Monitoring, Modeling and Visualization System of Traffic Air Pollution – A Case Study for the City of Skopje

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Abstract - Air quality dispersion models can be used to provide information about the impact of individual emission sources or source categories on the air quality and to predict air quality as a result of changes in emissions, such as increase of traffic, emission control measures, etc. Dispersion models can be used to complement the data gained by monitoring as the spatial coverage of air quality information provided by monitoring is often limited. They are also an important tool for supporting air quality improvement plans and programmes. In this paper, based on combination of few existing air pollution models, we are presenting, as a main contribution of this paper, the first this-kind of study for the city of Skopje. This study uses measurements for emissions of many physical and chemical parameters from traffic sources in order to produce the general picture of the pollution on annual level. Our system based on real time air pollution visualization is easy extendible to national and trans-boundary levels, that is one of the most important EU recommendations. At the same time, this is the first step in building the real time decision (not only prediction) support system.

Keywords-dispersion; modelling;traffic;monitoring;system; visualization;air;pollution

I. INRODUCTION

Air pollution is a global threat to human health which is growing daily. It can be described as the pollution of the atmosphere with gases, or dust of solid materials, particulate matter as well as other substances that can endanger human health, animal life and plant life, reducing visibility and a number of other consequences.

Problems such as global warming, acid rain and ozone destruction are well known, although it may seem distant from our everyday life in urban environments. These are global issues affecting the entire world community. In addition to these global problems, these recent decades, an important and worrying issue for the experts for healthy environment, as well as for all residents in urban areas is the air pollution in the most populated urban places. The relationship of air pollution and health status of the people is top priority issue. It is estimated that worldwide, 2 million people and more than half of them are in developing countries, die every year from air pollution. In many cities worldwide there are health risks from exposure to particulate matter (PM) and Ozone (O3) [19]. The majority, 51% of the European population lives in these urban areas, and their daily activities and economic activities are concentrated in, or around that area [16]. Transport by motor vehicles across the road infrastructure close to the residential buildings is the main and immediate source of air pollution in this areas. The lack of knowledge of the health impacts from pollution, is a big obstacle in defining the actions and mobilizing local, and international resources. [19]

Although the network of monitoring stations is very important in such an urban environment because it provides information on actual concentrations of certain parameters of air, it cannot cover every point of interest. Consequently, only the most important points could be monitored.

Air dispersion modelling could be used to estimate and predict the concentration of the pollutants in air using mainly emission and meteorological data. Air dispersion models include mathematical algorithms based on combination of physical and chemical parameters so that they can simulate the spread of pollutants in the air as well as the complex processes of air pollution creation. Dispersion modelling of air will allow the implementation of effective control of pollution as well as the development of strategy to reduce emissions of harmful substances that pollute the air. In this way, it will be possible to develop a plan to reduce the environmental pollution and satisfy the EU environmental air quality standards [20].

In addition, we propose a particular system for urban environment air quality monitoring, modelling and visualization (applied for our city's environment because each environment has its own space, meteorological parameters and configurations) that:

1. Extends monitored air pollution data (that is the number of points representing monitoring stations in real-time [18]) to each particular point above the rooftops of the city and visualizes on map in continuous color coded layer, taking the limit values for color coding according the limits defined by EU environmental air quality standards per

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parameter.

2. Predicts the air pollution from street network traffic, on street canyons level, in the most traffic jammed parts of the city's street sections applying the Operational Street Pollution Model (OSPM) [17] to our environment configuration.

3. Visualizes the air pollution as the network of sections, by developing effective and usable visualization tool as a part of our system.

The idea with this kind of system is to raise the public awareness and to help the city planners and regulatory institutions to get real-time feedback in one smart city concept.

In Section II of the paper, we will present the state of the art in Monitoring, Modeling and visualization of traffic air pollution. The case study will be described in Section III while the paper will be concluded in Section IV.

