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Momir Prascevic, Darko Mihajlov, Dragan Cvetkovic

# The Correlation between Harmonica Indices and Noise Indicators

*Environmental Noise Directive requires the use of common noise indicators in member countries of the European Union as physical quantities that describe the environment noise created by different sources of noise. The END noise indicators are expressed in decibel unit which is logarithmic in nature, and usually complicated to explain and relatively far-removed from perception of people. Two French organizations suggested a new environmental noise index called Harmonica index based on measurement data obtained by noise monitoring and take into account both the overall environmental noise load and noise peaks from sudden noise events. In order to determine adequacy of Harmonica indices and relationship between the Harmonica indices and the END noise indicators, the correlation analysis was carried out and the correlation coefficient was determined for different combination of the Harmonica indices and the END noise indicators. The results of the correlation analysis on the sample of noise monitoring data in the city of Niš are presented in this paper after overview the END noise indicators and Harmonica index.*

***Keywords***: *Noise indicator, Harmonica index, Correlation analysis*

## 1. Introduction

Environmental noise caused by traffic, construction, industrial and recreational activities is the main local environmental problem and the source of an increasing number of complaints from the public. There are different estimates of the population exposed to unacceptable noise levels [1-4]. The different estimates are due to impact of the following factors: different noise level tolerance of the population, different types of environmental noise sources, different methods for obtaining noise exposure information, and different noise indicators.

Regarding the state of the used noise indexes in European countries, there was a need to harmonize noise indicators. By adopting the Directive on the Assessment and Management of Environmental Noise (END), 2002/49/EC [5], the basic principles of a harmonized European noise policy were defined. One of the key elements of the Environmental Noise Directive is the assessment of environmental noise by common noise indicators and common assessment methods. Adopting the Environmental Noise Directive and the common noise indicators, the environmental noise assessment in different countries could be compared.

The first strategic noise maps are available to the public [6]. However, it currently remains difficult for people to understand the environmental noise data due to various noise indicators that are expressed in decibel unit which is logarithmic in nature, and usually complicated to explain and relatively far-removed from perception of people. Also, the noise indicators very often are expressed in dB(A), which further complicates the understanding of noise indicators values.

Two French organizations specialized for management and organization of urban noise observatories in France, have worked on a proposal for a new index closer to the perception of the people [7, 8]. They suggested a new environmental noise index called Harmonica (HARMOnised Noise Information for Citizens and Authorities) index. The Harmonica index is based on measurement data obtained by noise monitoring and take into account both the overall environmental noise load and noise peaks from sudden noise events.

In order to determine adequacy of Harmonica indices and relationship between the Harmonica indices and the usual used noise indicators proposed by END, the correlation analysis was carried out and the correlation coefficient was determined for different combination of the Harmonica indices and the END noise indicators. The results of the correlation analysis on the sample of noise monitoring data in the city of Niš are presented in this paper.

## 2. Overview of END noise indicators

END requires the use of harmonized common noise indicators in member countries of the European Union as physical quantities that describe the environment noise created by different sources of noise. The common noise indicators are:

- the day-evening-night noise indicator, $L_{den}$[dB(A)] - indicator describing the annoyance caused by noise within 24 hours, i.e. for the day-evening-night;
- the daily noise indicator, $L_d$ [dB(A)] - indicator describing the annoyance caused by noise within the day (day lasts 12 hours);
- the evening noise indicator, $L_e$ [dB(A)] - indicator describing the annoyance caused by noise during the evening (evening lasts 4 hours);
- the night-time noise indicator, $L_n$ [dB(A)] - indicator describing the annoyance caused by noise at night (evening lasts 8 hours).

The day-evening-night noise indicator is defined by the following formula:

$$L_{\mathrm{den}} = 10\,\mathbf{log}\frac{1}{24}\left(12\cdot 10^{0.1\cdot L_{\mathrm{day}}} + 4\cdot 10^{0.1\cdot(L_{\mathrm{evening}}+5)} + 8\cdot 10^{0.1\cdot(L_{\mathrm{night}}+10)}\right), \qquad (1)$$

where:

$L_{day}$ - the A-weighted long-term average sound level determined over all the day periods of a year,

$L_{evening}$ - the A-weighted long-term average sound level determined over all the evening periods of a year,

$L_{night}$ - the A-weighted long-term average sound level determined over all the night periods of a year.

