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URBAN NOISE MODELLING IN BOKA KOTORSKA BAY

ABSTRACT

Traffic is the most significant noise source in urban areas. The village of Kamenari in Boka Kotorska Bay is a site where, in a relatively small area, road traffic and sea (ferry) traffic take place at the same time. Due to the specificity of the location, i.e. very rare synergy of sound effects of road and sea traffic in the urban area, as well as the expressed need for assessment of noise level in a simple and quick way, a research was conducted, using empirical methods and statistical analysis methods, which led to the creation of acoustic model for the assessment of equivalent noise level (L_{eq}). The developed model for noise assessment in the Village of Kamenari in Boka Kotorska Bay quite realistically provides data on possible noise levels at the observed site, with very little deviations in relation to empirically obtained values.

KEY WORDS

community noise; acoustic modelling; traffic; environment pollution

1. INTRODUCTION

The fact is that there is an entire number of sources of pollution that may endanger the environment. Pollution effects in the majority of cases remain unnoticed because there is no adequate technology (or it is not applied) and monitoring, or we are not aware of the presence and consequences. A typical example of environmental pollutant, whose presence and negative impacts on the living world remain long hidden, is the community noise. All negative effects, brought by the increase in noise, can be observed through the physiological and psychological effects of noise on human health [1] and the living nature around us. It is extremely important to take timely and preventive action in order to eliminate or at least mitigate the negative effects that increased noise has on the human quality of life. Compared to other environmental factors, there is a little “understanding” for the control of community noise. Planning the use of living space, while not taking into account the levels of noise to which people are exposed, significantly increases the noise exposure of the population and its negative effects [2]. Traffic is indicated as a known source of environmental noise. Whether road, rail, air or sea traffic, noise generated when these are performed, indicates the need for constant monitoring and adjusting to legally defined limits. Assessment of noise generated in road traffic has been carried out for a long time, with a limited number of receivers, with simplified qualitative analyses and simplified calculations. Experience has shown that this approach often does not allow getting acceptable and realistic results, as well as a clear picture of the real impact of noise on the environment in the right way. The development of computer modelling techniques allow modelling of the most complex scenarios of road traffic noise generation and propagation, with satisfactory precision and fast enough. Sea traffic noise in the world and in scientific circles is mostly treated from the aspect of the impact on the living world under water. The impact on the human environment is limited to the area in and around the port, residential areas on the ship/boat and machine plants. The presence of sea traffic noise in urban areas is almost inconceivable, but there are places where people are exposed to the combined effects of noise generated by road and sea traffic. One of these places is the Village of Kamenari in Boka Kotorska Bay, where road traffic on the "Adriatic highway" takes place in the immediate vicinity of residential buildings, and ferry boats ply at the same time. The aim of this paper is to examine the specific situation and develop a model for the assessment of noise in the urban area generated by road and sea traffic.

2. METHODS

When it comes to modelling of environmental noise, this primarily refers to practical engineering method. Using the engineering method we come to the model by including in the calculation all independent contributors that cause noise increase. Common to all models is that they are based on empirical results of conducted experiments on the measurement of equivalent sound level - L_{eq} (dB) [3], statistical analysis of the collected data, and usage simplicity. Road and sea traffic are identified as the main contributors of noise at the observed location.

Previous studies show that in creating the model, where road traffic appears as source, a whole range of factors may significantly affect the authenticity and applicability of the developed model. The basic parameters for the assessment of road traffic noise can be: the quantity of vehicles, i.e. the flow of vehicles, speed at which vehicles travel, existence of barriers in the immediate vicinity of road, surface covering the road, road gradient, distance from the traffic lane [4]. The importance of trucks and buses in contributing to high levels of noise was proved [5].

The traffic flow, in most of the used models, is generally accepted as a very influential parameter. The variation of L_{eq} can be adequately represented by a logarithmic equation of the form:

$$L_{eq} = C \log q \tag{1}$$

where q is the traffic flow of vehicles per hour and C is a constant.

Constant C varies between 7.5 and 11.5, for different types of flow, urban conditions and gradients [4]. A general value of C=10 is accepted by the most researchers [6].

The percentage of heavy vehicles has a significant effect on the produced noise level [7]. Heavy vehicles produce a noise level 5-10 dB greater than the light ones [6]. In most of the existing noise prediction models, the vehicles are classified in two classes: the class of light vehicles and the class of heavy vehicles.

