov-Smirnov (K.S.)

test. IBM SPSS version 26 was used to conduct the statistical analysis of the data. P values less than 0.05 were deemed significant for differences.

## 5. Results

### 5.1. Descriptive statistics of the noise levels

Table 3 displays the findings for the noise levels in the workplaces, which varied from 72.1 dB (A) to 93.7 dB (A). The mean noise levels were measured for all workplaces at 81.48 dB (A). The maximum and minimum noise levels were measured in SC1 and GL1 workplaces, respectively. The results of all statistical tests are provided in the supplementary information file. A substantial difference in noise levels was observed between the workplaces, as indicated by the one-way ANOVA analysis results (p value <0.05). In order to compare the mean noise levels between the workplaces, Duncan's post hoc test was employed. The results showed that there was no significant difference between the F1, PD1, and PS2 workplaces (p value = 0.22), F2 and GL2 (p value = 0.07), PD1 and SBM2 (p value = 0.12), G and PD2 (p value = 0.43), and GL1 and GL2 (p value = 0.19). The findings showed that the noise data were not normal (P<0.05) for four workplaces: SBM1, G, GL1, GL2, and PS2, according to the one-sample Kolmogorov-Smirnov (KS) test. Therefore, the noise levels showed significant heterogeneity among these workplaces. The results of the one-sample t-test showed that the noise levels for all workplaces, except for those of the SC2 and SBM1 workplaces, were significantly different, with a standard value of 85 dB (A) (P<0.05). The present research concluded that 79.47% of all the measured stations were within the safe limit (69 ≤SPL<85 dB(A)) and that 20.53% were within the high-risk limit (SPL ≥ 85 dB(A)).

### 5.2. Spatial pattern analysis of the noise level

For the noise data, noise-themed maps of the workplaces were created using the Golden Software Surfer's IDW technique. The results of the noise spatial distribution for each workplace are shown in Fig. 3. For SC1 and SC2 workplaces, the thematic maps showed that the highest noise values (> 85 dB (A)) were in the vicinity of the sand screens. The stone crusher's funnels were the area around which the lowest noise values were interpolated. High levels of noise were present in the SBM1 and SBM2 workspaces, close to equipment such as sprays and ball millings. For the PD1 and PD2 workplaces, the highest noise level was interpolated around the press. The G workplace had a sieve, fourteen ball millings, and twenty-one mixers. In this workplace, the highest noise was interpolated around the ball milling, and the lowest noise was around the mixer. The highest noise level was interpolated at the digital printing device, ceramic side wear device, glazing device, engobe device, water cabin, fan, and brush, according to the spatial distribution of noise in the GL1 and GL2 workplaces. The furnace entry and center sections of the furnace were interpolated to have the highest noise levels for the F1 and F2 workplaces, respectively. The load/unload and shearing device areas of the PS1 and PS2 workplaces had the highest noise levels, according to the spatial distribution of the noise.

**Table 2.** The weighting factor based on the rule of 3 dB (A) studied in the ceramic industry.

| Noise contour (dB (A)) | | |
|---|---|---|
| Lower limit | Upper limit | Weight factor ($W_i$) |
| 69 | 72 | 0.0312 |
| 72 | 75 | 0.0625 |
| 75 | 78 | 0.0125 |
| 78 | 81 | 0.25 |
| 81 | 84 | 0.5 |
| 84 | 87 | 1 |
| 87 | 90 | 2 |
| 90 | 93 | 4 |
| 93 | 96 | 8 |

**Table 3.** Descriptive statistics of noise levels in workplaces in the ceramic industry.

| Workplace | N total | Min | Max | Mean | SD | Skew. | Kur. | T test | K. S | CV |
|---|---|---|---|---|---|---|---|---|---|---|
| | - | | | dB(A) | | | | Sig. | | % |
| SC1 | 26 | 84.5 | 93.7 | 89.97$^{a}$ | 2.22 | -0.87 | 0.70 | 0.00 | 0.06 | 2.47 |
| SC2 | 28 | 79.4 | 91.2 | 86.21$^{b}$ | 3.86 | -0.28 | -1.28 | 0.10 | 0.18 | 4.47 |
| SBM1 | 66 | 78 | 92.5 | 84.65$^{c}$ | 2.67 | 0.35 | 1.20 | 0.30 | 0.02 | 3.15 |
| SBM2 | 82 | 76.5 | 88.8 | 83.28$^{d}$ | 2.70 | -0.35 | -0.15 | 0.00 | 0.20 | 3.24 |
| PD1 | 46 | 74.6 | 85.9 | 79.30$^{g}$ | 3.08 | 0.22 | -0.82 | 0.00 | 0.20 | 3.89 |
| PD2 | 30 | 77.5 | 85.1 | 81.01$^{f}$ | 2.05 | 0.20 | -0.91 | 0.00 | 0.20 | 2.53 |
| G | 44 | 76.8 | 87 | 81.53$^{ef}$ | 2.74 | -0.11 | -0.88 | 0.00 | 0.05 | 3.36 |
| GL1 | 51 | 69 | 82.5 | 76.50$^{hi}$ | 2.59 | -0.64 | 1.92 | 0.00 | 0.00 | 3.38 |
| GL2 | 48 | 72.7 | 82.5 | 77.36$^{i}$ | 2.34 | 0.32 | -0.49 | 0.00 | 0.05 | 3.02 |
| F1 | 33 | 76 | 82 | 79.44$^{g}$ | 1.65 | -0.46 | -0.80 | 0.00 | 0.20 | 2.08 |
| F2 | 32 | 75.5 | 80.7 | 78.55$^{gh}$ | 1.27 | -0.58 | -0.02 | 0.00 | 0.20 | 1.62 |
| PS1 | 40 | 75.1 | 90.4 | 82.54$^{de}$ | 4.04 | 0.06 | -0.94 | 0.00 | 0.20 | 4.89 |
| PS2 | 39 | 72.1 | 85.5 | 78.93$^{g}$ | 4.91 | -0.03 | -1.75 | 0.00 | 0.00 | 6.22 |
| **Total** | 565 | 69.00 | 93.70 | 81.4$^{8}$ | 2.78 | - | - | - | - | 3.41 |

Table abbreviations: N total→ total number of samples measured; Min→ minimum; Max→ maximum; SD→ standard deviation; K. S → one-sample Kolmogorov–Smirnov test; CV→ coefficient of variation; T test → one-sample t test; Kur. → Kurtosis; Skew. → Skewness.

