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Determination of the Equivalent Continuous Sound Level (Leq) in Industrial Indoor Space Using GIS-based Noise Mapping

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ABSTRACT

Background: The present study aimed to replace the integrated sound level meter by the noise map of a work environment in order to estimate the equivalent continuous sound level (L_{eq}) as an important quantity in the noise monitoring of continuous noise sources.
Methods: In this theoretical-experimental study, the grid method was initially used. Sound pressure level (SPL) was measured at the selected stations in three noisy industrial halls. Data analysis was performed in ArcGIS 10.2 software, and the noise map was plotted for each hall separately. Afterwards, the different zones with various SPL intervals were calculated on each noise map, and L_{eq} was determined. For the comparisons, L_{eq} was also calculated using logarithmic equations, based on which the integrated sound level meters were programmed.
Results: The proposed method was highly accurate with the relative error of less than 2%. Furthermore, it decreased the number of mathematical operations 7-15 times compared to the conventional logarithmic method.
Conclusion: According to the results, the available GIS-based software could be accurately replaced by the routine L_{eq} measurement hardware to estimate the L_{eq} spatial noise in noisy industrial environments.

1. Introduction

Today, noise is considered to be a damaging factor for human health in various indoor and outdoor environments. In acoustics, noise is defined as the audible energy, which might adversely affect the physical and mental health of living organisms [1]. According to the literature, exposure to excessive noise may lead to hypertension, impaired consciousness, insomnia, stress, tinnitus, and hearing loss [2]. These health effects indicate that noise exposure is currently a major issue in public and occupational environments; as such, noise monitoring is of paramount importance. In this regard, sound level measurement is an inherent element of noise control programs, as well as a pre-requisite to determining the priorities for the identification of areas affected by excessive and efficiency of noise control programs [3]. Since sound energy and sound level could change remarkably depending on time and place, a quantity known as equivalent continuous sound level (Leq) has been fashioned, which is defined as a stable, uniform sound for a given period in a specific location with the same energy level as a non-uniform sound [4].

Leq could be described mathematically, as follows [5]:

$$L_{eq} = \frac{1}{T} \int_0^T 10^{\frac{Leq}{10}}\, dt \qquad (1)$$

where T and L_{pi} represent time and acoustic pressure level function, respectively.

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In cases where the sound level at certain points of a noisy environment does not alter with time and the sound pressure level (SPL) varies from one place to another, the spatial changes in the sound level should be considered. In other words, the distribution of spatial variations in SPL should be estimated. For instance, this method is applicable in an industrial workplace where there are continuous, persistent sounds [4].

Currently, the knowledge on SPL in noisy environments is only based on the points where sound measurement could be performed. Since these SPLs are spatially correlated, their independent inclusion in estimations may lead to errors. Evidently, the understanding of the exact pattern of the spatial distribution of sound data requires special tools that are able to consider the spatial correlations between SPLs [6]. Geographic information system (GIS) is an efficient technology for the development of sound maps, which allows the analysis of the spatial and temporal variations of sound [7]. This high-precision technology could be used to provide sound maps in only a few measured points in a specific area.

Accurate measurement of SPL in an environment yields reliable data for the development of a sound map for the environment. Therefore, access to a few points of SPL data obtained by relevant measurement devices largely contributes to the estimations in the other points with unknown sound levels using GIS [8]. As a result, the developed noise map allows the calculation of the L_{eq} quantity.

In recent decades, GIS has been extensively used for noise mapping [9-11]. However, few studies have been focused on the noise mapping of indoor environments, and most of the studies in this regard have only addressed traffic, urban, and environmental noise [12-14]. Among the rare indoor studies, noise quantities and thorough noise analysis are scarce, and a simple description of the noise status has mostly been presented [15-17].