Vehicle speed is an important parameter for the prediction of traffic noise. Passenger vehicles in free flow, for a change in speed of 10 km/h, increase the mean emitted noise by 2 dB. For trucks, it is 2.2 dB and 1.6 dB for busses [8]. Delany et al. accept that there is an interaction between speed and percentage of heavy vehicles [4]. They identify two speed regions: above 50 Km/h where most traffic will operate under fairly free flow conditions, whilst below this speed the majority of the situations will not be freely flowing.

Road gradient has a marked effect on the actual noise generated by the individual vehicles. On roads with a gradient the driver has to accelerate or use the brakes more frequently than on straight roads. Moreover, on steep gradients heavy vehicles moving downhill are likely to overrun in low gear and emit more noise than on the level. The produced noise depends on the combination of flow, traffic composition and slope [7].

The ground surface has also a significant effect on the measured noise level. The interaction between the tyres and the road surface affects directly the noise level generated by traffic [8]. The noise distributed among the tyres is smaller on porous surfaces than on dense surfaces. In general, finer grating results in a lower rolling noise level.

The effect of a facade of a building behind the reception point will increase the noise level [4]. Measurements performed at 1 m from an unbroken brick surface indicate an increase of 2.3 dB in measured noise level. This increase is greater for narrow streets with buildings on both sides (urban canyon) [9]. At distances of more than 20 m from the buildings this façade effect would be negligible.

Taking into account previous experiences in the field of road traffic noise modelling, the flow of passenger vehicles and the flow of freight vehicles and buses were taken into account as basic input parameters in the model creation. Other factors, such as vehicle speed, the presence of buildings or barriers, type of surface and road gradient were taken into account according to inputs defined by the Italian C.R.N. noise prediction model [10, 11]. This model represents a modification of the German standard RLS 90, adapted to the Italian framework. The relation between the traffic parameters and the mean sound energy level is assumed, and the traffic flow is modelled as a linear source placed in the centre of the road. According to C.R.N. standard, the equivalent noise level has to be corrected because of the mean flux velocity (ΔL_v), correction for road gradient (ΔL_g), correction for the presence of reflective façade (ΔL_f), traffic coefficient (ΔL_{VB}) and correction for the road pavement (ΔL_p).

For the experiment purpose, the calculation of corrections was performed according to formula:

$$\Delta L = \Delta L_v + \Delta L_g + \Delta L_f + \Delta L_p + \Delta L_{VB} \tag{2}$$

According to C.R.N. standard, $\Delta L_v = 0$ dB for the mean flux velocity from 30 km/h to 50 km/h. This value was selected due to the fact that vehicle speed is limited to 40 km/h across the experiment sites.

The value of correction for the road gradient $\Delta L_g = 0$ dB. The correction is not calculated for the roads with gradient less than 5% (in our case road gradient is 0%).

ΔL_{VB} is a coefficient that takes into account the presence of traffic lights (+1.0 dB) or slow traffic (-1.5 dB).

The value for the experiment purpose is: ΔL_{VB} =- 1.5 dB.

The correction for the road pavement, for the smooth asphalt value is: ΔL_p =- 0.5 dB

The correction for the presence of reflective façade (for the opposite side from the façade) is: ΔL_F = 1.5 dB

The total calculated correction value according to formula (2) is:

$$\Delta L = 0\text{ dB} + 0\text{ dB} - 1.5\text{ dB} - 0.5\text{ dB} + 1.5\text{ dB}$$

$$\Delta L = - 0.5\text{ dB}$$

The most powerful sources of noise on ferryboats are: the main diesel engine, propeller, diesel generator, turbo generator, compressor, refrigeration machinery, system of ventilation and air cooling, ventilators for forced air flow, ventilators for ventilation of engine room and various types of pumps. Generally, operating diesel engines have a higher sound level than other types of machines installed on the ferryboat. The noise generated by the main engine and propellers is primary during operating performance of the ferryboat (sailing and docking). During the "idling" (when the ferryboat is on load) the primary noise source can be auxiliary power systems or, for example, the usage of sound signalling device [13]. In this particular case, the noise created by the operating and auxiliary systems on ferryboats is shown throughout the number of arrivals/departures of a certain type of a ferryboat. Type 1 presents an older ferryboat, of smaller capacity, on which the methods of acoustical planning are not applied. Type 2 presents a newer ferryboat of larger capacity, which meets the requirements of IMO resolution on permitted noise levels on boats [14]. The noise generated by passenger vehicles, freight vehicles and buses during loading/unloading from the ferry boat is presented throughout vehicle flow in the observed time interval. Due to the influence on the generated noise regarding to distance from the source (ferries), the selected experiment positions were at a distance from 5 m to 100 m from the ferries port. In order to obtain the noise prediction model as realistic as possible, care was taken that the meteorological conditions had been taken into account [15, 16]. The experiment was conducted under conditions favourable to the sound propagation (dry weather, wind speed less than 5 m/s, without negative temperature gradient nearby). The sound was propagated above the solid surface, while meeting the condition that the ratio of the sum of the height of receiver (microphone) and sources (vehicles and ferries) with the distance between them was higher than 0.1 [17].

