Urban air pollution assessment through satellite and in-situ data in relation with health aspects

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Abstract. MODIS Terra/Aqua time-series satellite and in- situ monitoring data of particle matter PM2.5 and PM10 have been used in an effort to qualitatively assess distribution of aerosols in the greater metropolitan are of Bucharest, Romania during 2010-2011 period. It was found that PM2.5 and PM10 aerosols exhibit their highest concentration mostly in the central part mainly due to road traffic as well as in the industrialized parts outside of city's centre. Many epidemiological studies examining the relationships between adverse health outcomes and exposure to air pollutants in urban agglomerations use ambient air pollution measurements like as PM10 and PM2.5 levels as a proxy for personal exposure levels. The measurements of environmental concentrations of particulate matter air pollutants have been correlated with some meteorological parameters (air temperature and pressure, relative humidity, wind intensity) in urban and periurban subtest areas. Accurate information of urban air pollution is required for environmental and health policy, but also to act as a basis for designing and stratifying future monitoring networks. Epidemiological studies aim to detect the relative risks associated with particulate matter and gases present in the lower atmosphere.

Keywords. Particle matter PM10 and PM2.5, MODIS time-series satellite data, urbanization, children health, Bucharest, Romania.

1. Introduction

Aerosols are ever-present and highly-varying constituents of lower atmosphere. They play active roles in many physical and chemical processes that shape the composition of the atmosphere and thereby affect cloud formation, visibility, and air quality. Atmospheric aerosols represent one of the most important parameters affecting the Earth's energy balance and hydrological cycle, climate and human health. Atmospheric pollution was monitored in Bucharest by means of an extended network of eight ground stations. As the network's capacity to monitor aerosols in the lower troposphere is limited, MODIS Terra/Aqua time-series satellite data used provide a better spatial distribution of aerosols in relation with sources of aerosols' emissions. The influence of aerosol particles on climate, and how their properties are perturbed by anthropogenic activity, is one of the key uncertainties in climate change assessments. In spite of improvements in air quality observed in Bucharest metropolitan area between 1990 and 1997, still concentrations of particulate matter PM and other pollutants have not shown a significant decrease. Bucharest inhabitants and Romanian citizens are still exposed to concentrations exceeding the recommendations of the World Health Organization (WHO). Nevertheless, air pollution remains one of the most urgent environmental problems in Romania, and for Bucharest city too. Air particles pollutants have health effects on urban populations exposed at the micro or neighborhood scale being suspected of playing a significant role in the rapid increase in urban asthma [1]. The epidemiological research on the mutagenic effects of airborne particulate matter pointed their capability to reach deep lung regions, being vehicles of toxic substances. Toxicological studies, currently attempt to identify relation between particle characteristics responsible for adverse biological responses, and suggest that the chemical composition of PM (which reflects differences in source contributions) plays an important role in these responses [2]. The current study presents a spatio-temporal analysis of the aerosol concentrations in relation with meteorological parameters in two size fractions (PM10 and PM2.5) and possible health effects on children in Bucharest metropolitan area.

2. Air pollution with particle matter (PM) and health

While air pollution is a complex mixture of compounds in gaseous (ozone, CO and nitrogen oxides) and particle phases, the strongest evidence of linking air pollution with human health, especially on respiratory effects, centers on the particulate matter (PM) which is comprised of heterogeneous compounds varying in size, number, chemical composition, surface area, phase, concentration and source. In the atmospheric sciences, function of their generation sources and formation mechanisms, the fine PM mode includes particles of radius lower than 1 μm (PM1 < 1 μm) and PM coarse mode includes particles of radius greater than 1 μm (PM1 > 1 μm) [3].

According to health experts, the PM fraction of radius lower than 100 μm (PM100 < 100 μm) is known as inhalable PM. Also, was defined another finer size fraction of radius lower than 4 μm (PM4 < 4 μm) that can penetrate the conductive airways of the human tracheobronchial tree that distributes the inhaled air to the gas-exchange airways in the lungs. This fraction is known as respirable PM (US-NIOSH—National Institute for Occupational Safety and Health, Centres for Disease Control and Prevention-guidelines- http://www.cdc.gov/niosh/). Particle matter of radius lower than 2.5 μm (PM2.5 < 2.5 μm is known as alveolar fraction of particles).

