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ORIGINAL SCIENTIFIC PAPER

Measuring and assessment of road traffic air pollution assessment on the motorway e-661 at the locations near the mahovljani and gradiska interchange

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Abstract: The paper gives an overview of different air pollution models in projects and studies in the field of road traffic. A brief description is given for the presented models with key elements for their application. Special emphasis in the paper is given to the application of the current model in the Republic of Srpska. Literature analysis in the field of air pollution modeling has shown that there are a large number of air pollution models. The most comprehensive model in terms of applicability and available data is the COPERT IV model, which is widely used in the European Union.

Keywords: traffic, air pollution, models

INTRODUCTION

The emission of air pollutants can lead to various negative effects. The most relevant and probably best analyzed are the effects on health resulting from the air pollutants. However, other damages are also relevant, such as construction and material damages, loss of crops and biodiversity [7].

Air pollution can be defined as the presence of any substance or several substances in the atmosphere, which are undesirable or harmful to human health, either externally or internally, or the presence of which either directly or indirectly impairs human well-being [18].

Air pollution directly affects the deaths of about seven million people worldwide each year. Data from the World Health Organization show that 9 out of 10 people breathe the air that contains high levels of pollutants. Air pollution worldwide contributes to 7.6% of all deaths in 2016 [22].

In the European Union, air pollution continues to have a significant impact on the health of people, especially in urban areas. Major air pollutants in the European Union are: carbon monoxide (CO), nitrogen oxides (NO_X, NO and NO_2, sulfur dioxide (SO_2), suspended particles ($PM_{2,5}$ and PM_{10}) and ground-level ozone (O_3). Estimates of the impact on human health, which can be attributed to exposure to air pollution, indicate that in 2016, the concentration of $PM_{2.5}$ suspended particles is solely responsible for about 412,000 premature deaths, which resulted from a long-term exposure in Europe [9].

According to measurements performed by the Republic Hydrometeorological Institute in the territory of the Republic of Srpska in 2018, the air quality was classified into the following three categories [19]:

- Category I - clean or slightly polluted air was recorded in the agglomeration of Banja Luka and Trebinje;
- Category II - moderately polluted air was not recorded in any agglomeration;
- Category III - excessively polluted air was recorded in the agglomeration of Doboj (suspended particles PM_{10} and suspended particles $PM_{2.5}$), in agglomeration Prijedor (suspended particles PM_{10} and suspended particles $PM_{2.5}$) and in the agglomeration of Bijeljina (nitrogen dioxide NO_2) (Republic Hydrometeorological Institute, 2019).

In order to examine the key causes of air pollution, researchers around the world apply various methods and models for examining the impact of air pollution resulting from road transport. Some of the key models used in evaluating the impact of air pollution resulting from road traffic shall be presented further in this paper.

MODELLING OF AIR POLLUTION IN EUROPE

Pollutant emissions occur in the planetary boundary layer, which is the lowest part of the troposphere and is in direct contact with the Earth's surface [3]. Atmospheric pollution modeling is used to describe causal links between emissions, meteorological parameters, pollutant concentration, etc. Valuation of emission measurement results is a procedure where the measurement results are compared with the stipulated limit values.

The division of models describing air pollution can be performed in a number of ways. The researchers have classified the models for air pollution modeling into three categories, i.e. dispersion, statistical and physical models [1].

Dispersion models calculate the concentrations of pollutants from the emission inventory and the meteorological variables according to the solutions of various equations, which represent relevant physical processes. The most commonly used model is the Gaussian dispersion model [6]. According to WHO, the Gaussian model is particularly useful for describing the dispersion of pollutants at local level [21]. Gauss's equation is used to calculate the dispersion in conditions where the emission source is downwind, in advection conditions and with the defined direction of the wind. Characteristic picture related to Gaussian model of dispersion:

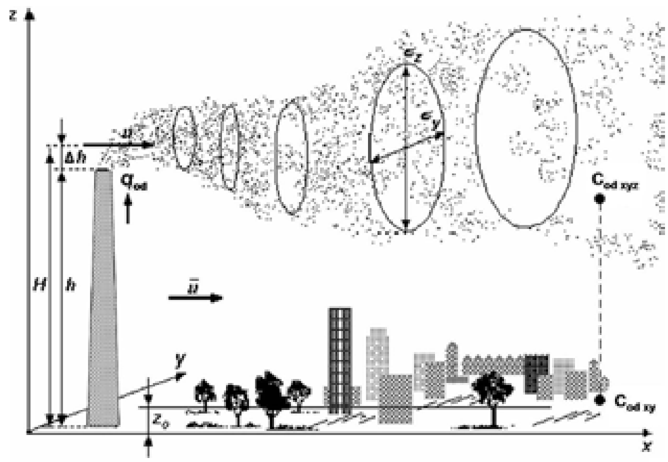

Figure 1. Gaussian spread model [15]

$$C_{od,xyz} = \frac{q_{od}}{2\pi\bar{u}\sigma_y\sigma_z} exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{exp\left[-\frac{(Z-H)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(Z+H)^2}{2\sigma_z^2}\right]\right\} \quad (1)$$

$$\sigma_y = Ax^a \qquad A = 0{,}08\left(6m^{-0{,}3} + 1 - ln\frac{H}{Z_0}\right) \qquad a = 0{,}367(2{,}5 - m) \quad (2)$$

$$\sigma_z = Bx^b \qquad B = 0{,}38m^{1{,}3}\left(8{,}7 - \ln\frac{H}{Z_0}\right) \qquad b = 1{,}55exp(-2{,}35m) \quad (3)$$

where: C - is concentration of pollutants, Q_1 - is the emission factor per unit of length, u - is average wind speed, θ - is the angle between the street and the direction of the wind x, y, z - are spatial coordinates, H - effective height of the source, p - half of the length from the source line, σ_z and σ_y - vertical and lateral dispersion parameters.

In contrast to deterministic modeling, statistical models calculate concentrations by statistical methods from meteorological and traffic parameters, after the corresponding statistical ratio from the measured concentrations has been empirically obtained. Key statistical modeling methods are regression, multiple regression techniques, time series, and artificial neural networks [1].

Some authors have analyzed and compared three classes of hierarchical models and they came to the conclusion that the model with a complex hierarchical structure is generally preferable to a model with complex space-time covariance[4]. Nevertheless, in the absence of adequate computational resources, one can choose a model that is simple in its structure and with a simple covariance function, as it shows good prediction characteristics at reasonable computational costs.

In a physical model, a physical experiment simulates a real process on a smaller scale in a laboratory, which models important characteristics of the original processes that are being studied [17]. Typical experimental devices, such as air tunnels, are being used, where atmospheric flows are simulated inside a tunnel. This type of physical modeling conducted in an air tunnel, where atmospheric flows are modeled by air as a liquid medium, is also referred to by various researchers as liquid modeling ([17]; [20]).

Contemporary software tools are based on these models. Additionally, air pollution models are the basis for the development of strategic, legal and regulative framework.

Contemporary tools in the analysis of air pollution

The application of software tools for the calculation of pollutant's emissions by road traffic enables the creation of high-quality, comparable and standardized databases, and faster and simpler analysis of a large number of data.

Mostly applied in the USA is the atmospheric dispersion modeling system AERMOD [5]. It is an integrated system that includes several models: model for dispersion in the atmosphere (AERMOD model), terrain processor AERMAP (which is used in the presence of complex terrain for estimating the height of the scale of each receptor), meteorological processor AERMET, (which is used for preparation of inputs for the simulations by dispersion model), AERSURFACE model (used for determining the geophysical parameters being entered into the AERMET). AERMOD can simultaneously simulate multiple sources of different shapes, ground-level or elevated, floating or non-floating, emitting one or multiple pollutants. AERMOD is capable of explaining the inhomogeneous vertical structure of the boundary layer (also by using the vertical profile of meteorological variables). Vertical mixing is limited in the case of stable conditions. This model enables modelling of the spatial spread of pollution.