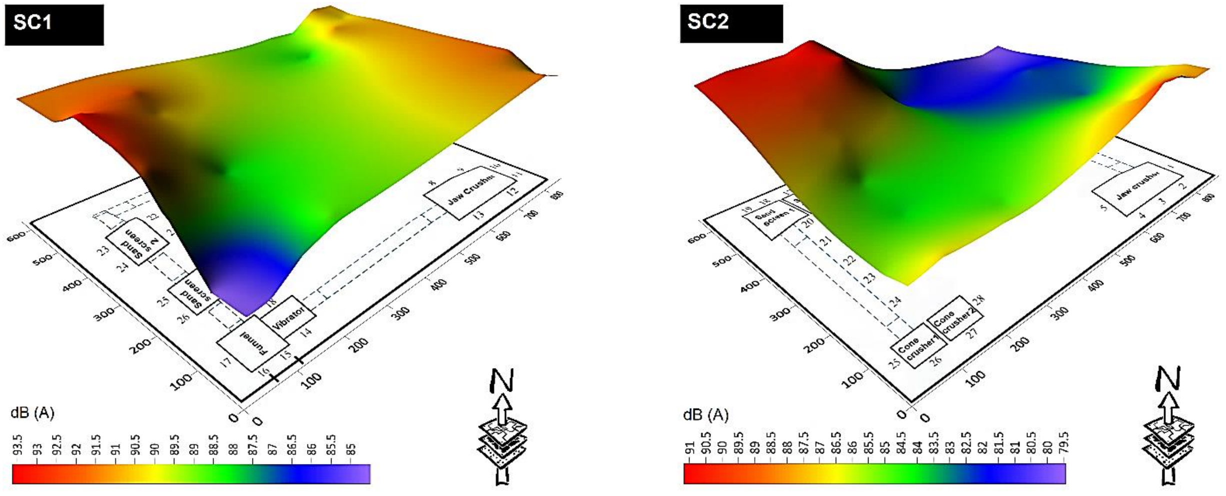

**Fig. 3.** Spatial pattern of SPL in workplaces

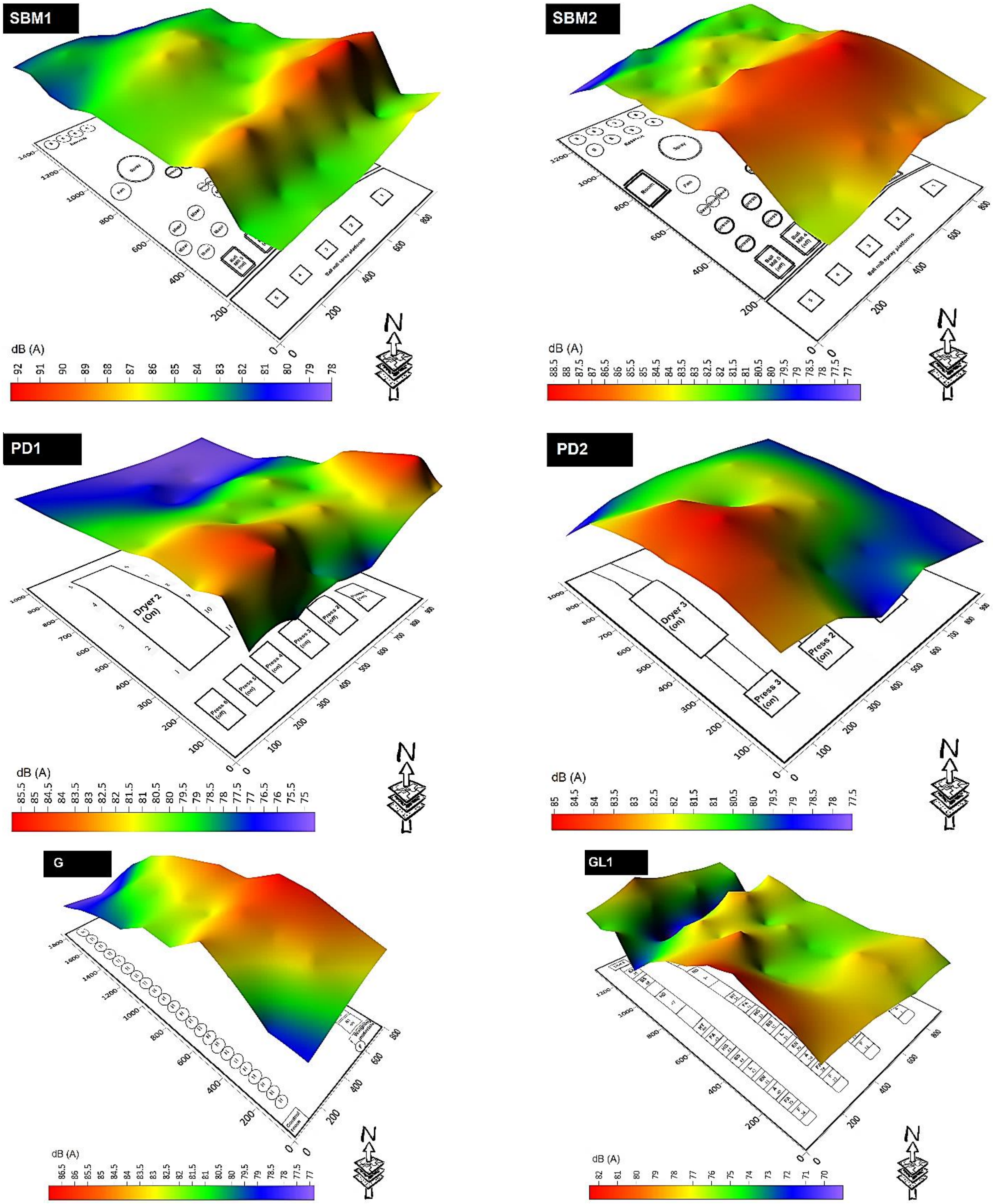

**Fig. 3.** (Continued) Spatial pattern of SPL in workplaces

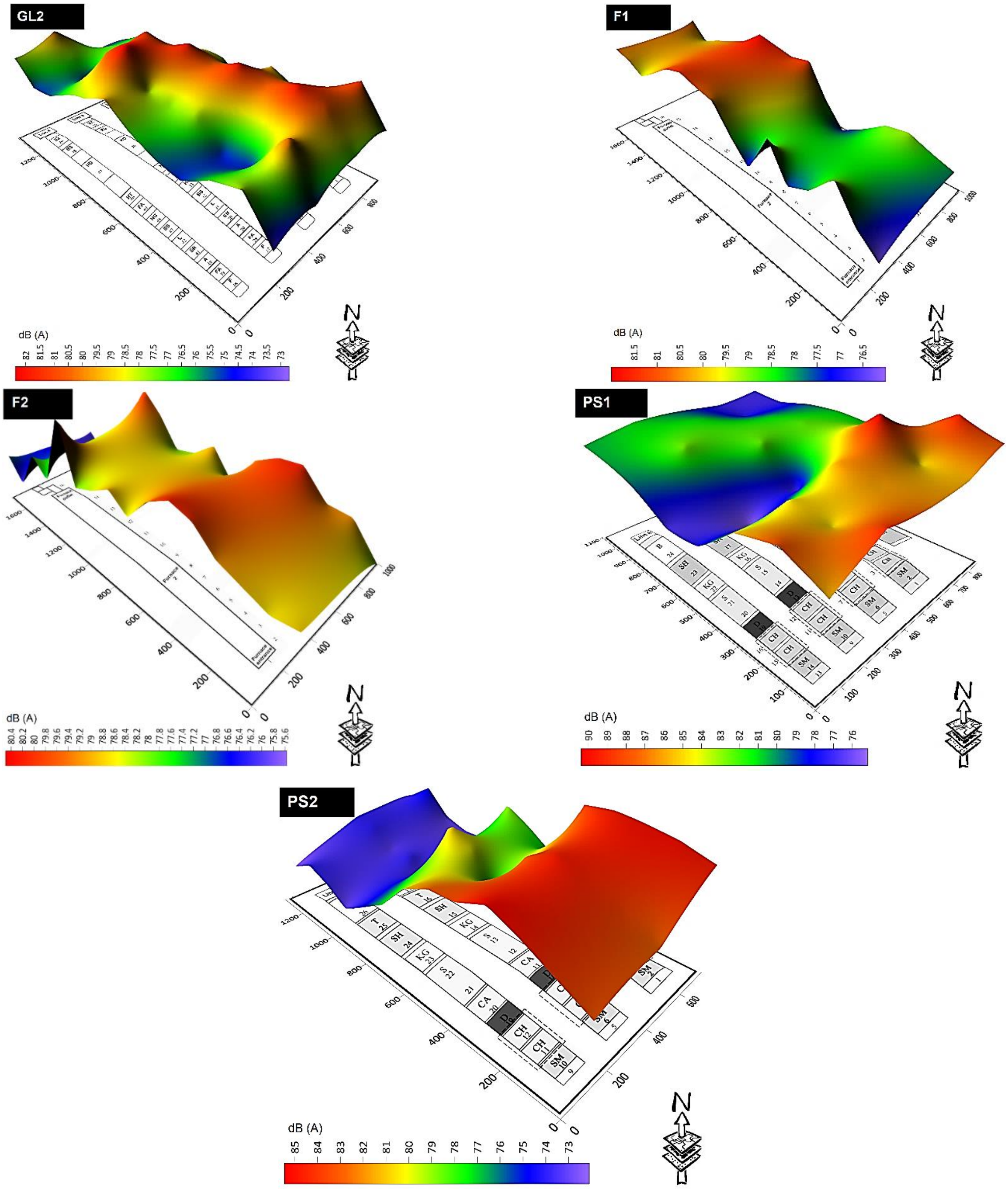

**Fig. 3.** (Continued) Spatial pattern of SPL in workplaces.

### 5.3. Continuous noise index of $W_{HC}$

When multiple devices are operating simultaneously, there may be an issue with continuous noise pollution, as evidenced by increased WHC index readings. Table 4 and Figure 4 display the findings of the WHC's continuous noise index estimation. The predicted range of this index's value for the ceramic industry was 0.056 to 0.99. The average WHC index value for the ceramic industry came out to be 0.63, indicating that workers were negatively impacted by constant noise brought on by multiple devices operating at the same time. The value of the WHC index for workplaces was organized in descending order as follows: SC1> SC2> SBM1> SBM2> PS2> G> PD2> PS1> F1> PD1> GL2> F2> GL1. When the WHC index is near 1, it means that working conditions are not good for employees and that wearing personal protective equipment is essential. As a result, the predicted values of this index for the workplaces in SC1, SC2, SBM1, SBM2, and PS2 were very close to 1, indicating that the workers there did not have pleasant working conditions.