A year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances [5].

The A-weighted long-term average sound levels for different day periods of a year are defined by the following formulas:

$$L_{\mathrm{day}} = 10\,\mathbf{log}\left[\frac{1}{N}\sum_{i=1}^{N}10^{0.1\cdot L_{\mathrm{d},i}}\right], \qquad (2)$$

$$L_{\mathrm{evening}} = 10\,\mathbf{log}\left[\frac{1}{N}\sum_{i=1}^{N}10^{0.1\cdot L_{\mathrm{e},i}}\right], \qquad (3)$$

$$L_{\mathrm{night}} = 10\,\mathbf{log}\left[\frac{1}{N}\sum_{i=1}^{N}10^{0.1\cdot L_{\mathrm{n},i}}\right], \qquad (4)$$

where N is the number of days in a year, $N = 365$.

The values of noise indicators for i-th day in year are determined based on the continuous measurement of the equivalent noise level in day periods, or by sampling techniques during day periods and the equivalent noise level determination based on the following equation:

$$L_{\mathrm{day},i} = 10\,\mathbf{log}\left[\frac{1}{N}\sum_{i=1}^{N}10^{0.1\cdot(L_{\mathrm{Aeq},T})_i}\right]. \qquad (5)$$

The similar equations are applied for $L_{evening,i}$ and $L_{night,i}$.

### 3. Overview of Harmonica index

The Harmonica index is based on measurement data obtained by noise monitoring and take into account both the overall environmental noise and noise peaks from sudden noise events. The Harmonica index reconcile energy-based indicators which represent the average noise energy levels over a given period (like $L_{Aeq}$) and event-based indicators that focus on noise peaks that occur over a given period (like $L_{AE}$).

The Harmonica index is an adimensional index based on a scale of 0 to 10 and the hourly Harmonica index (HHI) can be calculated by the following mathematical formula [7]:

$$HHI = BGN + EVT\,, \tag{6}$$

where *BGN* is background noise sub-index, and *EVT* is peak noise sub-index.

A component related to the background noise [7] can be calculated as:

$$BGN = 0.2\text{x}(L_{\text{A95eq}} - 30)\,, \tag{7}$$

where: $L_{\text{A95eq}}$ is the background noise level during the one-hour period, where the background noise being calculated every second by the noise level exceeded 95% of the time during the previous ten minute period.

An event-related component [7], which represents the acoustic energy provided by noise peaks that emerge above the background noise, can be calculated as:

$$EVT = 0.25\text{x}(L_{\text{Aeq}} - L_{\text{A95eq}})\,, \tag{8}$$

where $L_{\text{Aeq}}$ is the equivalent noise level during a one-hour period.

In order to reflect daily variations of environmental noise, the Harmonica index can be calculated as an hourly index, allowing a clear representation of the daily variation of environmental noise levels, taking both background noise and noise peaks into account. Average indices for daytime period (6 am - 10 pm) and night period (10 pm to 6 am) and for the entire day (24h) can be also calculated as the arithmetic mean of hourly values. It is also easy to calculate the average values for long-term period (week, month, and year) as the arithmetic mean of the daily values.

The Harmonica index is graphically represented as a triangle (*BGN* component) on top of a rectangle (*EVT* component). Three colors (green, orange and red) are used for color representation of the Harmonica index. The color scale is shown in Table 1.

**Table 1**

| Color | Day (from 6 am to 10 pm) | Night (from 10 pm to 6 am) | Harmonica index score |
|---|---|---|---|
| green | between 0 and 4 | between 0 and 3 | Quiet |
| orange | between 4 and 8 | between 3 and 7 | Noisy |
| red | over 8 | over 7 | Very noisy |

### 4. Calculation of END noise indicators and Harmonica indices

The results of permanent road noise monitoring with two monitoring terminals were used for calculation of END noise indicators and Harmonica indices. The procedure of permanent road traffic noise monitoring in Nis that began on January 1, 2014 is based on Brüel&Kjær's Environmental Noise Management System. The first results of noise monitoring in the city of Niš can be found in [9-11]. The results of broadband $L_{\text{Aeq}}$ for April, continuously measured at half-second intervals at two locations, one near the intersection of two main city roads (marked NMT-1) and other at the facade of the building near the main city road (marked NMT-2.3) were used for END noise indicators and the Harmonica indices calculation according to the equations (1) – (8).