In California, the software tool CALINE 4 is used [2]. The model uses emissions of polluting substances generated from road traffic, terrain geometry and meteorology to predict pollutant concentrations in the air in the vicinity of roads. Carbon monoxide, nitrogen dioxide and suspended particles can be predicted.

In the European Union, the software tool COPERT IV is used for determining the quantities of emitted gaseous polluting substances generated from road traffic [10]. This software tool uses AADT (Annual Average Daily Traffic), mileage crossed, speed and other data, such as e.g. the temperature of the environment, and it calculates the emission and the consumption of energy for a particular state or region. The software tool COPERT IV estimates the emission of the most significant pollutants (CO, NOX, NO2, SO2, PM2.5, PM10, O3, etc.) This model returns the amounts of emitted substances.

The German-Swiss model (HBEFA) was developed with the aim of determining the emission of all relevant categories of road vehicles in the two countries [12]. The emission factors in this model were not represented as a continuous function (for example of the average speed), but rather as a parametric discrete function that depended on the traffic flow. Traffic flow parameters are described based on manner in which the speed changes. The characteristics of the speed changes enable calculation of a wide range of kinematic parameters, which describe the traffic flow.

In addition to these solutions, numerous models and software tools are used in the world, but for the purposes of this paper, only the most significant ones according to the author's knowledge are specified.

Regulations of significance

The regulations for assessing air pollution generated from road transport includes agreements, conventions, standards, laws, rulebooks, ordinances, technical instructions and similar.

The most significant international agreement related to air pollution, which limits emission of pollutants, is the Kyoto Protocol [11]. It defines legal obligations to reduce greenhouse gas emissions (*greenhouse gas* - GHG).

Particular attention in the European Union, within the White Paper, is dedicated to environmental issues, i.e. GHG emissions [8]. A total of ten goals have been defined, the achievement of which will lead to structural changes in the traffic system of the EU by the year 2050. The defined goals are in line with the targets to reduce GHG emissions by 20% by 2030 and by 70% by 2050, compared to 2008 levels. In addition to this, several regulations and directives have been defined, in particular:

- Regulation (EU) No 1293/2013 of the European Parliament and of the Council of 11 December 2013 on the establishment of a Programme for the Environment and Climate Action (LIFE) and repealing Regulation (EC) No 614/2007;
- The revised Directive on limit values of national emissions (*National Emission Ceilings Directive* 2016/2284/EC), with more strict ceilings for national emissions of the six major pollutants (NO_x, VOC, SO_2, NH_3, $PM_{2.5}$ и CH_4), as well as measures to reduce soot;
- Directive on the quality of ambient air (*Ambient Air Quality Directive* (AAQD) 2008/50/EC);
- Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment;
- Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the strategic assessment of the effects of certain plans and programmes on the environment;
- Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing Infrastructure for Information on Spatial Planning (INSPIRE).

Legislation of the European Union is being transposed in the Republic of Srpska through the AQUIS. The assessment of air quality, i.e. emission of pollutants, is carried out on the basis of the following regulations and standards:

- Law on Environmental Protection ("Official Gazette of the Republic of Srpska", No. 71/12 and 79/15);
- Law on air protection ("Official Gazette of the Republic of Srpska", No. 124/11 and 46/17);
- Regulation on air quality values ("Official Gazette of the Republic of Srpska", No. 124/12);
- Regulation on conditions for air quality monitoring ("Official Gazette of the Republic of Srpska", No. 124/12);
- Regulation on designation of zone and agglomeration ("Official Gazette of the Republic of Srpska", No. 100/12);
- BAS ISO/IEC 17025:2055, IDT: General requirements for the completeness of test and calibration laboratories;
- BAS EN 14625:2005, IDT: Ambient air quality - Standard method for measuring ozone concentration by ultraviolet photometry;
- BAS EN 14211:2005, IDT: Ambient air quality -

