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*Professional paper*

# ANALYSIS OF MEASURED ROAD AND RAILWAY TRAFFIC NOISE LEVELS WITH NOISE MAPPING AND PROPOSED ACTIVITIES

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## ABSTRACT

Due to the fast process of urbanization and the increase in the development of transport infrastructure, there is an increase in noise levels caused by road and railway traffic in urban areas, which represents one of the most important today's problems. The goal of this paper is to find out the current noise levels of road and railway traffic. Measuring road traffic noise levels in the area of the city of Zenica and the railway traffic noise in the vicinity of the Railway Station in Kakanj has been done. In the end, the analysis of the obtained results and comparisons with the values regulated by the law as allowed values were performed. Noise level maps were also plotted as one of the contributions to solving the problem of environmental noise.

Keywords: noise; road traffic noise; noise measuring devices; noise map

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## 1. INTRODUCTION

When the term "the noise" is used, in most cases there was a reaction from people as if it was some normal phenomenon, but in essence, it is an important environmental problem [1].

The term noise refers to urban environments where people are exposed to various noises every day. In today's urban environment, the worst noise pollution comes from external sources such as road and rail traffic noise. Knowledge of the noise levels' peak values in a particular area is very important for taking some actions for preventing or reducing harmful effects on human health. In addition to air, water, and soil pollutants, noise is also a great enemy of man. If a person was exposed for a longer time to noise levels higher than 90 dB it may cause serious health problems [1].

Road traffic noise is the largest source of environmental noise (about 90% of the population is affected by noise levels greater than 65 dB(A)). The impact of rail traffic noise is also not negligible (about 1.7% of the population is affected by noise levels greater than 65 dB(A)) [2], especially in densely populated areas through which railways pass. Noise from railway traffic bothers people less than road noise, because although it is stronger, it lasts for a short time, during the passage of trains in the timetable. That's about 20% of the total time.

The first part of this paper contains information about road and rail traffic noise as one of the most common noise sources in the environment. The basic concepts are explained and an overview of how the participation of different types of vehicles in traffic contributes to different noise levels is given. The second part consists of legislation that prescribes how noise measurement must be performed. The devices used in this experiment for the noise measurement are calibrated sound level meter Brüel&Kjaer Type 2250 with installed software BZ 5504 and one mobile device with installed free and open-source mobile application NoiseCapture. Devices used for this purpose primarily use system software that allows the device to manage its resources. Application software that deals with the implementation of specific tasks will also be considered. In the last part, selected points for the road and rail traffic noise measuring were described.

The third part contains a detailed presentation of performed measurements and an analysis of the obtained results. Besides the measurement results, a display of a noise map for both road and rail traffic was presented, leading to a good insight into the current noise levels. The chapter is closed by conclusions for answering the questions such as: whether the measured noise levels are within the allowable limits, whether the hardware, as well as the software of the expensive sound level meter, is better and more reliable than the mobile device hardware and software. In the end, some ideas to eliminate this very important problem were proposed.

## 2. THE NOISE OF ROAD AND RAIL TRAFFIC

Noise defines as any undesirable and unpleasant sound that endangers human health and hearing in many ways [3]. Although not always the only cause of citizens' complaints, road traffic is the dominant noise source in the urban environment. The general rule that applies to all types of traffic is: heavier vehicles are noisier than smaller and lighter ones. It is known that the greater the traffic frequency of cars or trucks on the road, the greater the noise level will be, as shown in Figure 1.