The END noise indicators were calculated using Brüel&Kjær's Environmental Noise Management Client Software Type 7843-C. The daily values of noise indicators for April 2015 are shown in Figure 1 and Figure 2, for measurement locations NMT-1 and NMT-2.3, respectively. In addition to the common noise indicators, $L_{Aeq,total}$, the A-equivalent sound pressure level averaged over 24h, is also shown in the figures. It can be noted that the averaged difference between corresponding noise indicators for measurement location NMT-1 and NMT-2.3 is about 10 dB(A).

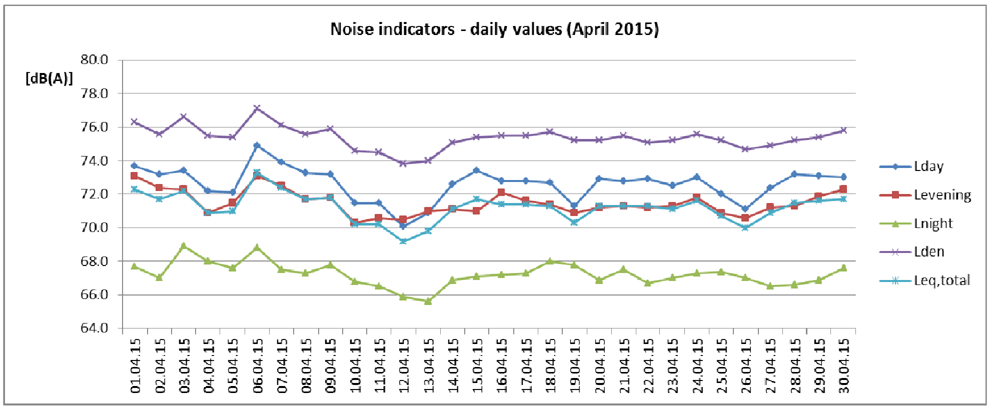


**Figure 1.** Daily values of noise indicators for NMT-1

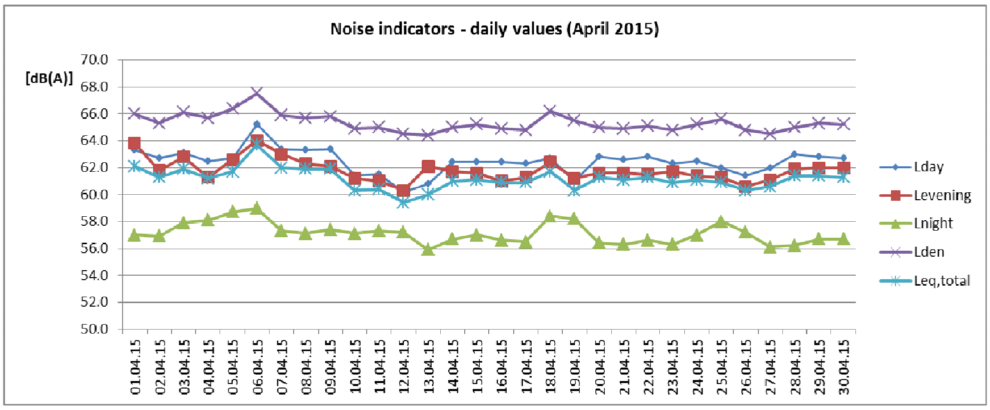


**Figure 2.** Daily values of noise indicators for NMT-2.3

The Harmonica indices were calculated using "Toots" software developed to calculate the Harmonica index. $L_{Aeq}$ values sampled with a 500 ms interval, recreating into the $L_{Aeq}$ (1 second), were used as the input data for "Toots" software. The averaged hourly values of Harmonica indices for April 2015 are shown in Figure 3 and Figure 4, for measurement locations NMT-1 and NMT-2.3, respectively. The values of EVG and BGN sub-indices are also shown in the same figures as well as the three monthly averaged values: one for the day period (6am - 10pm), one for the night period (10pm - 6am), and one for the entire day (24h).

