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Assessment of Representative Measurement Time Intervals for Environmental Noise Monitoring

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Abstract: Road traffic noise monitoring is of great importance for the health of people living in urban areas. Noise monitoring is carried out in several possible ways, depending on the available economic, technical and human resources, as well as the reliability of the measurement results, which is expressed through the measurement uncertainty with the appropriate confidence interval. The paper systematically analyzes the results of long-term continuous environmental noise monitoring at nine distinctive locations next to the main city roads in the territory of the city of Nis (Serbia), with road traffic as the dominant noise source. The goal of the research is to define the season, month and day of the week that are representative of the application of monitoring in practice, in terms of the smallest deviations from the annual values of noise indicators. The results obtained in the paper show that spring, March and Friday as the day of the week best correspond to the set criteria.

Keywords: environmental noise indicators; environmental noise monitoring; road traffic noise; sampling methods; sample representativeness

1 INTRODUCTION

Road traffic noise is an important factor in the life quality in urban areas. The impact of road traffic noise on human health is the subject of numerous studies [1-4] that indicate the need for a strategic approach to solving this problem.

Research conducted in the previous period indicates that a large percentage of the population in urban areas is exposed to noise levels that exceed the limits established by regulations [5]. Data on noise pollution in European cities indicate the need to adopt a special management policy for environmental noise protection across Europe. In order to undertake common measures and harmonize national regulations, all European Union countries have adopted a uniform policy regarding noise protection through Directive 2002/49/EC [6] for environmental noise assessment and management. The Directive, as a basic activity for reducing the impact of environmental noise, requires the creation of strategic noise maps. Also, the Directive defines the following noise indicators: day-noise indicator L_{day}, evening-noise indicator L_{evening}, night-noise indicator L_{night}, and day-evening-night noise indicator L_{den}. The noise indicator L_{den} is calculated based on the estimated or measured values of L_{day}, L_{evening} and L_{night} as follows [6]:

$$L_{\text{den}} = 10\log\left[\frac{1}{24}\left(\begin{array}{l} 12\cdot 10^{\frac{L_{\text{day}}}{10}} + \\ +4\cdot 10^{\frac{L_{\text{evening}}+5}{10}} + \\ +8\cdot 10^{\frac{L_{\text{night}}+10}{10}} \end{array}\right)\right], \text{dB} \tag{1}$$

The harmful noise impact on the population is assessed based on noise indicator values.

Calculating the noise indicator values is a basic task when creating strategic noise maps. It is performed according to the prescribed methodology (CNOSSOS-EU) using appropriate software packages (e.g. Predictor-LimA). In situations where strategic noise maps do not exist, when their validation is needed [7], when changed noise emission conditions appear for any reason, or when there is a legal need and obligation, noise indicator values can also be obtained by measurements.

In order to obtain long-term noise indicator values for road traffic noise, it is necessary to select a specific noise monitoring method specified by the standard ISO 1996-2:2017 [8]. The noise monitoring method determines the measurement time interval (MTI). The first method is unattended continuous long-term monitoring, where the MTI can be the same as the observation time interval (OTI), e.g. one calendar year or MTI can consist of one or several mutually unrelated long-term measurement intervals where the sum of all MTIs is less than the OTI. The second method is the monitoring with a series of short-term attended measurements, where the MTI consists of several mutually unrelated short-term measurement intervals of e.g. 30 minutes [8]. The next step is to develop a noise monitoring program with measurement dynamics that will include all changes in the noise source operation (various road traffic scenarios) and meteorological conditions within the OTI.

The review of the most modern noise monitoring methods showed that researchers use different noise monitoring methods in order to obtain reliable data on long-term noise indicator values in locations with dominant traffic noise in a simpler and faster way. With the same motive, the authors of this paper present the research results and the conclusions reached by analyzing the databases of continuous long-term (annual) noise monitoring at several locations in the city of Niš in the previous 10 years. The goal of the research is to choose the optimal season, month of the year, and day of the week during which it is sufficient to perform continuous noise measurements, without the measurement results significantly deviating from the values obtained by annual monitoring. At the same time, the obtained solution should be common to all measurement points included in the research.

In this paper, the noise monitoring method applied at 14 different measurement points in the city of the Niš is shown after state-of-the-art review of different noise monitorig method in the world. Then, based on the analysis of measurement data at 14 different measurement points over a period of 10 years, the optimal period of the year when noise measurements should be were proposed performed in order to obtain reliable measurement results.