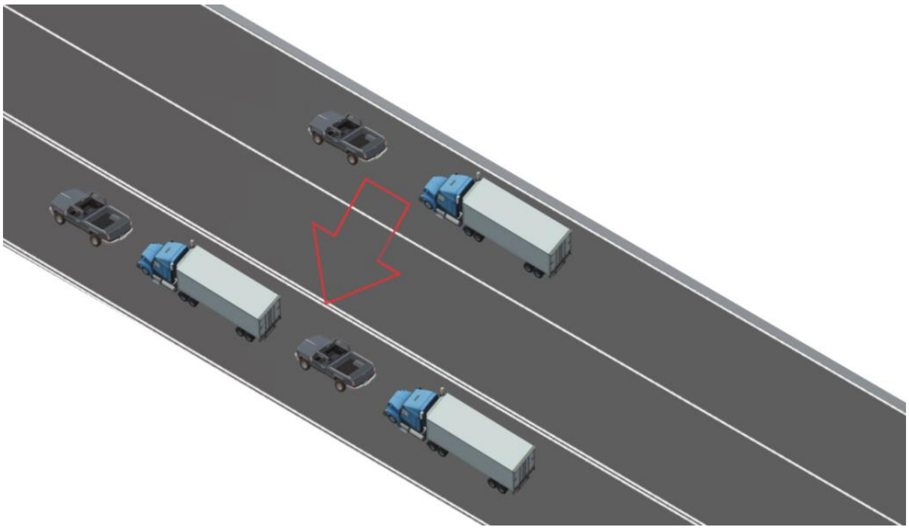

Figure 1. Noise increases by 3dB for each doubling of traffic

The automobile moving at an average speed of 105 km/h produces twice the noise level of one moving at 50 km/h [3]. One heavy truck moving at 70 km/h produces a noise level like 28 individual vehicles [3]. Also, the noise depends on the topography of the terrain, meteorological conditions, and, background noise. Among the most significant noise sources of rail traffic are [4]:

1. The locomotive and rail vehicles propulsion system;
2. The interaction of wagon wheels, locomotives, and rail vehicles with rails;
3. The braking process;
4. The additional equipment such as the ventilation, sirens, air conditioning, and heating;
5. Aerodynamic noise, especially in trains moving at high speeds.

Rail traffic requires three times less land area with the approximately same load (cargo). Road traffic has the greatest need for land area per person transported. Road traffic requires an average of 84.5 m² of land area per person, while rail traffic only requires 8.9 m². The high-speed city railway occupying 5.0 m² can replace a sixteen-lane road with a width of 55 m which speaks in favor of significantly rational savings in railway space [5].

It should be also noted the significant savings brought by rail traffic, both from the economic and environmental protection aspect compared to road traffic.

## 3. REGULATIONS AND LEGISLATION FOR NOISE

In the territory of the Federation of Bosnia and Herzegovina, there is a law regulating the noise, and that is the Law on Noise Protection ("Službene novine FBIH", No. 110/12) and the Law on Noise Protection ("Službene novine ZDK", No. 1/14). The Law consists of general provisions, the highest allowed noise level in dBA (decibel A-scale), protection measures, including chapters on measurement, monitoring, supervision, and penal provisions [6]. The Law does not follow the structure of the Environmental Noise Assessment and Management Directive (Directive 2002/49/EC) and, does not provide an adequate legal framework for its transposition into the legal system of the Federation of Bosnia and Herzegovina.

Noise protection should be day and night. In terms of this Law, the day lasts from 06 to 22 hours and the night from 22 to 06 hours [6].

The following tables (Table 1 and Table 2) show the permitted noise levels depending on the purpose of the area where the measurement is performed and the correction of the measured noise level before comparison with the permitted values.

Table 1. Permitted external noise level for planning new facilities or noise sources [7]

| Area (zone) | Purpose of the area | The greatest permitted level (dBA) | | |
|---|---|---|---|---|
| | | Equivalent $L_{eq}$ [1] | | Peak level |
| | | day | night | $L_1$ [2] |
| I | Hospital-spa | 45 | 40 | 60 |
| II | Tourist, recreational, recovery | 50 | 40 | 65 |
| III | Pure residential, educational and health institutions, public green and recreational areas | 55 | 45 | 70 |
| IV | Commercial, business, residential, and residential along traffic corridors, warehouses without heavy transport | 60 | 50 | 75 |
| V | Business, administrative, trade-craft, service (communal service) | 65 | 60 | 80 |
| VI | Combined - industrial, storage, service, and traffic area in a residential area | 65 | 55 | 80 |
| VII | Industrial, storage, service, and traffic area without housing | 70 | 70 | 85 |

