POTENTIAL OF OPEN SOURCE GIS FOR MANAGEMENT OF TRAFFIC AIR POLLUTION

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Abstract

Air quality remains as one of the pressing problems of urban areas. While air pollution modelling is a well-established field of research in environmental engineering, the challenge is to integrate **G**eographic **I**nformation **S**ystem - GIS as a scientific tool for analysis within the environmental policy-making and management process.

This work aims to visualize modeled results from atmospheric dispersion of pollutants caused by traffic, using capabilities of open source GIS tool, e.g. QGIS. Supporting air dispersion modelling, QGIS provides release of information in a convenient and easily understandable way, which can be quickly distributed to necessary sides for further management and decision making.

Keywords – QGIS; air pollution; traffic; dispersion modelling

INTRODUCTION

High air pollution in urban areas has been a major contributing factor towards degrading the ambient air quality day by day [1]. Contributing for over 60% of air pollution, exhaust emissions from road traffic are identified as a very serious problem [2].

The process of air pollution analysis is complex, dynamic, and involves large volumes of data as well as spatially distributed results from dispersion models [3]. To accomplish all the requirements of air pollution analysis, a combination of dispersion model and GIS should be used.

Dispersion model can analyze not only the current air pollution situation, but also can predict emission amounts influenced by changes in specific traffic conditions or management policies.

GIS, as a technology that can handle information on both location and its characteristics within a single system, has visualization capabilities that are widely used [4]. Nowadays, GIS as management and supporting system enables integration and analysis of numerous modeled data for the impact of air pollutants on the environment [5]. Hence, the interface of dispersion model with a GIS platform offers substantial support for modeling traffic plans and control schemes [6].

As more and more GIS programs are being made available by open-source communities, we opted for Quantum GIS (QGIS) software to achieve the coupling with dispersion modeling. As a practical example of integration between QGIS and selected dispersion model AEOLIUS, calculations are prepared and presented for a crossroad in central area of the town of Bitola. Calculations comprise introduction of congestion payment and traffic calming as a measures for traffic management. These measures are analyzed through min/max values of traffic volumes and changes in traffic speed.

The goal of integration between QGIS and dispersion model is to present a GIS supported air pollution platform, very helpful for visualization of results and necessary for making future simulations and performing geo-referenced pollution predictions, which can then be used as a basis for traffic management and control.

GIS AND AIR POLLUTION

A **G**eographic **I**nformation **S**ystem (GIS) is a computer-based information system which enables capturing, modeling, manipulating, retrieving, analyzing and presenting geographically referenced data [5].

GIS is one of the information systems that offer management of data with spatial and time attributes, e.g., manages spatial description of urban environment [7]. GIS permits to map directly the pollution process and to get pollutants concentrations at given position on the map [8].

Integrated with dispersion models, GIS offers several possibilities for understanding the air pollution problems [9]:

- makes it easier to place the air pollution sources/values at the correct location, for example by making it easy to display and edit the total urban network of road links
- gives a good overview of where to expect high impacts of air pollution
- makes it possible to search for geographically linked data in the database.

Whereas GIS is used for data management and geo-statistical analysis, the dynamic modeling of air pollution is mostly solved independently in the framework of standalone computer programs. In spite of wide range of functions, which are implemented in GIS for spatial data management, existing GIS do not offer effective programming environment [7]. On the opposite side, GIS offer more functions for storage and visualization of data.

Therefore, GIS is mostly used in the frame of modeling of air pollution for pre-processing (data input, data analysis, estimation of model parameters) and post-processing (spatial data management and visualization, printing maps, presentation of results) [7]. This means that GIS serves as the data stores, which can manage all the data together with model outputs to carry out map compositions and further analysis.

OPEN SOURCE GIS VS COMMERCIAL SOFTWARE

Open source software is generally free software that can be used in research or business. Open source developers choose to make the source code of their software publicly available for the good of the community and to publish their software with an open source license – meaning that other developers can see how it works and add to it [10].