Respirable suspended particulate matter or PM10and PM2.5 are known to have detrimental effects on human health and the relationship between air pollutants and health has been widely studied, an increase in yearly mean PM10 concentration increases the number of respiratory hospital admissions and the mortality rate [4].

Anyway, presently in air quality standards PM10 and PM2.5 are usually selected as monitoring parameters in worldwide environmental issues. Thus, in air quality, the coarse fraction is considered the one between 2.5 μm and 10 μm (PM2.5–PM10), whereas PM2.5 is considered the fine fraction.

Many epidemiological studies examining the relationships between adverse health outcomes and exposure to air pollutants in urban agglomerations use ambient air pollution measurements like as PM10 and PM2.5 levels as a proxy for personal exposure levels [5].

In addition to the local and regional anthropogenic PM sources, both the levels and composition of air PM depend on meteorological parameters (temperature, humidity, precipitation, winds etc.), climatologically conditions (photochemistry, resuspension of soil particles, rain scavenging potential, re-circulation of air masses, dispersive atmospheric conditions) and on the geography (topography, soil cover and proximity to arid or sea zones) of a given region. Therefore, wide variations in PM levels and physico-chemical characteristics may be expected when considering different land cover regions (urban, rural, industrial, etc) [6]. Emissions of various air pollutants from an ever increasing vehicle fleet, deteriorating traffic congestion, and establishment of small- and medium-scale factories with poor emission control technologies in urban settings are contributing immensely to poor air quality, [7], [8].

Health effects due to air pollution is becoming a major public health problem with growing traffic congestion and establishment of small- to medium-scale industries with poor emission controls in metropolitan area of Bucharest. In Romania, among the leading causes of death include: ischemic heart diseases 23.0% (of all causes), cerebrovascular diseases 20.2%, hypertensive heart disease 6.5%, cirrhosis of liver 4.3%, lung cancer 3.4%, lower respiratory infections 2.5% and breast cancer 1.3%. The high mortality rate due to cardiovascular diseases is of particular concern. Leading risk factors and their share (as estimated percentages of total deaths) are high blood pressure (31.8%), tobacco consumption (16.3%), high serum cholesterol (14.4%), high body mass index (13.9%), alcohol consumption (12.4%), low fruit and vegetable intake (7.1%) and physical inactivity (6.6%) [9]. Atmospheric particulates, especially secondary anthropogenic fine particles, have been proven to have a major impact on human health. Generally speaking, the total daily mortality rate increases by approximately 1% for every 10 μg/m3 of PM10 concentration [10].

3. Satellite remote sensing for air pollution monitoring

Over the past few decades, remotely sensed data of various spatial, spectral, angular, and temporal resolutions have been widely used to study the land use/cover changes associated with urban growth, and to retrieve land surface biophysical parameters, such as vegetation fraction cover, built-up indices and land surface temperatures, which are good indicators of conditions of urban ecosystem.

Satellite remote sensing imagery is an important tool for monitoring the global aerosol budget and their radiative effects on climate. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor provides a unique opportunity for deriving spectral information of aerosol properties over land and ocean in the visible and infrared wavelength region. The aerosol data derived from the two MODIS sensors are useful for several applications like as: the investigation of the regional and global aerosol distribution, air pollution monitoring, radiative forcing and climate response, aerosol interactions with clouds. The data quality is essential for all these applications, while the required accuracy of the retrievals depends on the spatial and temporal resolution.

Geospatial Earth Observation data provided by satellite sensors are very useful tools for urban patterns surface analysis.

Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard the National Aeronautics and Space Administration’s Terra and Aqua satellite platforms provide aerosol retrievals over land and ocean surfaces. The aerosol products available over land include AOD (Aerosol Optical Depth) at three visible wavelengths, a measure of the fraction of AOD attributed to fine-mode particles. The MODIS algorithms have been under continuous development, and have received an improved aerosol determination, via processing to Collection 5 (C005) [11], [12]. The MODIS data are available at different processing levels, level 1.0 (geolocated radiance and brightness temperature), level 2.0 (retrieved geophysical data products) and level 3.0 (gridded points) [13]. MODIS measures AOD with an estimated uncertainty of _0.05AOD_0.15 for Level 2 over land [14] at 0.47 and 0.66 μm with 500-m spatial resolution extrapolated at 0.55 μm [15]. The MODIS aerosol retrieval is calculated on a 10-km _ 10-km resolution (Level 2), which is retrieved from the higher-resolution radiance measurements (Level 1B). Clouds are screened within the Level 2 box [12] and the aerosol retrievals are performed if there is a sufficient number (approximately 10%) of no cloudy pixels. Therefore, the Level 2 products may be valid even when the box has cloud coverage of approximately 90%. Depending on the quality of the retrieval (and the number of valid pixels), the 10-km retrieval is assigned a quality assurance (QA) value. These 10-km retrievals are aggregated to 1-degree box (Level 3) and are derived from weighted QA Level 2 retrieval. The C005 (version 5.1) Level 2 and Level 3 Terra and Aqua MODIS AOD550 are obtained from LAADS web (http://ladsweb.nascom.nasa.gov/) and Giovanni website (http://disc.sci.gsfc.nasa.gov/giovanni/) over Bucharest and compared to each other and with ground measured AOD during the period of 2010-2011.

IKONOS imagery which has 1m spatial resolution in panchromatic mode and 4 m in visible bands 1, 2, 3 and NIR band was used for high resolution Bucharest test area mapping. This imagery is produced by merging 11-bit of 1 m resolution panchromatic (0.45-0.90 μm) and 4 m resolution multi-spectral - blue (045-0.53 μm), green (0.52-0.61 μm), red (0.64-0.72 μm) and near infrared (0.77-0.88 μm).

Satellite remote sensing derived biogeophysical parameters of Earth's cover provide great potential for urban land cover analysis in relation with environmental pollution and extreme climate events like heat waves impacts on urban ecosystems.

The aerosol parameters can be measured directly in situ or derived from satellite remote sensing observations. All these methods are important and complementary.

Like for many cities in the world, for Bucharest metropolitan zone in Romania have been set up fixed air quality gravimetric monitoring stations to record on a continuing basis the air quality and to measure concentrations of major pollutants at roadside and urban background locations. Also, according with European Community and national legislation have been set short- and long-term air quality thresholds on acceptable concentration levels of different pollutants in the lower atmosphere. Based on observations made at existing monitoring stations, advisories and warnings are issued when concentration of one or more pollutants exceeds these limits. The planning authorities may also use measurements at ground monitoring stations to decide pollution abatement measures and to examine the effectiveness of these measures. Long-term measurements at pollution monitoring stations in Bucharest and its surroundings may be used to investigate the relationship between the population exposure to air pollutants and the incidence rate of respiratory or other diseases.

4. Study area and data used

Urban metropolitan area Bucharest described by a star-shaped pattern (Figure 1), placed in the South – Eastern part of Romania, is bounded by latitudes 44.33 °N and 44.66 °N and longitudes 25.90 °E and 26.20 °E. Its central region has the main coordinates: latitude 44°25′N, longitude 26°06′E. The city is crossed by the Dâmbovita and Colentina rivers and is surrounded by forests, which makes Bucharest a city with large green areas, which have come parks and, at the same time, places for rest and entertainment, such as: Baneasa, Herastrau, Floreasca, Tei, Lebada Fun area. Herastrau Park is the largest in the city, being situated on the Colentina River, including the Herastrau and Floreasca lakes, providing special opportunities of entertainment.