2 STATE-OF-THE-ART REVIEW OF NOISE MONITORIG METHOD

The choice of noise monitoring method is influenced by available economic, technical and human resources. Long-term unattended measurements require the installation of specific noise monitoring terminals, supported by software for processing large measurement databases. Additional problems for the implementation of long-term unattended measurements are the provision of conditions for the installation and operation of noise monitoring terminals, such as adequate location and continuous power supply. Short-term attended measurements require the mandatory engagement of technical personnel and are performed with portable equipment that is more economically accessible and has a more universal application.

An important element when adopting the monitoring method, in a qualitative sense, is the reliability of the measurement results which is expressed through the measurement uncertainty with the appropriate confidence interval [8]. True or completely reliable annual noise indicator values can be obtained only in the case of continuous long-term monitoring during one calendar year. This approach takes into account all factors that influence the variability of the noise level during the OTI. For example, the city of Niš, Serbia, has the results of continuous annual noise monitoring during the last 10 years at several locations in the city that are dominantly exposed to road traffic noise [9, 10]. Dublin in Ireland [11] and Gdansk in Poland [12] are only some of the European cities where continuous annual long-term noise monitoring is carried out. This type of monitoring is technically and financially very demanding, so in practice, it is carried out relatively rarely, mainly for the purpose of scientific research or informing the public about the noise level at certain locations (dynamic noise maps). A more acceptable solution is the noise indicators assessment based on long-term monitoring, which is based on the sampling technique. This technique implies that the minimum number of measurement samples is selected with the shortest possible MTI (e.g. one season, one month of the year, one week of the year or one whole day during the year) within the OTI (e.g. one calendar year), where the selected measurement sample must be representative [13]. The noise indicator values obtained by the sampling technique must therefore also contain information on the measurement uncertainty, which includes several partial uncertainties [8]. The variability of the noise source operating mode has a particular influence on the value of the total measurement uncertainty, which in this particular case is directly related to the choice of the measurement sample. The method of unbiased selection of the measurement sample for the purposes of assessing long-term noise indicators is not defined by the standard. In practice, this problem is solved by subjectively deciding on the MTI and measurement date, primarily based on experience and specific traffic conditions at the measurement location. The intention is the intuitive choice of one or more connected days during the OTI, with the subjective assumption that the traffic characteristics (structure and number of individual vehicle categories) and meteorological conditions will correspond to the average traffic conditions and meteorological conditions during the OTI. In this way, the principles of impartiality, as well as the precision and accuracy of the noise indicator values obtained based on sampling measurement against the true values that would be obtained by continuous measurement during the entire OTI, would be fulfilled. Impartiality implies the absence of a difference between the arithmetic mean value of the sample distribution and the true value of the noise indicator. Precision is inversely proportional to the sample distribution standard deviation. Accuracy represents the difference between the true value and the value obtained by sampling.

In general, there are two approaches for estimating the annual noise indicator values using the sampling technique. The first approach is a simple random sampling during one day of the year (the first case), or during several unrelated days (the second case). The second case may refer, for example, to one randomly or purposefully selected day in each week, month, or season. The first case is valid when all samples (days of the year) are homogeneous, i.e. when the traffic characteristics (structure and vehicle number of certain categories) are stable (the same or slightly different) every day of the year and when meteorological conditions do not affect the measurement results. The second sampling case is used when individual samples are not homogeneous, or when meteorological conditions affect the measurement results. In situations where pronounced daily fluctuations in the structure and vehicle number are present, the second sampling approach is recommended, which implies stratified sampling. With this approach, continuous measurements are made over a longer period (several days), which includes all changes in the character of road traffic, whereby the measurements are repeated for different meteorological conditions. The assessment of long-term noise indicator values is performed in both approaches by calculating the energy mean value of the measurement results obtained for each day. On that occasion, the main reason for the deviation of estimated long-term noise indicator values from the true values is the fact that with the sampling technique there is a possibility of choosing a measurement sample that is not representative, that is, homogeneous.

The application of different sampling approaches in practice, with the aim of minimizing the MTI (number of days) and obtaining reliable long-term (annual) noise indicator values with satisfactory measurement uncertainty, is a topic of interest for numerous researchers. The results of multi-year continuous long-term monitoring in one of the main city squares in Valencia (Spain) show that simple random sampling for at least six days a year gives more reliable results compared to stratified sampling [14]. Based on continuous long-term monitoring at 14 measurement points in Barcelona (Spain) between 2010 and 2015 [15], the researchers propose a temporal sampling strategy that increases the accuracy of long-term noise level estimation and enables the estimation error to be determined according to the number of sampling days.