**Table 4.** The value of the constituent parameters of the $W_{HC}$ index.

| Workplace | Class (dB (A)) | Designation area between contours | $S_{0i}$ (m$^2$) | $S_0$ (m$^2$) | $K_{65\text{-}85dB\ (A)}$ |
|---|---|---|---|---|---|
| **SC1** | 84-85 | +84 | 1.41 | 514.72 | 0.93 |
| | 85-9۴ | +85 | 513.30 | | 1 |
| **SC2** | 79.4-80 | +79.4 | 3.40 | 504.06 | 0.29 |
| | 80-85 | +80 | 192.32 | | 0.93 |
| | 85-91.2 | +85 | 308.34 | | 1 |
| **SBM1** | 87-80 | +87 | 12.37 | 1082.39 | 0.29 |
| | 80-85 | +80 | 512.50 | | 0.93 |
| | 85-92.5 | +85 | 557.52 | | 1 |
| **SBM2** | 76.5-80 | +76.5 | 61.15 | 951.26 | 0.29 |
| | 80-85 | +80 | 507.14 | | 0.93 |
| | 85-88.8 | +85 | 382.97 | | 1 |
| **PD1** | 74.6-80 | +74.6 | 396.50 | 643.05 | 0.091 |
| | 80-85 | +80 | 245.21 | | 0.93 |
| | 85-85.9 | +85 | 1.33 | | 1 |
| **PD2** | 77.5-80 | +77.5 | 155.51 | 607.99 | 0.17 |
| | 80-85 | +80 | 452.48 | | 0.93 |
| | 85-85.1 | +85 | 0 | | 1 |
| **G** | 76.8-80 | +76.8 | 144.20 | 861.11 | 0.15 |
| | 80-85 | +80 | 657.48 | | 0.93 |
| | 85-87 | +85 | 59.43 | | 1 |
| **GL1** | 69-70 | +69 | 2.00 | 833.31 | 0.025 |
| | 70-80 | +70 | 807.40 | | 0.031 |
| | 80-82.5 | +80 | 23.91 | | 0.93 |
| **GL2** | 72.7-80 | +72.7 | 842.31 | 1032.23 | 0.058 |
| | 80-82.5 | +80 | 189.92 | | 0.93 |
| **F1** | 76-80 | +76 | 408.80 | 817.49 | 0.12 |
| | 80-82 | +80 | 408.69 | | 0.93 |
| **F2** | 75.5-80 | +75.5 | 810.87 | 811.43 | 0.11 |
| | 80-80.7 | +80 | 0.56 | | 0.93 |
| **PS1** | 75.1-80 | +75.1 | 170.34 | 676.02 | 0.10 |
| | 80-85 | +80 | 324.37 | | 0.93 |
| | 85-90.5 | +85 | 181.47 | | 1 |
| **PS2** | 76.5-80 | +76.5 | 61.15 | 951.26 | 0.14 |
| | 80-85 | +80 | 507.14 | | 0.93 |
| | 85-88.8 | +85 | 382.97 | | 1 |

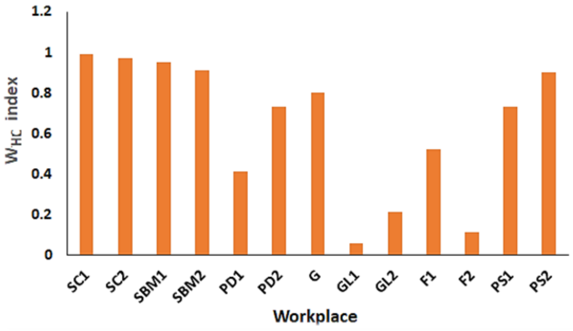

**Fig. 4.** $W_{HC}$ index value for workplaces.

### *5.4. Prioritization of noise control*

In Table 5, the values of parameters for NCPI calculation are displayed. Furthermore, the workplace priorities for the use of noise control measures are shown in Figure 5. NCPI values in this study ranged from 0.124 to 3.99. Since the SC1 workplace had the greatest degree of noise pollution, with an NCPI score of 3.99, the workplace was given priority for the execution of noise control measures. Moreover, the SC2 workplace came in second, while SBM1 came in third. The GL1 workplace was deemed to be the least important.