The present study aimed to introduce a novel method to estimate the L_{eq} in a working environment by employing a noise map, in which the data were obtained using a simple sound level meter (SLM). The proposed method is aimed at eliminating the need for complex devices (e.g., integrated SLM [ISLM]) for sound measurement, which may not be available in some cases due to their high cost and scarcity. Instead of utilizing costly hardware devices, industrial noise is planned to be estimated using the visual and computational features of GIS. Accordingly, the SPL could be estimated in other points where the sound level is unknown by limited measurements using simple instruments and GIS technology. This method saves time and is cost-efficient in noise monitoring processes and provides abundant information for experts.

2. Materials and Methods

In this theoretical-experimental study, the noise map provided by GIS was used for the estimation of L_{eq} in an indoor environment instead of an ISLM device. The experimental processes of the study were conducted in three industrial noisy environments with uniform, continuous sound. These locations were selected since there are only few similar studies for the comparison of the results to ensure the accuracy of the data obtained from the theoretical stage of the research. Considering the uniform operation of machinery in the selected industrial halls, SPL was constant and almost unchanged over time. Moreover, due to the high level of background noise inside the halls, other noise sources (e.g., human communications) had no significant effects on the total SPL.

2.1. Calculation of Noise L_{eq} with Temporal and Spatial Variations

When SPL has spatial and temporal variations, the Leq quantity could be easily determined using the noise map provided by the GIS. In order to calculate the L_{eq} in a specific point, temporal integration should be initially determined at a given interval for a specific point. This parameter could be noted for the M measurements within time period T, as follows [5]:

$$L_{eq\,(temporal)} = 10 \log \left[\frac{1}{T} \sum_{j=1}^{j=M} t_i \; 10^{\frac{Lpi}{10}} \right] \quad (2)$$

At the next stage, spatial integration must be performed on all the specified points and calculated using the following equation [4]:

$$L_{eq\,(spatial)} = 10 \log \left[\frac{1}{N} \sum_{i=1}^{i=N} 10^{\frac{Leq\,(spatial)}{10}} \right] \quad (3)$$

where N represents the number of the points where SPL is measured within the T interval in an indoor environment.

2.2. Determining the Mean Values of the Data

If data are measured at higher intervals than one unit, the weighted average of the data could be calculated using the following equation [4]:

$$\overline{X} = \frac{\sum_{i=1}^{n} x_i \; f_i}{\sum_{i=1}^{n} f_i} \quad (4)$$

where f_i is the percentage frequency, and x_i denotes the midpoint of each distance. As such, if f_i represents the percentage of the i area (A_i) and x_i represents the mean sound pressure level in the i area (L_{pi}), Equation 3 will be modified, as follows:

$$L_{eq} = 10 \log \left[\frac{1}{\sum_{i=1}^{N} f_i} \sum_{i=1}^{N} 10^{\frac{Lpi}{10}} \times f_i \right] \quad (5)$$

it will pressure of according to sound pressure level it.

2.3. Determining the L_{eq} Using the Noise Map

The GIS technology is commonly used to provide noise maps, especially in urban areas. Furthermore, it enables the provision of noise maps for indoor environments (e.g., factories and industrial workplaces). In the present study, the floor of the halls was initially divided into squares in order to prepare the noise map of an industrial hall with noisy machines, and the center of each square was considered as the measurement point (grid method) [17]. Considering that the accuracy of noise maps depends on the distance between the measurement points, the minimum possible distances were selected (2×2 and 1×1 m). Afterwards, the SPL was measured in all the determined points using a simple SLM (Cel-231, UK), which was calibrated using an acoustic calibrator (Cel-110.2) prior to each measurement. All the measurements were performed in accordance with the ISO-9612:2009 standard, and the SLM device was set to A-weighting scale and slow response speed.

The obtained data were analyzed using the ArcGIS 10.2 software, and the noise map of each hall was provided using the Geostatistical Analyst tool. Following that, the Raster Calculator command was applied in order to determine the area of each zone representing the SPL at a given interval. Based on the same logic, Equation 4 could be converted to calculate the L_{eq}, as follows:

$$L_{eq} = \frac{\sum_{i=1}^{i=7} A_I \; L_{pi}}{\sum_{I=1}^{I=7} A_i} \quad (6)$$

Where A_i is the percentage of the i areas, and L_{pi} shows the midpoint of the SPL within the i^{th} interval.

