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Occupational noise mapping and exposure assessment in a steel factory (Case study: Bandar-Anzali Steel Ingot Factory, Iran)

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Abstract

There are a wide range of equipments and machinery in the steel ingot industry, and most of them, are a source of noise pollution. The purpose of this study is to determine the main sources of noise, the daily exposure of labors and to investigate the noise-induced hearing loss (NIHL) prevalence in Anzali Steel Ingot factory. After a walk-through survey of existing units and the factory work schedule, 21 sampling points were selected in the process, office and service units of the factory. The field measurements were conducted at specific hours of two different work-shift days using a portable sound pressure level (SPL) meter. Noise map of the factory revealed that in almost 68% of job groups in the factory, daily-averaged noise level is greater than the occupational exposure limit (OEL). Also, the daily-averaged exposure of workers in all process units was more than the limits. Workers in furnace installation, electricity and facility units experienced the highest exposure with a daily exposure of more than 100 dB(A). A significant correlation was observed between the daily exposure level and NIHL (p-value=0.022) at $\alpha=0.05$ significance level. The NIHL in the process units increased between 1.25 and 7.5 dB(A), annually. The maximum increase was observed at units whose workers' noise exposure was within 5 dB(A) of the exposure limits, due to not using personal protective equipment (PPE). The daily exposure of the workers, who spend at least 25 % of daily working time in the furnace installation area, was above 100 dB(A), despite regular wearing of earplugs. Due to the ineffectiveness of the exposure time reduction, the best solution for these workers is to increase the noise reduction coefficient of the chamber's walls in the furnace installation unit, installing barriers in the furnace installation open area and increasing the number of chambers. In other process units, full inspection of the regular wearing of the PPE over a period of time is recommended. Thereafter the hearing loss of workers should be checked again and in case of inefficiency, changing the workplace of workers in different process units is recommended to reduce the exposure.

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Introduction

Noise pollution may generally be considered as unpleasant and disturbing sounds that physically and physiologically disrupt human life (Szalma & Hancock, 2011; Khan et al., 2018; Basu et al., 2021). Noise pollution is one of the negative impacts of sound that despite its short and long-term effects on the human auditory, cardiovascular and nervous systems plays a small role in the field of environmental pollution (Basner et al., 2014; Gourévitch et al., 2014). One of the reasons for neglecting this type of pollution is the existence of more important and fundamental unresolved environmental issues, especially in developing countries. In many of these countries, the air and land pollution are still very critical and there is no priority to address newborn issues such as noise, visual and light pollutions. However, to achieve sustainable development, various aspects of environmental pollution, including noise pollution, must be considered and addressed (Yuan et al., 2019; Bragdon, 2016). Another reason is the lack of awareness of people who do not accept the noise as pollution and make it seem natural.