**Table 5.** Values of parameters for NCPI calculation.

| Workplace | Class (dB (A)) | Weight factor ($W_i$) | Number of workers exposed to noise ($P_i$) | Exposure time to noise ($t_i$) | $\sum_{i=1}^{n} W_i \times P_i \times t_i$ | $\sum PT$ |
|---|---|---|---|---|---|---|
| **SC1** | 84-87 | 1 | 0 | 7.5 | 210 | 52.58 |
| | 87-90 | 2 | 2 | 7.5 | | |
| | 90-93 | 4 | 4 | 7.5 | | |
| | 93-94 | 8 | 1 | 7.5 | | |
| **SC2** | 79.4-81 | 0.25 | 0 | 7.5 | 86.25 | 37.5 |
| | 81-84 | 0.5 | 1 | 7.5 | | |
| | 84-87 | 1 | 1 | 7.5 | | |
| | 87-90 | 2 | 1 | 7.5 | | |
| | 90-91.2 | 4 | 2 | 7.5 | | |
| **SBM1** | 78-81 | 0.25 | 1 | 7.5 | 91.87 | 67.5 |
| | 81-84 | 0.5 | 2 | 7.5 | | |
| | 84-87 | 1 | 3 | 7.5 | | |
| | 87-90 | 2 | 2 | 7.5 | | |
| | 90-92.5 | 4 | 1 | 7.5 | | |
| **SBM2** | 76.5-78 | 0.0125 | 0 | 7.5 | 84.37 | 90 |
| | 78-81 | 0.25 | 3 | 7.5 | | |
| | 81-84 | 0.5 | 3 | 7.5 | | |
| | 84-87 | 1 | 3 | 7.5 | | |
| | 87-88.8 | 2 | 3 | 7.5 | | |
| **PD1** | 74.6-75 | 0.0625 | 3 | 7.5 | 22.31 | 90 |
| | 75-78 | 0.0125 | 3 | 7.5 | | |
| | 78-81 | 0.25 | 3 | 7.5 | | |
| | 81-84 | 0.5 | 2 | 7.5 | | |
| | 84-85.9 | 1 | 1 | 7.5 | | |
| **PD2** | 77.5-78 | 0.0125 | 0 | 7.5 | 58.12 | 105 |
| | 78-81 | 0.25 | 5 | 7.5 | | |
| | 81-84 | 0.5 | 5 | 7.5 | | |
| | 84-85.1 | 1 | 4 | 7.5 | | |
| **G** | 76.8-78 | 0.0125 | 0 | 7.5 | 56.25 | 82.5 |
| | 78-81 | 0.25 | 2 | 7.5 | | |
| | 81-84 | 0.5 | 4 | 7.5 | | |
| | 84-87 | 1 | 5 | 7.5 | | |
| **GL1** | 69-72 | 0.0312 | 3 | 7.5 | 20.57 | 165 |
| | 72-75 | 0.0625 | 0 | 7.5 | | |
| | 75-78 | 0.0125 | 12 | 7.5 | | |
| | 78-81 | 0.25 | 4 | 7.5 | | |
| | 81-82.5 | 0.5 | 3 | 7.5 | | |
| **GL2** | 72.7-75 | 0.0625 | 1 | 7.5 | 42.46 | 187.5 |
| | 75-78 | 0.0125 | 8 | 7.5 | | |
| | 78-81 | 0.25 | 10 | 7.5 | | |
| | 81-82.5 | 0.5 | 6 | 7.5 | | |
| **F1** | 76-78 | 0.0125 | 2 | 7.5 | 45.18 | 150 |
| | 78-81 | 0.25 | 12 | 7.5 | | |
| | 81-82 | 0.5 | 6 | 7.5 | | |
| **F2** | 75.5-78 | 0.0125 | 2 | 7.5 | 28.31 | 127.5 |
| | 78-80.7 | 0.25 | 15 | 7.5 | | |
| **PS1** | 75.1-78 | 0.0125 | 3 | 7.5 | 127.78 | 150 |
| | 78-81 | 0.25 | 4 | 7.5 | | |
| | 81-84 | 0.5 | 6 | 7.5 | | |

| Workplace | Class (dB (A)) | Weight factor ($W_i$) | Number of workers exposed to noise ($P_i$) | Exposure time to noise ($t_i$) | $\sum_{i=1}^{n} W_i \times P_i \times t_i$ | $\sum PT$ |
|---|---|---|---|---|---|---|
| | 84-87 | 1 | 3 | 7.5 | | |
| | 87-90 | 2 | 3 | 7.5 | | |
| | 90-90.5 | 4 | 1 | 7.5 | | |
| **PS2** | 72.1-75 | 0.0625 | 8 | 7.5 | 56.62 | 195 |
| | 75-78 | 0.0125 | 4 | 7.5 | | |
| | 78-81 | 0.25 | 4 | 7.5 | | |
| | 81-84 | 0.5 | 8 | 7.5 | | |
| | 84-85.5 | 1 | 2 | 7.5 | | |