Standard method for measuring concentration of nitrogen-dioxide and nitrogen-monoxide by chemiluminescence;
- BAS EN 14212:2005, IDT: Ambient air quality - Standard method for measuring concentration of sulfur-dioxide by ultraviolet fluorescence;
- BAS En 14626:2005, IDT: Ambient air quality - Standard method for measuring concentration of carbon-monoxide by non-dispersive infrared spectroscopy;
- BAS EN 12341:1998, IDT: Analyzing suspended particles, RM_{10} fractions.

Regulation on air quality values ("Official Gazette of the Republic of Srpska", No. 124/12) sets the air quality values for the purpose of air quality management on the territory of the Republic of Srpska. If no limit of tolerance is prescribed for some particular polluting substance, its limit value is taken as a tolerable value. Air quality categories are determined once a year for the previous calendar year.

EXAMPLE OF PRESENTATION OF THE RESULTS OF AIR QUALITY ANALYSIS IN THE REPUBLIC OF SRPSKA

For the purpose of environmental air quality assessment in the exploitation phase of the motorway E-661 (Banja Luka – Gradiška), the impact of air pollution on the environment was assessed at the following two locations on the Motorway E-661: the location "Mahovljanska petlja" [13] and "Gradiščanska petlja" [14].

At the location "Mahovljanska petlja" (Mahovljani Intersection) in Laktaši, air quality sampling was performed from 10:00 hrs on 15 October 2018 until 10:00 hrs on 22 October 2018. The location of the measuring point is next to the motorway – chainage km40+600.00, cross-section PR 80. While at the location "Gradiščanska petlja" (Gradiška Intersection) in the settlement of Čatrnja, Municipality of Gradiška, air quality sampling was performed from 09:00 hrs on 12 June 2018 until 09:00 hrs on 19 June 2018. The measurement was performed in the courtyard of an individual residential building immediately next to the highway, i.e. the measuring point is at the distance of about 75 m from the motorway. There were no physical obstacles between the air quality measurement station and the motorway. The examination was carried out according to the principle of 24-hour sampling for 7 days at the particular measurement site.

Monitoring of the concentration of SO_2 is performed on the SO_2 concentration measurement analyzer, Model T 100 (*UV Fluorescence* SO_2 *Analyzer*) and UV fluorescence method, measuring range 0-20 ppm. Monitoring concentration of NO_x is performed on the analyzer for measuring the concentration of NO_x, NO, NO_2, Model T 200 (*Chemiluminescence NO/NO_2/NO_x Analyzer)*. To determine the level of pollution for NO_x, NO, NO_2 the method of chemiluminescence, measuring range 0-2000 ppb, is used. For monitoring of suspended particles up to 10µg/m^3 the β-ray absorption method is used, the requirements of which are set out in the standard BAS EN 10473. PM_{10} and $PM_{2.5}$ are the fractions of suspended particles (PM - *particulate matter*) that passes through the filter for sampling and measuring PM_{10} and $PM_{2.5}$ fractions, with the efficiency of 50% of the catchment of particles of aerodynamic diameter of 10 µm, or 2.5 µm. The sampling and analysis is carried out by the VAM 1020 device (*Particulate Monitor*). Monitoring of ground ozone emission is carried out by the reference UV photometric method, measuring range 0-10 ppm, Model T 400 (*UV absorption O_3 analyzer*). For carbon monoxide (CO) monitoring, Model T 300 analyzer (MODEL T 300 *Gas Filter Correlation* CO *Analyzer*) and non-dispersive infrared spectrometric method (NDIR) of the measuring range of 0-1000 ppm.

The measuring site "Mahovljanska petlja" is located about 700 meters from the center of Laktaši towards the northwest, on the southwest part of the Lijevče field. It is part of a spacious alluvial terrace plane with an absolute height of 126 meters. The space is in direct contact with the foothill slopes located at the western part of Lijevče field.