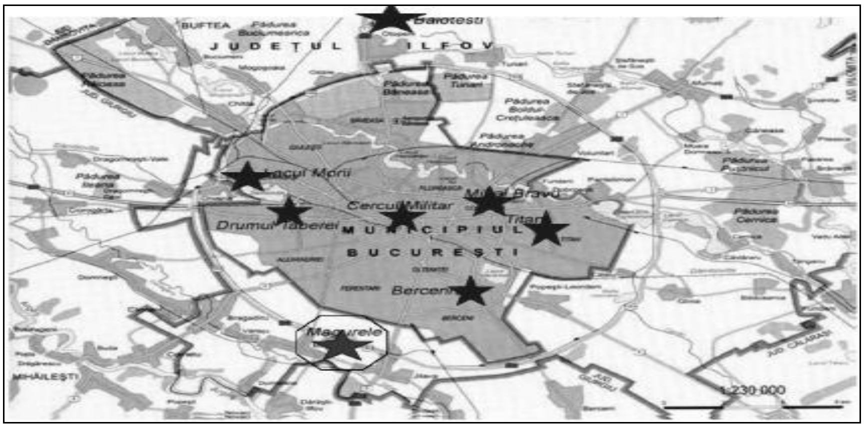

Figure 1. Test site urban Bucharest area and pollution monitoring stations

Bucharest is one of the most crowded capital in Eastern Europe and maybe the most polluted. Economical development results in traffic increase (presently six times increase in comparison to 1990 year) as well as some industries placed in the surroundings of the city whose activities generates high concentration of heavy metals (sometimes above the acceptable limits). The emission inventory prepared for the air pollutants in Bucharest by the local Environmental Protection Agency (EPA) having as reference 2001 year includes a number of 430 point sources (stacks) identified in the Bucharest agglomeration, area sources generated by the distribution of area emission sources due to residential heating, and area sources generated by the distribution of traffic emissions.

Daily average particle matters concentrations PM10 and PM2.5 for Bucharest metropolitan area have been provided by air pollution network (8 monitoring stations, represented in Fig.1: EPA - urban background; Drumul Taberei, Titan, Berceni-industrial; Cercul Militar, Mihai Bravu,-traffic; Balotesti- rural; Magurele-periurbn)- belonging to Bucharest Environmental Protection Agency (http://www.apmb.ro). The C005 (version 5.1) Level 2 and Level 3 Terra and Aqua MODIS AOD550 for period 01/01/2010- 31/12/2011 have been also used. Meteorological variables (air temperature, relative humidity, sea level atmospheric pressure) have been provided by http://www.wunderground.com, and http://www.meteoromania.ro and in-situ measurements. ENVI 4.7, IDL 6, ORIGIN 7.0 and MS Excel 2003 software were used for data processing, and time series analysis respectively. The objective of this work was to document the seasonal and inter-annual patterns of the aerosol loading over the Bucharest metropolitan area.

5. Results

Atmospheric particulate matter (PM) of both natural and anthropogenic origin evolves in the lower atmosphere of urban areas as a consequence of the multiple physico-chemical processes that can affect this matter from its release point, as a primary aerosol, or via gas-to-particle conversion processes that give rise to a secondary aerosol. PM measured at test site Bucharest is the result of an ensemble of processes and features that configure the adequate scenario to provide an aerosol with unique and specific characteristics. The knowledge of local sources (motor vehicles, open fires, domestic combustion heaters, industry and soil) is a starting point for characterizing a great number of aerosol properties, other features have to be taken into account as the result of processes that take place at regional to long-distance scales.

Aerosol pollution, especially from particles smaller than 10 μm in diameter, is associated with the growing problem of “haze’’ in urban-periurban and industrial areas being under heavy particulate loading, low wind speed and shallow inversion layers, which are most common in autumn and winter seasons. At higher concentrations these aerosols are responsible for both direct and indirect risks (e.g. public health and visibility) and concern has recently focused on the fine particulate matter (PM2.5), which is known to be linked more directly to adverse health effects than coarser matter.

The mean daily values of PM2.5 and PM10 concentrations show significant variations from day to day mainly due to the thermodynamic conditions in the planetary boundary layer (PBL), which can either favor or adversely affect air pollutants dispersion. Environmental weather conditions such as air temperature, relative humidity, air pressure and short wave radiation can also influence chemical reactions leading to secondary aerosol formation. On average, a seasonal variation was found as higher values occurred in winter than in summer. This pattern is mainly linked to the great seasonal difference in the typical meteo-climatic conditions in the land area of Bucharest. In summertime, the higher average wind velocity and the broader mixing layer improve the dispersion of pollutants in the atmosphere. In winter season, very frequent and persistent thermal inversions and fog situations at ground level cause a considerable amount of air pollutants to accumulate in the lower layers of the atmosphere.