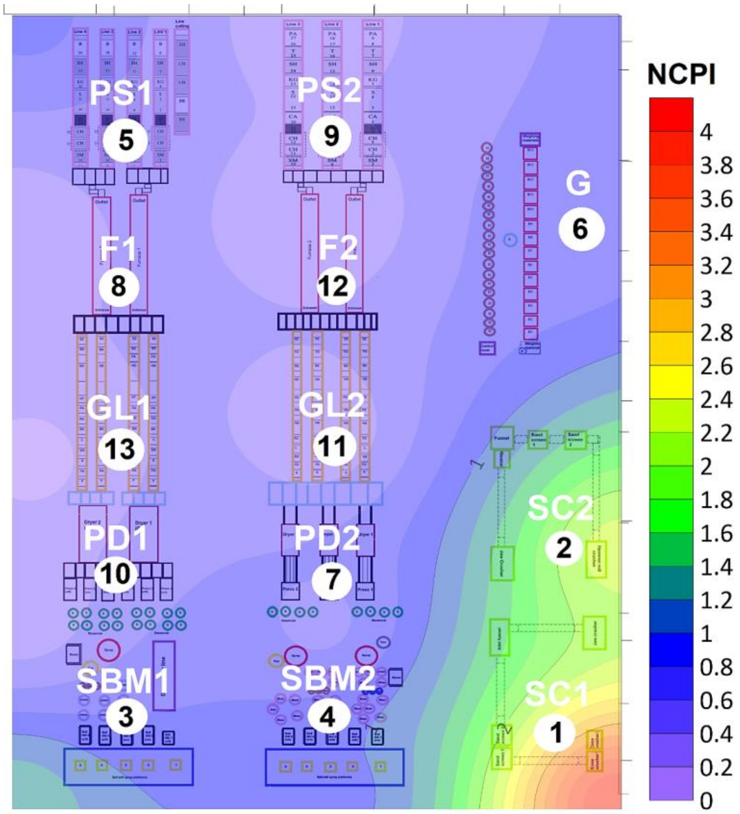

**Fig.5.** Prioritization of workplaces based on NCPI.

## 6. Discussion

### *6.1. Noise exposure assessment*

According to the Centers for Disease Control and Prevention (CDC), the third-most common chronic physical condition is noise-induced hearing loss (NIHL). Disease prevention is more cost-effective and superior to therapy. Workers may be able to prevent NIHL by being aware that undesired noise can be damaging, as well as by knowing the real safe noise exposure limit [49,50]. Thirteen workplaces where workers in the ceramic sector were directly exposed to noise were examined for this study. The average noise level in the studied ceramic industry workplaces was measured at 81.48 dB (A). The industry, as a whole, uses a variety of equipment that can produce noise levels up to 93 dB (A). The study's findings demonstrated that the stone crusher workplace was mostly responsible for noise emissions. In this workplace, there were large jaw crushers and large-toothed kibbler rollers that could make coarse primary crushing of moderately dry or brittle clays. These crushers compress the mineral lumps between a stationary and a moving hard surface. Impact forces are used to reduce particle size; raw materials are broken into little bits by the fast-revolving hammers. Noise emissions from this process exceed the allowable limit. The ceramic industry uses other advanced mechanical equipment, such as conveyor belts, sprays, ball milling, stirrers, slurry dryers, presses, pumps, glaze drain tanks, roll box transfer machines, furnaces, color router printing machines, polishers, chillers, pelletizer machines, and ceramic cutting and processing machines. These result in distinct noise exposure profiles for workers in the ceramic industry based on the type of work they do with the equipment, giving rise to distinct occupational classes.

The findings of noise exposure values documented in prior research indicated that the mean noise levels in the studies ceramic sector were comparatively lower than those in other industries: textiles (weaving: 88–86 dB (A), and preparing: 63–93 dB (A)) in Ethiopia [51], beverage cans manufacturing (92–98 dB (A)), steel reinforcement forming for concrete (91–95 dB (A)), steel sheets forming and processing (87–91 dB (A)) in Saudi Arabia [52], manufacturing industry (82.8 dB (A)) in China [53], automotive industry (85 dB (A)) in China [54], transportation equipment manufacturing industry (84.3-90.3 dB (A)) in China [55], construction equipment operators (>85 dB (A)) in Iran [56], automotive assembly industry (83.41 dB (A)) in Iran [57], ceramic industry (82.3 - 92.6 dB (A)) in Iran [26], workshops of car oil change (95 dB (A)) and aluminum makers (98.4 dB (A)) in Iran [58], food manufacturing (90–92 dB (A)) in US, food processing (88–94 dB (A)) in UK, paper manufacturing (90–92 dB (A)) in US, printing and publishing (82–93 dB (A)) in US, petroleum and coal products manufacturing (87–92 dB (A)) in US [59], chemical industry (91–100 dB (A)) in South Korea [60], steel industry (90–100 dB (A)) in UK [59], small scale hand tools manufacturing industry (81-110 dB (A)) in India [61], and petrochemical industry (88–93 dB (A)) in Iran [62]. Nonetheless, the noise levels and exposure profile may vary based on the industry's equipment type and manufacturing process.

### 6.2. Evaluation of indices

Ibáñez-Forés et al. [63] suggested using the WHC index to evaluate the efficacy of anti-noise solutions for machinery and equipment used in the tile and ceramic industry. Nevertheless, there aren't many noise climate studies that use the WHC index. As such, comparing the findings of this study to those of other studies is not straightforward. There is only one study by Kosała & Stępień that used the WHC index to evaluate continuous noise pollution during two working shifts in quarries. They concluded that shift 2 workers would gain more from this in terms of acoustics because WHC values close to zero indicated a positive acoustic environment in the quarry [10]. However, the current study's findings demonstrated that the ceramic industry's noise climate was not ideal. Stone crusher workers in the ceramic sector were at high risk of exposure to noise.

Noise emission prevention comprises management techniques that reduce the quantity of noise. Eliminating the source of dangerous noise is the best course of action, according to Oltean Dumbrava et al. If removal is not an option, the next best option to protect workers from dangerous noise might be to replace noisy equipment with quieter equipment. If the first two control approaches are ineffective in reducing hazardous noise, engineering controls may be built to either remove the noise at the source or lower it to tolerable levels. The workplace must be physically altered to implement engineering controls. Redesigning machinery to eliminate noise sources and building barriers to keep workers from being affected by noise are two examples of these modifications [64]. The NCPI index was used in this study to prioritize noise management in the ceramic industry's workplaces. The ceramics sector has not prioritized noise management via the NCPI until recently. Because of this, it is not feasible to compare the findings of this investigation with those of previous investigations. However, this index has been utilized in the rubber sector to determine which areas to prioritize when it comes to noise management.

According to estimates from Gol Mohammadi et al., the tire industry's NCPI values varied from 0.006 to 1.369. The weighting factor for the noise pressure level in this investigation was determined using the 3 dB (A) criterion [65]. Furthermore, a study on estimating NCPI values in the oil refinery business was carried out by Mousavi et al. According to their findings, the NCPI ranged from 0.84 to 1.25 in various workplaces [32]. The current study's findings demonstrated that the NCPI was a thorough index that could be utilized for planning and managing noise control in the ceramic industry, as well as for prioritizing workplaces. Actually, by integrating helpful criteria to determine how different workplaces contribute to noise pollution, NCPI establishes a framework for prioritizing and ranking noise control solutions. In this study, interviews with senior staff members and managers in each workplace helped identify the number of workers, the length of exposure, and the locations of the workers' workspaces. The numbers obtained for the sound emission rate were then used to calculate the NCPI.

