

# Evaluating the Air Pollution Impact Using Environmental Monitoring, Dispersion Modeling and Volunteered Geographic Information Systems

DANIEL DUNEA<sup>1\*</sup>, STEFANIA IORDACHE<sup>1\*</sup>, TROND BOHLER<sup>2</sup>, FLORIAN HUBER<sup>3</sup>, PETER LEITNER<sup>3</sup>

<sup>1</sup> Valahia University of Targoviste, 13 Sinaia Alley, 130004, Targoviste, Romania

<sup>2</sup> NILU – Norwegian Institute for Air Research, Postboks 100, 2027 Kjeller, Norway

<sup>3</sup> SYNNO GmbH, Otto-Bauer-Gasse 5/14, Wien, 1060, Austria

*The paper describes the application of real-time environmental monitoring, local and long-range transport dispersion modeling and Volunteered Geographic Information (VGI) systems that can improve the fast knowledge regarding the air pollution status to determine the actual outdoor conditions for living in a specific urban area. A case study using such techniques is presented for a pollution event with fine particulate matter (PM<sub>2.5</sub>) in Targoviste, Romania. PM<sub>2.5</sub> time series were recorded during the pollution event by two optical monitoring systems providing an average of 184.1, maximum of 323, and minimum of 107 µg m<sup>-3</sup> (DustTrack™ 8533 EP system), and 177.4, 321 and 93 µg m<sup>-3</sup> (Rokidair microstation), respectively. PM<sub>2.5</sub> concentrations and forward trajectories were computed using two programs: BREEZE® AERMOD 7.9 and HYSPLIT dispersion model. The obtained results emphasize the usefulness of embedding dispersion modeling advanced tools to supplement monitoring results and to characterize the source apportionment.*

*Keywords: Breeze Aermod model, HYSPLIT dispersion model, advanced sequential monitoring, intelligent environmental e-platforms*

Future major challenges in the development of the society will occur in the near future from the intensive urbanization as a strong factor that causes environmental pollution and climate change from local to global scales. Cities are anthropogenic modified ecosystems, in which the interactions between human and natural organization systems are significant. A wide range of scientists has initiated the modeling of such complex ecosystems addressing the challenging societal issues arriving with urbanization [1]. In this context, air pollution and associated environmental processes in urban areas are major environmental challenges affecting significantly the health of inner citizens [2, 3]. The latest scenarios concerning the trends of air pollution have estimated that poor quality of air due to high concentrations of airborne pollutants and population growth in urban areas will become the main environmental risk factors influencing morbidity and mortality of inner residents in the coming decades [4]. The most important stressors of air quality in urban areas are nitrogen oxides, ground-level ozone and particulate matter (PM) resulting from industrial, traffic and domestic heating emissions, which are influenced significantly by topography, local weather conditions and air mass trajectories [5]. Through the recent review of the health effects of air pollution, prolonged exposure to high levels of contaminants may cause major adverse health effects on the population at or near air-polluted areas [6]. According to the World Bank, every year approximately 800,000 people die prematurely from lung cancer, cardiovascular and respiratory diseases caused by outdoor air pollution. By exposed to air pollution, children and elders are the most affected categories of population [7]. Safe levels of exposure or thresholds of combined presence of air contaminants below which no adverse health effects occur are difficult to establish [8].

The paper summarizes several techniques that can improve the fast knowledge regarding the air pollution status in a specific urban area to determine the actual

outdoor conditions for living by employing real-time environmental monitoring, local and long-range transport dispersion modeling, and Volunteered Geographic Information (VGI) Systems. A case study using such techniques is presented for a pollution event with fine particulate matter (PM<sub>2.5</sub>) in Targoviste, Romania.