The idea behind open source software is that users are effectively co-developers, suggesting ways to improve it and helping to hunt out bugs and problems. This means that everyone if wish, can modify it to own needs, port it to new operating systems and share it with others, something that is not possible with commercial systems [10].

The reasons why QGIS was chosen as open sources software were several.

The features of QGIS are easy to work with and a simple map can be generated quickly. When selecting a GIS software program, one of the central features to look for is the capability to create maps. Some of the more complex features such as thematic mapping and querying take more time to understand, and learn to successfully apply it [11]. Some of the more basic features that GIS users would expect are surprisingly not available, such as text or graphic insertion and any image-related manipulation (clipping) or high resolution image export. However, for a free program it is remarkably sophisticated with some very valuable GIS tools [11]. What stands out the most about this program is its editing tools – the ability to easily create, edit and delete shapefiles and files within it [11]. The raster georeferencing plugin is also a remarkable feature.

In the table 1 the most prominent characteristics of QGIS are presented, which were most relevant for its choice in this analysis.

Table 1: QGIS prominent characteristics

Cost	QGIS is freely downloadable open source GIS software that has a popular desktop option, mobile, and web component.
Licensing	No licensing concerns or licensing key. QGIS can be loaded on any computer.
Development process	QGIS is developed and has a paid core of developers but also depends in part on volunteers.
Platform	QGIS is cross-platform and can be installed and run on Windows, Mac or Linux machines.
Loading time	QGIS has a faster startup time than other commercial software.
Extensibility	QGIS functionality can be extended thorough scripting (Python) and plugins.
Support	QGIS offers peer support via the gis.stackexchange.com site and OSGeo.org's mailing lists.
Adoption	QGIS' acceptance is growing but is mostly popular in academic circles and in arenas where open source software is the norm.

Source: [12]

QGIS would satisfy any GIS user who is in need of viewing and manipulating geospatial files in a variety of formats, and is interested in creating simple maps with these datasets [11].

INTEGRATION: AEOLIUS DISPERSION MODEL AND QGIS

Basic method for air pollution assessment and prediction are dispersion models [13]. But, their application involves unsteadiness and uncertainties, primarily caused by the proper selection and use of dispersion model [8].

The selection of dispersion model depends on the [14]:

- conditions within the area under research (topographic and meteorological conditions),
- scale (single street, zone or area of the city),
- availability and quality of the input data (if deficient and low quality input data are only available, no sophisticated dispersion model needs to be applied),
- experience of the user,
- available financial resources,
- purpose and the results needed for.

Dispersion modeling of traffic air pollution is very complex because of the numerous variables such as the types of pollutants (i.e., CO, NO_x, PM etc.); the time of day; photo-chemical reactions; meteorological conditions; amount and composition of traffic flow; topography; buildings height and concentration (i.e. "the urban canyon effect"); and scale/resolution. Because of these numerous factors, the models developed for traffic related air pollution are data intensive and necessitate complex formulae [15].

Nevertheless, complex dispersion models have limited application in developing countries with high density urbanized areas, limited regulations and sparse input data.

Considering the above selection characteristics, AEOLIUS model, developed by the Meteorological office in London, was chosen as dispersion model most suitable for the town of Bitola.

Most dispersion models have a output formats in tabular form, but unfortunately do not integrate the information into a spatial database which would allow urban planners and decision makers to easily access and interpret the information [16]. AEOLIUS is such a model. Linking up this dispersion models with a QGIS environment is a mean to resolve this shortcoming.

AIR POLLUTION ON A CROSSROAD IN CENTRAL AREA OF BITOLA TOWN: A PRACTICAL EXAMPLE FOR INTEGRATION

In order to show practically how this integration works and its potential for air management, a crossroad in the central area of Bitola town is selected. AEOLIUS is applied for calculation of pollution amount for each of four street segments, comprising the crossroad, after which concentrations are presented in QGIS.

Traffic data, e.g., traffic volumes for each crossroad section, categorized by vehicle class (passenger cars, HDV and buses and motorcycles) were obtained as a result of manual traffic counts performed for the need of Traffic study for the town in Bitola in 2011. As input data for AEOLIUS model, the total hourly traffic volumes are used.