The SC1 and SC2 workplaces were given top priority in regard to noise control measures, according to the NCPI calculation results. Using SDMats is consistent with the NIOSH Prevention by Design (PtD) approach, which advocates "engineering out" hazardous noise before exposure occurs. Accordingly, the main approach to noise control in this workplace is to swap out noisy machinery or equipment for quieter models. By blocking a noise source's path, e.g., by covering a noisy motor with insulation, one can also reduce noise. The third workplace where reducing noise emissions was given top priority was SBM2. Ball mills were found to have the largest estimated contributions to noise emissions in these workplaces. The main sources of noise in ball milling are collisions between the processed material, the cylinder wall lining, and the metal balls in the drum. In essence, ball mill noise is steady-state noise with high sound energy and low, medium, and high-frequency components spread over a broad frequency spectrum. The best solution to reduce ball milling noise pollution is to use a soundproof cover, replace the manganese steel cover with a rubber cover, improve ventilation, reduce heat loss, and add a chamber to the ball milling. In some studies, the cylinder muffler method has been proposed, in which an elastic buffer is installed between the inner wall and the lining plate to effectively remove noise from the ball milling [66]. For other workplaces, noise control methods can be applied, as presented in various studies [64]. It is frequently possible to reduce the amount of noise in these workplaces by taking direct action at the source of the noise. Compressors, motors for the handling and preparation equipment, and pneumatic filter cleaning systems are a few examples of the primary sources of noise. Building up noise-blocking walls or enclosing noisy equipment are two ways to accomplish noise protection. Additionally, the air gap between the first and second walls ensures a higher level of noise shielding, which makes double walls or sheathing in a double-shelled building extremely efficient. The pressing machines used in the ceramic industry, especially those handling granule shaping applications, constitute major components of harmful noise. The frequent use of pneumatic hammers and stamping machines also produces dangerous noise. When pressing machines are used extensively and do not receive proper maintenance, they always produce abnormally loud noises [64]. Because the aforementioned procedures are ineffective in reducing vibrations and noise from multiple facilities, such as presses and mixing facilities, vibration insulation is required to prevent the transfer of vibrations and noise.

Other effective methods to lessen vibration and noise include metal suspensions, rubber-metal connections, felt, rubber, and cork components; additionally, a bitumen layer or a single engine bed can be used to insulate the entire base from vibration. Using silencers near the source of noise and swapping out fast-turning fans for larger ones with a slower rotation are two other ways to lessen noise emissions at work. When belt drives are utilized in place of gears and hydraulic or pneumatic equipment is substituted for mechanical equipment, noise reduction can be substantial. Additionally, noise is reduced by replacing the silencers on schedule. The majority of the dangerous noise produced by cutting and packaging equipment can be greatly reduced with a competent maintenance program. Examples include making sure that all moving components are properly lubricated, aligning and balancing squaring equipment, and maintaining the right alignment and balance of color router printing, polishing, drying, and pelletizer machines [67,68]. Since the hazards cannot be totally removed by removal, replacement, or engineering controls, the next step is to reduce noise exposure by utilizing administrative controls. For instance, the ceramics sector might change the work schedules to avoid exposing workers to excessive noise. The final option for removing exposure to dangerous noise is to implement a hearing loss prevention program (HLPP) [7]. However, HLPP is typically less effective than removal, replacement, and engineering controls because it depends on human activities to reduce noise. The Occupational Safety and Health Administration (OSHA) advises wearing personal protective equipment (PPE) and implementing a hearing conservation program. Earmuffs and earplugs are examples of single hearing protection devices that should be worn when the noise level is 85 dB (A) or greater [7]. Commonly used hearing protection devices offer either single or dual protection. A dual-protection tool used when the noise level for an 8-hour exposure is more than 105 dB (A) is the earplug with earmuff combination. Since the workers in the investigated workplaces were not subjected to such elevated noise levels for 7.5 hours, it was anticipated that wearing earplugs would greatly reduce noise levels. The effective A-weighted noise level (ENL) for earplugs with a noise reduction rating (NRR) of 31 dB (A) was determined using the following formula in accordance with NIOSH standards [7]:

$$\mathrm{ENL} = \mathrm{dBA} - (\mathrm{NRR} - 7) \tag{6}$$

Figure 6 illustrates the daily noise dosage computed in the absence and in the presence of earplugs with an NRR of 31 dB (A). The figure shows how wearing earplugs can lower the daily noise dosage (D) to acceptable levels in the majority of areas in the production zones. As an illustration, employees in the stone crusher workplace who did not wear earplugs were subjected to a daily noise dose that could vary from 1069 to 7445% with an average of 4231.16%; however, when earplugs were worn, this daily noise dose was lowered to less than 16%. Therefore, when wearing protective gear made up of earmuffs and earplugs, the ENL further decreased. Thus, it is recommended that employees who must spend a lot of time in the workplace use these dual protection devices.

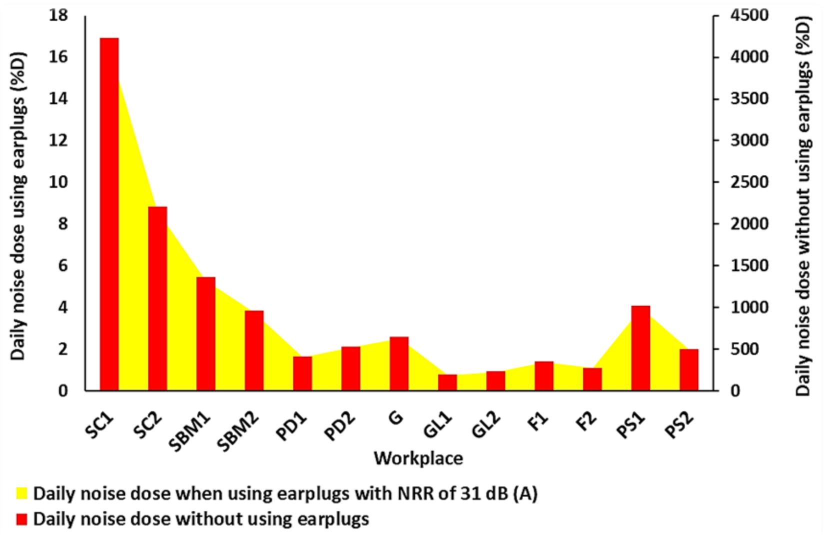

**Fig. 6.** Average daily dose of noise.

The HLPP program for the ceramic sector can be divided into three phases based on the NIOSH standard: before employment, after employment, and administrative actions for remedy. During the pre-employment stage, it is recommended to do audiometric testing on all field workers and maintain a log of their audiogram results, particularly the Hearing Threshold Level (HTL), to assess any changes in their hearing from their baseline audiogram. At the post-employment stage, it is recommended to conduct a periodic assessment of noise levels in the workplace, conduct an annual audiometric evaluation of staff members, and mandate the use of hearing protection devices (earmuffs in the control room and earplugs everywhere in the workplace) by all workers. Administrative remedies include raising employee awareness of potential noise-related harm to their auditory systems, enforcing engineered solutions for dominating noise sources, establishing long-term circulation between employees inside and outside of workplaces every week, and periodically evaluating the efficacy of implemented HLPP.