[1] $L_{eq}$ is the mean energy value of noise of variable level equivalent to continuous level noise measured for at least 15 minutes in the periods from 06 to 22 hours (day) or from 22 to 06 hours (at night) [6]

[2] $L_1$ indicates the noise level that is exceeded 1% of the time and the shortest period measurement is 15 minutes [6]

Table 2. Correction of the measured noise levels before comparison with the permitted levels from table 1 [7]

| Influencing factors | Correction for $L_{eq}$ (dBA) | Correction for $L_1$ (dBA) |
|---|---|---|
| Aircraft noise | -5 | -10 |
| Railway noise | -5 | Impulse |
| Impulse noise | +5 | +10 |
| Prominent tones | +5 | +5 |

## 4. RESEARCH METHODS

### 4.1. Noise measurement devices

One of the goals of this paper is to analyze and compare the obtained results of measured noise using a sound level meter and application for noise measurement on a smartphone. For the experiments, Brüel&Kjaer Type 2250 sound level meter is used, shown in Figure 2, with its integrated software and software BZ-5503 that comes with the device and is used to facilitate data processing. For comparison of the obtained results, a free mobile application (NoiseCapture) available on the Google Play platform is used.

A sound level meter is designed to measure sound levels in a standardized manner [8]. It consists of a microphone, preamplifier, processor, and, a reading unit. The microphone converts the sound signal into an equivalent electrical signal. The electrical signal generated by the microphone is low, so it must be amplified before processing by the processor [8]. NoiseCapture is a free application for android which allows users to measure and share data (Google Play on the mobile phone Samsung A21s). This application currently has more than one hundred thousand downloads. The logo of the application is shown in Figure 3.

Figure 2. H and-held Analyzer Type 2250 [8]

Figure 3. Logo of NoiseCapture application [9]

4.2. Measurement of road and rail traffic noise

One of the first steps in measuring road and rail noise is to select measurement locations. For measuring road traffic noise, the measurement was performed at six measuring points in the area of the city of Zenica (Table 3 and Figure 4). Measurement of rail traffic noise was performed at thirteen locations near the Railway Station in Kakanj (Table 4 and Figure 5). Nine measurements refer to the noise level during the arrival of the freight or passenger train at the station. Measuring points for road traffic has been chosen in such a way as to encompass one closed circle showing locations with higher and low traffic frequency.

The passengers and cargo vehicles frequency was monitored at the measuring points of road traffic. Measurements at the locations Travnička Street, and Fakultetska Street, Zenica was performed using a sound level meter Brüel&Kjaer Type 2250 and a mobile phone Samsung Galaxy A21S.

Table 3. Locations of measuring points of road traffic in the area of the City of Zenica

| Measuring point | Label | Name of the location |
|---|---|---|
| 1 | MM1 | Travnička Street |
| 2 | MM2 | Fakultetska Street |
| 3 | MM3 | Fakultetska Street |
| 4 | MM4 | Sarajevska Street |
| 5 | MM5 | Zacarina Street |
| 6 | MM6 | ZAVNOBiH Street |

Based on the values obtained from the measurements at these locations, the final value of the deviation from the mobile noise meter and Brüel&Kjaer can be taken, and based on that, the possibility of measuring at several locations using a mobile phone was created.

Figure 4. Display of measuring points in the area of the City of Zenica

Table 4. Locations of measuring points of road traffic in the area of the Railway Station in Kakanj

