ISSN 1848-0071
574+556(496.5)=111
Recieved: 2017-09-26
Accepted: 2018-01-11
Professional paper

THE IMPACT OF VEHICLES ON AIR QUALITY IN ZAGREB AND KOROMAČNO, CROATIA

PETRA BONAČIĆ BARTOLIN, ZORAN LULIĆ

Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia
e-mail: petra.bonacic.bartolin@fsb.hr

The paper was presented at 4th International Symposium on Environmental Management - Towards Circular Economy, December 7th – 9th 2016, Zagreb, Croatia

This paper describes and analyses concentrations of main traffic related air pollutants and their impact on air quality, which affects the quality of human life. The data are obtained from the measuring stations in Zagreb and Koromačno (Croatia). These two places were chosen because of their diversity, related to traffic density – Zagreb is capital of Croatia, and Koromačno is a small town in Istria region. Due to a specific way of pollution assessment, the data are presented in diagrams using an application, designed for this purpose, which enables easy comparisons and interpretation of the data. The results of this research indicate specific patterns of changes in the pollutant concentrations in relation to emissions of road motor vehicles.
Key words: air quality, directive 2008/50/EC, traffic, vehicle emission.

Utjecaj cestovnog prometa na kvalitetu zraka u gradu Zagrebu i Koromačnu, Hrvatska. Unutar ovog rada opisane su i analizirane koncentracije glavnih onečišćujućih tvari uzrokovane cestovnim prometom i njihov utjecaj na kvalitetu zraka. Koncentracija onečišćujućih tvari bitno utječe na kvalitetu ljudskog života te na okoliš u cjelini. U Republici Hrvatskoj, podaci o koncentracijama onečišćujućih tvari dobivaju se na mjernim postajama za stalno praćenje kvalitete zraka pa su za potrebe ovog rada uzeti oni sa mjernih postaja u Gradu Zagrebu i naselju Koromačno (Hrvatska). Zagreb i Koromačno su odabrani zbog svoje raznolikosti, vezane uz gustoću cestovnog prometa - Zagreb je glavni grad Hrvatske, a Koromačno je malo naselje u Istarskoj županiji. Zbog specifičnog načina procjene onečišćenja, podaci su prikazani dijagramima pomoću aplikacije koja je namijenjena toj svrsi, što omogućuje jednostavnu usporedbu i tumačenje podataka. Rezultati ovog istraživanja pokazuju specifične obrasce promjena koncentracija onečišćujućih tvari u odnosu na emisije cestovnog prometa.
Ključne riječi: kvaliteta zraka, direktiva 2008/50/EC, cestovni promet, emisije, motorna vozila.

INTRODUCTION

Air pollution has a significant impact on human health, the environment and the world economy [1]. Daily, air pollution is closely associated with adverse health effects such as respiratory diseases, cardiovascular diseases and allergies [2]. Continuous growth of industry and technology development, economic growth and ever-increasing population growth, which is a result of extending human lifespan are responsible for air pollution [3]. Work places and jobs of today are related to human mobility and consequently, growth in the number of motor vehicles, and the road traffic congestion is inevitable [4]. In order to improve the life quality it is important to investigate how increasing number of motor vehicle affects air quality [5]. Also, it is necessary to study the European directives and laws of the Republic of Croatia related to environmental protection in order to be informed about the most dangerous pollutants and the threshold limit value of these substances in the air, as well as the methods of measurement and the period of time when they should be applied. It is also important to be familiar with the basic concepts related to air quality, such as air quality index, on the one hand, and with appropriate regulations (directives, laws, policies) that include long-term goals and measures for their implementation, on the other hand. One of the most important directives, the *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe* defines the limit values for particular pollutants [6]. Since this Directive is mandatory for all Member States of the European Community, this paper gives a short overview of the fundamental regulations of this Directive. An analysis of the data on pollutant concentrations is carried out in terms of the limit values specified in the Directive [7].