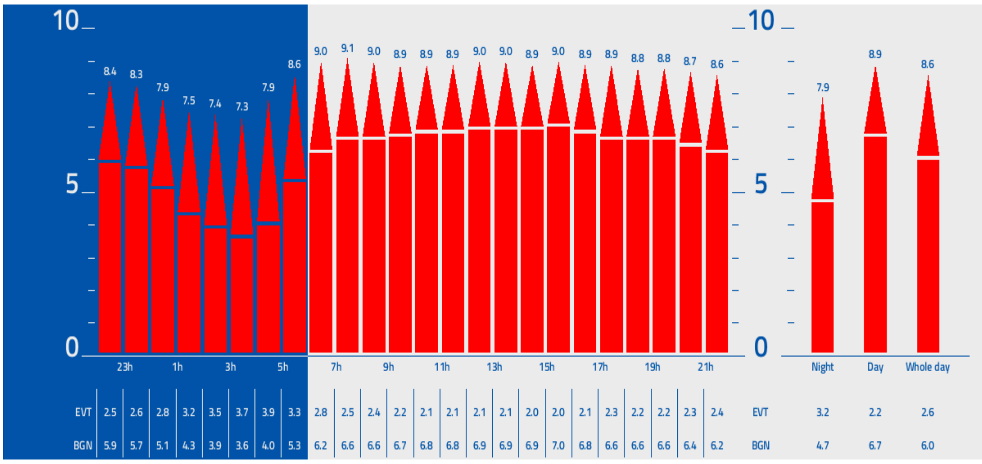


**Figure 3.** The averaged hourly values of Harmonica indices for NMT-1

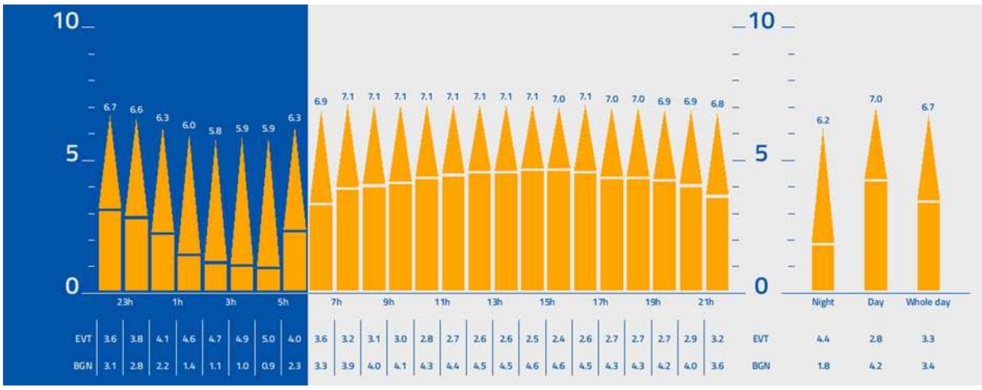


**Figure 4** The averaged hourly values of Harmonica indices for NMT-2.3

The daily values of Harmonica indices for April 2015 are shown in Figure 5 and Figure 6, for measurement locations NMT-1 and NMT-2.3, respectively. In addition to the values of Harmonica indices obtained by "Toots" software (the averaged hourly values for day period from 6am to 10pm marked as day18, the night period from 10pm to 6am, and the whole day), the averaged hourly values for day period from 6am to 6pm marked as day12, the evening period from 6pm to 10pm were calculated and also shown in the figures. It can be noted that the averaged difference between corresponding Harmonica indices for measurement location NMT-1 and NMT-2.3 is about 1.5 to 2.

According to the values of the Harmonica indices, the sound environment near the location NMT-1 can be assessed as VERY NOISY. Also, the sound environment near the location NMT-2.3 can be assessed as NOISY.