Analysis comprises two measures for traffic management: introduction of congestion payment and traffic calming. For the first one, maximal and minimal hourly traffic volumes are used as a basis to show difference in traffic flows, considering that the payment will impact on number of vehicles entering in the town centre. In the second one, calculations are performed considering traffic speed changes, comprising traffic speed in real conditions and decreased traffic speed as a result of introduced traffic calming measure (for example, road humps).

Hence, congestion payment and traffic calming are taken into account as one of the many measures for traffic management and control, which can be analyzed in similar way.

In QGIS, each street of the crossroad is represented by a segment corresponding to a record in the database. Additionally, streets may be hierarchically characterized, according to traffic intensity, hourly variation, street width, dominant use, such as: private or public transport; light or heavy duty; commercial or residential; and other urban criteria [9]. But, this kind of detailed categorization was not in the focus in this analysis.

First, for each street segment of the crossroad, a dispersion model AEOLIUS is used to estimate the resulting immissions. Calculations in AEOLIUS are based on geometrical characteristics of streets (width and height), traffic speed, traffic volumes, wind speed and background pollution, which was not taken into account, in order to obtain only the traffic contribution in air pollution. As a source for input data in the model, the Traffic study for the town of Bitola, urban plans and wind rose were used.

In AEOLIUS, hourly concentrations in ppb are calculated for NO_x, CO, SO_2, C_6H_6 (benzene) and C_4H_6 (1,3 butadiene) and in μgm^{-3} for PM_{10}. For NO_x further calculations are made for an hourly concentration of NO_2 and a 98 percentile value of NO_2. The concentrations calculated are leeward concentrations where leeward is defined as the side of the street from where the wind is blowing.

Next, in QGIS the results for particles (PM_{10}) are presented.