Since the experiment was conducted at the positions close to the sea coast (3 m-5 m), the sea condition in accordance with the "Beaufort Scale" was taken as a parameter that significantly affects the generation of noise [18]. As the measurements were performed under conditions where the wind speed did not exceed the value of 5 m/s, the sea condition according to the "Beaufort" scale was recorded during the measurements in the range of 0-3. When selecting the positions for the measurement of equivalent noise level (L_{eq}), care was taken that the requirements defined by ISO 1996 standard were met [17]. The instrument was placed at a distance of 1.2 m in relation to the surface, a minimum of 1 m in relation to any reflective surface and distance of 5.5 m in relation to the road axis (two-lane road, 7 m wide). Measurements were performed at three measurement sites (Position 2, Position 3 and Position 5) (*Figure 1*), near the seaside (positioning on the opposite side was impossible due to houses very close to the road). The measurement period was May-June 2012, by a random day selection, in the period from 8 a.m. to 8 p.m., in measurement intervals of 1 hour. The necessary data were collected by a two-person team, which simultaneously counted the vehicles on the highway, vehicles from the ferries, ferries approaches/departures and controlled noise measurement. The measurements were performed by modular precise noise analyzer which met the prescribed IEC60804 standard. The set frequency range from 6.3 Hz to 20 kHz corresponded to the frequency range for tertiary noise analysis. A/C-weighting curve was set (C-weighting due to noise emitted on low frequency by ferry) for frequency weighting with the rapid response time of 0.125 s. The dynamic range of the instrument for tone signal at the frequency of 1 kHz was set for the maximum value of 140 dB. Before and after completion of measurement, the device was verified by using the sound calibrator, which produced a sound level of 94 dB at a frequency of 1,000 Hz, with the accuracy of ± 0.25 dB. "Free-field" microphone, size of 0.5 inches, a working range from 2.6 Hz to 20 kHz was used during the measurement.

Figure 1 - Satellite imagery of the Village Kamenari with measurement sites

Table 1 – Characteristic values

X1 – Vehicles moving on the highway
X2 – Freight vehicles and buses moving on the highway
X3 – Number of arrivals/departures of the ferryboat type 1
X4 – Number of arrivals/departures of the ferryboat type 2
X5 – Freight vehicles and buses loading/unloading from the ferryboat
X6 – Vehicles loading/unloading from the ferryboat
X7 – Sea condition
Y – Equivalent noise level $L_{eq,1h}$ [dB]

Table 2 – Statistical data analysis and correlation matrix

Variable	X1	X2	X3	X4	X5	X6	X7	Y
Number of Points	648	648	648	648	648	648	648	648
Missing Points	0	0	0	0	0	0	0	0
Maximum Value	74	7	4	2	68	21	3	74.3
Minimum Value	4	0	0	0	48	1	0	62.3
Range	70	7	4	2	20	20	3	12
Average	37.4459	3.0318	1.9873	0.4777	57.1019	6.3503	0.5796	67.7459
Standard Deviation	14.8912	1.3128	1.0377	0.6262	4.1031	3.3395	0.5676	2.1920

Correlation Matrix

	X1	X2	X3	X4	X5	X6	X7	Y
X1	1.0000	0.3095	0.2738	0.2286	0.9297	0.1294	-0.0717	0.1708
X2	0.3095	1.0000	0.1885	0.2231	0.0518	-0.0333	0.0353	0.3613
X3	0.2738	0.1885	1.0000	-0.4641	0.4429	0.2233	-0.0418	0.3004
X4	0.2286	0.2231	-0.4641	1.0000	0.0732	-0.1143	-0.0626	0.1253
X5	0.9297	0.0518	0.4429	0.0732	1.0000	0.1836	-0.0998	0.2553
X6	0.1294	-0.0333	0.2233	-0.1143	0.1836	1.0000	-0.0672	0.0242
X7	0.0717	0.0353	-0.0418	-0.0626	-0.0998	-0.0672	1.0000	0.0303
Y	0.1708	0.3613	0.3004	0.1253	0.2553	0.0242	0.0303	1.0000