To date, the impacts of noise pollution have been conducted in various fields including road traffic (Khan et al., 2018; Tezel et al., 2019; Sánchez et al., 2018) health centers (Yarar et al., 2019) construction (Choi et al., 2021) and educational environments (Hinojo et al., 2019). In addition to urban environments noise, the effect of noise produced in industrial areas on labors who are exposed to this noise throughout their work life is also considered in the field of occupational health from about 4 decades ago (Rongen et al., 2013). Large, medium and small producers in developing countries have not paid required attention to noise control programs (Ning et al., 2019; Orkomi et al., 2013; Pathak et al., 2008). Due to its nature, there are variety noise pollution sources in each industry (Rao, 2019). Since noise pollution is known for its adverse effects on hearing loss, the importance of noise sources in any industry depends directly on the number of workers (Orkomi et al., 2013). The steel industry is the second largest industry in the world after the oil employing about 50 million people. A vast number of studies have been conducted on the noise's negative effect on workers in steel factories (Zamanian et al., 2013; Pandya & Dharmadhikari, 2002; Shirali et al., 2019). Steel industry is one of the most important ones in any country due to its profit and it is considered as one of the industries with high level of noise pollution (Golmohammadi et al., 2014; Zhao et al., 2012). In the steel industry, equipments such as pumps, compressors, furnaces, motors, air blowing systems, cooling towers, gas and steam ducts, and rolling mills comprise the most important sources of noise (Pandya & Dharmadhikari, 2002; Madias, 2014) which causes various complications such as permanent hearing loss and neurological problems in workers (Golmohammadi et al., 2014; Forouharmajd and Shabab, 2015). Based on the literature, the noise caused by equipment in steel industry is higher than the 8 *hr* averaged OEL of 85 dB(A). A survey of noise pollution at four iron and steel plants in Tanzania revealed that the average occupational exposure level among the 253 workers who did not use PPE was 92 dB(A), and that almost 90% of the measurements were higher than OEL (Nyarubeli et al., 2018; Nyarubeli et al., 2019). Omer Ahmed (2012) investigated the occupational noise exposure and its annoyance in a steel plant. The results showed that about 89% of workers are exposed to the noise with equivalent A-weighted sound pressure level ($L_{A,eq}$) above the OEL. Forouharmajd and Shabab (2015) examined noise pollution in the metal smelting industry. They showed that the arc furnace unit is the noisiest part with the daily-averaged $L_{A,eq}$ of 109 dB(A). Also, except the control room, the noise level is higher than the OEL in other units. Miri et al. (2020) studied the NIHL of workers in a steel plant between 2012 and 2016. An increase in hearing loss has been observed at different frequencies in each ear, and the 8 hr averaged $L_{A,eq}$ was above the OEL in 64% of factory units. Hojati et al. (2016) showed that the daily-averaged $L_{A,eq}$ in about 56% of the total measuring stations in a steel ingot factory are greater than the allowable limits. They recorded the highest value of sound pressure level (SPL) in the electric arc furnace and ladle furnace with 112.2 and 97 dB(A), respectively.

Permanent NIHL has long been recognized as an occupational disease, with more than 12 percent of the world's population at risk for noise-induced hearing loss (Thai et al., 2021). About 25% of workers in the United States are generally exposed to occupational noise (Teixeira et al., 2021). About 30% of workers, who experience hearing loss, have a hearing loss caused by their workplaces (Hwang et al., 2009). NIHL in steel industry is recognized as the most crucial problem due to noise exposure, which varies according to the noise level in different units, exposure time, use of PPE and the personal characteristics (Jongkamonwiwat et al., 2020; Golmohammadi et al., 2021). Noise levels above 80 dB(A) is hazardous to health in the workplace (Vakili et al., 2020; Ismaila & Odusote, 2014). In a study conducted on steel workers in Isfahan, the average permanent hearing loss in both ears was estimated as 14 dB(A) and the onset of negative hearing damages in both ears was considered to be 4 years on average. It was also suggested that workplaces should be changed to a quieter unit after a maximum of 17 years of work experience, to reduce the hearing loss damages (Golmohammadi et al., 2001). Loud noise at work can also cause tensions and aggression in individuals and reduce the performance of workers. As a result, considering the importance of noise pollution in the steel plant and the large employment in this industry, the priority and necessity of this research becomes clear to assess the occupational noise exposure in different units of the steel ingot factory in Bandar-Anzali, Iran. The field measurement algorithm is described in section 2. Then the noise map of the factory along with the worker's daily exposure is reported and discussed in section 3. Eventually, section 4 concludes the article.

Materials and methods

Study area

Bandar-Anzali is a coastal city in Guilan Province with a temperate and humid climate, located at 37.46 northern latitude and 49.48 eastern longitude and 26 meters below sea level. The distance of the city from the center of the province (Rasht) is 40 km. The steel ingot factory (Figure 1) is located 35 km from Rasht-Anzali road and is found in the town No.1 of Anzali free zone. The factory has been operating since 2007. The feed of the factory is the scrap and sponge iron and the product is a six-meter steel ingot with a cross-sectional area of 150 by 150 mm^2 and its monthly production capacity is about 4000 tons and operates in two 12-hour shifts, with an average of 90 workers per shift.