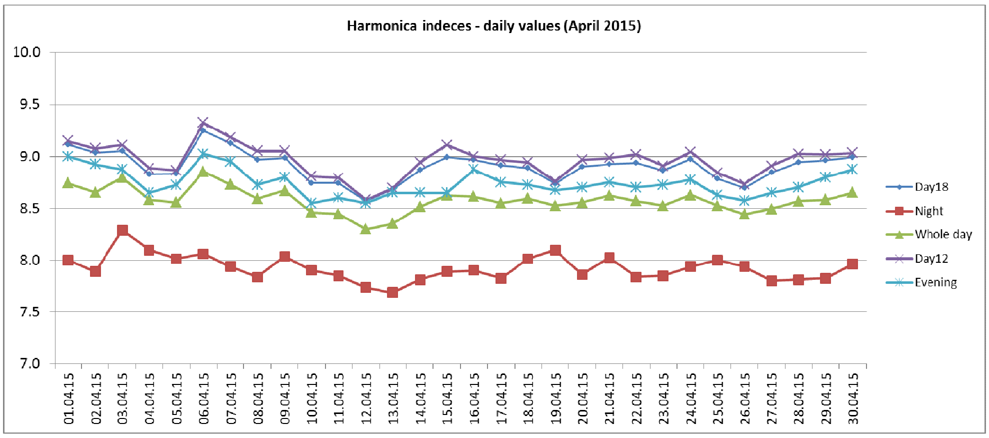


**Figure 5.** Daily values of Harmonica indices for NMT-1

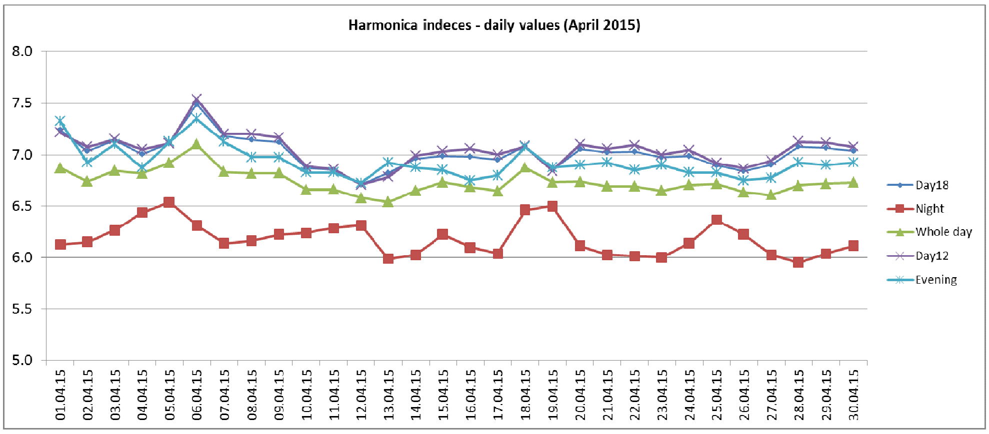


**Figure 6.** Daily values of Harmonica indices for NMT-2.3

## 5. Correlation analysis between noise indicators and Harmonica indices

In order to determine adequacy of Harmonica indices and relationship between the Harmonica indices and the END noise indicators, the correlation analysis was carried out and the correlation coefficient was determined for different combination of the Harmonica indices and the END noise indicators.

The correlation is a technique for investigating the relationship between two quantitative, continuous variables. Pearson's correlation coefficient (r) is a measure of the strength of the association between the two variables e.g., between an independent and a dependent variable or between two independent variables. In correlation analysis the Pearson correlation coefficient, *r*, is estimated as a measure of the strength of the association between the two variables. The Pearson's correlation coefficient ranges from -1 to +1. Positive correlation indicates that both variables increase or decrease together, whereas negative correlation indicates that as one variable increases, so the other decreases, and vice versa. The sign of the correlation coefficient indicates the direction of the association. The magnitude of the correlation coefficient indicates the strength of the association.

The Pearson correlation coefficient, *r*, for two variables *x* and *y* is defined by the following formula:

$$r = \frac{\mathbf{cov}(x, y)}{\sqrt{s_x^2 \cdot s_y^2}}, \tag{9}$$

where $\mathbf{cov}(x, y)$ is the covariance of *x* and *y* defined as:

$$\mathbf{cov}(x, y) = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{n-1}, \tag{10}$$

$s_x^2$ and $s_y^2$ are the samples variances of x and y, defined as:

$$s_x^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \quad \text{and} \quad s_y^2 = \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1} \tag{11}$$

The first step in studying the relationship between two variables is to draw a scatter plot of the variables to check for linearity. The correlation coefficient should not be calculated if the relationship is not linear. The example of scatter plots for corresponding combination of noise indicators and Harmonica indices are shown in Figure 7 and Figure 8, for measurement locations NMT-1 and NMT-2.3, respectively. The scatter plots for other combination of noise indicators and Harmonica indices are similar and point to linearity of corresponding variables. The trend line is add in the figures as well as squared value of Pearson correlation coefficient.