## Experimental part

A top-down approach was applied in Targoviste (Latitude 44° 56'2"N, Longitude 25° 26'2"E, altitude 280 m), a city with 73,964 inhabitants from Romania. Receptor modelling based on the profile of emission sources, past and real-time PM measurements in a designated sampling point, data analysis, and dispersion modeling were applied in this study. The modeling problem, which was analyzed using dispersion software, is related to the source apportionment in the case of a PM<sub>2.5</sub> pollution event recorded by two real-time optical monitors i.e., DustTrack™ 8533 EP with heated inlet ([www.tsi.com](http://www.tsi.com)) and Rokidair microstation, a system designed and developed during the Rokidair project ([www.rokidair.ro](http://www.rokidair.ro)). The instruments were placed out in the open on tripods with an inlet height between 1.50 and 1.60 m away from obstructions that may disturb wind currents (fig. 1). A gravimetric sampler from Mega System (<http://www.megasystemsrl.com/en/>) was used to calibrate the optical instruments.

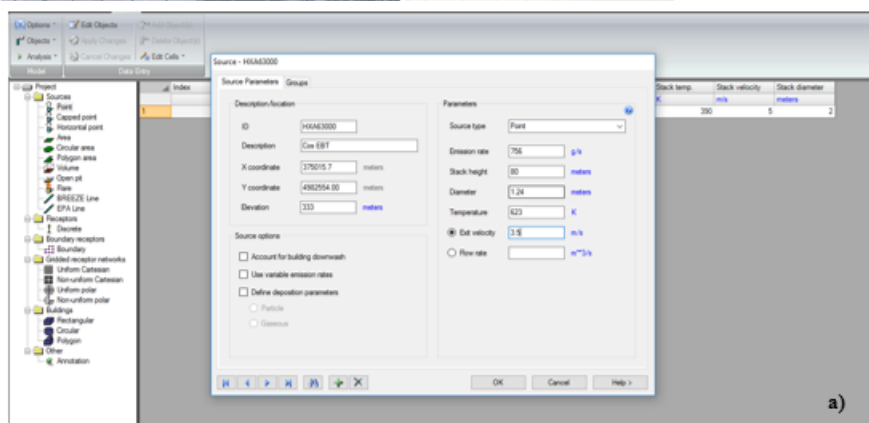
The sampling point was located at 5.9 km south-east from the identified major emission source i.e., an industrial chimney of a pigments' factory. The source has the following characteristics: chimney height (80 m), diameter (1.24 m), gas exit temperature (150 °C), gas speed (3.5 m/s), gas flow (4.22 m<sup>3</sup>/s), and release quantity of 756 g/s.

The dispersion modeling was performed for the atmospheric conditions occurring in 4 December 2016, when the very high concentrations of PM<sub>2.5</sub> were recorded in the designated sampling point. PM<sub>2.5</sub> concentrations and trajectories were computed using two programs: BREEZE® AERMOD 7.9 (Trinity Consultants, Dallas, TX, USA, 2015) and HYSPLIT dispersion model [9].

\* emails: [ddunea@yahoo.com](mailto:ddunea@yahoo.com); [stefania.iordache@yahoo.com](mailto:stefania.iordache@yahoo.com)

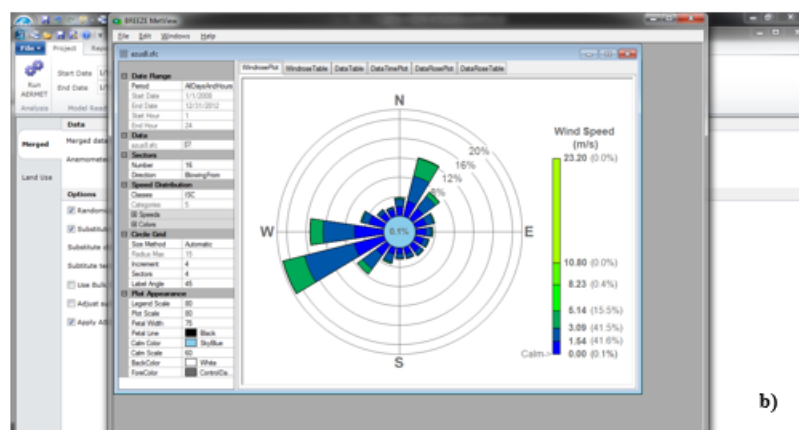


Fig. 1. The complex monitoring of particulate matter fractions used in one of the sampling points of the Rokidair project (Mega System gravimetric sampler - left, Rokidair real-time monitoring system - center, and DustTrak 8533 EP size-segregated monitor - on tripod, right) located 5.9 km south-east from the identified major emission source



a)