This factory is located in Bandar-Anzali industrial town, where various factories are facing the problem of noise pollution and have not adopted a proper control strategy to deal with this problem. Nevertheless, no comprehensive study has been conducted on noise pollution in Anzali Steel Ingot factory. This study can be a kind of leading survey dealing with noise pollution exposure in different types of factories in this industrial town.

Data gathering and procedure

To determine the workers' exposure to the occupational noise and identify noise pollution sources in the study area, field measurements have been conducted on two different shift-days and specified hours (8.00 am, 10.00 am, 12.00 noon, 1.00 pm and 3.00 pm). A digital mini SPL meter TES 1353H with a measuring range of 30-130 dB and the accuracy of 0.1 dB in A/C classes was used. The device was placed approximately 1.5 m from the ground and at a distance of at least 1 m from obstacles and walls (ISO 3746, 1995). The sampling duration was 4 minutes per measurement. Due to the hourly or daily schedules of machineries in each unit, the measurements were repeated in two days and the above mentioned hours at each sampling point. Using data recorded at each sampling point during working hours, the daily-averaged noise was calculated using Equation (1) (Barron, 2002).

$$L_{A,eq,T} = 10 \log \frac{\left(\sum_{i=1}^{n} t_i \times 10^{L_{A,eq,i}}\right)}{T} \quad (1)$$

in which $L_{A,eq,T}$, n , t_i, $L_{A,eq,i}$ and T are daily-averaged A-weighted SPL, number of measured SPLs at each point, time interval i (*hr*), SPL value in the time interval t_i and work-shift time which is equal to 12 *hr*. The noise map in different units of the factory was produced in ArcGIS 10.7 software. Then, the daily-averaged occupational exposure of workers was determined. Furthermore, the workers' NIHL trend was assessed by collecting a ten-year archive of audiometry results and medical records.

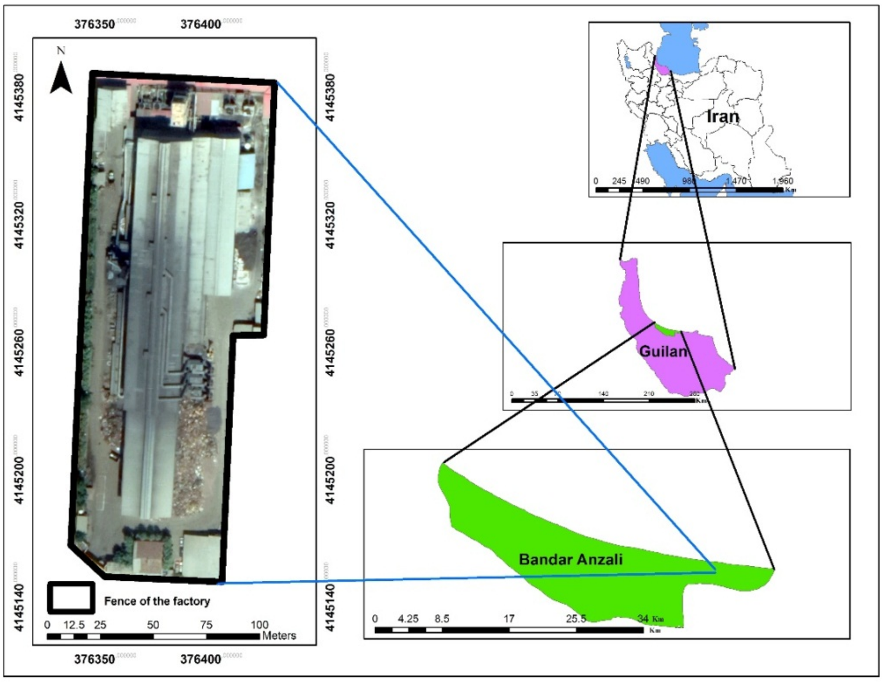

Figure 1. The location of the steel ingot factory in Bandar Anzali.