As the relationships between corresponding noise indicators and Harmonica indices are linear, the Pearson correlation coefficient was calculated using the equations (9) to (11). The results of the Pearson correlation coefficient for different combination of noise indicators and Harmonica indices are given in Table 2. Variation of the Pearson correlation coefficient for hourly Harmonica indices and additional noise indicator $L_{\mathrm{Aeq,total,1h}}$ are shown in Figure 9 and Figure 10, for measurement locations NMT-1 and NMT-2.3, respectively.

The obtained high values of the Pearson correlation coefficient point to the high strength of the association of noise indicators and Harmonica indices.

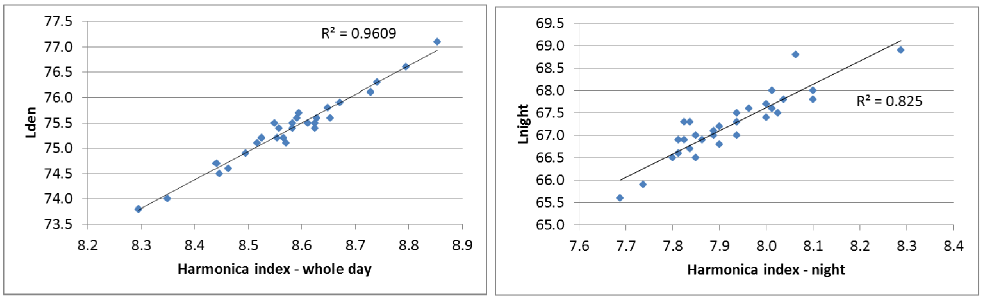


**Figure 7.** Scatter plots for NMT-1

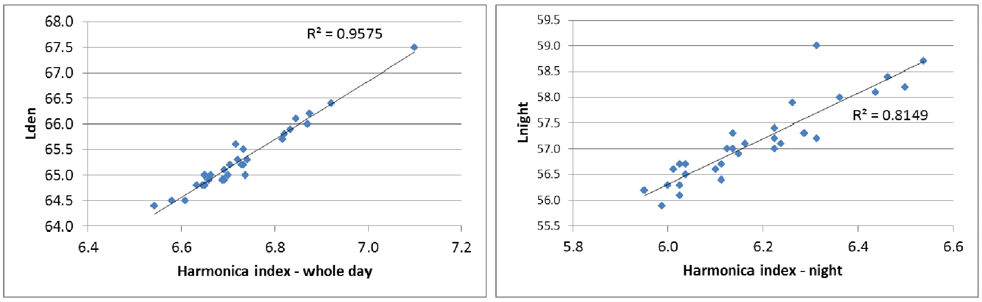


**Figure 8.** Scatter plots for NMT-2.3

**Table 2**

| Pearson correlation coefficient, *r* | | | Noise indicators: common $L_{den}$ | common $L_{day}$ | common $L_{evening}$ | common $L_{night}$ | additional $L_{Aeq,total,24h}$ | additional $L_{Aeq,total,1h}$ |
|---|---|---|---|---|---|---|---|---|
| Harmonica indices | NMT-1 | Hour | | | | | | 0.988 |
| | NMT-2.3 | | | | | | | 0.980 |
| | NMT-1 | Day (18h) | | 0.980 | | | | |
| | NMT-2.3 | | | 0.965 | | | | |
| | NMT-1 | Day (12h) | | 0.992 | | | | |
| | NMT-2.3 | | | 0.988 | | | | |
| | NMT-1 | Evening | | | 0.985 | | | |
| | NMT-2.3 | | | | 0.971 | | | |
| | NMT-1 | Night | | | | 0.908 | | |
| | NMT-2.3 | | | | | 0.903 | | |
| | NMT-1 | Whole day | 0.980 | | | | 0.953 | |
| | NMT-2.3 | | 0.979 | | | | 0.898 | |