Fig. 2. The workspace of *BREEZE*<sup>®</sup> AERMOD 7.9 software showing the source characterization (a) and AERMET/METVIEW component required for meteorological data handling (b)



b)

AERMOD model integrated in *BREEZE*<sup>®</sup> AERMOD 7.9 software allows enhanced treatment of plume rise and plume penetration from stationary emission sources for elevated inversions improving computation of meteorological data and atmospheric stability (fig. 2). The model provided potential isolines of concentration for various scenarios based on emission regime, PM emission rates ( $\text{g s}^{-1}$ ) and different time intervals. Meteorological data required in the model were available from an automated weather station located near the sampling point (50 m).

The HYSPLIT model ([http://ready.arl.noaa.gov/HYSPLIT\\_disp.php](http://ready.arl.noaa.gov/HYSPLIT_disp.php)) computes simple air parcel trajectories, complex transport, dispersion, chemical transformation, and deposition simulations. HYSPLIT has been used in a variety of simulations describing the atmospheric transport, dispersion, and deposition of pollutants and hazardous materials [9]. The calculation method uses a hybrid method between the Lagrangian model (uses a moving frame of reference for the advection and diffusion calculations as the trajectories or air parcels move from their initial location), and the Eulerian model (uses a fixed three-dimensional grid as a frame of reference to compute pollutant air concentrations) [9].

An analysis of  $\text{PM}_{2.5}$  time series recorded during the pollution event occurring in the morning of 4 December 2016 (maximum concentration of approximately  $322 \mu\text{g m}^{-3}$ ) was performed to obtain descriptive, associative, and comparative statistics of the data set. The analysis of variance (ANOVA) provided the statistical significance of comparisons. Pearson correlation was used to estimate the strength of tested linear relationships.

### Results and discussions

From the world's largest cities to the smaller ones, the authorities must take action to enhance their institutional and technical capabilities to monitor, forecast, and control air quality in urban areas. The need for implementing preventive actions to reduce the risk of exposure to air pollution of their citizens must be a priority. The existing monitoring infrastructure and associated conventional Decision Support Systems applied today do not assess completely and timely the micro-scale dynamics of the air pollution processes. Consequently, various micro-environments are occurring at city level making difficult the conventional measurements of air quality in view of

insuring a global covering of the city at spatial level. Thus, the forecasting of potential pollution episodes in a specific microenvironment and their associated health effects are also problematic [10]. One solution could be the integration of VGI component by encouraging the citizens to contribute with quasi-empirical georeferenced data e.g., GPS tracks, heart rates, street pictures, physical symptoms, respiratory events, visual observations of emissions. This information can be further processed and extrapolated based on state-of-the-art models and expert information to improve the characterization of outdoor microenvironments in a city.

#### PM<sub>2.5</sub> pollution event identified by real-time environmental monitoring

The main real-time instrumentation for continuous monitoring of particulate matter (PM) relies on TEOM, Beta Attenuation, and optical analyzers. Many urban areas do not have such PM monitoring systems, and most important, the early associated warning tools required to assist the population during pollution events. The reference method for the PM<sub>2.5</sub> measurement is described in EN 14907. Recently, on 21 May 2014, a revised standard for measuring PM<sub>2.5</sub>, namely EN 12341: 2014 came into effect, showing the importance of a reliable monitoring of airborne PM respiratory fractions. In this context, three monitoring systems were deployed to obtain correct measurements in the designated sampling point (fig. 1). The previous screenings performed in the area pointed out that the calculated average of PM<sub>2.5</sub> was approximately 20 µg m<sup>-3</sup> varying from 35-42 µg m<sup>-3</sup> (near the main road that links the town with the northern part of the county) to 10-12 µg m<sup>-3</sup> (middle of the University campus) and 6-8 µg m<sup>-3</sup> (near the border with Ialomita River) [11]. Consequently, during the identified pollution event, the concentrations were approximately ten times higher during at least 4 h (medians of concentrations were around 200 µg m<sup>-3</sup>). Figure 3 shows the concentrations measured by the real-time instruments. Both instruments had a sampling rate of 1 min, but the Rokidair microstation performed at each 5 min a calibration, which

lasted 1 minute. This is the reason that the measurements timing of the instruments presented differences at some points.