| Measuring point | Label | Noise map | Measurement location description |
|---|---|---|---|
| 1 | MM1 | Map No.1 | Measuring 3 m from the railway while the freight train is stopping at the station |
| 2 | MM2 | Map No.1 | Measuring approx. 200 m outside the station, 3 m along the railway when the train reaches a certain speed. |
| 3 | MM3 | Map No.1 | Measuring in front of a residential building (40 m from the railway) while freight train is stopping. |
| 4 | MM4 | Map No.2 | Measuring 3 m from the railway at the station when the train is not passing |
| 5 | MM5 | Map No.2 | Measuring in front of a residential building (40 m from the railway) when the train is not passing |
| 6 | MM6 | Map No.2 | Measuring approx. 200m outside the station, 3 m along the railway when the train is not passing |
| 7 | MM7 | Map No.1 | Measuring in front of a residential building (40 m from the railway) when a freight train is passing. |
| 8 | MM8 | Map No.1 | Measuring approx. 150m outside the station, 3 m along the railway when the train reaches a certain speed |
| 9 | MM9 | Map No.1 | Measuring approx. 70m outside the station, 3 m along the railway when the train reaches a certain speed |
| 10 | MM10 | Map No.2 | Measuring in front of a residential building (40 m from the railway) when the train is not passing |
| 11 | MM11 | Map No.1 | Measuring approx. 80 m outside the station, 3 m along the railway when the train reaches a certain speed |
| 12 | MM12 | Map No.1 | Measuring approx. 150 m outside the station, 3 m along the railway when the train reaches a certain speed |
| 13 | MM13 | Map No.1 | Measuring in front of a residential building (40 m from the railway) when a freight train is passing |

*Map No.1 reffers to the Figure 9
*Map No.2 reffers to the Figure 10

The remaining measuring points were measured just using the mobile phone application NoiseCapture.
The mobile phone model was used for the described conditions, which means that every other model of the mobile phone will show different results. It depends on the quality and sensibility of the microphone contained inside the mobile phone. The first measurement refers to the railway during the train stop when there is a large creak of wheels in contact with the railway.

Figure 5. Me assuring points display in the area of the Railway Station in Kakanj

The second measurements group is from the locations at a certain distance from the station when the train reaches a certain speed which eliminates the creak of the wheels and the siren sound that is characteristic of the train arrival. The third measurements group is performed in a populated area 40 m from the station (train stopping or passing through the station). One measurement was performed during the night when allowed noise levels were slightly less than during the day.
The remaining four measurements refer to the noise levels when there is no train traffic (approximately 80% of the total time). Two of them along the railway during the day, and the remaining two in front of the residential building 40 m from the station (one in the day and the other at the night).

## 5. RESULTS AND ANALYSIS OF RESULTS

### 5.1. Results of traffic noise measurements

The results for the first two measuring points were measured using a sound level meter Brüel&Kjaer Type 2250 and marked as MM1* and MM2*, while the other measurements were performed using the NoiseCapture mobile application, as shown in Table 5. It is important to note that all measurements were performed in 15 minutes.

Table 5. Road traffic measurements result using Brüel&Kjaer Type 2250 and NoiseCapture (Zenica)

| MM | Measuring time interval | Traffic frequency | | Measured values | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Passenger vehicles | Cargo vehicles | $L_{Aeq}$[1] [dB] | $L_{Cpeak}$[2] [dB] | $L_{AFmax}$[3] [dB] | $L_{AFmin}$[4] [dB] | $L_{AF90}$[5] [dB] |
| MM1* | 10:17 - 10:32 | 210 | 2 | 64.5 | 96.3 | 82.2 | 47.0 | 54.2 |
| MM2* | 10:38 - 10:53 | 95 | 3 | 61.0 | 97.5 | 79.4 | 46.3 | 52.6 |
| MM1 | 10:17 - 10:32 | 210 | 2 | 63.0 | / | 75.2 | 44.3 | 50.5 |
| MM2 | 10:38 - 10:53 | 95 | 3 | 58.2 | / | 72.6 | 43.8 | 49.3 |
| MM3 | 11:06 - 11:21 | 295 | 7 | 65.1 | / | 79.8 | 52.8 | 57.5 |
| MM4 | 14:55 - 15:10 | 475 | 1 | 71.0 | / | 83.8 | 57.7 | 62.8 |
| MM5 | 15:15 - 15:30 | 6 | 0 | 55.8 | / | 72.9 | 45.9 | 47.9 |
| MM6 | 15:43 - 15:58 | 192 | 3 | 64.9 | / | 86.7 | 46.8 | 52.6 |

[1]$L_{Aeq}$ is the 'A-weighted Leq sound level [10]
[2]$L_{CPeak}$ is the peak sound pressure level with 'C' frequency weighting [10].
[3]$L_{AFmax}$ is the maximum sound level with 'A' frequency weighting and fast Time weighting during the measurement period [10].
[4]$L_{AFmin}$ is the minimum sound level measured with 'A' frequency weighting and fast time weighting during the measurement period [10].
[5]$L_{AF90}$ is the noise level exceeded for 90% of the measurement period with 'A' frequency weighting calculated by statistical analysis from samples of the fast time-weighted sound level [10].