For this occasion, the days of the week were stratified into weekdays and weekend days. Statistical analysis of one-year experimental data from Vilnius (Lithuania) [16] shows that the annual value of L_{den} can be estimated with an expanded uncertainty of about 2,5 dB using one representative all-day noise measurement. At the same time, continuous measurements during one representative week, or seven non-consecutive days, give an expanded uncertainty value of 1,8 dB. The results of research conducted over 14 years in Krakow (Poland) [17] lead to concrete conclusions about the representativeness of the measurement sample in the methodology of traffic noise measurement and indicate the consequences of different selections of the measurement sample for determining long-term noise indicators in certain situations. On this occasion, two methods are analyzed simple sampling of measurement days from the whole year and measurement of several consecutive days.

3 NOISE MONITORING METHOD

Niš is a city in the south of Serbia (43°19′15″N 21°53′45″E), with 250000 inhabitants living on a territory of about 600 km^2, with an average population density of 300 inhabitants per 1 km^2, while around 180000 inhabitants live in the urban area, with a significantly higher population density.

Public city traffic in Niš is carried out exclusively by buses, and consists of 13 lines. According to the latest official data [18], 1044 mopeds, 1755 motorcycles, 76566 passenger cars, 433 buses, 5923 trucks and 36 work vehicles were registered in Niš in 2022.

In the immediate vicinity of the city roads (streets and boulevards) there are residential buildings, kindergartens, schools, faculties, hospitals, cultural facilities, administrative institutions and other buildings that are particularly noise sensitive. For this reason, noise monitoring is carried out on the territory of the city of Niš at locations of special importance, with the aim of informing the public and developing noise protection action plans.

During nine years, in the period from 2014 to 2022, continuous long-term unattended noise measurements were performed for the duration of one year at 14 different measurement points in the city. A Brüel & Kjær Environmental Noise Management System (ENMS) was used for noise measurements. The basic parts of the system are Software type 7843, the Noise Monitoring Terminals (NMTs) type 3639-B-203 (2 pieces), and the Vaisala Weather Transmitter WXT 520. The NMTs were mounted so that the measurement microphone was at a height of 4 m above the ground. The system has the ability to record sound during measurement and listen to noisy events in order to detect their nature. The measurements were organized and performed according to the current standard ISO 1996-2 [8].

Nine measurement points with relatively the same measurement conditions, i.e. traffic characteristics, were chosen to draw conclusions in accordance with the objective of the research: 1) a constant flow of vehicles of different classes: light motor vehicles (passenger cars, delivery vans ≤ 3,5 tons, sport utility vehicles, multi-purpose vehicles including trailers and caravans), medium heavy vehicles (medium heavy vehicles, delivery vans > 3,5 tons, buses, etc. with two axles and twin tyre mounting on rear axle), heavy vehicles (heavy duty vehicles, buses, with three or more axles), powered two-wheelers (mopeds, motorcycles); 2) Flat road. Constant road traffic ensures small fluctuations in the noise level over time and affects the homogeneity of the measurement sample population. The capacity of all roads next to the measurement points is such that the existing flow of at least 1200 vehicles/h during the day/evening and 400 vehicles/h during the night meets the condition of constant traffic on all roads [19]. Data on the measurement points locations and noise monitoring periods are given in Tab. 1.

Table 1 The measurement points locations and noise monitoring periods

Meas. point	Latitude and longitude	Street/Road	Monitoring period
MP1	43°20'2.56"N 21°52'51.85"E	12. February Boulevard	01.07.2016 ÷ 30.06.2017
MP2	43°19'0.50"N 21°54'45.53"E	Dr Zorana Đinđića Boulevard	01.09.2017 ÷ 31.08.2018
MP3	43°18'57.08"N 21°52'54.79"E	Dimitrija Tucovića Boulevard	01.09.2017 ÷ 31.08.2018
MP4	43°19'23.23"N 21°54'37.20"E	Nemanjića Boulevard	01.11.2019 ÷ 31.10.2020
MP5	43°19'4.98"N 21°54'13.53"E	Cara Dušana Street	01.11.2019 ÷ 31.10.2020
MP6	43°20'45.29"N 21°52'41.10"E	Jadranska Street / A4 Motorway	01.08.2021 ÷ 31.07.2022
MP7	43°19'13.34"N 21°53'28.09"E	The intersection of Gen. M. Lešjanina and Kneginje Ljubice Str.	01.01.2014 ÷ 31.12.2014
MP8	43°19'13.34"N 21°53'28.09"E	The intersection of Gen. M. Lešjanina and Kneginje Ljubice Str.	01.01.2015 ÷ 31.12.2015
MP9	43°19'13.32"N 21°54'1.09"E	The intersection of Sinđelićev trg and Vožda Karađorđa Street	01.01.2016 ÷ 31.12.2016