II. MONITORING, MODELING AND VISUALIZATION OF TRAFFIC AIR POLLUTION-STATE OF THE ART

Climate change of local, regional and global scale has an outstanding need for a systems that monitors, models and visualizes the distribution of air pollution emissions with high spatial resolution. There is a lot of interdisciplinary research in this area. In [11] and [13], the monitoring module of the system is based on network of sensor devices that among other parameters monitor air pollution and traffic data. Modelling module is always the required complement of a distributed data collection module for the prediction of the air pollution state. Air pollution monitoring data are correlated to health problems in [10]. In addition, in [12], an application that helps local government developing more accurate prevention and health care plans has been developed. Systems that use visualization of data and cloud solutions connected with air pollution data are described in [7], [8] and [21]. In [7], a geographical approach for air pollution map generation using parallel processing and cloud computing system is presented. In this way, the information is available anytime, anywhere. In [8] a system for processing large amounts of data is proposed. It uses GIS and air pollution visualization by introducing customized cloud computing technology with major goal on reducing the processing time of the visualization. In [21] BigSmog system using cloud computing framework and big spatio-temporal data for big smog analysis conducts parallel correlation analysis of the factors and scalable training of artificial neural networks for spatio-temporal approximation of the concentration of PM2.5. Global warming as air pollution related problem, especially for emission of greenhouse gases from traffic, is analyzed in [9]. A tool for emission estimation has been developed. Sensor-based Emissions Monitoring System is described in [14], while more general cloud computing for Internet of Things and sensing-based applications is presented in [15].

In our study, we combined and adopted many of these technics and technologies to develop a robust, long-term system for traffic air pollution monitoring, taking into account all the related parameters and providing in this way a case study as per EU recommendations with extensive number of experimental data. Our study is different from others because it was realized according to the EU Air quality directives as well as WHO (World Health Organization) recommendations, especially contributing in the process of real time air pollution visualization. In this way, it is easy extendible to national and trans-boundary levels, that is one of the most important EU recommendations. At the same time, this is the first step in building the real time decision (not only prediction) support system.

III. OUR CASE STUDY

A. Real-time monitoring data in city of Skopje

The real time monitoring data network of stations on the area of Skopje is composed of eight air quality measurement stations. These stations are:

- two *urban traffic stations*
  - "Centar"
  - "Rektorat"
- two *urban background stations*
  - "Karpos"
  - "Finki"
- one *suburban background station*
  - "Gazi Baba"
- one *urban industrial station*
  - "Lisice"
- two *rural industrial stations*
  - "Mrsevci"
  - "Miladinovci"

Seven of them are controlled and maintained by the "Ministry of environment and physical planning in Republic of Macedonia" (MOEPP) and one is controlled and maintained by our "Laboratory for Eco informatics at Faculty of computer science and engineering, Sts. Cyril and Methodius' University in Skopje" (Ecolab FINKI). The position and configuration of the network of the air quality measurement stations is as displayed on map in Figure 1.

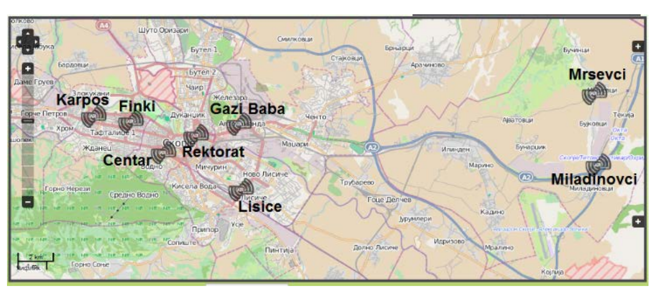

Figure 1. Map of air quality measuring stations

The measured air quality parameters are as follows:

- Particulate matter with diameter per particle less than 10 micrometers (PM10)
- Particulate matter with diameter per particle less than 2.5 micrometers (PM2.5)
- Ozone (O3)
- Carbon monoxide (CO)
- Nitrogen dioxide (NO2)
- Sulfur dioxide (SO2)

B. *Real-time visualization of the monitored data*

Workflow diagram of the visualization module of our system is presented in Figure 2.