3. RESULTS

To develop generated traffic noise a relationship is found between two or more variables and these relationships are expressed in a mathematical form. By conducting a series of experimental measurements, the sampling population of 648 data for each characteristic value was obtained, with the aim of obtaining the best possible accuracy of the noise prediction model. The measurements were focused on equivalent noise level, the number of vehicles moving on the road, vehicles loading/unloading from the ferryboat, the number and type of ferryboats that plied and the sea condition. Characteristic values recorded during the experiment are shown in *Table 1*.

After finalization of the process for experimental characteristic values collection non-linear regression multi-factorial analysis was done. By entering the experimental results in the program matrix (DataFit9 software version 9), the correlation matrix was obtained (*Table 2*).

Based on the data collected on different days, between 8.00 a.m. to 8.00 p.m., regression analysis was done according to formula:

$$Y = \log[a \cdot X1 + b \cdot X2 + c \cdot X3 + d \cdot X4 + e \cdot X5 + f \cdot X6 + g \cdot X7 + h] - 0.5 \quad (3)$$

Deduction Value of (– 0.5) in formula (3), presents total calculated correction (ΔL) according to formula (2).

The obtained values of regression coefficients with independent variables are given in *Table 3*.

Normality of residual distribution diagram is shown in *Figure 2*.

Variance analysis is shown in *Table 4*.

The best form of regression equation obtained is:

$$Y = \log(0.4892\,X1 + 2.1283\,X2 + 1.8163\,X3 + 0.9121\,X4 + 1.9061\,X5 + 3.2576\,X6 +$$

Table 3 – Values of coefficients with independent variables

Var.	Value	Standard Error	t-ratio	Prob(t)
a	0.4892	8.3734E-03	58.4236	0.0
b	2.1283	3.3561E-02	63.4184	0.0
c	1.8163	4.1760E-02	43.4938	0.0
d	0.9121	4.0211E-02	22.6822	0.0
e	1.9061	3.1693E-02	60.1441	0.0
f	0.0033	5.7179E-03	0.5697	0.5697
g	2.4227	3.3956E-02	0.7135	0.4766
h	77.8458	1.5185	51.2632	0.0

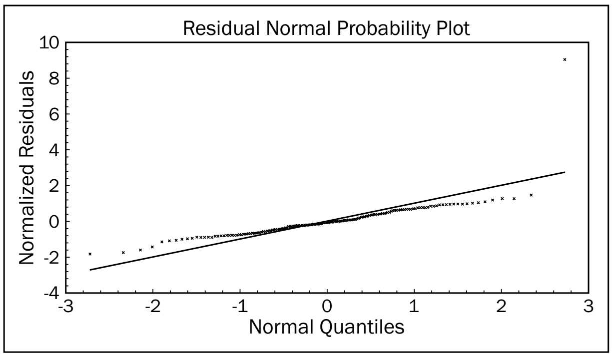

Figure 2 – Normality of residual distribution diagram

$+2.4227\ X7 - 7.8458) - 0.5$

Coefficient of Multiple Determinations

$R^2 = 0.96937$

As a part of this study, the statistical goodness-of-fit test was provided to test the prediction values against the field observed data. To test the validity of the model a total number of 157 measurements were taken at 3 sites (Position1, Position 4 and Position 6), different from those that were used for the construction of the model (Figure1). The t-paired test outputs are shown in table 5.

Table 4 – Variance analysis

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob (F)
Regres.	7	726.5958	103.7994	673.7876	0
Error	149	22.9539	0.15405		
Total	647	749.5498			

Table 5 – The t-Test paired two samples for means

Pearson Correlation	0.911
Hypothesized mean difference	0
Degree of freedom	156
t-statistics	0.03781
Level of significance	0.05
Probability two-tail	0.97132
t-critical two-tail	1.97402

Comparison of $L_{eq,1h}$ results obtained by experimental collection and the results obtained using the model is shown in *Figure 3*.