4 MEASUREMENT RESULTS AND DISCUSSIONS

Based on the database with the results of continuous yearly measurements, the following reports with the values of the noise indicators L_{day}, $L_{evening}$, L_{night}, and L_{den} were created using the software Brüel & Kjær Type 7843 for each measurement point:

- Daily reports - 365 reports,
- Monthly reports -12 reports,
- Seasonal reports (spring, summer, autumn, winter) - 4 reports,
- Annual report - 1 report.

Box plot (also known as Box and Whisker plot) was used to show the degree of dispersion and asymmetry of the deviations distribution of noise indicators values from the reference (annual) values, as well as to analyze the results for the necessary conclusions in the paper. A box plot gives a five-number summary of a set of data which is:

- Lower limit (W_1) - The minimum value in the dataset excluding the outliers.
- First quartile (Q_1) - 25% of the data lies below the First (Lower) quartile.

- Second quartile / Median (Q_2) - The mid-point of the dataset. Half of the values lie below it and half above.
- Third quartile (Q_3) - 75% of the data lies below the Third (Upper) quartile.
- Upper limit (W_2) - The maximum value in the dataset excluding the outliers.

A box plot consists of a rectangle whose sides show the values of the first and third quartiles, within which 50% of all results are located (Interquartile range: $IQR = Q_3 - Q_1$). The line inside the rectangle indicates the median, while the lower and upper limits are usually determined as follows: 1) $W_1 = Min$ if $Min > Q_1 - 1{,}5 \cdot IQR$, otherwise $W_1 = Q_1 - 1{,}5 \cdot IQR$; 2) $W_2 = Max$ if $Max < Q_1 - 1{,}5 \cdot IQR$, otherwise $W_2 = Q_3 + 1{,}5 \cdot IQR$.

Outliers are the data points below and above the lower and upper limits. These characteristics of the box plot enable a very good visualization of the distribution of noise indicator values in the subject research.

The first criterion for the selection of a representative sample to minimize the MTI is the deviation of the measured noise indicator values in the shorter MTI from the reference (annual) noise indicator values obtained by continuous monitoring during one year. The second criterion is the percentage of the number of measured noise indicator values in a shorter MTI with as few deviations as possible from the annual noise indicator values. It is desirable that these deviations be equal to or less than 0,5 dB, since the noise indicator values are rounded to the nearest integer value, and consequently have little effect on the outcome.

In the first phase of the research, seasonal noise indicator values were compared with annual noise indicator values. The deviations of the seasonal noise indicator values from the annual noise indicator values are shown using a box plot in Fig. 1.