EU DIRECTIVE 2008/50/EC

The implementation of the EU directives related to the environment, as well as monitoring air quality, and combating pollution forced local authorities to take on the responsibility of implementing effective countermeasures so as not to exceed the threshold limit values of air pollutants, as they are specified by directives and regulations. The Directive 2008/50/EC states that the public has a right to demand from local authorities to provide a quality environment for life, which means that the authorities should ensure that the air quality remains within the European permissible limits. In order to meet certain requirements described in specific laws and directives, it is necessary to develop mathematical models or applications for monitoring and forecasting air pollution. To be able to monitor the impact of pollutants on health, local authorities, together with the public, need precise and timely information. Data and information should not be collected only from several measuring stations in a city (macro level), but also at the micro level, in other words, levels of pollution should be monitored at street level [3]. The implementation of this approach leads to high quality and reliable monitoring of the impact of pollutants on inhabitants and to the establishment of a cause-effect relationship.

However, the establishment of such a network, the macro and micro level monitoring of air, is often expensive to set up and to maintain and requires a team of experts from different technical and scientific field. The Directive sets out the need to reduce pollution in Europe to a level that has minimal adverse impacts on human health, while considering the most vulnerable groups of the population and the environment as a whole, in order to improve the monitoring and assessment of air quality that includes the deposition of pollutants. It has also stressed the importance of harmonizing a common approach of all Member States of the European Community in the assessment of air quality as well as the importance of collecting data and measurements on population size and ecosystems exposed to air pollutants. To achieve this level of cooperation and joint approach, it is necessary to adequately divide and classify the area of each Member State of the European Community in zones or agglomerations so as to obtain the proper representation of data on the density of population. The Directive regulates the existing target values and limit values and long-term objectives of ensuring effective protection against harmful effects of pollutants on human health, vegetation and ecosystems and they should remain unchanged. Two types of particulate matter ($PM_{2.5}$ and PM_{10}) pose a great danger to human health, and are especially emphasized. The reason for this is the inability to define the minimum value at which the particulate matter is harmless to human health. This is why particulate matter needs to be continuously monitored and the concentration of these particles should be kept at a minimum. Therefore, limit values laid down in the Directive should be observed, with the aim to improve air quality for a majority of the population. If the alarm threshold is exceeded for particulate matter or for any type of pollutants, such as carbon oxides, sulphur, nitrogen oxides or ozone, it is necessary to take short-term measures or/and long-term effective measures to reduce the levels of certain pollutants and to identify the source pollutant emissions in order to reduce emissions at all levels (local, national and EU)[4].

AIR QUALITY

Air is a mixture of gases (nitrogen, oxygen, inert gases and water vapour in varying quantities) which forms the Earth's atmosphere and is one of the most important conditions for life on Earth [5]. The term "air quality" represents the state of the air around us in terms of its purity. Index of air quality is a relative measure of air pollution. An air pollutant, that is a consequence of air pollution (emissions), represents any substance present in ambient air, which can have and/or has adverse effects on human health and/or the environment in general [6].

Value of the air quality index is determined by the concentration of pollutants in accordance with the European Common Air Quality Index (CAQI) [7]. The CAQI model has been developed for calculating the air quality index taking gases and particles that pollute the air into consideration. The model is designed to facilitate comparison of air quality in European cities in real time. The European Air Quality Index is defined by five levels on a scale from 0 (low) to> 100 (very high) and it is the relative measure of the amount of air pollution (Table 1). The lower the value is, the better the air quality. Three basic pollutants in Europe, whose concentration values depend on the air quality index, are PM_{10} (coarse particulate matter), NO_2 (nitrogen oxide-IV), and O_3 (ozone). Equally important pollutants whose values are also taken into account are CO (carbon monoxide), $PM_{2.5}$ (fine particulate matter) and SO_2 (sulphur dioxide). The Air Quality Index for each pollutant is calculated based on the measured hourly concentration. The total index is the largest index of a pollutant at a given time measured at a specified air quality measuring station.