However, the correlation between the time series ( $n = 216$ ) provided by each instrument was very significant statistically (Pearson  $r = 0.96$ ;  $p < 0.001$ ; Mean absolute error = 10.7). T test showed no statistical difference between recorded time series ( $t = 1.25$ ;  $p = 0.2$ ).

Table 1 presents the statistical descriptors of PM<sub>2.5</sub> time series collected by two optical monitoring systems i.e., average of 184.1, maximum of 323, and minimum of 107 µg m<sup>-3</sup> for DustTrack™ 8533 EP system, and 177.4, 321 and 93 µg m<sup>-3</sup> for Rokidair microstation, respectively.

#### Dispersion modeling

Once the PM<sub>2.5</sub> pollution event was identified, dispersion modeling was applied to test the source apportionment. The problem regarding the dispersion of airborne pollutants in the atmospheric environment and the estimation of concentrations in various locations of a defined city has been addressed using both deterministic and non-deterministic models [12]. There are five basic types of deterministic models and their variants, as follows: box, Gaussian, Lagrangian, Eulerian, and dense gas models. Operational variables required for air pollutants' modeling to provide daily air quality forecasts are similar for particulate matter, NO<sub>x</sub> and SO<sub>x</sub>. On the other hand, PM<sub>2.5</sub> forecasting accuracy is dependent on the availability and precision of the meteorological data, inventory of emissions, and chemical reaction schemes required to configure optimally the model running conditions. The forecasting of a pollution episode requires supplemental details about PM<sub>2.5</sub> constituents, or potential emission source to elaborate proper recommendations to the public in relation to possible health effects or to support effective measures to reduce emissions, which contributed to the episode [10].

Firstly, we used AERMOD model, which is U.S. EPA approved for most regulatory air dispersion modeling. The main functions of the model are advanced meteorological preprocessor to compute site-specific planetary boundary layer (PBL) parameters; enhanced treatment of plume rise and plume penetration for elevated inversions; and improved computation of vertical profiles of wind, turbulence, and temperature. AERMOD system includes AERMET, a meteorological preprocessor that computes boundary layer and other

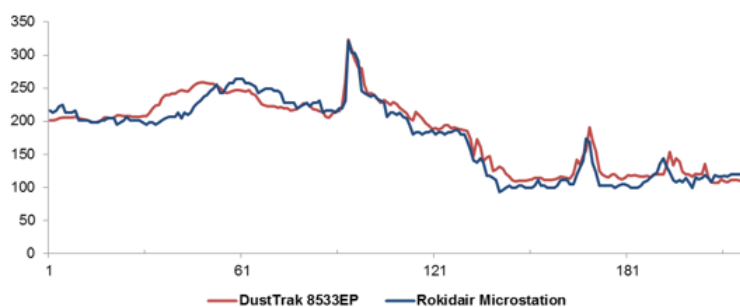


Fig. 3. Elevated PM<sub>2.5</sub> concentrations (µg m<sup>-3</sup>) recorded in 4 December 2016 in Targoviste city by two real-time instruments placed in the same location (fig. 3); time scale is in min

**Table 1**  
STATISTICAL DESCRIPTORS OF PM<sub>2.5</sub> TIME SERIES COLLECTED BY TWO OPTICAL MONITORING SYSTEMS (µg m<sup>-3</sup>); CV(%) – COEFFICIENT OF VARIATION