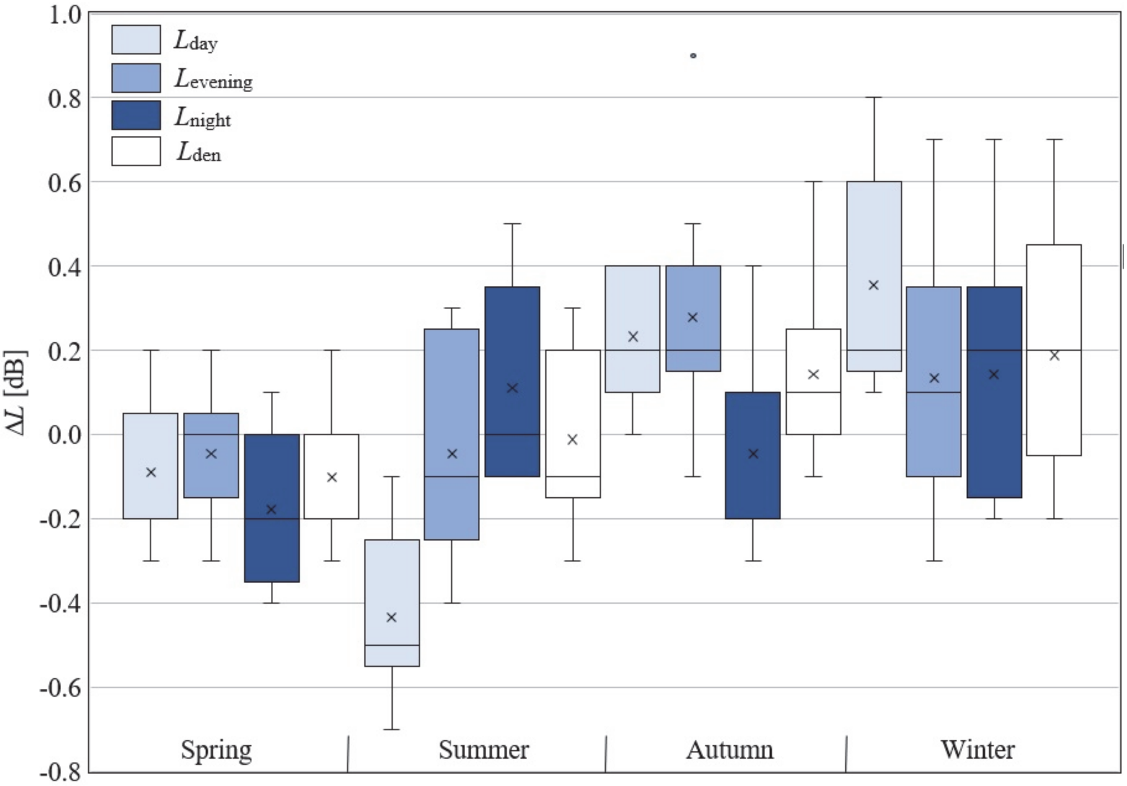

Figure 1 Deviations Δ*L* (in dB) of seasonal noise indicator values from annual noise indicator values (× - mean value, ° - outlier)

Deviation distributions of seasonal noise indicator values from annual noise indicator values, shown in Fig. 1, reveal that the measurement results in the case of spring months have the best characteristics (Tab. 2). Deviations of all measured noise indicator values during spring months are in the range of up to 0,4 dB per absolute value.

Fig. 2 shows the percentage of the number of seasonal noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB.

The results shown in Fig. 2 confirm the statement that 100% of the spring noise indicator values have deviations of 0,5 dB versus the annual noise indicator values. The ranking of the seasons in relation to the given criteria is shown in Tab. 2.

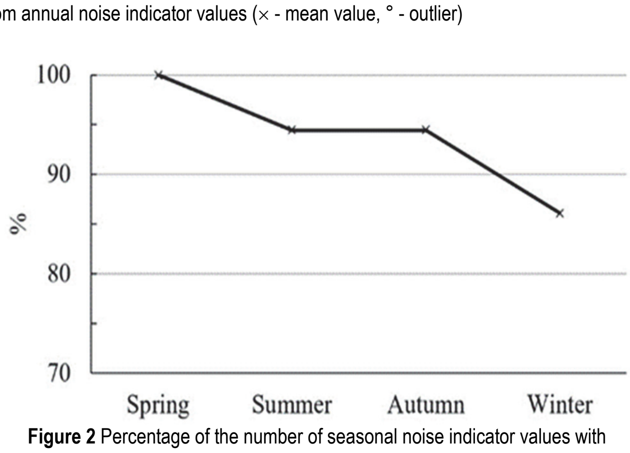

Figure 2 Percentage of the number of seasonal noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB

Table 2 Ranking of the seasons according to the highest percentage of the number of seasonal noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB

Range	Season	$\Delta L \le 0{,}5$ dB
1	Spring	100%
2	Summer, Autumn	94%
3	Winter	86%

In the second phase of the research, in search of a representative month for noise measurement, the monthly noise indicator values were compared with the annual noise indicator values. The deviations of the monthly noise indicator values from the annual noise indicator values are shown using a box plot in Fig. 3.

Deviation distribution of monthly noise indicator values from annual noise indicator values (Fig. 3) shows that the measurement results in the case of March have the best characteristics (Tab. 3).

The results show that the deviations of all measured noise indicator values during March, versus the reference values of the noise indicator during the whole year, are in the range of up to 0,5 dB per absolute value.