Table 1. Legend of the common air quality index (CAQI), source: www.airqualitynow.eu
Slika 1. Lokacije zagrebačkih mjernih postaja za stalno praćenje kvalitete zraka

Pollution	Index Value
Very low	0-25
Low	25-50
Medium	50-75
High	75-100
Very High	>100

Pollutant emission and main pollutants

Air pollution is a local, European, but also a global problem. There are many sources of air pollution, and they are divided into anthropogenic and biogenic sources of pollution. Anthropogenic sources refer to consequences of human activities (and include the energy sector, transport, industry, waste and households). According to the type, these sources are classified as point, line, surface and volume sources of pollution [1]. Point sources of pollution are sources that cover the area or location that emits high concentrations of pollutants regardless of whether the polluting source is located on the ground level or is above ground, for instance an industrial chimney. The line source represents vehicle emissions in road transport, while the surface source is two-dimensional, for example, a forest fire. The volume source is three-dimensional source (gas leaks in industrial plants). Biogenic source refers to the vegetation on the ground or in the sea as well as to water vapour which evaporates up from oceans and seas and, to certain extent, increases the amount of fine sea salt in the atmosphere [8]. Among the substances that pollute the air and whose impact is especially significant because of the effect on the human life quality and health, and the environment in general are particulate matter, sulphur oxides (SO_X), nitrogen oxides (NO_X), carbon monoxide (CO), volatile organic compounds and lead [9].

Measurement and monitoring of air quality

Measuring stations are places where current amounts of concentration of certain pollutants in the air are measured [10]. In Zagreb, there are six stations for continuous measurement of air quality, and the station locations are: the central part of the city - measuring station Zagreb 1, the eastern part of the city - measuring station Zagreb 2, the south-eastern part of the city - Zagreb 3, the north-western part of the city - Vrhovec, the northern part city - The Institute for Medical Research and Occupational Health and – the north-western part of the city of Zagreb - Bijenik (Šestine) (Figure 1).