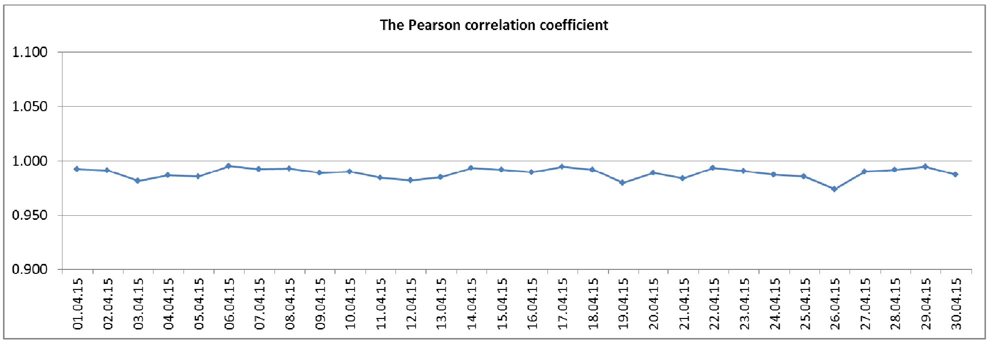


**Figure 9.** Variation of the Pearson correlation coefficient for hourly Harmonica indices and additional noise indicator $L_{Aeq,total,1h}$ for NMT-1

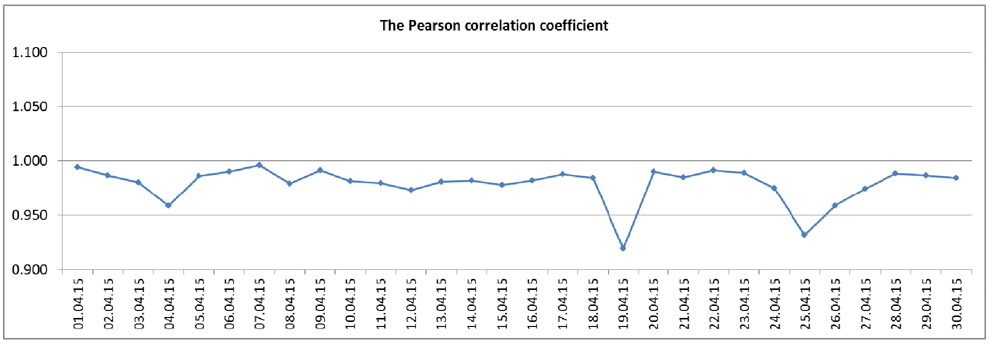


**Figure 10.** Variation of the Pearson correlation coefficient for hourly Harmonica indices and additional noise indicator $L_{Aeq,total,1h}$ for NMT-2.3

## 6. Conclusion

Adopting the Environmental Noise Directive and the common noise indicators, the environmental noise assessment in different countries is compared. The first strategic noise maps are available to the public after the first and second round. However, there are difficulties in understanding the environmental noise data due to using decibel unit which is logarithmic in nature, and usually complicated to explain and relatively far-removed from perception of people.

Because of that the new environmental noise index called Harmonica is suggested for the environmental noise assessment. This index has a many advantages:

- More easy to understand than decibels because it is based on a scale of 0 to 10;

- Easy to calculate using usually collected measurement data by noise measurement devices (A-weighted, equivalent continuous sound level for 1s, $L_{Aeq,1s}$);
- Possible to calculate for one-hour time sample;
- Take into account the two major components that affect the noise environment: background noise and noise events that exceed this background noise (noise peaks);
- More representative for people's perception of environmental noise than noise indicators currently used in the European regulation.

The results of permanent road noise monitoring with two monitoring terminals were used for calculation of common noise indicators and Harmonica indices and determination of adequacy of Harmonica indices and relationship between the Harmonica indices and the common noise indicators. The correlation analysis was carried out and the correlation coefficient was determined for different combination of the Harmonica indices and the noise indicators. The obtained high values of the Pearson correlation coefficient point to the high strength of the association of noise indicators and Harmonica indices and adequacy of Harmonica indices for environmental noise assessment.

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*Addresses:*

- Prof. DSc Eng. Momir Prascevic, University of Nis, Faculty of Occupational Safety, Carnojevica 10a, 18000, Nis, Serbia, momir.prascevic@znrfak.ni.ac.rs
- Ass. MSc Eng. Darko Mihajlov, University of Nis, Faculty of Occupational Safety, Carnojevica 10a, 18000, Nis, Serbia, darko.mihajlov@znrfak.ni.ac.rs
- Prof. DSc Eng. Dragan Cvetkovic, University of Nis, Faculty of Occupational Safety, Carnojevica 10a, 18000, Nis, Serbia, dragan.cvetkovic@znrfak.ni.ac.rs