4. DISCUSSION

Modelling is the process of theoretical assessment of the quantity in the observed interest region under specific conditions. Specific conditions under which an assessment is made may represent only the current picture or a permanent condition. In the real world, the environment has the characteristic of constant variability. The specific conditions under which the modelling of environmental noise is done will be only "snapshots" of the actual condition in the observed interest region within a given time domain [19]. This variability of conditions in the real world causes the variations of sound field in space and time. It helps us understand that the sound level values obtained by the developed

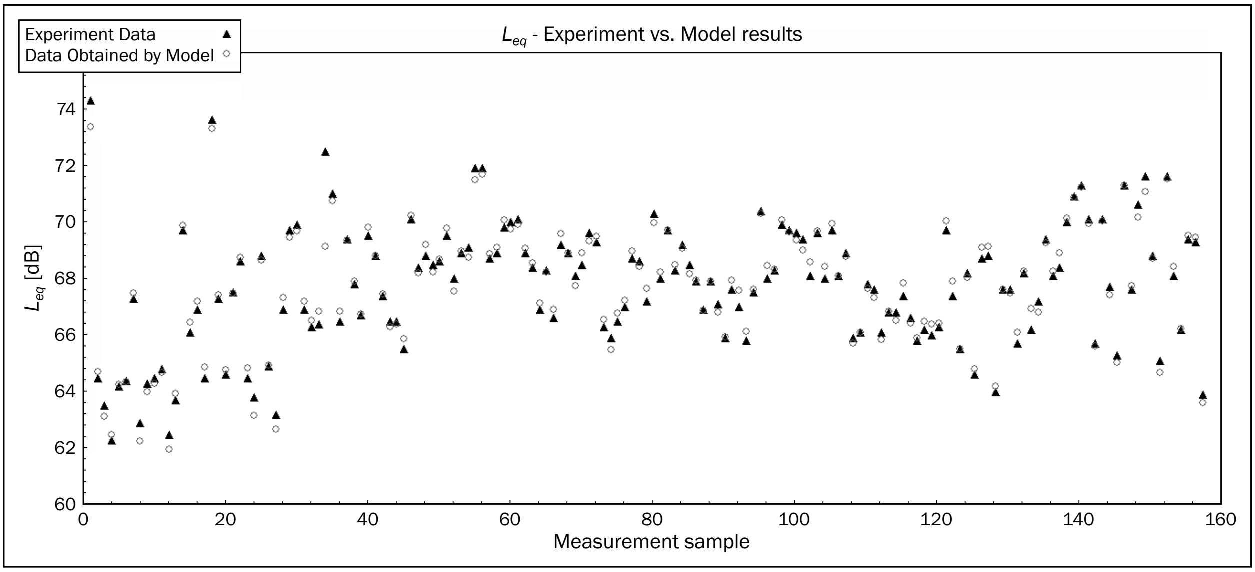

Figure 3 – Comparison of L_{eq} results obtained by experimental collection and the results obtained using the model

acoustic model will represent the values that may or may not occur in real space and time. Therefore, for the process of successful modelling of environmental noise, it is crucial to define the specific conditions that characterize the observed region as precisely as possible. This primarily means to detect noise sources. In urban areas where residential and commercial buildings are located in the immediate vicinity of roads, road traffic is highlighted as the most important noise source [20]. In our particular example this claim does not match entirely, regardless of the fact that the "Adriatic" highway passes through the populated place Kamenari. It means that frequent road traffic takes place just a few metres of distance from the residential and commercial buildings. Namely, other than road traffic, very frequent sea traffic takes place at the observed location. Precisely, six ferryboats of the company JSC "Maritime transport" - Kotor continuously ply at the given site. Ferryboats plying represents an important noise source and therefore is included as one of the two main sources in the creation of the acoustic model. The existence of two relevant noise sources at the given site represents a specific situation and also a unique case. It is very important during the modelling process to approximate the characteristics of the physical environment through which the sound wave will be transmitted from the source point to the receiver point [21]. The influence of the physical environment characteristics were calculated according to C.R.N. standard and presented as part of total correction coefficient (ΔL). The fact that the value of Prob(t) for almost all of the coefficients with independent variables is zero (*Table 3*), shows that the selection of independent model parameters has been adequate [22]. The exception are the value of coefficient f with parameter X6 (Prob(t)=0.5697) and the coefficient with parameter X7 (Prob(t)=0.4766). The probability that the value of these two independent variables will be equal to zero is 56.9% and 47.66%, respectively, and rejects the assumption about significant influence of the number of vehicles loading/unloading from the ferryboat, as well as the sea condition. This can be explained by the low vehicle speed and low engine speed of vehicles during the loading/unloading from the ferry. The sea condition did not significantly influence the amount of generated noise. This is supported by the fact that the measurements were carried out under conditions where the sea condition in accordance with Beaufort scale was in the range of 0-3, i.e. calm or a little wavy sea [18]. It can be seen from the analysis of variance (*Table 4*) that Prob(F)=0. This fact completely eliminates the hypothesis that all the parameters with the independent coefficients are equal to zero and confirms that the dependent variable Y can be determined by the assumed model [22]. It is seen from the normality of residual distribution diagram (*Figure 2*), that the residuals have normal distribution, but with a different environment (the line does not pass through coordinate beginning) and present deviations. This confirms the adequacy of the calculated regression coefficients (a-h) [22].