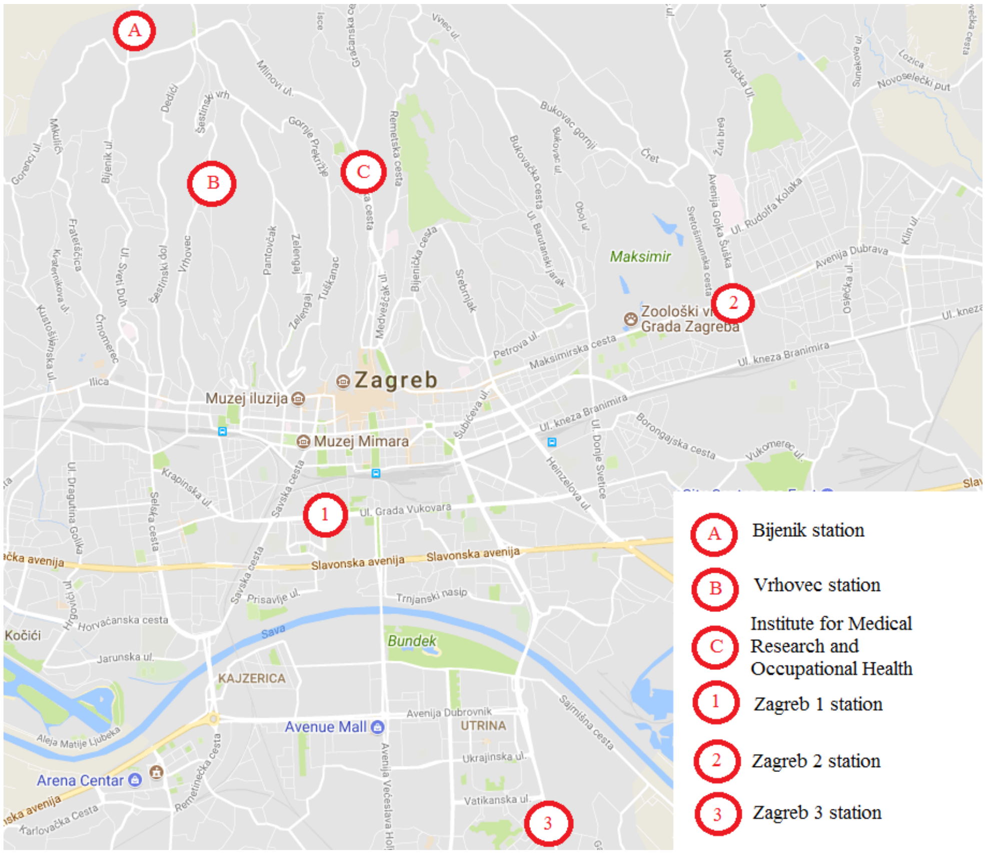

Figure 1. Locations of the Zagreb measuring stations for permanent monitoring of air quality
Slika 1. Lokacije zagrebačkih mjernih postaja za stalno praćenje kvalitete zraka

Measuring stations are relatively expensive and often there is an insufficient number of stations to give a more realistic picture of air pollution and pollutant concentration. Regardless of the measurement accuracy of the current concentration, measuring stations cannot give an estimate of pollutants elsewhere, or forecast future pollutant concentration, and are neither able to provide data for places where measuring stations do not exist. Scientists and engineers who are involved in this field are working on models which would be able to produce such forecasts and estimates. This would open up a possibility of timely informing the public about the risks of increased amounts of emissions in the air, and also of exerting some impact on a particular source of pollution so as to avoid unforeseen emissions or to reduce them. Assessing the air quality is not an easy assignment and there are a number of methods currently under investigation, each one having its advantages and disadvantages and often complementing each other. Estimating and monitoring the air quality related to transportation, i.e. regarding road traffic to be a cause of air pollution, may lead to reducing the impact of this pollution source because effective measures can be taken in a timely manner [11].

INFLUENCE OF MOTOR VEHICLES ON AIR QUALITY

A conventional motor vehicle is any vehicle that moves with the power of its internal combustion engine, which does not include vehicles moving on rails. In particular, one of the major causes of air pollution in Central and Eastern Europe is fossil fuel combustion from motor vehicles and energy production. A rough categorization of vehicles is a categorization in which a division of particular vehicles is presented based on their structures and operational principles and how these vehicles influence the concentration of pollutants in the atmosphere [12]. Road traffic generates a significant contribution to air pollution and causes sustained impact and long-term adverse effects on human health, particularly on the respiratory and cardiovascular system. Based on the research results the World Health Organization presented, particles $PM_{2.5}$ and PM_{10}, ozone and nitrogen oxides are components of air pollution to which special care should be taken when it comes to the quality of human life, and one of the sources that emit these dangerous pollutants is road traffic [3, 6].

This paper includes also research and a comparison of data on the concentration of pollutants collected from the measuring stations in Zagreb and Koromačno. Zagreb, the capital of Croatia, was selected as the largest and most densely populated city, in which the traffic is much denser than in other cities. Unlike Zagreb, Koromačno is chosen because of its low population density and geographical location on the coast of Istria. For comparison, it should be mentioned that according to census from 2011, Koromačno had 180 residents, and the City of Zagreb had 790,017 [14]. The data of the concentration of pollutants from October 2015 to October 2016 were considered, and after processing, these data were compared with the earlier results from the literature. The main focus of the study was observing values of concentration within one month (the first 15 days of each month) in order to compare the changes with daily increased and reduced traffic. For this purpose the information broadcast by radio stations and other sources informing drivers of traffic conditions was also collected. Based on the analysis of the measurement results, it was concluded that the concentrations of PM_{10} were higher than permitted in the area of Zagreb, Zagreb measuring station 1, and that during heavy traffic the values of concentration that were observed at the measuring stations were changing. This change in the values of concentrations on the measuring station in Koromačno can be caused by wind that carries these pollutants from major cities in Istria, but this could be a subject of another study.