After analyzing the measurement results from two locations Travnička Street (MM1) and Fakultetska Street, Zenica (MM2), measured by the sound level meter and mobile application, the results are surprisingly similar. The light wind was present during the measurement which may affect the quality of the measured values. Other meteorological conditions were consistent that making the measured values credible [11]. However, even under these conditions, the mobile phone with the free NoiseCapture application performed well. The results were lower only 1.5 dB at the MM1, and 2.8 dB at the MM2, with a value of a mean difference of 2.2 dB.

Based on the parameter LAeq (road traffic noise levels) in the daytime at six locations in the City of Zenica, as shown in Table 5, and according to the Law on Noise Protection of Zenica-Doboj Canton, a comparison between permitted and measured values of LAeq, was performed. In Figure 6 the measuring points MM1, MM2, MM3, and MM5 are the areas that belong to the zone with limit values of 55 dB, while the measuring points MM4 and MM6 are the areas with limit values of 65 dB. Based on a comparison between the sound level meter and application, in Figure 6 are displayed values as measured by Bruel&Kjaer, i.e., obtained measured values using application NoiseCaptured for measuring points MM3, MM4, MM5, and MM6 increased by 2.2 dB.

The results of measurements for railway traffic noise were obtained by using the mobile application NoiseCapture (Table 6).

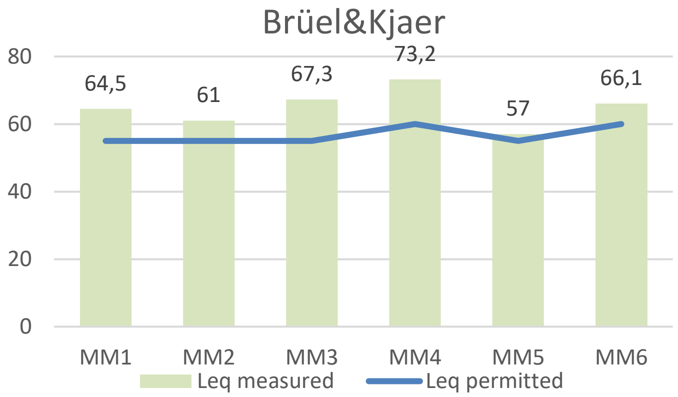


Figure 6. Deviations graph of measured and permitted values of Leq [dB] using Brüel&Kjaer for road traffic

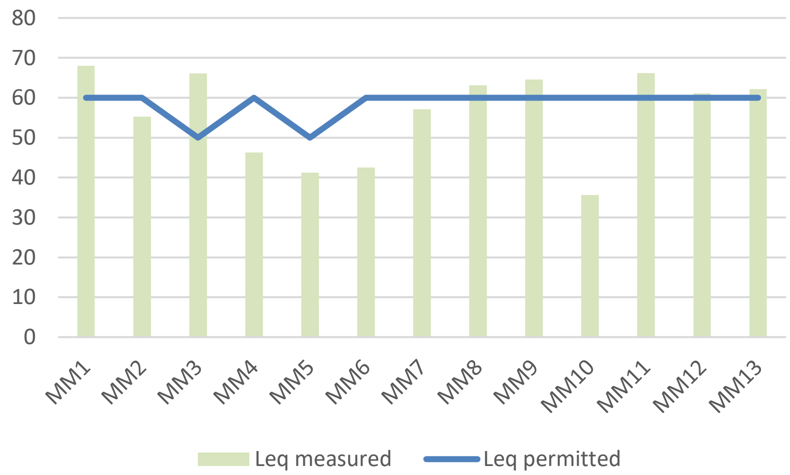


Figure 7. Deviations graph of measured and permitted values $L_{eq}$ [dB] using NoiseCapture for railway traffic