The predominant component in PM10 was PM2.5, as can be seen in Figure 2, which shows clear evidence that high mean PM10 and PM2.5 particle concentrations were observed in winter months, while the lowest mean PM10 and PM2.5 particle concentrations were recorded in the summer months at the Bucharest center test site. Observational results indicate that yearly average PM2.5 and PM10 concentrations had values of 35.96 and 40.91 μgm-3, respectively.

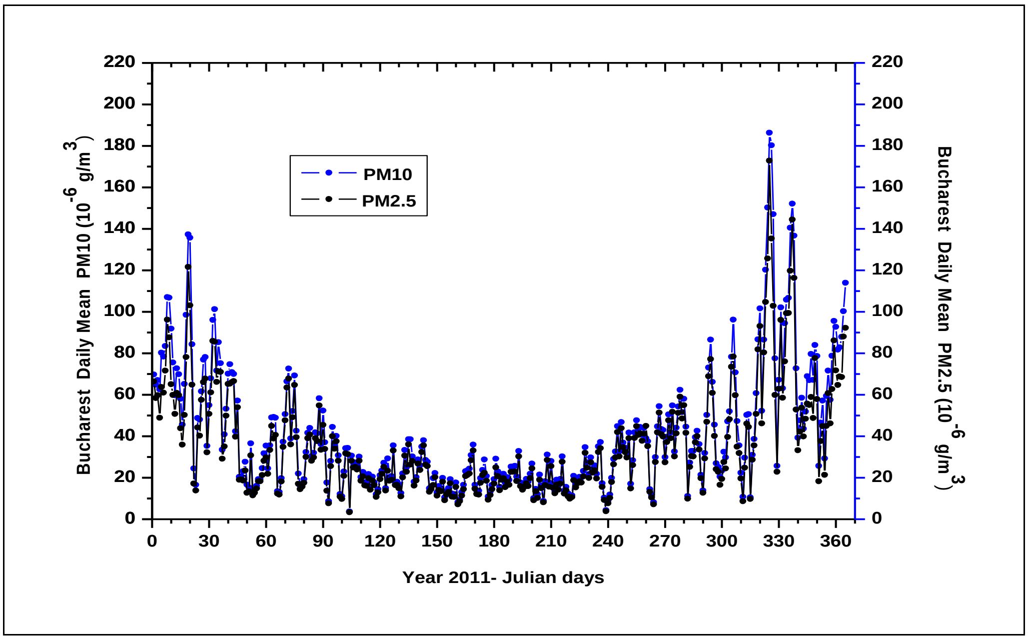

Figure 2. Daily mean variations of PM10 and PM2.5 concentrations (μ g/m3) during year 2011 in Bucharest center area

In spite of improvements in air quality observed in Bucharest and periurban areas between 1990 and 1997, after that concentrations of particulate matter PM have not shown a significant decrease. Bucharest inhabitants and Romanian citizens are still exposed to concentrations exceeding the recommendations of the World Health Organization (WHO), Bucharest city being one of the most air polluted city in Europe.

Fig. 3 shows the MODIS Land Cover Classification (Collection 5 IGBP Type_1 2005) 201 km Wide x 201 km High with user selected area marked for Bucharest metropolitan region, centered at latitude 44.43 N and longitude 26.09 E.