System	Count (n)	Average	Max	Min	Median	St. dev.	CV(%)	Skewness	Kurtosis	T test	Pearson correlation coeff.
DustTrack	216	184.1	323	107	202	53.4	29.04	-0.09	-1.19	1.25 ( $p=0.2$ )	0.96 ( $p<0.001$ )
Rokidair	216	177.4	321	93	198	56.7	31.983	-0.04	-1.21		

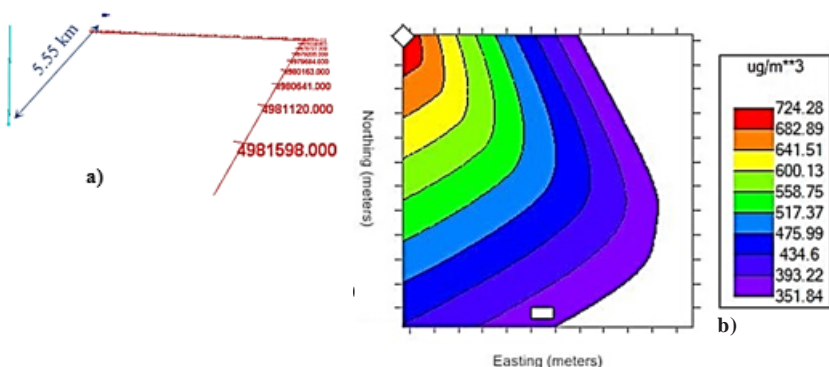


Fig. 4. Modeling results using Breeze Aermod for a stationary source (chimney) with a major contribution to the elevated  $PM_{2.5}$  concentrations (a) recorded in 4 December 2016 in Targoviste northern area; a distance of 5.55 km exists between source - rhombus and receptor - rectangle (b)

necessary parameters, and AERMAP, a terrain preprocessor that simplifies the computation of receptor elevations. Figure 4 shows the three-dimensional environment integrated in the software depicting the emission source (chimney) and the location of receptor, as well as the plume direction and associated isolines corresponding to the pollution event (4 December 2016 in Targoviste northern area).

Figure 5 shows the simulation results providing the highest estimated hourly concentration of  $329.7 \mu g m^{-3}$  at

real time monitors were 323 and  $321 \mu g m^{-3}$ ). There is a slight overestimation compared to the real measurements considering that in the area other emission sources are existing, which might have contributed to the total concentrations (e.g., street traffic, railway transport, emissions from a domestic wastes deposit).

Secondly, the application of HYSPLIT dispersion model using embedded GDAS meteorological database provided

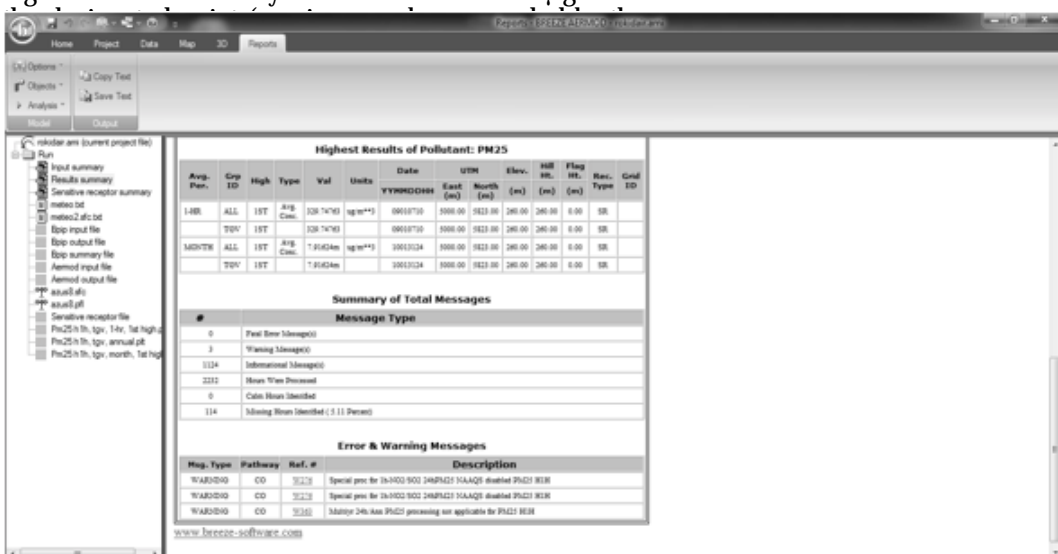


Fig. 5. Screen capture of the reports section corresponding to the pollution event recorded in 4 December 2016 in Targoviste northern area (Breeze Aermod 7.9)