Results and Discussion

Noise levels were measured at different hours of two working days in all units of the factory. The location of the process, office and service units is depicted in Figure 2. Also 21 sampling points are selected throughout the factory (Figure 2). As shown in Figure 2, the factory consists of *16* units. In each unit, considering the space size and the spatial variations of noise, at least one sampling point was selected. The daily-averaged SPL at these points were calculated, and the daily-averaged noise map (12-hour work shift) was produced (Figure 3).

The daily-averaged $L_{A,eq}$ varied from 60 dB(A) (in the medical services) to a maximum of 107 dB(A) in the furnace installation unit. This range of noise changes has been reported in almost all other studies conducted in this industry (Forouharmajd & Shabab, 2015; Hojati et al., 2016; Golmohammadi et al., 2001; Singh et al., 2013). The 12 *hr* averaged SPL is depicted in Figure 3. Hence, to compare the noise pollution contour with the standard limits, which is 85 dB(A) for an 8 *hr* of exposure, the effect of exposure time should be included via the correlation: $L_{A,eq,12} = 85 + \frac{3}{0.69} \times \ln(\frac{8}{12})$. Therefore, the 12 hr averaged OEL is 83.2 dB(A). As shown in Figure 3, the daily-averaged SPL is more than the OEL in almost all process units of the factory except the electricity unit.

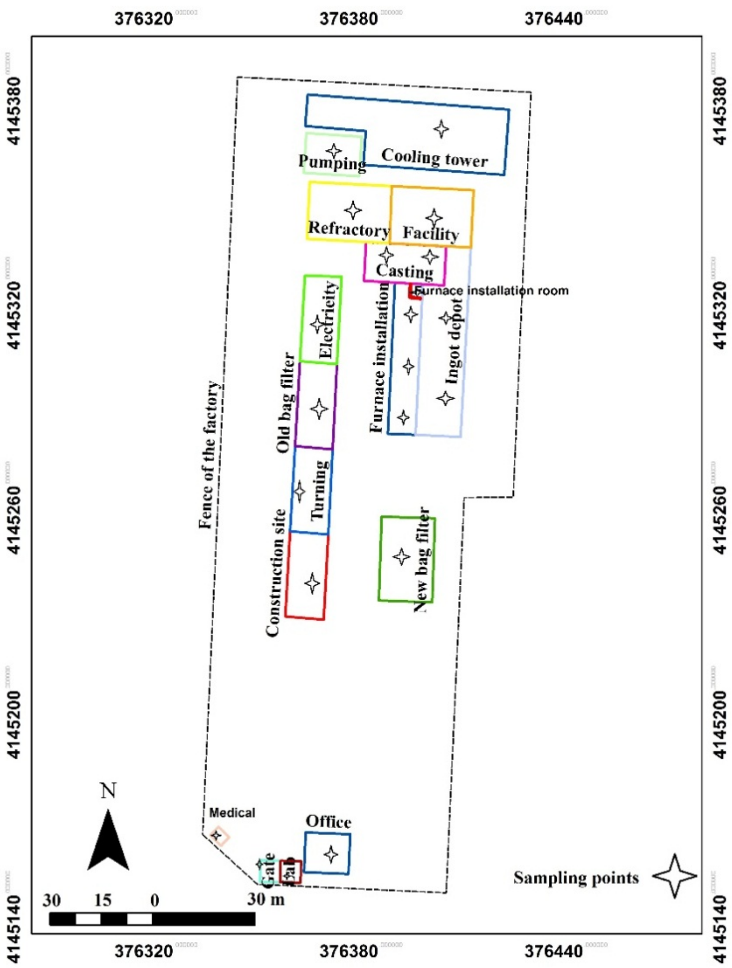

Figure 2. Schematic location map of existing units of the steel ingot factory.