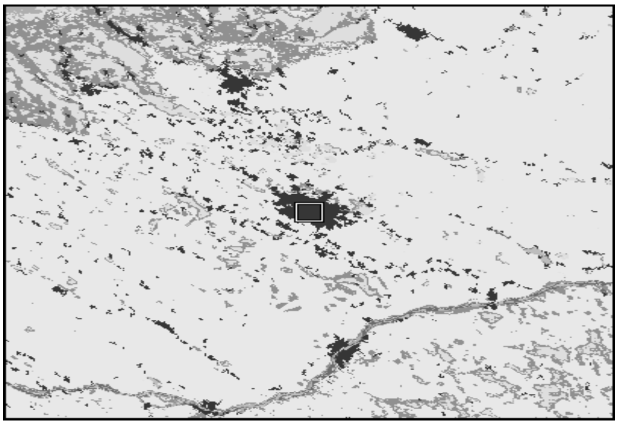

Figure 3. MODIS Land Cover Classifications for Bucharest metropolitan region

Figure 4. Aerosol concentration map derived from MODIS Terra AOD550 over Bucharest

Fig.4 shows aerosol concentration map derived from MODIS aerosol AOD550 aerosol optical thickness daily data. The monthly values are calculated if at least 10 daily ones are available for each month. The results reveal a significant month-to-month variability in all AOD550 values, underlying the influence of varying aerosol load function of season. The AOD550 values (Level 3) lie in a wide range, as low as 0.2 up to 0.5. Similar, or even higher monthly variability is observed for the Level 2 data. As regards the Level 3 Aqua AOD550, its increase seems to be more significant (27.9%) than that of Terra AOD550 (21.6%). Similar increases are found regarding the Level 2 data, which reach 14.5% and 34.1% for Terra and Aqua, respectively. Despite the fact that these values may composed of some uncertainties, all trends were found to be statistically significant at the 93% confidence level, underlying an increase in aerosol load road traffic points in Bucharest.

This study investigated respiratory health status of 7- to 10-year-old children in two settings of Bucharest town (urban and periurban- Magurele) using standard questionnaires which included the age, permanent residency, and location. A number of 70 children have been screened for a central Bucharest school (of which 67 children with permanent status) and 60 children for a periurban school. Information on socio-demographic characteristics and potential determinants of both outdoor and indoor air pollutants exposure levels were also obtained. Specific information collected included: income levels of the family; parents' education level; smoking status; chronic respiratory disease conditions in parents; housing characteristics. The respiratory health status of children in the two settings was compared.

In another study, more than 20 children between the age of 10 and 15 years who had moved from Bucharest urban high traffic-related polluted community to another community at 100 km far of Bucharest, an area of lower particulate matter concentration (PM10) showed increased growth in lung function compared to those who moved to communities with higher PM10.

Was found that children from the central urban setting had a significantly higher prevalence of wheezing and asthma during year 2011, most severe within winter months as compared to children from the periurban setting. ''Persistent cough'' was reported in 10.4% and 3.2% of children in the central urban Bucharest area and in the periurban area, respectively. Anyway, wheezing is the most important symptom for the identification of asthma in epidemiological studies and it has shown that this symptom has reasonably good specificity and sensitivity for bronchial hyper-responsiveness compared to other symptoms in both children and adults.

The accurate information on atmospheric pollution levels in Bucharest metropolitan area is very important for epidemiological studies in relation with health state regarding asthma symptoms.

6. Conclusion

The measurement of environmental concentrations of particulate matter air pollutants (especially PM10 and PM2.5) in Bucharest urban/periurban tested areas was correlated with the spatio-temporal assessment exposure of people affected by respiratory diseases like as asthma, which incorporates different layers of complexity.

Poor indoor and outdoor air quality was a major determinant of wheezing for the two study groups in Bucharest central and periurban areas. This study suggests that school children from urban areas of central Bucharest have poorer respiratory health status as compared to school children from periurban areas probably due to the effects of poor outdoor air quality mainly due to road traffic and small industries.

In order to evaluate the impact on health of atmospheric pollutants emitted by the industrial sources and road traffic which are the main contributors to "outdoor" air pollution in Bucharest metropolitan area, this paper provides a useful information on particulate matter concentrations and aerosol optical thickness for 2010-2011.

Management of urban health and quality of life is a continuing challenge because of urban growth and increasing of atmospheric pollution with particle materials and other components. Recent advances in geospatial research methods and analysis tools allow for spatially explicit characterization of air pollution in urban environments. In large sprawling cities, with a highly variable socio-economic fabric, uneven infrastructure and multiple housing types, health vulnerability as response to poor air quality is expected to be much complex.

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