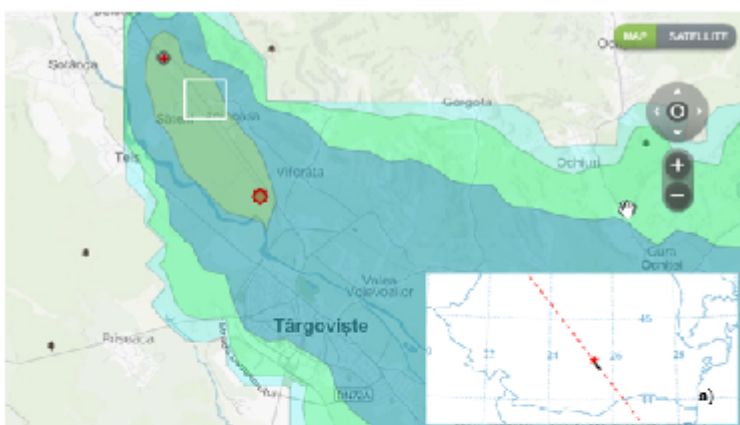
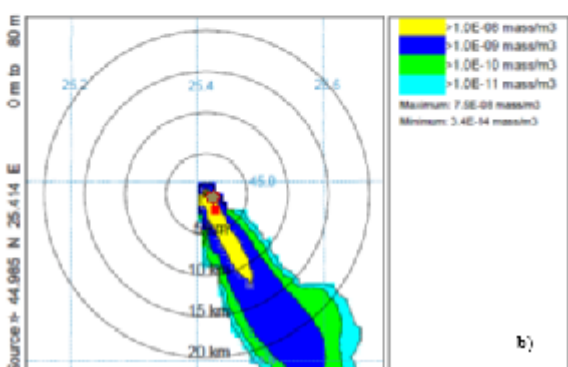


Fig. 6. Modeling results using HYSPLIT dispersion model showing particle cross-section (a), isolines of concentrations (b), and particle plots (c) simulated for hour 11 a.m. when the highest concentration was recorded by the optical monitors: star- chimney; circle -  $PM_{2.5}$  monitoring point; rectangle - area with the estimated maximum concentration.



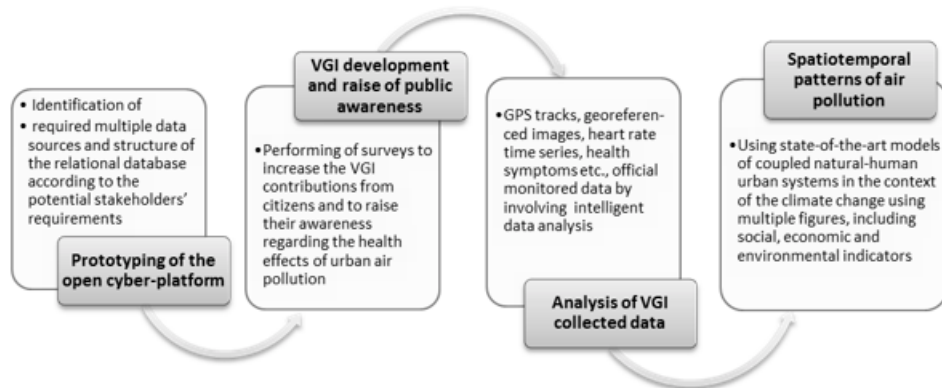


Fig. 7. Information flow for increasing the spatiotemporal quantity of air quality data using Volunteered Geographic Information (VGI)

the trajectory of the emissions from the potential source, the particle cross-sections and the particle plots. Figure 6 provides the forward trajectory of the plume towards southeast from the emission source. It may be observed that the  $PM_{2.5}$  monitoring point is located in the area estimated with highest concentrations, and on the direction of particles. The low altitude of particles determined by the meteorological conditions (fog) can explain the increased  $PM_{2.5}$  concentrations. The obtained results emphasize the usefulness of embedding dispersion modeling advanced tools to supplement monitoring results and to characterize the source apportionment.