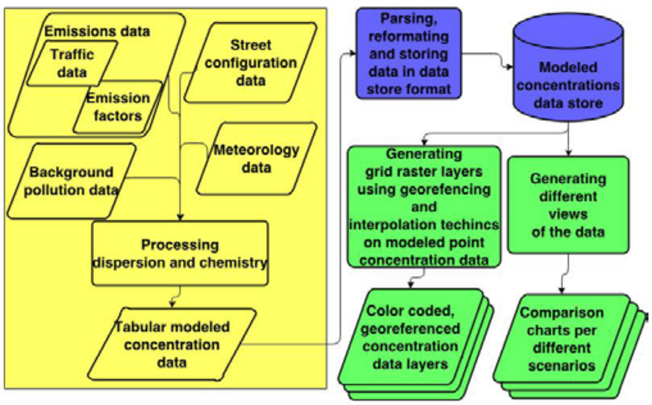

Figure 2. Schema of monitoring and real-time visualization of monitored data module of our system

The process of visualization is based on the newest 'up to time' data as the average of the air parameter concentration per hour for each parameter. The data are provided by the network described in section A and stored in the server database. They are used for generation of the grid raster layers by interpolation technique. The layers are color-coded and scaled from green to red depending of the concentration level. Then the geo- referenced interpolated concentration layers are automatically published as World Mapping Service (WMS) and publicly available at [18].

The client side that displays the web content layers uses the java script library that makes connection to the publicly available WMS server, catches the latest raster layer data and displays it. The view can be changed to view each air quality parameter layer separately or to view combination of two or more parameter layers together. An example of the real-time visualization on our web is shown in Fig 3.

Figure 3. Web real-time concentration visualization

C. *Modelling part - Application of our collected data in the model*

The model used in our work was OSPM (Operational street pollution model) [17]. In Figure 4 an extended visual based modelling module in our system is presented.

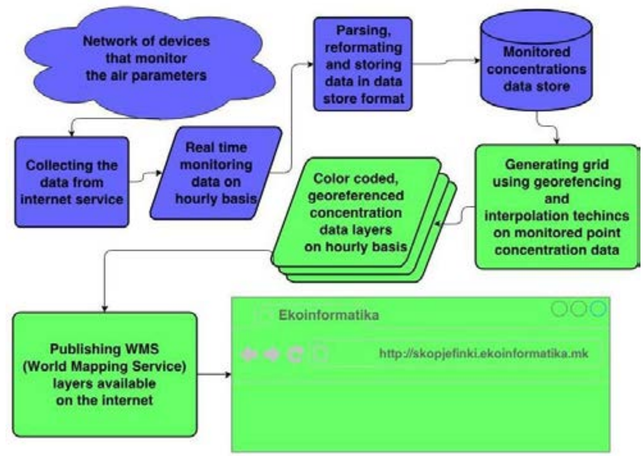

Figure 4. Extended visual based modelling module in our system

On the basis of the traffic data from one of the main streets in the city of Skopje, based on our extended visual based modelling module as described in Figure 4, we generated our modelled data charts in Part D of this Section.

The needed and collected information and data are on meteorological conditions and concentrations of air parameters in the area which is modelled in the duration of an entire year. This type of data is actually measured data or data previously obtained with a mean value over the years that actually reflect the meteorological situation at the level of a year. This data can also be data obtained with the prediction for next year which follows the use of modelling in order to obtain predictive model of pollution. The density of this type of data is on hourly level interval for one year timespan. These data contain data for temperature, speed and direction of wind, global solar radiation, and relative humidity, and also background concentrations of PM10, O3, CO, NO2, and PM2.5.

Emission information and data of the type of fuel used in transport and their composition in terms of substances important for pollution is taken (provided) from the largest supplier of fuel in the Republic of Macedonia, MAKPETROL.

Traffic information and data on the number of vehicles moving on the street are classified by the type of vehicle: bus, car, van, truck. The real distribution of flow per class is for 24 hours timespan. Also the distribution by volume and type/technology of motor vehicles and fuel has been determined. The classes of 'type/technology of motor vehicles and fuel' in our case are also provided. Data for the distribution of vehicles in terms of volume and type of engine and motor fuel are provided from city corresponding institutions.

Information and data of the average speed of vehicles that travel along the street. This parameter is taken to be 50 km / h (actual speed limit for the road).

Street configuration information and data about the height and placement of buildings along the 'Partizanski Odredi' street canyon (under investigation in this study) are presented in Figure 5.