Table 6. Results of railway traffic measurements using the NoiseCapture mobile application (Kakanj)

| Measuring point | Time of measuring | Measured values | | | | | |
|---|---|---|---|---|---|---|---|
| | | $L_{Aeq}$ [dB] | $L_{AFmax}$ [dB] | $L_{AFmin}$ [dB] | $L_{AF90}$ [dB] | $L_{AF50}$[1] [dB] | $L_{AF10}$[2] [dB] |
| MM1 | 10:13 - 10:28 | 73.0 | 91.9 | 41.3 | 43.8 | 46.2 | 55.1 |
| MM2 | 13:45 - 14:00 | 60.3 | 77.5 | 40.6 | 46.2 | 51.3 | 61.0 |
| MM3* | 22:30 - 22:45 | 71.1 | 88.1 | 35.7 | 40.4 | 46.4 | 58.4 |
| MM4 | 15:24 - 15:39 | 51.3 | 66.5 | 38.0 | 42.8 | 48.3 | 52.3 |
| MM5* | 22:52 - 23:07 | 46.2 | 63.7 | 33.2 | 36.3 | 40.9 | 48.2 |
| MM6 | 16:04 – 16:19 | 47.5 | 57.5 | 24.7 | 31.2 | 40.3 | 51.1 |
| MM7 | 16:45 – 17:00 | 62.1 | 86.2 | 23.6 | 40.8 | 46.9 | 57.2 |
| MM8 | 17:02 – 17:17 | 68.1 | 85.0 | 32.6 | 45.9 | 55.7 | 69.8 |
| MM9 | 15:41 – 15:56 | 69.6 | 84.9 | 25.5 | 45.4 | 52.4 | 74.5 |
| MM10 | 16:17 – 16:32 | 40.6 | 62.9 | 22.4 | 27.1 | 37.8 | 41.9 |
| MM11 | 13:51 – 14:06 | 71.2 | 87.5 | 37.9 | 43.8 | 55.1 | 74.7 |
| MM12 | 15:34 – 15:49 | 66.1 | 83.3 | 22.0 | 44.2 | 55.1 | 66.6 |
| MM13 | 16:53 - 17:08 | 67.2 | 82.2 | 25.3 | 43.5 | 52.9 | 72.2 |

*-measurement obtained during the night period¸
[1]$L_{AF50}$ is the noise level exceeded for 50% of the measurement period with 'A' frequency weighting calculated by statistical analysis from samples of the fast time-weighted sound level [10].
[2]$L_{AF10}$ is the noise level exceeded for 10% of the measurement period with 'A' frequency weighting calculated by statistical analysis from samples of the fast time-weighted sound level [10].

The measurement results at MM3 (night-time measurement, 40 m from the station) are similar to the results at MM1 (day-time measurement, next to the station). The reason for greater values for MM3 is the human factor. Namely, the measuring was performed at night, when a group of people was trying to steal some coal from the train wagon that had previously arrived. The driver gave siren warnings which influenced the noise measuring.
Before comparing the obtained values with permitted values from Table 1 for Zone IV, correction of the obtained results was applied. According to Table 2, the correction value for railway traffic is -5dB. The comparison of obtained corrected values and permitted values depending on the time of day or night was shown in Figure 7.

5.2. Noise maps
The noise map is the representation of the existing or projected state of the noise level in the observed area and is an integral part of spatial planning.
Based on the six measured locations other possible noises are predicted (Figure 8). The noise level measured in Travnička Street is around 64.5 dB, and Fakultetska Street is from 58 to 65 dB. Sarajevska Street, which is the street with the heaviest traffic frequency, is expected to have the highest noise level of 71 dB, Zacarina Street the least busy street has a noise level of 55.8 dB. ZAVNOBIH Street has a measured noise level of 64.9 dB.