Two main traffic related pollutants, NO_2 and PM_{10}, were selected for the purpose of creating diagrams. 3D spatial diagrams for Zagreb measuring station 1 and Koromačno station were based on data retrieved from the web site of the Agency for Environmental Protection iszz.azo.hr [16]. Cross-sections of 3D spatial diagrams (Figures 3) and a topographic diagram (Figures 4) were also created. The paper also presents the average value of daily concentrations of NO_2 and PM_{10} for October 2015 and 2016 for the purpose of data comparison on an annual level (Figure 5).

These particular data sets were chosen because the data integrity on other data sets was not satisfactory (there were big data gaps on the site of Environmental Protection Agency)

On the basis of the diagrams it can be concluded that there is a change in the values of pollutant concentration in time, and it appears to be correlated with density of traffic.

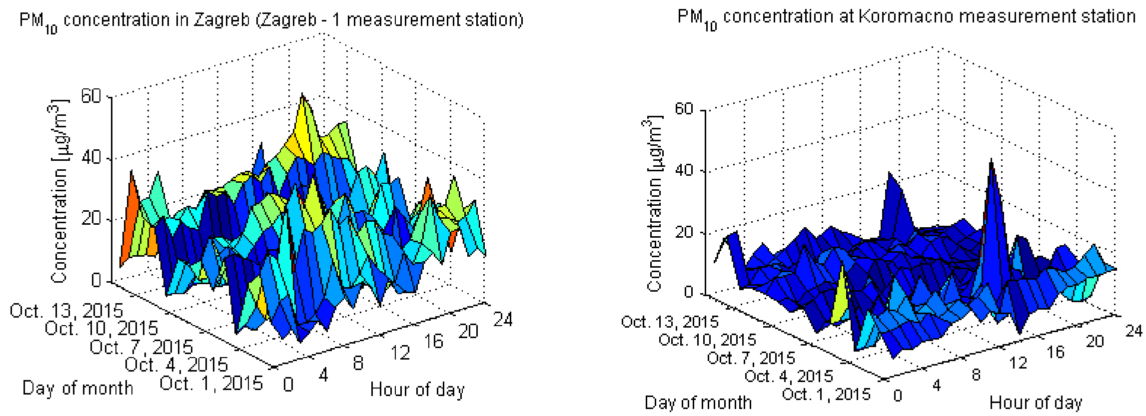

Figure 2. Spatial representation of pollutant PM_{10} in 24 hours, the first 15 days of October 2015, Zagreb and Koromačno
Slika 2. Prostorni prikaz vrijednosti koncentracija PM_{10} unutar 24 sata, prvih 15 dana u listopadu 2015., Zagreb i Koromačno

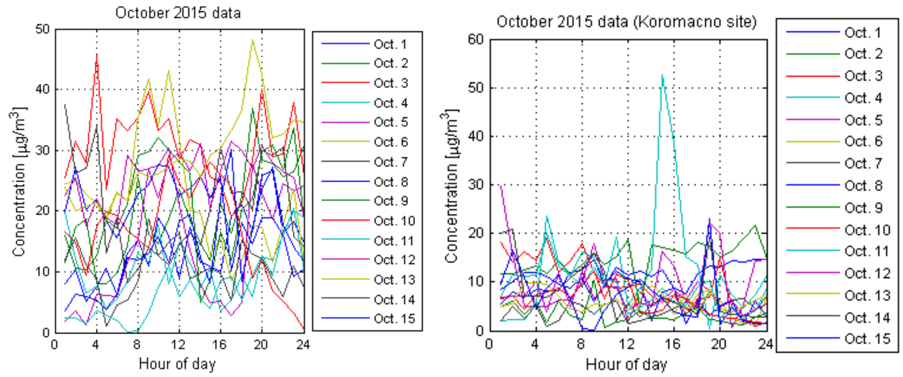

Figure 3. Cross-section diagram of pollutant PM_{10} in 24 hours, the first 15 days of October 2015, Zagreb and Koromačno
Slika 3. Prikaz presjeka prostornog dijagrama za vrijednosti koncentracija PM_{10} unutar 24 sata, prvih 15 dana u listopadu 2015., Zagreb i Koromačno