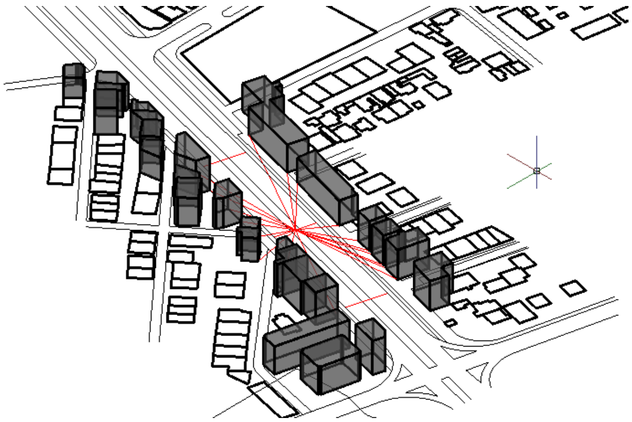

Figure 5. Part of the street 'Partizanski Odredi' together with the configuration of the buildings

D. Experimental work with model and results (charts with different views and grid raster layers)

In the model, we define three modelling scenarios about the flow of the vehicles. Each of these three scenarios has two sub scenarios (about the mean speed of the vehicles), resulting in total of 6 as follows.

Scenario 1 is a scenario that is based on the real measured data of flow of vehicles. In this scenario the vehicles per 24 hour period is 32000.

Scenario 2 is a scenario that is based on the double of (2x) real measured data of flow of vehicles. In this scenario the vehicles per 24 hour period is 64000.

Scenario 3 is a scenario that is based on the triple of (3x) real measured data of flow of vehicles. In this scenario the vehicles per 24 hour period is 96000.

The sub scenarios per every scenario refer to average speed of vehicles that travel along the street (50 km/h and 80 km/h).

In this way, we define the following six scenarios:

Scenario 1.1 (32000 vehicles/24h, 50 km/h)
Scenario 1.2 (32000 vehicles/24h, 80 km/h)

Scenario 2.1 (64000 vehicles/24h, 50 km/h)
Scenario 2.2 (64000 vehicles/24h, 80 km/h)

Scenario 3.1 (96000 vehicles/24h, 50 km/h)
Scenario 2.2 (96000 vehicles/24h, 80 km/h)

Results from the applied modeling for the above six scenarios are presented as charts on Figure 6-9.