L_{pi} =1/2 (Upper Limit of SPL at i^{th} Distance + Lower Limit of SPL at i^{th} Distance)

Since no temporal variations were observed in the SPL in the present study, and the sound level had no significant changes over time, Equation 5 was used to calculate the L_{eq} spatially. This equation provided an equivalent sound level between various stations in a particular hall. It is notable that in Equation 5, A_1, A_2, ..., A_n denote the percentage of the squares in areas 1, 2, …, n relative to the total area of the noise map, and L_{P1}, L_{P2}, ..., L_{Pn} represent the midpoint values of the SPL corresponding to the areas on the noise map.

2.4. Determining the Accuracy of the Results

In order to determine the accuracy of the obtained results from the noise map, the L_{eq} of the specific locations were compared to the calculations obtained by Equation 3. In order to calculate the precision of the applied interpolation methods for the development of the noise map in the ArcGIS software, the leave-one-out cross-validation technique was used [18]. According to the cross-validation, one point was temporarily removed from its neighboring areas and estimated. Following that, the eliminated values were returned, and this process was performed for the estimations in the other points. Finally, the results were presented in the form of a table with two columns, and the values were measured and predicted. Based on these values, the mean bias error (MAE) and mean absolute error (MBE) of the model could be determined. Accordingly, if the two values were close to zero, the model was considered to have high accuracy. MAE and MBE were defined, as follows [19]:

$$\text{MAE} = \frac{1}{n} \sum_{i=1}^{n} | \mathbf{Z}^* (\mathbf{x_i} - \mathbf{Z} (\mathbf{x_i}) | \quad (7)$$

$$\text{MBE} = \frac{1}{n} \sum_{i=1}^{n} (\mathbf{Z}^* (\mathbf{x_i}) - \mathbf{Z} (\mathbf{x_i})) \quad (8)$$

According to the results of the mentioned indices in the assessment of the geostatistical methods for the mapping of the noise levels in the studied areas, the inverse distance weighting (IDW) model (power: 2) was associated with the least error (MAE) and deviation (MBE) compared to the other models previously applied (e.g., Kriging, TPSS, and radical bias function). Therefore, all the noise maps were drawn using the IDW model.

3. Results and Discussion

The experimental stage of the present study was conducted in three noisy industrial halls, including a spinning factory, a boiler room, and a compressor unit in a gas station. Considering the uniform operation of machinery, the SPL was almost constant over time in the selected halls. Moreover, the background noise was predominant, prevented the significant effects of the other sound sources (e.g., human communications) on the measurements. The results of sound measurements in the prepared noise maps and in terms of the determined L_{eq} are further discussed in the following sections.

3.1. Spinning Hall

The spinning hall was a squared building with floor dimensions of 20×20 meters and nine spinning machines located at equal distances from each other, only one of which operated independently, generating a continuous and persistent sound. Considering the dimensions of the hall, a two-meter grid was applied to the floor plan, and the measurement points were selected within a two-meter distance from each other, resulting in a total of 110 measurement points. Figure 1-A depicts the arrangement of the machines in the spinning hall, with the horizontal positions of the measurement stations and blind points, which were occupied by the spinning machinery and other obstacles, causing the noise measurement to be impossible. As can be seen in Figure 1-A, the spinning machinery were of the ring-frame type with a rectangular shape, which are illustrated with long lines.

The SPL was measured at each station, and the data were analyzed in the ArcGIS software. Following that, the noise map was plotted (Figure 1-B). In Figure 1-B, the distribution of the noise levels within the spinning hall is indicated by some zones with various colors. According to the obtained results, a high noise range (96-98 dBA) was observed in the proximity of the operating machine (red area), while an SPL range of 83-84 dB_A was measured simultaneously (blue area) at the far corners from the operating machine.