The value of "t-ratio" for coefficients with independent variables (*Table 3*) tells us which of the independent variables has the greatest impact on the dependent variable Y, i.e. the equivalent noise level [22]. The greatest value of t-ratio=63.4184 is for parameter (b) with independent variable X2. This tells us that freight vehicles and buses moving on the highway, have the greatest impact on the equivalent noise level (Leq). Value of t-ratio=60.1441 for parameter (e) with independent variable X5 indicates great impact of freight vehicles and trucks loading/unloading from the ferryboat on the generated noise level. By comparing the value of t-ratio for coefficients c (t-ratio= 43.4937) and d (t-ratio=22.6821) with parameters X3 (arrivals/departures of the ferryboat type 1) and X4 (arrivals/departures of the ferryboat type 2) (*Table 3*), we come to the conclusion that sound events related to ferry boat Type 1 have significantly greater impact on level Leq than those related to ferryboat Type 2. This is explained by the fact that ferryboat Type 1 generates greater noise caused by ageing and failure to apply acoustic protection measures on the main and auxiliary power systems. The coefficient of non-linear regression analysis R^2 = 0.9677 is very close to the "best fit" value of R^2 = 1 [22].

A very important part of the experiment was validation of the development model. The paired t-test was carried out to provide the statistical test for the differences between the predicted results obtained by the model and the measured results from the field [22]. The null hypothesis was μ=0, that is the mean value of the differences between pairs of measured noise and predicted noise. The results from paired t-test at a significance level of 5% show that the critical value is greater than t-statistics (*Table 5*), so the null hypothesis is accepted. The Pearson correlation coefficient (0.911) between the measured and the predicted data indicates a very good correlation between the calculated and experimental data. The fact that the deviations of the predicted values from the actually measured values of equivalent noise levels are very small speaks about the good-fit of the model (*Figure 3*).

5. CONCLUSION

The model for the assessment of noise level in urban area that is simultaneously generated by road and sea traffic in the coastal area of Boka Kotorska Bay has been developed. The validity of the model is confirmed by very small deviations of the sound/noise levels empirically obtained, in comparison to the corresponding values obtained by the developed model. Freight vehicles and buses, whether transported by ferryboats or moving along the "Adriatic" highway, are highlighted as factors that specifically influence the assessed noise level. Significant influence on the level of environmental noise is done by the type of ferryboats used for transport of people and vehicles. By application of the developed model, in a very short period of time and in a simple way, it is possible to predict the noise level, without having to use precise noise instruments. With appropriate corrections in accordance to C.R.N. standard, a model can be applied at any urban site along the coast where the road and ferry traffic present a significant noise source. Future scope of research should comprise the analysis of influence under rainy and windy weather conditions.

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ABSTRAKT

MODEL ZA OCJENU KOMUNALNE BUKE U BOKOKOTORSKOM ZALIVU

Kao glavni izvor buke u urbanim sredinama označen je saobraćaj. Mjesto Kamenari u Bokokotorskom zalivu je sredina u kojoj se na relativno malom prostoru istovremeno odvija drumski i pomorski saobraćaj. Zbog specifičnosti pomenute lokacije, tj. veoma rijetke sinergije zvučnih efekata generisanih drumskim i pomorskim saobraćajem, kao i potrebe da se na brz i jednostavan način izvrši ocjena nivoa komunalne buke, sproveden je eksperiment sa ciljem da se dobije jedinstven model za ocjenu ekvivalentnog nivoa buke(Leq). Kao rezultat sprovedenog eksperimenta primjenom empirijskih metoda i statističkom analizom, dobijen je model za ocjenu nivoa ekvivalentne buke(Leq). Razvijeni model daje realne podatke o nivoima komunalne buke uz veoma mala odstupanja u odnosu na empirijski dobijene vrijednosti.

KLJUČNE RIJEČI

komunalna buka; akustičko modeliranje; saobraćaj; zagađenje životne sredine

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