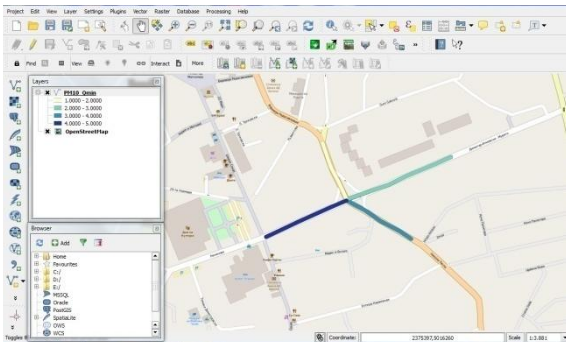

Fig. 1. Concentrations of PM_{10} for minimal traffic volumes

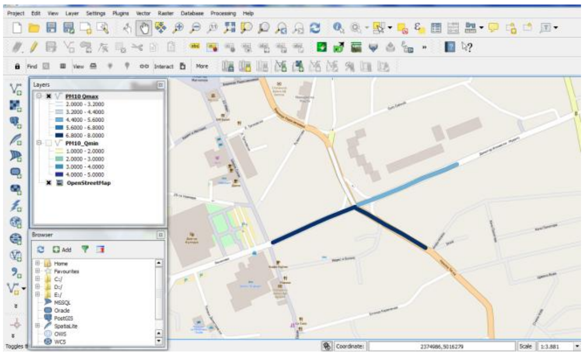

Fig. 2. Concentrations of PM_{10} for maximal traffic volumes

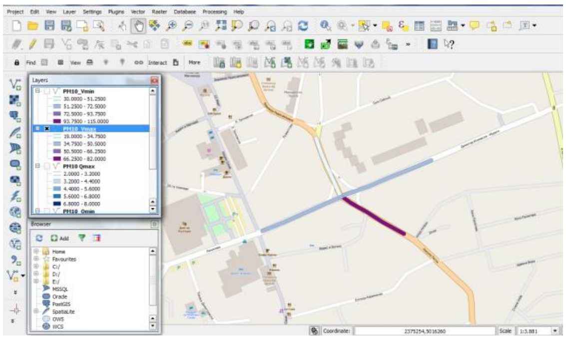

Fig. 3. Concentrations of PM_{10} for upper speed limit of 40 km/h

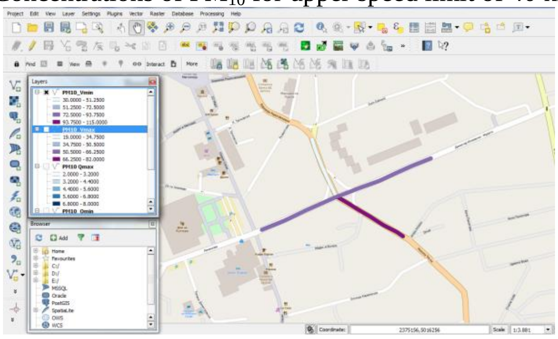

Fig. 4. Concentrations of PM_{10} for average speed limit of 20 km/h

The conclusion:

- figures 1 and 2 refer to congestion payment: the scale of colors more clearly shows that concentrations of PM_{10} are higher as traffic volumes are higher (i.e., congestion payment is better for air quality)
- figures 3 and 4 refer to traffic calming: the scale of colors more clearly shows that concentrations of PM_{10} are higher as traffic speed decreases (i.e., traffic calming endangers the air quality levels).

Hence, by integrating air quality modelling under GIS environment, the output of the pollutant records can be obtained in the form of spatial records, which can be used for the need of further management analysis.

CONTRIBUTION OF GIS FOR AIR POLLUTION MANAGEMENT AND CONTROL

Including large volumes of data, the analysis of traffic generated pollutants can be alleviated through integration of dispersion model and GIS [14]. At urban level, a detailed street network data is required for the simulation of traffic flows, traffic emissions and finally the resulting air quality. Using dispersion model, air pollution episodes are obtained and various scenarios of traffic planning and control can be analyzed.

Integrated with GIS, emissions can be accessed through the map by selecting an analyzed area. Displaying results of model calculations on a map can be used for decision making, public information on pollution levels and further simulation scenarios. These scenarios may involve [13]:

- different fleet composition and age structure of vehicles,
- speed limits,
- measures for traffic management ("green waves", introduction of roundabouts, traffic calming, congestion charges, road tolls, parking charges etc.)
- one way and transit line systems,
- closure of certain lanes/streets or urban zones,
- simulation of short-term events such as road construction, special events such as a major sport events or traffic accidents.

Several other indicators such as inhabitants per car use, inhabitant's growth rate, main urban attractors and traffic demand characteristics, may be used as a significant component in the database to complement the knowledge of the urban mobility and their impact on emissions [9].

In all these simulation scenarios, GIS systems can greatly improve the realistic representation of the traffic network, effective user-interfaces and efficient visualization of network solutions to maintain the air quality [6].

Additionally, GIS can be linked to the Internet to provide real time information about air pollution. This is helpful for planning of urban journeys, avoiding the most polluted places and for more positive attitude towards sustainable travel modes (public transport, cycling and walking).

Governmental agency can use short term traffic forecasting and management measures and air pollution modeling techniques to predict air pollution for urban network for one or two days in advance to provide a simple advisory system for decision-makers and the public. In the long term, being able to model and to visualize traffic related pollution would enable local decision-makers to evaluate the effectiveness of mitigation strategies and better plan new urban traffic system [15].

All these capabilities of GIS are expected to be beneficial for environmentalists, planners and decision makers so that they can reliably generate, simulate and analyse more information about air pollution [14].

CONCLUSION

Most urban environmental problems of air pollution do have an obvious spatial dimension that can be addressed by **G**eographic **I**nformation **S**ystem - GIS [13].

Considering that the use of GIS has been proven to be effective in analysis of traffic related air pollution [13], this paper presents the application of open source GIS, e.g., QGIS, in integration with dispersion model AEOLIUS. Air pollution analysis had been performed for selected crossroad in central area of Bitola town, demonstrating how QGIS can be effectively used for visualization of air pollution coming from urban traffic. Two traffic management measures are analyzed: introduction of congestion payment and traffic calming. Further, the results of this kind of analysis would allow urban planners and decision makers to easily access and interpret the information, achieving effective air pollution management and control.