Measuring location "Gradiščanska petlja" is located at about 6.5 km from the center of Gradiška towards the West, in the northwestern part of Lijevče field. It is part of a spacious alluvial terrace plane with an absolute height of 126 meters. The space is in direct contact with the foothill slopes located at the western part of Lijevče field.

Figure 2. Location of air quality measurement "Mahovljanska petlja" and "Gradiščanska petlja"

Several different factors are currently influencing the air quality in the measurement catchment area, the following:

- Intensity of traffic on the motorway E-661, intensity of traffic on the main road M-16 (Banja Luka-Gradiška) situated about 500 meters east from the measuring site ("Mahovljanska petlja"), intensity of traffic on the adjacent local roads especially on the local road Gradiška-Gornji Podgradci ("Gradiščanska petlja"), intensity of traffic on the adjacent roads, types of vehicles as well as the fuels used by the vehicles, quality of the roads,
- Furnaces in residential and commercial buildings in Laktaši and in surrounding rural settlements, which again depends on the season, weather conditions and the type of energy-generating product used in residential buildings for heating and other activities,
- Agricultural works on the surrounding agricultural lands,
- Hydro-meteorological circumstances.

When selecting micro-locations for fixed measurements, the following factors are taken into consideration: disturbance sources, safety, access, availability of electricity and telephone lines, visibility of the measuring spot in relation to the surroundings, safety of the public and of the technical staff, possibility of setting the site for taking samples of different polluting substances at the same location and requirements related to spatial planning.

The measuring station "Mahovljanska petlja" is set up within the courtyard of an individual residential building. The courtyard borders the motorway E-661 on the west side. In the process of expropriation, prior to the construction of the subject motorway, the house was purchased from the previous owners, and it is now used for the purposes of the PE "Autoputevi Republike Srpske", i.e. it is being rented to a family of three. In the vicinity of the measuring site, there is another individual residential building, located towards the center of Laktaši.

While the measuring station "Gradiščanska petlja" is set up within the courtyard of an individual residential building. The courtyard borders the motorway E-661 on the west side. In the vicinity of the measuring site, there is also a small steel-foundry, and several individual residential buildings that are situated more than 300 m from the measuring site. The site is extremely rural, with cultivated agricultural areas, livestock accommodation facilities - stables, and woodlots.

During measuring, sampling was carried out according to Article 9 of the Regulation on conditions for air quality monitoring ("Official Gazette of the Republic of Srpska", No. 124/12), i.e:

- suction pipe for taking air samples must be in the open so as to allow free air flow (in an arc of at least 2700) and without obstructions that could affect the air flow (most often this is the distance of several meters from buildings, balconies, trees and other objects or at least 0.5 m from the nearest building, in the case that the measuring site for sampling represents quality of the air in a building's surroundings),
- pipe height: 1.5-4m, 8m if the measuring site is representative for a large area,
- the suction pipe for sampling must not be mounted in the vicinity of an emission source,
- for the purpose of monitoring the effect of roads: no more than 25 m from the edge of an intersection, i.e. 10 m from the curb.

When selecting micro-locations for fixed measurements, the following factors are taken into consideration: disturbance sources, safety, access, availability of electricity and telephone lines, visibility of the measuring spot in relation to the surroundings, safety of the public and of the technical staff, possibility of setting the site for taking samples of different polluting substances at the same location and requirements related to spatial planning.