Table 1 shows the percentage of the area of each SPL range and midpoint of each range. The first adjacent area to the operating machine with the highest SPL range and midpoint of 97 dBA was the smallest area, covering less than 1% of the spinning hall. Although a specified pattern could not be inferred, further distance from the noise source seemed to increase the intervals.

However, the intervals of 84-86 and 90-92 dB_A were observed to the highest percentages in this area. In general, the percentage of the area attributed to the higher ranges than 90 dBA was approximately 42%.

Table 1: Distribution of SPL intervals in the spinning hall

Noise ranges (dB)	83-84	84-86	86-88	88-90	90-92	92-94	94-96	96-98
Percentage of frequency (%)	4.41	22.36	14.24	16.41	22	10.67	9.37	0.13
Midpoint	83.5	85	87	89	91	93	95	97

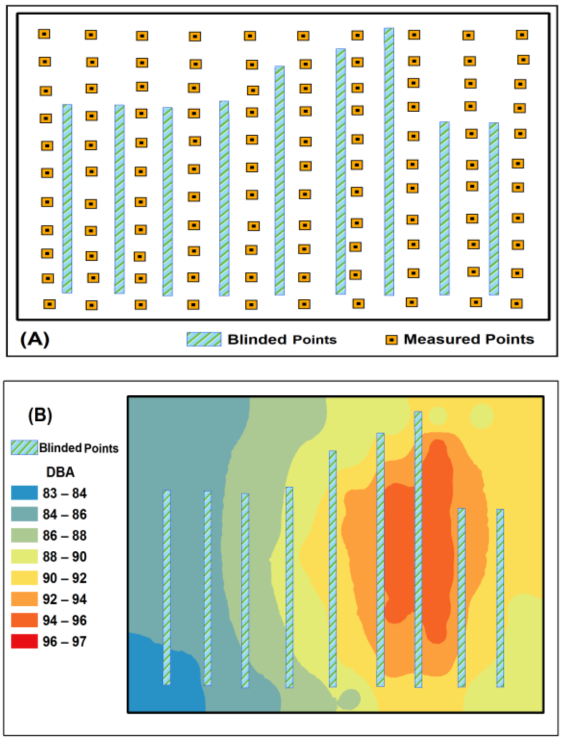

Figure 1: Arrangement of machinery in the spinning hall, with the horizontal positions of the measurement stations, and blinded

The information in Table 1 and the corresponding values were merged into Equation 5, and the noise map was employed to calculate the spatial Leq in the spinning hall, as follows:

$$L_{eq} = \frac{\sum_{i=1}^{i=7} A_i L_{pi}}{\sum_{i=1}^{i=7} A_i} = 89.11 \text{ dB} \quad (6)$$

In addition, the Leq of the spinning hall was calculated using a logarithmic equation, as follows:

$$L_{eq} = 10 \log \left[\frac{1}{110} \sum_{i=1}^{i=110} 10^{\frac{L_{pi}}{10}} \right] = 90.47\text{dB} \quad (7)$$

3.2. Boiler Room

Three boilers were installed in the selected boiler room, only one of which was operating during the measurements in the present study. Considering the size of the boiler room (9×14 m), the grid size of 1×1 meters was selected for sampling, resulting in 64 measurement stations, with the exception of the blind spots. Figure 2-A shows the arrangement of the boilers and measurement stations in the boiler room. As can be seen, almost half the space was occupied by the boilers and other machinery, leaving approximately 64 square meters for sampling.

The sound map of the boiler room is shown in Figure 2-B. As is depicted in this figure, an SPL range of 72-92 dBA was detected, which was classified into four smaller ranges in the sound map. The data obtained from the map are summarized in Table 2. According to the information in Table 2, the two intermediate SPL intervals (74-76 and 76-78 dB_A) were distributed in approximately 80% of the area. In addition, significantly smaller areas could be attributed to the extreme SPLs, especially those in the high extremes. Based on these data, the spatial Leq was determined to be 75.43 dBA, which was within the intermediate ranges.