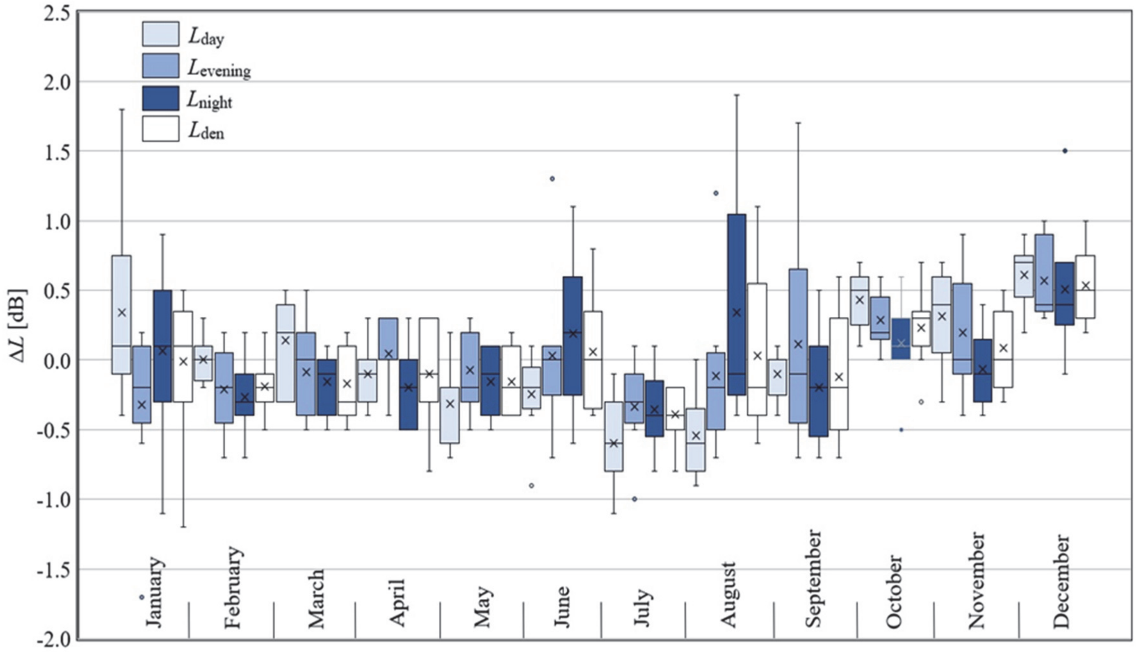

Figure 3 Deviations Δ*L* (in dB) of monthly noise indicator values from annual noise indicator values (× - mean value, ° - outlier)

Fig. 4 shows the percentage of the number of monthly noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB and ≤ 1,0 dB.

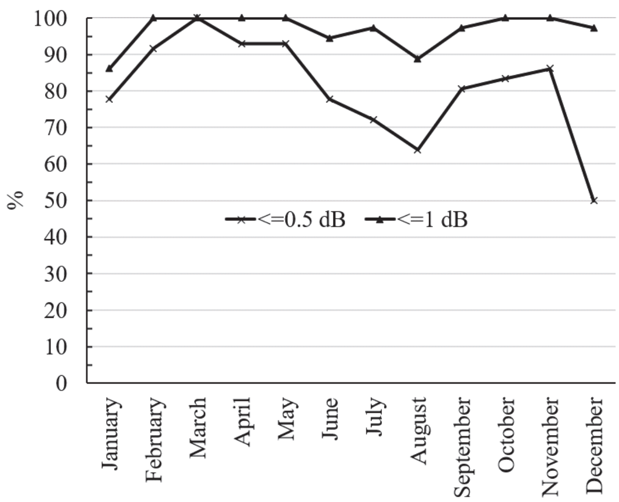

Figure 4 Percentage of the number of monthly noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB and ≤ 1,0 dB

Ranking of the first three months according to the highest percentage of the number of monthly noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB and ≤ 1,0 dB, according to the results of Fig. 4, is shown in Tab. 3.

Table 3 Ranking of the months according to the highest percentage of the number of monthly noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB and ≤ 1,0 dB

Range	Month	$\Delta L \le 0{,}5$ dB	$\Delta L \le 1{,}0$ dB
1	March	100%	100%
2	April	93%	100%
2	May	93%	100%

Based on the ranking results of the month in Tab. 3, it can be seen that the three most favorable months for noise monitoring belong to spring, with March being a representative month.