### *6.3. Research limitations*

Limitation 1: It can be challenging to estimate noise exposure levels using personal sound exposure meters (PSEMs) after accounting for the attenuation provided by hearing protection. Recording at least the C-weighted sound levels is required to compute this attenuation using the simplest estimation approach (the denominated SNR method). The primary issue is that most measurement devices do not allow for the simultaneous recording of two distinct weighted sound levels. This means that two separate measurements of noise levels must be made over the course of two working days. The first measurement should be an A-weighted sound level in order to meet the upper and lower exposure action values; the second measurement should be a C-weighted sound level to account for the attenuation provided by the hearing protector devices.

Limitation 2: The limitations of current noise mapping approaches are numerous. One drawback of these methods is that they only work with sound levels within specific frequency ranges and do not offer temporal or spectral information about the sound waves. Another drawback is that the existing methodology measures a smaller region with high-quality equipment and then extrapolates the data, which may overlook additional noise sources and amplify or lessen environmental effects. Furthermore, the existing methods can be expensive and time-consuming, needing millions of calculations to produce a noise map with an acceptable level of accuracy and sophisticated geometrical calculations for every receiver site. The uncertainty around noise maps can also impact how they are interpreted for worker safety planning, emphasizing the importance of comprehending the statistical significance of the findings. These limitations call for the development of new noise mapping prediction technologies that can enhance the current methods and provide better spatial and temporal coverage.

Limitation 3: Future research must address the limitations of the analyzed indexes. A drawback is the methodology and assessment of noise exposure do not evaluate several criteria, including age, weight, and gender of the workers. It is also assumed that workers spend most of their time in fixed workplaces. Future research should, therefore, create indices that consider both the workplace's volatility and the demographic characteristics of the workers.

### *6.4. Future research outlooks*

The issues and ramifications of noise in the ceramic industry could be the subject of several major areas of future study. Here are some potential research directions:

- Regulatory frameworks

Evaluate the effectiveness of existing noise regulations and standards in the ceramic industry and propose updates or new guidelines based on scientific evidence.

Explore international best practices in regulating industrial noise and assess their applicability in different industrial contexts.

- Technological innovations

Investigate the integration of artificial intelligence and machine learning algorithms for predictive maintenance of noisy industrial equipment in the ceramic industry to prevent malfunctions that lead to increased noise levels.

Explore the use of sound-absorbing materials and structures in industrial design to reduce noise propagation and improve acoustic comfort.

- Human health impacts

Conduct longitudinal studies to better understand the long-term health effects of exposure to industrial noise on workers, including cardiovascular, psychological, and cognitive impacts.

Investigate the relationship between noise exposure and sleep disturbances, stress levels, and overall quality of life among workers in the ceramic industry.

- Cross-disciplinary research

Foster collaboration between acousticians, engineers, public health experts, urban planners, and policymakers to address the multifaceted challenges of noise pollution in the ceramic industry.

Encourage interdisciplinary research projects that consider both technological solutions and the social implications of noise on workers of the ceramic industry.

- Research on multi-criteria decision-making techniques

As a supplement to the NCPI method, noise control techniques can be prioritized using multi-criteria decision-making techniques such as fuzzy hierarchical analysis, Vikor, and TOPSIS. Mousavi et al. determined the weights of effective criteria for selecting the optimal noise reduction solution in an oil refinery distillation unit using the FAHP hierarchical analysis approach. Using the TOPSIS technique, they concluded that the optimum method for reducing noise was to construct an enclosed chamber [69]. Also, Ishaqi et al. ranked the requirements and remedies for noise control in a glass manufacturing company using the AHP hierarchical analysis approach. With a final weight of 0.113, they determined that applying a full partition between the two main components was the optimum noise reduction option [70]. Only the ceramics industry was the subject of the current investigation. Consequently, it is advised additional research be carried out in additional operational workplaces and the NCPI index be used to rank noise control strategies across a range of sectors. The best options can then be chosen by applying multi-criteria decision-making techniques like ANP and FAHP.

## 7. Conclusion

The study demonstrated that some machinery and equipment used in the operating process of the ceramic industry had excessive noise levels. In general, the noise level in some workplaces, such as stone crushers, was unfavorable. The acoustic climate studies in the ceramic industry include the indices that are discussed in the article. The continuous noise index could be used to evaluate the efficacy of anti-noise solutions for machinery and equipment used in the ceramics sector. Higher WHC index values suggested that there may be a continuous noise pollution issue if multiple machines were operated simultaneously during a shift. The areas where operational staff were next to the machine were potentially dangerously noisy workplaces. These workplaces should have soundproof enclosures. According to the NCPI method's results, stone crushers were the top priority for remedial action to lower worker noise exposure. The expectation was that using earplugs would significantly lower noise levels since employees in the analyzed settings were not exposed to 105 dB (A) noise levels for 7.5 hours. Future research is necessary to better differentiate between various sound sources in terms of frequency, time pattern (fluctuation, emergence), and acoustic indices, as there is growing evidence of varying human responses to different sound sources. More longitudinal studies are required. To further advance our understanding of the human response to the wide range of potential negative effects of noise on health and quality of life, cross-sectional studies that use competing sound indices to assess noise exposure in greater detail, including background, could be helpful.

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