According to Figure 3, the maximum $L_{A,eq}$ is observed at furnace installation area and only in the room (chamber) that is located at the corner of this unit, the noise pollution situation is somewhat better and the daily-averaged $L_{A,eq}$ in the chamber is about 86 dB(A). Whereas, the daily-averaged noise in the office, medical, laboratory and the gate units was in healthy condition. In general, it can be said that 11 out of 16 units (68%) are polluted noise-wise. However, in most of the literature surveyed in this field, such unhealthy conditions have been reported in steel factories (Nyarubeli et al., 2019; Miri et al., 2020; Hojati et al., 2016). To determine the exposure level of workers, the hourly schedule of their activities in different units during a shift should be considered along with the noise map. This can be implemented either by installing a dosimeter on workers or by using a questionnaire for all labors in a work shift. In this study, the hourly schedule of workers' activities was determined by a questionnaire. Although the horizontal division of labor approach is organized in the factory, the labor does not spend the whole day in one unit due to the tasks assigned to them in other sections. Hence, their daily exposure is different from the averaged SPL (Figure 3). The daily exposure (12 *hr*) level of workers is calculated according to their daily activity and the daily-averaged SPL and the results are given in Table 1. According to Table 1, the exposure level in the furnace installation section is lower than the $L_{A,eq}$ of this section. That is because the workers in this section spend about 40% of their working time in the chamber in the corner of this unit. Also, since the workers of the electricity and facility units work approximately 25% of their working time in the furnace installation unit, the daily exposure of the workers of these units is much greater than the daily-averaged SPL in the facility and electricity units. Overall, the workers' exposure level in 75% of the units of this factory, or all workers of the process units, is higher than the allowable OEL.

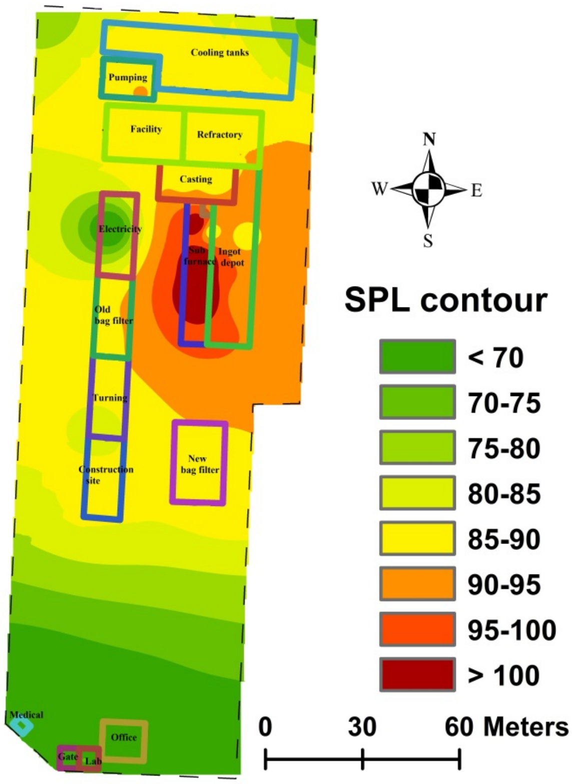

Figure 3. Daily-averaged $L_{A,eq}$ in Anzali Steel Ingot factory.

Table 1. Daily-averaged exposure level of workers in each unit

Unit	exposure level (dB(A))
Furnace installation	104.2
Facility	100.4
Electricity	100.2
Pumping	90.3
Old bag filter	88.7
New bag filter	88.7
Ingot depot	88.5
Casting	87.8
Refractory	87.7
Construction site	87.2
Cooling	85.6
Turning	84.4
Lab	70.1
Office	66.8
Gate	65.0
Medical service	60.5

The exposure of workers in process units has been reported to be more than the allowable limits in the similar literature (Nyarubeli et al., 2018; Nyarubeli et al., 2019; Ghavam Abadi et al., 2017). In addition to the occupational exposure analysis of individuals, the temporal trend of workers' NIHL was analysed by reviewing their recent 10-year medical records archives to examine the effects of noise exposure on workers' hearing in practice. It is noteworthy that the studied labors had 8 to 15 years of professional experience. Considering the left and right ear audiograms and using the classification provided by the American Speech-Language-Hearing association (ASHA) (1991), the average range of hearing loss of workers in different sectors is reported in Table 2.