The information in Table 2 and the corresponding values were merged into Equation 5, and the noise map was employed to calculate the spatial Leq of the boiler room, as follows:

$$L_{eq} = \frac{\sum_{i=1}^{i=4} A_i L_{pi}}{\sum_{i=1}^{i=4} A_i} = 75.08 \text{ dB} \quad (8)$$

Moreover, the Leq of the boiler room was calculated using logarithmic Equation 2, as follows:

$$L_{eq} = 10 \log \left[\frac{1}{64} \sum_{i=1}^{i=64} 10^{\frac{L_{pi}}{10}} \right] = 75.43 \text{ dB} \quad (9)$$

Table 2: Distribution of SPL intervals in the boiler hall

Noise ranges (dB)	72-74	75-76	76-78	78-92
Percentage of frequency (%)	23.3	40	36.6	0.1
Midpoint	73.5	75.5	77.5	78.5

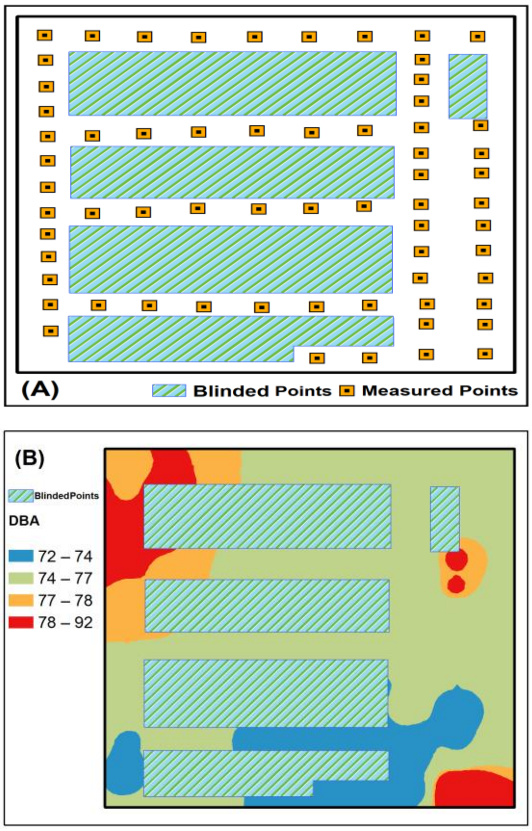

Figure 2: Arrangement of boilers and measurement stations in the boiler hall (A), noise map of the boiler hall (B)

3.3. Compressor Unit

Since the initial measurements in the present study indicated that the SPL of the compressors was almost constant and remained unchanged over time, the compressor unit in a gas station was selected as the third environment for noise sampling. Grid squares (1×1 m) were determined for SPL measurements; the size of the compressor unit was 9×6 meters. Noise measurements were carried out in 28 stations. Figure 3-A shows the measurement stations and arrangement of the machinery in the compressor unit. The noise map of this unit was plotted using the ArcGIS 10.2 software (Figure 3-B). A high SPL range could be observed in Figure 3-B, which may be attributed to the high noise level of the source, small size of the unit, reverberant nature of the building or a combination of these factors. Table 1 shows the distribution of the SPL intervals in the compressor unit. According to the information in Table 1, with the exception of the high-extreme interval of 96-97 dB_A, the other intervals covered a close proportion of this area.

The information in Table 3 was merged into Equation 5, and the noise map was employed to calculate the spatial L_{eq} of the compressor unit, as follows:

$$Leq = \frac{\sum_{i=1}^{i=4} A_i L_{pi}}{\sum_{i=1}^{i=4} A_i} = 92.87 \text{ dB} \qquad (10)$$

The following logarithmic Equation 2 was used again in order to calculate the L_{eq} of the compressor unit, which was estimated at 92.89 dB_A.

$$L_{eq} = 10 \log \left[\frac{1}{28} \sum_{i=1}^{i=28} 10^{\frac{L_{pi}}{10}} \right] = 92.89 \text{ dB} \qquad (11)$$