Air pollution calculations for characteristic road sections were carried out on the basis of a developed computer program, the basis of which is based on the settings of the German model defined in the guidelines for the calculation of air pollution on roads [16]. Calculations were performed on the basis of emission factors, i.e. the total amount of pollutant substances being emitted from the vehicles of a particular class, age, average fuel consumption and average speed of movement, taking into consideration the road section crossed (in km) and the AADT. The parameters of the components of the air pollutants in the form of the mean annual values and the values of the 95th percentile are determined on the basis of the deterministic law in the exponential form:

$$K_i(s) = K_{i^*} \times g(s) \times f_{vi} \times f_u \quad \left[\frac{mg}{m^3}\right] \tag{4}$$

where: K_{i^*} - is the reference concentration of the individual component *(i)* at the ground level at the edge of the carriageway, *g(s)* - is the function of dispersion of harmful substances, f_{vi} - is the function that takes into account specific traffic data, f_u - is the function by means of which the wind speed is taken into account.

The comparison of the average daily value of concentrations in the environment to the limit values taken from the Regulation on air quality values was carried out after collecting and processing of data from the field.

In the Table 1. and Table 2, basic statistical indicators are given: arithmetic mean, median, 98th percentile, measurement uncertainty, minimum value, maximum value, detection limit and quantification limit for the values measured at the location "Mahovljanska petlja" and "Gardiščanska petlja".

Table 1. Basic statistical indicators at the location "Mahovljanska petlja" (Mahovljani Intersection)

Pollutants	Arithmetic mean [µg/m³]	Median	98. precentil [µg/m³]	Measurement uncertainty	Minimal value [µg/m³]	Maximal value [µg/m³]	Detection limit [µg/m³]	Limit of quantification
SO_2	20.20	20.36	33.10	0.03	6.83	40.38	0.1	1
NO_2	25.80	25.72	38.06	0.03	11.08	39.26	0.1	1
ULP	41.82	36.61	83.24	0.03	18.20	106.55	10	100
O_3	30.24	28.44	73.43	0.03	4.06	79.26	1	4
CO	813.42	676.33	1808.95	0.03	256.52	2599.36	10	2
NO	31.07	25.07	79.41	0.03	10.08	192.92	0.1	1

Table 2. Basic statistical indicators at the location "Gradiščanska petlja" (Gradiška Intersection)

Pollutants	Arithmetic mean [µg/m³]	Median	98. precentil [µg/m³]	Measurement uncertainty	Minimal value [µg/m³]	Maximal value [µg/m³]	Detection limit [µg/m³]	Limit of quantification
SO_2	11.47	10.20	22.66	0.03	8.02	30.58	0.1	1
NO_2	70.48	68.29	86.14	0.03	61.63	93.74	0.1	1
ULP	25.84	20.10	100.71	0.03	5.49	117.80	10	100
O_3	714.40	678.60	119.99	0.03	26.34	125.22	1	4
CO	267.75	250.30	445.98	0.03	133.02	569.92	2	10
NO	134.60	12.20	36.66	0.03	6.71	54.60	0.1	1

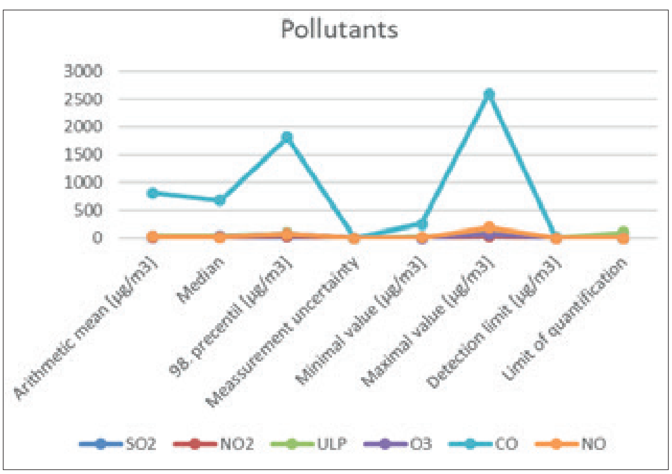

Figure 3. Basic statistical indicators at the location "Mahovljanska petlja" (Mahovljani Intersection)