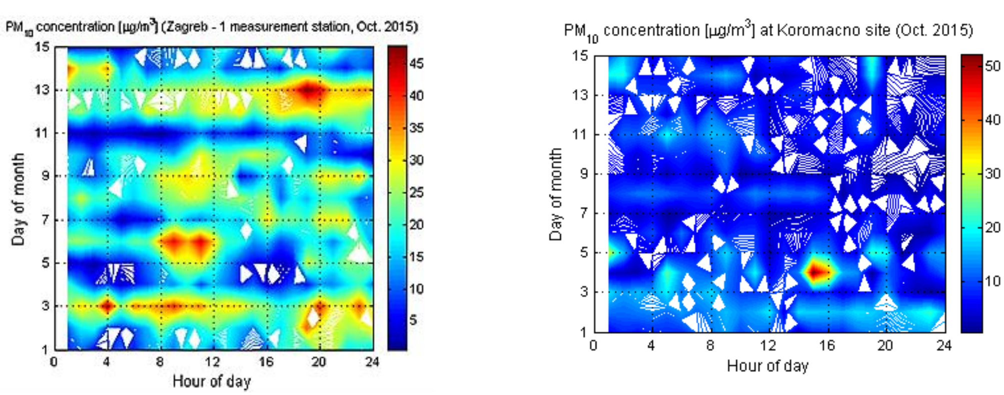

Figure 4. Topographical diagram of pollutant PM_{10} in 24 hours, the first 15 days of October 2015, Zagreb and Koromačno
Slika 4. Topografski prikaz vrijednosti koncentracija PM_{10} unutar 24 sata, prvih 15 dana u listopadu 2015., Zagreb i Koromačno

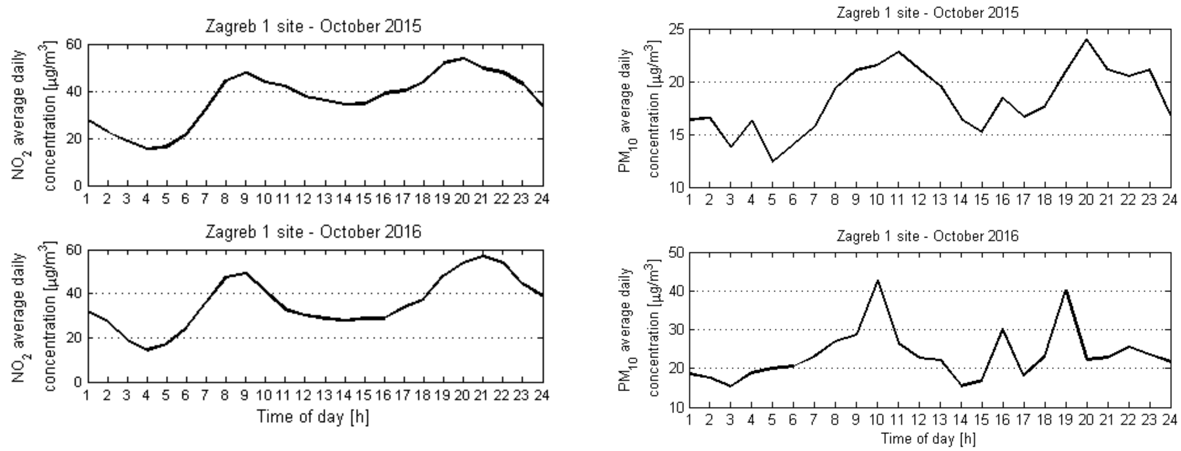

Figure 5. Average daily concentrations of pollutants NO_2 and PM in 24 hours, the first 15 days of October in 2015 and 2016 (Zagreb)
Slika 5. Prosječna dnevna koncentracija onečišćujućih tvari NO_2 i PM unutar 24 sata, prvih 15 dana u listopadu 2015. i 2016. (Zagreb)