Table 2. Workers NIHL in Bandar-Anzali Steel Ingot factory during the last decade

Unit	12 hr averaged exposure (dB(A))	Hearing loss			
		Normal	Mild HL	Moderate HL	Severe HL
Furnace installation	104.2				
Facility	100.4				
Electricity	100.2				
Bag filters	88.7				
Ingot depot	88.5				
Casting	87.8				
Refractory	87.7				
Construction site	87.2				
Lab	70.1				
Medical service	60.5				

According to Table 2, the range of average hearing loss in the last decade varies among individuals in each unit. For instance, in the furnace installation unit, some have more severe hearing loss and some have less, which may be related to differences in individual characteristics, exposure duration, and the use of PPE (Jongkamonwiwat et al., 2020; Golmohammadi et al., 2021). As shown in Table 2, workers experienced hearing loss in units where the daily exposure level exceeded the OEL. In this regard, a significant correlation (P-value=0.022) has been observed between the noise exposure level and the hearing loss statistically by applying the Pearson statistical test with a significance level of α=0.05. However, in units where the exposure level is above 100 dB(A) (occupational exposure time is more than 20 times the allowable exposure time), wearing PPE prevents severe hearing loss. While, in units such as bag filters where the exposure level is in the range of 5 dB(A) more than the allowable limit for 12 *hr* exposure, the lack of attention to PPE has caused severe hearing loss in some labors. A more detailed investigation of labors' hearing loss in process units during the last three years revealed that the average annual workers' hearing loss at 4 kHz increases between 1.25 and 7.5 dB(A). The maximum changes were observed in the electricity unit and the minimum one was related to the facility section. In a similar study conducted by Aliabadi et al. (2015) in a steel plant, the average annual hearing loss of workers in furnace, energy and cast iron units was reported 1.5 dB(A). It should be mentioned that the present study has some limitations. The most important limitation is the occupational or community noise exposure of the workers after the work hours is not considered in the NIHL assessment.

Conclusion

In the present study, noise pollution in Bandar-Anzali Steel Ingot factory, which is one of the noisiest factories in Anzali industrial town No.1, was investigated. Due to the lack of workers' awareness about noise pollution and the control methods, the importance of its negative effects has been neglected by workers despite annual audiometry. Therefore, in this research, in addition to field investigation of noise pollution and identification of the most polluted units of the factory, the exposure levels were determined and some practical solutions were advised to the workers in polluted areas. The results showed that in the polluted units, the workers' exposure level (although for a shorter time period), exceeds the allowable OEL, and the exposure is directly related to the workers' hearing loss. As such, most of the workers in the process units have experienced noticeable hearing loss and unfortunately this trend is on the increase annually. The hearing loss in the process units has been increased between 1.25 and 7.5 dB(A), annually. The highest changes in hearing loss were seen in units where the daily exposure of workers was approximately in the range of 5 dB(A) above the allowable OEL. This issue may be related to the lack of PPE wearing by the workers at these units. The most daily exposure has been observed in the furnace installation, facility and electricity units, whose workers spend part of their working time in the furnace installation area. Since their daily exposure is more than 100 dB(A), strategies such as exposure time reduction are practically ineffective. Hence, it can be concluded that, with the exception of the above mentioned three units, workers must use PPE on a regular basis in all process units with an exposure level of less than 90 dB(A). If, as a result, workers' hearing loss does not improve, their permanent hearing loss changes should be attenuated by moving the workers of these units to less exposed units and by simultaneously wearing PPE. This strategy requires increasing the skills of workers to work in other units as well. But for units with an exposure level above 100 dB(A), the only possible solutions are increasing the noise reduction coefficient of the chamber's walls in the furnace installation unit, installing barriers in the furnace installation open area and increasing the number of chambers. However, increasing workers' awareness about the importance of noise pollution and exposure to less polluted sections is prior to all the proposed solutions.

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