Open source GIS, or QGIS selected in this case, has application potential for pollution management, presenting the influence of different measures on urban air quality. Here, it's important to note, that QGIS could be used not only as a map viewer, but more as a tool for handling urban and traffic data.

In general, the synthesis of dispersion modeling and GIS in the frame of pollution in urban areas has the potential to create more sophisticated analyses that can support research and improve decision making processes in practice [7].

Modelling pollution dispersion with a QGIS platform is a powerful way of making the modelled results user-friendly and easily understandable for local authorities as well as the public [16]. Data sets created and organized under QGIS can be shared between various government entities (decision-makers) and the public.

Therefore, the scale of urban air pollution problems makes GIS a powerful tool for management of spatial and temporal data, complex analyses and visualization [3].

Today, GIS has been extensively used for air quality modelling purposes. GIS is surely one of the most used software platform for air pollution assessment [9]. These features justify choosing QGIS as an appropriate open source software for air pollution management and control in urban areas.

REFERENCES

[1]. Agrawal, I.C. et al., "GIS as modelling and decision support tool for air quality management: a conceptual framework", presented at the Environment planning conference, India, 2003.

[2]. Sivertsen, B., "Air quality management and abatement strategy planning", Norwegian Institute for Air Research NILU, Norway, 2001.

[3]. Matejicek, L., "Spatial modelling of air pollution in urban areas with GIS: a case study on integrated database development", Advances in geosciences, No. 4, European Geosciences Union, 2005, pp. 63–68.

[4]. Kawabata, M. and Ferreira, J. J., “GIS modeling of urban components to monitor and model urban respiration”, CSIS Discussion Paper No. 58, Center for Spatial Information Science, July, 2003.
[5]. Rahmatizadeha, Sh. et al. (2015, 12.20). Design and development of a customized GIS for air quality management. Available: www.isprs.org/proceedings/XXXV/congress/comm7/papers/212.pdf
[6]. Arampatzis, G. et al., “A GIS-based decision support system for planning urban transportation policies”, European Journal of Operational Research, Elsevier B.V., No. 152, 2004, pp. 465–475.
[7]. Benesova, L. and Matejicek, L. (2016, 01.19). Chapter 8: Modeling of environmental pollution in urban areas with GIS. Available: web.natur.cuni.cz/geografie/vzgr/monografie/modelling/modelling_benesova.pdf
[8]. Bozon , N. et al., “A GIS-based atmospheric dispersion model”, STIC & Environnement, Calais: France, 2009.
[9]. Endregard, G., “AirQUIS: A Modern Air Quality Management Tool”, Norwegian Institute for Air Research NILU, Norway.
[10]. Open source software – the advantages& disadvantages (2015, 12.08). Available: http://entrepreneurhandbook.co.uk/open-source-software/
[11]. Quantum GIS software: Application user review (2015, 12.10). Available: http://spatialnews.geocomm.com/articles/qgisreview/
[12]. QGIS versus ArcGIS (2015.12.15). Available: http://www.gislounge.com/qgis-versus-arcgis/
[13]. Fedra, K., “Urban environmental management: monitoring, GIS and modelling”, Computer, Environment and Urban Systems, No. 23, 1999, pp. 443-457.
[14]. Angelevska, B. and Markoski, A., “Decision making through integrated system for air quality assessment”, International virtual journal MTM Machines, Technologies, Materials; ISSN: 1213-0226, year III, Issue 11-12, Sofia, Bulgaria, 2009, pp.15-17.
[15]. McAdams, M., A. et al., “Predicting short term vehicular related air pollution for corridors: a case study in Istanbul, Turkey”, Third International Symposium on Air quality management at urban, regional and regional and global Scales & 14th IUAPPA Regional Conference, Istanbul, Turkey, Sept 26-30, 2005, pp. 20-28.
[16]. Wang, G. et al., “Modelling urban traffic air pollution dispersion”, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII, Part B8, Beijing, 2008, pp. 153-158.