APPLICATION FOR MONITORING POLLUTANT CONCENTRATION

Based on the data which were processed and studied at the measuring stations Zagreb and Koromačno, an application has been developed for monitoring pollutants measured at aforementioned sites. The application (Figure 6) collects data directly from the web site of the Environmental Protection Agency, and gives a graphical representation of the data. The application also calculates how much the value of the concentration of some pollutants exceeds the limit of the permitted values or alert thresholds. This application serves as a basis for tracking and bringing traffic density and the concentration of pollutants in the cause-effect relationship. Namely, the application provides the capability to monitor, display and count data on exceeding the permissible limit values, and based on these observations it can be seen that traffic is usually denser early in the morning when people travel to their work places and consequently the concentration of pollutants increases.

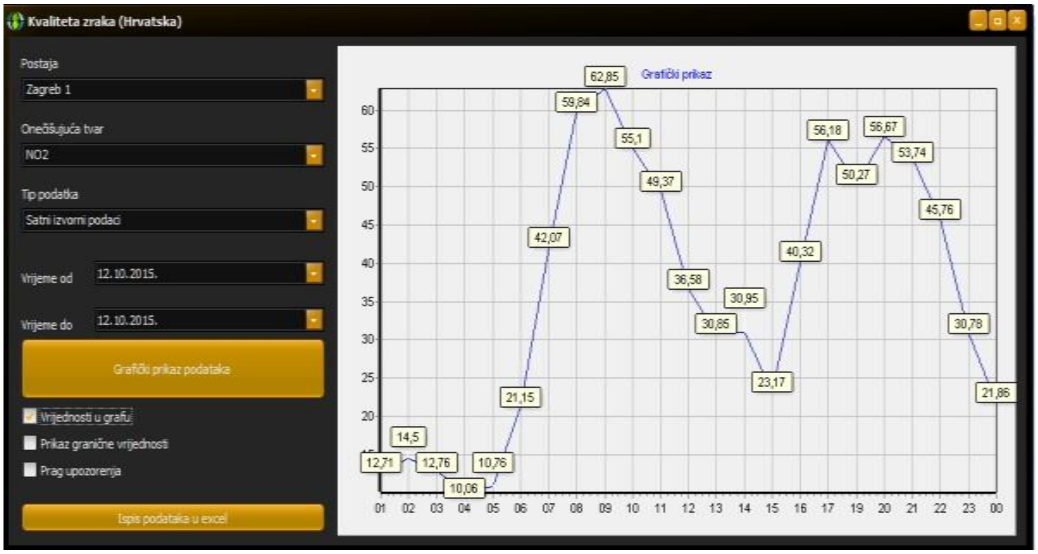

Figure 6. Application interface
Slika 6. Prikaz sučelja aplikacije

In Koromačno this is not the case, because the density of traffic in this town is much smaller than the density of traffic in Zagreb. The number of registered passenger cars in Zagreb amounts to 285,279 [17], while in the whole county of Istria there were 9, 429 registered cars in 2014 [18].

The horizontal axis, which is the result of the data processed by the application, shows the time (hours or days), and the vertical axis shows the concentration of an arbitrarily chosen pollutant at one of the measuring stations. The application currently offers the ability to select only the measuring stations and process the data from the area of Zagreb or Koromačno, however, it is designed to be easily extended to all cites in Croatia by supplementing the code. In addition to visual presentation of the pollutant concentration in relation to time, data on limit values and threshold warnings for a particular pollutant are incorporated in the application. When choosing one of these options or selecting both options, it can easily be seen whether the permitted values of pollutants whose concentrations are being observed have been exceeded. In this way data can be interpreted easily and quickly. Also, the application itself counts how many times a limit value has been exceeded, if such an event occurred, which, in turn, makes it easier for the user to process the data. There is also an option of saving the data to be withdrawn from the website of the Agency for Environmental Protection in the .csv format. Using these data and the diagrams created based on them, 3D spatial diagrams, cross-sections and topographic diagrams can be easily drawn, which was made for the purpose of this study.