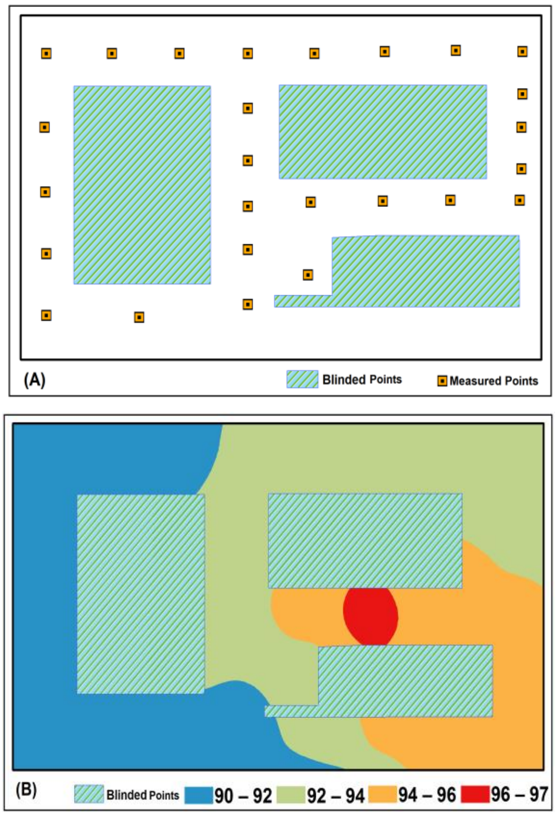

Figure 3: Measurement stations and the arrangement of machinery in the compressor unit (A), noise map of the compressor unit with different zones of SPL interval (B)

Table 3: Distribution of SPL intervals in the compressor room

Noise ranges (dB)	90-92	92-94	94-96	96-97
Percentage of frequency (%)	35.17	37.34	26.3	1.2
Midpoint	91	93	95	96.5

4. Conclusion

Undoubtedly, noise is a major threat to the health of employees in various industrial environments. To date, several studies have been focused on the monitoring and control of noise in various workplaces. The present study aimed to propose a novel technology-based method to simplify noise monitoring in working environments with continuous sound. Since no similar studies have been conducted in this regard, the results of the present study cannot be compared to the literature. Instead, the strengths and limitations of the current research will be discussed. As mentioned earlier, the proposed method has some advantages for noise monitoring. Firstly, instead of using advanced, costly ISLM devices, this novel method involves the use of a simple and inexpensive SLM, which is employed to determine the Leq in a given environment. Secondly, the noise map method could reduce the computations and save more time compared to conventional logarithmic equations. It is notable that the number of calculated sentences in conventional logarithmic equations is significantly higher compared to the noise mapping technique, while the accuracy remains unchanged. The percentage of the relative error is highly negligible (mostly less than 1%). These findings have been presented in Table 4.

Table 4: Comparison of Leq results obtained from the noise map and logarithmic equation

	The number of calculated sentences (logarithmic equation relative to the noise map method)	Percentage of relative error	L_{eq} (calculated using the noise map and eq. 5)	L_{eq} (calculated using logarithmic eq. 3)
Spinning hall	90.47	89.11	1.5	110.7
Boiler hall	75.43	75.08	0.46	64.4
Compressor room	92.89	92.87	0.02	28.4

Authors' Contributions

This article was carried out by all the authors. F.M., and Y.Kh., designed the manuscript and contributed to carry out data collection and data analysis and K.A., wrote the manuscript.

Conflict of Interest

The Authors declare that there is no conflict of interest.

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References

1. Amjad Sardrudi H, Dormohammadi A, Golmohammadi R, Poorolajal J. Effect of Noise Exposure on Occupational Injuries: a Cross-Sectional Study. *J Res Health Sci*. 2012; 12(2): 101-4.

2. Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. The Global Burden of Occupational Noise-Induced Hearing Loss. *Am J Ind Med.* 2005; 48(6): 446-58.