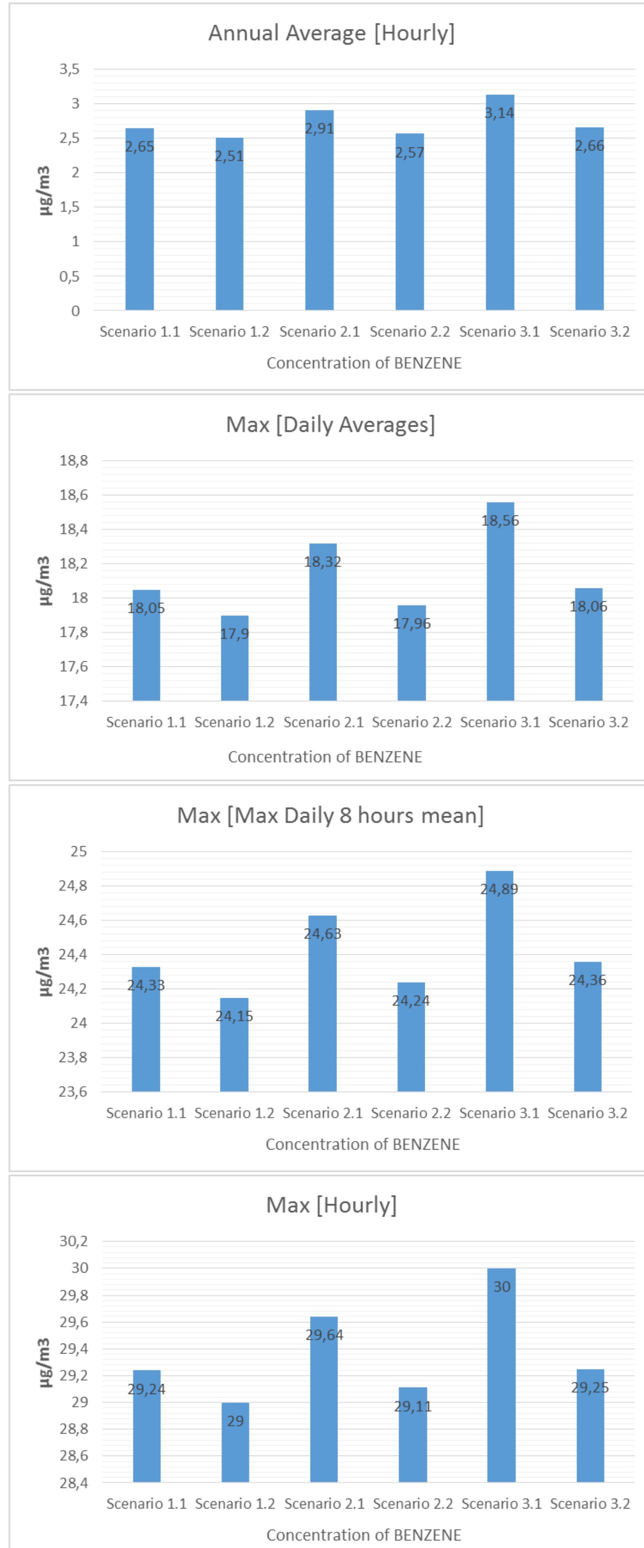

Figure 6. BENZENE Concentration Charts

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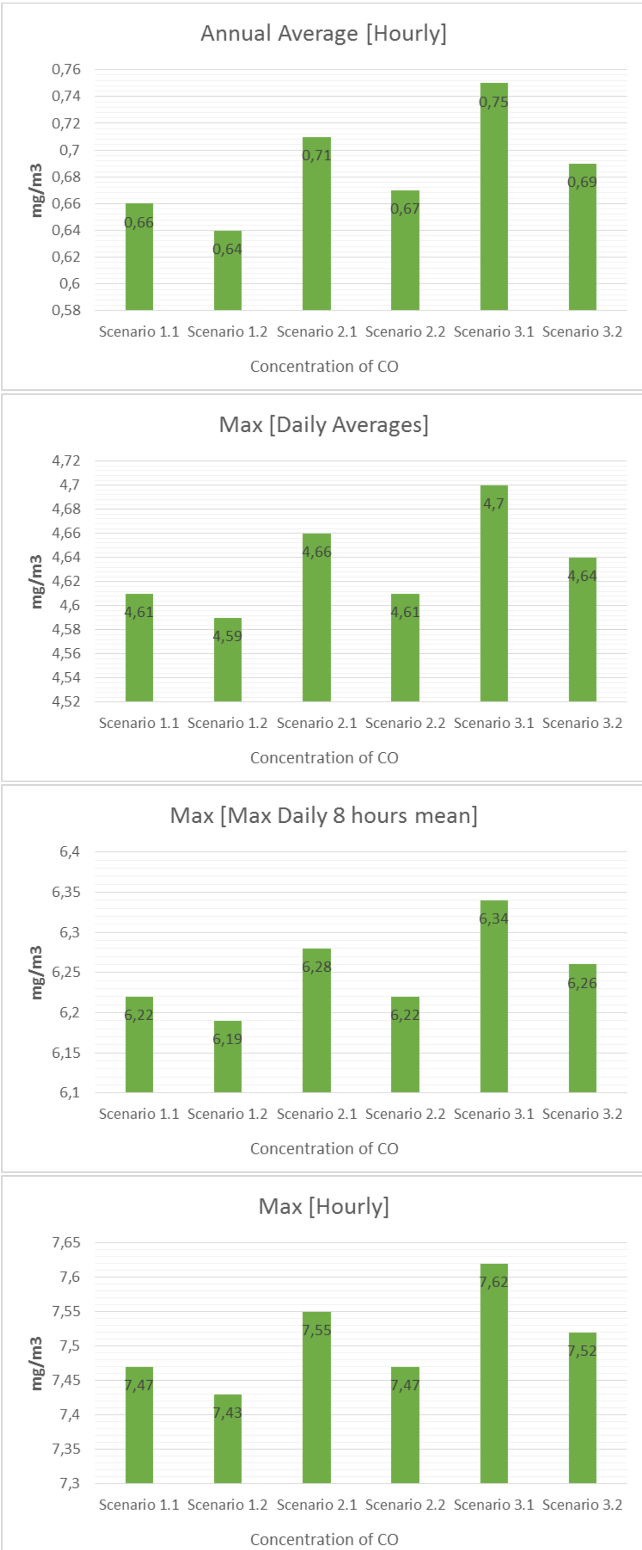