### Volunteered Geographic Information

In the last decade, two directions were used for a successful increasing of information amount regarding the air pollutants in urban microenvironments to complement the information from conventional air quality monitoring infrastructure:

(i) implications of citizens as observers of air pollution – educating the public and ensuring their participation in the developing and maintaining of environmental protection systems [13]. Lately, they can contribute for database completion in *Volunteered Geographic Information Systems (VGIS)* and for improving air protection policies through crowdsourcing. New European research projects such as MESAJ, Citi-Sense-Mob, OpenSense, Rokidair, hackAIR etc. envisage the developing of open platforms that will enable communities of citizens to easily set up air quality monitoring networks and engage their members in providing information for measuring and publishing outdoor air pollution levels;

(ii) developing of intelligent cyberinfrastructures (CI) allowing quick feedback from stakeholders – The CI is a feasible new approach in research and refers to an infrastructure based upon distributed computers, advanced information processing and communication technologies [14]. The CI can be the core of a system that provides intelligent on-line information to the users with portable devices such as smartphones and tablets enabling their feedback regarding the urban spatiotemporal dynamics of air pollution [15]. Using of the CI can enhance the communication between urban spatiotemporal dynamics, stakeholders and urban policy making facilitating the understanding of ecological consequence to human health and welfare [16]. Measuring of aerosols' size distribution and composition, and modeling their dispersion and transport play an important role in prevention of population regarding potential pollution episodes [17].

The VGI platform must be considered as an important component of the CI. Figure 7 presents our approach for the development of a successful VGI e-platform. The client-server structure will include three segments i.e., remote server with geospatial analysis functions, database server (middleware), and VGI interfaces on portable systems

(mobile applications). The information flow will be as follows: data producer (VGI contributors) – data provider – data consumer (citizens, decision factors).

The quest is on to research, identify and collect information sources for the anticipated meta-level information repositories i.e., open air quality and climate databases, news and content streams, experts and stakeholder networks, and relevant case studies, as well as to build meta-level open air pollution databases. Such tools will provide valuable insights on the availability, quality, and accessibility of data hubs and portals addressing air pollution for decision-making processes and compliance with EU air quality legislation.

### Conclusions

Monitoring and modeling applications allow the successful assessments of PM concentrations in urban areas allowing the forecasting of PM levels, and the source-receptor evaluation.

Furthermore, modeled scenarios can assist the ranking of exposure of the vulnerable groups of population in various microenvironments of a specific town supporting detailed epidemiological studies.

The obtained estimations of air quality can be correlated with potential health effects and thus provide useful information about the environmental conditions in certain areas. This information is very valuable especially for vulnerable groups of population, such as asthmatics, children and elders, who can act accordingly by avoiding certain areas or try to stay indoors during critical pollution events.

*Acknowledgements:* The research leading to these results has received funding from EEA Financial Mechanism 2009-2014 under the project ROKIDAIR Towards a better protection of children against air pollution threats in the urban areas of Romania contract no. 20SEE/30.06.2014. The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model used in this publication.