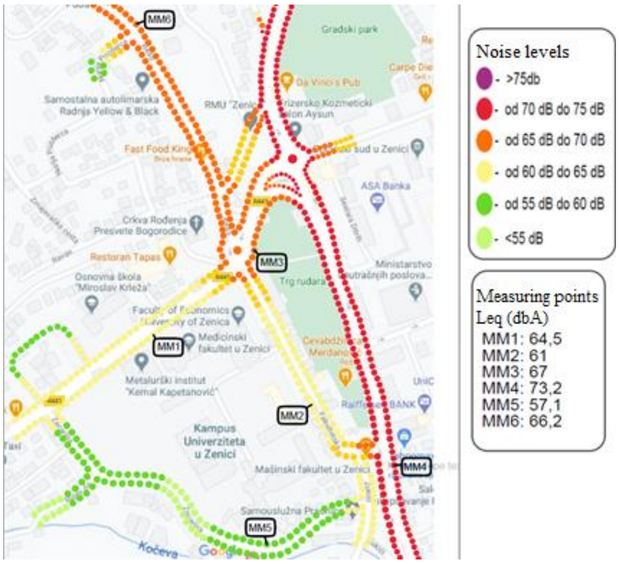


Figure 8. Road traffic noise map of the City of Zenica

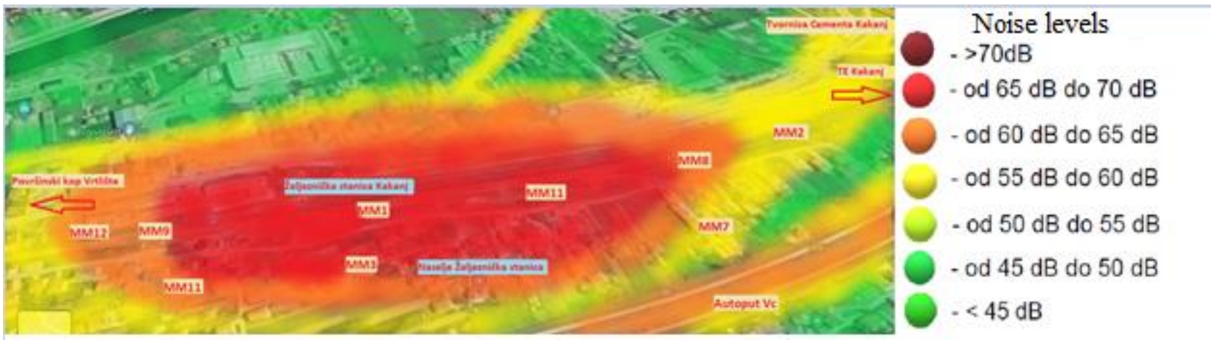


Figure 9. Rail traffic noise map in the area of Kakanj Railway Station during train arrival

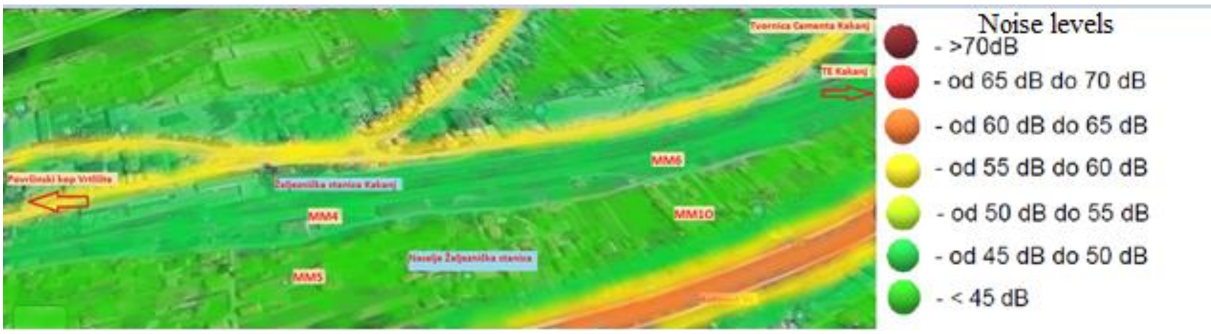


Figure 10. Rail traffic noise map in the area of Kakanj Railway Station (no train traffic)