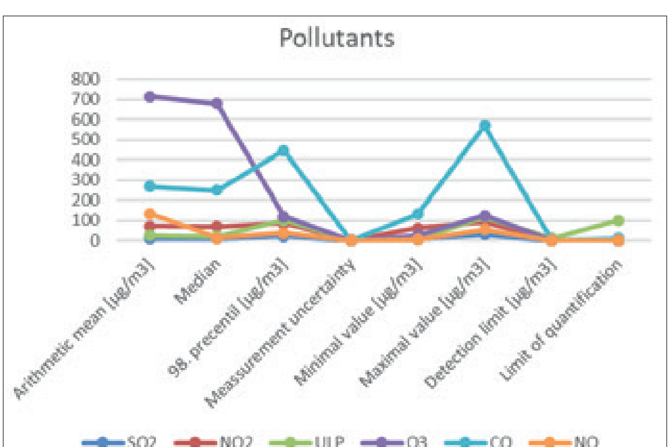

Figure 4. Basic statistical indicators at the location "Gradiščanska petlja" (Gradiška Intersection)

Based on the measurements carried out at the locations "Mahovljanska petlja" and "Gardiščanska petlja", it is notable that the average daily values of concentrations of SO_2, NO_2, ULP and CO in the environment, were below the air limit value and below the tolerable air value for protection of human health (sampling period 1 day).

Also, based on the measurements, it was determined that the average daily values of the concentration of O_3 in the environment was below the target air value for protection of human health (sampling period 8 hours).

The limit values of concentrations of NO in the air in the environment are not prescribed by the Regulation on air quality values.

CONCLUSION

Based on the models presented, it can be clearly concluded that there are different practices in the way of treating air pollution originating from road traffic in projects, studies and practices in the field of traffic.

On the analyzed example of the assessment of the environmental air quality in the exploitation phase of the motorway E-661 (Banja Luka – Gradiška) at two locations ("Mahovljanska petlja" and "Gardiščanska petlja"), 6 of the most frequent and most significant air pollutants in the Republic of Srpska were observed (SO_2, NO_2, ULP, CO, O_3 and NO). On this occasion, the following was established:

- Average daily values of sulphur-dioxide concentrations in the environment are below the limit value of air pollution and below the air pollution tolerance value for the protection of human health;

- Average daily values of nitrogen-dioxide concentrations in the environment are below the limit value of air pollution and below the air pollution tolerance value for the protection of human health;
- Average daily values of total floating/suspended particle concentrations in the environment are below the limit value of air pollution and below the air pollution tolerance value for the protection of human health;
- Average daily values of carbon-monoxide concentrations in the environment are below the limit value of air pollution and below the air pollution tolerance value for the protection of human health;
- Average daily values of ozone concentrations in the environment are below the target value of air pollution for the protection of human health;
- Average daily values of concentrations and maximum one-hour concentrations of nitrogen-monoxide have been measured, but this was not sufficient to draw conclusions about pollution at the locations where the measurement was carried out;
- Limit values of nitrogen-monoxide concentrations in the air in the environment are not prescribed by the Regulation on air quality values, and therefore had not been further analyzed, although this is necessary for the assessment of air quality, i.e. pollution assessment.

The methodology being applied in the Republic of Srpska, which is based on the German model, has to a large extent become obsolete. The disadvantages of this methodology are reflected in the fact that it relies only on the AADT and the road section traveled, while it does not take into consideration the effect of the very structure of a particular country's vehicle fleet and the extent of its use (average trip length). Therefore, there is a large space for improvement and for the application of newer tools.

Significant scope also exists in the improvement of the existing legislation, as is the practice in the surrounding countries, especially in the European Union. This primarily refers to amending current standards and regulations, in order to keep the pace with contemporary technological and technical solutions, which are used for treating air pollution in projects and studies in the field of traffic.

Bearing in mind that the COPERT IV model is recognized in the European Union, we are of the opinion that the introduction of this European model for evaluating the effect of air pollution when developing studies, would significantly contribute to the improvement of the existing practice in the Republic of Srpska.

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