3. Saffarzadeh M. Noise Pollution in Transportation Systems. *Tehran: Iran Department Environ;* 2003.

4. Peterson AP, Gross EE. Handbook of Noise Measurement. *Massachusetts, USA: GenRad*; 1974.

5. Georgiadou E, Kourtidis K, Ziomas I. Exploratory Traffic Noise Measurements at Five Main Streets of Thessaloniki, Greece. *Glob NestI Int J.* 2004; 6(1): 53-61.

6. Khosravi Y, Lashkari H, Asakereh H. Water Vapor Pressure Trends in South and Southwest Iran. *MAUSAM.* 2017; 68(2): 335-48.

7. De Kluijver H, Stoter J, Utrecht RC. Noise Mapping and Gis: Optimising Quality, Accuracy and Efficiency of Noise Studies. *In The 29th Int Congress Exhib Noise Control Eng*. 2000; 27: 30.

8. Majidi F, Rezai N. Study of Noise Map and Its Features in an Indoor Work Environment through GIS-Based Software. *J Hum Environ Health Promot*. 2016; 1(3): 138-42.

9. Kanjo E. Noisespy: A Real-Time Mobile Phone Platform for Urban Noise Monitoring and Mapping. *Mob Netw Appl*. 2010; 15(4): 562-74.

10. Alam W. GIS Based Assessment of Noise Pollution in Guwahati City of Assam, India. *Int J Environ Sci.* 2011; 2(2): 731.

11. Kurakula V, Skidmore A, Kluijver H, Stoter J, Dabrowska Zielinska K, Kuffer M. A GIS Based Approach for 3D Noise Modelling Using 3D City Models. *Int Institute for Geo-Information Sci Earth Obs*, *Enschede, The Netherlands: ITC*. 2007.

12. Tsai KT, Lin MD, Chen YH. Noise Mapping in Urban Environments: A Taiwan Study. *Appl Acoust*. 2009; 70(7): 964-72.

13. Ko JH, Chang SI, Lee BC. Noise Impact Assessment by Utilizing Noise Map and GIS: A Case Study in the City of Chungju, Republic of Korea. *Appl Acoust.* 2011; 72(8): 544-50.

14. Cai M, Zou J, Xie J, Ma X. Road Traffic Noise Mapping in Guangzhou Using GIS and GPS. *Appl Acoust*. 2015; 87: 94-102.

15. Khanzadeh F QA. Survey and Control of Noice in Chitsazi Factory of Tehran. *Tehran: University of Tehran, Faculty of Health Pub.* 1974.

16. Taghizadeh R, Zare M, Zare S. Mapping of Noise Pollution by Different Interpolation Methods in Recovery Section of Ghandi Telecommunication Cables Company. *J Occup Health Epidemiol.* 2013; 2(1): 1-11.

17. Mohammadpour H, Najarkola SA, Jalali M, Asl AH, Rahmati A. GIS-Based Noise and Hearing Loss Screening in Publishing Factory. *Health Scope*. 2013;2(3):156-61.

18. Khosravi Y, Balyani S. Spatial Modeling of Mean Annual Temperature in Iran: Comparing Cokriging and Geographically Weighted Regression. *Environ Model Assess.* 2019; 24(3): 341-54.

19. Chappell A, Renzullo LJ, Raupach TH, Haylock M. Evaluating geostatistical Methods of Blending Satellite and Gauge data to Estimate Near Real-Time Daily Rainfall for Australia. *J Hydrol.* 2013; 493: 105-14.

20. Moteallemi A, Bina B, Minaei M, Mortezaie S. The Evaluation of Noise Pollution at Samen district in Mashhad by Means of Geographic Information System (GIS). *Int J Occup Hyg*. 2017; 9(4): 179-85.

21. TAHLYAN D, OHRI A. GIS Based Simplistic Noise Prediction Model for Urban areas. *Int J Civ, Struct, Environ Infrastruct Eng Rese Dev.* 2015; 1(5): 75-82.