Figure 7. CO Concentration Charts

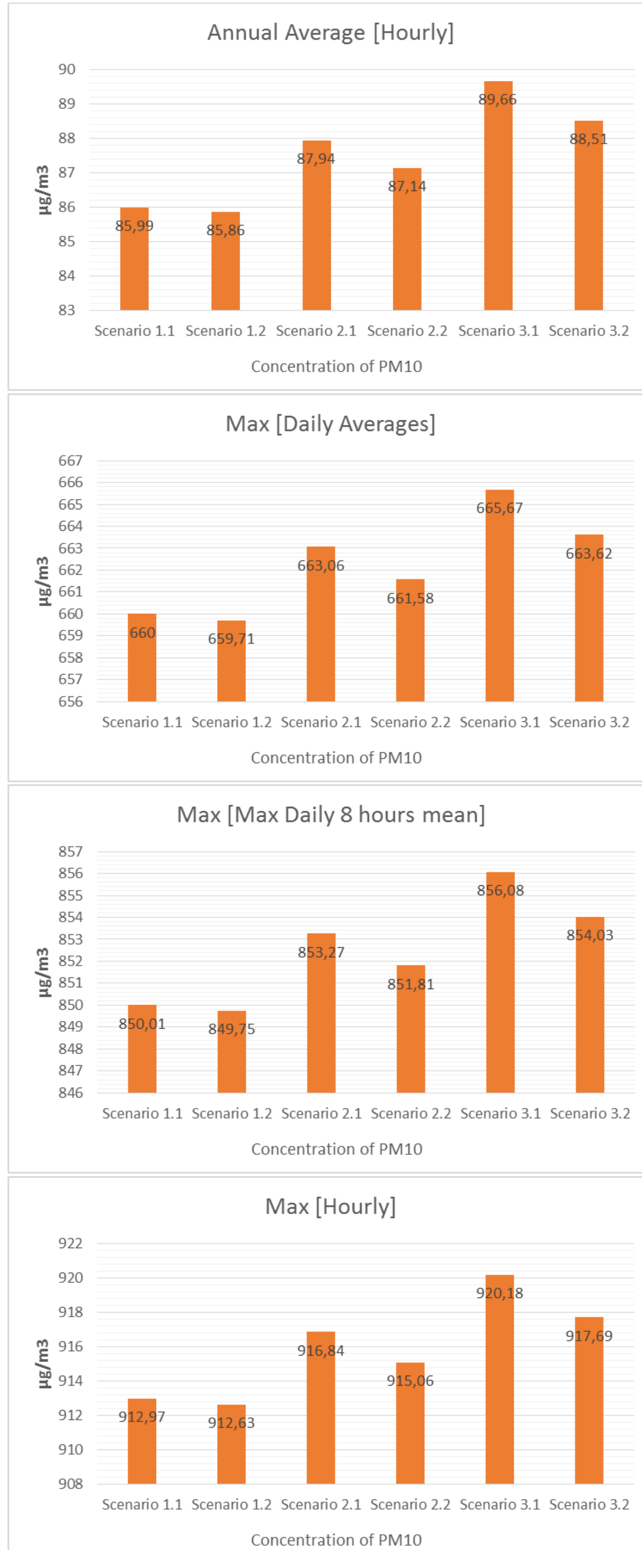

Figure 8. PM10 Concentration Charts

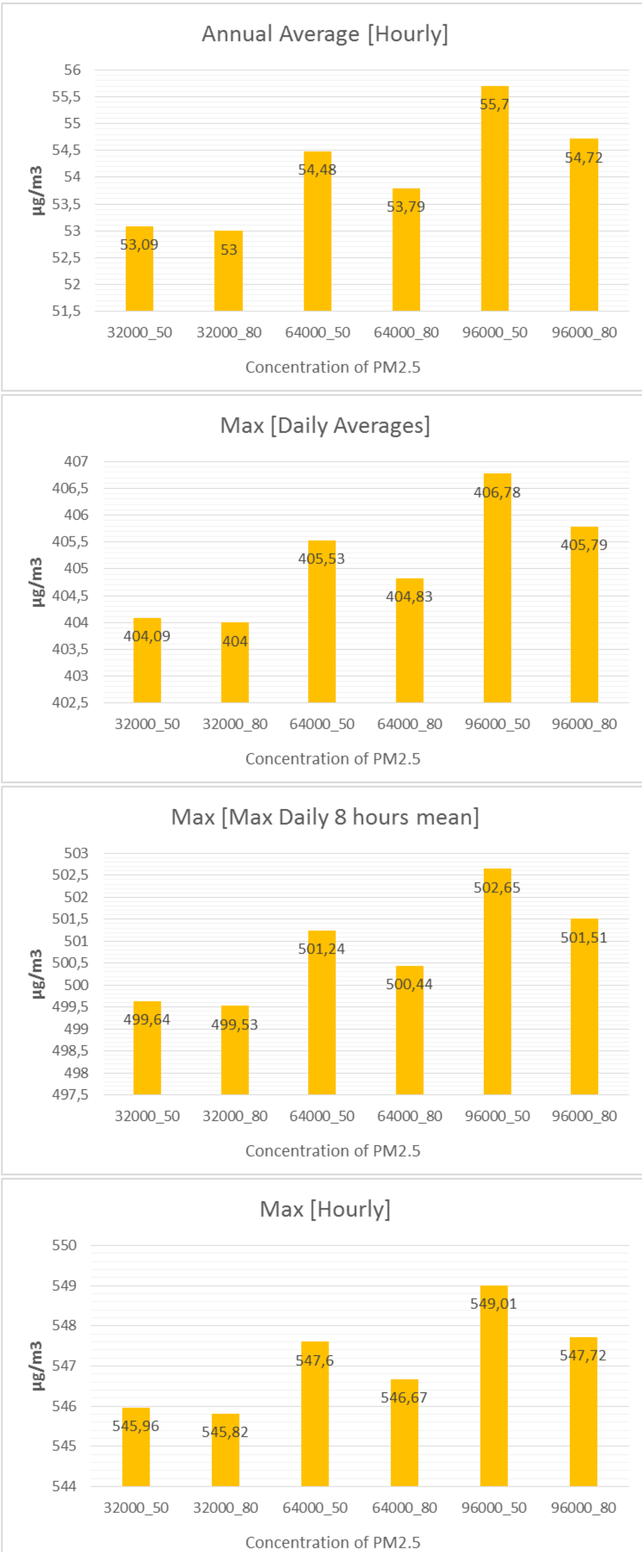

Figure 9. PM2.5 Concentration Charts

Visualization of the color coded concentration data layers on street network are given in Figure 10.

Figure 10. Color coded concentration data layers of street network

The suggested view is generated by interpolating measured data (as the average value for each parameter) and the layer is clearly represented by colors. In this way, the real situation of the street pollution in the last hour up to the present moment is presented. The data is collected and presented in real-time.

The aim for this kind of system is to be able to give not only automated real-time visualization of measured data, but also automated near-future modelled air pollution visualization, and make all of that available on the web like an internet service.

IV. DISCUSSION AND CONCLUSIONS

In this paper, we presented our system for monitoring modelling visualization of the traffic air pollution of the city of Skopje.

The benefit of this kind of system is the real-time aspect of the system with the combination of public availability of the generated color coded layers [18]. Another part that this system is incorporating inside is the prediction of the pollution by change of the traffic parameters using OSPM. This kind of visualization will be further improved in our future work.

From the experimental results we can conclude that the recommended limit values for health protection according to the latest EU Air quality standards (50 µg/m3 for pm10 daily average, 25 µg/m3 for pm2.5 yearly average) are significantly exceeded for PM10 and PM2.5 parameters concentration as it is visible from the Figures 8-9. The CO parameter values are in the normal range below the limit values of 30 mg/m3 according to WHO (World Health Organization). The Benzene is also in normal range below the 5 µg/m3 limit value as recommended by EU Air quality standards.

In the future, we plan to extend our study for other streets in the city of Skopje, as well as for other cities in our country and the Balkan region. We also plan to use the cloud computing for the process of modeling, visualization and other processing of these very large (big) air pollution data in real time.

The real time modelling and visualization of the air pollution is the first step that can lead to real time decision (not only prediction) support system. It will also allow better planning and abating decisions from the authorities on the local, regional or trans-boundary global level.

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