In order to evaluate a representative day of the week for noise monitoring, in the third phase of the research, the daily noise indicator values in March were compared with the annual noise indicator values. The deviations of daily noise indicator values from the annual noise indicator values are shown using a box plot in Fig. 5.

Deviations distribution of daily noise indicator values from annual noise indicator values (Fig. 5) shows that the measurement results on Friday have the best characteristics (Tab. 4). Values that are above the upper limit (outlies) during the evening reference time interval are the result of noisy events on MP3 (March 2, 2018; sirens of ambulance and police vehicles; $\Delta L_{evening}$ = 1,50 dB) and MP8 (March

27, 2015; taxi drivers' association protest; $\Delta L_{evening}$ = 1,90 dB).

Fig. 6 shows the percentage of the number of daily noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB, ≤ 0,7 dB, ≤ 1,0 dB, and ≤ 1,2 dB.

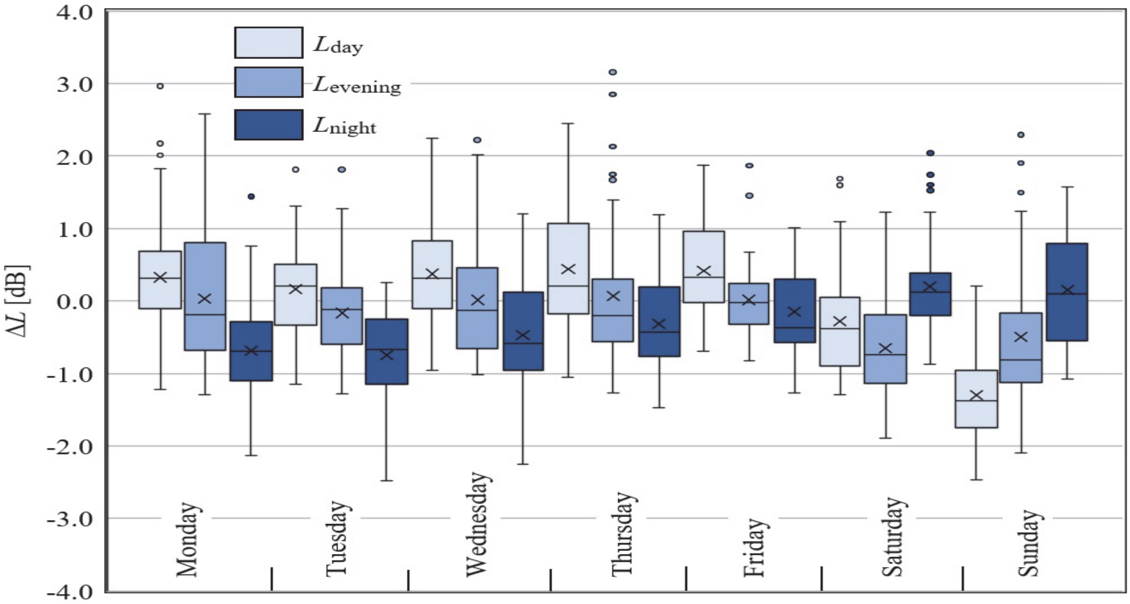

Figure 5 Deviations Δ*L* (in dB) of daily noise indicator values by day of the week in March from the annual noise indicator values (× - mean value, ° - outlier)

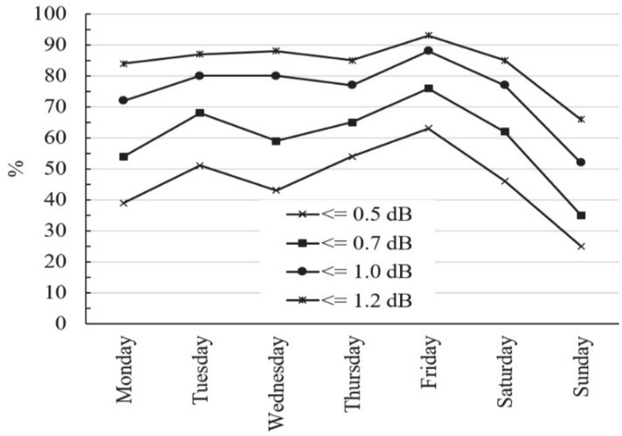

Figure 6 Percentage of the number of daily noise indicator values by days of the week in March with deviations from the annual noise indicator values that are ≤ 0,5 dB, ≤ 0,7 dB, ≤ 1,0 dB and ≤ 1,2 dB