CONCLUSION

The results of this study show that in order to obtain realistic data on the air quality a large number of accurate input data and measuring concentrations of pollutants are needed. The measured data have to be studied over a longer period (one year) with the aim of comparing the measured concentrations of individual data pollutants with the density of traffic. Based on the analysed pollutant concentration data in Zagreb and Koromačno, it can be concluded that the concentration of certain pollutants depends on the impact of traffic in the city, as they were considered within one year, from October 2015 to October 2016. From the spatial diagrams and their cross-sections it can be observed that the value of a selected pollutants such as NO_2 and PM (Zagreb), always increases at the time when traffic was the densest (arrival to and/or departure from the workplace, returning from weekend trips, etc.). One of the goals of this work was to develop an application. Further research will be focused on linking the concentration of pollutants and road transport with equations that describe this phenomenon.

REFERENCES

[1] G.D. Thurston, Outdoor Air Pollution: Sources, Atmospheric Transport, and Human Health Effects A2 – S.R. Quah, International Encyclopedia of Public Health (Second Edition), Oxford, Academic Press, 2017. p. 367-77.

[2] M. Čavrak, Z. Čarija, Z. Mrša. Dispersion modelling approach to monitoring and predicting industry induced air pollution, Engineering Review. 27-1 (2007), 19-25

[3] C. Borrego, J.H. Amorim, O. Tchepel, D. Dias, S. Rafael, Sá E, et al. Urban scale air quality modelling using detailed traffic emissions estimates, Atmospheric Environment. 131 (2016) 341-51.

[4] S. van den Elshout, K. Léger, H. Heich, CAQI Common Air Quality Index - Update with PM2.5 and sensitivity analysis, Science of the Total Environment. 488 (2014) 461-68.

[5] E. Fee, N. Blum, The Air We Breathe, American Journal of Public Health. 105 (2015) 1751-55.

[6] EU CR. Directive 2008/50/EE of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, 11 June 2008.

[7] C. Silveira, P. Roebeling, M. Lopes, J. Ferreira, S. Costa, J.P. Teixeira, et al. Assessment of health benefits related to air quality improvement strategies in urban areas: An Impact Pathway Approach, Journal of Environmental Management. 183 (2016) 694-702.

[8] A. McIntosh, J. Pontius, Chapter 3 - Air Quality and Atmospheric Science, Case Studies for Integrating Science and the Global Environment, Elsevier, Boston, Massachusetts, 2017. p. 255-359.

[9] S. Armenta, M. de la Guardia, Chapter 2 - Pollutants and Air Pollution, Comprehensive Analytical Chemistry, Elsevier, Valencia, Spain, 2016. p. 27-44.

[10] P. Aggarwal, S. Jain, Impact of air pollutants from surface transport sources on human health: A modeling and epidemiological approach, Environment International. 83 (2015) 146-57.

[11] F. Hülsmann, R. Gerike, M. Ketzel, Modelling traffic and air pollution in an integrated approach – the case of Munich, Urban Climate. 10 (2014) 732-44.

[12] S. Chen, S.Y. Bekhor, D.M. Broday, Aggregated GPS tracking of vehicles and its use as a proxy of traffic-related air pollution emissions, Atmospheric Environment. 142 (2016) 351-59.

[14] http://www.dzs.hr/Hrv/censuses/census2011/results/censustabshtm.htm, 5.11.2016.

[15] http://www.hak.hr/, 5.11.2016.

[16] http://iszz.azo.hr/iskzl/, 5.11.2016.

[17] http://www1.zagreb.hr/zgstat/o_zagrebu_stat.html, 5.11.2016. [18] https://www.istraistria.hr/index.php?id=1409, 5.11.2016.