For measurement points, MM1, MM2, MM8, MM9, MM11, and MM12 along the railway at different distances, and points MM3, MM7, and MM13 measured in a residential area are referred to as the noise levels when the railway traffic operates. For these measurements, the noise map is presented in Figure 9. The second noise map (Figure 10) refers to when there is no railway traffic, and four measurements were performed for the drawing of this map. Measurements at the point MM4 and MM5 were performed at locations along the railway, and measurements at the point MM5 and MM10 were measured in the residential area. All results from the second map are within the permitted limits, so green is the dominant color on the map.

Noise levels are divided so that burgundy and red colors refer to higher noise levels, i.e., higher than permitted limits while the green color symbolizes the noise levels within the permitted limits. On the noise map, noise levels for other locations outside these thirteen measuring points were constructed with the assumption that the noise spreads evenly for locations that have similar characteristics t the measured ones. The displayed map clearly shows areas with high noise levels and gives a clear overview of the noise distribution for the specified areas. An important fact shown on the map is that a large part of the residential area near the Railway station is daily exposed to excessive noise caused by rail traffic (red zone). Also, it is said that by leaving the train away from the station and increasing the train speed (when there is no braking and the siren sound) the noise levels go back to allowed values (yellow zone). The latter confirms the assumption that the population living near the station is exposed to excessive noise levels due to railway traffic, and the noise levels are within the permitted values when there is no railway traffic (green zone).

## 6. CONCLUSION

Based on the analysis of the results obtained in the measuring road traffic noise section following can be concluded:

- After comparing the obtained results between the sound level meter Brüel&Kjaer Type 2250 and the mobile application NoiseCapture the deviations in the range of 1 to 3 dB between the two devices are negligible.
- The Mobile application downloaded on a mobile phone whose cost price is significantly lower than the Brüel&Kjaer Type 2250 sound level meter is compatible for measuring noise levels in described conditions.
- The Mobile application is suitable for indicative measurements, i.e., whether if necessary or not to perform measurements with a sound level meter.
- The results of measurements with a mobile phone are significantly affected by the sensitivity of the microphone of the specified model of mobile phone used during the investigation.
- In the road traffic measurement, the deviation of the measured values from the permitted values was observed.
- At all six measuring points, the noise levels exceed the permitted value by an average of 8.16 dB Leq.
- The highest deviation to the permitted value was measured at the measuring point MM4 (13.2 dB more than allowed)
- The population living near the railway station is exposed to higher values of noise levels than the permitted values. This problem is present both day and night time.
- The measurement of the distances from the station shows that the railway traffic noise level outside the station is within the permitted value when the train reaches the desired speed.
- The railway traffic can meet legal regulations related to noise if some solutions for railway stations are taken and if there is a constant improvement of the railway infrastructure.
- The measurement values used for making Map No. 2 show that the highest impact on the noise level specified in the residential area near the Railway station has railway traffic, even though other measuring locations were placed near heavy industrial plants and highways.
- The solution for the elimination of traffic noise affecting the health of the local population is the construction of sound barriers at the railway station. That would solve the exposure problem of both the local inhabitants and wildlife.
- The level of road traffic noise could be controlled by encouraging the use of public transport to reduce the number of cars on the street, relocating part of the traffic outside the city zone if possible, and improving the traffic culture of individuals.
- The solution to reducing the noise levels for the local population is the trees and shrubs planted along with the railway station.
- The most expensive but also the best long-term solution for railway traffic

noise is the replacement of old trains with more modern ones because the current trains are old as well as rails.
- The measured values of noise levels from this paper can be used for raising awareness of excessive noise, and to give a realistic display of the current state of noise levels for used locations.
- Since the problem of excessive noise significantly affects the health of the inhabitants, it is necessary to do some serious research in the future on the topic of road and railway traffic noise levels in Bosnia and Herzegovina.

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Conflicts of Interest
The authors declare no conflict of interest.

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