### References

1. BATISTA, F., LUISA team, Modelling urbanization processes in Europe, 1st EC-JRC Urbanization Workshop, Ispra, 27th May 2015, <https://ec.europa.eu/jrc/en/luisa/>
2. BRAUER, M., AMANN, M., BURNETT, R.T., COHEN, A., DENTENER, F., EZZATI, M., et al., Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution, *Environ. Sci. Technol.* **46**, 2012, p. 652–660.
3. NEDELESCU, M., BACONI, D., NEAGOE, A., IORDACHE, V., STAN, M., et al. Environmental metal contamination and health impact assessment in two industrial regions of Romania, *Science of The Total Environment*, <http://dx.doi.org/10.1016/j.scitotenv.2016.12.053>
4. OECD, The OECD Environment Outlook 2050: The Consequences of Inaction, <http://www.oecd.org/environment/oecdenvironmentaloutlookto2050theconsequencesofinaction.htm>

5. DUNEA, D., IORDACHE, S., Time Series Analysis of Air Pollutants Recorded from Romanian EMEP Stations at Mountain Sites, *Environ. Eng. Manag. J.*, **14**(11), 2015, p. 2725-2735.
6. WHO Regional Office for Europe, Review of evidence on health aspects of air pollution – REVIHAAP Project Technical Report. 2013, [http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf?ua=1](http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf?ua=1)
7. POPE, C.A., DOCKERY, D.W., Health effects of fine particulate air pollution: lines that connect, *J. Air Waste Manag. Assoc.*, **56**(6), 2006, p. 709-742.
8. DUNEA, D., IORDACHE, S., LIU, H.-Y., BOHLER, T., POHOATA, A., RADULESCU, C., Quantifying the impact of PM<sub>2.5</sub> and associated heavy metals on respiratory health of children near metallurgical facilities, *Environmental Science and Pollution Research Journal* **23**(15), 2016, p. 15395-15406.
9. ROLPH, G.D., Real-time Environmental Applications and Display sYstem (READY) Website (<http://www.ready.noaa.gov>). NOAA Air Resources Laboratory, College Park, MD, 2017.
10. DUNEA, D., IORDACHE, S., POHOATA, A., Fine Particulate Matter in Urban Environments: A Trigger of Respiratory Symptoms in Sensitive Children, *Int. J. Environ. Res. Public. Health.*, **13**(12), 2016, p. 1246.
11. IORDACHE, S., DUNEA, D., PREDESCU, L., DUMITRU, D., PREDESCU, M., Assessment of fine and submicrometric fractions of particulate matter in Valahia University campus, SGEM2016 Conference Proceedings, June 28 - July 6, Book 4, Vol. 2, 2016, p. 235-242 pp.
12. VAZ, A.I.F., FERREIRA, C., Air pollution control with semi-infinite programming, *Applied Mathematical Modelling* **33** (4), 2009, p. 1957-1969.
13. CASTELL, N., KOBERNUS, M., LIU, H.-Y., SCHNEIDER, P., LAHOZ, W., BERRE, A.J., NOLL, J., Mobile technologies and services for environmental monitoring: The Citi-Sense-MOB approach. *Urban Climate*, <http://dx.doi.org/10.1016/j.uclim.2014.08.002>, 2014.
14. IORDACHE, S., DUNEA, D., LUNGU, E., PREDESCU, L., DUMITRU, D., IANACHE, C., IANACHE, R., A Cyberinfrastructure for Air Quality Monitoring and Early Warnings to protect Children with Respiratory Disorders, Proceedings of The 20th International Conference on Control Systems and Computer Science (CSCS20-2015) Bucharest, 2015, p. 789-796.
15. GOVINDARAJU, R.S., ENGEL, B., EBERT, D. et al., Vision of Cyberinfrastructure for End-to-End Environmental Explorations (C4E4), [http://dx.doi.org/10.1061/\(ASCE\)1084-0699\(2009\)14:1\(53\)](http://dx.doi.org/10.1061/(ASCE)1084-0699(2009)14:1(53))
16. CYRDAS Report, Cyberinfrastructure for the Atmospheric Sciences in the 21st Century, [http://www.cisl.ucar.edu/cyrdas/cyrdas\\_report\\_final.pdf](http://www.cisl.ucar.edu/cyrdas/cyrdas_report_final.pdf)
17. VASILESCU, J., NEMUC, A., MARMUREANU, L., NICOLAE, D., Aerosol size distribution and composition near Bucharest during May 2010, *Environ. Eng. Manag. J.*, **10** (1), 2011, p. 121-126

---

Manuscript received: 10.01.2017