Table 4 Ranking of the days of the week in March according to the highest percentage of the number of noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB, ≤ 0,7 dB, ≤ 1,0 dB and ≤ 1,2 dB

Range	Day	$\Delta L \le 0,5$ dB	$\Delta L \le 0,7$ dB	$\Delta L \le 1,0$ dB	$\Delta L \le 1,2$ dB
1	Friday	63%	76%	88%	93%
2	Thursday	54%	65%	77%	85%
3	Tuesday	51%	68%	80%	87%

Table 5 Deviations distribution of spring, March, and daily (for Friday) noise indicator values from annual noise indicator values, in dB

	Spring				March				Friday		
	L_{day}	$L_{evening}$	L_{night}	L_{den}	L_{day}	$L_{evening}$	L_{night}	L_{den}	L_{day}	$L_{evening}$	L_{night}
W_1	−0,30	−0,30	−0,40	−0,30	−0,30	−0,50	−0,50	−0,50	−0,70	−0,80	−1,30
W_2	0,20	0,20	0,10	0,20	0,50	0,50	0,10	0,20	1,90	0,70	1,00
Q_1	−0,20	−0,15	−0,35	−0,20	−0,30	−0,40	−0,40	−0,40	−0,05	−0,20	−0,60
Q_2	−0,20	0	−0,20	−0,20	0,20	0	−0,10	−0,30	0,30	0,10	−0,40
Q_3	0,05	0,05	0	0	0,40	0,20	0	0,10	0,95	0,30	0,30
IQR	0,25	0,20	0,35	0,20	0,70	0,60	0,40	0,50	1,00	0,50	0,90
Outlies	No	No	No	No	No	No	No	No	No	1,50 1,90	No
L_{mv} *⁾	−0,09	−0,04	−0,18	−0,10	0,14	−0,09	−0,16	−0,17	0,40	0,10	−0,20

*⁾ mean value (× in Fig. 1, Fig. 3 and Fig. 5)

Ranking of the first three days of the week according to the highest percentage of the number of noise indicator values with deviations from the annual noise indicator values that are ≤ 0,5 dB, ≤ 0,7 dB, ≤ 1,0 dB and ≤ 1,2 dB, according to the results from Fig. 6, is shown in Tab. 4.

The results of the ranking of the days of the week in Tab. 4 confirm that Friday in March is the representative day for environmental noise measurement in the city of Niš when road traffic is the dominant noise source.

Comparative analysis of data from Tab. 5 shows, as expected, that as the sampling duration (MTI) decreases from one season (three months) to one day, the interval $W_1 \div W_2$ increases, as well as the *IQR* value. The data obtained for Friday in March show that very satisfactory data can be obtained with several daily monitoring.

5 CONCLUSION

The environmental noise monitoring, especially at locations in cities that are particularly polluted by road traffic noise, is a necessary activity that precedes the development of noise protection action plans and strategic noise mapping. The monitoring results represent the long-term noise indicator values, which are directly related to the possible consequences for the population health in those locations. Also, in many real situations, there is a need for urgent assessment of long-term noise indicator values at locations in the environment that are not covered by strategic noise maps. In both cases, there is a common interest obtaining reliable data on noise indicator values based on one-time noise monitoring with the shortest possible measurement time interval.

The assessment of the minimum representative measurement time interval for environmental noise monitoring is primarily based on traffic characteristics. In the case of roads with a large and continuous day flow of traffic, when the fluctuations in noise level over time are small, it is possible, based on relatively short measurements, to arrive at reliable noise indicator values that refer to a longer period of time. The selection of a representative sample is additionally influenced by the daily habits and needs of the population for transportation (primarily going to and from work), as well as the stability of meteorological conditions during the year.

By analyzing the results of long-term environmental noise monitoring at nine locations with predominantly road traffic noise, it is concluded that at the given measurement points in the city of Niš, with the existing characteristics and dynamics of road traffic, it is sufficient to perform a one-time noise monitoring either during three spring months, or only during march, or only during all Fridays in March, provided that the noise indicator values obtained would not differ by more than 0,5 dB from those obtained by long-term (yearly) noise monitoring. At the same time, samples with a longer measurement time interval have greater reliability or representativeness.

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